STATE OF NEW MEXICO
ENVIRONMENTAL IMPROVEMENT BOARD

IN THE MATTER OF THE APPEALS
OF THE AIR QUALITY PERMIT
NO. 7482-M1 ISSUED TO 3 BEAR
DELAWARE OPERATING – NM LLC

EIB No. 20-21(A)

AND

REGISTRATION NOS. 8720, 8730, AND 8733
UNDER GENERAL CONSTRUCTION PERMIT
FOR OIL AND GAS FACILITIES

EIB No. 20-33(A)

WildEarth Guardians,
Petitioner.

WILDEARTH GUARDIANS' NOTICE OF INTENT TO PRESENT TECHNICAL AND NON-TECHNICAL TESTIMONY

Pursuant to the July 20, 2020 Procedural Order in these matters, consolidated for hearing, WildEarth Guardians ("Guardians") hereby gives notice that it intends to present both non-technical and technical testimony at the hearing in this matter scheduled for September 23, 2020 before the New Mexico Environmental Improvement Board ("Board").

Guardians will present non-technical testimony from Nathalie Eddy and Rebecca Sobel related to the interests of Guardians and its' members in this matter.

Guardians will present technical testimony from Dr. Ranjit (Ron) Sahu, Ph.D., QEP, CEM (Nevada) an expert witness with over thirty years of experience in the fields of environmental, mechanical, and chemical engineering. Dr. Sahu's written technical testimony is attached here. Dr. Sahu's resumé is attached as Attachment A to his written technical testimony; and his Expert Litigation Support list is attached as Attachment B to his written technical testimony. There are seven exhibits attached to Dr. Sahu's written technical testimony.

Respectfully submitted this 3rd day of August, 2020,

/s/ Daniel L. Timmons
Daniel L. Timmons
WildEarth Guardians
301 N. Guadalupe Street, Suite 201
Santa Fe, NM 87501
dtimmons@wildearthguardians.org

/s/ Samantha Ruscavage-Barz
Samantha-Ruscavage-Barz
WildEarth Guardians
301 N. Guadalupe Street, Suite 201
Santa Fe, NM 87501
sruscavagebarz@wildearthguardians.org

Counsel for Petitioner WildEarth Guardians

CERTIFICATE OF SERVICE

I hereby certify that on August 3, 2020 I filed and served the foregoing **WILDEARTH GUARDIANS' NOTICE OF INTENT TO PRESENT TECHNICAL AND NON-TECHNICAL TESTIMONY** by electronic mail delivery to the following:

public.facilitation@state.nm.us
Administrator, Environmental Improvement Board

John Volkerding
JVNatrc@aol.com
Hearing Officer and Board Chair, Environmental Improvement Board

Karla Soloria
ksoloria@nmag.gov
Counsel for the Environmental Improvement Board

Lara Katz
Lara.Katz@state.nm.us
Counsel for the New Mexico Environment Department

Chris Colclasure
Beatty & Wozniak, P.C.
CClolclasure@bwenergylaw.com
Counsel for Applicant 3 Bear Delaware Operating – NM LLC

Jody Rittenhouse
Beatty & Wozniak, P.C.
jrittenhouse@bwenergylaw.com
Counsel for Applicant 3 Bear Delaware Operating – NM LLC

Adam G. Rankin
Holland & Hart LLP
agrankin@hollandhart.com
Counsel for Applicant Spur Energy Partners, LLC

Jill H. Van Noord
Holland & Hart LLP
jhvannord@hollandhart.com
Counsel for Applicant Spur Energy Partners, LLC

Louis W. Rose
Montgomery & Andrews, P.A.
Lrose@montand.com
Counsel for Applicant XTO Energy Inc.

Kari E. Olson
Montgomery & Andrews, P.A.
kolson@montand.com
Counsel for Applicant XTO Energy Inc.

Andrew Torrant
Exxon Mobil Corporation
Andrew.j.torrant@exxonmobil.com
Counsel for Applicant EXT Energy Inc.

/s/ Samantha Ruscavage-Barz
Counsel for Petitioner WildEarth Guardians

EXPERT REPORT

by

Dr. Ranajit (Ron) Sahu, Consultant[1]

In support of Petitioner in

EIB No. 20-33(A) and EIB No. 20-21(A)

"If you find yourself in a hole, stop digging" – Will Rogers.

I. Introduction

WildEarth Guardians (hereafter "Guardians" or "Petitioner") has submitted two petitions in administrative appeals (now consolidated) to the State of New Mexico Environmental Improvement Board (hereafter "EIB") challenging the legality of the New Mexico Environment Department's (NMED's) approval of air pollution permits for oil and gas production facilities in Eddy and Lea Counties in southeast New Mexico.[2] The first challenges the approval of a modification permit for a natural gas processing plant[3] ("3-Bear") and has been docketed as EIB 20-21 (A). The second challenges the approval of general permit registration, often referred to as General Construction Permit (GCP) applications, for three oil and gas production facilities (registration numbers 8729[4], 8730[5], and 8733[6]) and has been docketed as EIB 20-33 (A). While

[1] Resume provided in Attachment A.

[2] The area in which the facilities are located is generally referred to as the New Mexico portion of the Permian Basin. In addition to Eddy and Lea counties, this New Mexico portion of the Permian also extends to portions of Chavez and Roosevelt counties. See, "Future Year 2028 Emissions from Oil and Gas Activity in the Greater San Juan Basin and Permian Basin, Final Report. Prepared for BLM New Mexico State Office and Western States Air Resources Council and Western Regional Air Partnership, Ramboll, August 2018." (Exhibit 2)

[3] Air Quality Permit No. 7482-M1 (IDEA ID No. 38067 - PRN20190001) - 3 Bear Delaware Operating - NM LLC – 3 Bear Libby Gas Plant. New Source Review – Significant Revision approved on April 8, 2020. The 3 Bear Permit allows the emissions of 71.5 additional tons per year of VOCs (total of 182.8 tons per year) and 21.1 additional tons per year of NOx (total of 145.1 tons per year).

[4] XTO Energy Company, Corral Canyon 23, issued February 26, 2020. The GCP registrations authorize additional up to 95 tons per year of NOx and 95 tons of VOCs.

[5] XTO Energy Company, Big Eddy Unit DI 38, issued February 26, 2020.

[6] Spur Energy Partners LLC, Dorami 2H, 4H and 9H Federal Oil Tank Battery, issued February 27, 2020.

distinct and separate appeals, both challenge the failure of the NMED to properly account for the impacts of allowing additional NO_x and VOC air emissions—both ozone precursors—from these facilities on regional ground-level ozone concentrations and violations of the National Ambient Air Quality Standards (NAAQS). In particular, both appeals challenge NMED's conclusions that approving the permit and registrations would not contribute to violations of the ozone NAAQS in accordance with the New Mexico State Implementation Plan (SIP).

The New Mexico SIP prohibits the approval of permits that would authorize air pollution that causes or contributes to violations of the national ambient air quality standards. Ozone data from three monitoring sites in southeast New Mexico—Carlsbad and Carlsbad Caverns National Park in Eddy County and Hobbs in Lea County—are currently in violation of 2015 ozone NAAQS of 70 parts per billion (ppb).[7] While EPA has not yet formally designated the southeastern New Mexico area as ozone non-attainment, these monitors demonstrate non-attainment. It is my opinion that, given the data from these three monitors, the area is already out of compliance with the ozone standard and therefore should be considered to be in a state of actual non-attainment with the ozone NAAQS. Given existing monitoring data, prior modeling conducted by others (as discussed in this report), and the large increases in emissions of NO_x and VOC due to oil and gas sources and activities in the area, it is my professional opinion that it is simply a matter of when and not if such a designation will occur, what its severity will be, and what the geographical extent of the non-attainment area will be.[8]

Therefore, from a technical standpoint, the monitors in Eddy and Lea counties clearly show ozone pollution levels violating the NAAQS, demonstrating actual non-attainment of the ozone NAAQS, irrespective of the formal attainment designation status. Accordingly, it does not make sense that NMED is continuing to issue general permit registrations and permit approvals for oil and gas sources (of which the three registrations and one permit modification in the appeals at issue in the current petitions are just examples) with allowable and actual NO_x and VOC increases. Permitting any new source of emissions in this region will contribute to violations of the NAAQS.

I have carefully reviewed the NMED's responses to the two petitions, which make similar technical arguments. Basically, NMED takes the position that its approval of these types of registrations and permits is not causing and would not cause or contribute to violations of the ozone NAAQS. For the reasons stated in this report, I disagree with the NMED's position.

In this report I am not commenting on the specific deficiencies of the 3 Bear permit or on any of the specific conditions of the GCPs. My comments support the Petitioner's position that these

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[7] The Carlsbad monitor is in violation of 2008 ozone NAAQS, which is set at 75 ppb.
The 2015 NAAQS was recently reaffirmed by the EPA Administrator. https://www.epa.gov/newsreleases/ozone-pollution-continues-decline-under-president-trump-epa-proposes-retain-existing

[8] This is consistent with NMED's answer to the 20-33(A) petition when it notes that it may "…have to go through the process of Non-Attainment designation under the oversight of the U.S. Environmental Protection Agency, which will entail determining the boundaries of the area, the level of non-attainment ranging from minimal to severe, and the degree to which natural occurrences or activities in other states are contributing to the problem…" NMED answer to GCP appeals at 3(e).

permits and registrations should not be issued at this time since they allow the emissions of more precursor NO_x and VOC emissions while the area is clearly in ozone non-attainment based upon the monitored levels of ozone in the area monitors.

II. Basics of Ozone Formation in the Troposphere

As summarized by Finlayson-Pitts et. al., and in simplified fashion:

> "Unlike some other pollutants of concern such as CO or SO2, ozone is a secondary pollutant formed in the ambient air through a complex set of sunlight-initiated reactions of its precursors, primary emissions of NO_x (NO_2+NO) and volatile organic compounds (VOC) from both mobile and stationary sources. The term VOC encompasses all organics (e.g., hydrocarbons, aldehydes, alcohols, nitrogen and sulfur-containing organics, etc.) which react in the troposphere and hence contribute to ozone formation. Other acronyms commonly used for reactive organics include NMOG (non-methane organic gases), NMHC (non-methane hydrocarbons) and HC (hydrocarbons); the latter two are often used in a more restrictive sense, excluding aldehydes, nitrogen compounds, etc."[9]

There is no disagreement on this point. NMED, in its answers to the petitions, states similarly that ozone is not directly emitted into the atmosphere by most sources but is, rather, a "secondary pollutant" formed by a complex series of photochemical reactions between VOCs and NO_x in the presence of sunlight.[10]

In its answers to the petitions, NMED further states that these reactions do not take place instantaneously, but instead can take hours or days. Further, ozone levels at a particular location can result from VOC and NO_x emissions "that occurred hundreds or even thousands of miles away."[11] By this, NMED seems to imply that only VOC and NO_x emissions that occur far away can create ozone in a given area, minimizing the role of local or proximate sources of NO_x and VOCs and their role in local ozone formation. While such "transport" ozone is certainly a factor, significant ozone levels can also be created due to local or nearby (i.e., at distances much less than "hundreds" or "thousands" of miles) sources of VOCs and NO_x. As I note in later discussion, NMED is or should be well aware of this.

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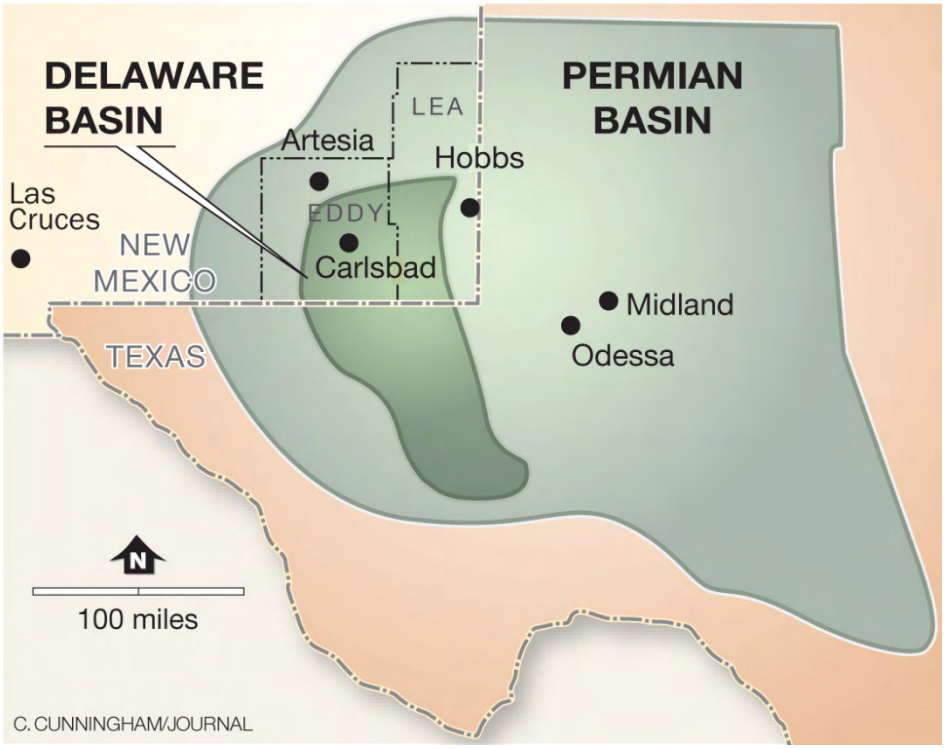
[9] Finlayson-PittsB.J., et. al., Atmospheric Chemistry of Tropospheric Ozone Formation: Scientific and Regulatory Implications, Air & Waste, August 1993, p. 1091-.

[10] NMED answer to 3-Bear appeal at 3(d). NMED answer to GCP appeals at 3(d). I note however, that in its legal notice for the 3-Bear permit modification (Exhibit 1) NMED only identifies VOCs as precursors for ozone omitting NO_x ("…VOCs are a pre-cursor to ozone…") and not NO_x. I am presuming that this is an oversight.

[11] NMED answer to 3-Bear appeal at 3(d). NMED answer to GCP appeals at 3(d).

III. Brief Description of the Area

The figure below shows the general area of southeastern New Mexico, including Eddy and Lea counties. It also shows the so-called Permian Basin (and other named basins, such as the Delaware Basin) which account for the extensive oil and gas operations in the area.[12]



The figure below shows the level of oil and gas activities in the area around 2014.[13]

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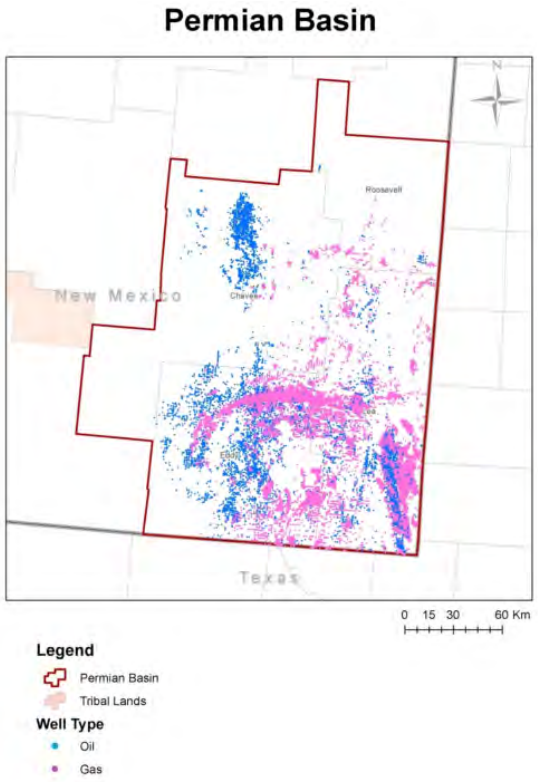
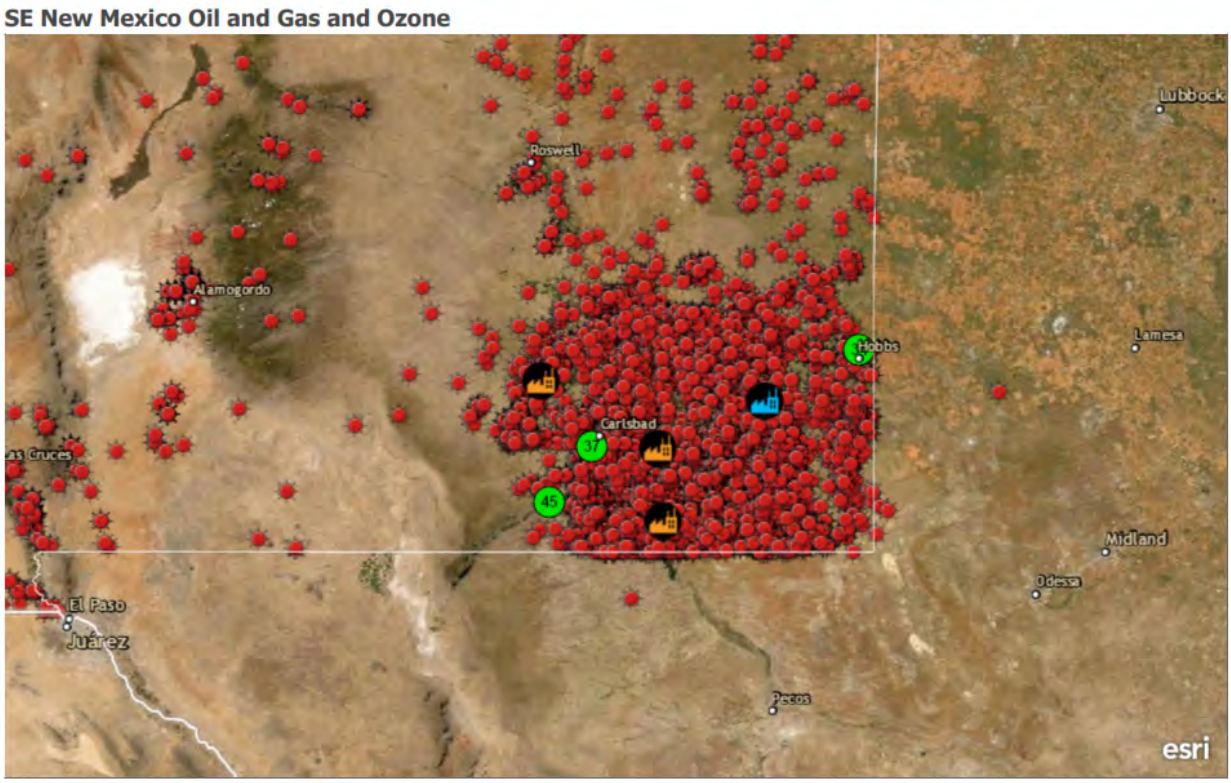
[12] See, for example, https://www.abqjournal.com/928256/oil-map-sidebar.html
"The Permian Basin in southeastern New Mexico and West Texas is one of the best producing oil zones in the U.S. today, particularly for plays in the Delaware Basin – an oval-shaped shale-rock formation within the Permian that protrudes from southwest Texas northward into Lea and Eddy counties."



[13] Exhibit 2. Future Year 2028 Emissions from Oil and Gas Activity in the Greater San Juan Basin and Permian Basin, Final Report. Prepared for BLM New Mexico State Office and Western States Air Resources Council and Western Regional Air Partnership, Ramboll, August 2018.

And, finally, the figure below shows the oil and gas permits granted by the NMED in recent years in southeastern New Mexico, including the large numbers in Eddy and Lea counties. It also shows the location of the ozone monitors in southeast New Mexico, identified as green circles, including at Carlsbad Caverns, Carlsbad, and Hobbs.[14]



[14] This map was prepared by WildEarth Guardians with the platform ArcGIS.com using coordinate data from NMED. The map also shows the location of the Carlsbad Caverns, Carlsbad, and Hobbs ozone monitors (green circles).

IV. Ozone Monitoring Data in the Area

The tables below show the annual first, second, third, and fourth maximum 8-hour ozone readings at the three monitors in Eddy and Lea counties between 2015 and 2019. These are the three official ozone monitors in these two counties. The values are shown in parts per million (ppm) -i.e., 70 ppb equals 0.070 ppm.

Hobbs, NM 8-Hour Ozone Readings (in ppm), 2015-2019

	2015	2016	2017	2018	2019
1st Max.	0.070	0.069	0.080	0.083	0.082
2nd Max.	0.069	0.066	0.074	0.078	0.075
3rd Max.	0.069	0.065	0.072	0.077	0.073
4th Max.	0.067	0.065	0.069	0.076	0.070
Number of Days Above NAAQS	0	0	3	6	3

Carlsbad, NM 8-Hour Ozone Readings (in ppm), 2015-2019

	2015	2016	2017	2018	2019
1st Max.	0.069	0.065	0.082	0.096	0.095
2nd Max.	0.068	0.064	0.078	0.095	0.092
3rd Max.	0.067	0.064	0.077	0.091	0.084
4th Max.	0.067	0.063	0.076	0.083	0.080
Number of Days Above NAAQS	0	0	10	18	19

Carlsbad Caverns National Park 8-Hour Ozone Readings, 2015-2019

	2015	2016	2017	2018	2019
1st Max.	0.068	0.070	0.069	0.099	0.082
2nd Max.	0.068	0.069	0.065	0.081	0.080
3rd Max.	0.065	0.069	0.065	0.080	0.078
4th Max.	0.065	0.069	0.065	0.080	0.074
Number of Days Above NAAQS	0	0	0	10	6

A violation of the 8-hour ozone NAAQS is triggered when the three-year average of the annual fourth highest daily reading exceeds the NAAQS of 70 ppb (i.e., 0.070 ppm).[15] This three year average value is referred to as the "design value." Based on the monitoring data shown above, all three ozone monitors are in violation of the ozone NAAQS, with the design value at the Carlsbad monitor even violating the earlier ozone NAAQS adopted in 2008, which limited 8-hour concentrations to no more than 75 ppb (i.e., 0.075 ppm).[16]

[15] See 40 C.F.R. 50.19(b).

The table below shows that the design values at the Eddy and Leacounty monitors have increased over the last five years. The table below shows the 2017-2019 data which confirms NAAQS violations at all three monitors.

8-Hour Ozone Design Values for Lea and Eddy County, New Mexico Monitoring Sites

Monitor	Monitor ID	2015-2017 Design Value	2016-2018 Design Value	2017-2019 Design Value
Hobbs	350250008	0.067	0.070	0.071
Carlsbad	350151005	0.068	0.074	0.079
Carlsbad Caverns	350150010	0.066	0.071	0.073

Therefore, at this point, all three ozone monitors in both Eddy and Lea Counties are in nonattainment, with 2017-2019 design values all above the 2015 ozone NAAQS of 0.070 parts per million. This is also confirmed by EPA's data.[17] It is also clear that all three monitoring sites have recorded regular exceedances of the ozone NAAQS since 2015.

As I note below, NMED does not dispute this data. In its answers to the petitions, NMED confirms that "[T]he Department does not dispute that design values calculated based on data from air quality monitors in Hobbs and Carlsbad in 2017, 2018, and 2019 show levels of ozone above the federal 2015 National Ambient Air Quality Standard ("NAAQS")."[18]

And, the NMED's modeling protocol for its upcoming Ozone Attainment Initiative (OAI) also confirms the ozone exceedances at not just these southeastern New Mexico monitors but also others throughout the state:

> "The New Mexico Air Quality Control Act (NMAQCA) requires the NMED to develop a plan to address elevated ozone levels when air quality is within 95% of the ozone NAAQS (74-3-5.3, NMSA 1978). The ozone NAAQS was revised in 2015 with a threshold of 0.070 ppm (70 ppb) with the relevant metric being the ozone Design Value (DV) that is expressed as the three-year average of the fourth highest Daily Maximum Average 8-hour (DMAX8) ozone concentrations. Figure 1-1 displays the trends in observed ozone DVs at 8 New Mexico monitoring sites from 2013 to 2018 and compares them with the 70 ppb 2015 ozone NAAQS (red

[16] The 2008 ozone NAAQS remain applicable as promulgated at 40 C.F.R. 50.15.

[17] https://www.epa.gov/sites/production/files/2020-05/o3_designvalues_2017_2019_final_05_26_20.xlsx

[18] NMED answer to 3-Bear appeal at 3(d). NMED answer to GCP appeals at 3(d).

line) and 95% of the 70 ppb NAAQS (i.e., ≥ 67 ppb; black line). This results in 7 counties in New Mexico under NMED jurisdiction with measured 2016-2018 ozone DVs at or exceeding 95% of the 70 ppb ozone NAAQS, as shown in Figure 1-1.[19]

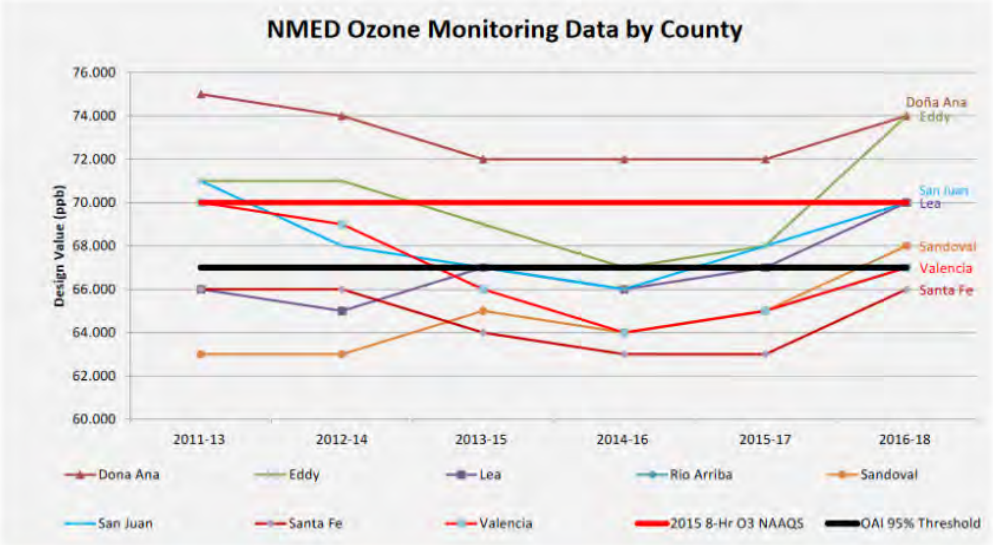
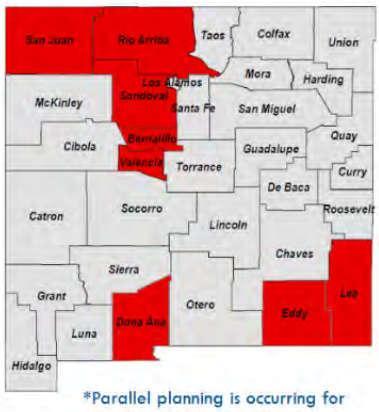


Figure 1-1. Trends in observed ozone DVs between 2013 and 2018 at 7 monitoring sites in New Mexico (Source: https://www.env.nm.gov/air-quality/wp-content/uploads/sites/2/2019/10/OAI_Presentation_09262019.pdf).

[19] Exhibit 3. Ramboll and Westar, New Mexico Ozone Attainment Initiative Photochemical Modeling Study – Draft Modeling Protocol, May 2020. Hereafter "Draft OAI Modeling Protocol." Note that Figure 1-1 does not reflect further increases in the measured design values at each of the three regional air quality monitors based on 2017-2019 data.

Figure 1-2[20] shown below, also from the Draft OAI Modeling Protocol confirms the ozone exceedances in Eddy and Lea counties.



- Counties within 95% of the standard:
  - San Juan (Navajo Lake, 70 ppb)
  - Doña Ana (several monitors, 74 ppb)
  - Eddy (Carlsbad, 74 ppb)
  - Lea (Hobbs, 70 ppb)
  - Rio Arriba (Coyote, 67 ppb)
  - Sandoval (Bernalillo, 68 ppb)
  - Valencia (Los Lunas, 67 ppb)

Figure 1-2. 7 counties in New Mexico under the jurisdiction of the NMED whose observed 2016-2018 ozone DVs are at or exceed 95% of the 2015 ozone NAAQS (70 ppb) (Source: https://www.env.nm.gov/air-quality/wp-content/uploads/sites/2/2019/10/OAI_Presentation_09262019.pdf).

[20] As with Figure 1-1 above, Figure 1-2 does not reflect further increases in the measured design values at each of the three regional air quality monitors based on 2017-2019 data.

V. NMED's Acknowledgement of the Area's Non-Attainment Status and Need for Action

Based on the monitored ozone values shown in the previous section, NMED provides the following general commentary:

> "The process of determining whether an area is in attainment or in nonattainment of a NAAQS is triggered when the 'design value' (DV) for a pollutant is shown to be in excess of the standard. The DV is the three-year average of the annual fourth-highest daily monitored value. Thus, each year, for each NAAQS standard, the DV is calculated by averaging the fourth highest monitored reading for the previous year with the fourth highest reading of the two previous years. The resulting calculated value is the DV for that pollutant for that year. For ozone, this calculated value is compared to the 8-hour NAAQS ozone standard, which is 0.070 ppm. If the calculated DV is 0.0705 or above, it is rounded up to 0.071 ppm (0.0704 is rounded down to 0.070). At 0.071 the design value is in exceedance of the 8-hour NAAQS ozone standard. DVs for each monitor for each year are submitted to EPA for verification."[21]

Specifically, NMED then confirms that the high ozone monitored values at the Eddy and Lea county monitors have exceeded the NAAQS in recent years.

> "The Carlsbad monitor has monitored exceedances resulting in the DV exceeding the 8-hour ozone NAAQS in the years 2017, 2018, and 2019. The Carlsbad monitored design values are 0.076, 0.083, and 0.080 ppm, for each year, respectively. Similarly, the ozone monitor in Hobbs showed a DV exceedance in 2018. However, in 2019 the Hobbs monitor's DV demonstrated compliance with the NAAQS with a design value of 0.070 ppm.[22]

NMED acknowledges that it is required to address these high ozone readings, acknowledging that:

> "…The Air Quality Control Act requires the state to develop a plan, including regulations, to reduce ozone precursors in areas of the state that are exceeding 95% of the ozone standard. The AQB has been working diligently[23] to address

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[21] Exhibit 4. NMED Air Quality Bureau Memo dated April 1, 2020. "How Ozone Trends at New Mexico's Ozone Monitoring Stations are Being Addressed"

[22] Note that the NMED misstates the design value based on the fourth-highest daily 8-hour average for a single year. As explained above, the design value is calculated based on a three-year average of the fourth-highest daily 8-hour average. Accordingly, the NMED's statement that the Hobbs Monitor demonstrated compliance with the ozone NAAQS based on 2019 monitored data alone is inaccurate. As shown in the table on page 8 above, the 2017-2019 design value for the Hobbs monitoring station (350250008) is 0.071 ppm, exceeding the 0.070 ppm ozone NAAQS.

[23] I would disagree that NMED's efforts have been "diligent" given the amount of time this problem has manifested itself and also by the fact that NMED continues to issue permits for oil and gas sources at a rapid clip in spite of these clear monitored ozone increases. Also, I note for the record that the draft modeling protocol for the OAI

> the rising ozone in those areas through its Ozone Attainment Initiative (OAI), which will include proposal of new regulations for reducing ozone precursors. The OAI is the vehicle through which NMED will investigate and implement strategies to ensure the region's 8-hour ozone levels return to full attainment status." (emphasis added)

I should also note that in the legal notice for the 3-Bear permit modification, NMED states that "[T]o determine compliance with national ambient air quality standards for ozone, NMED uses air monitors to monitor ozone concentrations."[24] Yet, clearly, it does not seem to be "using" such data, which clearly shows monitored ozone concentrations exceeding the ozone NAAQS, with at least some contributions from local and proximate sources.

Moreover, the GCP-Oil & Gas states that NMED must deny a registration where "The Facility is located in a nonattainment area [defined by 20.2.72.216 and 20.2.79 NMAC]." 20.2.79 NMAC defines "nonattainment area" as "for any air pollutant an area which is shown by monitored data or which is calculated by air quality modeling (or other methods determined by the administrator to be reliable) to exceed any national ambient air quality standard for such pollutant. Such term includes any area identified under Subparagraphs (A) through (C) of Section 107(d)(1) of the federal Clean Air Act." While I am not a legal expert and offer no legal conclusions, my technical expertise enables me to say unequivocally that the area in which the facilities at issue are located is clearly shown by monitored data to exceed the NAAQS for ozone.

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modeling is dated May 2020. This is hardly diligent when modeling going back years, as I note later, clearly showed that ozone levels in the area would continue to rise.

[24] Exhibit 1. Legal Notice and Preliminary Determination for an Air Quality Permit for 3 Bear Delaware Operating-NM LLC

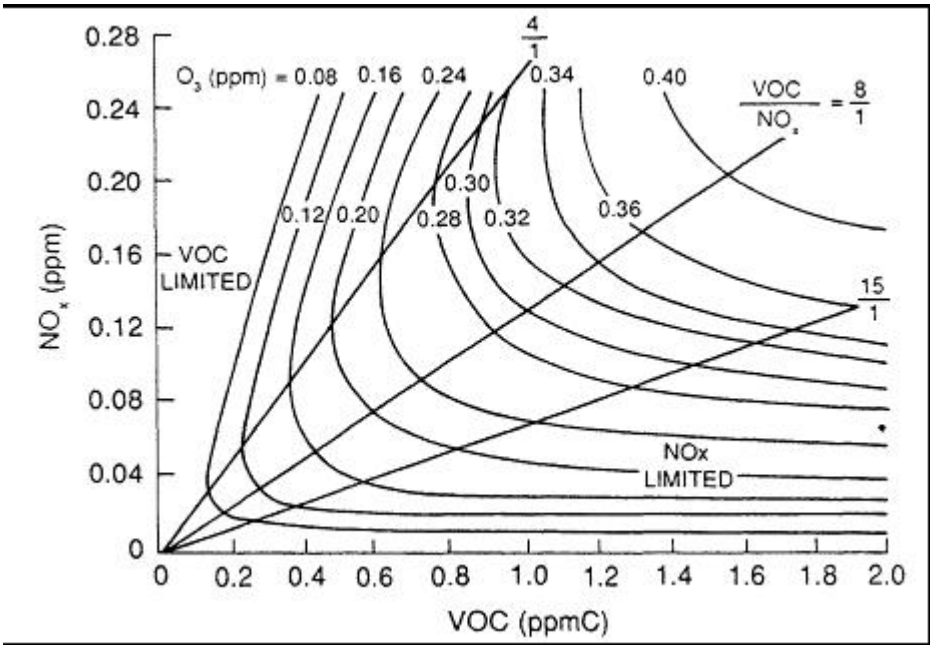
VI. NMED's Answers to the Petitions and Technical Discussion

In this section, I highlight the main technical points in the NMED's answers to the petitions as well as my technical comments.

VI.1 Determining the Ozone Impacts from Specific Sources

In its answers to the petitions, NMED states that "…it is not possibleto do such source-specific modeling for ozone given the complex nature of its formation in the atmosphere and the fact that it is not emitted directly from anthropogenic sources. Ozone modeling has to be done on a regional basis and is technically complex and extremely costly. The Department is currently conducting such modeling in connection with its Ozone Attainment Initiative, and expects that modeling to be completed in the fall of 2020. The modeling will provide the scientific basis for rulemaking and enforcement efforts aimed at preventing the areas of the State that are registering design values near or above the current ozone NAAQS from being designated as Non-Attainment'."[25] (emphasis added)

I disagree. Agencies have been making ozone determinations from individual sources as well as from regional sources (which is what the collection of oil and gas sources in Eddy and Lea counties represent) since at least the early 1980s.. The earliest example is the use of the so-called EKMA model, for which a typical example is provided below.



The idea is to determine the ozone levels by knowing the ambient levels of NO_x and VOCs. The EKMA model was widely used for decades to determine effective ozone reduction strategies.

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[25] NMED answer to 3-Bear appeal at 3(e). NMED answer to GCP appeals at 3(e). I note, however, that in its legal notice (Exhbit 1) for the 3-Bear permit modification, NMED states that it "…does not require an individual ozone ambient impact analysis for each application." (emphasis added). Not "requiring" is, of course, not the same as "not possible." Similarly, that something is "costly" does not make it "not possible".

Second, and more relevant, EPA has provided guidance for determining so-called Modeled Emission Rates for Precursors (MERPs),[26] specifically for individual sources. While this guidance was developed for Prevention of Significant Deterioration (PSD) sources, it can be directly applied as an analytical tool to estimate the contribution of any source, including non-PSD oil and gas sources, to ambient ozone levels based on their NO_x and VOC emissions. So, NMED's claim that it is "not possible" to assess the ozone impacts of increased NO_x and VOC emissions, except via complex photo-chemical modeling, is simply incorrect.

Third, there is no doubt that there will be some increase in ozone levels when NOx and VOC emissions are increased. And, NMED seems to acknowledge as much, including the direct impacts of oil and gas NO_x and VOC emissions from the Permian:

> "Given the probability of contributions from oil and gas operations in the state, the first step of what will likely be several rulemakings under the OAI will be to reduce ozone precursors from the oil and gas industry located within the Permian and San Juan Basins. The Department intends to submit proposed rules to the Environmental Improvement Board by the end of 2020. It is anticipated that other rulemakings will follow, targeting emissions reductions from other industrial sectors, as well as the transportation sector."[27]

Given all of the above, I respectfully disagree that NMED cannot reasonably assess the ozone increases that will undoubtedly occur as a direct result of its allowing permitting of oil and gas facilities such as the ones that are the subject of the current appeals. While quantitative methods exist, even qualitative methods exist and are appropriate to use and rely upon to guide regulatory action.

IV.2 Do Oil and Gas Activities Cause or Contribute to the Exceedances of the Ozone NAAQS

Finally, in its answers to the petitions, NMED denies that the permitted activities at the Facility can be deemed to "cause or contribute" to exceedances of the ozone NAAQS. It "affirmatively states" that, given the many contributing sources to ozone formation in New Mexico – including natural sources such as biogenic emissions, stratospheric intrusions, lightning, and wildfires, as well as transportation, and interstate and international transport from other states such as Texas and other countries such as Mexico – it is impossible to make a finding in a particular permitting action that a single source emitting relatively miniscule amounts of ozone precursors is "causing or contributing"[28] to monitored exceedances of the NAAQS.

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[26] https://www.epa.gov/sites/production/files/2019-05/documents/merps2019.pdf
"This guidance reflects the EPA's recommendations for how air agencies conduct air quality modeling and related technical analyses to satisfy compliance demonstration requirements for ozone and secondary $PM_{2.5}$ under the Prevention of Significant Deterioration (PSD) permitting program."

[27] NMED Air Quality Bureau Memo dated April 1, 2020. "How Ozone Trends at New Mexico's Ozone Monitoring Stations are Being Addressed"

[28] NMED answer to 3-Bear appeal at 3(f).

Similarly, for the GCP registration sources, the NMED states that "…it is impossible to make a finding in the context of a particular GCP registration that a single source emitting relatively miniscule amounts of ozone precursors is violating the ozone NAAQS."[29]

I disagree. There is significant evidence available to NMED, as shown by just a few examples I discuss below, that emissions from oil and gas activities, and therefore increased emissions from the 3 Bear facility and the GCP registration sources, are directly contributing to increases in ozone levels in southeastern New Mexico and violations of the NAAQS. Regardless of whether NMED deems increased emissions to be "miniscule" it is technically reasonable to conclude that they are contributing to violations of the ozone NAAQS.

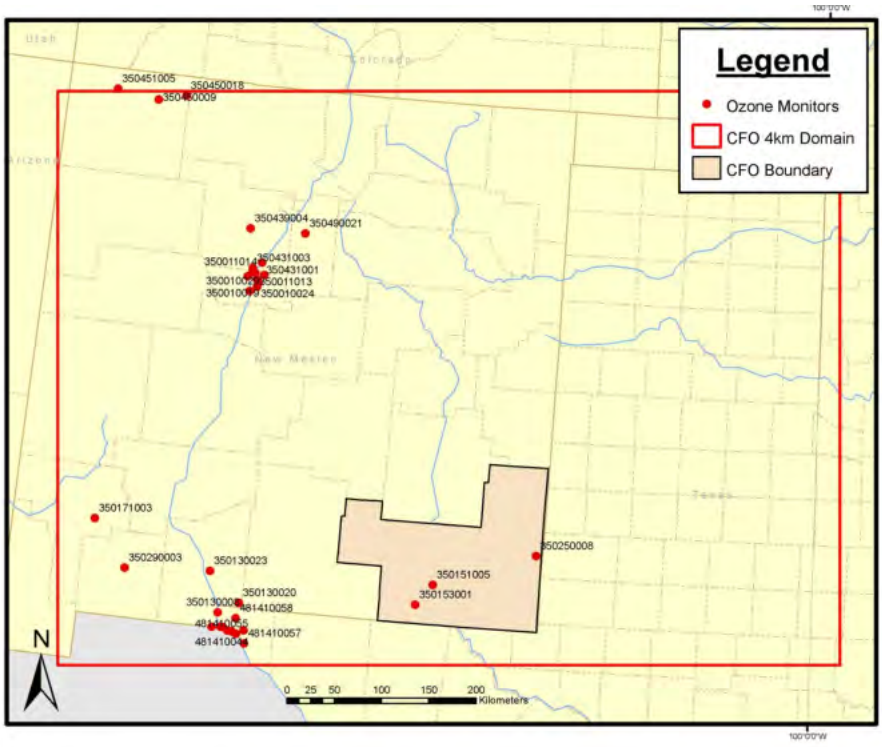
Example 1 – 2013 Modeling Conducted by URS for the Carlsbad Field Office (CFO) of the Bureau of Land Management (BLM).[30]

In a 2013 modeling effort conducted on behalf of the BLM's Carlsbad Field Office, URS, an international engineering firm that has since been acquired by international firm, AECOM, using the photochemical model CAMx, and using a 4 km x 4 km grid as shown below predicted future ozone levels, including at the three ozone monitors (also shown below) which I noted previously.

The whole purpose of the analysis was to analyze potential air quality impacts resulting from future oil and gas development in the BLM's CFO Planning Area.

[29] NMED answer to GCP appeals at 3(f).

[30] Exhibit 5. URS, Air Resources Technical Support Document, Carlsbad Field Office (CFO), Oil and Gas Resource Management Plan Revision, prepared for the Bureau of Land Management, CFO, and BLM, New Mexico State Office, April 2013.



Map 4-2. Ozone Monitors in the 4 km Domain

Table 4-3. 2008 Active Ozone Monitors in the 4 km Domain

Monitor ID	Location Description	Monitor Type
CFO		
350151005	Holland St., Carlsbad	SLAMS
350153001	Carlsbad Caverns National Park	NPS
350250008	Hobbs-Jefferson	SLAMS

The results of the 2013 modeling, shown below are clear. Even without accounting for the tremendous increase in emissions due to the dramatic expansion in Permian oil and gas activity in recent years, the 2013 modeling showed the highlighted projected 2017 design values at the three monitors. All were over 70 ppb, in excess of the NAAQS, as seen in the highlighted text below.

Table 4-17. Future Design Values for Monitors in 4 km Domain

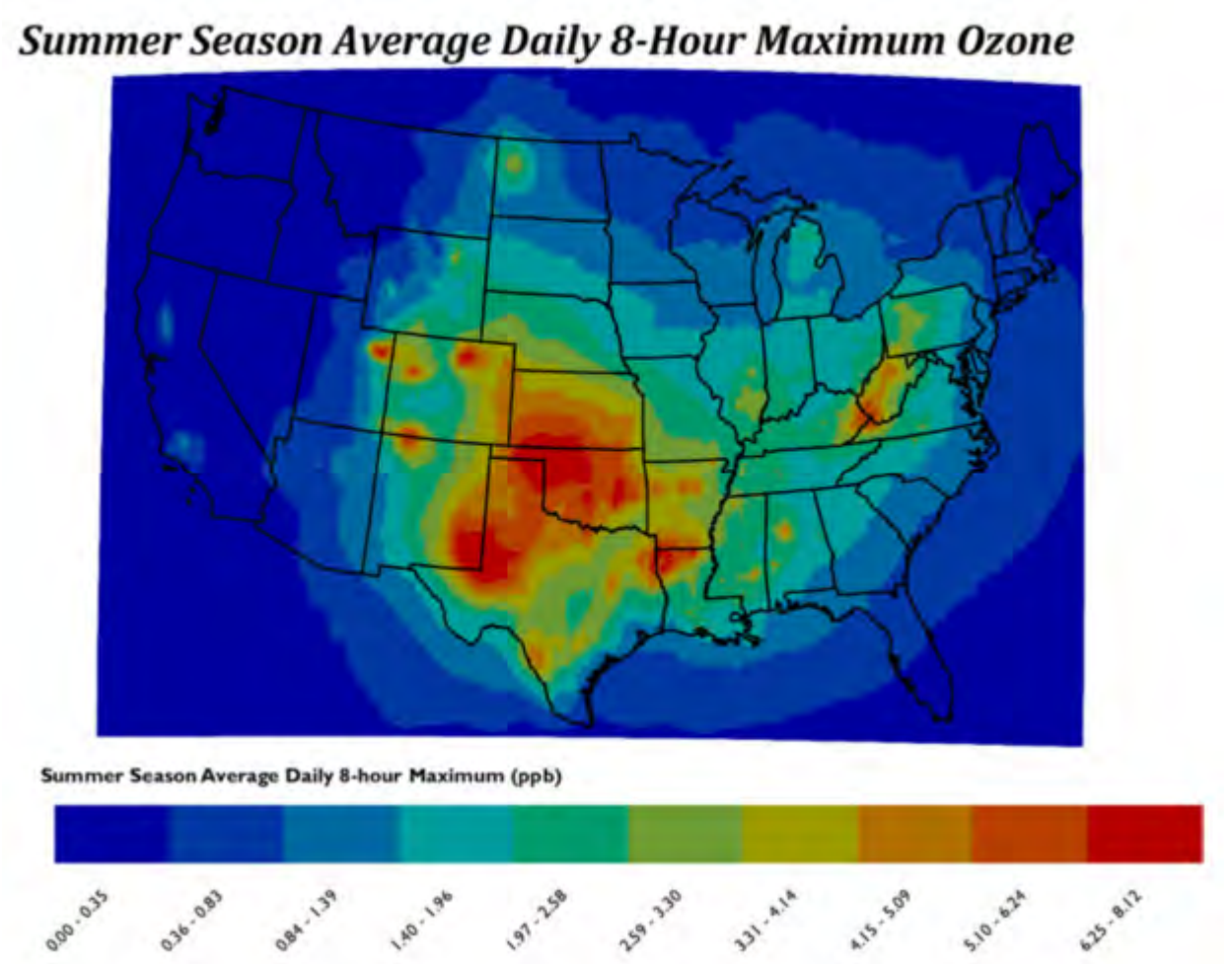
Monitor ID	Location Description	2008b1	2017a1		RFDOTB		RFDOTBX	
		DVB (ppb)	RRF	DVF (ppb)	RRF	DVF (ppb)	RRF	DVF (ppb)
CFO								
350151005	Holland St., Carlsbad	67	1.14	76	1.14	77	1.14	76
350153001	Carlsbad Caverns NP	66	1.14	75	1/14	75	1.14	75
350250008	Hobbs-Jefferson	63	1.15	72	1.15	72	1.15	72

Example 2 – Oil and Gas Impacts by EPA[31]

In this peer-reviewed analysis, EPA used 2011 inventory data for oil and gas activities and made projections of summer-season ozone and annual $PM_{2.5}$ (another pollutant for which NO_x is a precursor) levels due to oil and gas activity emissions..

A graphical presentation of their results, clearly showing the impacts in southeastern New Mexico is shown below. The figure shows that oil and gas emissions can contribute between 6.25 to 8.12 ppb to summer-season 8-hour ozone levels in southeastern New Mexico.

[31] Exhibit 6. Fann, N., et. al., Assessing Human Health $PM_{2.5}$ and Ozone Impacts from U.S. Oil and Natural Gas Sector, Office of Air Quality Planning and Standards, U.S. EPA, Environ Sci Technol. 2018 August 07; 52(15): 8095–8103. doi:10.1021/acs.est.8b02050



Example 3 – 2016 Southern New Mexico Ozone Study (SNMOS)[32]

This study was prepared by Ramboll (the same consultant assisting NMED with the OAI work) and University of North Carolina. Its goal was to study the factors contributing to high ozone levels in Doña Ana county. It used the CAMx photochemical model and used 4-km and 12-km grids in the analysis.

While this study was focused on ozone exceedances in Doña Ana county and the apportionment of contributing sources, it clearly notes the importance of New Mexico oil and gas emissions.

> "• New Mexico anthropogenic emission sources that contributed the most ozone to New Mexico monitors in the SNMOS 4-km grid were: (1) on-road mobile; (2) offroad mobile; (3) oil and gas; and (4) power plants.

[32] Exhibit 7. Kemball-Cook, S., et. al., Southern New Mexico Ozone Study, Technical Support Document, October 19, 2016.

> • Oil and gas emissions are the largest New Mexico anthropogenic contribution at the Carlsbad monitor due to its closer proximity to the Permian Basin. The impact of oil and gas sources increases in 2025 due to projected growth in Permian Basin emissions."[33] (emphasis added)

Further, the impact of the Permian sources on Eddy county's Carlsbad monitor is unambiguously discussed in the Draft OAI Modeling Protocol as followed, based on the SNMOS modeling:

> "With one exception, onroad Mobile source emissions are the largest contributing source sector in New Mexico to 2011 ozone DVs in southeastern New Mexico with the contribution at the Solano monitoring site being higher than the others. The one exception is the Carlsbad monitoring site in Eddy County where O&G emissions is the largest contributing source sector in New Mexico due to its close proximity to the Permian Basin. Although onroad mobile source emissions are the largest contributor in 2011, it is also the source Sector whose New Mexico ozone contribution is reduced the most in 2025, by over a factor of two. This is in contrast to O&G whose contribution at the Carlsbad monitoring site is projected to increase between 2011 and 2025, although future year projections of O&G emissions are highly uncertain. In any event, by 2025 the SNMOS estimate that on-road mobile, non-road mobile and O&G source sectors in New Mexico will contribute the most…" [34] (emphasis added)

The SNMOS, in 2016 correctly concluded that oil and gas emissions are the "largest contributing source" to the Eddy County monitor and it also projected increases of ozone at this monitor, which are now being evidenced based on the data I have discussed previously.

For the NMED to deflect, as it has done in answers to petitioners that it is or may be only natural and distant anthropogenic sources of NO_x and VOC that are responsible for the ozone levels at the Carlsbad (and the other two Eddy and Lea county monitors) is to willfully ignore the clear implications from the results of the existing scientific studies summarized above. This, in my view, directly supports the petitioners' contention that regional oil and gas activity, including the permitting of new and/or modified stationary sources, is a primary cause of the increasing ozone pollution levels in the area. There is no need to reconfirm, via the current OAI effort, what is clear from this and the other examples I have cited – that NMED's permitting of oil and gas sources is contributing to ozone increases in southeastern New Mexico, hence contributing to the area's ozone problem generally, and more specifically to the monitored violations of the ozone NAAQS.

Example 4 – National Park Service (NPS) Carlsbad Caverns

As a final example of the common knowledge that oil and gas sources are responsible for elevated ozone levels in southeastern New Mexico, I provide the excerpt below on air quality at

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[33] *Ibid*., p. 81.

[34] Draft OAI Modeling Protocol, p. 11-12.

the Carlsbad Caverns National Park, a Class I area, deserving of the highest levels of protection under the Clean Air Act.

> "Carlsbad Caverns National Park is a moderately sized park located within southwest New Mexico that preserves a portion of the northern Chihuahuan Desert. Maintaining excellent air quality is critical to preserving and protecting the natural resources. Through the Clean Air Act of 1970 and subsequent amendments, the park is classified as a Class 1 air quality area. This classification helps protect the air quality of the park at the highest level.
>
> There are numerous human-made pollution sources that may impact air quality at the park and within the region. These include, but are not limited to, power generating plants within the region, the many wells producing oil and gas within the area, and nearby refineries. Air quality can also be affected by natural conditions such as when strong winds from the west create huge dust storms that drop visibility significantly in the area. Despite growing concerns over air quality and pollution in the park, there are still a number of days when visibility is excellent with views of the Davis Mountains located 140 miles south of the park from the visitor center.
>
> With oil and gas activities increasing in the Black River valley to the south of the park, the National Park Service has recently installed a Portable Ozone Monitoring Site (POMS) unit to record ozone levels during the warm months of the year."[35] (emphasis added)

[35] https://www.nps.gov/cave/learn/nature/airquality.htm.
I have not reviewed the ozone data from the POMS at the Caverns referenced by the NPS.

VII. Conclusion

Based on my review of existing ozone monitoring data, various modeling results, and NMED's own documents, it is clear that ozone levels in Eddy and Lea counties violate the ozone NAAQS based on 2017-2019 data. Thus, irrespective of the formal attainment designation of the area, it should be considered to be in a state of actual non-attainment (i.e., violation) of the ozone NAAQS.

My overall impression of NMED's position in its answers is that the ozone levels at the Eddy and Lea county monitors are mostly ("larger portion") due to precursor anthropogenic emissions (from "hundreds" and "thousands" of miles away, being transported to the region), and natural sources with local sources contributing "miniscule" amounts of such precursors, without specifying what "miniscule" might be.

As I have shown above this is simply untrue. Prior modeling as well as the vast increase in local precursor emissions[36] from oil and gas sources since such modeling clearly shows that significant ozone is generated from such precursor emissions in the area, as a consequence of NMED's granting of permits like the ones at issue in these appeals.

Further, NMED's contention that it is "not possible" to make a determination that any individual source "causes or contributes" to exceedances of the ozone NAAQS is inaccurate. There are existing and readily-available analytical tools, such as the MERP, that allow for quantitative estimates of impacts on ozone levels to be calculated for incremental additions of VOCs or NO_x without requiring complex photo-chemical modeling. Finally, in the absence of modeling or analytical data demonstrating otherwise, it is my professional judgment that it is reasonable to presume that *any* additional emissions of VOCs or NO_x in Eddy and Lea counties, such as from the particular facilities at issue in this matter, will contribute to violations of the ozone NAAQS in the area.

[36] There is no question that there has been tremendous growth of NO_x and VOC emissions in southeastern New Mexico driven by the exploration and production activities in Eddy and Lea counties. For example, in 2011, annual oil and gas industry emissions reported in the National Emissions Inventory were 127,029 tons of VOCs and 42,196 tons of NO_x. Most recent estimates from the Western Regional Air Partnership estimate annual oil and gas emissions will reach 225,636 tons of VOCs and 101,531 tons of NO_x by 2028. Much of this is due to a surge in oil and gas production activity in southeastern New Mexico.

Attachment A

RANAJIT (RON) SAHU, Ph.D, QEP, CEM (Nevada)

CONSULTANT, ENVIRONMENTAL AND ENERGY ISSUES

311 North Story Place
Alhambra, CA 91801
Phone: 702.683.5466
e-mail (preferred): ronsahu@gmail.com; sahuron@earthlink.net

EXPERIENCE SUMMARY

Dr. Sahu has over thirty years of experience in the fields of environmental, mechanical, and chemical engineering including: program and project management services; design and specification of pollution control equipment for a wide range of emissions sources including stationary and mobile sources; soils and groundwater remediation including landfills as remedy; combustion engineering evaluations; energy studies; multimedia environmental regulatory compliance (involving statutes and regulations such as the Federal CAA and its Amendments, Clean Water Act, TSCA, RCRA, CERCLA, SARA, OSHA, NEPA as well as various related state statutes); transportation air quality impact analysis; multimedia compliance audits; multimedia permitting (including air quality NSR/PSD permitting, Title V permitting, NPDES permitting for industrial and storm water discharges, RCRA permitting, etc.), multimedia/multi-pathway human health risk assessments for toxics; air dispersion modeling; and regulatory strategy development and support including negotiation of consent agreements and orders.

He has over twenty seven years of project management experience and has successfully managed and executed numerous projects in this time period. This includes basic and applied research projects, design projects, regulatory compliance projects, permitting projects, energy studies, risk assessment projects, and projects involving the communication of environmental data and information to the public.

He has provided consulting services to numerous private sector, public sector and public interest group clients. His major clients over the past twenty five years include various trade associations as well as individual companies such as steel mills, petroleum refineries, cement manufacturers, aerospace companies, power generation facilities, lawn and garden equipment manufacturers, spa manufacturers, chemical distribution facilities, and various entities in the public sector including EPA, the US Dept. of Justice, several states, various agencies such as the California DTSC, various municipalities, etc.). Dr. Sahu has performed projects in all 50 states, numerous local jurisdictions and internationally.

In addition to consulting, for approximately twenty years, Dr. Sahu taught numerous courses in several Southern California universities including UCLA (air pollution), UC Riverside (air pollution, process hazard analysis), and Loyola Marymount University (air pollution, risk assessment, hazardous waste management). He also taught at Caltech, his alma mater (various engineering courses), at the University of Southern California (air pollution controls) and at California State University, Fullerton (transportation and air quality).

Dr. Sahu has and continues to provide expert witness services in a number of environmental areas discussed above in both state and Federal courts as well as before administrative bodies (please see Annex A).

EXPERIENCE RECORD

2000-present **Independent Consultant.** Providing a variety of private sector (industrial companies, land development companies, law firms, etc.), public sector (such as the US Department of Justice), and public interest group clients with project management, environmental consulting, project management, as well as regulatory and engineering support consulting services.

1995-2000 Parsons ES, **Associate, Senior Project Manager and Department Manager for** Air Quality/Geosciences/Hazardous Waste Groups, Pasadena. Responsible for the management of a group of approximately 24 air quality and environmental professionals, 15 geoscience, and 10 hazardous waste professionals providing full-service consulting, project management, regulatory compliance and A/E design assistance in all areas.

Parsons ES, **Manager for Air Source Testing Services**. Responsible for the management of 8 individuals in the area of air source testing and air regulatory permitting projects located in Bakersfield, California.

1992-1995 Engineering-Science, Inc. **Principal Engineer and Senior Project Manager** in the air quality department. Responsibilities included multimedia regulatory compliance and permitting (including hazardous and nuclear materials), air pollution engineering (emissions from stationary and mobile sources, control of criteria and air toxics, dispersion modeling, risk assessment, visibility analysis, odor analysis), supervisory functions and project management.

1990-1992 Engineering-Science, Inc. **Principal Engineer and Project Manager** in the air quality department. Responsibilities included permitting, tracking regulatory issues, technical analysis, and supervisory functions on numerous air, water, and hazardous waste projects. Responsibilities also include client and agency interfacing, project cost and schedule control, and reporting to internal and external upper management regarding project status.

1989-1990 Kinetics Technology International, Corp. **Development Engineer.** Involved in thermal engineering R&D and project work related to low-NOx ceramic radiant burners, fired heater NOx reduction, SCR design, and fired heater retrofitting.

1988-1989 Heat Transfer Research, Inc. **Research Engineer**. Involved in the design of fired heaters, heat exchangers, air coolers, and other non-fired equipment. Also did research in the area of heat exchanger tube vibrations.

EDUCATION

1984-1988 Ph.D., Mechanical Engineering, California Institute of Technology (Caltech), Pasadena, CA.

1984 M. S., Mechanical Engineering, California Institute of Technology (Caltech), Pasadena, CA.

1978-1983 B. Tech (Honors), Mechanical Engineering, Indian Institute of Technology (IIT) Kharagpur, India

TEACHING EXPERIENCE

Caltech

"Thermodynamics," Teaching Assistant, California Institute of Technology, 1983, 1987.

"Air Pollution Control," Teaching Assistant, California Institute of Technology, 1985.

"Caltech Secondary and High School Saturday Program," - taught various mathematics (algebra through calculus) and science (physics and chemistry) courses to high school students, 1983-1989.

"Heat Transfer," - taught this course in the Fall and Winter terms of 1994-1995 in the Division of Engineering and Applied Science.

“Thermodynamics and Heat Transfer,” Fall and Winter Terms of 1996-1997.

U.C. Riverside, Extension

"Toxic and Hazardous Air Contaminants," University of California Extension Program, Riverside, California. Various years since 1992.

"Prevention and Management of Accidental Air Emissions," University of California Extension Program, Riverside, California. Various years since 1992.

"Air Pollution Control Systems and Strategies," University of California Extension Program, Riverside, California, Summer 1992-93, Summer 1993-1994.

"Air Pollution Calculations," University of California Extension Program, Riverside, California, Fall 1993-94, Winter 1993-94, Fall 1994-95.

"Process Safety Management," University of California Extension Program, Riverside, California. Various years since 1992-2010.

"Process Safety Management," University of California Extension Program, Riverside, California, at SCAQMD, Spring 1993-94.

"Advanced Hazard Analysis - A Special Course for LEPCs," University of California Extension Program, Riverside, California, taught at San Diego, California, Spring 1993-1994.

"Advanced Hazardous Waste Management" University of California Extension Program, Riverside, California. 2005.

Loyola Marymount University

"Fundamentals of Air Pollution - Regulations, Controls and Engineering," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1993.

"Air Pollution Control," Loyola Marymount University, Dept. of Civil Engineering, Fall 1994.

"Environmental Risk Assessment," Loyola Marymount University, Dept. of Civil Engineering. Various years since 1998.

"Hazardous Waste Remediation" Loyola Marymount University, Dept. of Civil Engineering. Various years since 2006.

University of Southern California

"Air Pollution Controls," University of Southern California, Dept. of Civil Engineering, Fall 1993, Fall 1994.

"Air Pollution Fundamentals," University of Southern California, Dept. of Civil Engineering, Winter 1994.

University of California, Los Angeles

"Air Pollution Fundamentals," University of California, Los Angeles, Dept. of Civil and Environmental Engineering, Spring 1994, Spring 1999, Spring 2000, Spring 2003, Spring 2006, Spring 2007, Spring 2008, Spring 2009.

International Programs

"Environmental Planning and Management," 5 week program for visiting Chinese delegation, 1994.

"Environmental Planning and Management," 1 day program for visiting Russian delegation, 1995.

"Air Pollution Planning and Management," IEP, UCR, Spring 1996.

"Environmental Issues and Air Pollution," IEP, UCR, October 1996.

PROFESSIONAL AFFILIATIONS AND HONORS

President of India Gold Medal, IIT Kharagpur, India, 1983.

Member of the Alternatives Assessment Committee of the Grand Canyon Visibility Transport Commission, established by the Clean Air Act Amendments of 1990, 1992.

American Society of Mechanical Engineers: Los Angeles Section Executive Committee, Heat Transfer Division, and Fuels and Combustion Technology Division, 1987-mid-1990s.

Air and Waste Management Association, West Coast Section, 1989-mid-2000s.

PROFESSIONAL CERTIFICATIONS

EIT, California (#XE088305), 1993.

REA I, California (#07438), 2000.

Certified Permitting Professional, South Coast AQMD (#C8320), since 1993.

QEP, Institute of Professional Environmental Practice, since 2000.

CEM, State of Nevada (#EM-1699). Expiration 10/07/2021.

PUBLICATIONS (PARTIAL LIST)

"Physical Properties and Oxidation Rates of Chars from Bituminous Coals," with Y.A. Levendis, R.C. Flagan and G.R. Gavalas, *Fuel*, **67**, 275-283 (1988).

"Char Combustion: Measurement and Analysis of Particle Temperature Histories," with R.C. Flagan, G.R. Gavalas and P.S. Northrop, *Comb. Sci. Tech.* **60**, 215-230 (1988).

"On the Combustion of Bituminous Coal Chars," PhD Thesis, California Institute of Technology (1988).

"Optical Pyrometry: A Powerful Tool for Coal Combustion Diagnostics," *J. Coal Quality*, **8**, 17-22 (1989).

"Post-Ignition Transients in the Combustion of Single Char Particles," with Y.A. Levendis, R.C. Flagan and G.R. Gavalas, *Fuel*, **68**, 849-855 (1989).

"A Model for Single Particle Combustion of Bituminous Coal Char." Proc. ASME National Heat Transfer Conference, Philadelphia, **HTD-Vol. 106**, 505-513 (1989).

"Discrete Simulation of Cenospheric Coal-Char Combustion," with R.C. Flagan and G.R. Gavalas, *Combust. Flame*, **77**, 337-346 (1989).

"Particle Measurements in Coal Combustion," with R.C. Flagan, in "**Combustion Measurements**" (ed. N. Chigier), Hemisphere Publishing Corp. (1991).

"Cross Linking in Pore Structures and Its Effect on Reactivity," with G.R. Gavalas in preparation.

"Natural Frequencies and Mode Shapes of Straight Tubes," Proprietary Report for Heat Transfer Research Institute, Alhambra, CA (1990).

"Optimal Tube Layouts for Kamui SL-Series Exchangers," with K. Ishihara, Proprietary Report for Kamui Company Limited, Tokyo, Japan (1990).

"HTRI Process Heater Conceptual Design," Proprietary Report for Heat Transfer Research Institute, Alhambra, CA (1990).

"Asymptotic Theory of Transonic Wind Tunnel Wall Interference," with N.D. Malmuth and others, Arnold Engineering Development Center, Air Force Systems Command, USAF (1990).

"Gas Radiation in a Fired Heater Convection Section," Proprietary Report for Heat Transfer Research Institute, College Station, TX (1990).

"Heat Transfer and Pressure Drop in NTIW Heat Exchangers," Proprietary Report for Heat Transfer Research Institute, College Station, TX (1991).

"NOx Control and Thermal Design," Thermal Engineering Tech Briefs, (1994).

“From Purchase of Landmark Environmental Insurance to Remediation: Case Study in Henderson, Nevada,” with Robin E. Bain and Jill Quillin, presented at the AQMA Annual Meeting, Florida, 2001.

“The Jones Act Contribution to Global Warming, Acid Rain and Toxic Air Contaminants,” with Charles W. Botsford, presented at the AQMA Annual Meeting, Florida, 2001.

PRESENTATIONS (PARTIAL LIST)

"Pore Structure and Combustion Kinetics - Interpretation of Single Particle Temperature-Time Histories," with P.S. Northrop, R.C. Flagan and G.R. Gavalas, presented at the AIChE Annual Meeting, New York (1987).

"Measurement of Temperature-Time Histories of Burning Single Coal Char Particles," with R.C. Flagan, presented at the American Flame Research Committee Fall International Symposium, Pittsburgh, (1988).

"Physical Characterization of a Cenospheric Coal Char Burned at High Temperatures," with R.C. Flagan and G.R. Gavalas, presented at the Fall Meeting of the Western States Section of the Combustion Institute, Laguna Beach, California (1988).

"Control of Nitrogen Oxide Emissions in Gas Fired Heaters - The Retrofit Experience," with G. P. Croce and R. Patel, presented at the International Conference on Environmental Control of Combustion Processes (Jointly sponsored by the American Flame Research Committee and the Japan Flame Research Committee), Honolulu, Hawaii (1991).

"Air Toxics - Past, Present and the Future," presented at the Joint AIChE/AAEE Breakfast Meeting at the AIChE 1991 Annual Meeting, Los Angeles, California, November 17-22 (1991).

"Air Toxics Emissions and Risk Impacts from Automobiles Using Reformulated Gasolines," presented at the Third Annual Current Issues in Air Toxics Conference, Sacramento, California, November 9-10 (1992).

"Air Toxics from Mobile Sources," presented at the Environmental Health Sciences (ESE) Seminar Series, UCLA, Los Angeles, California, November 12, (1992).

"Kilns, Ovens, and Dryers - Present and Future," presented at the Gas Company Air Quality Permit Assistance Seminar, Industry Hills Sheraton, California, November 20, (1992).

"The Design and Implementation of Vehicle Scrapping Programs," presented at the 86th Annual Meeting of the Air and Waste Management Association, Denver, Colorado, June 12, 1993.

"Air Quality Planning and Control in Beijing, China," presented at the 87th Annual Meeting of the Air and Waste Management Association, Cincinnati, Ohio, June 19-24, 1994.

Annex A

Expert Litigation Support

A. Occasions where Dr. Sahu has provided Written or Oral testimony before Congress:

1. In July 2012, provided expert written and oral testimony to the House Subcommittee on Energy and the Environment, Committee on Science, Space, and Technology at a Hearing entitled "Hitting the Ethanol Blend Wall – Examining the Science on E15."

B. Matters for which Dr. Sahu has provided affidavits and expert reports include:

2. Affidavit for Rocky Mountain Steel Mills, Inc. located in Pueblo Colorado – dealing with the technical uncertainties associated with night-time opacity measurements in general and at this steel mini-mill.
3. Expert reports and depositions (2/28/2002 and 3/1/2002; 12/2/2003 and 12/3/2003; 5/24/2004) on behalf of the United States in connection with the Ohio Edison NSR Cases. *United States, et al. v. Ohio Edison Co., et al.*, C2-99-1181 (Southern District of Ohio).
4. Expert reports and depositions (5/23/2002 and 5/24/2002) on behalf of the United States in connection with the Illinois Power NSR Case. *United States v. Illinois Power Co., et al.*, 99-833-MJR (Southern District of Illinois).
5. Expert reports and depositions (11/25/2002 and 11/26/2002) on behalf of the United States in connection with the Duke Power NSR Case. *United States, et al. v. Duke Energy Corp.*, 1:00-CV-1262 (Middle District of North Carolina).
6. Expert reports and depositions (10/6/2004 and 10/7/2004; 7/10/2006) on behalf of the United States in connection with the American Electric Power NSR Cases. *United States, et al. v. American Electric Power Service Corp., et al.*, C2-99-1182, C2-99-1250 (Southern District of Ohio).
7. Affidavit (March 2005) on behalf of the Minnesota Center for Environmental Advocacy and others in the matter of the Application of Heron Lake BioEnergy LLC to construct and operate an ethanol production facility – submitted to the Minnesota Pollution Control Agency.
8. Expert Report and Deposition (10/31/2005 and 11/1/2005) on behalf of the United States in connection with the East Kentucky Power Cooperative NSR Case. *United States v. East Kentucky Power Cooperative, Inc*., 5:04-cv-00034-KSF (Eastern District of Kentucky).
9. Affidavits and deposition on behalf of Basic Management Inc. (BMI) Companies in connection with the BMI vs. USA remediation cost recovery Case.
10. Expert Report on behalf of Penn Future and others in the Cambria Coke plant permit challenge in Pennsylvania.
11. Expert Report on behalf of the Appalachian Center for the Economy and the Environment and others in the Western Greenbrier permit challenge in West Virginia.
12. Expert Report, deposition (via telephone on January 26, 2007) on behalf of various Montana petitioners (Citizens Awareness Network (CAN), Women's Voices for the Earth (WVE) and the Clark Fork Coalition (CFC)) in the Thompson River Cogeneration LLC Permit No. 3175-04 challenge.
13. Expert Report and deposition (2/2/07) on behalf of the Texas Clean Air Cities Coalition at the Texas State Office of Administrative Hearings (SOAH) in the matter of the permit challenges to TXU Project Apollo's eight new proposed PRB-fired PC boilers located at seven TX sites.
14. Expert Testimony (July 2007) on behalf of the Izaak Walton League of America and others in connection with the acquisition of power by Xcel Energy from the proposed Gascoyne Power Plant – at the State of Minnesota,

Office of Administrative Hearings for the Minnesota PUC (MPUC No. E002/CN-06-1518; OAH No. 12-2500-17857-2).

15. Affidavit (July 2007) Comments on the Big Cajun I Draft Permit on behalf of the Sierra Club – submitted to the Louisiana DEQ.

16. Expert Report and Deposition (12/13/2007) on behalf of Commonwealth of Pennsylvania – Dept. of Environmental Protection, State of Connecticut, State of New York, and State of New Jersey (Plaintiffs) in connection with the Allegheny Energy NSR Case. *Plaintiffs v. Allegheny Energy Inc., et al.,* 2:05cv0885 (Western District of Pennsylvania).

17. Expert Reports and Pre-filed Testimony before the Utah Air Quality Board on behalf of Sierra Club in the Sevier Power Plant permit challenge.

18. Expert Report and Deposition (October 2007) on behalf of MTD Products Inc., in connection with *General Power Products, LLC v MTD Products Inc*., 1:06 CVA 0143 (Southern District of Ohio, Western Division) .

19. Expert Report and Deposition (June 2008) on behalf of Sierra Club and others in the matter of permit challenges (Title V: 28.0801-29 and PSD: 28.0803-PSD) for the Big Stone II unit, proposed to be located near Milbank, South Dakota.

20. Expert Reports, Affidavit, and Deposition (August 15, 2008) on behalf of Earthjustice in the matter of air permit challenge (CT-4631) for the Basin Electric Dry Fork station, under construction near Gillette, Wyoming before the Environmental Quality Council of the State of Wyoming.

21. Affidavits (May 2010/June 2010 in the Office of Administrative Hearings))/Declaration and Expert Report (November 2009 in the Office of Administrative Hearings) on behalf of NRDC and the Southern Environmental Law Center in the matter of the air permit challenge for Duke Cliffside Unit 6. Office of Administrative Hearing Matters 08 EHR 0771, 0835 and 0836 and 09 HER 3102, 3174, and 3176 (consolidated).

22. Declaration (August 2008), Expert Report (January 2009), and Declaration (May 2009) on behalf of Southern Alliance for Clean Energy in the matter of the air permit challenge for Duke Cliffside Unit 6. *Southern Alliance for Clean Energy et al., v. Duke Energy Carolinas, LLC*, Case No. 1:08-cv-00318-LHT-DLH (Western District of North Carolina, Asheville Division).

23. Declaration (August 2008) on behalf of the Sierra Club in the matter of Dominion Wise County plant MACT.us

24. Expert Report (June 2008) on behalf of Sierra Club for the Green Energy Resource Recovery Project, MACT Analysis.

25. Expert Report (February 2009) on behalf of Sierra Club and the Environmental Integrity Project in the matter of the air permit challenge for NRG Limestone's proposed Unit 3 in Texas.

26. Expert Report (June 2009) on behalf of MTD Products, Inc., in the matter of *Alice Holmes and Vernon Holmes v. Home Depot USA, Inc., et al.*

27. Expert Report (August 2009) on behalf of Sierra Club and the Southern Environmental Law Center in the matter of the air permit challenge for Santee Cooper's proposed Pee Dee plant in South Carolina).

28. Statements (May 2008 and September 2009) on behalf of the Minnesota Center for Environmental Advocacy to the Minnesota Pollution Control Agency in the matter of the Minnesota Haze State Implementation Plans.

29. Expert Report (August 2009) on behalf of Environmental Defense, in the matter of permit challenges to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

30. Expert Report and Rebuttal Report (September 2009) on behalf of the Sierra Club, in the matter of challenges to the proposed Medicine Bow Fuel and Power IGL plant in Cheyenne, Wyoming.

31. Expert Report (December 2009) and Rebuttal reports (May 2010 and June 2010) on behalf of the United States in connection with the Alabama Power Company NSR Case. *United States v. Alabama Power Company*, CV-01-HS-152-S (Northern District of Alabama, Southern Division).

32. Pre-filed Testimony (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed White Stallion Energy Center coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

33. Pre-filed Testimony (July 2010) and Written Rebuttal Testimony (August 2010) on behalf of the State of New Mexico Environment Department in the matter of Proposed Regulation 20.2.350 NMAC – *Greenhouse Gas Cap and Trade Provisions,* No. EIB 10-04 (R), to the State of New Mexico, Environmental Improvement Board.

34. Expert Report (August 2010) and Rebuttal Expert Report (October 2010) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana) – Liability Phase.

35. Declaration (August 2010), Reply Declaration (November 2010), Expert Report (April 2011), Supplemental and Rebuttal Expert Report (July 2011) on behalf of the United States in the matter of DTE Energy Company and Detroit Edison Company (Monroe Unit 2). *United States of America v. DTE Energy Company and Detroit Edison Company*, Civil Action No. 2:10-cv-13101-BAF-RSW (Eastern District of Michigan).

36. Expert Report and Deposition (August 2010) as well as Affidavit (September 2010) on behalf of Kentucky Waterways Alliance, Sierra Club, and Valley Watch in the matter of challenges to the NPDES permit issued for the Trimble County power plant by the Kentucky Energy and Environment Cabinet to Louisville Gas and Electric, File No. DOW-41106-047.

37. Expert Report (August 2010), Rebuttal Expert Report (September 2010), Supplemental Expert Report (September 2011), and Declaration (November 2011) on behalf of Wild Earth Guardians in the matter of opacity exceedances and monitor downtime at the Public Service Company of Colorado (Xcel)'s Cherokee power plant. No. 09-cv-1862 (District of Colorado).

38. Written Direct Expert Testimony (August 2010) and Affidavit (February 2012) on behalf of Fall-Line Alliance for a Clean Environment and others in the matter of the PSD Air Permit for Plant Washington issued by Georgia DNR at the Office of State Administrative Hearing, State of Georgia (OSAH-BNR-AQ-1031707-98-WALKER).

39. Deposition (August 2010) on behalf of Environmental Defense, in the matter of the remanded permit challenge to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

40. Expert Report, Supplemental/Rebuttal Expert Report, and Declarations (October 2010, November 2010, September 2012) on behalf of New Mexico Environment Department (Plaintiff-Intervenor), Grand Canyon Trust and Sierra Club (Plaintiffs) in the matter of *Plaintiffs v. Public Service Company of New Mexico* (PNM), Civil No. 1:02-CV-0552 BB/ATC (ACE) (District of New Mexico).

41. Expert Report (October 2010) and Rebuttal Expert Report (November 2010) (BART Determinations for PSCo Hayden and CSU Martin Drake units) to the Colorado Air Quality Commission on behalf of Coalition of Environmental Organizations.

42. Expert Report (November 2010) (BART Determinations for TriState Craig Units, CSU Nixon Unit, and PRPA Rawhide Unit) to the Colorado Air Quality Commission on behalf of Coalition of Environmental Organizations.

43. Declaration (November 2010) on behalf of the Sierra Club in connection with the Martin Lake Station Units 1, 2, and 3. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Case No. 5:10-cv-00156-DF-CMC (Eastern District of Texas, Texarkana Division).

44. Pre-Filed Testimony (January 2011) and Declaration (February 2011) to the Georgia Office of State Administrative Hearings (OSAH) in the matter of Minor Source HAPs status for the proposed Longleaf Energy Associates power plant (OSAH-BNR-AQ-1115157-60-HOWELLS) on behalf of the Friends of the Chattahoochee and the Sierra Club).

45. Declaration (February 2011) in the matter of the Draft Title V Permit for RRI Energy MidAtlantic Power Holdings LLC Shawville Generating Station (Pennsylvania), ID No. 17-00001 on behalf of the Sierra Club.

46. Expert Report (March 2011), Rebuttal Expert Report (June 2011) on behalf of the United States in *United States of America v. Cemex, Inc.*, Civil Action No. 09-cv-00019-MSK-MEH (District of Colorado).

47. Declaration (April 2011) and Expert Report (July 16, 2012) in the matter of the Lower Colorado River Authority (LCRA)'s Fayette (Sam Seymour) Power Plant on behalf of the Texas Campaign for the Environment. *Texas Campaign for the Environment v. Lower Colorado River Authority,* Civil Action No. 4:11-cv-00791 (Southern District of Texas, Houston Division).

48. Declaration (June 2011) on behalf of the Plaintiffs MYTAPN in the matter of Microsoft-Yes, Toxic Air Pollution-No (MYTAPN) v. State of Washington, Department of Ecology and Microsoft Corporation Columbia Data Center to the Pollution Control Hearings Board, State of Washington, Matter No. PCHB No. 10-162.

49. Expert Report (June 2011) on behalf of the New Hampshire Sierra Club at the State of New Hampshire Public Utilities Commission, Docket No. 10-261 – the 2010 Least Cost Integrated Resource Plan (LCIRP) submitted by the Public Service Company of New Hampshire (re. Merrimack Station Units 1 and 2).

50. Declaration (August 2011) in the matter of the Sandy Creek Energy Associates L.P. Sandy Creek Power Plant on behalf of Sierra Club and Public Citizen. *Sierra Club, Inc. and Public Citizen, Inc. v. Sandy Creek Energy Associates, L.P.,* Civil Action No. A-08-CA-648-LY (Western District of Texas, Austin Division).

51. Expert Report (October 2011) on behalf of the Defendants in the matter of *John Quiles and Jeanette Quiles et al. v. Bradford-White Corporation, MTD Products, Inc., Kohler Co., et al.,* Case No. 3:10-cv-747 (TJM/DEP) (Northern District of New York).

52. Declaration (October 2011) on behalf of the Plaintiffs in the matter of *American Nurses Association et. al. (Plaintiffs), v. US EPA (Defendant)*, Case No. 1:08-cv-02198-RMC (US District Court for the District of Columbia).

53. Declaration (February 2012) and Second Declaration (February 2012) in the matter of *Washington Environmental Council and Sierra Club Washington State Chapter v. Washington State Department of Ecology and Western States Petroleum Association,* Case No. 11-417-MJP (Western District of Washington).

54. Expert Report (March 2012) and Supplemental Expert Report (November 2013) in the matter of *Environment Texas Citizen Lobby, Inc and Sierra Club v. ExxonMobil Corporation et al.,* Civil Action No. 4:10-cv-4969 (Southern District of Texas, Houston Division).

55. Declaration (March 2012) in the matter of *Center for Biological Diversity, et al. v. United States Environmental Protection Agency,* Case No. 11-1101 (consolidated with 11-1285, 11-1328 and 11-1336) (US Court of Appeals for the District of Columbia Circuit).

56. Declaration (March 2012) in the matter of *Sierra Club v. The Kansas Department of Health and Environment*, Case No. 11-105,493-AS (Holcomb power plant) (Supreme Court of the State of Kansas).

57. Declaration (March 2012) in the matter of the Las Brisas Energy Center *Environmental Defense Fund et al., v. Texas Commission on Environmental Quality,* Cause No. D-1-GN-11-001364 (District Court of Travis County, Texas, 261st Judicial District).

58. Expert Report (April 2012), Supplemental and Rebuttal Expert Report (July 2012), and Supplemental Rebuttal Expert Report (August 2012) on behalf of the states of New Jersey and Connecticut in the matter of the Portland Power plant *State of New Jersey and State of Connecticut (Intervenor-Plaintiff) v. RRI Energy Mid-Atlantic Power Holdings et al.,* Civil Action No. 07-CV-5298 (JKG) (Eastern District of Pennsylvania).

59. Declaration (April 2012) in the matter of the EPA's EGU MATS Rule, on behalf of the Environmental Integrity Project.

60. Expert Report (August 2012) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana) – Harm Phase.

61. Declaration (September 2012) in the Matter of the Application of *Energy Answers Incinerator, Inc.* for a Certificate of Public Convenience and Necessity to Construct a 120 MW Generating Facility in Baltimore City, Maryland, before the Public Service Commission of Maryland, Case No. 9199.

62. Expert Report (October 2012) on behalf of the Appellants (Robert Concilus and Leah Humes) in the matter of Robert Concilus and Leah Humes v. Commonwealth of Pennsylvania Department of Environmental Protection and Crawford Renewable Energy, before the Commonwealth of Pennsylvania Environmental Hearing Board, Docket No. 2011-167-R.

63. Expert Report (October 2012), Supplemental Expert Report (January 2013), and Affidavit (June 2013) in the matter of various Environmental Petitioners v. North Carolina DENR/DAQ and Carolinas Cement Company, before the Office of Administrative Hearings, State of North Carolina.

64. Pre-filed Testimony (October 2012) on behalf of No-Sag in the matter of the North Springfield Sustainable Energy Project before the State of Vermont, Public Service Board.

65. Pre-filed Testimony (November 2012) on behalf of Clean Wisconsin in the matter of Application of Wisconsin Public Service Corporation for Authority to Construct and Place in Operation a New Multi-Pollutant Control Technology System (ReACT) for Unit 3 of the Weston Generating Station, before the Public Service Commission of Wisconsin, Docket No. 6690-CE-197.

66. Expert Report (February 2013) on behalf of Petitioners in the matter of Credence Crematory, Cause No. 12-A-J-4538 before the Indiana Office of Environmental Adjudication.

67. Expert Report (April 2013), Rebuttal report (July 2013), and Declarations (October 2013, November 2013) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).

68. Declaration (April 2013) on behalf of Petitioners in the matter of *Sierra Club, et al., (Petitioners) v Environmental Protection Agency et al. (Resppondents),* Case No., 13-1112, (Court of Appeals, District of Columbia Circuit).

69. Expert Report (May 2013) and Rebuttal Expert Report (July 2013) on behalf of the Sierra Club in connection with the Luminant Martin Lake Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 5:10-cv-0156-MHS-CMC (Eastern District of Texas, Texarkana Division).

70. Declaration (August 2013) on behalf of A. J. Acosta Company, Inc., in the matter of *A. J. Acosta Company, Inc., v. County of San Bernardino*, Case No. CIVSS803651.

71. Comments (October 2013) on behalf of the Washington Environmental Council and the Sierra Club in the matter of the Washington State Oil Refinery RACT (for Greenhouse Gases), submitted to the Washington State Department of Ecology, the Northwest Clean Air Agency, and the Puget Sound Clean Air Agency.

72. Statement (November 2013) on behalf of various Environmental Organizations in the matter of the Boswell Energy Center (BEC) Unit 4 Environmental Retrofit Project, to the Minnesota Public Utilities Commission, Docket No. E-015/M-12-920.

73. Expert Report (December 2013) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).

74. Expert Testimony (December 2013) on behalf of the Sierra Club in the matter of Public Service Company of New Hampshire Merrimack Station Scrubber Project and Cost Recovery, Docket No. DE 11-250, to the State of New Hampshire Public Utilities Commission.

75. Expert Report (January 2014) on behalf of Baja, Inc., in *Baja, Inc., v. Automotive Testing and Development Services, Inc. et. al*, Civil Action No. 8:13-CV-02057-GRA (District of South Carolina, Anderson/Greenwood Division).

76. Declaration (March 2014) on behalf of the Center for International Environmental Law, Chesapeake Climate Action Network, Friends of the Earth, Pacific Environment, and the Sierra Club (Plaintiffs) in the matter of *Plaintiffs v. the Export-Import Bank (Ex-Im Bank) of the United States*, Civil Action No. 13-1820 RC (District Court for the District of Columbia).

77. Declaration (April 2014) on behalf of Respondent-Intervenors in the matter of *Mexichem Specialty Resins Inc., et al., (Petitioners) v Environmental Protection Agency et al.,* Case No., 12-1260 (and Consolidated Case Nos. 12-1263, 12-1265, 12-1266, and 12-1267), (Court of Appeals, District of Columbia Circuit).

78. Direct Prefiled Testimony (June 2014) on behalf of the Michigan Environmental Council and the Sierra Club in the matter of the Application of DTE Electric Company for Authority to Implement a Power Supply Cost Recovery (PSCR) Plan in its Rate Schedules for 2014 Metered Jurisdictional Sales of Electricity, Case No. U-17319 (Michigan Public Service Commission).

79. Expert Report (June 2014) on behalf of ECM Biofilms in the matter of the US Federal Trade Commission (FTC) v. ECM Biofilms (FTC Docket #9358).

80. Direct Prefiled Testimony (August 2014) on behalf of the Michigan Environmental Council and the Sierra Club in the matter of the Application of Consumers Energy Company for Authority to Implement a Power Supply Cost Recovery (PSCR) Plan in its Rate Schedules for 2014 Metered Jurisdictional Sales of Electricity, Case No. U-17317 (Michigan Public Service Commission).

81. Declaration (July 2014) on behalf of Public Health Intervenors in the matter of *EME Homer City Generation v. US EPA* (Case No. 11-1302 and consolidated cases) relating to the lifting of the stay entered by the Court on December 30, 2011 (US Court of Appeals for the District of Columbia).

82. Expert Report (September 2014), Rebuttal Expert Report (December 2014) and Supplemental Expert Report (March 2015) on behalf of Plaintiffs in the matter of *Sierra Club and Montana Environmental Information Center (Plaintiffs) v. PPL Montana LLC, Avista Corporation, Puget Sound Energy, Portland General Electric Company, Northwestern Corporation, and Pacificorp (Defendants)*, Civil Action No. CV 13-32-BLG-DLC-JCL (US District Court for the District of Montana, Billings Division).

83. Expert Report (November 2014) on behalf of Niagara County, the Town of Lewiston, and the Villages of Lewiston and Youngstown in the matter of CWM Chemical Services, LLC New York State Department of Environmental Conservation (NYSDEC) Permit Application Nos.: 9-2934-00022/00225, 9-2934-00022/00231, 9-2934-00022/00232, and 9-2934-00022/00249 (pending).

84. *Declaration (January 2015) relating to Startup/Shutdown in the MATS Rule (EPA Docket ID No. EPA-HQ-OAR-2009-0234) on behalf of the Environmental Integrity Project.*

85. Pre-filed Direct Testimony (March 2015), Supplemental Testimony (May 2015), and Surrebuttal Testimony (December 2015) on behalf of Friends of the Columbia Gorge in the matter of the Application for a Site Certificate for the Troutdale Energy Center before the Oregon Energy Facility Siting Council.

86. Brief of Amici Curiae Experts in Air Pollution Control and Air Quality Regulation in Support of the Respondents, On Writs of Certiorari to the US Court of Appeals for the District of Columbia, No. 14-46, 47, 48. *Michigan et. al., (Petitioners) v. EPA et. al., Utility Air Regulatory Group (Petitioners) v. EPA et. al., National Mining Association et. al., (Petitioner) v. EPA et. al.,* (Supreme Court of the United States).

87. Expert Report (March 2015) and Rebuttal Expert Report (January 2016) on behalf of Plaintiffs in the matter of *Conservation Law Foundation v. Broadrock Gas Services LLC, Rhode Island LFG GENCO LLC, and Rhode Island Resource Recovery Corporation (Defendants)*, Civil Action No. 1:13-cv-00777-M-PAS (US District Court for the District of Rhode Island).

88. Declaration (April 2015) relating to various Technical Corrections for the MATS Rule (EPA Docket ID No. EPA-HQ-OAR-2009-0234) on behalf of the Environmental Integrity Project.

89. Direct Prefiled Testimony (May 2015) on behalf of the Michigan Environmental Council, the Natural Resources Defense Council, and the Sierra Club in the matter of the Application of DTE Electric Company for Authority to Increase its Rates, Amend its Rate Schedules and Rules Governing the Distribution and Supply of Electric Energy and for Miscellaneous Accounting Authority, Case No. U-17767 (Michigan Public Service Commission).

90. Expert Report (July 2015) and Rebuttal Expert Report (July 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).

91. Declaration (August 2015, Docket No. 1570376) in support of "Opposition of Respondent-Intervenors American Lung Association, et. al., to Tri-State Generation's Emergency Motion;" Declaration (September 2015, Docket No. 1574820) in support of "Joint Motion of the State, Local Government, and Public Health Respondent-Intervenors for Remand Without Vacatur;" Declaration (October 2015) in support of "Joint Motion of the State, Local Government, and Public Health Respondent-Intervenors to State and Certain Industry Petitioners' Motion to Govern, *White Stallion Energy Center, LLC v. US EPA*, Case No. 12-1100 (US Court of Appeals for the District of Columbia).

92. Declaration (September 2015) in support of the Draft Title V Permit for Dickerson Generating Station (Proposed Permit No 24-031-0019) on behalf of the Environmental Integrity Project.

93. Expert Report (Liability Phase) (December 2015) and Rebuttal Expert Report (February 2016) on behalf of Plaintiffs in the matter of *Natural Resources Defense Council, Inc., Sierra Club, Inc., Environmental Law and Policy Center, and Respiratory Health Association v. Illinois Power Resources LLC, and Illinois Power Resources Generating LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (US District Court for the Central District of Illinois, Peoria Division).

94. Declaration (December 2015) in support of the Petition to Object to the Title V Permit for Morgantown Generating Station (Proposed Permit No 24-017-0014) on behalf of the Environmental Integrity Project.

95. Expert Report (November 2015) on behalf of Appellants in the matter of *Sierra Club, et al. v. Craig W. Butler, Director of Ohio Environmental Protection Agency et al.,* ERAC Case No. 14-256814.

96. Affidavit (January 2016) on behalf of Bridgewatch Detroit in the matter of *Bridgewatch Detroit v. Waterfront Petroleum Terminal Co., and Waterfront Terminal Holdings, LLC.*, in the Circuit Court for the County of Wayne, State of Michigan.

97. Expert Report (February 2016) and Rebuttal Expert Report (July 2016) on behalf of the challengers in the matter of the Delaware Riverkeeper Network, Clean Air Council, et. al., vs. Commonwealth of Pennsylvania Department of Environmental Protection and R. E. Gas Development LLC regarding the Geyer well site before the Pennsylvania Environmental Hearing Board.

98. Direct Testimony (May 2016) in the matter of Tesoro Savage LLC Vancouver Energy Distribution Terminal, Case No. 15-001 before the State of Washington Energy Facility Site Evaluation Council.

99. Declaration (June 2016) relating to deficiencies in air quality analysis for the proposed Millenium Bulk Terminal, Port of Longview, Washington.

100. Declaration (December 2016) relating to EPA's refusal to set limits on PM emissions from coal-fired power plants that reflect pollution reductions achievable with fabric filters on behalf of Environmental Integrity Project, Clean Air Council, Chesapeake Climate Action Network, Downwinders at Risk represented by Earthjustice in the matter of *ARIPPA v EPA, Case No. 15-1180.* (D.C. Circuit Court of Appeals).

101. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Huntley and Huntley Poseidon Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

102. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Backus Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

103. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Drakulic Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

104. Expert Report (January 2017) on the Environmental Impacts Analysis associated with the Apex Energy Deutsch Well Pad on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

105. Affidavit (February 2017) pertaining to deficiencies water discharge compliance issues at the Wood River Refinery in the matter of *People of the State of Illinois (Plaintiff) v. Phillips 66 Company, ConocoPhillips Company, WRB Refining LP (Defendants)*, Case No. 16-CH-656, (Circuit Court for the Third Judicial Circuit, Madison County, Illinois).

106. Expert Report (March 2017) on behalf of the Plaintiff pertaining to non-degradation analysis for waste water discharges from a power plant in the matter of *Sierra Club (Plaintiff) v. Pennsylvania Department of Environmental Protection (PADEP) and Lackawanna Energy Center*, Docket No. 2016-047-L (consolidated), (Pennsylvania Environmental Hearing Board).

107. Expert Report (March 2017) on behalf of the Plaintiff pertaining to air emissions from the Heritage incinerator in East Liverpool, Ohio in the matter of *Save our County (Plaintiff) v. Heritage Thermal Services, Inc. (Defendant), Case No. 4:16-CV-1544-BYP*, (US District Court for the Northern District of Ohio, Eastern Division).

108. Rebuttal Expert Report (June 2017) on behalf of Plaintiffs in the matter of *Casey Voight and Julie Voight (Plaintiffs) v Coyote Creek Mining Company LLC (Defendant),* Civil Action No. 1:15-CV-00109 (US District Court for the District of North Dakota, Western Division).

109. Expert Affidavit (August 2017) and Penalty/Remedy Expert Affidavit (October 2017) on behalf of Plaintiff in the matter of *Wildearth Guardians (Plaintiff) v Colorado Springs Utility Board (Defendant,)* Civil Action No. 1:15-cv-00357-CMA-CBS (US District Court for the District of Colorado).

110. Expert Report (August 2017) on behalf of Appellant in the matter of *Patricia Ann Troiano (Appellant) v. Upper Burrell Township Zoning Hearing Board (Appellee)*, Court of Common Pleas of Westmoreland County, Pennsylvania, Civil Division.

111. Expert Report (October 2017), Supplemental Expert Report (October 2017), and Rebuttal Expert Report (November 2017) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant,)* Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).

112. Declaration (December 2017) on behalf of the Environmental Integrity Project in the matter of permit issuance for ATI Flat Rolled Products Holdings, Breckenridge, PA to the Allegheny County Health Department.

113. Expert Report (Harm Phase) (January 2018), Rebuttal Expert Report (Harm Phase) (May 2018) and Supplemental Expert Report (Harm Phase) (April 2019) on behalf of Plaintiffs in the matter of *Natural Resources Defense Council, Inc., Sierra Club, Inc., and Respiratory Health Association v. Illinois Power Resources LLC, and Illinois Power Resources Generating LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (US District Court for the Central District of Illinois, Peoria Division).

114. Declaration (February 2018) on behalf of the Chesapeake Bay Foundation, et. al., in the matter of the Section 126 Petition filed by the state of Maryland in *State of Maryland v. Pruitt (Defendant)*, Civil Action No. JKB-17-2939 (Consolidated with No. JKB-17-2873) (US District Court for the District of Maryland).

115. Direct Pre-filed Testimony (March 2018) on behalf of the National Parks Conservation Association (NPCA) in the matter of *NPCA v State of Washington, Department of Ecology and BP West Coast Products, LLC*, PCHB No. 17-055 (Pollution Control Hearings Board for the State of Washington.

116. Expert Affidavit (April 2018) and Second Expert Affidavit (May 2018) on behalf of Petitioners in the matter of *Coosa River Basin Initiative and Sierra Club (Petitioners) v State of Georgia Environmental Protection Division, Georgia Department of Natural Resources (Respondent) and Georgia Power Company (Intervenor/Respondent)*, Docket Nos: 1825406-BNR-WW-57-Howells and 1826761-BNR-WW-57-Howells, Office of State Administrative Hearings, State of Georgia.

117. Direct Pre-filed Testimony and Affidavit (December 2018) on behalf of Sierra Club and Texas Campaign for the Environment (Appellants) in the contested case hearing before the Texas State Office of Administrative Hearings in Docket Nos. 582-18-4846, 582-18-4847 (Application of GCGV Asset Holding, LLC for Air Quality Permit Nos. 146425/PSDTX1518 and 146459/PSDTX1520 in San Patricio County, Texas).

118. Expert Report (February 2019) on behalf of Sierra Club in the State of Florida, Division of Administrative Hearings, Case No. 18-2124EPP, Tampa Electric Company Big Bend Unit 1 Modernization Project Power Plant Siting Application No. PA79-12-A2.

119. Declaration (March 2019) on behalf of Earthjustice in the matter of comments on the renewal of the Title V Federal Operating Permit for Valero Houston refinery.

120. Expert Report (March 2019) on behalf of Plaintiffs for Class Certification in the matter of *Resendez et al v Precision Castparts Corporation* in the Circuit Court for the State of Oregon, County of Multnomah, Case No. 16cv16164.

121. Expert Report (June 2019), Affidavit (July 2019) and Rebuttal Expert Report (September 2019) on behalf of Appellants relating to the NPDES permit for the Cheswick power plant in the matter of *Three Rivers Waterkeeper and Sierra Club (Appellees) v. State of Pennsylvania Department of Environmental Protection (Appellee) and NRG Power Midwest (Permittee)*, before the Commonwealth of Pennsylvania Environmental Hearing Board, EHB Docket No. 2018-088-R.

122. Affidavit/Expert Report (August 2019) relating to the appeal of air permits issued to PTTGCA on behalf of Appellants in the matter of *Sierra Club (Appellants) v. Craig Butler, Director, et. al., Ohio EPA (Appellees)* before the State of Ohio Environmental Review Appeals Commission (ERAC), Case Nos. ERAC-19-6988 through -6991.

123. Expert Report (October 2019) relating to the appeal of air permit (Plan Approval) on behalf of Appellants in the matter of *Clean Air Council and Environmental Integrity Project (Appellants) v. Commonwealth of Pennsylvania Department of Environmental Protection and Sunoco Partners Marketing and Terminals L.P.*, before the Commonwealth of Pennsylvania Environmental Hearing Board, EHB Docket No. 2018-057-L.

124. Expert Report (December 2019) on behalf of Earthjustice in the matter of *Objection to the Issuance of PSD/NSR and Title V permits for Riverview Energy Corporation*, Dale, Indiana, before the Indiana Office of Environmental Adjudication, Cause No. 19-A-J-5073.

125. Affidavit (December 2019) on behalf of Plaintiff-Intervenor (Surfrider Foundation) in the matter of *United States and the State of Indiana (Plaintiffs), Surfrider Foundation (Plaintiff-Intervenor), and City of Chicago (Plaintiff-Intervenor) v. United States Steel Corporation (Defendant),* Civil Action No. 2:18-cv-00127 (US District Court for the Northern District of Indiana, Hammond Division).

126. Declaration (February 2020) in support of Petitioner's Motion for Stay of PSCAA NOC Order of Approval No. 11386 in the matter of the *Puyallup Tribe of Indians v. Puget Sound Clean Air Agency (PSCAA) and Puget Sound Energy (PSE), before the State of Washington Pollution Control Hearings Board*, PCHB No. P19-088.

C. Occasions where Dr. Sahu has provided oral testimony <u>in depositions, at trial or in similar proceedings</u> include the following:

127. Deposition on behalf of Rocky Mountain Steel Mills, Inc. located in Pueblo, Colorado – dealing with the manufacture of steel in mini-mills including methods of air pollution control and BACT in steel mini-mills and opacity issues at this steel mini-mill.

128. Trial Testimony (February 2002) on behalf of Rocky Mountain Steel Mills, Inc. in Denver District Court.

129. Trial Testimony (February 2003) on behalf of the United States in the Ohio Edison NSR Cases, *United States, et al. v. Ohio Edison Co., et al.*, C2-99-1181 (Southern District of Ohio).

130. Trial Testimony (June 2003) on behalf of the United States in the Illinois Power NSR Case, *United States v. Illinois Power Co., et al.*, 99-833-MJR (Southern District of Illinois).

131. Deposition (10/20/2005) on behalf of the United States in connection with the Cinergy NSR Case. *United States, et* al. *v. Cinergy Corp., et al.*, IP 99-1693-C-M/S (Southern District of Indiana).

132. Oral Testimony (August 2006) on behalf of the Appalachian Center for the Economy and the Environment re. the Western Greenbrier plant, WV before the West Virginia DEP.

133. Oral Testimony (May 2007) on behalf of various Montana petitioners (Citizens Awareness Network (CAN), Women's Voices for the Earth (WVE) and the Clark Fork Coalition (CFC)) re. the Thompson River Cogeneration plant before the Montana Board of Environmental Review.

134. Oral Testimony (October 2007) on behalf of the Sierra Club re. the Sevier Power Plant before the Utah Air Quality Board.

135. Oral Testimony (August 2008) on behalf of the Sierra Club and Clean Water re. Big Stone Unit II before the South Dakota Board of Minerals and the Environment.

136. Oral Testimony (February 2009) on behalf of the Sierra Club and the Southern Environmental Law Center re. Santee Cooper Pee Dee units before the South Carolina Board of Health and Environmental Control.

137. Oral Testimony (February 2009) on behalf of the Sierra Club and the Environmental Integrity Project re. NRG Limestone Unit 3 before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.

138. Deposition (July 2009) on behalf of MTD Products, Inc., in the matter of *Alice Holmes and Vernon Holmes v. Home Depot USA, Inc., et al*.

139. Deposition (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed Coleto Creek coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

140. Deposition (October 2009) on behalf of Environmental Defense, in the matter of permit challenges to the proposed Las Brisas coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

141. Deposition (October 2009) on behalf of the Sierra Club, in the matter of challenges to the proposed Medicine Bow Fuel and Power IGL plant in Cheyenne, Wyoming.

142. Deposition (October 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed Tenaska coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH). (April 2010).

143. Oral Testimony (November 2009) on behalf of the Environmental Defense Fund re. the Las Brisas Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.

144. Deposition (December 2009) on behalf of Environmental Defense and others, in the matter of challenges to the proposed White Stallion Energy Center coal fired power plant project at the Texas State Office of Administrative Hearings (SOAH).

145. Oral Testimony (February 2010) on behalf of the Environmental Defense Fund re. the White Stallion Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.

146. Deposition (June 2010) on behalf of the United States in connection with the Alabama Power Company NSR Case. *United States v. Alabama Power Company*, CV-01-HS-152-S (Northern District of Alabama, Southern Division).

147. Trial Testimony (September 2010) on behalf of Commonwealth of Pennsylvania – Dept. of Environmental Protection, State of Connecticut, State of New York, State of Maryland, and State of New Jersey (Plaintiffs) in connection with the Allegheny Energy NSR Case in US District Court in the Western District of Pennsylvania. *Plaintiffs v. Allegheny Energy Inc., et al.,* 2:05cv0885 (Western District of Pennsylvania).

148. Oral Direct and Rebuttal Testimony (September 2010) on behalf of Fall-Line Alliance for a Clean Environment and others in the matter of the PSD Air Permit for Plant Washington issued by Georgia DNR at the Office of State Administrative Hearing, State of Georgia (OSAH-BNR-AQ-1031707-98-WALKER).

149. Oral Testimony (September 2010) on behalf of the State of New Mexico Environment Department in the matter of Proposed Regulation 20.2.350 NMAC – *Greenhouse Gas Cap and Trade Provisions,* No. EIB 10-04 (R), to the State of New Mexico, Environmental Improvement Board.

150. Oral Testimony (October 2010) on behalf of the Environmental Defense Fund re. the Las Brisas Energy Center before the Texas State Office of Administrative Hearings (SOAH) Administrative Law Judges.

151. Oral Testimony (November 2010) regarding BART for PSCo Hayden, CSU Martin Drake units before the Colorado Air Quality Commission on behalf of the Coalition of Environmental Organizations.

152. Oral Testimony (December 2010) regarding BART for TriState Craig Units, CSU Nixon Unit, and PRPA Rawhide Unit) before the Colorado Air Quality Commission on behalf of the Coalition of Environmental Organizations.

153. Deposition (December 2010) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana).

154. Deposition (February 2011 and January 2012) on behalf of Wild Earth Guardians in the matter of opacity exceedances and monitor downtime at the Public Service Company of Colorado (Xcel)'s Cherokee power plant. No. 09-cv-1862 (D. Colo.).

155. Oral Testimony (February 2011) to the Georgia Office of State Administrative Hearings (OSAH) in the matter of Minor Source HAPs status for the proposed Longleaf Energy Associates power plant (OSAH-BNR-AQ-1115157-60-HOWELLS) on behalf of the Friends of the Chattahoochee and the Sierra Club).

156. Deposition (August 2011) on behalf of the United States in *United States of America v. Cemex, Inc.*, Civil Action No. 09-cv-00019-MSK-MEH (District of Colorado).

157. Deposition (July 2011) and Oral Testimony at Hearing (February 2012) on behalf of the Plaintiffs MYTAPN in the matter of Microsoft-Yes, Toxic Air Pollution-No (MYTAPN) v. State of Washington, Department of Ecology and Microsoft Corporation Columbia Data Center to the Pollution Control Hearings Board, State of Washington, Matter No. PCHB No. 10-162.

158. Oral Testimony at Hearing (March 2012) on behalf of the United States in connection with the Louisiana Generating NSR Case. *United States v. Louisiana Generating, LLC*, 09-CV100-RET-CN (Middle District of Louisiana).

159. Oral Testimony at Hearing (April 2012) on behalf of the New Hampshire Sierra Club at the State of New Hampshire Public Utilities Commission, Docket No. 10-261 – the 2010 Least Cost Integrated Resource Plan (LCIRP) submitted by the Public Service Company of New Hampshire (re. Merrimack Station Units 1 and 2).

160. Oral Testimony at Hearing (November 2012) on behalf of Clean Wisconsin in the matter of Application of Wisconsin Public Service Corporation for Authority to Construct and Place in Operation a New Multi-Pollutant Control Technology System (ReACT) for Unit 3 of the Weston Generating Station, before the Public Service Commission of Wisconsin, Docket No. 6690-CE-197.

161. Deposition (March 2013) in the matter of various Environmental Petitioners v. North Carolina DENR/DAQ and Carolinas Cement Company, before the Office of Administrative Hearings, State of North Carolina.

162. Deposition (August 2013) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).

163. Deposition (August 2013) on behalf of the Sierra Club in connection with the Luminant Martin Lake Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 5:10-cv-0156-MHS-CMC (Eastern District of Texas, Texarkana Division).

164. Deposition (February 2014) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).

165. Trial Testimony (February 2014) in the matter of *Environment Texas Citizen Lobby, Inc and Sierra Club v. ExxonMobil Corporation et al.,* Civil Action No. 4:10-cv-4969 (Southern District of Texas, Houston Division).

166. Trial Testimony (February 2014) on behalf of the Sierra Club in connection with the Luminant Big Brown Case. *Sierra Club v. Energy Future Holdings Corporation and Luminant Generation Company LLC*, Civil Action No. 6:12-cv-00108-WSS (Western District of Texas, Waco Division).

167. Deposition (June 2014) and Trial (August 2014) on behalf of ECM Biofilms in the matter of the *US Federal Trade Commission (FTC) v. ECM Biofilms* (FTC Docket #9358).

168. Deposition (February 2015) on behalf of Plaintiffs in the matter of *Sierra Club and Montana Environmental Information Center (Plaintiffs) v. PPL Montana LLC, Avista Corporation, Puget Sound Energy, Portland General Electric Company, Northwestern Corporation, and Pacificorp (Defendants)*, Civil Action No. CV 13-32-BLG-DLC-JCL (US District Court for the District of Montana, Billings Division).

169. Oral Testimony at Hearing (April 2015) on behalf of Niagara County, the Town of Lewiston, and the Villages of Lewiston and Youngstown in the matter of CWM Chemical Services, LLC New York State Department of

Environmental Conservation (NYSDEC) Permit Application Nos.: 9-2934-00022/00225, 9-2934-00022/00231, 9-2934-00022/00232, and 9-2934-00022/00249 (pending).

170. Deposition (August 2015) on behalf of Plaintiff in the matter of *Conservation Law Foundation (Plaintiff) v. Broadrock Gas Services LLC, Rhode Island LFG GENCO LLC, and Rhode Island Resource Recovery Corporation (Defendants)*, Civil Action No. 1:13-cv-00777-M-PAS (US District Court for the District of Rhode Island).

171. Testimony at Hearing (August 2015) on behalf of the Sierra Club in the matter of *Amendments to 35 Illinois Administrative Code Parts 214, 217, and 225* before the Illinois Pollution Control Board, R15-21.

172. Deposition (May 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., (Plaintiffs) v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).

173. Trial Testimony (October 2015) on behalf of Plaintiffs in the matter of *Northwest Environmental Defense Center et. al., (Plaintiffs) v. Cascade Kelly Holdings LLC, d/b/a Columbia Pacific Bio-Refinery, and Global Partners LP (Defendants)*, Civil Action No. 3:14-cv-01059-SI (US District Court for the District of Oregon, Portland Division).

174. Deposition (April 2016) on behalf of the Plaintiffs in *UNatural Resources Defense Council, Respiratory Health Association, and Sierra Club (Plaintiffs) v. Illinois Power Resources LLC and Illinois Power Resources Generation LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (Central District of Illinois, Peoria Division).

175. Trial Testimony at Hearing (July 2016) in the matter of Tesoro Savage LLC Vancouver Energy Distribution Terminal, Case No. 15-001 before the State of Washington Energy Facility Site Evaluation Council.

176. Trial Testimony (December 2016) on behalf of the challengers in the matter of the Delaware Riverkeeper Network, Clean Air Council, et. al., vs. Commonwealth of Pennsylvania Department of Environmental Protection and R. E. Gas Development LLC regarding the Geyer well site before the Pennsylvania Environmental Hearing Board.

177. Trial Testimony (July-August 2016) on behalf of the United States in *United States of America v. Ameren Missouri*, Civil Action No. 4:11-cv-00077-RWS (Eastern District of Missouri, Eastern Division).

178. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Huntley and Huntley Poseidon Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

179. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Backus Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

180. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Drakulic Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

181. Trial Testimony (January 2017) on the Environmental Impacts Analysis associated with the Apex energy Deutsch Well Pad Hearing on behalf citizens in the matter of the special exception use Zoning Hearing Board of Penn Township, Westmoreland County, Pennsylvania.

182. Deposition Testimony (July 2017) on behalf of Plaintiffs in the matter of *Casey Voight and Julie Voight v Coyote Creek Mining Company LLC (Defendant)* Civil Action No. 1:15-CV-00109 (US District Court for the District of North Dakota, Western Division).

183. Deposition Testimony (November 2017) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant,)* Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).

184. Deposition Testimony (December 2017) on behalf of Plaintiff in the matter of *Wildearth Guardians (Plaintiff) v Colorado Springs Utility Board (Defendant)* Civil Action No. 1:15-cv-00357-CMA-CBS (US District Court for the District of Colorado).

185. Deposition Testimony (January 2018) in the matter of National Parks Conservation Association (NPCA) v. State of Washington Department of Ecology and British Petroleum (BP) before the Washington Pollution Control Hearing Board, Case No. 17-055.

186. Trial Testimony (January 2018) on behalf of Defendant in the matter of *Oakland Bulk and Oversized Terminal (Plaintiff) v City of Oakland (Defendant,)* Civil Action No. 3:16-cv-07014-VC (US District Court for the Northern District of California, San Francisco Division).

187. Trial Testimony (April 2018) on behalf of the National Parks Conservation Association (NPCA) in the matter of NPCA v State of Washington, Department of Ecology and BP West Coast Products, LLC, PCHB No. 17-055 (Pollution Control Hearings Board for the State of Washington.

188. Deposition (June 2018) (harm Phase) on behalf of Plaintiffs in the matter of *Natural Resources Defense Council, Inc., Sierra Club, Inc., and Respiratory Health Association v. Illinois Power Resources LLC, and Illinois Power Resources Generating LLC (Defendants)*, Civil Action No. 1:13-cv-01181 (US District Court for the Central District of Illinois, Peoria Division).

189. Trial Testimony (July 2018) on behalf of Petitioners in the matter of *Coosa River Basin Initiative and Sierra Club (Petitioners) v State of Georgia Environmental Protection Division, Georgia Department of Natural Resources (Respondent) and Georgia Power Company (Intervenor/Respondent)*, Docket Nos: 1825406-BNR-WW-57-Howells and 1826761-BNR-WW-57-Howells, Office of State Administrative Hearings, State of Georgia.

190. Deposition (January 2019) and Trial Testimony (January 2019) on behalf of Sierra Club and Texas Campaign for the Environment (Appellants) in the contested case hearing before the Texas State Office of Administrative Hearings in Docket Nos. 582-18-4846, 582-18-4847 (Application of GCGV Asset Holding, LLC for Air Quality Permit Nos. 146425/PSDTX1518 and 146459/PSDTX1520 in San Patricio County, Texas).

191. Deposition (February 2019) and Trial Testimony (March 2019) on behalf of Sierra Club in the State of Florida, Division of Administrative Hearings, Case No. 18-2124EPP, Tampa Electric Company Big Bend Unit 1 Modernization Project Power Plant Siting Application No. PA79-12-A2.

192. Deposition (June 2019) relating to the appeal of air permits issued to PTTGCA on behalf of Appellants in the matter of *Sierra Club (Appellants) v. Craig Butler, Director, et. al., Ohio EPA (Appellees)* before the State of Ohio Environmental Review Appeals Commission (ERAC), Case Nos. ERAC-19-6988 through -6991.

193. Deposition (September 2019) on behalf of Appellants relating to the NPDES permit for the Cheswick power plant in the matter of *Three Rivers Waterkeeper and Sierra Club (Appellees) v. State of Pennsylvania Department of Environmental Protection (Appellee) and NRG Power Midwest (Permittee)*, before the Commonwealth of Pennsylvania Environmental Hearing Board, EHB Docket No. 2018-088-R.

194. Deposition (December 2019) on behalf of the Plaintiffs in the matter of David Kovac, individually and on behalf of wrongful death class of Irene Kovac v. Bp Corporation North America Inc., Circuit Court of Jackson County, Missouri (Independence), Case No. 1816-CV12417.

195. Deposition (February 2020) on behalf of Earthjustice in the matter of *Objection to the Issuance of PSD/NSR and Title V permits for Riverview Energy Corporation*, Dale, Indiana, before the Indiana Office of Environmental Adjudication, Cause No. 19-A-J-5073.

Exhibits

EXHIBIT 1

LEGAL NOTICE
and
Preliminary Determination for an Air Quality Permit for
3 Bear Delaware Operating- NM LLC

3 Bear Delaware Operating - NM LLC, 1512 Larimer St, Suite 540, Denver, CO has submitted an air quality permit application to the Air Quality Bureau (AQB), New Mexico Environment Department (NMED) for an air quality permit to modify 3 Bear Libby Gas Plant. The application file has been assigned Permit No. 7482M1. The exact location of the facility is at latitude 32 degrees, 32 minutes, 32.5 seconds and longitude -103 degrees, 31 minutes, 32.6 seconds, Datum: WGS84. This facility is located approximately 16.2 miles SW of Monument, in Lea County, NM.

The proposed modification will consist of equipment addition to the facility and revision of emissions resulting in increased quantities of regulated air contaminants. The facility will receive up to 60 MMscf/day of gas from three surrounding compressor stations owned and operated by 3 Bear Libby to separate natural gas liquids from the field gas, producing natural gas liquids and a residue gas for transmission to a pipeline. The proposed construction will consist of eight operating compressor engines, one gunbarrel tank, four condensate tanks, one slope oil tank, one produced water tank, one amine regenerator heater, one hot oil heater, one amine unit, one condensate loadout, one thermal oxidizer, one maintenance flare, one tank flare, process piping fugitives and haul road fugitives. This public notice reflects a revision to the current application requesting the addition of four engines for an alternative operating scenario between Caterpillar and Waukesha engines.

Total air pollutant emissions to the atmosphere are estimated to be approximately as follow: Parentheses note changes in emissions from previous construction permit – 7482. The emissions for the facility are expressed in tons per year (tpy). Nitrogen Oxides (NOx) at 145.1 tpy (+21.1 tpy); Carbon Monoxide (CO) at 241.7 tpy (+113.8 tpy); Volatile Organic Compounds (VOC) at 182.8 tpy (+71.5 tpy); Sulfur Dioxide (SO_2) at 238.4 tpy (-0.4 tpy); Particulate Matter (PM) at 9.1 tpy (+1.2 tpy), Particulate Matter 10 microns or less (PM_{10}) at 8.9 tpy (+2.3 tpy), and Particulate Matter 2.5 microns or less ($PM_{2.5}$) at 8.9 tpy (+2.7 tpy), and greenhouse gas (CO_2e) > 75,000 tpy. These emission estimates could change slightly during the course of the Department's review of the application.

The NMED has conducted a preliminary review of the information submitted with the permit application. The preliminary review and applicant's analysis of ambient air quality impacts indicates that the facility's air emissions will meet the air quality standards for NOx, CO, SO_2, PM, PM_{10} and $PM_{2.5}$. VOCs are a pre-cursor to ozone and the NMED does not require an individual ozone ambient impact analysis for each application. To determine compliance with national ambient air quality standards for ozone, NMED uses air monitors to monitor ozone concentrations. A full review will evaluate the estimated emission rates for the pollutants listed in this public notice and determine compliance with ambient air quality requirements and standards.

Based on the applicant's analysis, a preliminary determination is that this facility will comply with the requirements of Title 20, New Mexico Administrative Code (NMAC), Chapter 2, Parts 1, 3, 7, 35, 38, 61, 70, 71, 72, 73, 75, 77, 80 and 82; 40 CFR 50; 40 CFR 60 Subparts Dc, JJJJ and OOOOa; 40 CFR 63 Subparts ZZZZ; 40 CFR 68 and the New Mexico Air Quality Control Act. Therefore, the preliminary intent of NMED is to issue the air quality permit on or before April 8, 2020. This source is a PSD minor source according to 20.2.74 NMAC.

To ensure compliance with state and federal air regulations, the permit is expected to include conditions that limit the emissions and conditions that will require record keeping and reporting to the Department.

The permit application is available for review in electronic or hard copy at the Air Quality Bureau Office, 525 Camino de los Marquez Suite 1, Santa Fe, New Mexico. To arrange viewing of this application contact Arianna Espinoza, at 505-476-4367 or arianna.espinoza@state.nm.us. The permit application is also available at the NMED Hobbs Field Office, located at 2120 N. Alto, Hobbs, NM 88240 for public review.

All interested persons have thirty (30) days from the date this notice is published, to notify the Department in writing of their interest in the permit application. The written comments should refer to the company name, facility name and Permit No. (or send a copy of this notice along with your comments). The written comments shall state the nature of the issues raised and how it relates to the requirements of applicable state and federal air quality regulations and the Clean Air Act. The written comments should be mailed to Julia Kuhn, New Mexico Environment Dept., Air Quality Bureau, Permit Section, 525 Camino de los Marquez Suite 1, Santa Fe, NM 87505-1816.

The Department will notify all persons, who have provided written comments as to when and where the Department's analysis may be reviewed. Although all written comments will be made part of the public record, any person who does not express interest in writing before the end of this first thirty (30) day period will not receive such notification.

If the Department receives written public comment before the end of the Department's thirty (30) day public notice, the Department's analysis will be made available for review for thirty (30) days at the NMED district or field office nearest to the source before the permit will be issued. Written comments on the analysis or permit application may be submitted to the Department during this second thirty (30) day period or at any time before the permit is issued or denied.

Questions or comments not intended to be part of the public record can be directed to Julia Kuhn at 505-476-4376. General information about air quality and the permitting process can be found at the Air Quality Bureau's web site. The regulation dealing with public participation in the permit review process is 20.2.72.206 NMAC. This regulation can be found in the "Permits" section of this web site. Este es un aviso de la oficina de Calidad del Aire del Departamento del Medio Ambiente de Nuevo México, acerca de las emisiones producidas por un establecimiento en esta área. Si usted desea información en español, por favor comuníquese con esa oficina al teléfono 505-476-5557.

Notice of Non-Discrimination

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Part 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, or if you believe that you have been discriminated against with respect to a NMED program or activity, you may contact: Kristine Yurdin, Non-Discrimination Coordinator, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502, (505) 827-2855, nd.coordinator@state.nm.us. You may also visit our website at https://www.env.nm.gov/non-employee-discrimination-complaint-page/ to learn how and where to file a complaint of discrimination.

EXHIBIT 2

Future Year 2028 Emissions from Oil and Gas Activity in the Greater San Juan Basin and Permian Basin

Final Report

Prepared for:
Bureau of Land Management
New Mexico State Office
301 Dinosaur Trail
Santa Fe, NM 87508

Tom Moore
Western States Air Resources Council
and Western Regional Air Partnership
3 Caliente Road, #8
Santa Fe, NM 87508

Prepared by:
John Grant, Rajashi Parikh,
Amnon Bar-Ilan
Ramboll
773 San Marin Drive, Suite 2115
Novato, California, 94998
www.ramboll.com
P-415-899-0700
F-415-899-0707

August 2018

RAMBOLL

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EXECUTIVE SUMMARY

This study provides a future year forecast of criteria air pollutant (CAP) and greenhouse gas (GHG) emissions for oil and gas (O&G) exploration and production operations in the Greater San Juan Basin in Colorado and New Mexico and the portion of the Permian Basin in New Mexico. This analysis was sponsored by the United States (US) Bureau of Land Management (BLM), jointly with the Western Regional Air Partnership (WRAP). The overall effort for the Greater San Juan and Permian basins included development of comprehensive O&G emission inventory inputs (documented in Grant et al. [2016][1]), development of baseline 2014 O&G emission inventories (documented in Parikh et al. [2017][2]), and development of future year O&G emission inventories (documented herein).

The Greater San Juan Basin consists of Archuleta and La Plata counties in south-western Colorado and Cibola, Los Alamos, McKinley, Rio Arriba, San Juan, Sandoval, and Valencia counties in north-western New Mexico. The Permian Basin in this study is limited to the portion of the Permian Basin in south-eastern New Mexico, comprised of Chavez, Eddy, Lea, and Roosevelt counties. Although the Permian Basin extends into several counties in West Texas, the Texas portion of the basin is not part of this study.

In 2014, the Greater San Juan Basin consisted of close to 25,000 active O&G wells which produced over one trillion cubic feet of natural gas per year and 6.5 million barrels of oil per year. Future year 2028 Greater San Juan Basin emissions were forecast from base year 2014 emissions assuming (1) continuation of historical declines in existing 2014 active well count, gas production and oil production and (2) additional production from development areas included in the Colorado Air Resource Management Modeling Study, version 2.0 (CARMMS 2.0) as shown in Table ES-1. Overall changes to O&G activity metrics across all well types (i.e., shale and non-shale natural gas, shale and non-shale oil, and coalbed methane) were estimated to decrease by 2% for active well counts, decrease by 26% for gas production, increase by 362% for oil production, and increase by 148% for spud count.

[1] https://www.wrapair2.org/pdf/2016-11y_Final%20GSJB-Permian%20EI%20Inputs%20Report%20(11-09).pdf
[2] https://www.wrapair2.org/pdf/2014_SanJuan_Permian_Baseyear_EI_Final_Report_10Nov2017.pdf

Table ES-1. Greater San Juan Basin historical 2014 and forecast 2028 O&G activity.

Area	Active Well Count	Gas Production (BCF/yr[1])	Oil Production (MMbbl/yr[2])	Spud Count
2014 Historical				
Basin-wide Totals	24,870	1,060	6.1	122
2028 Forecast				
Non-Shale	22,319 [3]	296 [3]	3.6 [3]	29 [4]
TRFO Shale	45 [4]	1 [4]	0.0 [4]	4 [4]
Southern Ute Shale	400 [4]	204 [4]	0.4 [4]	96 [4]
Mancos Shale	1,513 [4]	283 [4]	24.0 [4]	173 [4]
Basin-wide Totals	**24,277**	**784**	**28.0**	**302**

[1] billion cubic-feet per year
[2] million barrels per year
[3] basis: O&G activity declined from 2014 based on historical trends
[4] basis: CARMMS 2.0

In 2014, the portion of the Permian Basin in New Mexico consisted of over 28,000 active O&G wells which produced over 117 million barrels of oil per year. There were over 1,000 wells spudded in the Permian Basin in 2014. Future year 2028 Greater San Juan Basin emissions were forecast from base year 2014 emissions based on US Energy Information (EIA) Annual Energy Outlook (AEO) forecasts of O&G production. Active O&G well count was estimated to increase to 35,000 wells in 2028 and oil production was estimated to increase to 154 million barrels of oil per year.

Emissions control resulting from on-the-books regulations such as New Source Performance Standards (NSPS) OOOO, OOOOa, and JJJJ and the 2016 BLM Methane Rule were also included in Greater San Juan and Permian Basin 2028 future year emission inventory forecasts.

Table ES-2 summarizes total emissions from O&G operations in the Greater San Juan and Permian Basin by state. In addition to nitrogen oxides (NOx) and volatile organic compounds (VOCs), emissions of carbon monoxide (CO), particulate matter (PM), sulfur oxides (SOx), and carbon dioxide equivalents (CO_2e) are reported. In the Greater San Juan Basin, 72% of 2028 basin-wide NOx emissions and 93% of 2028 basin-wide VOC emissions were from O&G activity in New Mexico. 28% of 2028 basin-wide NOx emissions and 7% of 2028 basin-wide VOC emissions were from O&G activity in Colorado. Colorado comprises a smaller fraction of VOC emissions than NOx emissions as a result of coalbed methane wells which emit small amounts of VOC relative to other O&G wells; coalbed methane wells are the predominant well type in the Colorado portion of the basin.

Table ES-2. Future year 2028 emissions from O&G operations in the Greater San Juan and Permian Basins.

County	Emissions (tpy [1])					
	NOx	VOC	CO	SOx	PM	CO_2 (e) [2]
Greater San Juan Basin						
Colorado	16,679	4,680	14,026	56	425	3,284,403
New Mexico	43,136	64,429	69,529	267	1,382	16,287,496
Totals	**59,815**	**69,109**	**83,555**	**323**	**1,806**	**19,571,899**
Permian Basin (excludes Texas portion of the Permian Basin)						
New Mexico Totals	**30,351**	**121,644**	**25,819**	**12,393**	**719**	**15,682,752**

[1] tons per year

[2] GHG emissions for sources without source category classification (SCC) were not estimated

Figure ES-1 shows 2014 and 2028 Greater San Juan Basin-wide NOx and VOC emissions by mineral designation. Changes from 2014 to 2028 Greater San Juan Basin NOx emissions by mineral estate were small (4% decrease for federal, 4% decrease for private/state fee, and 11% increase for tribal sources). Changes from 2014 to 2028 Greater San Juan Basin VOC emissions by mineral estate were small for private/state fee (8% decrease) and tribal (3% increase); more substantial reductions are shown for federal mineral estate (23% decreases), primarily as the result of implementation of the 2016 BLM Methane Rule which requires emission control for existing and new federal sources. The 2016 BLM Methane Rule is focused primarily on natural gas venting and leak sources and therefore results in reductions to both VOC and methane (CH_4) emissions.

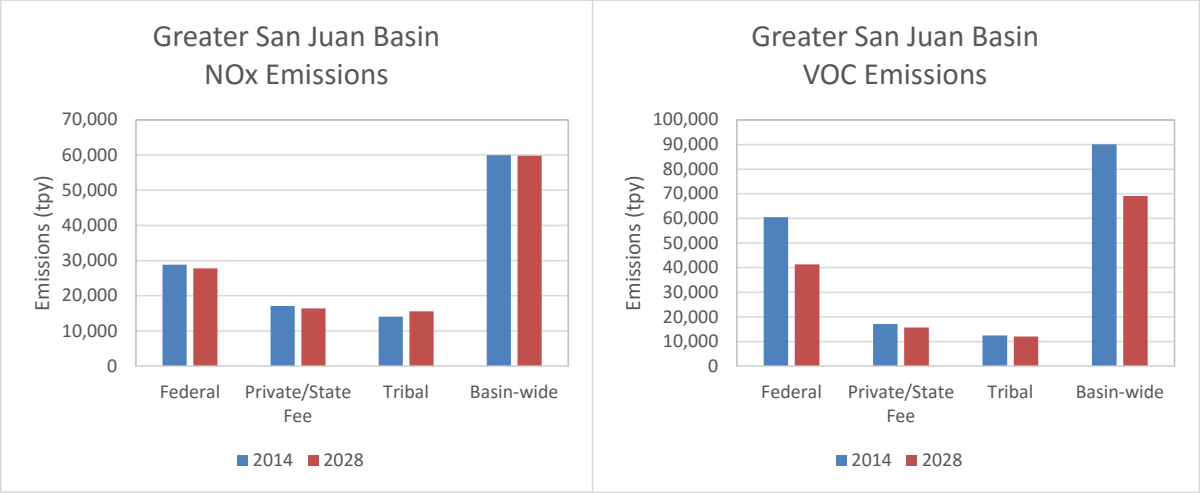

Figure ES-1. Greater San Juan Basin NOx (left panel) and VOC (right panel) emissions by mineral designation.

Figure ES-2 shows 2014 and 2028 Permian Basin-wide NOx and VOC emissions by mineral designation. There are no tribal mineral designation sources in the Permian Basin. From 2014 to 2028, Permian Basin NOx emissions by mineral estate decreased by 15% for federal sources and 11% for non-federal sources. From 2014 to 2028 Permian Basin VOC emissions by mineral estate decreased by 34% for federal sources and increased by 19% for non-federal sources. Substantial reductions to federal VOC emissions (34% decrease) are primarily a result of implementation of the 2016 BLM Methane Rule which requires emission control for existing and new federal sources.

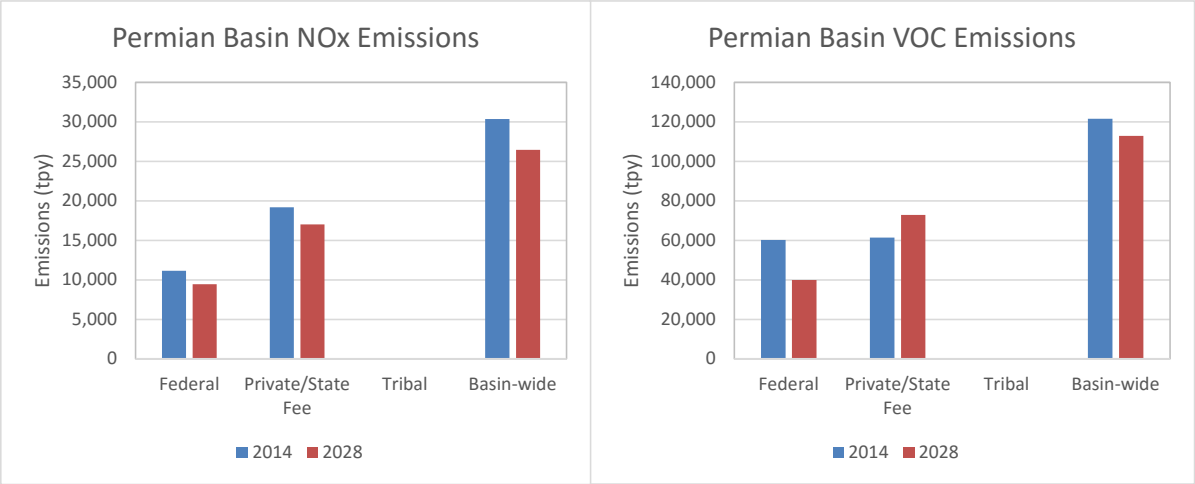

Figure ES-2. Permian Basin (New Mexico only) NOx (left panel) and VOC (right panel) emissions by mineral designation.

The contents of the report by Chapter are summarized as follows:

- Chapter 1.0 provides introductory information on study scope;
- Chapter 2.0 describes development of Greater San Juan Basin future year 2028 emission forecasts;
- Chapter 3.0 describes development of Permian Basin future year 2028 emission forecasts;
- Chapter 4.0 presents summaries in graphical and tabular formats of future year 2028 emission forecasts.

1.0 INTRODUCTION

This document outlines the methodologies used to develop 2028 emissions forecasts from O&G sources in the Greater San Juan and Permian basins. These methodologies use as a starting point the 2014 baseline Greater San Juan Basin and Permian Basin O&G emissions inventories, described in the emissions report, "Development of Baseline 2014 Emissions from Oil and Gas Activity in Greater San Juan Basin and Permian Basin"[3] (Parikh et. al 2017).

1.1 Pollutants

The following criteria air pollutants (CAPs) are estimated in this study:

- Nitrogen oxides (NOx)
- Volatile organic compounds (VOCs)
- Carbon monoxide (CO)
- Particulate matter (PM)
- Sulfur oxides (SOx)

The following greenhouse gases (GHGs) are estimated in this study:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

1.2 Temporal and Geographical Scope

Future year annual total emission inventories were developed for calendar year 2028.

The geographic scope of the inventories is (1) the Greater San Juan Basin in north-western New Mexico and south-western Colorado and (2) the portion of the Permian Basin in New Mexico. Greater San Juan Basin boundaries are based on American Association of Petroleum Geologists[4] (AAPG) San Juan Basin consistent with the US Environmental Protection Agency (EPA) Greenhouse Gas Reporting Protocol (GHGRP) basin definition. The Greater San Juan Basin includes Archuleta and La Plata counties in Colorado and Cibola, Los Alamos, McKinley, Rio Arriba, San Juan, Sandoval, and Valencia counties in New Mexico. Permian Basin boundaries are limited to the portion of the Permian Basin in south-eastern New Mexico as defined by the AAPG[4], including Chavez, Eddy, Lea, and Roosevelt counties. The geographic scope also considers activities by mineral estate ownership: Federal, Bureau of Indian Affairs (BIA or tribal), and state/private fee.

Figure 1-1 through Figure 1-4 show the boundaries of the Greater San Juan and Permian basins, with 2014 well locations extracted from the IHS database overlaid. Figure 1-1 presents wells by type and Figure 1-2 present wells by mineral designation for the Greater San Juan Basin. Figure 1-3 presents wells by type and Figure 1-4 present wells by mineral designation for the Permian Basin.

[3] https://www.wrapair2.org/pdf/2014_SanJuan_Permian_Baseyear_EI_Final_Report_10Nov2017.pdf
[4] http://ngmdb.usgs.gov/Geolex/stratres/provinces

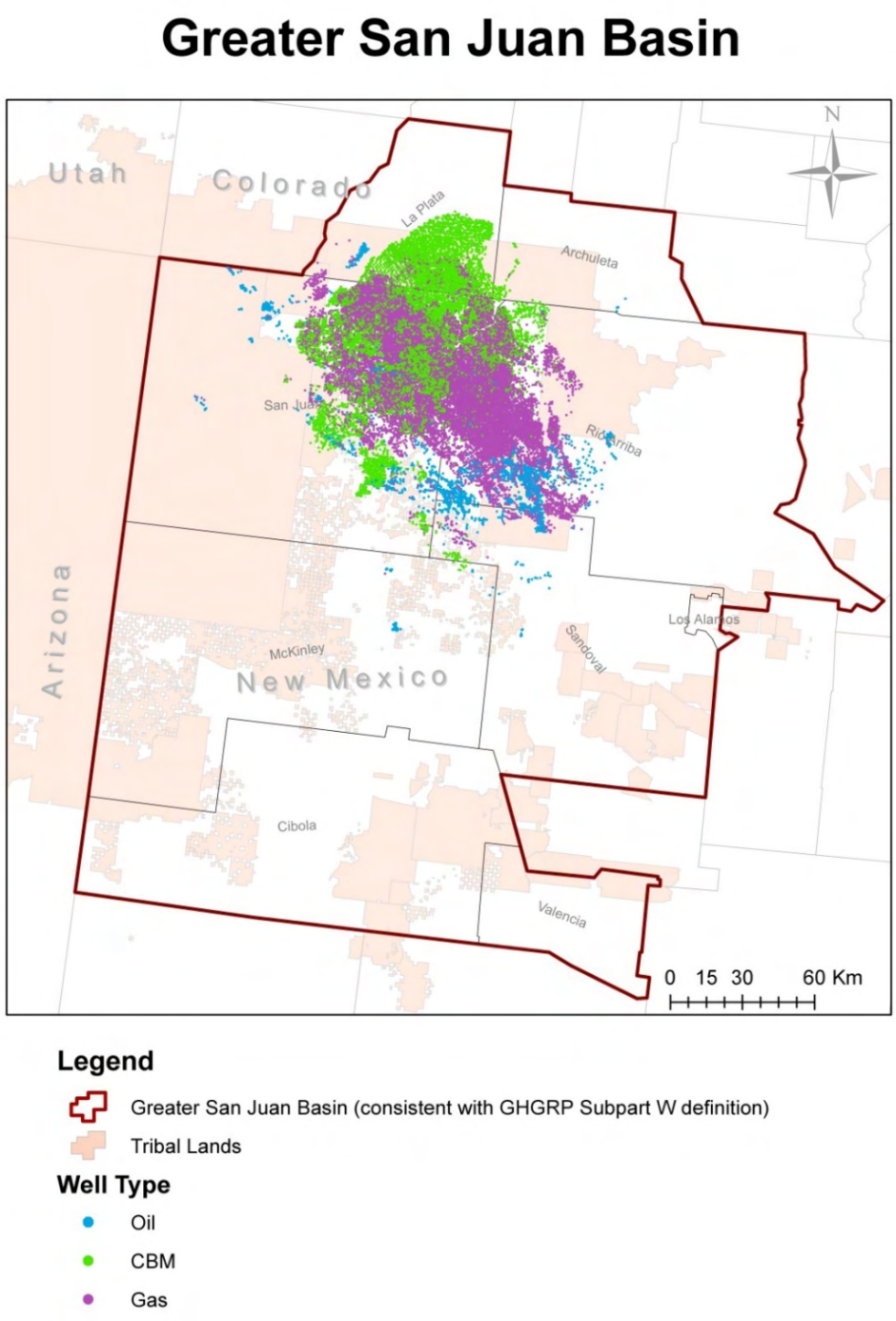

Figure 1-1. Greater San Juan Basin boundaries overlaid with 2014 O&G well locations by well type.[5,6]

[5] Includes data supplied by IHS Inc., its subsidiary and affiliated companies; Copyright (2017) all rights reserved.
[6] Coalbed Methane (CBM)

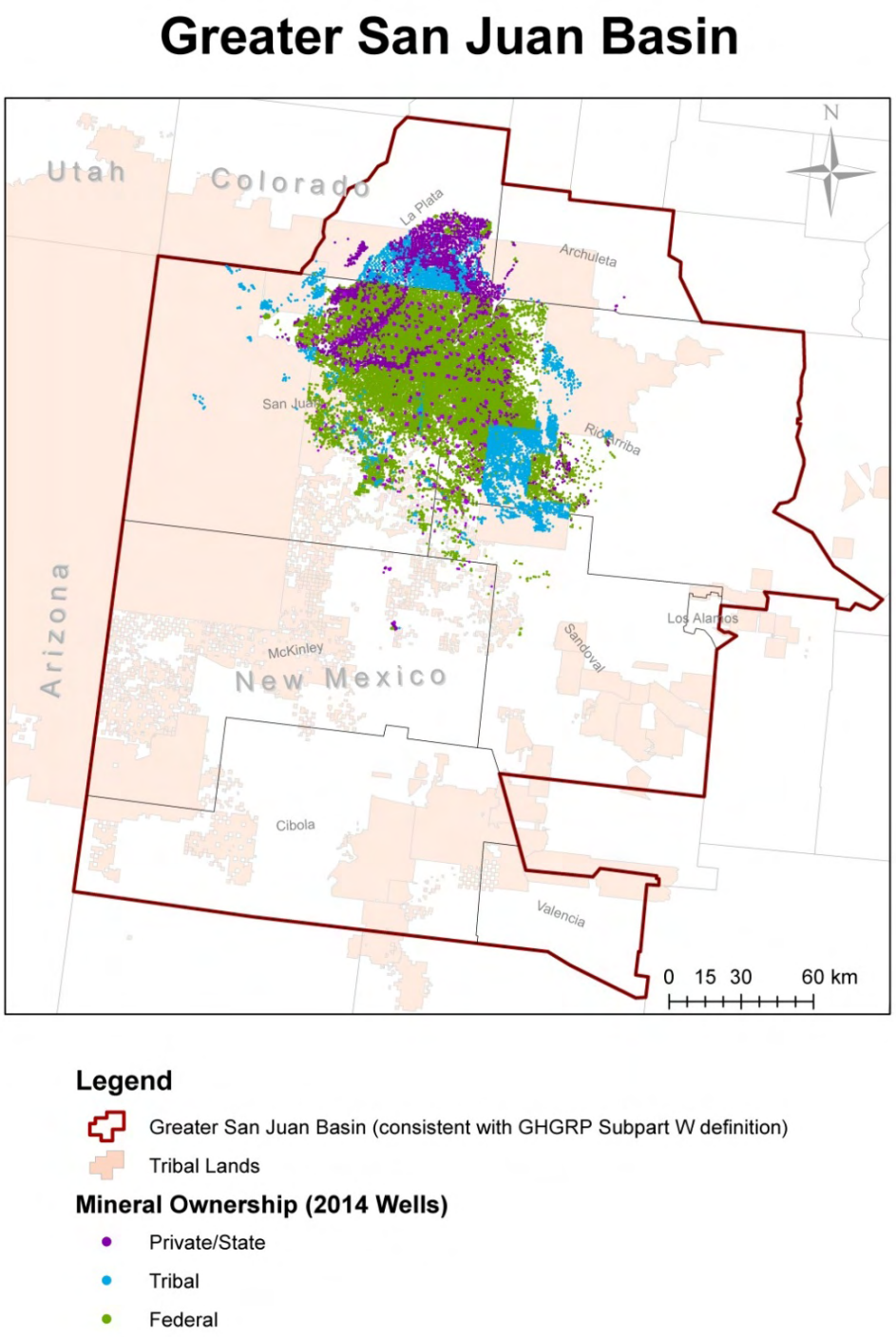

Figure 1-2. Greater San Juan Basin boundaries overlaid with 2014 O&G well locations by mineral designation.[5]

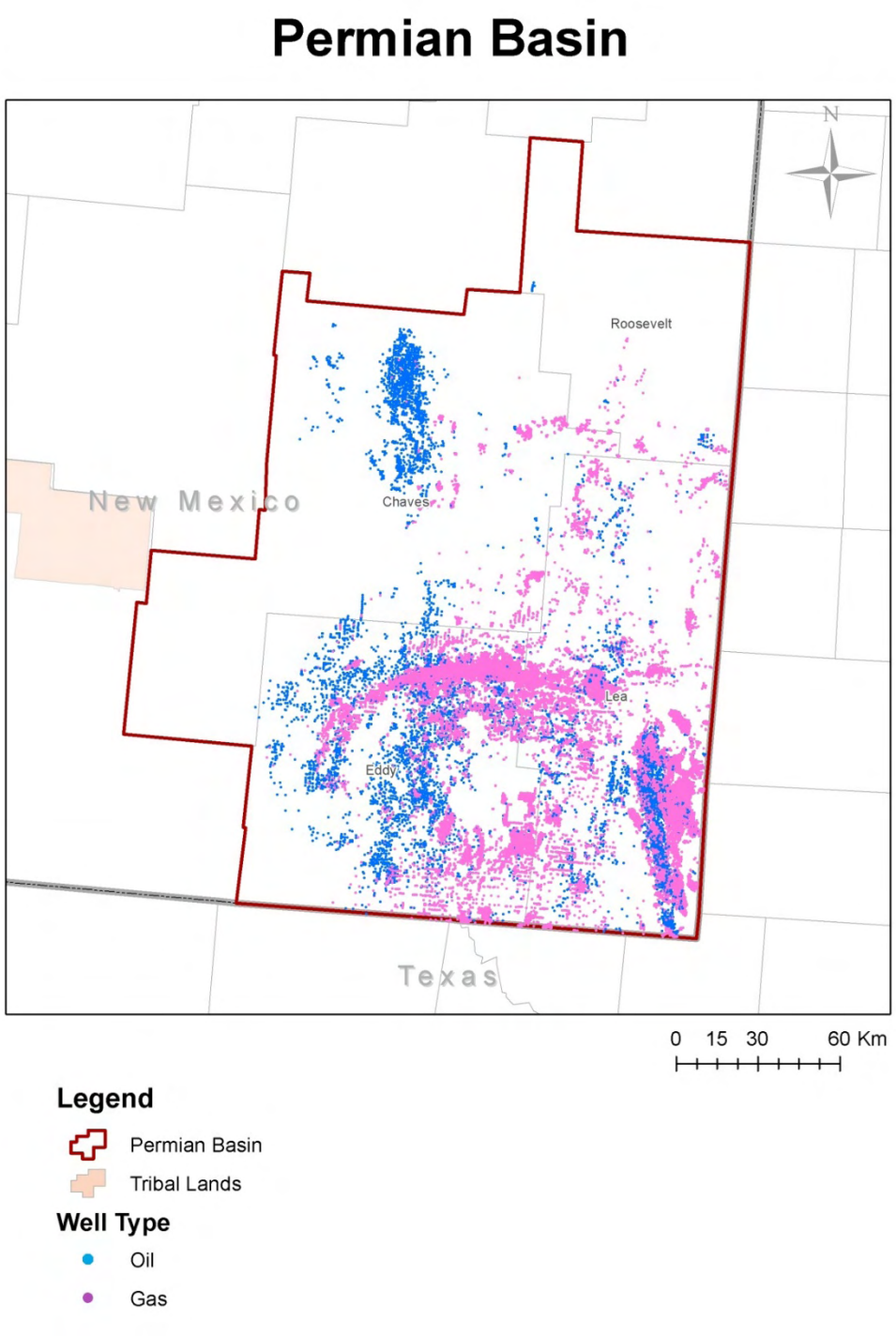

Figure 1-3. Permian Basin boundaries overlaid with 2014 O&G well locations by well type.[5]

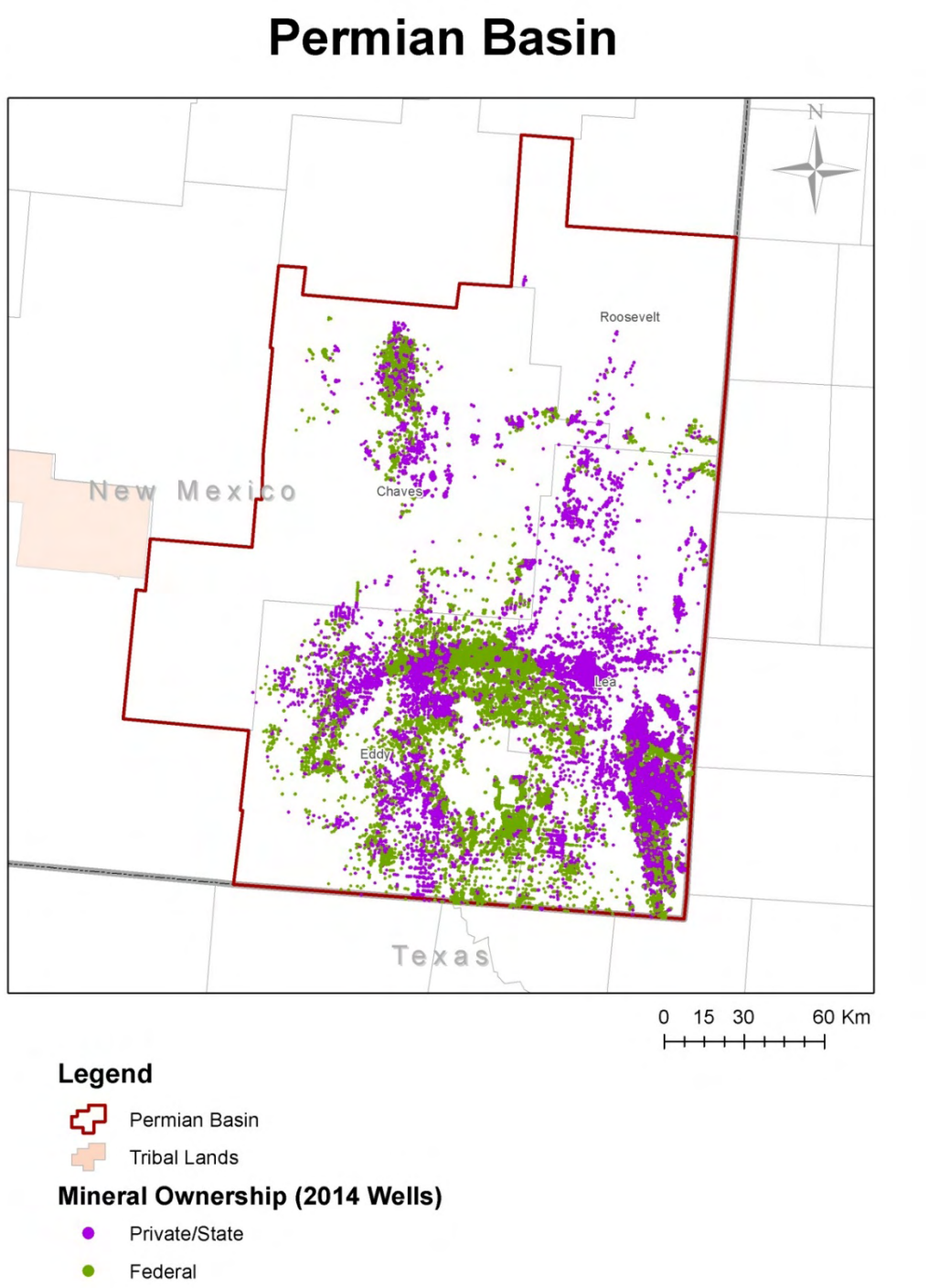

Figure 1-4. Permian Basin boundaries overlaid with 2014 O&G well locations by mineral designation. [5]

1.3 Forecast Overview

Future year O&G emission inventory forecasts typically account for changes to O&G activity and emission reductions resulting from on-the-books regulations. A brief discussion of future year emissions inventory development and uncertainty is provided in this section.

Figure 1-5 shows, graphically, typical O&G activity forecast methodology. As shown, there are fundamental relationships between O&G activity forecast metrics. Drilling schedules (and the fraction of wells drilled which ultimately produce O&G) determine the number of active wells that are added to a basin. As new wells are brought on line, they add O&G production; the relationship between well age and O&G production (i.e., the well production decline curve) is typically combined with active well count by age to develop production forecasts. Decline in existing active well counts as old wells are taken out of production and the decline in existing well O&G production are also important to capture in O&G activity forecasts.

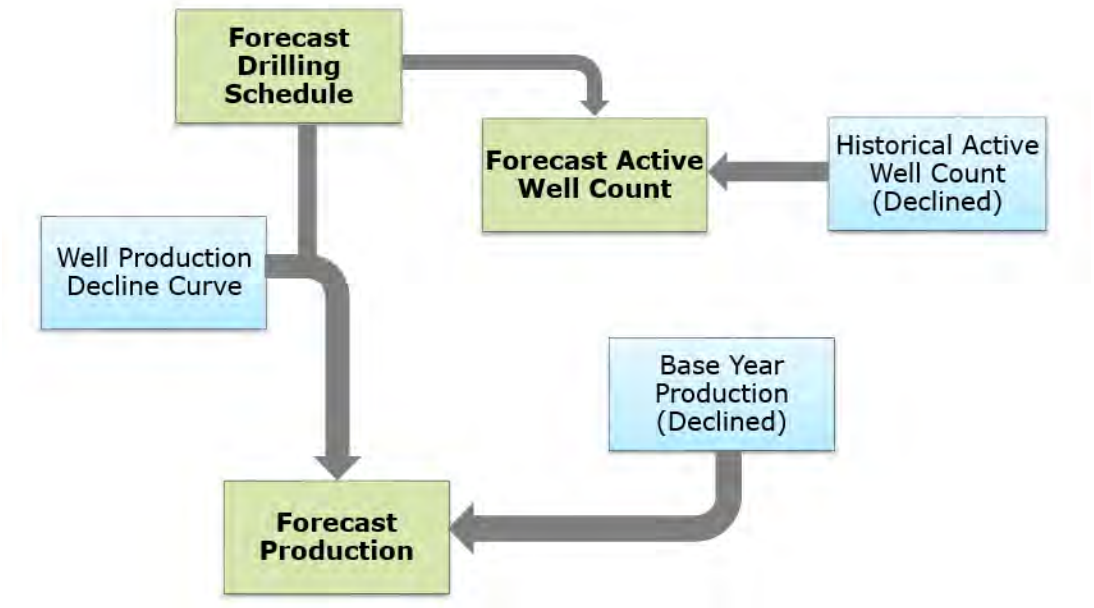

Figure 1-5. Typical O&G activity forecast methodology.

Future forecast O&G activity are typically speculative for several reasons. Future O&G development (i.e. drilling and midstream buildouts) and future management of existing O&G well sites and midstream facilities are dependent on the choices made by several individual operators in a given basin. In general, O&G development is dependent on both economics (e.g., cost of drilling and estimated revenue from natural gas and/or oil production) and regulatory decisions (e.g., permit issuance and National Environmental Policy Act [NEPA] approval). Well-site and midstream facility operation decisions are similarly dependent on economics (e.g., production revenue and maintenance costs) and regulatory decisions (e.g., continued permit issuance).

Typically, future year control estimates are developed based on an estimate of future year control prevalence and associated emission rate reductions. Accurate estimation of regulatory program effects on future year emissions is challenging for several reasons. For example, control programs such as New Source Performance Standards (NSPS) apply to new or modified sources only. Inventories have typically not accounted for NSPS modified sources because information has not been available to determine the prevalence of sources that fall under the modified provision. Additionally, when O&G activity forecasts are based on simple multiplicative factors (rather than treating sources that existed in the base year separately from sources added in future years), such as a basin-wide gas production increase of 30% from base year to future year, new sources are typically represented conservatively as only increases above base year emissions (because of existing well O&G production decline and attrition, new sources are typically expected to represent a larger fraction of sources).

1.4 2016 BLM On-the-books Methane Rule

At the time that future year emissions were developed for this analysis, all provisions of the 2016 BLM Methane Rule were in effect. On April 4, 2018, the US District Court stayed the following provisions of the 2016 BLM Methane Rule[7]:

- 43 CFR 3179.7 (gas capture percentage requirement)
- 43 CFR 3179.9 (measuring and reporting volumes of gas vented or flared)
- 43 CFR 3179.201 (equipment requirements for pneumatic controllers)
- 43 CFR 3179.202 (requirements for pneumatic diaphragm pumps)
- 43 CFR 3179.203 (storage vessels)
- 43 CFR 3179.301 - 3179.305 (leak detection and repair)

The future status of the above and other provisions of the Rule are uncertain; therefore, we did not update the emission inventory to reflect the current status of the Rule at the time that this report is published. Qualitatively, removing controls that were applied in the inventory developed in this report per the current stayed provisions would affect emissions as follows:

- **43 CFR 3179.7 (gas capture percentage requirement)**: Negligible emission reductions were estimated to result from this provision for the Permian and Greater San Juan basins; therefore, removing control assumptions for this provision will have no effect on emissions estimates.
- **43 CFR 3179.9 (measuring and reporting volumes of gas vented or flared)**: Negligible emission reductions were estimated to result from this provision for the Permian and Greater San Juan basins; therefore, removing control assumptions for this provision will have no effect on emissions estimates.
- **43 CFR 3179.201 (equipment requirements for pneumatic controllers)**: Low-bleed devices (i.e., 6 cfh per device) were assumed at existing federal well-sites in the Permian and Greater San Juan basins. In the absence of this provision, VOC and methane emissions at existing federal wells will be higher than estimated in this study.

[7] https://www.blm.gov/programs/energy-and-minerals/oil-and-gas/operations-and-production/methane-and-waste-prevention-rule

- **43 CFR 3179.202 (requirements for pneumatic diaphragm pumps)**: Emission reductions resulting from this provision were not estimated for the Permian and Greater San Juan basins; therefore, the absence of this provision will have no effect on emissions estimates.
- **43 CFR 3179.203 (storage vessels)**: Condensate and oil storage tanks at existing federal wells in the Permian and Greater San Juan basins with the potential to emit more than 6 tpy VOC were assumed to be controlled by flare or VRU. In the absence of this provision, VOC and methane emissions from existing federal wells will be higher than estimated in this study.
- **43 CFR 3179.301 - 3179.305 (leak detection and repair)**: Implementation of leak detection and repair programs was assumed at existing federal well-sites. In the absence of this provision, VOC and methane emissions from existing federal wells will be higher than estimated in this study.

2.0 San Juan Future Year Emission Inventory Methodology

This section provides 2028 emission inventory development methodology for the Greater San Juan Basin for nonpoint and point sources. Forecasts account for changes to O&G activity and emission reductions resulting from on-the-books regulations.

Greater San Juan Basin emission forecasts are based on (1) emission estimates from new development in the US Bureau of Land Management (BLM) Colorado Air Resource Management Modeling Study 2.0 (CARMMS 2.0; Vijayaraghavan et al., 2017) and (2) declines in existing non-shale O&G activity based on historical trends.

2.1 CARMMS 2.0 O&G Emissions Integration

CARMMS 2.0 includes O&G activity forecasts relevant to the Greater San Juan Basin for the following areas:

- Mancos Shale
- Southern Ute Indian Tribe Shale Development (SUIT)
- Tres Rios Field Office (TRFO)
- Farmington Field Office (FFO)

Figure 2-1 shows the TRFO, FFO, and SUIT areas in southwest Colorado and northwest New Mexico; the Mancos Shale (not shown) intersects TRFO, SUIT, and FFO areas.

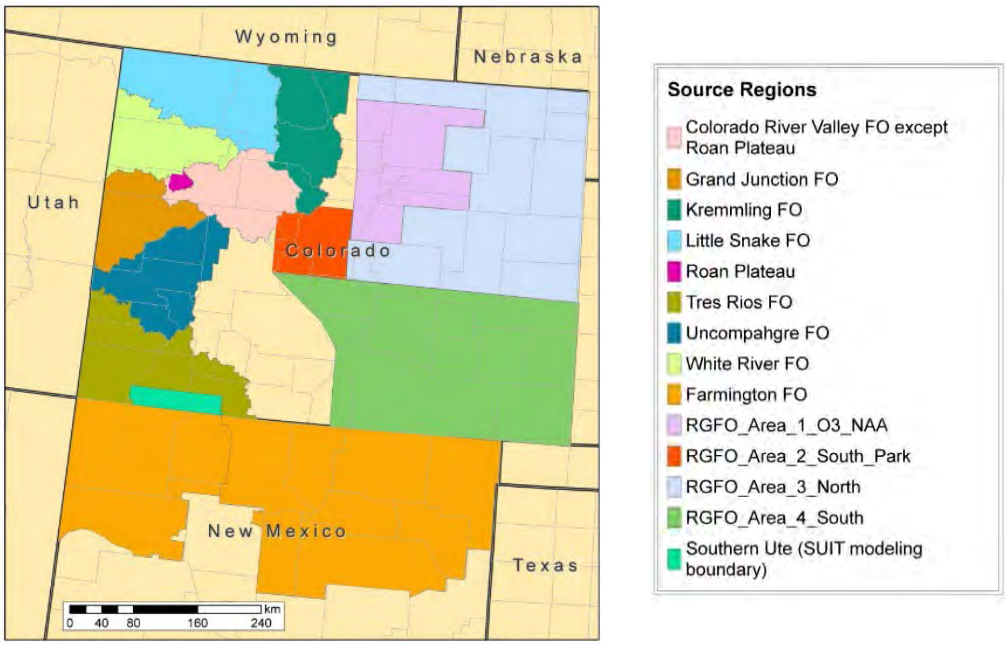

Figure 2-1. Colorado field office planning areas (source: Vijayaraghavan et al., 2017).

CARMMS 2.0 future year O&G emissions were developed for low, medium, and high scenarios and incorporate the effects on emissions of on-the-book regulations (Vijayaraghavan et al., 2017). The low and high scenarios are intended to bound future year O&G development activity; the medium scenario assumes the same level of development as the high scenario with additional emission controls. The low scenario is based on recent year O&G development levels and the high scenario is based on Reasonably Foreseeable Development (RFD) estimates for the above specified development areas. Ramboll estimated future year forecasts based on CARMMS 2.0 low or high scenario 2025 emissions for each area within the Greater San Juan Basin (Grant et al., 2017[8]). Medium scenario emissions were not used because the medium scenario was developed assuming emission controls beyond those required in on-the-books regulations. CARMMS 2.0 O&G emissions include sources in addition to those included in the base year 2014 Greater San Juan Basin emission inventory such as vehicle traffic, well site construction, and fugitive dust emission sources. CARMMS 2.0 emissions from sources outside the scope of the base year 2014 Greater San Juan Basin emission inventory were not integrated into the 2028 future year inventory.

2.1.1 Mancos Shale

CARMMS 2.0 Mancos shale 2025 low scenario emissions were integrated into the 2028 future year Greater San Juan Basin inventory based on the assumption that oil and natural gas prices will not be favorable to CARMMS 2.0 high scenario development. The price of crude oil since late-2014 has generally remained below $65 per barrel[9]. The price of natural gas since early-2009 has generally remained below $5 per million BTU[10] (with the exception of brief spikes in January 2010, February 2014, and January 2018). Based on the assumption that natural gas and oil prices remain at recent levels, selection of the low scenario is warranted. CARMMS 2.0 Mancos Shale 2025 nonpoint emissions were incorporated as-is for calendar year 2028. All CARMMS 2.0 non-federal well emissions were assigned to “private/state fee” mineral estate and all federal emissions were assigned to “federal” mineral estate. Tribal Mancos Shale activity is accounted for in the SUIT area Shale inventory. Spatial allocation of Mancos Shale emissions was estimated based on CARMMS 2.0 Mancos Shale spatial allocations.

2.1.2 SUIT Shale

CARMMS 2.0 SUIT area shale 2025 “high scenario” emissions were integrated into the 2028 future year inventory because the high scenario is consistent with the upcoming SUIT Shale Supplemental Environmental Impact Statement (SEIS). The SUIT Shale SEIS development forecast was used because preparation of an SEIS document suggests that approvals are already being sought for this level of development. CARMMS 2.0 Mancos Shale 2025 nonpoint emissions were incorporated as-is for calendar year 2028. All SUIT area shale emissions were assigned to “tribal” mineral estate and were spatially allocated consistent with CARMMS 2.0 assumptions.

[8] https://www.wrapair2.org/pdf/OG_ForecastMethod_13Sep2017_memo.pdf
[9] US EIA Petroleum Data, Cushing, OK WTI Spot Price FOB.
[10] US EIA Natural Gas Data, Henry Hub Natural Gas Spot Price : https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm

2.1.3 TRFO Shale Gas

Outside of Mancos Shale and SUIT shale development, CARMMS 2.0 assumed additional shale gas development in the TRFO in northern area of Greater San Juan Basin. CARMMS 2.0 "low scenario" TRFO shale gas 2025 future emissions were integrated into the 2028 future year inventory. As mentioned above, the price of natural gas since early-2009 has generally remained below $5 per million BTU[11] (with the exception of brief spikes in January 2010, February 2014, and January 2018). Based on the assumption that the natural gas price remains at recent levels, selection of the low scenario is warranted. All non-federal well emissions were assigned to "private/state fee" mineral estate and all federal emissions were assigned to "federal" mineral estate. CARMMS 2.0 spatial allocations were used to allocate TRFO shale gas emissions to individual counties.

2.1.4 TRFO Development-Phase Emissions

CARMMS 2.0 TRFO 2025 low scenario CBM development phase[12] emissions (from drilling, hydraulic fracturing, and completion activities) were integrated into the 2028 inventory based on CARMMS 2.0 spatial allocations. As mentioned above, the price of natural gas since early-2009 has generally remained below $5 per million BTU[13] (with the exception of brief spikes in January 2010, February 2014, and January 2018). Based on the assumption that the natural gas price remains at recent levels, selection of the low scenario is warranted. All non-federal well emissions were assigned to "private/state fee" mineral estate and all federal emissions were assigned to "federal" mineral estate.

2.1.5 Summary of CARMMS 2.0 Integration

CARMMS O&G emissions that were incorporated into the future year 2028 Greater San Juan Basin emission inventory are shown in Table 2-1. As noted above, CARMMS 2.0 O&G emissions include sources in addition to those included in the base year 2014 Greater San Juan Basin emission inventory such as vehicle traffic, well site construction, and fugitive dust emission sources. CARMMS 2.0 emissions from sources outside the scope of the base year 2014 Greater San Juan Basin emission inventory were not integrated into the 2028 future year inventory and are not included in Table 2-1.

[11] US EIA Natural Gas Data, Henry Hub Natural Gas Spot Price : https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm
[12] Development phase refers to drilling and completion activities during well "development"
[13] US EIA Natural Gas Data, Henry Hub Natural Gas Spot Price : https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm

Table 2-1. Summary of 2025 spuds from CARMMS 2.0 study incorporated into future year 2028 Greater San Juan Basin Inventory.

Well Type	Emissions (tpy[3])					Wells Added from 2014 to 2028	2028 Spuds
	NOx	VOC	CO	SOx	PM		
TRFO CBM[1]	9	1	9	0	0	not applicable[1]	29
TRFO Shale Gas[2]	70	31	61	0	2	45	4
SUIT Shale	1,695	540	1,809	2	83	400	96
Mancos Shale	2,190	4,615	2,887	4	104	1,513	173

[1] Includes only development phase emissions from CARMMS 2.0.
[2] Includes only shale gas wells not in SUIT Shale or Mancos Shale.
[3] tons per year

2.2 Non-Shale Oil, Non-Shale Gas, and CBM Forecast

Historical non-shale oil, non-shale gas, and CBM well activity trends were developed to estimate declines in existing production phase emissions; control factors were also developed to account for the effects of regulatory control programs on emissions from non-shale oil, non-shale gas, and CBM wells.

2.2.1 O&G Activity Forecast

Recent trends in Greater San Juan Basin O&G activity show declines in activity across all O&G activity metrics evaluated in this study. Ramboll estimated decline factors based on recent O&G activity trends. Since O&G activity is estimated to decline across all O&G activity metrics evaluated, no additional controls were applied (i.e. the emission rate per unit O&G activity in the future year is assumed equivalent to the base year).

2028 Non-shale oil, non-shale gas, and CBM production-phase emissions forecasts for the Greater San Juan Basin are based on the following O&G activity metrics:

- Well counts by type (gas, oil, CBM)
- Gas production by type (primary, associated, CBM)
- Liquid Hydrocarbon production by type (oil, condensate)

Non-shale oil and non-shale gas development phase emissions in future year 2028 were assumed negligible in the Colorado portion of the Greater San Juan Basin. The assumption of negligible non-shale gas and non-shale oil well drilling in the portion of the Greater San Juan Basin in Colorado is consistent with the most recent year of spuds data available (2016) in which 2 non-CBM and 20 CBM wells were drilled in the Colorado portion of the basin. TRFO CBM development emissions from CARMMS 2.0 were included in the Colorado portion of the Greater San Juan Basin as described above.

Non-shale oil, non-shale gas, and CBM development phase emissions in future year 2028 were assumed to be negligible in the New Mexico portion of the Greater San Juan Basin. The assumption of negligible non-shale gas, non-shale oil, and CBM well drilling in the portion of the

Greater San Juan Basin in New Mexico is consistent with recent spuds trends in which spud count has decreased substantially in the basin; in the New Mexico portion of the basin there were 141 spuds in 2014, 75 spuds in 2015, and 18 spuds in 2016. Future spudding activity in the basin is assumed to be from the Mancos Shale.

Oil Well Counts

Historical Greater San Juan Basin 1970–2016 active oil well counts are shown in Figure 2-2 with the 2028 forecast. Oil well counts have remained relatively constant in recent years, therefore, the 2028 forecast was set equal to the oil well count in 2016, the most recent year with complete O&G activity data at the time these forecasts were developed.

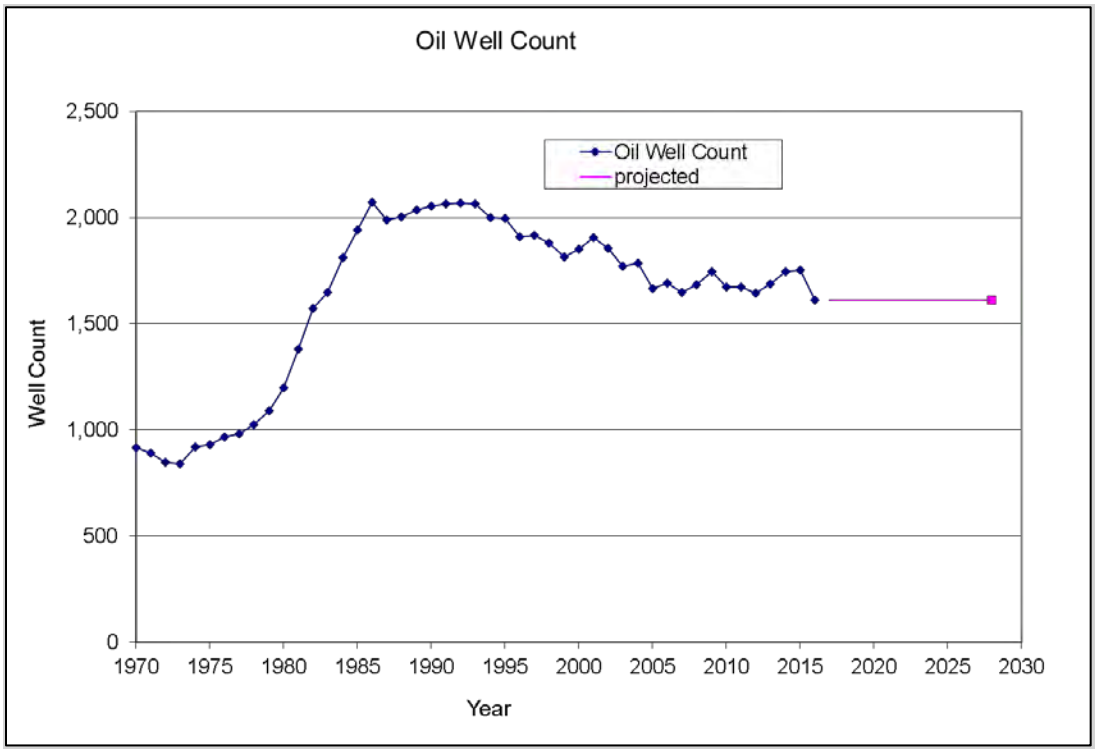

Figure 2-2. Greater San Juan Basin historical oil well count and 2028 forecast.[5]

Conventional Gas Well Counts

Historical Greater San Juan Basin 1970–2016 active gas well counts are shown in Figure 2-3 with the 2028 forecast. Gas well counts have steadily decreased in recent years; the 2028 forecast was estimated to decrease from 2016 consistent with recent historical declines.

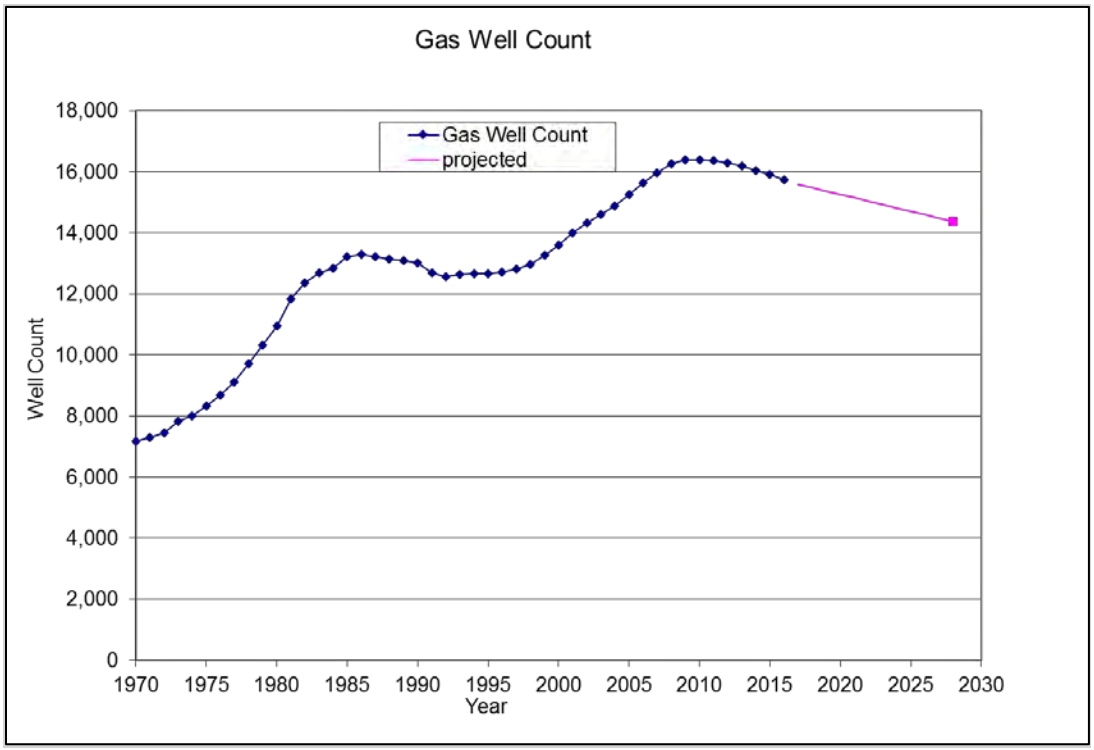

Figure 2-3. Greater San Juan Basin historical gas well count and 2028 forecast.[5]

CBM Well Counts

Historical Greater San Juan Basin 1970–2016 active CBM well counts are shown in Figure 2-4 with the 2028 forecast. CBM well counts have decreased monotonically in recent years; the 2028 forecast was estimated to decrease from 2016 based on recent historical declines.

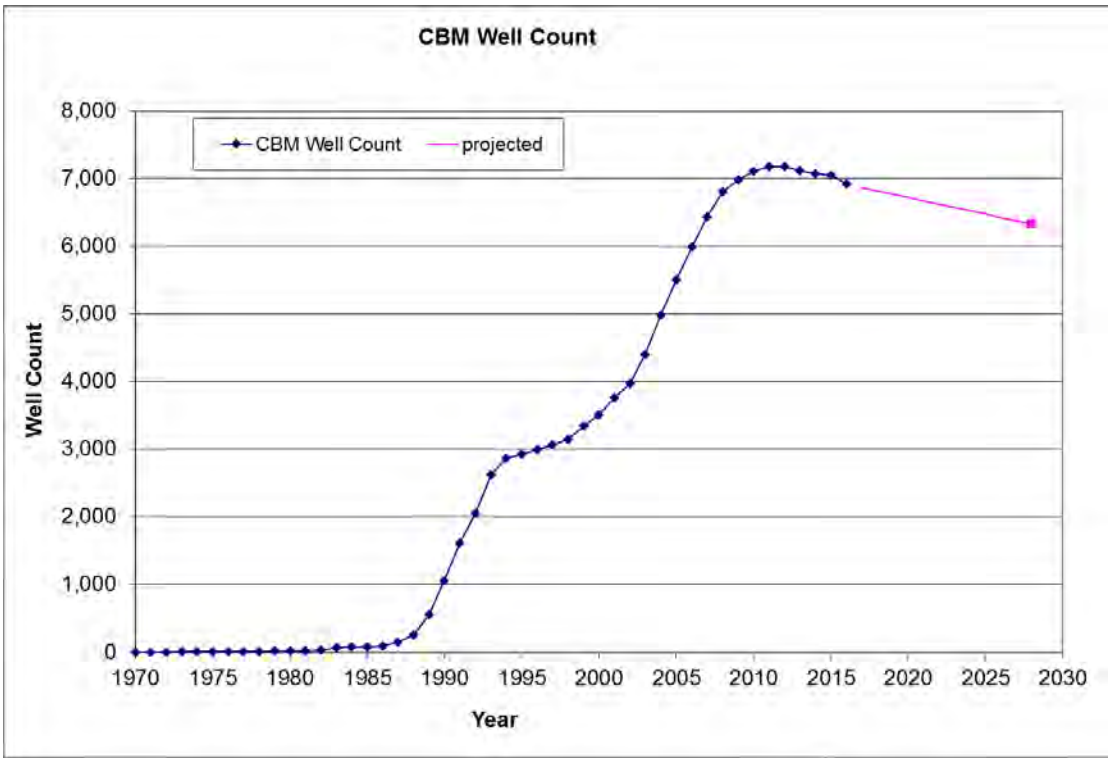

Figure 2-4. Greater San Juan Basin historical CBM well count and 2028 forecast.[5]

Associated Gas Production

Historical Greater San Juan Basin 1970–2016 associated gas production is shown in Figure 2-5 with the 2028 forecast. Associated gas production declined from 1989 through 2010, remained relatively constant from 2009 to 2013, increased substantially from 2013 to 2015, and then declined from 2015 to 2016. The future year 2028 association gas production forecast was estimated to be equal to the 20-year average associated gas production from 1997 to 2016.

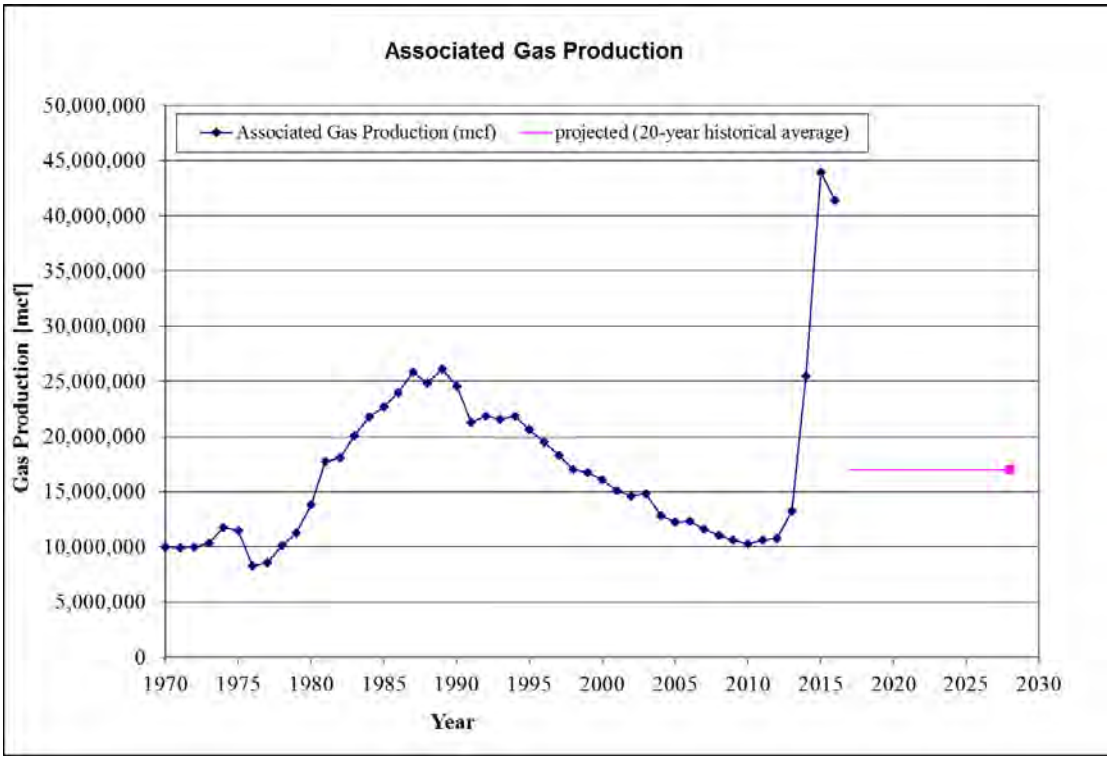

Figure 2-5. Greater San Juan Basin historical associated gas production and 2028 forecast.[5]

Primary Gas Production

Historical Greater San Juan Basin 1970–2016 primary gas production is shown in Figure 2-6 with the 2028 forecast. Primary gas production has steadily decreased in recent years; the 2028 forecast was estimated to decrease from 2016 consistent with recent historical declines.

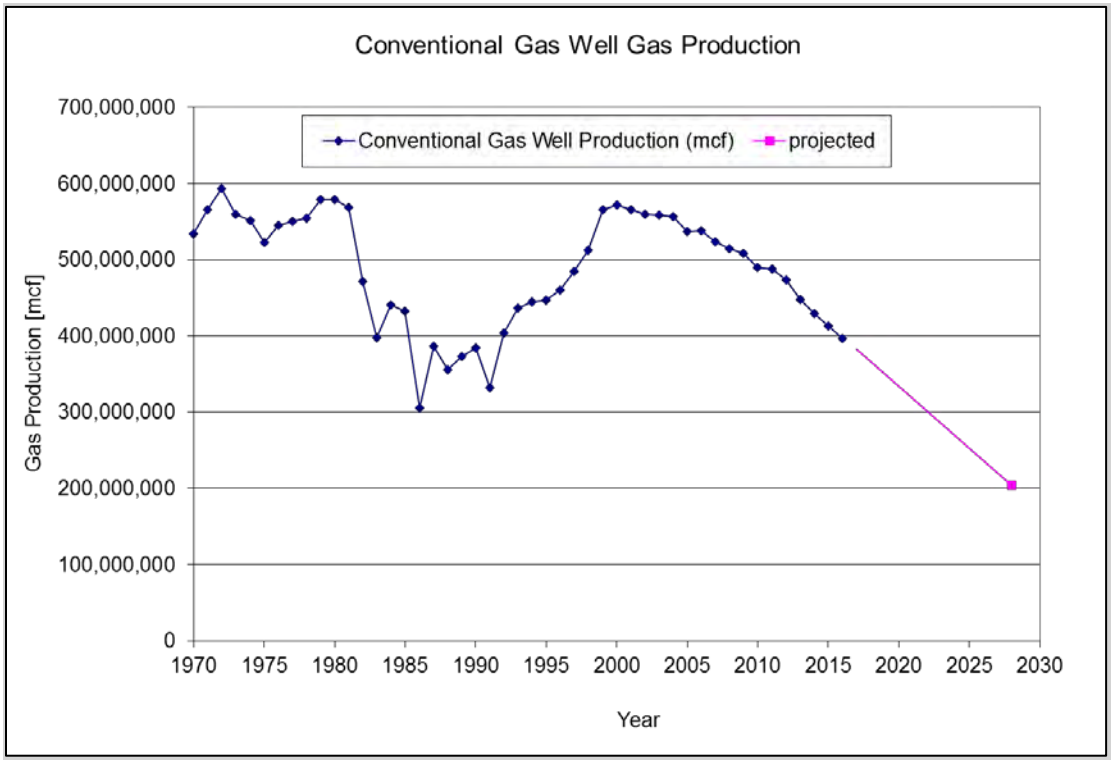

Figure 2-6. Greater San Juan Basin historical primary gas production and 2028 forecast.[5]

CBM Well Gas Production

Historical Greater San Juan Basin 1970–2016 CBM gas production is shown in Figure 2-7 with the 2028 forecast. CBM gas production has steadily decreased in recent years; the 2028 forecast was estimated to decrease from 2016 consistent with recent historical declines.

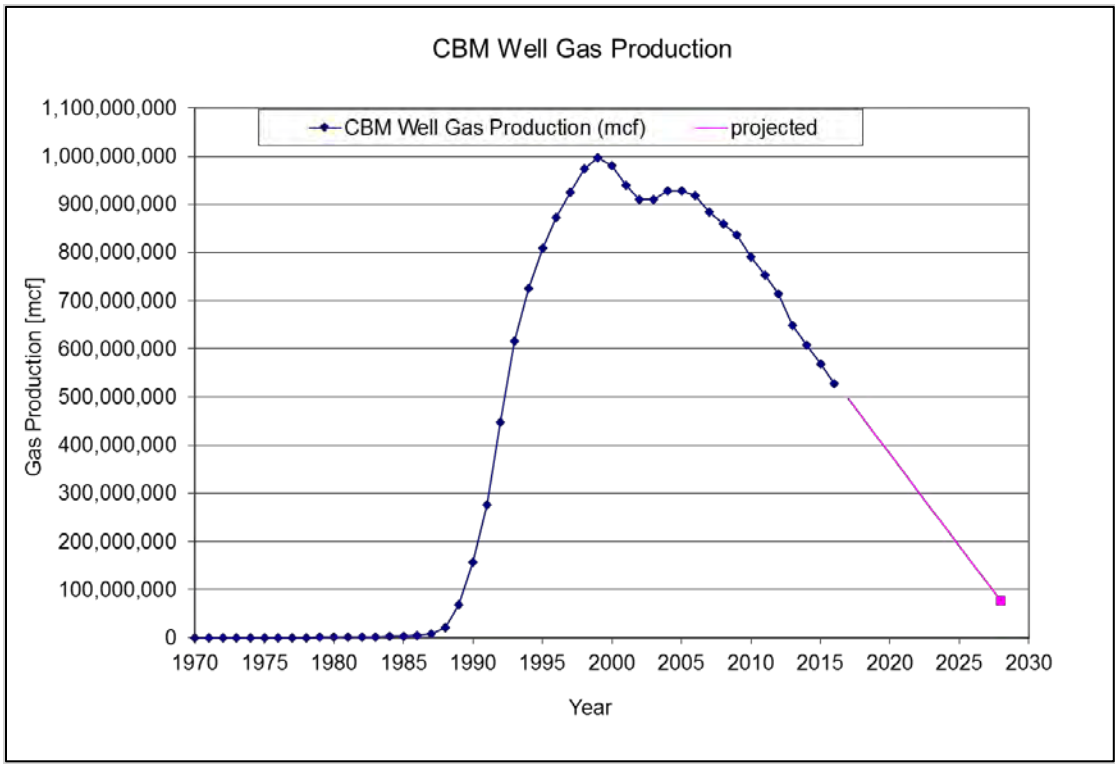

Figure 2-7. Greater San Juan Basin historical CBM gas production and 2028 forecast.[5]

Oil Well Oil Production

Historical Greater San Juan Basin 1970–2016 oil well oil production is shown in Figure 2-8 with the 2028 forecast. Oil well oil production declined from 1986 through 2010, remained relatively constant from 2010 to 2012, increased substantially from 2012 to 2015, and then declined from 2015 to 2016. The future year 2028 oil well oil production forecast was estimated to be equal to the 20-year average oil well oil production from 1997 to 2016.

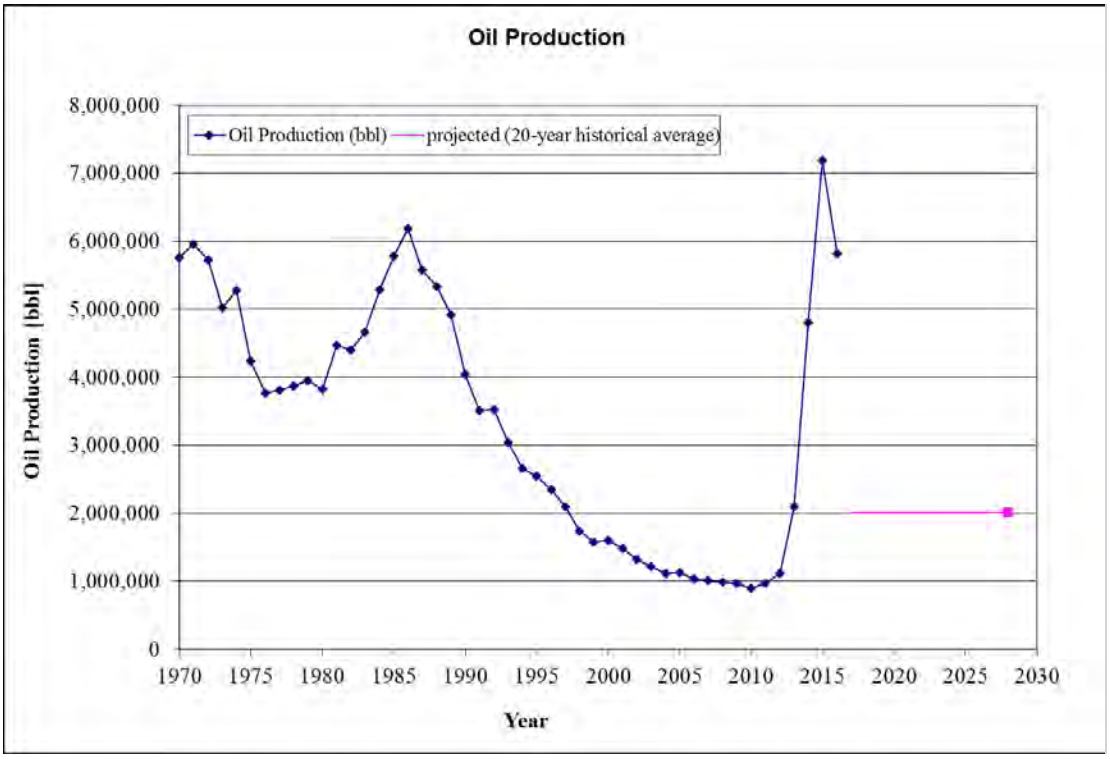

Figure 2-8. Greater San Juan Basin historical oil well oil production and 2028 forecast.[5]

Condensate Production

Historical Greater San Juan Basin 1970–2016 condensate production is shown in Figure 2-9 with the 2028 forecast. Annual condensate production has remained between 1.4 million barrels and 2.1 million barrels since 1992 with a declining trend from 1994 to 2010, an increasing trend from 2010 to 2015 and decline from 2015 to 2016. Future year 2028 condensate production was estimated to be equal to 2016 condensate production.

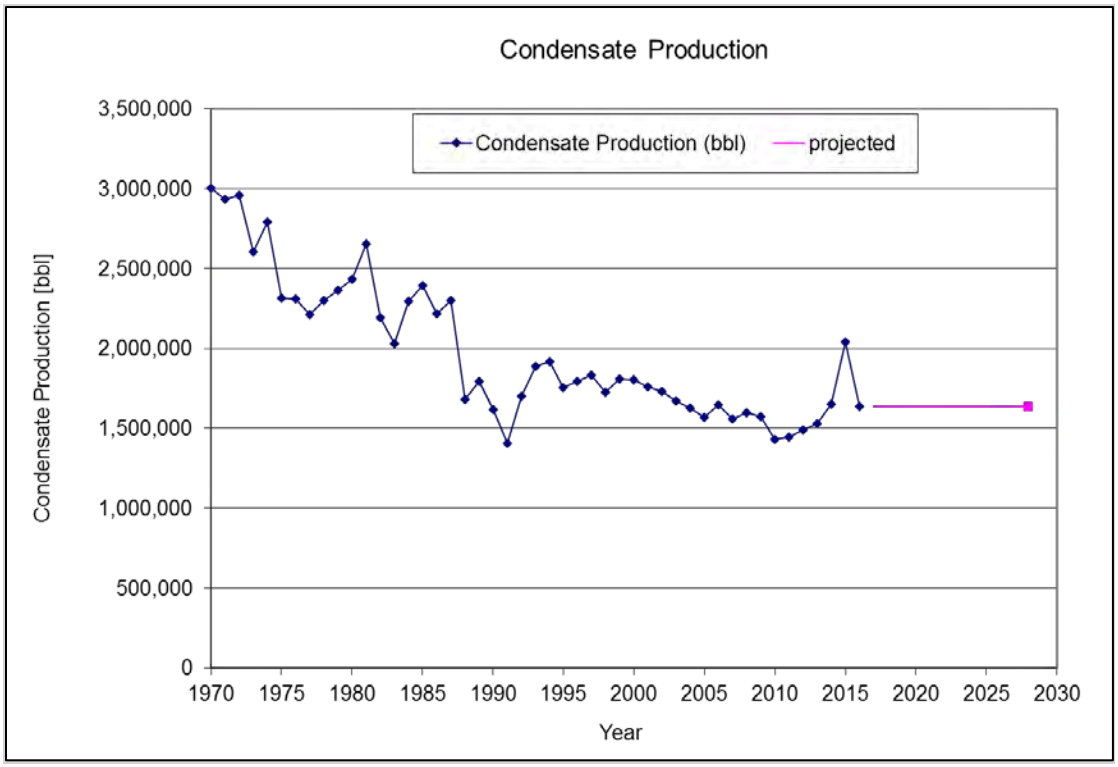

Figure 2-9. Greater San Juan Basin historical condensate production and 2028 forecast.[5]

2.2.1.1 O&G Activity Scaling Factor Development

The 2028 to 2014 ratio of each O&G activity metric described above comprise the emission forecast scaling factors for non-shale oil, non-shale gas, and CBM activity in the Greater San Juan Basin as shown in Equation 1.

$$f_{i,} = W_{i,2028} / W_{i,2014} \qquad \text{(Equation 1)}$$

where:

f_i is the scaling factor for parameter *i* (non-shale oil, non-shale gas, or CBM well gas production, oil production, or active well count)
$W_{i,2014}$ is the historical value of parameter *i* in 2014
$W_{i,2028}$ is the forecast value of parameter *i* in 2028

The O&G activity scaling factor associated with each emission source category is shown in Table 2-2. The O&G activity scaling factor estimates for the Greater San Juan Basin are presented in Table 2-3.

Table 2-2. Scaling parameter for each O&G source category considered in this inventory.

Nonpoint Source	Well Type	Scaling Parameter
Artificial Lift Engines	Oil Wells	Oil Well Count
Blowdown Venting	All Wells	Total Well Count
Blowdown Venting	Oil Wells	Oil Well Count
Blowdown Venting	Gas Wells	Gas Well Count
Blowdown Venting	CBM Wells	CBM Well Count
Blowdown Flaring	All Wells	Total Well Count
Blowdown Flaring	Oil Wells	Oil Well Count
Blowdown Flaring	Gas Wells	Gas Well Count
Blowdown Flaring	CBM Wells	CBM Well Count
Wellhead Compressor Engines	All Wells	Total Well Count
Wellhead Compressor Engines	Oil Wells	Oil Well Count
Wellhead Compressor Engines	Gas Wells	Gas Well Count
Wellhead Compressor Engines	CBM Wells	CBM Well Count
Lateral Compressor Engines	All Wells	Total Well Count
Lateral Compressor Engines	Oil Wells	Oil Well Count
Lateral Compressor Engines	Gas Wells	Gas Well Count
Lateral Compressor Engines	CBM Wells	CBM Well Count
Casinghead Gas Venting	Oil Wells	Oil Well Gas Production
Casinghead Gas Flaring	Oil Wells	Oil Well Gas Production
Condensate Tanks	Gas Wells	Gas Well Oil Production
Condensate Tank Flaring	Gas Wells	Gas Well Oil Production
Oil Tank Losses	Oil Wells	Oil Well Oil Production
Oil Tank Flaring	Oil Wells	Oil Well Oil Production
Dehydrator Venting and Flaring	All Wells	Total Gas Production
Dehydrator Venting and Flaring	Oil Wells	Oil Well Gas Production
Dehydrator Venting and Flaring	Gas Wells	Gas Well Gas Production
Dehydrator Venting and Flaring	CBM Wells	CBM Well Gas Production
Fugitive Components	All Wells	Total Well Count
Fugitive Components	Oil Wells	Oil Well Count
Fugitive Components	Gas Wells	Gas Well Count
Fugitive Components	CBM Wells	CBM Well Count
Heaters	All Wells	Total Well Count
Heaters	Oil Wells	Oil Well Count
Heaters	Gas Wells	Gas Well Count
Heaters	CBM Wells	CBM Well Count
Pneumatic Controllers	All Wells	Total Well Count
Pneumatic Controllers	Oil Wells	Oil Well Count
Pneumatic Controllers	Gas Wells	Gas Well Count
Pneumatic Controllers	CBM Wells	CBM Well Count
Pneumatic Pumps	All Wells	Total Well Count
Pneumatic Pumps	Oil Wells	Oil Well Count
Pneumatic Pumps	Gas Wells	Gas Well Count
Refracing Engines	All Wells	Total Well Count
Refracing Engines	Oil Wells	Oil Well Count

Nonpoint Source	Well Type	Scaling Parameter
Refracing Engines	Gas Wells	Gas Well Count
Refracing Engines	CBM Wells	CBM Well Count
Oil Well Truck Loading	Oil Wells	Oil Well Oil Production
Gas Well Truck Loading	Gas Wells	Gas Well Oil Production
Water Pump Engines	All Wells	Total Well Count
Water Pump Engines	Oil Wells	Oil Well Count
Water Pump Engines	Gas Wells	Gas Well Count
Water Pump Engines	CBM Wells	CBM Well Count
Water Tank Venting and Flaring	All Wells	Total Gas Production
Water Tank Venting and Flaring	Oil Wells	Oil Well Oil Production
Water Tank Venting and Flaring	Gas Wells	Gas Well Condensate Production
Water Tank Venting and Flaring	CBM Wells	CBM Well Gas Production
Workover Rigs	All Wells	Total Well Count
Workover Rigs	Oil Wells	Oil Well Count
Workover Rigs	Gas Wells	Gas Well Count
Workover Rigs	CBM Wells	CBM Well Count

Table 2-3. Summary of 2028 to 2014 scaling ratio by O&G activity metric for the Greater San Juan Basin.

Surrogate	2028/2014 Scaling Ratio
Gas Well Count	0.90
Oil Well Count	0.92
CBM Well Count	0.89
Condensate Production	0.99
Oil Well Oil Production	0.42
Gas Well Gas Production	0.48
Associated Gas Production	0.67
CBM Well Gas Production	0.12
All Wells Counts	0.90
All Wells Oil Production	0.56
All Wells Gas Production	0.28

2.2.2 Controls

Emissions control effects resulting from regulatory programs were incorporated into future year emission estimates for non-shale O&G sources. As shown in Table 2-3, declines are predicted in all O&G activity metrics from 2014 to 2028. The amount of new non-shale development is expected to be limited and the prevalence of modified sources is unknown; therefore, we have conservatively assumed no effects on emissions resulting from New Source Performance Standards (NSPS). Colorado Department of Public Health and Environment (CDPHE) Regulation 7 requirements apply to O&G emission sources in Colorado that are not on tribal land. In the base year 2014 Greater San Juan Basin emission inventory, county-wide emissions from La Plata and Archuleta counties were estimated based on the 2014 SUIT

emission inventory (CDPHE, 2017). Relative to total 2014 Greater San Juan Basin O&G production in Colorado, wells subject to Regulation 7 (i.e., in Colorado and not on tribal land) accounted for 12% of gas production and 11% of oil production (CDPHE, 2017). Given the basis of the 2014 base year emission inventory (2014 SUIT inventory) for wells subject to Regulation 7 and the small fraction of base year 2014 Greater San Juan Basin O&G production in Colorado from wells subject to Regulation 7, we have not estimated emission reductions resulting from Regulation 7. The 2016 BLM Methane Rule[14] applies to existing and new sources as summarized in Table 2-4. We have incorporated emission reductions resulting from the 2016 BLM Methane Rule for emissions from federal mineral estate as described below.

[14] https://www.blm.gov/programs/energy-and-minerals/oil-and-gas/operations-and-production/methane-and-waste-prevention-rule

Table 2-4. Summary of 2016 BLM Methane Rule applicability to Greater San Juan Basin emission inventory.

Source Category	Regulation	Enforcing Agency	Applicability	Effective Date
Pneumatic Controllers	**2016 BLM Methane Rule**: Requires operators to replace high-bleed pneumatic controllers with low-bleed or no-bleed pneumatic controllers.	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase-in from January 2017
Storage Tanks	**2016 BLM Methane Rule**: Requires operators to route storage vessel vapor gas to a sales line, if the storage vessel has the potential to emit at least 6 tpy of VOCs.	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase-in from January 2017
Associated Gas Venting and Flaring	**2016 BLM Methane Rule**: Requires increases to the amount of casinghead gas that is captured to 90 percent in 2020, 95 percent in 2023, and 98 percent in 2026.	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase-in from January 2017
Fugitives	**2016 BLM Methane Rule**: Leak Detection and Repair (LDAR) programs are required at applicable well sites.	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase in from January 2017
Pneumatic Pumps	**2016 BLM Methane Rule**: Operator must replace pneumatic diaphragm pumps that operate 90 or more days per year with zero-emissions pumps, if technical feasible and not unduly costly, or route pneumatic diaphragm pump emissions to a control device.	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase in from January 2017
Liquids Unloading	**2016 BLM Methane Rule:** Operator must use best practices to limit emissions associated with liquids unloading (e.g., use of plunger lifts, staying on-site during manual purging).	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase in from January 2017

2.2.2.1 2016 BLM Methane Rule for Pneumatic Devices

Pneumatic device control factors were developed according to 2016 BLM Methane Rule requirements.

I. Federal existing and new wells: All pneumatic devices were assumed to be low-bleed (i.e. less than 6 standard cubic-feet per hour bleed rate)[14].

II. Non-federal wells: No change resulting from 2016 BLM Methane Rule.

2.2.2.2 2016 BLM Methane Rule for Crude Oil and Condensate Tanks

Crude oil and condensate tank control factors were developed according to 2016 BLM Methane Rule requirements.

The 2016 BLM Methane Rule requires control of new and existing tanks that emit over 6 tons per year VOC[14]. The rule requires that storage vessel vapor gas be routed to a sales line, if the storage vessel has the potential to emit at least 6 tpy of VOCs starting from January 2015 unless technically infeasible or unduly costly.

Ramboll estimated control scalars for tanks at all federal (existing and new) wells. Control factors are based on application of control to tanks with the potential to emit 6 tons per year VOC, but not to tanks with the potential to emit less than 6 tons per year VOC. 99% percent of federal oil tank and 70% of federal condensate tank emissions were assumed to be controlled by vapor recovery unit (VRU)[15].

2.2.2.3 2016 BLM Methane Rule for Associated Gas Venting and Flaring

The 2016 BLM Methane Rule requires operators to increase capture of casinghead gas. By 2026 98% of casinghead gas must be captured. Greater San Juan Basin-wide, over 99% of base year 2014 casinghead gas was assumed to be captured. Given that basin-wide casinghead gas capture estimates in base year 2014 met 2026 operator specific limits, no additional control was estimated for this source category. The casinghead gas provision of the 2016 BLM Methane Rule was designed to address casinghead gas releases in new development areas (such as the Bakken) where lack of gas gathering infrastructure led to substantial casinghead gas releases. The Greater San Juan Basin is a mature O&G development area with substantial gas gathering infrastructure, so the assumption that it already is in compliance with 2016 BLM Methane Rule capture requirements is reasonable.

2.2.2.4 2016 BLM Methane Rule for Fugitive Devices

The 2016 BLM Methane Rule requires routine fugitive leak monitoring at well sites. LDAR program requirements specify that LDAR surveys are conducted twice annually after the initial survey. LDAR implementation is assumed to result in 50% reductions to fugitive component

[15] The fraction of crude oil and condensate tanks with emissions greater than 6 tons per year VOC was estimated based on base year 2014 tank flashing emission factors and per well production activity from IHS database. We assumed that all production at each well site was sent to a single tank (i.e. multi-tank sites were not considered) because information was not available to estimate the number of tanks per well site.

emissions at all (existing and new) federal wells based on average reductions from annual and quarterly inspections assumed in CDPHE (2014).

2.2.2.5 2016 BLM Methane Rule for Pneumatic Pumps

Emission control factors for pneumatic pumps resulting from the 2016 BLM Methane Rule were not estimated. 2016 BLM Methane Rule requirements apply only to diaphragm pumps but not lean glycol circulation pumps or piston-driven chemical injection pumps. The base year inventory was based on generic pneumatic pump configurations which did not distinguish pump type. Not including additional control of pneumatic pumps per on-the-books regulations is consistent with CARMMS 2.0 low and high scenario inventories.

2.2.2.6 2016 BLM Methane Rule for Liquids Unloading

The 2016 BLM Methane Rule requires the use of best practices to limit emissions associated with liquids unloading (e.g., use of plunger lifts, staying on-site during manual purging). It was not feasible to estimate the effect of 2016 BLM Methane Rule requirements on liquids unloading emission rates in the Greater San Juan Basin because information on the extent to which best practices were employed in base year 2014 is not available. Emission control factors for liquids unloading resulting from the 2016 BLM Methane Rule were not estimated.

2.2.2.7 Summary

Greater San Juan Basin future year 2028 control factors are presented in Table 3-4 for non-shale O&G emissions.

Table 2-5. Percent reduction in Greater San Juan Basin future year 2028 nonpoint emissions resulting from emission control programs[16].

Well Type	Nonpoint Source	Federal Sources Only				
		NOx	VOC	CO	SOx	PM_{10}
Gas Wells	Condensate Tanks	-100%	-63%	-100%		
	Fugitive Components		-50%			
	Pneumatic Devices		-55%			
Oil Wells	Oil Tanks	-100%	-94%	-100%		
	Fugitive Components		-50%			
	Pneumatic Devices		-53%			
CBM Wells	Fugitive Components		-50%			
	Pneumatic Devices		-57%			

[16] GHG emission reductions are based on criteria pollutant emission reductions. Methane and CO_2 emission reductions are assumed equivalent to VOC emissions reductions for tank losses, fugitive components, and pneumatic devices. Methane, CO_2, and N_2O emission reductions are assumed equivalent to NOx emission reductions for flaring.

2.3 Permitted (Point) Emissions Forecast

Recent trends in gas production show substantial declines from 1999 peak Greater San Juan Basin production (Figure 2-10). As described above, non-shale gas production declines are estimated to continue to 2028. Based on the assumption that midstream capacity formerly available to declining non-shale production would be used by increasing shale production, forecast 2028 point source O&G emissions were assumed to be equal to base year emissions. Emissions from SUIT Shale SEIS Central Delivery Point facilities were added consistent with CARMMS 2.0.

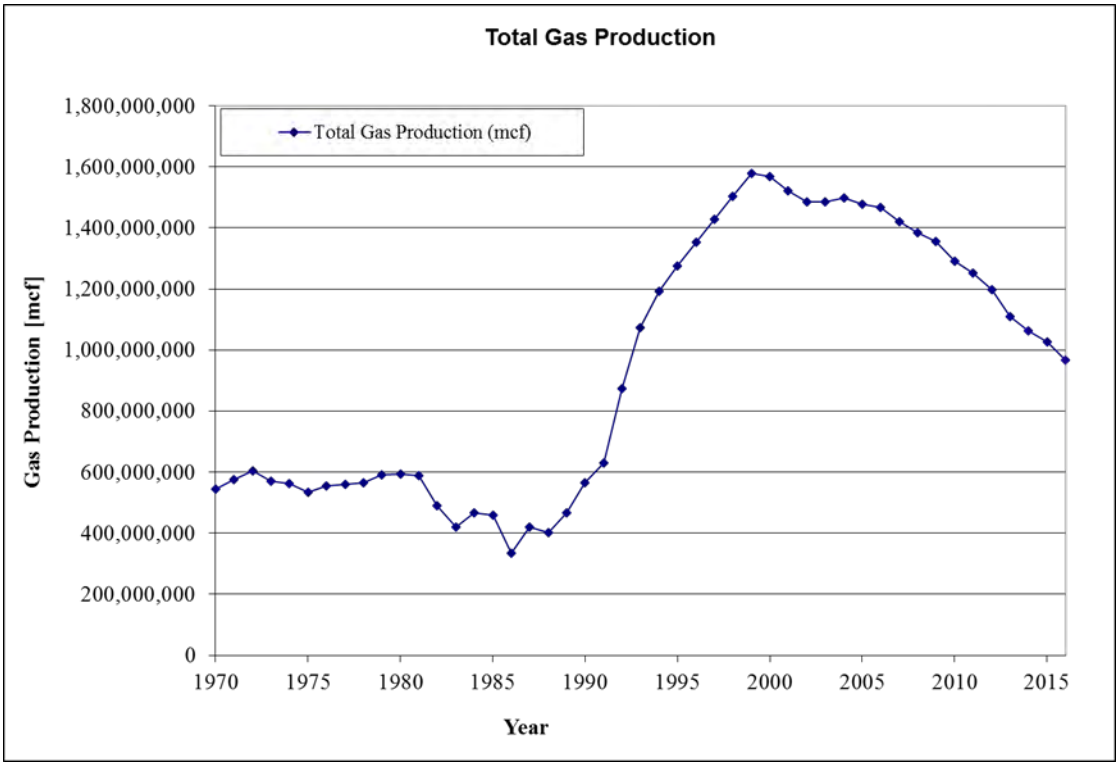

Figure 2-10. Greater San Juan Basin historical total gas production.[5]

3.0 PERMIAN FUTURE YEAR EMISSION INVENTORY

Permian Basin 2014 base year emissions were forecast to future year 2028, accounting for changes to O&G activity and emission control program effects. O&G activity forecast factors were limited to estimates of future changes to O&G production. The use of additional O&G activity metrics (e.g., active well count and spuds) to estimate additional scaling factors would allow O&G forecasts to be more closely to specific activity drivers (e.g., spuds for drill rigs and active well count for pneumatic controllers); however, only O&G production forecasts are available at this time for the Permian Basin.

3.1 O&G Activity Forecasts

Permian Basin 2014 to 2028 O&G activity scaling factors were developed based on US Energy Information Administration (EIA) Annual Energy Outlook (AEO) forecasts. EIA publishes activity forecasts by Oil and Gas Supply Module region (Figure 3-1). Ramboll obtained shale play-level forecasts from EIA staff which include the Avalon/Bone Springs and Wolfcamp shale plays which are in the portion of the Permian Basin in New Mexico[17] (Figure 3-2). Table 3-1 shows EIA forecasts applicable to the Permian Basin. Per EIA staff, information released by EIA as part of the AEO is limited to shale play-level data provided by email to Ramboll[17] and Oil and Gas Supply Module region-level data available online. EIA does not release more detailed information because of forecast uncertainty for smaller formations.

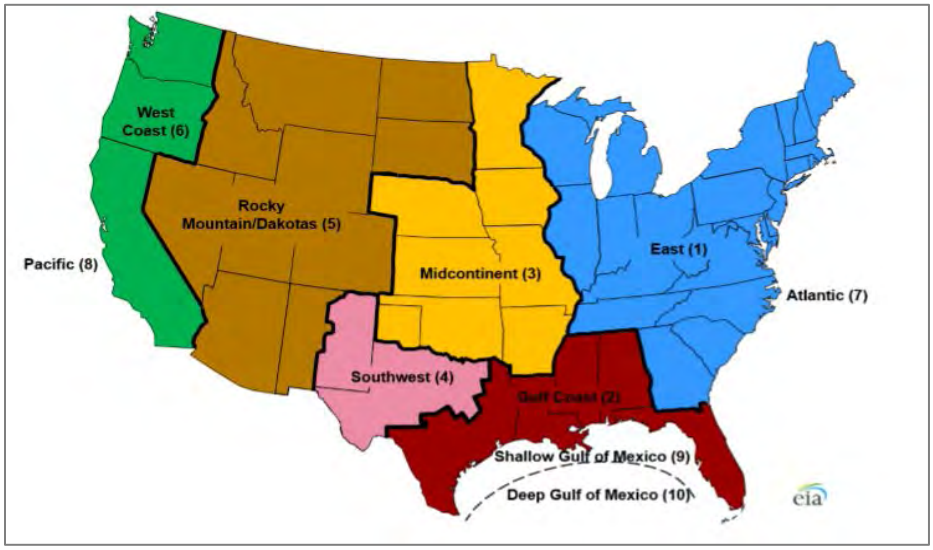

Figure 3-1. EIA Oil and Gas Supply Module regions[18].

[17] Email from John Staub (EIA), June 28, 2017

[18] Source: EIA (2017), "Assumptions to the Annual Energy Outlook 2017", (Figure 9.1), available online at https://www.eia.gov/outlooks/aeo/assumptions/

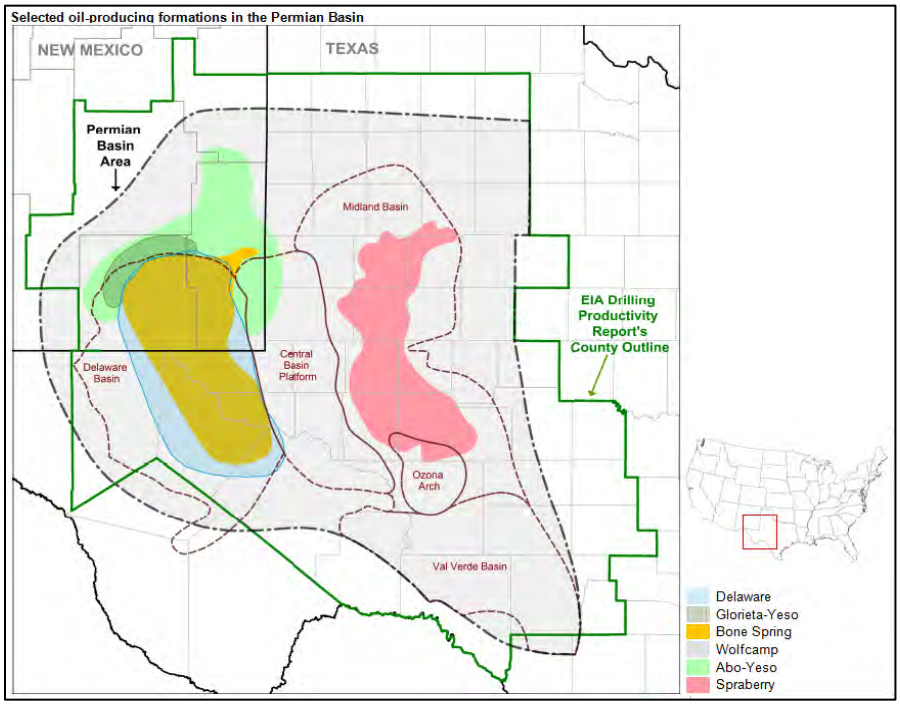

Figure 3-2. Permian Basin oil plays [19].

Table 3-1. 2017 AEO O&G production estimates for 2014 and forecasts to 2028[17].

Region / Tight Oil Play (states)	Oil Production (million barrels per day)		Gas Production (trillion cubic feet per year)	
	2014	2028	2014	2028
Southwest Region-wide				
Southwest (NM & TX) [B]	0.88	0.64	3.56	3.15
Tight Oil Plays in the Permian Basin (New Mexico)				
Avalon/Bone Springs (NM & TX)	0.19	0.34	not available	
Wolfcamp (NM & TX)	0.20	0.73		
Spraberry (TX)	0.47	0.98		
Other (several states[A])	0.65	0.54		

[A] Includes tight oil plays in the Permian and other US O&G Basins which are not available by play (e.g. Delaware and "Glorieta and Yeso" tight oil plays). EIA does not release more detailed information because of forecast uncertainty for smaller formations.

[B] Excludes oil production from Avalon/Bone Springs, Wolfcamp, and Spraberry shale plays

The ratio of EIA AEO 2028 to 2014 Southwest Oil and Gas Supply Module region gas production is the gas production scaling ratio.

EIA shale play-level oil production along with Southwest Oil and Gas Supply Module region oil production were used to estimate a Permian Basin-wide oil production scaling factor. IHS Enerdeq 2014 oil production estimates by well include a reservoir and well type designation for

[19] https://www.eia.gov/todayinenergy/detail.php?id=17031

each well. Based on the well type and reservoir name associated with each O&G well, the well was assigned to an EIA shale play or the Southwest Oil and Gas Module region. The ratio of EIA AEO 2028 to 2014 oil production was applied to each well's oil production based on the associated shale play or region to estimate each well's 2028 forecast. The summation of 2028 forecasts across all wells is the 2028 to 2014 scaling ratio.

Table 3-2 shows O&G activity forecast scalars. Gas well O&G activity scalars were based on gas production forecasts, oil well O&G activity scalars were based on oil production, and midstream O&G activity scalars were based on gas production. This methodology is similar to the methodology used in the 2011 EPA modeling platform (EPA, 2014a), with modifications because the 2014 base year inventory includes emissions by well type (in EPA [2014a] oil and gas well type specific emissions are not available for several source categories such as drill rigs and water tanks).

Table 3-2. Permian Basin Future Growth (2028/2014) Scaling Factors.

Surrogate	Oil Wells	Gas Wells	Total
Oil Production	1.30	1.81	1.31
Gas Production	0.88	0.88	0.88

3.2 Controls

Emissions control resulting from regulatory programs such as EPA's NSPS Subpart OOOO and OOOOa[20], EPA's NSPS JJJJ standards[21], EPA's off-road diesel engine tier standards[22], the 2016 BLM Methane Rule[14] and state specific regulatory programs were incorporated into future year emission estimates. Emission control estimates are based on the suite of regulations that were "on-the-books" at the time that this future year emission inventory was developed. Emission control assumptions for fugitive components (LDAR), green completions at oil wells, and pneumatic pumps are based on NSPS OOOOa provisions. EPA is conducting ongoing activities that may lead to future changes to NSPS OOOOa[23,24].

Accurate accounting of emission control effects is dependent on several factors such as the level of emission control in the base year and expected control program penetration in future years. In cases where emission control is applied to new or modified sources only (e.g. NSPS Subpart OOOO), estimates of the prevalence of control application to "modified" sources have not been developed. Therefore, we applied controls to only added emissions; this methodology is consistent with EPA modeling platform future year O&G emission estimation methodology (EPA, 2014a). Table 3-3 below summarizes "on-the-books" federal and state regulations that affect emissions source categories in the O&G industry.

[20] https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-industry
[21] https://www.epa.gov/stationary-engines/new-source-performance-standards-stationary-spark-ignition-internal-combustion
[22] https://www.epa.gov/vehicles-and-engines
[23] https://www.awma-rmss.org/wp-content/uploads/Update-on-Air-Quality-Guidance-and-Regulations-Aug-13-2018_.pdf
[24] https://hy-bon.com/blog/recent-changes-and-update-on-nsps-ooooa/

Table 3-3. Summary of federal and state "on-the-books" regulations affecting O&G source categories considered in this inventory.

Source Category	Regulation	Enforcing Agency	Applicability	Effective Date
Drill Rigs, Fracturing Engines	**Nonroad engine Tier standards (1-4)**: Limits emission rates for compression ignition engines.	US EPA	All applicable off-road mobile engine categories	Phase-in from 1996 - 2014
Pneumatic Controllers	**NSPS Subpart OOOO**: Six standard cubic-feet per hour (scfh) at well sites (i.e. low bleed gas-driven pneumatic controllers). **2016 BLM Methane Rule**: Requires operators to replace high-bleed pneumatic controllers with low-bleed or no-bleed pneumatic controllers.	US EPA and US BLM	Non-Federal: New and modified[1] sources only (NSPS OOOO and OOOOa) Federal: new and existing sources (NSPS OOOO, NSPS OOOOa, and 2016 BLM Methane Rule)	NSPS OOOO: August 2011 2016 BLM Methane Rule: Phase-in from January 2017
Compressor Engines, Artificial Lift Engines	**NSPS Subpart JJJJ**: Limits emission rates for spark ignition engines.	US EPA	New and modified spark-ignition engines	Phase-in from 2005 to 2011
Well Completions	**NSPS Subpart OOOO and OOOOa**: Green completions required at gas and oil well sites except for specific well types (wildcat, delineation, oil wells with a gas-oil ratio of less than 300 standard cubic-feet of gas per barrel, and oil wells for which a gas pipeline is not available). **2016 BLM Methane Rule:** Compliance with NSPS Subpart OOOO and OOOOa requirements is sufficient for compliance with 2016 BLM Methane Rule.	US EPA and BLM	All applicable completions	NSPS OOOO and OOOOa: Phase-in from 2015
Storage Tanks	**NSPS Subpart OOOO and OOOOa**: Storage vessels with VOC emissions equal to or greater than 6 tpy must reduce emissions by at least 95 percent. This can be accomplished by routing emissions to a combustion device. **2016 BLM Methane Rule**: Requires operators to route	US EPA and US BLM	Non-Federal: New and modified[1] sources only (NSPS OOOO and OOOOa)	NSPS OOOO and OOOOa: August 2011 2016 BLM Methane Rule:

Source Category	Regulation	Enforcing Agency	Applicability	Effective Date
	storage vessel vapor gas to a sales line, if the storage vessel has the potential to emit at least 6 tpy of VOCs.		Federal: New and existing sources (2016 BLM Methane Rule)[2]	Phase-in from January 2017
Associated Gas Venting and Flaring	**2016 BLM Methane Rule**: Rule requires increases to the amount of casinghead gas that is captured to 90 percent in 2020, 95 percent in 2023, and 98 percent in 2026.	US BLM	Non-Federal: not applicable Federal: new and existing sources (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase-in from January 2017
Fugitives	**2016 BLM Methane Rule and NSPS Subpart OOOOa**: LDAR programs are required at applicable well sites.	US EPA and US BLM	Non-Federal: new and modified sources (NSPS OOOOa) Federal: new and existing sources (2016 BLM Methane Rule)	NSPS OOOOa : Phase in from 2015 2016 BLM Methane Rule: Phase in from January 2017
Pneumatic Pumps	**NSPS Subpart OOOOa**: Route emissions from pneumatic diaphragm pumps to existing onsite control device, if available. **2016 BLM Methane Rule**: Operator must replace pneumatic diaphragm pumps that operate 90 or more days per year with zero-emissions pumps, if technical feasible and not unduly costly, or route pneumatic diaphragm pump emissions to a control device.	US EPA and BLM	Non-Federal: new and modified sources (NSPS OOOOa) Federal: new and existing wells (2016 BLM Methane Rule)	NSPS OOOOa: Phase in from 2015 2016 BLM Methane Rule: Phase in from January 2017
Liquids Unloading	**2016 BLM Methane Rule:** Operator must use best practices to limit emissions associated with liquids unloading (e.g., use of plunger lifts, staying on-site during manual purging).	US BLM	Federal: new and existing wells (2016 BLM Methane Rule)	2016 BLM Methane Rule: Phase in from January 2017

[1] The fraction of sources that would be classified as "modified" under NSPS OOOO and/or NSPS OOOOa is unavailable. Controls were applied to new sources only.
[2] If an operator determines that VRU installation is technically infeasible or unduly costly, the operator may instead route the tank vapor gas to a combustor or flare.

The methodology used to estimate each control's effect on nonpoint source O&G emissions is presented below. Point source O&G emissions may also be subject to additional control per requirements such as NSPS Subpart OOOO, NSPS Subpart OOOOa, and the 2016 BLM Methane Rule; however, information was not readily available from point source emission inventory databases upon which to estimate the effect on emissions of such controls. Point source O&G emission forecasts do not include additional control resulting from regulatory control programs.

3.2.1 Nonroad Diesel Engine Standards and Fuel Sulfur Standards

EPA MOVES 2014a (EPA, 2015) was run with default inputs for base year 2014 and future year 2028. Model outputs were used to develop basin-wide emissions per unit population for "other oil field equipment" (SCC 2270010010) for base year 2014 and future year 2028. Emissions per unit population reflect the predicted fleet mix of engines – for various tier standards from baseline uncontrolled engines through Tier IV engines – and are used as a representation of fleet turnover for drilling rigs and fracing engines. The ratios of 2028 to 2014 per unit emissions are the control factors estimates which account for federal non-road tier standards and diesel fuel sulfur standards.

3.2.2 New Source Performance Standards and 2016 BLM Methane Rule for Pneumatic Devices

Pneumatic device control factors were developed according to NSPS Subpart OOOO and OOOOa and 2016 BLM Methane Rule requirements.

III. Federal wells: Pneumatic devices at all (existing and new) wells were assumed to be low-bleed (i.e. less than 6 standard cubic-feet per hour bleed rate)[14].

IV. Non-federal wells: Pneumatic devices at new wells were assumed to be low-bleed devices and pneumatic devices at existing wells were assumed to be unchanged from the base year.

3.2.3 New Source Performance Standards and 2016 BLM Methane Rule for Completions

NSPS Subpart OOOO and OOOOa require control of emissions from (i) hydraulically fractured gas well completions by flare from August 23, 2011 to December 31, 2014 and with green completion technology from January 1, 2015[25] and (ii) hydraulically fractured oil well completions by green completion technology from September18, 2015[26]. It was assumed that all completions in future year 2028 will use green completion technology with 99% control efficiency.

[25] Fact Sheet: Summary of Requirements for Processes and Equipment at Natural Gas Well Sites. https://www.epa.gov/sites/production/files/2016-09/documents/20120417_natural_gas_summary_gas_well.pdf

[26] Fact Sheet Proposed Climate, Air Quality and Permitting Rules for the Oil and Natural Gas Industry https://www.epa.gov/sites/production/files/2016-09/documents/og_fs_081815.pdf

3.2.4 New Source Performance Standards and 2016 BLM Methane Rule for Crude Oil and Condensate Tanks

Crude oil and condensate tank control factors were developed according to NSPS Subpart OOOO and OOOOa and 2016 BLM Methane Rule requirements.

I. NSPS Subpart OOOO requires control of condensate and oil tank VOC emissions for tanks that emit over 6 tons per year VOC if the source was constructed or modified after August 23, 2011, NSPS OOOOa extends the requirements to control of methane emissions. The compliance deadline was April 15, 2014 for tanks constructed after April 12, 2013 and April 15, 2015 for tanks constructed between August 23, 2011 and April 12, 2013[27].

II. 2016 BLM Methane Rule requires control of new and existing tanks that emit over 6 tons per year VOC[14]. The rule requires that storage vessel vapor gas be routed to a sales line, if the storage vessel has the potential to emit at least 6 tpy of VOCs starting from January 2015 unless technically infeasible or unduly costly.

Ramboll estimated control scalars for tanks at new non-federal wells and all federal (existing and new) wells. Control factors are based on application of control to tanks with the potential to emit 6 tons per year VOC, but not to tanks with the potential to emit less than 6 tons per year VOC. For non-federal well tank emissions added after base year 2014, 73% percent of oil tank and 77% of condensate tank emissions were assumed to be controlled by flare[28]. For all federal well tank emissions, 73% percent of oil tank and 77% of condensate tank emissions were assumed to be controlled by VRU.

3.2.5 New Source Performance Standards for Compressor Engines

US EPA NSPS Subpart JJJJ[21] requirements are applicable to natural gas-fueled nonpoint artificial lift engines and wellhead compressor engines as well as natural gas-fueled point source reciprocating engines. Permian Basin gas production is estimated to decline from base year 2014 to future year 2028, so the effects of NSPS Subpart JJJJ are expected to be limited to engine turnover and limited new midstream infrastructure build-outs. Information necessary (e.g., fleet turnover rates and engine specific emission rates) to estimate the effects of NSPS Subpart JJJJ on applicable point source engines was not readily available; therefore, future year 2018 forecasts were not adjusted to incorporate the effects of NSPS Subpart JJJJ on point source engine emissions (i.e., fleet turnover of point source engines between 2014 and 2028 is not accounted for). Artificial lift engine emission factor estimates in base year 2014 were below NSPS Subpart JJJJ requirements, hence no additional control was estimated for this source category.

[27] Fact Sheet: Final Updates to Requirements for Storage Tanks Used in Oil and Natural Gas Production and Transmission. https://www.epa.gov/sites/production/files/2016-09/documents/20120417_natural_gas_summary_gas_well.pdf

[28] The fraction of crude oil and condensate tanks with emissions greater than 6 tons per year VOC was estimated based on base year 2014 tank flashing emission factors and per well production activity from IHS database. We assumed that all production at each well site was sent to a single tank (i.e. multi-tank sites were not considered) because information was not available to estimate the number of tanks per well site.

3.2.6 2016 BLM Methane Rule for Associated Gas Venting and Flaring

Under this rule, operators are required to increase capture of casinghead gas. By 2026 98% of casinghead gas must be captured. Permian Basin-wide, over 99% of base year 2014 casinghead gas was estimated to be captured; 94% of casinghead gas that was not captured was flared and the remaining 6% was vented. Given that basin-wide casinghead gas capture estimates in base year 2014 met 2026 operator specific limits, no additional control was estimated for this source category. The casinghead gas provision of the 2016 BLM Methane Rule was designed specifically to address casinghead gas releases in new development areas (such as the Bakken) where lack of gas gathering infrastructure led to substantial casinghead gas releases. The Permian Basin is a mature O&G development area with substantial gas gathering infrastructure, so the assumption that it already is in compliance with 2016 BLM Methane Rule capture requirements is not unexpected.

3.2.7 New Source Performance Standards and 2016 BLM Methane Rule for Fugitive Devices

NSPS Subpart OOOOa requires routine fugitive leak monitoring for well sites and compressor stations constructed or modified after September 18, 2015. The 2016 BLM Methane Rule has similar fugitive leak monitoring requirements for both existing and new wells starting from January 2015. Gas production is estimated to decline from 2014 to 2028, hence no additional control was applied to non-federal gas wells fugitive component emissions. LDAR program requirements specify that LDAR surveys are conducted twice annually after the initial survey. LDAR implementation is assumed to result in 50% reductions to fugitive component emissions at new non-federal wells and all (existing and new) federal wells based on average reductions from annual and quarterly inspections reductions assumed in CDPHE (2014).

3.2.8 New Source Performance Standards and 2016 BLM Methane Rule for Pneumatic Pumps

Emission control factors for pneumatic pumps resulting from NSPS Subpart OOOOa and the 2016 BLM Methane Rule were not estimated. NSPS Subpart OOOOa and the 2016 BLM Methane Rule requirements apply only to diaphragm pumps but not lean glycol circulation pumps or piston-driven chemical injection pumps. The base year inventory was based on generic pneumatic pump configurations which did not distinguish pump type. Not including additional control of pneumatic pumps per on-the-books regulations is consistent with CARMMS 2.0 low and high scenario inventories.

3.2.9 New Source Performance Standards and 2016 BLM Methane Rule for Liquids Unloading

The 2016 BLM Methane Rule requires the use of best practices to limit emissions associated with liquids unloading (e.g., use of plunger lifts, staying on-site during manual purging). It was not feasible to estimate the effect of 2016 BLM Methane Rule requirements on liquids unloading emission rates in the Permian Basin because information on the extent to which best practices were employed in base year 2014 is not available. Emission control factors for liquids unloading resulting from the 2016 BLM Methane Rule were not estimated.

3.2.10 Summary

Permian Basin future year 2028 control factors are presented in Table 3-4.

Table 3-4. Percent reduction in Permian Basin future year 2028 nonpoint emissions resulting from emission control programs[29].

Well Type	Nonpoint Source	Existing Federal					New Federal					New Non-Federal				
		NOx	VOC	CO	SOx	PM_{10}	NOx	VOC	CO	SOx	PM_{10}	NOx	VOC	CO	SOx	PM_{10}
Gas Wells	Condensate Tanks	-100%	-65%	-100%	0%	0%	-100%	-65%	-100%	0%	0%	128%	-63%	128%	0%	0%
	Drilling Engines						-69%	-39%	-87%	-57%	-83%	-69%	-39%	-87%	-57%	-83%
	Fracing Engines						-48%	-48%	-83%	-56%	-73%	-48%	-48%	-83%	-56%	-73%
	Fugitive Components		-50%					-50%								
	Pneumatic Devices		-37%					-37%								
	Initial Completions						-100%	-97%	-100%	0%	0%	-100%	-97%	-100%	0%	0%
Oil Wells	Oil Tanks	-100%	-63%	-100%	0%	0%	-100%	-63%	-100%	0%	0%	175%	-81%	175%	0%	0%
	Drilling Engines						-67%	-38%	-87%	-57%	-82%	-67%	-38%	-87%	-57%	-82%
	Fracing Engines						-48%	-48%	-83%	-56%	-73%	-48%	-48%	-83%	-56%	-73%
	Fugitive Components		-50%					-50%					-50%			
	Pneumatic Devices		-37%					-37%					-37%			
	Initial Completions						-100%	-97%	-100%	0%	0%	-100%	-97%	-100%	0%	0%

[29] GHG emission reductions are based on criteria pollutant emission reductions. Methane and CO_2 emission reductions are assumed equivalent to VOC emissions reductions for tank losses, fugitive components, pneumatic devices, and initial completion losses. Methane, CO_2, and N_2O emission reductions are assumed equivalent to NOx emission reductions for flaring. For engines, CO_2 and N_2O emission reductions are assumed negligible; methane emission reductions are assumed equivalent to VOC emission reductions.

4.0 SUMMARY RESULTS

Future year forecast emission inventory summaries are provided below for the Greater San Juan and Permian basins. Additional summary tables and charts and detailed emission inventory data are available in spreadsheets posted on the Greater San Juan and Permian Basin O&G Emission Inventory Project website[30].

4.1 Greater San Juan Basin

Greater San Juan Basin future year 2028 emission inventory forecasts by county are shown in Table 4-1 for all pollutants.

Table 4-1. 2028 future year Greater San Juan Basin emission inventory forecast.

County [1]	Criteria Air Pollutant Emissions (tpy)					Greenhouse Gas Emissions (tpy) [2]			
	NOx	VOC	CO	SOx	PM	CO_2	CH_4	N_2O	CO_2e
Archuleta, CO	765	161	683	1	22	59,741	1,524	1	161,532
La Plata, CO	15,913	4,519	13,343	56	403	1,307,753	16,316	17	3,122,871
Colorado Subtotals	***16,679***	***4,680***	***14,026***	***56***	***425***	***1,367,494***	***17,840***	***18***	***3,284,403***
Cibola, NM	294	10	0	0	1	0	0	0	0
McKinley, NM	238	458	360	5	13	168,844	1,764	3	210,144
Rio Arriba, NM	14,714	26,185	26,039	38	448	2,667,920	83,245	27	4,979,516
Sandoval, NM	691	2,068	1,077	1	25	159,995	4,689	1	277,179
San Juan, NM	27,197	35,703	42,052	223	894	7,470,316	115,219	126	10,820,056
Valencia, NM	3	5	1	0	0	179	20	0	602
New Mexico Subtotals	***43,136***	***64,429***	***69,529***	***267***	***1,382***	***10,467,254***	***204,937***	***157***	***16,287,496***
Basin-wide Totals	**59,815**	**69,109**	**83,555**	**323**	**1,806**	**11,834,748**	**222,777**	**175**	**19,571,899**

[1] Negligible O&G emissions from O&G sources Los Alamos County, New Mexico.
[2] GHG emissions for sources without SCC were not estimated

[30] https://www.wrapair2.org/SanJuanPermian.aspx

2014 and 2028 annual emission totals are shown in Figure 4-1. Emission changes from base year 2014 to future year 2028 are in the range of a 46% decrease (CH_4) to a 6% increase (PM); NOx emissions changed by less than 1% and VOC emissions decreased by 23%. Decreases in VOC emissions are the result of several factors including the application of emission reductions resulting from on-the-books regulatory control programs (e.g., 2016 BLM Methane Rule).

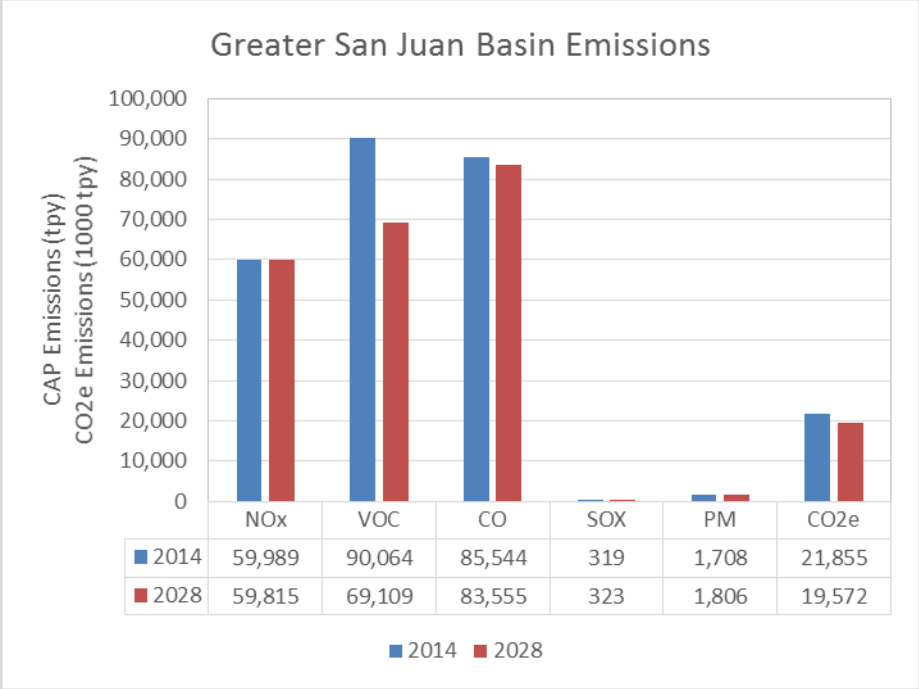

Figure 4-1. Greater San Juan Basin 2014 base year and 2028 future year emissions[31].

4.2 Permian Basin

Permian Basin future year 2028 emission inventory forecasts by county are shown in Table 4-2 for all pollutants.

Table 4-2. 2028 future year Permian Basin emission inventory forecast (excludes Texas portion of the Permian Basin).

	Criteria Air Pollutant Emissions (tpy)					Greenhouse Gas Emissions (tpy) [1]			
County	NOx	VOC	CO	SOx	PM	CO_2	CH_4	N_2O	CO_2e
Chaves	691	3,731	706	89	8	132,509	13,016	2	406,369
Eddy	11,521	52,748	12,424	4,992	216	3,679,132	174,386	57	7,358,809
Lea	14,141	56,060	12,006	7,515	317	3,834,441	201,415	57	8,081,957
Roosevelt	120	354	134	20	1	24,974	1,184	0	49,929
Totals	**26,473**	**112,893**	**25,270**	**12,616**	**541**	**7,671,057**	**390,001**	**116**	**15,897,063**

[1]GHG emissions for sources without SCC were not estimated

[31] GHG emissions for sources without SCC were not estimated

2014 and 2028 total annual emissions are shown in Figure 4-2. Changes in emissions from base year 2014 to future year 2028 are in the range of a 25% decrease (N_2O and PM) to a 9% increase (CO_2); emissions decreased by 13% for NOx and 7% for VOC. Decreases in NOx and VOC emissions result from a 12% decrease in gas production from 2014 to 2028 and on-the-books emission control program (e.g., NSPS and 2016 BLM Methane Rule) effects which more than offset 30% oil production growth.

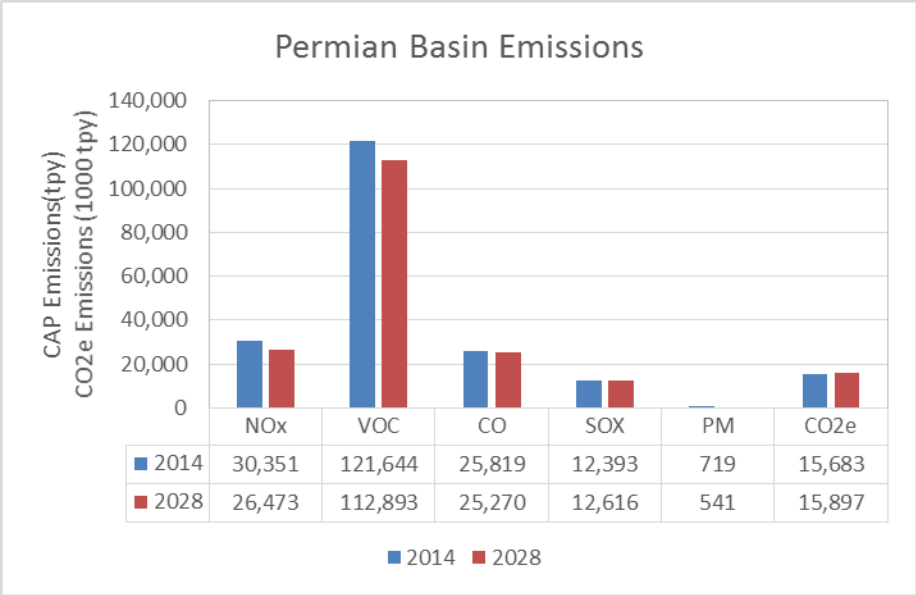

Figure 4-2. Permian Basin 2014 base year and 2028 future year emissions (excludes Texas portion of the Permian Basin)[31].

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EXHIBIT 3

May 2020

NEW MEXICO OZONE ATTAINMENT INITIATIVE PHOTOCHEMICAL MODELING STUDY - DRAFT MODELING PROTOCOL

RAMBOLL

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Western States Air Resources Council

NEW MEXICO OZONE ATTAINMENT INITIATIVE PHOTOCHEMICAL MODELING STUDY - DRAFT MODELING PROTOCOL

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Prepared by	**Ralph Morris, Marco Rodriguez, Tejas Shah, Jeremiah Johnson, Fiona Jiang, Tom Moore, Mary Uhl**

Ramboll
7250 Redwood Blvd.
Suite 105
Novato, CA 94945

T +1 415 899 0700
www.ramboll.com

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ACRONYMS AND ABBREVIATIONS

3SAQS	Three-State Air Quality Study
AIRS	Aerometric Information Retrieval System
AMET	Atmospheric Model Evaluation Tool
APCA	Anthropogenic Precursor Culpability Assessment
AQ	Air Quality
AQS	Air Quality System
BC	Boundary Condition
BLM	Bureau of Land Management
CAMx	Comprehensive Air-quality Model with extensions
CARB	California Air Resources Board
CASTNet	Clean Air Status and Trends Network
CB6r2	Carbon Bond mechanism version 6, revision 2
CMAQ	Community Multiscale Air Quality modeling system
CONUS	Continental United States
CPC	Center for Prediction of Climate
CSAPR	Cross State Air Pollution Rule
CSN	Chemical Speciation Network
EC	Elemental Carbon Fine Particulate Matter
ECMWF	European Center for Medium Range Weather Forecasting
EGU	Electrical Generating Units
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FB	Fractional Bias
FE	Fractional Error
FRM	Federal Reference Method
GCM	Global Chemistry Model
GEOS-Chem	Goddard Earth Observing System (GEOS) global chemistry model
GIRAS	Geographic Information Retrieval and Analysis System
IMPROVE	Interagency Monitoring of PROtected Visual Environments
IWDW	Intermountain West Data Warehouse
LCP	Lambert Conformal Projection
LSM	Land Surface Model
MADIS	Meteorological Assimilation Data Ingest System
MATS	Modeled Attainment Test Software
MCIP	Meteorology-Chemistry Interface Processor
MEGAN	Model of Emissions of Gases and Aerosols in Nature
MNGE	Mean Normalized Gross Error
MNB	Mean Normalized Bias
MNE	Mean Normalized Error
MOVES	Motor Vehicle Emissions Simulator
MOZART	Model for OZone And Related chemical Tracers
MPE	Model Performance Evaluation
MSKF	Multi-Scale Kain-Fritsch Cumulus Parameterization
NAAQS	National Ambient Air Quality Standard
NAM	North American Mesoscale Forecast System

NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCDC	National Climatic Data Center
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NH_4	Ammonium Fine Particulate Matter
NMB	Normalized Mean Bias
NME	Normalized Mean Error
NMED	New Mexico Environmental Division
NO_2	Nitrogen Dioxide
NO_3	Nitrate Fine Particulate Matter
NOAA	National Oceanic and Atmospheric Administration
OA	Organic Aerosol Fine Particulate Matter
OAI	Ozone Attainment Initiative
OC	Organic Carbon Fine Particulate Matter
OSAT	Ozone Source Apportionment Technology
PAVE	Package for Analysis and Visualization
PBL	Planetary Boundary Layer
PGM	Photochemical Grid Model
PM	Particulate Matter
PPB	Parts Per Billion
PPM	Piecewise Parabolic Method
QA	Quality Assurance
QC	Quality Control
RMP	Resource Management Plan
RRF	Relative Response Factor
SCC	Source Classification Code
SIP	State Implementation Plan
SMOKE	Sparse Matrix Kernel Emissions modeling system
SNMOS	Southern New Mexico Ozone Study
SOA	Secondary Organic Aerosol
SO_2	Sulfur Dioxide
SO_4	Sulfate Fine Particulate Matter
TCEQ	Texas Commission on Environmental Quality
UNC-IE	University of North Carolina Institute for the Environment
USFS	United States Forest Service
VERDI	Visualization Environment for Rich Data Interpretation
VMT	Vehicle Miles Traveled
WBD	Wind Blown Dust model
WAQS	Western Air Quality Study
WESTAR	Western States Air Resources Council
WestJumpAQMS	West-Wide Jump-Start Air Quality Modeling Study
WESTUS	Western United States
WRAP	Western Regional Air Partnership
WGA	Western Governors' Association
WRF	Weather Research Forecast model

1. INTRODUCTION

This document is a Modeling Protocol and an informal Quality Assurance Project Plan (QAPP) for the New Mexico (NM) Ozone Attainment Initiative (OAI) Photochemical Modeling Study ("NM OAI Study"). The New Mexico Environmental Division (NMED) has contracted with a team consisting of Western States Air Resources Council (WESTAR) and Ramboll US Corporation to conduct the NM OAI Study. The NM OAI Study leverages the 2014 photochemical grid model (PGM) modeling platform developed by the Western Regional Air Partnership (WRAP) in the Western Air Quality Study (WAQS) and enhances it by adding a 4-km grid resolution modeling domain over New Mexico. 2023 future year modeling, source apportionment and control measure evaluation will be performed to assist the NMED in ozone air quality planning for the state.

1.1 NM OAI Project Genesis

The NMED Air Quality Bureau has authority over air quality management activities throughout the state of New Mexico, with the exception Bernalillo County and Tribal Lands. The City of Albuquerque/Air Quality Division has authority in Bernalillo County and, except for where Tribal Implementation Plans have been approved, EPA oversees air quality issues in Tribal Lands. The New Mexico Air Quality Control Act (NMAQCA) requires the NMED to develop a plan to address elevated ozone levels when air quality is within 95% of the ozone NAAQS (74-3-5.3, NMSA 1978[1]). The ozone NAAQS was revised in 2015 with a threshold of 0.070 ppm (70 ppb) with the relevant metric being the ozone Design Value (DV) that is expressed as the three-year average of the fourth highest Daily Maximum Average 8-hour (DMAX8) ozone concentrations. Figure 1-1 displays the trends in observed ozone DVs at 8 New Mexico monitoring sites from 2013 to 2018 and compares them with the 70 ppb 2015 ozone NAAQS (red line) and 95% of the 70 ppb NAAQS (i.e., ≥ 67 ppb; black line). This results in 7[2] counties in New Mexico under NMED jurisdiction with measured 2016-2018 ozone DVs at or exceeding 95% of the 70 ppb ozone NAAQS, as shown in Figure 1-1.

[1] https://law.justia.com/codes/new-mexico/2017/chapter-74/article-2/section-74-2-5.3/

[2] 8 total counties in New Mexico if you also include Bernalillo County whose air quality is under the jurisdiction of the City of Albuquerque.

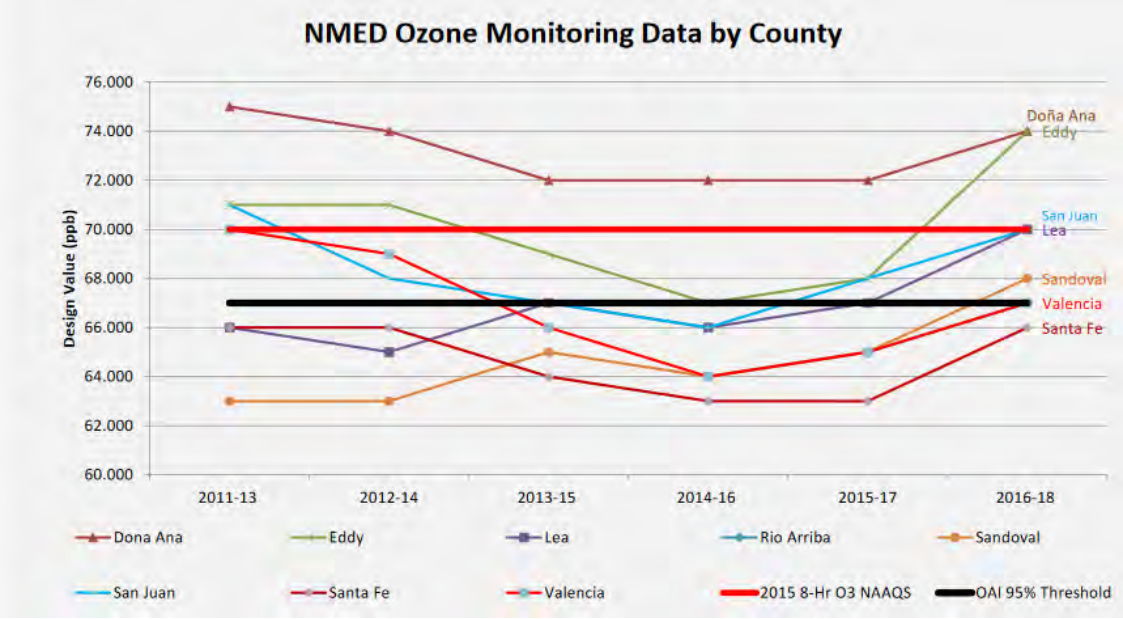

Figure 1-1. Trends in observed ozone DVs between 2013 and 2018 at 7 monitoring sites in New Mexico (Source: https://www.env.nm.gov/air-quality/wp-content/uploads/sites/2/2019/10/OAI_Presentation_09262019.pdf).

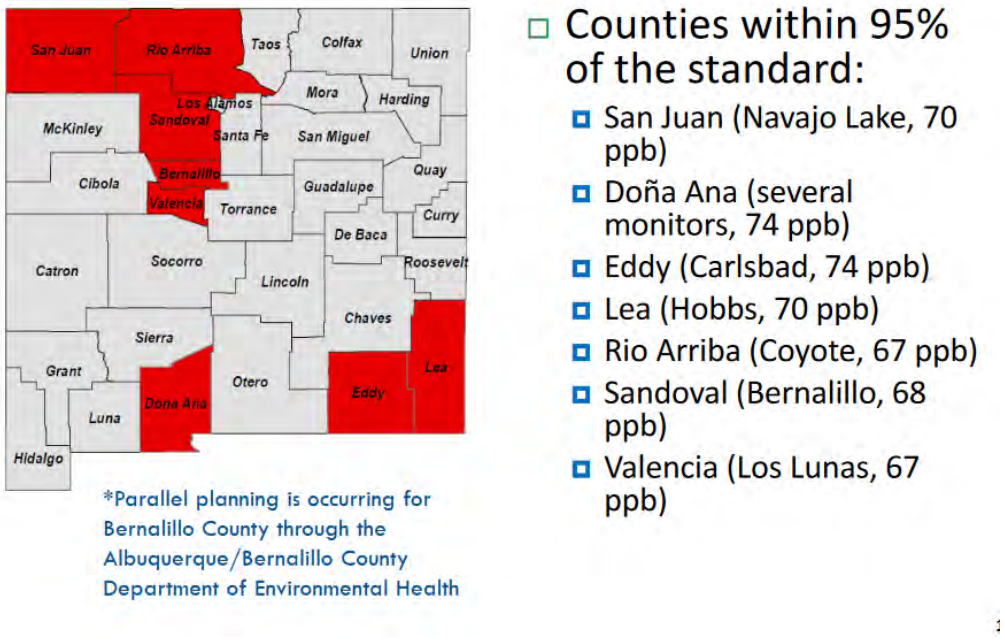

Figure 1-2. 7 counties in New Mexico under the jurisdiction of the NMED whose observed 2016-2018 ozone DVs are at or exceed 95% of the 2015 ozone NAAQS (70 ppb) (Source: https://www.env.nm.gov/air-quality/wp-content/uploads/sites/2/2019/10/OAI_Presentation_09262019.pdf).

To address the high observed ozone concentrations in New Mexico, the NMED has embarked on an Ozone Attainment Initiative (OAI[3]) to protect the ozone attainment status of the state and ensure health and welfare of the residents of the state for future generations. The OAI was initiated in Spring 2018. As part of the OAI, NMED released a Request for Proposal (RFP#20 667 4040 0001) the NM OAI Study. The NM OAI Study PGM modeling was awarded to a contracting team of WESTAR and Ramboll. This Modeling Protocol is the first major deliverable under that contract.

1.2 Overview of NM OAI Study Modeling Approach

This Modeling Protocol describes the modeling activities to be performed under the NM OAI Study. The NM OAI Study will conduct PGM modeling by enhancing the WRAP/WAQS 2014 modeling platform[4] to use a 4-km grid resolution domain covering New Mexico and surrounding areas, especially the oil and gas (O&G) production regions in the Permian and San Juan Basins. The NM OAI Study PGM modeling will conduct 2014 base year modeling and model performance evaluation as well as 2023 future year modeling. The 2023 future year modeling will include ozone source apportionment and control measure sensitivity modeling. The NM OAI Study PGM modeling will be conducted in accordance with EPA's guidance for ozone State Implementation Plan (SIP) attainment demonstration modeling.

1.2.1 EPA Guidance for Ozone Attainment Demonstration Modeling Protocols

A comprehensive Modeling Protocol for an 8-hour ozone SIP attainment demonstration study consists of many elements. Its main function is to serve as a roadmap for planning and communicating how a modeled attainment demonstration will be performed before it occurs. The protocol guides the technical details of a modeling study and provides a formal framework within which the scientific assumptions, operational details, commitments and expectations of the various participants can be set forth explicitly.

On November 28, 2018 EPA released a final 8-hour ozone modeling guidance (EPA, 2018d) that replaces the previous final guidance (EPA, 2007) and draft guidance (EPA, 2014d). The EPA 2018 ozone modeling guidance is similar to the draft 2014 guidance with updates (e.g., slight modification to the recommended ozone DV projection approach). As stated in EPA's latest modeling guidance (EPA, 2018d, pp. 15):

> "The most important function of the modeling protocol is to serve as a blueprint for planning how the modeled demonstration will be performed. The protocol should be a valuable communication device by which air agencies, EPA, and other stakeholders can assess the applicability of default recommendations and develop area-specific alternatives, where needed, prior to conducting the work to build the modeling system. A suitable protocol should lead to extensive participation by stakeholders in developing the demonstration. It should also reduce the risk of spending time and resources on efforts that are unproductive or inconsistent with EPA rules, policy, and guidance. While the modeling protocol

[3] https://www.env.nm.gov/air-quality/o3-initiative/

[4] http://views.cira.colostate.edu/wiki#WAQS-2014-Modeling-Platform

is initially developed at the beginning of a modeling exercise to foster communication, it is advisable to modify the document as needed throughout the modeling process when alterations from the original modeling plan are necessary. Again, any changes to the protocol should be fully communicated between affected air agencies, stakeholders, and the EPA."

1.2.1.1 Contents of the Modeling Protocol

EPA's 8-hour ozone SIP modeling guidance identifies specific "core elements" that should be part of any ozone SIP Modeling Protocol. These "core elements" are repeated below along with where they are addressed in this NM OAI Study Modeling Protocol (EPA, 2018d, pp. 15-16):

- Overview of the air quality issue being considered including historical background: Chapter 1 provides an overview of ozone issues in New Mexico including past and related ozone modeling studies for the region.
- List of the planned participants in the analysis and their expected roles: The principal participants in the NM OAI Study are listed in Table 1-1 at the end of Chapter 1.
- Schedule for completion of key steps in the analysis and final documentation: The current schedule is presented in Tables 1-2 and 1-3 at the end of Chapter 1.
- Description of the conceptual model for the area: The Conceptual Model of ozone formation in the NM OAI Study is provided in Section 1.4.
- Description of periods to be modeled, how they comport with the conceptual model, and why they are sufficient: Chapter 3 presents the Episode Selection and justifies the selection of the summer of 2014 modeling period for the NM OAI Study.
- Models to be used in the demonstration and why they are appropriate: Model selection and justification is presented in Chapter 2.
- Description of model inputs and their expected sources (e.g., emissions, meteorology, etc.): The source of data and description of the model inputs are given in Chapters 4, 5 and 6.
- Description and justification of the domain to be modeled (expanse and resolution): Domain selection and justification is provided in Chapter 4.
- Process for evaluating base year model performance (meteorology, emissions, and air quality) and demonstrating that the model is an appropriate tool for the intended use: The procedures for conducting the 2014 base case photochemical modeling and model performance evaluation is given in Chapter 7. Procedures for conducting the meteorological modeling and evaluation are provided in Chapter 5. Emission inputs are discussed in Chapter 6.
- Description of the future years to be modeled and how projection inputs will be prepared: Future year modeling procedures are provided in Chapter 8.
- Description of the NAAQS attainment test procedures and (if known) planned weight of evidence, and/or description of the procedures for calculating RPGs from the modeling outputs, as applicable: The ozone attainment demonstration procedures for the 2023 future years are described in Chapter 9 along with

potential additional weight of evidence (WOE) analysis to support the modeled attainment demonstration.

- Expected diagnostic or supplemental analyses needed to develop weight of evidence analyses: Potential WOE analysis are described in Chapter 9.
- Commitment to specific deliverables fully documenting the completed analysis: Deliverables to support the modeling component of the NM OAI Study are listed at the end of Chapter 9 with schedule for the deliverables listed in Tables 1-2 and 1-3.
- Quality Assurance Project Plan (QAPP): Although not part of EPA's guidance Modeling Protocol. Elements of a QAPP are contained throughout the Modeling Protocol and in each process of the PGM database development. Chapter 10 discusses the contents of a QAPP and where they can be found in this Modeling Protocol.

1.3 Related Studies

There are numerous other studies related to the NM OAI Study whose results may provide insight or provide data useful to the study that are summarized below.

1.3.1 Historic EPA and More Recent EPA-MJO-States Modeling Platforms

EPA routinely develops national PGM modeling platforms that are used to evaluate the air quality impacts of national rules, make transport assessments, such as the Cross-State Air Pollution Rule (CSAPR[5]), or other regional air quality analysis, such as the recent 2028 national regional haze modeling.[6] The national PGM modeling platforms typically coincide with the triennial National Emission Inventory (NEI[7]) years (e.g., 2008, 2011, 2014). Below we discuss the current (May 2020) status of EPA's more recent national PGM modeling platforms.

2011v6.3 Modeling Platform: The EPA 2011v6.3[8] PGM modeling platform is the result of many years of development and refinements (e.g., v6.0, v6.1 and v6.2[9]). It consists of a base year 2011 meteorological conditions and emissions and three future year emission scenarios: 2017, 2023 and 2028. It has been used in numerous EPA rulemakings (e.g., CSAPR Update). As with the other recent EPA modeling platforms, the 2011v6.3 modeling platform uses a 12-km grid resolution continental U.S. (12US2) modeling domain that is the red domain shown in Figure 1-3.

2014v7.1 Modeling Platform: The EPA 2014v7.1[10] PGM modeling platform was used in the 2014 National Air Toxics Assessment (NATA[11]) modeling. It also uses the 12-km 12US2 modeling (Figure 1-3, red domain). 2014 was a relatively low ozone year in the eastern U.S. so EPA did not pursue using the 2014 platform for national rulemakings

[5] https://www.epa.gov/csapr
[6] https://www.epa.gov/visibility/technical-support-document-epas-updated-2028-regional-haze-modeling
[7] https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei
[8] https://www.epa.gov/air-emissions-modeling/2011-version-63-platform
[9] https://www.epa.gov/air-emissions-modeling/2011-version-6-air-emissions-modeling-platforms
[10] https://www.epa.gov/air-emissions-modeling/2014-version-71-platform
[11] https://www.epa.gov/national-air-toxics-assessment

(except for the NATA) developed a 2016 modeling platform for ozone, $PM_{2.5}$ and regional haze modeling.

2015 Alpha Modeling Platform: EPA has made data available to model 2015 using data based on the 2014v7.1 platform. However, a full 2015 PGM modeling platform was never developed.

2016 Modeling Platform: The EPA, Multi-Jurisdictional Organizations (MJOs), and states conducted a collaborative national emissions modeling platform[12] (2016 EMP) to develop a 2016 emissions inventory of comparable or better quality than the NEI, with projections to 2023 and 2028. Separately, EPA developed a 2016 PGM modeling platform that used the same 12-km grid resolution continental U.S. domain used in previous EPA PGM platforms (e.g., 2011) but added an expanded 36-km grid resolution 36US3 domain as shown in Figure 1-3. EPA has released several versions of their 2016 36/12-km PGM modeling platforms as follows:

- 2016v7.1 Alpha[13] PGM platform was available in June 2019 and uses the 2016 EMP Alpha version emissions, which were based mainly on the 2014 NEIv7.1 emissions (called the 2016fd emissions scenario by EPA).
- The 2016v7.2 Beta (called 2016ff by EPA) PGM platform uses the 2016 EMP Beta version emissions[14] from the EPA/MJO/states emissions collaborative study. The original 2016v7.2 Beta PGM platform was released in March 2019 through the Intermountain West Data Warehouse (IWDW[15]). EPA made some updates to the 2016v7.2 PGM platform and used the 2016v7.2 Beta Prime (called 2016fg by EPA) modeling platform for their preliminary 2028 regional haze modeling. Details on EPA's 2016v7.2 modeling platform are contained in a Technical Support Document (TSD; EPA, 2019).
- The final EPA 2016v1[16] (called 2016fh by EPA) PGM modeling platform uses the 2016 EMP version 1 emissions[17] from the EPA/MJO/states emissions collaborative study. It was released in November 2019 with updates to Commercial Marine Vessels (CMV) occurring in February 2020 and WRAP region O&G data, and is also available on the IWDW. The 2016v1 inventory included emission projections for 2023 and 2028.

[12] http://views.cira.colostate.edu/wiki/wiki/9169
[13] https://www.epa.gov/air-emissions-modeling/2016-alpha-platform
[14] http://views.cira.colostate.edu/wiki/wiki/10197
[15] http://views.cira.colostate.edu/iwdw/
[16] https://www.epa.gov/air-emissions-modeling/2016v1-platform
[17] http://views.cira.colostate.edu/wiki/wiki/10202

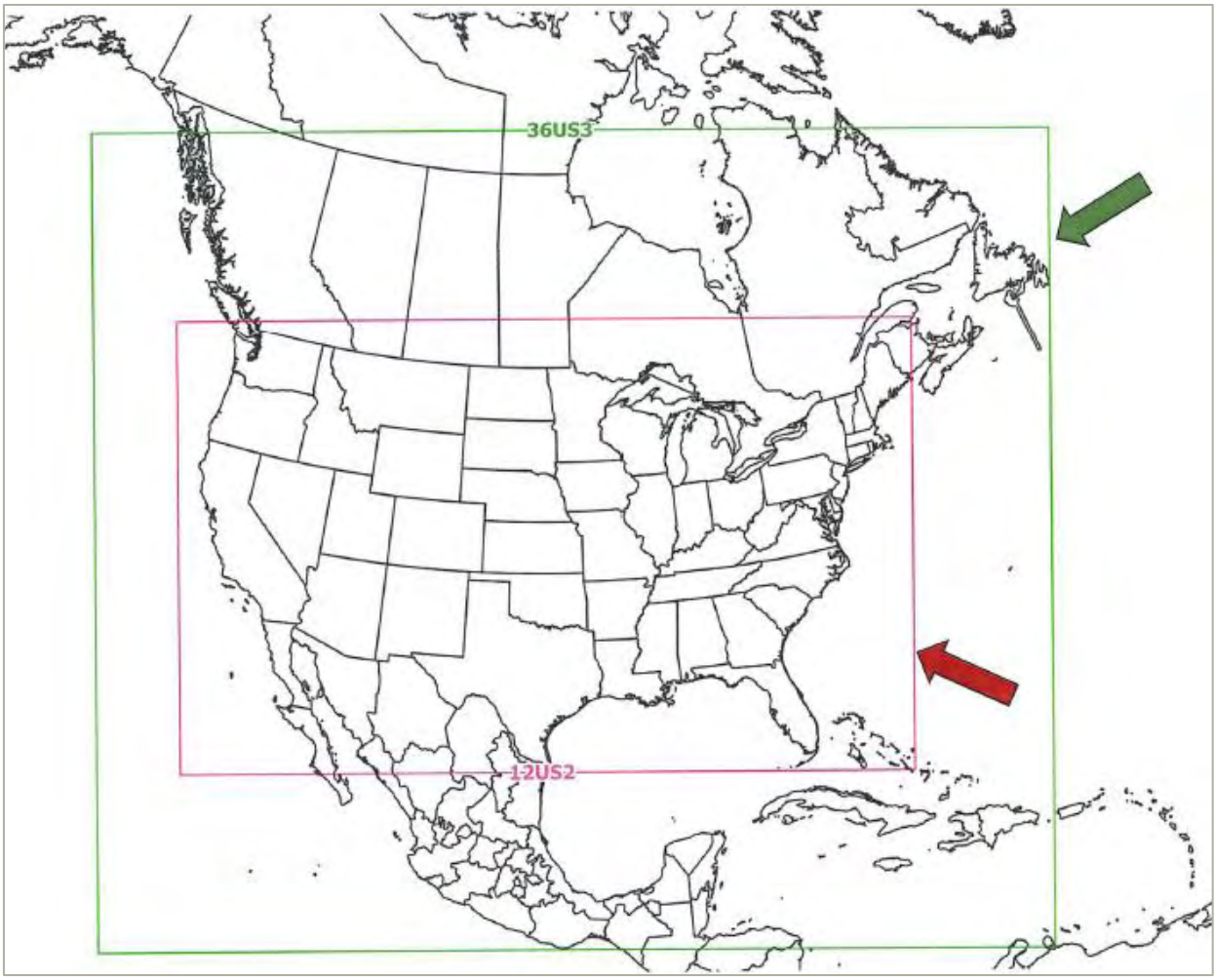

Figure 1-3. 36-km grid resolution 36US3 domain (green) and 12-km grid resolution 12US2 domain (red) used in EPA's 2016 modeling platform.

1.3.2 Denver Ozone SIP Modeling and Analysis

The Denver Metropolitan (DM) and North Front Range (NFR) ozone nonattainment area (NAA) has undergone several rounds of ozone SIPs to address attainment of a series of ozone NAAQSs.

Denver 2003 EAC SIP: The 2003 Denver Early Action Compact (EAC) SIP modeling performed 36/12/4/1.33 km photochemical modeling of the DM/NFR NAA for a summer 2002 period using the meteorological based on the MM5 model (McNally, Tesche and Morris, 2003), EPS3 emissions and CAMx photochemical grid models. The 1.33-km fine grid was ultimately not used because of little improvement in model performance over using a 4-km resolution grid at the expense of high additional computational requirements. The Denver EAC SIP developed an Ozone Action Plan[18] and

[18] http://www.colorado.gov/airquality/tech_doc_repository.aspx?action=open&file=EAC_SIP_031104-aqcc_DRAFT.pdf

demonstrated that the region would attain the 1997 ozone NAAQS by 2007 (Morris et al., 2004a,b,c,d).

Denver 2008 Ozone SIP: The 2008 Denver ozone SIP[19] modeling used the MM5 meteorological, SMOKE/CONCEPT emissions and CAMx photochemical grid models (Morris et al., 2007). The CONCEPT model was interfaced with link-based Vehicle Miles Traveled (VMT) and other mobile source activity data (e.g., speeds, fleet mix, temporal variations, etc.) from a Traffic Demand Model (TDM) operated by DRCOG, on-road emission factors from the MOBILE6 model and hourly meteorological data from MM5 to generate detailed on-road mobile source emissions for the DMA. Other emission inputs were generated using SMOKE. The MM5/SMOKE/CONCEPT/CAMx modeling system was applied to the June-July 2006 period and used to demonstrate that the DMA/NFR region would attain the 1997 8-hour ozone NAAQS by 2010 (Morris et al., 2008a,b,c; 2009a,b).

The 2008 ozone SIP 2006 modeling platform was also used to investigate improvements to the modeling system (Morris et al., 2011) and evaluate the VOC/NOx emissions inventory that suggested 2006 oil and gas emissions in Weld County were understated (Morris, Tai and Sturtz, 2011).

Denver 2016 Ozone SIP: The 2016 Denver ozone SIP[20] modeling addressed the 2017 attainment of the DM/NFR Moderate NAA under the 2008 ozone NAAQS (RAQC and CDPHE, 2016). The 2016 ozone SIP used a 2011 36/12/4-km modeling platform based on the WRAP/WAQS modeling platform available on the IWDW and adding a 4-km domain focused on Colorado (Ramboll and Alpine, 2015; 2016a,b; 2017).

The 2016 Denver ozone SIP 2011 36/12/4-km modeling platform was used to conduct additional future-year sensitivity modeling and other analysis in anticipation of the requirements needed to attain the 2015 ozone NAAQS. These results were presented at a November 2, 2017 Modeling Forum[21] and included the following:

- 2017 local source contributions to ozone concentrations in the DM/NFR NAA;
- Contributions of international anthropogenic emissions to 2011 ozone concentrations in the DM/NFR NAA; and
- Preliminary 2023 ozone projections and sensitivity to VOC/NOx anthropogenic emissions reductions.

Current Denver Ozone SIP 2020 and 2023 Attainment Demonstration Modeling: Current Denver ozone SIP efforts are using a 2016 36/12/4-km CAMx modeling platform based in part on EPA's 2016v1 modeling platform with new WRF meteorological modeling and a 4-km domain covering Colorado added. The new Denver 2016 36/12/4-km CAMx platform will be used to demonstrated attainment in 2020 to address the area as a

[19] https://www.colorado.gov/airquality/documents/deno308/

[20] https://raqc.org/sip/moderate-area-2008-8-hour-ozone-standard-state-implementation-plan/

[21] https://raqc.org/reports/?titlePost=Modeling+Forum

Serious NAA under the 2008 ozone NAAQS and in 2023 to address the area as a Moderate NAA under the 2015 ozone NAAQS.

1.3.3 West-wide Jumpstart Air Quality Modeling Study

The Western Regional Air Partnership (WRAP) initiated a new round of regional ozone, particulate matter, visibility and deposition modeling for the western U.S. starting with the West-wide Jumpstart Air Quality Modeling Study (WestJumpAQMS[22]; ENVIRON, 2013). WestJumpAQMS performed 36/12/4-km modeling for the 2008 calendar year with the 12-km domain focused on the western U.S., and the 4-km domain focused on the states of CO, NM, UT and WY (ENVIRON and Alpine, 2012). The WestJumpAQMS was completed in September 2013 and calculated, among other things, the contributions of transport to ozone in the Denver area and contributions of emissions from Colorado (including Denver) to downwind ozone and $PM_{2.5}$ concentrations (ENVIRON, Alpine and UNC, 2013). The 2008 base year from the WestJumpAQMS platform was used in the development of the 3-State Data Warehouse and Air Quality Study, the predecessor to the Intermountain West Data Warehouse and Western Air Quality Study, described next.

1.3.4 Intermountain West Data Warehouse and Western Air Quality Study

The WRAP Intermountain West Data Warehouse (IWDW[23]) was developed to be a repository and source of ambient air quality and modeling data that can be used by the western states. The Western Air Quality Study (WAQS) developed 2011 PGM modeling platforms to assess air quality, visibility and deposition in the western states and was used to populate the IWDW. The WAQS started by enhancing the WestJumpAQMS 2008 WRF/SMOKE/CAMx/CMAQ 36/12 km database and making it available through the IWDW. WAQS then developed new 2011 WRF/SMOKE/CAMx/CMAQ modeling platforms (Adelman, Shankar, Yang and Morris, 2014; 2016; Adelman and Baek, 2015) that was also made available through the IWDW. IWDW is not only a source of modeling data, but also includes data analysis and visualization tools and is a repository of data from other modeling studies.

1.3.5 Southern New Mexico Ozone Study (SNMOS)

The Southern New Mexico Ozone Study (SNMOS[24]) conducted WRF meteorological, SMOKE emissions and CAMx ozone modeling for a 2011 base and 2025 future year using a 12/4-km modeling domain, as shown in the right panel of Figure 1-4. SNMOS found that a vast majority of ozone in Southwestern New Mexico is due to ozone transport from outside of New Mexico. For example, Figure 1-4 (left panel) displays the 2011 and 2025 ozone contributions to the ozone Design Value (DV) at the Desert View monitoring site in Dona Ana County by geographic regions within the 12/4-km PGM modeling domain also shown in Figure 1-4. Only 3 percent of the 2011 ozone DV at Desert View is due to anthropogenic emissions from New Mexico, and New Mexico

[22] http://www.wrapair2.org/pdf/WestJumpAQMS_FinRpt_Finalv2.pdf

[23] http://views.cira.colostate.edu/iwdw/

[24] https://www.wrapair2.org/SNMOS.aspx

emissions contribute less than 2 percent of the projected 2025 ozone DV at Desert View.

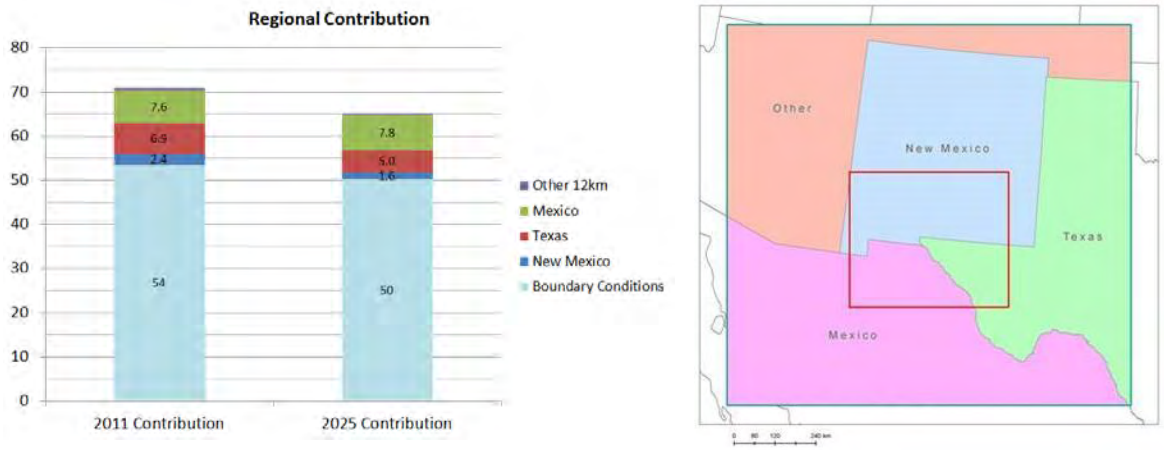

Figure 1-4. Contributions of geographic regions (including Boundary Conditions) to the 2011 and 2025 ozone Design Values at Desert View monitoring site in Dona Ana County in Southwestern New Mexico.

The SNMOS 2011 and 2025 ozone source apportionment modeling also obtained contributions by Source Sector in addition to the four Source Regions depicted in the left panel of Figure 1-4. Figure 1-5 displays the Source Sector contributions to the 2011 and 2025 ozone DV at Desert View monitor as well as the 10 highest Source Groups (i.e., Source Sector emissions from Source Regions) contributions. On-road mobile sources has the highest contribution to ozone DVs in both 2011 and 2025 (Figure 1-5, top panel), but that is mainly due to on-road mobile source emissions in Texas and Mexico that are the two highest contributing Source Groups (Figure 1-5, bottom panel).

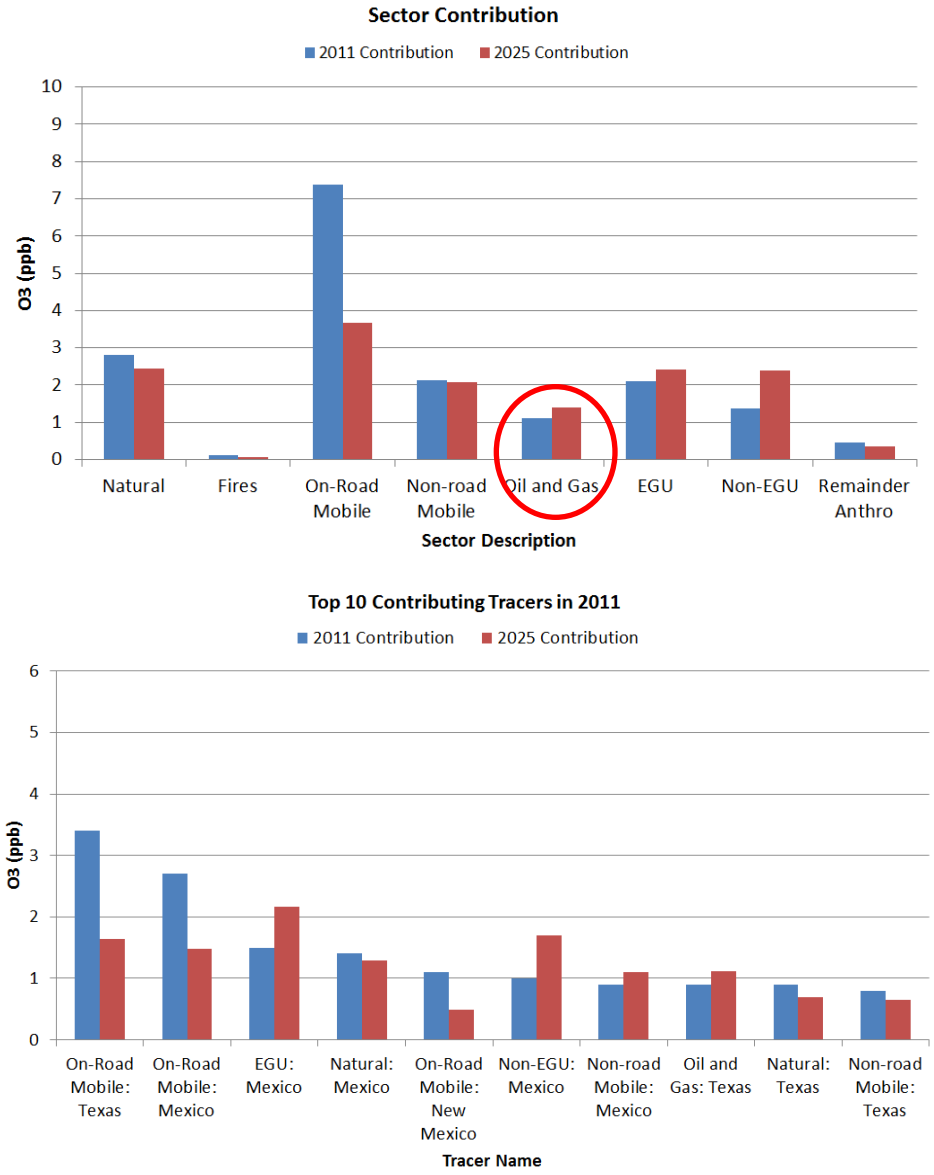

Figure 1-5. Contributions of Source Sector emissions within the 12/4-km modeling domain to the 2011 and 2025 ozone Design Value at Desert View monitoring site (top) and top ten Source Group contributions (bottom).

Figure 1-6 examines the contributions of emissions from New Mexico to 2011 and 2025 ozone DVs at nine monitoring sites in Southeast New Mexico. With one exception, on-road mobile source emissions are the largest contributing Source Sector in New Mexico to 2011 ozone DVs in southeastern New Mexico with the contribution at the Solano monitoring site being higher than the others. The one exception is the Carlsbad monitoring site in Eddy County where O&G emissions is the largest contributing Source Sector in New Mexico due to its close proximity to the Permian Basin. Although on-road mobile source emissions are the largest contributor in 2011, it is also the Source

Sector whose New Mexico ozone contribution is reduced the most in 2025, by over a factor of two. This is in contrast to O&G whose contribution at the Carlsbad monitoring site is projected to increase between 2011 and 2025, although future year projections of O&G emissions are highly uncertain. In any event, by 2025 the SNMOS estimate that on-road mobile, non-road mobile and O&G Source Sectors in New Mexico will contribute the most, with New Mexico EGU and non-EGU point sources and other anthropogenic emission Source Sectors having relatively lower ozone contributions.

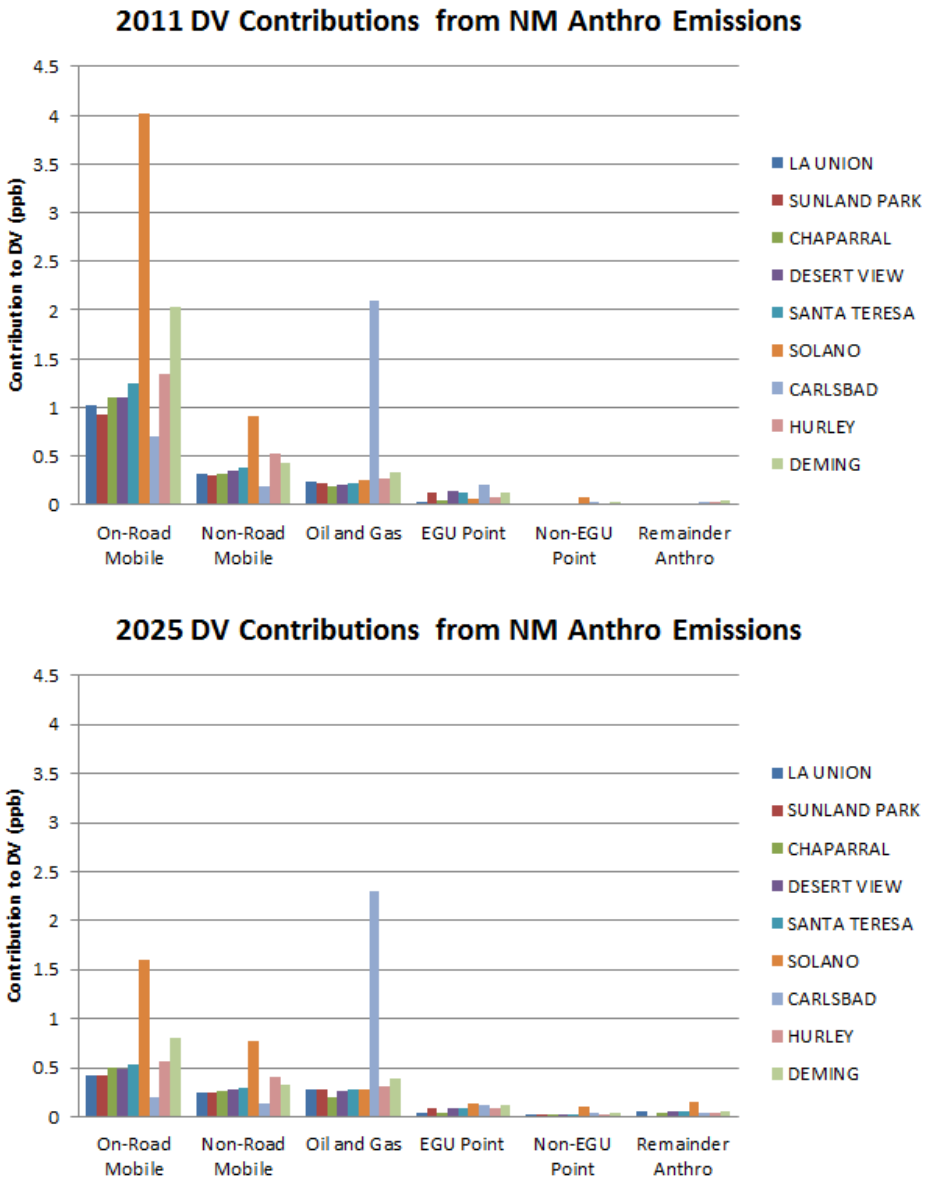

Figure 1-6. Contributions of major Source Sectors in New Mexico to 2011 (top) and 2025 (bottom) ozone DVs at nine monitoring sites in Southwestern New Mexico.

1.3.6 City of Albuquerque Ozone Modeling Study

The City of Albuquerque conducted an ozone modeling study[25] for two episodes in 2017: June 12-16, 2017 and July 3-14, 2017. The purpose of the study was to better understand the source of high ozone concentrations in Bernalillo County and what types of control strategies, if needed, would be most effective at reducing ozone concentrations in the County.

Figure 1-7 displays the maximum ozone DVs in Albuquerque from 2013 to 2018 and their relationship with the 80, 75 and 70 ppb ozone NAAQS. 2016 is a low point in the ozone DV trend (~65 ppb) followed by increases so by 2018 the maximum Bernalillo County ozone DV is at the 2015 ozone NAAQS.

The City of Albuquerque Ozone Modeling Study conducted WRF meteorological and SMOKE emissions modeling using a 12/4-km CAMx ozone modeling database, with the 4-km domain covering New Mexico and the 12-km domain covering the western states (Figure 1-7, right panel).

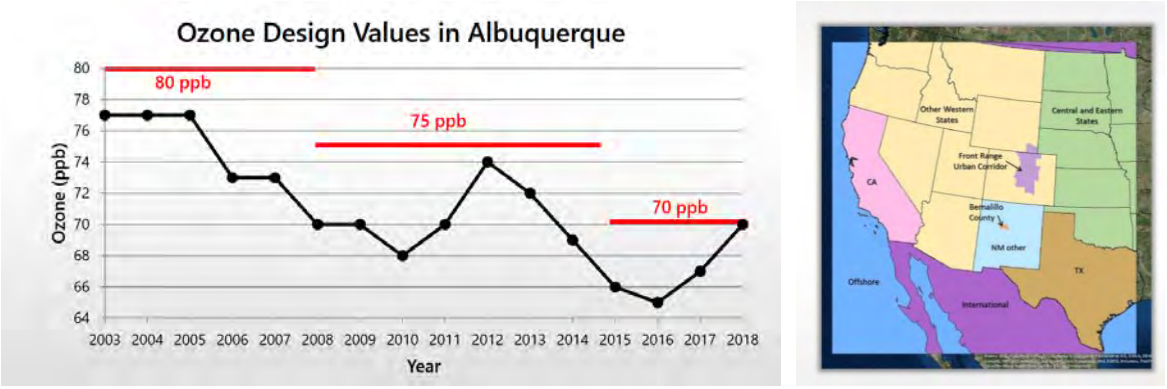

Figure 1-7. Trends in maximum ozone Design Values in Albuquerque from 2013 to 2018 (left) and 12-km modeling domain and source apportionment geographic regions (right).

Ozone source apportionment was performed to determine the geographic regions (Figure 1-7, right) that contributed to elevated ozone concentrations in Albuquerque. Figure 1-8 displays the contributions to ozone concentrations in Albuquerque for the June and July episodes. Anthropogenic emissions from New Mexico contributed 14% and 24% to ozone in Albuquerque during the, respectively, June and July 2017 episodes. And anthropogenic emissions from Bernalillo County accounted for up to 75% of the New Mexico contribution.

[25] https://www.cabq.gov/airquality/documents/06-ken-craig-sonoma-technology-inc-ozone-modeling-presentation-10-17-2018-aqcb-meeting.pdf

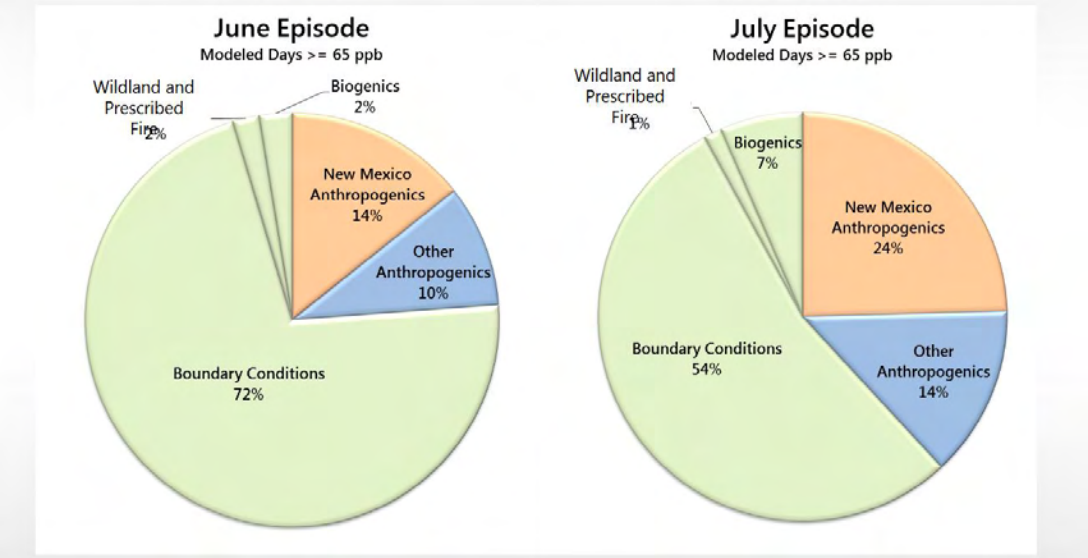

Figure 1-8. Contributions to ozone in Albuquerque during the June and July 2017 modeling episodes.

Although only two short episodes were modeled, so any conclusions are limited to those conditions, the City of Albuquerque Ozone Modeling Study concluded as follows:

- Transport from outside of New Mexico is always important and accounts for over half of the ozone in Albuquerque.
- Local emissions in Albuquerque and Bernalillo County are also important with half of the locally generated ozone due to on-road mobile sources in 2017.
- On high ozone days for the two modeled episodes, contributions from major power plants in northern New Mexico were small at sites in Albuquerque.
- Impacts from man-made emissions in western states, including California, are non-negligible.
- Ozone contributions from wildfire smoke were important for both episodes.
- As on-road mobile source emissions are reduced, emissions from non-road and non-mobile sources are becoming increasingly important. NOx emission controls are more effective at reducing high ozone concentrations in Albuquerque than VOC controls.
- Ozone in Albuquerque is sensitive to emissions from O&G sources throughout New Mexico.

1.3.7 Relationship Between Meteorology and Ozone in the Intermountain West Region

Reddy and Pfister (2016) and CDPHE and RAQC (2016c) analyzed meteorological factors that contributed to the interannual variability in midsummer ozone concentrations focusing mainly on Utah and Colorado. They analyzed ozone and

meteorology for July during 1995-2013 and found several meteorological variables that were able to explain the years with higher ozone formation conditions. The most powerful meteorological variable for describing high ozone formation potential conditions (i.e. ozone conducive conditions) was the height of the 500 hPa[26] pressure level. The current Denver ozone SIP modeling study extended the analysis of meteorology conducive to ozone formation and observed ozone trends analysis of Reddy and Pfister (2016) and CDPHE and RAQC (2016c) to include the most recent years (through 2018) and for summer-average conditions. Figure 1-9 shows the relationship between summer-average 500 hPa heights and summer-average ozone at the Rocky Flats North (RFNO) monitoring site northwest of downtown Denver and the years 1995-2018, results for the other sites are similar.

Figure 1-10 displays the correlation between elevated ozone concentrations and 500 hPa heights in the western U.S. and some of the sites in New Mexico are also weakly to moderately correlated to the 500 hPa heights like the sites in Denver and Utah. Elevated ozone at sites in northwestern New Mexico show less correlation with 500 hPa heights as it is believed that the large point source NOx and oil and gas NOx and VOC emissions in the region swamp the signal.

[26] hPa is100 Pa where Pa is short for Pascal that is a unit of pressure where 500 hPa = 500 mb.

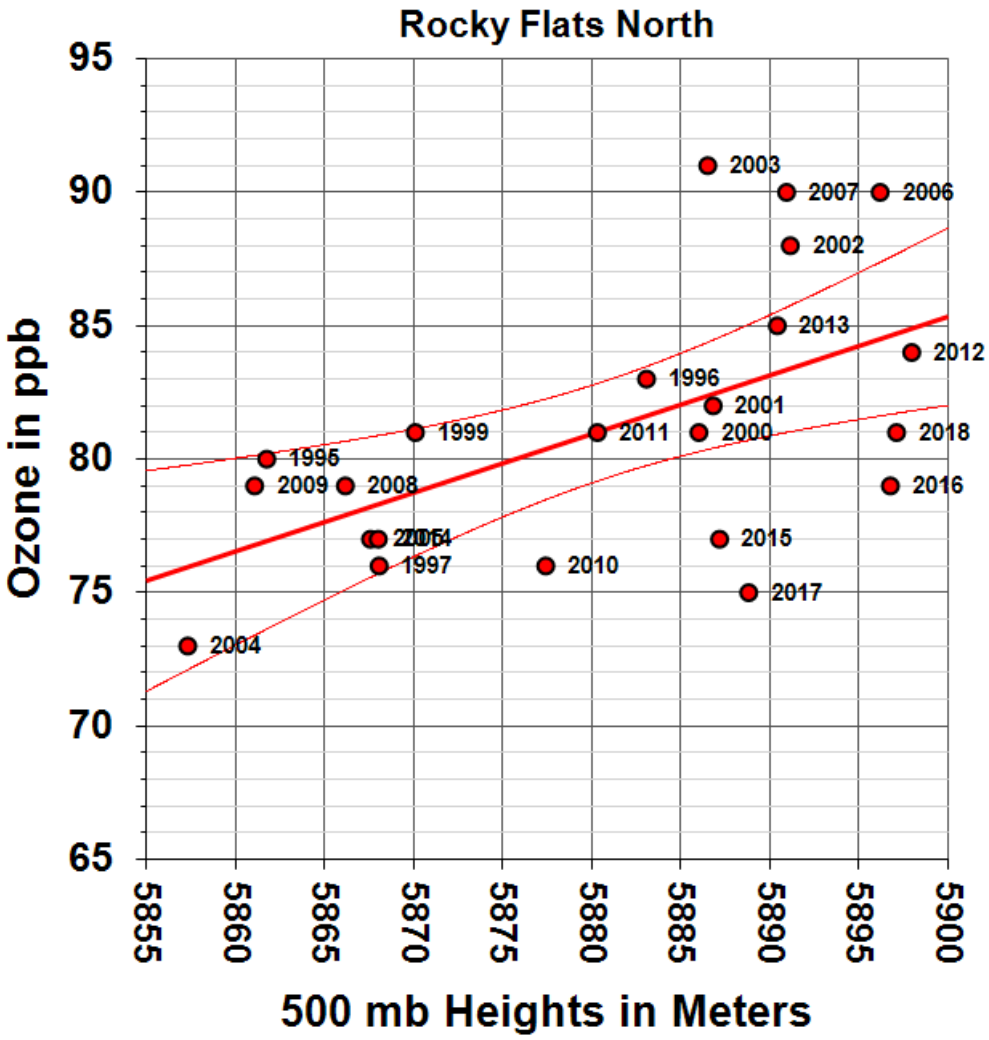

Figure 1-9. Linear regression of the annual 4th highest MDA8 ozone concentrations and mean July through August NCEP/NCAR Reanalysis 500 hPa (or 500 mb) heights for the DM/NFR NAA region at the Rocky Flats North (RFNO) monitoring site for the years 1995 to 2018.

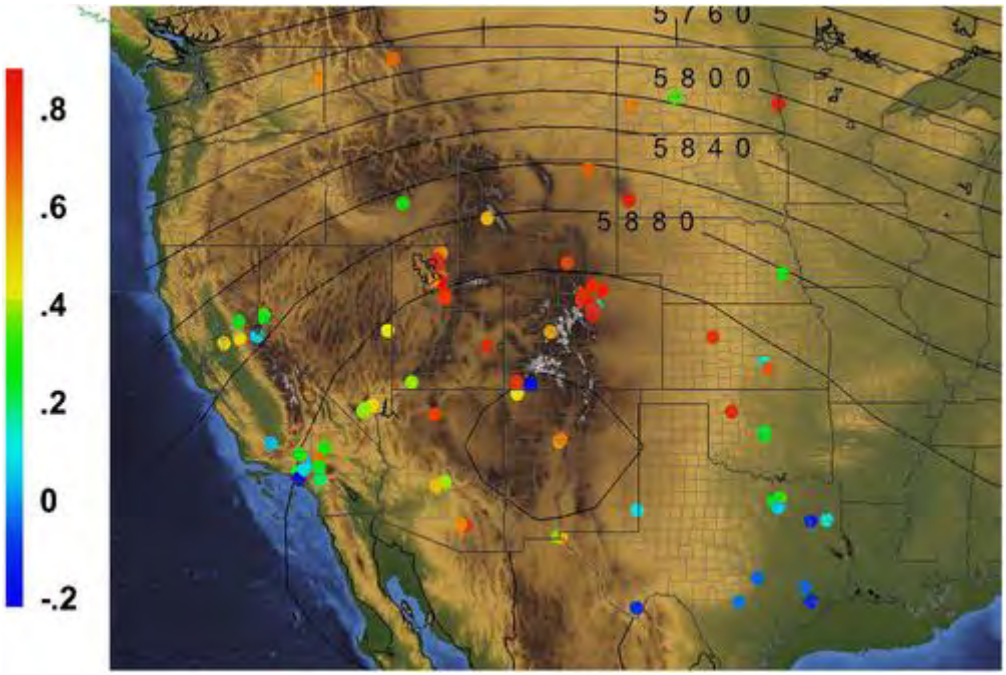

Figure 1-10. Correlation between 500 hPa heights and elevated ozone concentrations for monitoring sites in the western U.S.[27]

1.3.8 The Four Corners Air Quality Task Force

The Four Corners Air Quality Task Force (FCAQTF) was convened by the states of New Mexico and Colorado in 2005 and comprised of over 100 members and over 150 of interested parties. Its goals were to address air quality issues in the Four Corners region and consider mitigation options to reduce air pollution and acid deposition and improve visibility in the region. They found that transport from outside of the region was the largest contributor to ozone concentrations. Several large power plants and O&G production in the San Juan Basin, as well as mobile sources, also contributed to ozone in the region. The FCAQTF was completed in November 2007 with the release of a report[28] that contained over 100 potential mitigation measures for reducing emissions in the Four Corners region. The FCAQTF has been replaced by the Four Corners Air Quality Group (FCAQG[29]).

1.3.9 Other Studies

There are numerous other studies that may also be relevant to the NM OAI Study.

- Summary of State Regulations Applicable to Oil and Gas Sources in the WESTAR-WRAP Region (PDF) and companion spreadsheet (XLS)
- Final Work Products - Low and High Emissions Scenarios

[27] https://agupubs.onlinelibrary.wiley.com/cms/asset/192a6975-cd1c-4bce-a20a-a2a049ca4df6/jgrd52767-fig-0001-m.png
[28] https://www.env.nm.gov/wp-content/uploads/sites/2/2016/11/4CAQTF_Report_FINAL.pdf
[29] https://www.env.nm.gov/air-quality/fcaqg/

I. WESTAR-WRAP region Future Year Oil and Gas Emission Inventories for Two Additional Scenarios: Declined Vertical Wells and Increased Horizontal Wells Memorandum
II. Future Year Lower Scenario Inventory Spreadsheet
III. Future Year Higher Scenario Inventory Spreadsheet

- OGWG Projected Emissions from Baseline Year Emissions Inventory – October 11, 2019
  I. Final Report (revised version of March 5, 2020) and Inventory Spreadsheet for the "Continuation of Historical Trends" projection inventory. These data will be used in modeling and control analyses for Regional Haze planning.
  II. State of Colorado projections methodology (PDF) (January 2, 2020, data are included in Final Report and Inventory Spreadsheet above).
- OGWG Baseline Year Alaska and Intermountain Region Emissions Inventory revised final deliverables – Sept. 2019
  I. The Revised Final Report and Inventory Spreadsheet were completed in mid-Sept. and posted on Sept. 23, 2019. These files completely replace the previously posted July 2019 report and spreadsheet, while the gas profile information posted in July is unchanged. The July report and spreadsheet files have been removed to avoid confusion. The Revised Final Report includes updates from the July postings to include the: 1) Colorado O&G emissions based on new inventories provided by Colorado Department of Public Health and Environment and Southern Ute Indian Tribe and 2) Williston Basin casinghead gas emission inventory to correct emissions that were biased low based on EPA O&G Tool inputs.
- OGWG Emissions Survey for State Air Agencies and O&G Operators
  I. Complete survey (January 2019)
  II. Fleet turnover and controls-focused survey (January 2019)

San Juan & Permian Basins' O&G 2014 Emission Inventory Project

The National Park Service (NPS) has conducted studies of visibility impairment and nitrogen/sulfur deposition at National Parks throughout the U.S. For example, the Rocky Mountain Atmospheric Nitrogen and Sulfur Study (ROMANS) studied nitrogen deposition and potential mitigation scenarios at Rocky Mountains National Park (RMNP). RMNP studies have included data collection, data analysis, modeling and the development of a nitrogen deposition reduction plan. Details on these activities can be found at:

https://www.colorado.gov/pacific/cdphe/rocky-mountain-national-park-initiative

http://www.nature.nps.gov/air/studies/romans.cfm

The Bureau of Land Management (BLM) has conducted several iterations of the Colorado Air Resource Management Modeling Study (CARMMS) using a CAMx 4-km modeling database with a 4-km grid resolution domain covering Colorado and northwest New Mexico. Future year source apportionment modeling was conducted to assess the ozone, $PM_{2.5}$, visibility and sulfur and nitrogen deposition impacts at Class I

and sensitive Class II Area due to oil and gas and mining development on Federal lands in Colorado and northern New Mexico.

https://www.blm.gov/sites/blm.gov/files/documents/files/program_natural%20resources_soil%20air%20water_airco_quicklins_CARMMS2.0.pdf

1.4 New Mexico Conceptual Models for High Ozone Concentrations

There are three interrelated but distinct Conceptual Models of ozone formation within New Mexico: southeastern New Mexico, Albuquerque and surrounding areas, and northwestern New Mexico. They share the attribute that ozone transport dominates ozone concentrations on all days. Days with the highest local ozone formation are typically hot summer days with slow winds and without an excessive amount of precipitation (summer monsoon).

1.4.1 Southeastern New Mexico

Ozone at monitoring sites in southeastern New Mexico, including Dona Ana, Eddy and Lea Counties, is dominated by ozone transport from outside of New Mexico. This transport includes long-range transport from the remainder of U.S. and global sources (e.g., Asia) as well as medium-range transport from Texas and Mexico. Current year on-road mobile source emissions tend to be the largest contributing Source Sector within southwestern New Mexico and nearby areas, with non-road mobile and O&G sources also contributing. With the exception of emissions from Mexico, the contributions of Electrical Generating Units (EGU) and other large industrial point sources tends to be smaller than the other Source Sectors.

The SNMOS discussed in Section 1.3.5 provides more details on the sources that contribute to elevated ozone concentrations in southeastern New Mexico. It found only 3% of the 2011 ozone Design Value was due to emissions from New Mexico. Emissions from nearby areas in Mexico and Texas contribute the most after long-range transport of ozone.

1.4.2 City of Albuquerque

Ozone transport also dominates elevated ozone concentrations in and near the City of Albuquerque. The Albuquerque modeling study discussed in Section 1.3.6 provides details on source contributions, but sources within New Mexico contributed a large fraction (e.g., 14% and 24%) to elevated ozone in Albuquerque with emissions from Albuquerque contributing up to 75% of the New Mexico contribution. Emissions from on-road and non-road mobile and state-wide O&G also have substantial contributions.

1.4.3 Northwest New Mexico

Although ozone transport dominates ozone in the New Mexico Four Corners region, there are significant contributions due to local power plants and O&G production in the San Juan Basin. The FCAQTF identified numerous local control measures that could mitigate elevated ozone concentrations in the region (see Section 1.3.7).

1.5 Overview of the Modeling Approach

The NM OAI Study will conduct photochemical modeling for a 2014 base and 2023 future year and perform 2023 ozone source apportionment and control strategy sensitivity modeling.

1.5.1 Episode Selection

The May-August 2014 modeling period was selected as it has a high quality emissions inventory with western state updates and has a PGM platform already developed from the WRAP/WAQS regional haze modeling (see Chapter 3 for more details).

1.5.2 Model Selection

Details on the rationale for model selection are provided in Chapter 2. The Weather Research Forecast (WRF) prognostic meteorological model was selected with the 4-km grid covering New Mexico. Emissions modeling will be performed using the Sparse Matric Operator Kernel Emissions (SMOKE) model for most source categories. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) will be used for biogenic emissions and there are special processors for fires, windblown dust (WBD), lightning NOx (LNOx) and oceanic sea salt (NaCl) and Dimethyl Sulfide (DMS) emissions. The 2014 version of the MOtor Vehicle Emissions Simulator (MOVES2014b) on-road mobile source emissions model will be used with SMOKE-MOVES and WRF meteorological data to generate on-road mobile source emissions for the 4-km New Mexico and 12-km western U.S. modeling domains.

The Comprehensive Air-quality Model (CAMx) photochemical grid model (PGM) will be used because it supports two-way grid nesting, includes a subgrid-scale Plume-in-Grid module, contains a well-vetted ozone source apportionment tool and has a rich and successful history of application to the region.

1.5.3 Domain Selection

The same 36-km 36US and 12-km 12WUS2 modeling domains as used in the WRAP/WAQS 2014 modeling will be used in the NM OAI Study modeling. A higher resolution 4-km domain will be added covering New Mexico and adjacent areas. New 2014 36/12/4-km WRF meteorological modeling will be conducted to provide the higher resolution meteorological fields needed for the 4-km New Mexico domain. Details on the domain definition are presented in Chapter 4.

1.5.4 Base and Future Year Emissions Data

The 2014 base year emissions data will be based on the WRAP/WAQS 2014v2 emissions that was in turn based on the 2014NEIv2 with updates from western states. New emissions will be generated for natural emission sources (e.g., biogenic and LNOx) as needed. 2023 future year emissions will be mostly based on the EPA 2016v1 emissions (2023fh inventories). 2023 mobile source emissions will be created using SMOKE-MOVES modeling with 2023 MOVES emission factor look-up table and 2014 WRF meteorology. 2023 O&G emissions for the WRAP states will be based on the WRAP 2023 O&G emissions. The 2014 and 2023 emissions for New Mexico will be reviewed by NMED and updated as needed.

1.5.5 Emissions Input Preparation and QA/QC

Quality assurance (QA) and quality control (QC) of the emissions datasets are some of the most critical steps in performing air quality modeling studies. Because emissions processing is tedious, time consuming and involves complex manipulation of many different types of large databases, rigorous QA measures are a necessity to prevent errors in emissions processing from occurring. The NM OAI Study modeling study will perform a multistep emissions QA/QC approach as developed for the WRAP 2002 modeling (Adelman, 2004) and following the procedures in EPA's latest ozone modeling guidance (EPA, 2018a, pp. 60) and Section 2.20 of the SMOKE User's Manuel (UNC, 2018, pp. 94). This includes the initial emissions QA/QC by the NMED of their emissions for New Mexico as well as QA/QC by the WESTAR/Ramboll team.

1.5.6 Meteorology Input Preparation and QA/QC

The CAMx 2014 36/12/4-km meteorological inputs will be based on a new 2014 WRF meteorological modeling conducted by the Ramboll. The new WRF 2014 36/12/4-km modeling will be evaluated against measured meteorological parameters in a model performance evaluation. The 2014 36/12/4-km WRF output will be processed by WRFCAMx processors to generate meteorological inputs for CAMx. Details on the NM OAI Study 2014 36/12/4-km WRF modeling are provided in Chapter 5.

1.5.7 Initial and Boundary Conditions Development

Initial concentrations (IC) and Boundary Conditions (BCs) are important inputs to PGMs. We intend to run approximately the first two-weeks of May on the 36/12/4-km domains to spin-up the model before the first high ozone day in New Mexico (68 ppb on May 17). This will "wash out" the influence of the ICs before elevated ozone concentrations occur in New Mexico.

BCs for the 36-km 36US domain will be based on a 2014 simulation of the GEOS-Chem global chemistry model conducted by WRAP processed by the GC2CAMx converter. The result is day-specific diurnally varying BCs for the lateral boundaries around the 36-km 36US modeling domain (i.e., GCBC). The top BC (TopCon) will be based on a zero-gradient assumption where concentrations above the top of the model (at 50 mb, or ~19-km above sea level) are assumed to be the same as in the top vertical layer of the model.

1.5.8 Air Quality Modeling Input Preparation and QA/QC

Each step of the air quality modeling will be subjected to QA/QC procedures. These procedures include verification of model configurations, confirmation that the correct data were used and were processed correctly and other procedures. Visualization of model inputs are a critical component of the QA/QC process.

1.5.9 Model Performance Evaluation

The Model Performance Evaluation (MPE) will follow EPA's MPE recommendations in their ozone modeling guidance (EPA, 2007; 2014d; 2018a) and other sources (e.g., Simon, Baker and Phillips, 2012; Emery et al., 2016) and use many elements in EPA Region 8's MPE checklist (EPA, 2015a). The CAMx 2014 36/12/4-km base case

simulation will focus on ozone and precursor model performance within the 4-km New Mexico domain. Details on the MPE are provided in Chapter 7.

1.5.10 Diagnostic Sensitivity Analyses

Depending on the results of the CAMx 2014 base case modeling and MPE, diagnostic sensitivity tests may be conducted to try and improve model performance. The definition of these diagnostic sensitivity tests will depend on the results of the initial MPE. The WRAP/WAQS development of the CAMx 2014 36/12-km modeling database conducted numerous sensitivity tests[30] leading to the final 2014v2 base case.

Under the NM OAI Study we expect most of the sensitivity tests to be conducted for the 2023 future-year where both emissions control strategy sensitivity and ozone source apportionment modeling is planned.

1.5.11 Future Year Control Strategy Modeling

Future year modeling for ozone will be performed for the 2023 future year. A CAMx 2023 36/12/4-km base case simulation will be conducted and projected 2023 ozone DVs calculated. The procedures to calculate projected 2023 ozone DVs will follow EPA's latest guidance (EPA, 2018d). These procedures use the modeling results in a relative fashion to scale the current year observed 8-hour ozone Design Values (DVCs) to project future year ozone Design Values (DVFs). The scaling factors are called Relative Response Factors (RRFs) and are the ratio of the future-year to current-year modeling results for the 10 highest base year modeled MDA8 ozone days near the monitoring site. EPA has developed the Speciated Modeled Attainment Test (SMAT[31]) tool that includes the recommended procedures in the latest EPA guidance for projecting ozone DVFs.

2023 future year control strategy sensitivity modeling will be performed. The future year controls will be defined by the NMED.

1.5.12 Future Year Source Apportionment Modeling

2023 future year ozone source apportionment modeling will be conducted using the CAMx Anthropogenic Precursor Culpability Assessment (APCA) ozone source apportionment tool. The WRAP 2014 GEOS-Chem global chemistry base case, ZROW and NAT simulation will be processed to isolate the contributions of U.S. anthropogenic, International anthropogenic and natural sources to the BCs. Within New Mexico, contributions will be obtained for the major Source Sectors. A NM OAI Study 2023 ozone source apportionment plan will be developed and discussed with NMED.

1.6 Project Participants and Contacts

The NMED is leading the NM OAI Study that is being carried out by the contracting team of WESTAR and Ramboll. Key participants in the NM OAI Study and their contact information are provided in Table 1-1.

[30] http://views.cira.colostate.edu/iwdw/docs/waqs_2014v1_shakeout_study.aspx
[31] https://www.epa.gov/scram/photochemical-modeling-tools

Table 1-1. Key participants and contact information for the NM OAI Study.

Organization	Individual(s) [Roll]	Address	Contact Information
New Mexico Environmental Division (NMED) Air Quality Bureau (AQB)			
NMED	Kerwin Singleton	Planning Section Chief NMED/AQB 525 Camino de los Marquez, Suite 1 Santa Fe, NM 87505	Bus: (505) 476-4350 Cell: (505) 669-3371 kerwin.singleton@state.nm.us
NMED	Bob Spillers	NMED/AQB 525 Camino de los Marquez, Suite 1 Santa Fe, NM 87505	Robert.Spillers@state.nm.us
NMED	Liz Busby-Kuehn	NMED/AQB 525 Camino de los Marquez, Suite 1 Santa Fe, NM 87505	Elizabeth.Kuehn@state.nm.us
NMED	Mike Baca	NMED/AQB 525 Camino de los Marquez, Suite 1 Santa Fe, NM 87505	michael.baca1@state.nm.us
Contractors (modeling team)			
WESTAR	Mary Uhl [Project Manager]	Executive Director WESTAR 3 Caliente Road #8 Santa Fe, NM 87508	Bus: (505) 930-5197 Fax: (505) 954-1216 maryuhl@westar.org
WESTAR	Tom Moore [Co-Principal Investigator]	WRAP Air Quality Program Manager c/o CSU/CIRA 1375 Campus Delivery Fort Collins, CO 80523-1375	Bus: (970) 49-8837 Cell: (970) 988-4055 tmoore@westar.org
Ramboll	Mr. Ralph Morris [Co-Principal Investigator]	Managing Principal Ramboll 7250 Redwood Blvd., Suite 105 Novato, CA 94945	bus: (415) 899-0708 Cell: (415) 713-2840 rmorris@ramboll.com
Ramboll	Marco Rodriguez [PGM Modeling Expert]	Ramboll 702 West Drake Road Building F Fort Collins, CO 80526	bus:(970) 237-4332 mrodriguez@ramboll.com
Ramboll	Tejas Shah [Emissions Modeling Expert]	Ramboll 7250 Redwood Blvd., Suite 105 Novato, CA 94945	bus: (415) 899-0735 tshah@ramboll.com
Ramboll	Jeremiah Johnson [Meteorological Modeling Expert]	Ramboll 7250 Redwood Blvd., Suite 105 Novato, CA 94945	Bus: (415) 899-0752 jjohnson@ramboll.com

1.7 Communication

Frequent communication between the NMED and the WESTAR and Ramboll modeling team and other potentially participants is anticipated. These communications will include e-mails, conference calls and potentially face-to-face meetings.

1.8 Schedule

The task structure and schedule for the NM OAI Study key deliverables are shown in Table 1-2. The study will be continuously documented with PowerPoint presentations and other documents that will be presented to the NMED each month in a webinar whose current schedule and topics are shown in Table 1-3. After each webinar, and with approval of the NMED, the presentations will be posted to a NM OAI Study webpage that will be hosted on the WRAP website. There are two formal reports for the study: (1) a 2014 base case modeling and model performance evaluation report prepared under Task 5, with a draft report currently scheduled for delivery in September 2020; and (2) an Air Quality Technical Support Document (AQTSD) that documents the entire study including the 2023 modeling prepared under Task 7, with a draft report currently scheduled for delivery in November 2020..

Table 1-2. Current schedule for NM OAI Study.

Task	Deliverable	Date
1. Formal Modeling Protocol/QAPP and Work Plan		
	Kick-Off Conference Call	Apr 2020
	Draft Modeling Protocol/QAPP and Work Plan	May 2020
	Webinar PPT on final approach and project plan	May 2020
	Final Modeling Protocol/QAPP and Work Plan	May2020
	Response-to-Comments (RTC) Document	May 2020
2. Base Year Meteorological Modeling (Met)		
2.1 Evaluate Met Modeling	*Webinar PPT on WAQS 12-km WRF MPE and WAQS 12-km PGM ozone performance in New Mexico*	May 2020
2.2 Additional Met Modeling	*Webinar PPT on WRF 4-km MPE in New Mexico and Comparison with WAQS 12-km WRF*	Jun 2020
2.3 Process Met Data	PGM summer 2014 36/12/4-km meteorological inputs	Jun 2020
3. Boundary Conditions (BC)		
3.1 Evaluate BC Data	*Webinar PPT on WRAP/WAQS 2014 GEOS-Chem BCs and latest updates to GEOS-Chem*	Jun 2020
4. Base Year (2014) and Future Year (2023) Emissions		
4.1 & 4.3. 2014 and 2023 Emissions for 4-km New Mexico Domain	*Webinar PPT on recommended sources for 2014 and 2023 emissions in the 4-km New Mexico domain*	May 2020

Task	Deliverable	Date
	Webinar PPT and tile plots/excel spreadsheets for selected 2014 and 2023 emissions for sources in the 4-km NM domain	Jun 2020
4.2 Mobile Sources		
4.2.1 Evaluate Mobile Emissions	*Webinar PPT on options for 2014 & 2023 mobile source emission inputs and advantages/disadvantages*	Jun 2020
	Webinar PPT on final 2014 & 2023 selected mobile source emissions options	Jun 2020
4.2.3 Prepare Mobile Source Emission Inputs	*Webinar PPT on SMOKE-MOVES modeling to generate 2014 and 2023 mobile source emission inputs for 4-km NM domain*	Aug 2020
	Model-ready 2014/2023 mobile source emissions inputs	Aug 2020
4.4 Biogenic/Natural Emissions	*Webinar PPT on biogenic and natural emission modeling*	Jul 2020
	Model-ready 2014 natural emissions inputs (Bio, LNOx, Fires)	Jul 2020
4.5 SMOKE Modeling	*Webinar PPT on SMOKE modeling 2014/2023 anthropogenic emissions*	Aug 2020
	Model-ready 2014/2023 anthropogenic emissions inputs	Aug 2020
4.6 FY Emissions Strategies	*Webinar PPT on FY 2023 SMOKE control/strategies*	Aug 2020
	Summary tables and tile plots of emissions for 2023 scenarios	Aug 2020
5. 2014 Base Year (2014) Air Quality Modeling		
	Webinar PPT on final 2014 base case and MPE	Sep 2020
	Draft report on 2014 base case, MPE and Tasks 2-5	Sep 2020
	Final Report on 2014 base case, MPE & Tasks 2-5	Oct 2020
	RtC on 2014 base case and MPE report	Oct 2020
6. Future Year (2023) Air Quality Modeling		
6.1 FY PGM Modeling	*Webinar PPT on FY 2023 PGM Modeling*	Oct 2020
	Difference plots of FY-BY Ozone Concentrations	Oct 2020
6.2 Modeled Attainment Test	*Webinar PPT on FY ozone DV projections*	Oct 2020

Task	Deliverable	Date
6.4 FY Source Apportionment	*Webinar PPT on FY Source Apportionment Modeling*	Nov 2020
	Interactive Excel spreadsheets with Source Apportionment modeling Results	Nov 2020
6.3 FY Controls Modeling	*Webinar PPT on FT control strategy/sensitivity*	Nov 2020
	Excel Spreadsheet of 2023 ozone DV projections	Nov 2020
7. Air Quality Technical Support Document and Data Transfer		
	Draft Air Quality Technical Support Document (AQTSD)	Nov 2020
	Final Air Quality Technical Support Document (AQTSD)	Dec 2020
	RtC document on AQTSD comments	Dec 2020
	Data Transfer of BY and FY modeling databases and results	Dec 2020

Table 1-3. Current schedule for monthly webinars for the NM OAI Study.

Webinar No.	Webinar Topics by Task	Date
1.	1. Modeling Protocol and Work Plan 2.1 Evaluate Existing Met 4.1 Recommend 2014 and 2023 Emissions 4.2.1 Recommend 2014 & 2023 Mobile Source Emissions	May 2020
2.	2.2 Additional Met Modeling 3.1 Evaluate BC Data 4.1 Summary of 2014 and 2023 Emissions	Jun 2020
3.	4.2.1 Summary of 2014 and 2023 Mobile Source Emissions 4.4 2014 Natural Emissions Results (e.g., Biogenic and LNOx)	Jul 2020
4.	4.2.3 2014 & 2023 SMOKE-MOVES Results for 4-km NM Domain 4.5 2014 & 2023 SMOKE Emissions Modeling Results	Aug 2020
5.	4.6 FY Emissions Strategy Results 5. 2014 CAMx Base Case Modeling and MPE	Sep 2020
6.	6.1 2023 CAMx Modeling Results 6.2 2023 Ozone Design Value Projections	Oct 2020
7.	6.3 2023 Control Strategy Results 6.4 2023 Source Apportionment Modeling Results	Nov 2020

2. MODEL SELECTION

This section introduces the models to be used in the NM OAI Study. The selection methodology presented follows EPA's guidance for regulatory modeling in support of ozone attainment demonstrations (EPA, 2007; 2014d; 2018d). Unlike some of EPA's previous ozone modeling guidance that specified a particular ozone model to be used (e.g., EPA's 1991 ozone modeling guidance that specified the Urban Airshed Model [UAM; Morris and Myers, 1990]), the EPA now recommends that models be selected for ozone, $PM_{2.5}$ and regional haze SIP modeling on a case-by-case basis (EPA, 2018d). The latest EPA ozone guidance (EPA, 2018d) explicitly mentions the CMAQ and CAMx PGMs as the most commonly used PGMs that would satisfy EPA's selection criteria but notes that this is not an exhaustive list and does not imply that they are "preferred" over other PGMs that could also be considered and used with appropriate justification. EPA's ozone modeling guidance lists several criteria for model selection that are paraphrased as follows (EPA, 2018d, pp. 24-27):

- It should not be proprietary;
- It should have received a scientific peer review;
- It should be demonstrated to be applicable to the problem on a theoretical basis;
- It should be used with data bases which are available and adequate to support its application;
- It should be shown to have performed well in past modeling applications;
- It should be applied consistently with an established protocol on methods and procedures;
- It should have a user's guide and technical description;
- The availability of advanced features (e.g., probing tools or science algorithms) is desirable; and
- When other criteria are satisfied, resource considerations may be important and are a legitimate concern.

For the NM OAI Study, we will use the same WRF/SMOKE/MOVES2014/MEGAN/CAMx modeling system as used in many recent studies and satisfies all the selection criteria above. The CAMx modeling system was used in the Western Regional Air Partnership (WRAP) West-wide Jump Start Air Quality Modeling Study (WestJumpAQMS; ENVIRON, 2011; ENVIRON and Alpine, 2012; ENVIRON, Alpine and UNC, 2013), Western Air Quality Study (WAQS; Adelman, Shankar, Yang and Morris, 2014; 2016), EPA's September 2019 Regional Haze modeling (EPA, 2019) and transport (CSAPR) modeling, and for a series of Denver ozone SIP modeling [e.g., 2003 EAC SIP (Morris et al., 2004c,b,c,d), 2008 SIP (Morris et al., 2007; 2008a,b,c) and 2016 SIP (Ramboll and Alpine, 2016a,b; 2017a; RAQC and CDPHE, 2017)] so has a long history of demonstrated success for simulating ozone concentrations in the western U.S.

2.1 Meteorological Model

The Weather Research and Forecasting (WRF) Model is a mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs (Skamarock, 2004; 2006; Skamarock et al., 2005; 2008; 2019). The Advanced Research WRF (ARW) version of WRF will be used in the NM OAI Study. It features multiple dynamical cores, sophisticated data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF allows researchers the ability to conduct simulations reflecting either real data or idealized configurations. WRF provides operational forecasting a model that is flexible and efficient computationally, while offering the advances in physics, numerics, and data assimilation contributed by the research community.

WRF is publicly available, has full documentation and has demonstrated success in simulating meteorological conditions in New Mexico and Intermountain West (IMW) to support PGM modeling efforts in numerous studies (e.g., SNOMS, WRAP WestJumpAQMS and WAQS, EPA national studies and more recent Denver ozone SIPs).

2.2 Emissions Models

2.2.1 Sparse Matrix Operator Kernel Emissions (SMOKE)

The Sparse Matrix Operator Kernel Emissions (SMOKE) is an emissions modeling system that generates hourly gridded speciated emission inputs of mobile, non-road, area, point, fire and biogenic emission sources for PGMs (Coats, 1995; Houyoux and Vukovich, 1999; UNC, 2019). As with most "emissions models," SMOKE is principally an emission processing system and not a true emissions modeling system in which emissions estimates are simulated from "first principles." This means that, except for mobile sources, its purpose is to provide an efficient, modern tool for converting an existing base emissions inventory data that is typically at the county or point source level into the hourly gridded speciated formatted emission files required by a PGM. SMOKE will be used to prepare emission inputs for non-road mobile, non-point (area) and point sources. SMOKE performs three main functions to convert emissions to the hourly gridded emission inputs for a PGM: (1) spatial allocation, spatial allocates county-level emissions to the PGM model grid cells typically using a surrogate distribution (e.g., population); (2) temporal allocation, allocates annual emissions to time of year (e.g., monthly or seasonally) and day-of-week (typically weekday, Saturday and Sunday); and (3) chemical speciation, maps the emissions to the species in the chemical mechanism used by the PGM, most important for VOC and $PM_{2.5}$ emissions.

2.2.2 MOtor Vehicle Emissions Simulator (MOVES)

The MOtor Vehicle Emissions Simulator (MOVES2014b) is EPA's latest on-road mobile source emissions model that was first released in July 2014 (EPA, 2014a,b,c). MOVES2014 includes the latest on-road mobile source emissions factor information. The NM OAI Study will use a version 2014b of MOVES (MOVES2014b[32]) with CB6 species that was released in August 2018.

2.2.3 SMOKE-MOVES

SMOKE-MOVES uses an Emissions Factor (EF) Look-Up Table from MOVES, vehicle miles travelled (VMT) and other activity data and hourly gridded meteorological data (typically from WRF) for the base modeling year and generates hourly gridded speciated on-road mobile source emissions inputs. SMOKE-MOVES will be used to generate on-road mobile source emissions for the 4-km New Mexico domain using the 4-km WRF data developed in this study. It will also be used to generate mobile source emissions inputs for the 12-km western U.S. domain.

2.2.4 Model of Emissions of Gases and Aerosols from Nature (MEGAN)

Biogenic emissions will be generated using version 3.1 of the Model of Emissions of Gases and Aerosols from Nature (MEGAN). MEGAN is the latest biogenic emissions model that was originally developed by researchers from the National Center for Atmospheric Research (NCAR) and is currently supported by the University of California at Irvine. MEGAN includes the full range of ozone and PM precursor species from biogenic sources (Guenther and Wiedinmyer, 2004; Wiedinmyer, Sakulyanontvittaya and Guenther, 2007). The NM OAI Study will use the latest version of MEGAN v3.1 that includes more western states plant emissions data that were implemented by WRAP (Sakulyanontvittaya, Yarwood and Guenther, 2012).

2.3 Photochemical Grid Model

2.3.1 Comprehensive Air-quality Model with extensions (CAMx)

The Comprehensive Air-quality Model with Extensions (CAMx; Ramboll, 2018a) is a state-of-science "One-Atmosphere" multi-scale photochemical grid model capable of addressing ozone, particulate matter (PM), visibility and acid deposition at regional, urban and local scale typically for periods of a year. CAMx is a publicly available open-source computer modeling system for the integrated assessment of gaseous and particulate air pollution. Built on today's understanding that air quality issues are complex, interrelated, and reach beyond the urban scale, CAMx is designed to (a) simulate air quality over many geographic scales, (b) treat a wide variety of inert and chemically active pollutants including ozone, inorganic and organic $PM_{2.5}$ and PM_{10} and mercury and toxics, (c) provide source-receptor, sensitivity, and process analyses and (d) be computationally efficient and easy to use.

The U.S. EPA has approved the use of CAMx for numerous ozone and PM State Implementation Plans throughout the U.S. (including the Denver 2003, 2008 and 2016 ozone SIPs) and has used this model to evaluate regional mitigation strategies

[32] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100V7H1.pdf

including those for most recent national transport rules, such as the Cross-State Air Pollution Rule (CSAPR) and CSAPR Update. The most recent version of CAMx is Version 7.0 that was used in the WRAP/WAQS 2014v2 modeling and EPA's recent national Regional Haze modeling (EPA, 2019). The latest EPA ozone guidance (EPA, 2018d, pp. 24) explicitly mentions the CMAQ and CAMx PGMs as the most commonly used PGMs that would satisfy EPA's selection criteria but notes that this is not an exhaustive list and does not imply that they are "preferred" over other PGMs that could also be considered and used with appropriate justification. EPA has conducted an analysis of the appropriateness for using CAMx and CMAQ for single-source ozone and secondary $PM_{2.5}$ modeling justifying their use (EPA, 2017c).

2.4 Final Justification for Model Selection

At the beginning of this Chapter we presented EPA's criteria for model selection (EPA, 2018d). The proposed WRF/SMOKE/MOVES/CAMx modeling system satisfies all of these criteria as follows:

- It should not be proprietary: The WRF[33], SMOKE[34], MOVES[35], MEGAN[36] and CAMx[37] models are all publicly available at no cost and can be downloaded from their websites.
- It should have received a scientific peer review: All the models considered have been published in 100s of peer-review journal articles. The CAMx model has been subject to their own peer-review reports[38] and an assessment by EPA that they are suitable for ozone SIP modeling (EPA, 2018d).
- It should be appropriate for the specific application on a theoretical basis: The WRF model was designed to simulate time varying three-dimensional meteorological fields and provide all the meteorological information necessary for ozone modeling. The SMOKE, MOVES and MEGAN models provide the hourly gridded speciated emissions information required for ozone modeling. And the CAMx model was designed to have all the processes necessary to simulate ozone formation in the troposphere.
- It should be used with data bases which are available and adequate to support its application: The procedures outlined for the development of the 2014 modeling platform to support ozone modeling of New Mexico use databases that are adequate to support the meteorological, emission and photochemical model applications.
- It should be shown to have performed well in past modeling applications: The WRF/SMOKE/CAMx modeling system has a demonstrated history in simulating ozone formation in the western U.S. in general and New Mexico in particular. CAMx was used in the New Mexico EAC SIP, FCAQTF, CARMMS, WRAP WAQS[39]

[33] https://www.mmm.ucar.edu/weather-research-and-forecasting-model
[34] https://www.cmascenter.org/smoke/
[35] https://www.epa.gov/moves
[36] http://lar.wsu.edu/megan/
[37] http://www.camx.com/
[38] https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/1399874
[39] http://views.cira.colostate.edu/tsdw/

and WestJumpAQMS[40], and Denver ozone SIP modeling, including the 2008[41] and 2016[42] Denver ozone SIPs.

- It should be applied consistently with an established protocol on methods and procedures: The NM OAI Study WRF/SMOKE/CAMx application methodology follows the established procedures used in the past (e.g., see studies discussed above) with enhancements (i.e., 4-km New Mexico domain and use of latest model versions).
- It should have a user's guide and technical description: Each of the models cited has a technical description and procedures for application (see websites in footnotes). The CAMx model has an up-to-date and comprehensive user's guide (Ramboll, 2018a) that has a detailed technical description and procedures for application.
- The availability of advanced features (e.g., probing tools or science algorithms) is desirable: One of the reasons for selecting CAMx is due to the availability of advanced features such as the Plume-in-Grid module and Ozone Source Apportionment Technology (OSAT/APCA) in addition to latest science updates (e.g., CB6 chemistry and Decoupled Direct Method).
- When other criteria are satisfied, resource considerations may be important and are a legitimate concern: CAMx is computationally efficient and supports both MPI and OpenMP multi-processing approaches and allows for layer collapsing. CMAQ does not support OpenMP or allow for layer collapsing so runs over 1.5 times slower than CAMx.

[40] http://wrapair2.org/WestJumpAQMS.aspx

[41] https://www.colorado.gov/airquality/documents/deno308/

[42] https://raqc.org/sip/moderate-area-2008-8-hour-ozone-standard-state-implementation-plan/

3. EPISODE SELECTION

EPA's current and past 8-hour ozone modeling guidance (EPA, 2007; 2014d; 2018d) contains recommended procedures for selecting modeling episodes for demonstrating attainment of the ozone NAAQS. The NM OAI Study modeling will use the summer of 2014 as the base year modeling period because it is representative of high ozone conditions and has available modeling databases to leverage for the analysis.

3.1 Candidate Year for Modeling Episodes

Given the need to leverage an existing photochemical grid model (PGM) modeling platform for the NM OAI Study, there are only two candidate years for episode selection, 2014 and 2016. The WRAP/WAQS has developed a PGM modeling platform for the 2014 year and the EPA/MJO collaborative emissions study and EPA have built a PGM modeling platform for 2016. EPA's previous PGM modeling platform was for 2011, which is too old. And EPA is working on a new PGM modeling platform for 2017 that is not yet available.

3.2 EPA Episode Selection Criteria

EPA's 8-hour ozone SIP modeling guidance (EPA, 2018d) identifies specific criteria to consider when selecting one or more episodes for use in demonstrating attainment of the 8-hour ozone NAAQS. This guidance builds off the 1-hour ozone modeling guidance (EPA, 1991) and the original (EPA, 2007) and revised draft (EPA, 2014d) 8-hour ozone modeling guidance that recommends selecting multiple episodes representing diverse meteorological conditions that lead to exceedances of the ozone NAAQS in the region under study. For the NM OAI Study, an entire summer ozone season will be modeled to capture a wide range of different types of meteorological and emission conditions that lead to observed ozone high ozone concentrations at monitoring sites in New Mexico.

Below we address each of EPA's episode selection criteria (EPA, 2018a, pp. 19) and the justification for using the summer 2014 modeling period for the NM OAI Study.

3.2.1 Model a Time Period that Corresponds to a Year with an Available National Emissions Inventory (NEI) and has Air Quality and Meteorological Data Available

NEI's are prepared every three years. The most recent currently available NEIs are for the 2011 and 2014 years. The 2017 NEI is in preparation and a usable version is not yet available. Thus, the 2014NEI is the latest NEI available.

3.2.2 Model Time Periods in which Observed Ozone Concentrations are Close to the Appropriate Base Year Ozone Design Values*.*

Appendix A presents the observed MDA8 ozone concentrations at monitoring sites within the proposed 4-km New Mexico domain including those in New Mexico (FIP State Code = 35). Observed DMAX8 ozone concentrations that exceed the 2015 ozone NAAQS are colored red. And ozone values that are above approximately 95% of the 2015 ozone NAAQS but below the ozone NAAQS (i.e., 67 ppb ≤ ozone < 70 ppb) are

colored yellow. The number of 2015 ozone NAAQS exceedances (i/e/., 71 ppb or higher) and between 67 and 71 ppb in the three main geographic regions in New Mexico are shown in Table 3-1.

For southeast New Mexico (e.g., Dona Ana County), the peak ozone in 2016 (79 ppb) is higher than in 2014 (76 ppb), but there are many more ozone exceedances days in 2014 (8) than 2016 (3). Both potential candidate modeling years have comparable levels to the observed highest 2014-2016 ozone DV in southeast New Mexico (74 ppb).The highest 2014-2016 ozone DV in northwest New Mexico is 70 ppb in San Juan County. Both candidate modeling years have a highest observed MDA8 ozone in 2014 and 2016 of 69 ppb and two days per year with ozone between 67 and 71 ppb.

Finally, for Bernalillo and Valencia Counties 2016 has a higher peak ozone than 2014 (70 vs. 68 ppb) and more days per year between 67 and 71 ppb (5 vs. 3 days per year).

Table 3-1. Maximum observed DMAX8 ozone concentrations and number of days ozone is above the 2015 ozone NAAQS or between 67 and 71 ppb in the three geographic regions of New Mexico and the 2014 and 2016 candidate modeling years.

NM Region	Max Ozone		Days ≥ 71 ppb		Days ≥ 67 ppb	
	2014	2016	2014	2016	2014	2016
NM All Sites	76	79	8	3	24	27
Albuquerque[a]	68	70	0	0	3	5
Southeast NM	76	79	8	3	21	22
Northwest NM	69	69	0	0	2	2

The Albuquerque geographic region in this table included Bernalillo and Valencia Counties.

3.3 Episode Selection Conclusions

Based on the above analysis, the May-August summer season of 2014 was selected for modeling, because:

- 2014 has a PGM modeling database developed by the WRAP/WAQS.
- It corresponds with a NEI emissions year.
- The 2014 emissions have been reviewed and updated by the western states.
- The ozone air quality is comparable to current ozone DVs.
- It has more ozone exceedance days (8) than the other candidate year (3).

4. MODELING DOMAIN SELECTION AND DATA AVAILABILITY

This Chapter summarizes the definition of the horizontal modeling domains for the NM OAI Study PGM modeling. This includes the map projection, domain coverage, grid resolution and grid nesting. As the vertical structure of the PGM model will be defined based on the vertical structure of the WRF meteorological model, it is discussed in Chapter 5. This Chapter also discusses emissions, aerometric and other data available for use in model input preparation and performance testing.

4.1 Horizontal Domain

The NM OAI Study modeling will use the same 36-km 36US and 12-km 12WUS2 domains as used in the WRAP/WAQS 2014 modeling platform. A 4-km New Mexico domain will be added to the 36/12-km domain structure. Figure 4-1 displays the 36/12/4-km domain structure with Figure 4-2 showing the 4-km New Mexico domain. New WRF 2014 36/12/4-km meteorological modeling will be conducted to generate finer scale 4-km meteorological conditions for the New Mexico domain and consistent meteorology among the 36/12/4-km domains.

CAMx will be run using the 36/12/4-km domain structure shown in Figure 4-1 using two-way interactive grid nesting.

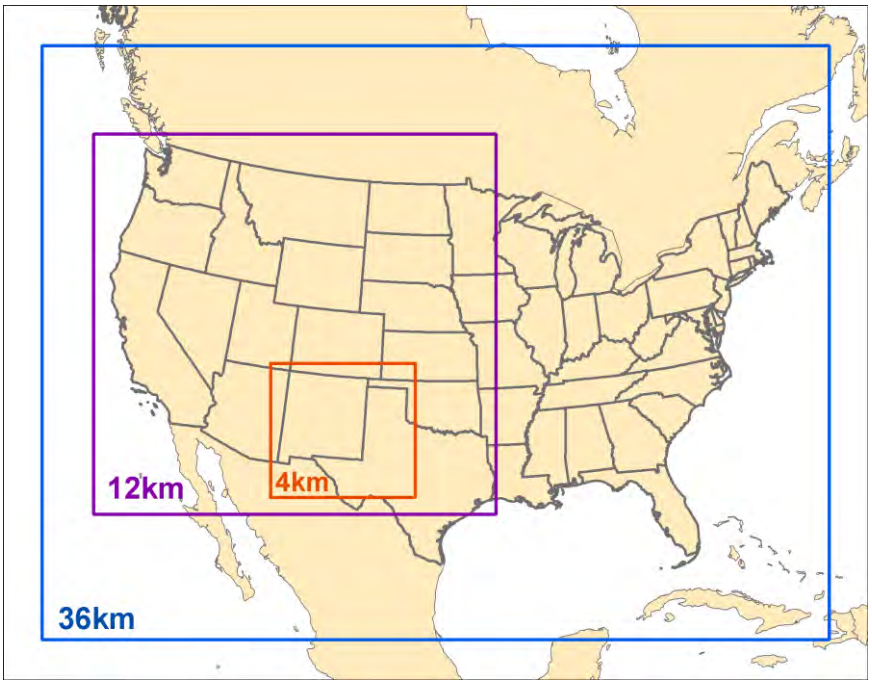

Figure 4-1. NM OAI Study modeling 2014 36/12/4-km PGM and emissions modeling domains.

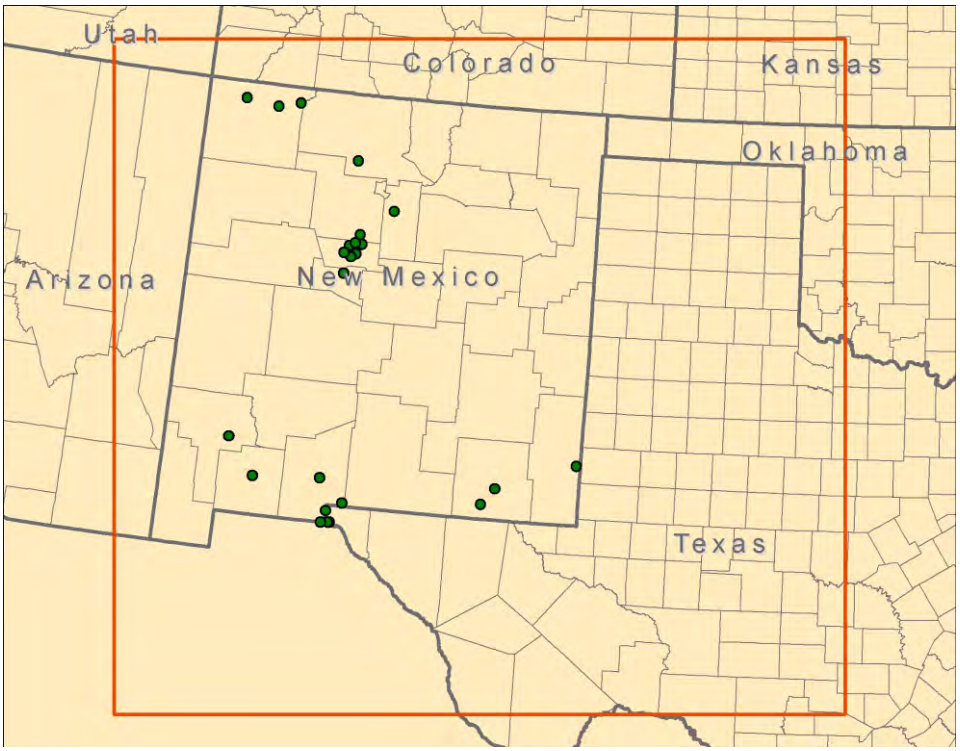

Figure 4-2. 4-km New Mexico modeling domain for PGM and emissions modeling, with locations of ozone monitors that were operating during some portion of 2014.

Table 4-1. Lambert Conformal Conic (LCC) projection parameters for the NM OAI Study 36/12/4 modeling domains.

Parameter	Value
Projection	Lambert-Conformal
1st True Latitude	33 degrees N
2nd True Latitude	45 degrees N
Central Longitude	-97 degrees W
Central Latitude	40 degrees N

Table 4-2. Grid definitions for CAMx NM OAI Study 2014 36/12/4-km modeling domains.

Grid	Origin (SW) (km)	Extent (NE) (km)	NX	NY
36-km	(-2736, -2088)	(2592, 1944)	148	112
12-km*	(-2388, -1236)	(336, 1344)	227	215
4-km*	(-1192, -1120)	(-212, -212)	245	227

*Definition includes outer row/column of buffer cells required by CAMx for nested domains

4.2 Data Availability

The CAMx modeling system requires emissions, meteorology, surface characteristics, initial and boundary conditions (IC/BC), and ozone column data for defining the inputs.

4.2.1 Emissions Data

Except for on-road mobile source emissions for the 4-km domain, the 2014 base year anthropogenic emissions inventory for New Mexico will be based on the WAQS 2014v2 emissions. The NMED will review the WAQS 2014v2 emissions for New Mexico and provide updates as needed. The sources of the 2014 emissions data are as follows.

- Major point source SO_2 and NO_x emissions will be based off measured Continuous Emissions Monitor (CEM) data that are available online from the EPA Clean Air Markets Division (CAMD[43]) website. These data are hour-specific for SO_2, NO_x, and heat input. The temporal variability of other pollutant emissions (e.g., PM) from the CEM sources will be simulated using the hourly CEM heat input data using the annual emissions from the WAQS 2014v2 emissions inventory.
- WRAP developed new 2014 oil and gas emissions for WRAP states that includes New Mexico that will be used. Outside of the WRAP states the EPA 2014NEI will be used.
- On-road mobile sources will be based on the EPA's MOVES2014 on-road emissions model (EPA, 2014a,b,c). The WAQS 36/12-km 2014v2 emissions will be used as is. Within the New Mexico 4-km domain, SMOKE-MOVES will be used

[43] http://www.epa.gov/AIRMARKETS/

with EPA's MOVES2014 2014 emission factor (EF) table and county-level vehicle activity data and 2014 hourly 4-km WRF meteorology developed in this study.

- The 2014 fire emissions developed for the 2014NEI and then updated by the WRAP Fire and Smoke Work Group will be used.
- 2014 biogenic emissions will be generated for the 36/12/4-km domains using version 3.1 of the Model of Emissions of Gases and Aerosols in Nature (MEGAN[44]) that was updated by WRAP[45] to include western U.S. plant types.
- Mexico and Canada emissions will be based on the EPA 2014 modeling platform.

4.2.2 Air Quality Data

Data from ambient air quality monitoring networks for gaseous species are used in the model performance evaluation. Table 4-3 summarizes routine ambient gaseous and PM monitoring networks available in the U.S. For this project only the routine ozone monitoring sites within the New Mexico 4-km modeling domain operating during 2014 (Figure 4-2) will be used to perform an operational evaluation of the CAMx 2014 4-km base case simulation.

[44] http://acd.ucar.edu/~guenther/MEGAN/MEGAN.htm

[45] http://www.wrapair2.org/pdf/WGA_BiogEmisInv_FinalReport_March20_2012.pdf

Table 4-3. Overview of routine ambient data monitoring networks.

Monitoring Network	Chemical Species Measured	Sampling Period	Data Availability/Source
The Interagency Monitoring of Protected Visual Environments (IMPROVE)	Speciated PM25 and PM10 (see species mappings)	1 in 3 days; 24 hr average	http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm
Clean Air Status and Trends Network (CASTNET)	Speciated PM25, Ozone (see species mappings)	Approximately 1-week average	http://www.epa.gov/castnet/data.html
National Atmospheric Deposition Program (NADP)	Wet deposition (hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium)), Mercury	1-week average	http://nadp.sws.uiuc.edu/
Air Quality System (AQS) or Aerometric Information Retrieval System (AIRS)	CO, NO2, O3, SO2, PM25, PM10, Pb	Typically, hourly average	http://www.epa.gov/air/data/
Chemical Speciation Network (CSN)	Speciated PM	24-hour average	http://www.epa.gov/ttn/amtic/amticpm.html
Photochemical Assessment Monitoring Stations (PAMS)	Varies for each of 4 station types.		http://www.epa.gov/ttn/amtic/pamsmain.html
National Park Service Gaseous Pollutant Monitoring Network	Acid deposition (Dry; SO4, NO3, HNO3, NH4, SO2), O3, meteorological data	Hourly	http://www2.nature.nps.gov/ard/gas/netdata1.htm

4.2.3 Ozone Column Data

Additional data used in the air quality modeling include ozone column data from the Ozone Monitoring Instrument (OMI) which continues the Total Ozone Mapping Spectrometer (TOMS) record for total ozone and other atmospheric parameters related to ozone chemistry (OMI officially replaced the TOMS ozone column satellite data on January 1, 2006). OMI data are available every 24-hours and are obtained from the TOMS ftp site.[46] The CAMx o3map program reads the OMI ozone column txt file data and interpolates to fill gaps and generated gridded daily ozone column input data. The OMI data are used in the CAMx (TUV) radiation models to calculate photolysis rates. The CAMx o3map processor also allows for the use of episode and monthly average data, although in this study daily data are used. Note that a new ozone column satellite product is available (OMPS) that may be used if appropriate.

4.2.4 Meteorological Data

Meteorological data for PGM modeling will be obtained from the WRF meteorological model as described in Chapter 5.

4.2.5 Initial and Boundary Conditions Data

Boundary conditions (BCs) for the 36-km 36US domain for both the base and future years will be derived from the output from a 2014 simulation of the GEOS-Chem global chemistry model conducted by WRAP.

[46] ftp://toms.gsfc.nasa.gov/pub/omi/data/

5. WRF METEOROLOGICAL MODELING

This chapter describes how the Weather Research Forecasting (WRF) meteorological model will be used to generate 2014 36/12/4-km meteorological inputs for CAMx photochemical grid modeling. The WRF model contains separate modules to compute different physical processes, such as surface energy budgets and soil interactions, turbulence, cloud microphysics, and atmospheric radiation. Within WRF, the user has many options for selecting the different schemes for each type of physical process. The WRF Pre-processing System (WPS) generates the initial conditions (ICs) and boundary conditions (BCs) and analysis fields used by WRF, based on topographic datasets, land use information, and larger-scale atmospheric and oceanic models.

5.1 Description of WRF

WRF's research and operational application ensures state-of-the-science physics and adaptability to a wide range of environments, through a broad selection of physics options, allowing us to develop the best-performing configuration for simulating meteorology in the region.

The non-hydrostatic version of the Advanced Research version of the Weather Research and Forecast (WRF-ARW) model (Skamarock et al., 2005; 2008; 2019) is a three-dimensional, limited-area, primitive equation, prognostic model that has been used widely in regional air quality model applications. WRF is a next-generation mesoscale prognostic meteorological model routinely used in urban- and regional-scale photochemical, fine particulate and regional haze regulatory modeling studies. Developed jointly by the National Center for Atmospheric Research (NCAR) and NCEP, WRF is maintained and supported as a community model by researchers and practitioners around the globe. It is suitable for use in a broad spectrum of applications across scales ranging from hundreds of meters to thousands of kilometers.

5.2 WRF Model Domain

The PGM (CAMx) 2014 36/12/4-km modeling domains were shown in Figure 4-1 in the previous Chapter. The WRF 2014 36/12/4-km modeling domains are defined slightly larger than the PGM 36/12/4-km domains so that any modeling artifacts that occur near the WRF boundaries as the BCs come into dynamic balance with the WRF numerical algorithms are not present in the PGM meteorological inputs.

5.3 WRF Model Configuration

Below we summarized the proposed WRF configuration and input to be used to generate 2014 36/12/4-km meteorological inputs for the PGM 2014 photochemical modeling. WPS and WRF version 4.2 are used for this modeling analysis. Previous studies utilizing WRF at high resolution over New Mexico, such as the WRAP WestJumpAQMS, WAQS, Southern New Mexico Ozone Study (SNMOS) and EPA modeling platform development, have evaluated different configurations of WRF. Table 5-1 below summarizes the WRF configurations used in the WAQS 2014 and EPA 2014/2015/2016 WRF modeling. Preliminary analysis of WAQS 12 km model performance in New Mexico shows superior summertime precipitation performance

compared to EPA 2014 WRF modeling. Therefore, we propose that the NM OAI Study match the WRF physics configuration options used by 2014 WAQS modeling, except where noted below.

We propose to match the NM OAI 36/12-km WRF/PGM grid configuration (e.g., horizontal domains and vertical layer structure) with the WAQS 2014 WRF/PGM grid configuration in order the facilitate the use of data between the two studies. The following paragraphs describe the proposed WRF configuration for the NM OAI 2014 photochemical modeling.

5.3.1 Model Vertical Resolution

The WAQS 2011/2014 WRF modeling used 36 vertical levels (35 vertical layers) from the surface to a 50 mb (hPa) height (approximately 19-km above sea level). The EPA 2014 and 2015 WRF modeling used 35 vertical layers also up to a 50 mb height. Table 5-1 displays the 36-vertical layer structure used in the WAQS 2011/2014 WRF modeling that will be the layer structure proposed for our WRF 2014 NM OAI 36/12/4-km modeling.

Table 5-1. WRF 36 level vertical layer structure for the NM OAI study. This is the same WRF layer structure as used in WAQS 2011/2014 WRF modeling.

WRF Layer	Sigma	Pressure (mb)	Height (m)	Thickness (m)
36	0.0000	50.00	19260	2055
35	0.0270	75.65	17205	1850
34	0.0600	107.00	15355	1725
33	0.1000	145.00	13630	1701
32	0.1500	192.50	11930	1389
31	0.2000	240.00	10541	1181
30	0.2500	287.50	9360	1032
29	0.3000	335.00	8328	920
28	0.3500	382.50	7408	832
27	0.4000	430.00	6576	760
26	0.4500	477.50	5816	701
25	0.5000	525.00	5115	652
24	0.5500	572.50	4463	609
23	0.6000	620.00	3854	461
22	0.6400	658.00	3393	440
21	0.6800	696.00	2954	421
20	0.7200	734.00	2533	403
19	0.7600	772.00	2130	388
18	0.8000	810.00	1742	373
17	0.8400	848.00	1369	271
16	0.8700	876.50	1098	177
15	0.8900	895.50	921	174
14	0.9100	914.50	747	171
13	0.9300	933.50	577	84
12	0.9400	943.00	492	84
11	0.9500	952.50	409	83
10	0.9600	962.00	326	82
9	0.9700	971.50	243	82
8	0.9800	981.00	162	41
7	0.9850	985.75	121	24
6	0.9880	988.60	97	24
5	0.9910	991.45	72	16
4	0.9930	993.35	56	16
3	0.9950	995.25	40	16
2	0.9970	997.15	24	12
1	0.9985	998.58	12	12
0	1.0000	1000.00	0	

5.3.2 Vertical Coordinate

Since its inception, WRF has used the eta (sometimes called sigma or "terrain-following") vertical coordinate system. One weakness of the eta coordinate is that

variations in terrain (especially steep topography) can increase numerical errors in the model. To reduce these errors, Park et al., (2018) developed a hybrid sigma–pressure coordinate that is now included as the default vertical coordinate system for the WRF model (Skamarock et al., 2019).

In Figure 5-1, we present vertical cross sections of layer interface heights over the Rocky Mountains during a strong near-surface wind event (Park et al., 2018). The left panel shows the results using the eta or terrain-following vertical coordinate and the right panel shows the same results but using the hybrid vertical coordinate. The eta coordinate cross-sections show the influence of terrain extending high into the stratosphere. This is a representation of numerical noise and results in erroneous vertical motion in the model. Park et al., (2018) found that the simulation using the eta vertical coordinate produced high turbulence forecasts aloft which were not observed by pilots or soundings. In CAMx, erroneous vertical motion can help transport stratospheric ozone toward the surface. In contrast, the same simulation using the hybrid vertical coordinate produced lower turbulence forecasts that agreed more closely with observations. The hybrid vertical coordinate cross-sections show a gradual damping of terrain effects with increasing altitude until the layer interfaces are flat aloft. The purpose of using the hybrid vertical coordinate in the CAMx is to better represent ozone in the upper troposphere and lower stratosphere. Eliminating this source of numerical noise reduces spurious downward transport of stratospheric ozone.

We will use a new version of the WRFCAMx processor that has been updated to use WRF's hybrid vertical coordinate.

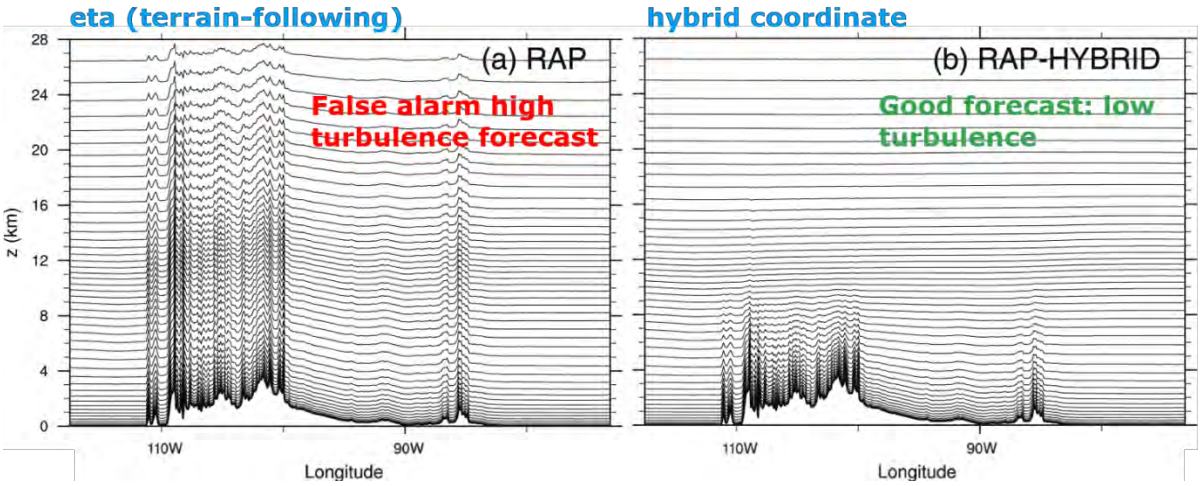

Figure 5-1. Cross-sections of layer interface heights over the Rocky Mountains for the eta (left panel) and hybrid (right panel) vertical coordinates for the WRF-Based Rapid Refresh (RAP) model. Adapted from Park et al., (2018).

5.3.3 Topographic Inputs

Topographic information for WRF will be based on a combination of the standard WRF terrain databases and high-resolution terrain. The 36-km 36US domain will use the 10-minute global data, the 12-km 12WUS2 domain will use the 2-minute data, and the 4-km New Mexico domain will use the 30 second data.

5.3.4 Vegetation Type and Land Use Inputs

Vegetation type and land use information will use the United States Geological Survey (USGS) land use databases from the most recently released WRF databases provided with the WRF distribution. Standard WRF surface characteristics corresponding to each land use category will be employed.

5.3.5 Atmospheric Data Inputs

WRF relies on other model or re-analysis output meteorological fields to provide initial and boundary conditions (IC/BC) and fields for the four-dimensional data assimilation (FDDA). FDDA refers to the nudging of the WRF meteorological fields to observed analysis fields so that the WRF meteorological fields better represent what was observed and prevent the model from drifting away from the observed meteorology. As seen in Table 5-2, both the WAQS 2014 and EPA 2014/2015/2016 12-km WRF modeling used the 12-km resolution North American (NAM) analysis fields for IC/BC and analysis nudging.

We propose to use both NAM and the ~30 km European Center for Medium-Range Weather Forecasting (ECMWF) Re-Analysis (ERA5[47]) dataset analysis fields for IC/BC and FDDA. We have found from previous work that the ERA-Interim (lower resolution predecessor to ERA5) dataset has lower humidity near the surface and higher humidity aloft, leading to lower convective available potential energy (CAPE), which lowers overall precipitation rates, especially during the summer Monsoon season. Many WRF simulations of the southwest U.S. summer Monsoon have featured an over-prediction of summertime (convective) precipitation when the NAM analysis fields are used. The Southern New Mexico Ozone Study (SNMOS) conducted PGM ozone sensitivity modeling using meteorological fields based on WRF simulations using the NAM and ERA analysis fields and found that the PGM ozone performance using the WRF/ERA meteorological inputs produced superior ozone performance than when WRF/NAM inputs were used.[48]

The ERA5 is a fairly new analysis fields product that has not been used in WRF modeling as extensively as the ERA fields. We will conduct WRF and PGM sensitivity modeling using the NAM and ERA5 analysis fields to determine which configuration provides the best meteorological inputs and potentially resultant ozone model performance. The ERA5 fields will be objectively re-analyzed using meteorological observational data to the higher resolution for the 36-km and 12-km grid domains using the OBSGRID program. These fields are used both to initialize the model and used with analysis nudging (on selected domains) to guide the model to best match the observations. The initialization dataset with the best WRF performance will be chosen for the final PGM configuration.

[47] https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era5

[48] https://www.wrapair2.org/SNMOS.aspx

5.3.6 Time Integration

Third-order Runge-Kutta integration will be used (rk_ord = 3). The maximum time step, defined for the outer-most domain (36 km) only, should be set by evaluating the following equation:

$$dt = \frac{6dx}{F_{map}}$$

Where dx is the grid cell size in km, Fmap is the maximum map factor (which can be found in the output from REAL.EXE), and dt is the resulting time-step in seconds. For the case of the 36 km RPO domain, dx = 36 and Fmap = 1.08, so *dt* should be taken to be less than 200 seconds. Longer time steps risk CFL errors, associated with large values of vertical velocity, which tend to occur in areas of steep terrain (especially during stable conditions typical of winter). For this WRF run, adaptive time-stepping will be used with a maximum timestep of 180s.

5.3.7 Diffusion Options

Horizontal Smagorinsky first-order closure (km_opt=4) with sixth-order numerical diffusion and suppressed up-gradient diffusion (diff_6th_opt=2) will be used.

5.3.8 Lateral Boundary Conditions

Lateral boundary conditions will be specified from the initialization dataset on the 36-km WRF domain with continuous updates nested from each "parent" domain to its "child" domain, using one-way nesting (feedback=0).

5.3.9 Top and Bottom Boundary Conditions

The implicit Rayleigh dampening for the vertical velocity will be used for the top boundary conditions. Consistent with the model application for non-idealized cases, the bottom boundary condition was selected as physical, not free-slip.

5.3.10 Sea Surface Temperature Inputs

The water temperature data for the refined WRF configurations will be taken from the Fleet Numerical Meteorology and Oceanography Center (FNMOC)[49]. The FNMOC product has horizontal resolution of about 9-km in the mid-latitudes but is produced *four* times per day using AVHRR satellite sensors and in-situ observations.

5.3.11 Four Dimensional Data Assimilation (FDDA)

Analysis nudging will be used for winds, temperature, and humidity on the 36-km and 12-km domains. Both surface and aloft nudging will be used but nudging for temperature and mixing ratio will not be not performed within the boundary layer. Observation nudging will not be performed even on the 4-km domain.

[49] http://www.usgodae.org/cgi-bin/datalist.pl?summary=Go&dset=fnmoc_ghrsst

5.3.12 New Lightning Data Assimilation

More recently, the assimilation of lightning data in WRF simulations has been shown to improve the locations and amounts of convective precipitation. The use of lighting detection networks, such as the National Lightning Detection Network (NLDN), have been used in WRF simulations and used to force deep convection (thunderstorms) when lightning is observed and only allow shallow convection when lightning is not present. The use of the new lightning assimilation approach has been demonstrated to improve both WRF convective precipitation as well as PGM concentration and deposition performance (Heath et al., 2016). The new lightning data assimilation algorithms will not be used in the 2014 WRF modeling for the NM OAI Study for the following reasons: (1) it would have to be tested and evaluated and there is insufficient time in the schedule to conduct such diagnostic testing; (2) the NLDN data used to date with the WRF lightning assimilation is a commercial product that is expensive and not in the budget; and (3) the implementation of the lightning detection data assimilation in WRF has a flaw that it doesn't distinguish between no lightning detects and missing data and suppresses convection in areas with missing data (e.g., over the Gulf of Mexico).

5.3.13 PBL and LSM Physics Options

The YSU Planetary Boundary Layer (PBL) and Noah Land Surface Model (LSM) physics options will be used in the NM OAI Study 2014 36/12/4-km modeling. Previous WRF sensitivity modeling for the IMW region found the YSU/Noah PBL/LSM schemes produces the most realistic meteorological fields. Note that EPA's 2014/2015/2016 WRF modeling uses the ACM2 PBL and Pleim-Xiu (PX) LSM schemes (Table 5-2). The WAQS tried to evaluate WRF using the ACM2/PX PBL/LSM and found it more difficult to implement and didn't always run so that annual fields could not be generated. Furthermore, the PX LSM scheme requires each run segment of a WRF run soil moisture inputs to be initialized using the previous WRF run segment PX output so that an annual WRF simulations must be run in series. This contrasts with the Noah LSM scheme that initializes soil moisture based on observations with some spin-up time (typically 12-hours) that allows annual WRF runs to be performed using parallel run segments (e.g., 5.5 day run segments). Thus, annual WRF simulations using the YSU/NOAH PBL/LSM physics options can be completed much faster than when ACM2/PX is used.

5.3.14 Remaining WRF Physics Options

Table 5-2 lists the remaining WRF physics options for the NM OAI Study 2014 36/12/4-km WRF application. These are standard WRF physics options and consistent with the WRF options used in the WAQS 2014 and EPA 2014/2015/2016 WRF modeling. Our preliminary comparison of 2014 WAQS and 2014 EPA WRF modeling for summertime precipitation performance in New Mexico finds that WAQS WRF outperformed EPA WRF modeling. Therefore, we propose to use the same microphysics and cumulus schemes for the NM OAI Study as used in 2014 WAQS (Thompson and Multi-Scale Kain-Fritsch, respectively).

Table 5-2. Proposed NM OAI 2014 WRF model configuration and comparison with the WRF configuration used in the WAQS 2014 and EPA 2014/2015 WRF modeling.

WRF Option	Proposed NM OAI	2014 WAQS	2014/2015 EPA
Domains run	36/12/4-km	36/12/4-km	12-km
Microphysics	Thompson	Thompson	Morrison 2
LW Radiation	RRTMG	RRTMG	RRTMG
SW Radiation	RRTMG	RRTMG	RRTMG
Sfc Layer Physics	MM5 similarity	MM5 similarity	MM5 similarity
LSM	Noah	Noah	Pleim-Xiu
PBL scheme	Yonsei University (YSU)	YSU	ACM2
Cumulus	36/12/4-km Multi-scale Kain Fritsch	36/12-km Multi-scale_Kain Fritsch; 4-km None	Kain-Fritsch
BC, IC Analysis Nudging Source	12-km NAM/ERA5	12-km NAM	12-km NAM
Analysis Nudging Grids	36/12-km	36/12-km	12-km
Obs Nudging	None	4-km	None
Sea Sfc Temp	FNMOC	FNMOC	FNMOC

5.3.15 Application Methodology

The WRF model will be executed in 5.5-day blocks initialized at 12Z every five days. Model results will be output every 60 minutes, split at twelve (12) hour intervals. Twelve (12) hours of spin-up is included in each 5-day block before the data is used in the subsequent evaluation and PGM meteorological inputs.

5.4 WRF Model Evaluation

Quantitative and qualitative evaluations of the NM OAI Study 2014 WRF 36/12/4-km simulation will be conducted. The quantitative evaluations compare integrated surface hourly meteorological observations with WRF predictions matched by time and location. The qualitative evaluations compared time series plots of modeled wind speed and wind direction to the observations at specific sites. The evaluation is conducted for meteorological observation sites across the western U.S., with particular focus on sites within the 4-km New Mexico domain.

5.4.1 Quantitative Evaluation Using METSTAT

A quantitative model performance evaluation of the NM OAI Study 2014 WRF modeling will be performed using the publicly-available METSTAT software (Ramboll Environ, 2015) evaluation tool. Output from the WRF meteorological model will be compared

against meteorological observations from the various networks operating in the study area. This is carried out both graphically and statistically to evaluate model performance for surface winds, temperatures, humidity, and the placement, intensity, and evolution of key weather phenomena. The purpose of these evaluations is to establish a first-order acceptance/rejection of the simulation in adequately replicating the weather phenomena in the study area. Thus, this approach screens for obvious model flaws and errors.

5.4.1.1 Quantitative Statistics

The quantitative analysis will be conducted using METSTAT. Statistical measures calculated by METSTAT include observation and prediction means, prediction bias, and prediction error that are given as follows.

Mean Observation (M_o) is calculated using values from all sites for a given time period by Eq. **(5-1)**:

$$M_o = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I} O_j^i \qquad (5\text{-}1)$$

where O^i_j is the individual observed quantity at site i and time j, and the summations are over all sites (I) and over time periods (J).

Mean Prediction (M_p) is calculated from simulation results that are interpolated to each observation used to calculate the mean observation for a given time period by Eq. **(5-2)**:

$$M_p = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I} P_j^i \qquad (5\text{-}2)$$

where P^i_j is the individual predicted quantity at site i and time j. Note the predicted mean wind speed and mean resultant direction are derived from the vector-average (for east-west component u and north-south component v), from which the

Bias (B) is calculated as the mean difference in prediction-observation pairings with valid data within a given analysis region and for a given time period by Eq. **(5-3)**:

$$B = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right) \qquad (5\text{-}3)$$

Gross Error (E) is calculated as the mean *absolute* difference in prediction-observation pairings with valid data within a given analysis region and for a given time period by Eq. **(5-4)**:

$$E = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P_j^i - O_j^i\right| \qquad (5\text{-}4)$$

Note that the bias and gross error for winds are calculated from the predicted-observed residuals in speed and direction (not from vector components *u* and *v*). The direction error for a given prediction-observation pairing is limited to range from 0 to ±180°.

Root Mean Square Error (RMSE) is calculated as the square root of the mean squared difference in prediction-observation pairings with valid data within a given analysis region and for a given time period by Eq **(5-5)**:

$$RMSE = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)^2\right]^{\frac{1}{2}} \quad (5\text{-}5)$$

The RMSE, as with the gross error, is a good overall measure of model performance. However, since large errors are weighted heavily (due to squaring), large errors in a small sub-region may produce a large RMSE even though the errors may be small and quite acceptable elsewhere.

5.4.1.2 METSTAT Processing

METSTAT was developed to calculate and graphically present statistics associated with temporally paired meteorological model predictions and observations. The horizontal analysis range can be given for an entire output grid, by a coordinate box, or as a list of specific site identifiers (such as WBAN or AIRS numbers), as labeled on the observational file. This allows for an evaluation at a single site, a subset of specific sites (e.g., within a state) or over an entire regional domain. The program then proceeds to calculate statistics for each hour and for each day of the time window.

The process involves statistical comparisons of model data from the WRF grid cells to observational measurements located with each grid cell. METSTAT evaluates wind speed and direction, air temperature, and air humidity using both bias and error statistics. METSTAT has been widely applied to WRF runs for many years, across many modeling domains. Using a consistent definition of the statistical quantities to be calculated and a consistent methodology for pairing observations in time, METSTAT allows for more straightforward comparisons between model applications in widely different regions and time periods.

5.4.2 Statistical Benchmarks

METSTAT calculates statistical performance metrics for bias, error and correlation for surface winds, temperature, and mixing ratio (i.e., water vapor or humidity). To evaluate the performance of a meteorological model simulation for air quality model applications, a number of performance benchmarks for comparison are typically used. Table 5-3 lists the meteorological model performance benchmarks for simple (Emery et al., 2001) and complex (Kemball-Cook et al., 2005) situations. The simple benchmarks were developed by analyzing well-performing meteorological model evaluation results for simple, mostly flat terrain conditions and simple meteorological conditions (e.g., stationary high pressure) that were mostly conducted to support air quality modeling studies (e.g., ozone SIP modeling). The complex benchmarks were developed during the Western Regional Air Partnership (WRAP) regional haze modeling and are

performance benchmarks for more complex conditions, such as the complex terrain of the Rocky Mountains and Alaska (Kemball-Cook et al., 2005). McNally (2009) analyzed multiple annual runs that included complex terrain conditions and suggested an alternative set of benchmarks for temperature under more complex conditions. The purpose of the benchmarks is to understand how good or poor the results are relative to other model applications run for the U.S.

The NM OAI Study 2014 WRF application will compare the WRF meteorological variables to the benchmarks as an indication of WRF model performance. These benchmarks include bias and error in temperature, wind direction and mixing ratio as well as the wind speed bias and Root Mean Squared Error (RMSE) between the models and databases.

Table 5-3. Meteorological model performance benchmarks for simple and complex conditions.

Parameter	Emery et al. (2001)	Kemball-Cook et al. (2005)	McNally (2009)	Resulting Criteria
Conditions	Simple	Complex	Complex	Complex
Temperature Bias	≤ ±0.5 K	≤ ±2.0 K	≤ ±1.0 K	≤ ±1.0 K
Temperature Error	≤ 2.0 K	≤ 3.5 K	≤ 3.0 K	≤ 3.0 K
Temperature IOA	≥ 0.8	(not addressed)	(not addressed)	≥ 0.8
Humidity Bias	≤ ±1.0 g/kg	≤ ±0.8 g/kg	≤ ±1.0 g/kg	≤ ±1.0 g/kg
Humidity Error	≤ 2.0 g/kg	≤ 2.0 g/kg	≤ 2.0 g/kg	≤ 2.0 g/kg
Humidity IOA	≥ 0.6	(not addressed)	(not addressed)	≥ 0.6
Wind Speed Bias	≤ ±0.5 m/s	≤ ±1.5 m/s	(not addressed)	≤ ±1.5 m/s
Wind Speed RMSE	≤ 2.0 m/s	≤ 2.5 m/s	(not addressed)	≤ 2.5 m/s
Wind Speed IOA	≥ 0.6	(not addressed)	(not addressed)	≥ 0.6
Wind Dir. Bias	≤ ±10 degrees	(not addressed)	(not addressed)	≤ ±10 degrees
Wind Dir. Error	≤ 30 degrees	≤ 55 degrees	(not addressed)	≤ 55 degrees

The output from the 2014 36/12/4-km WRF simulations will be compared against meteorological data obtained from the National Climate Data Center's (NCDC) global-scale, quality-controlled DS3505 integrated surface hourly observational (ISHO) data (NOAA-NCDC, 2015) as verification data. Global hourly and synoptic observations are compiled from numerous sources into a single common ASCII format and common data model. The DS3505 database contains records of most official surface meteorological stations from airports, military bases, reservoirs/dams, agricultural sites, and other sources dating from 1901 to the present.

A standard set of statistical metrics from the METSTAT package will be used. These metrics will be calculated on hourly, daily and monthly time frames for wind speed, wind direction, temperature, and humidity at the surface, using all available observational weather data. The WRF surface meteorological model performance metrics will be compared against the simple and complex model performance goals using "soccer plots." Soccer plots use two WRF performance metrics as X-axis and Y-axis values (e.g., temperature bias as X, and temperature error as Y) along with the

performance benchmarks. The closer the symbols are to the zero origin, the better the model performance. It is also easy to see when the two WRF performance metrics fall within the benchmark lines. Figure 5-2 displays an example WRF monthly temperature soccer plot from the 2011 WRF simulations used in the 2017 Denver ozone SIP modeling. We will present WRF 2014 monthly-averaged surface meteorological model performance from the 4-km New Mexico domain with additional performance products produced for the 12-km 12WUS2 and 36-km 36US domains.

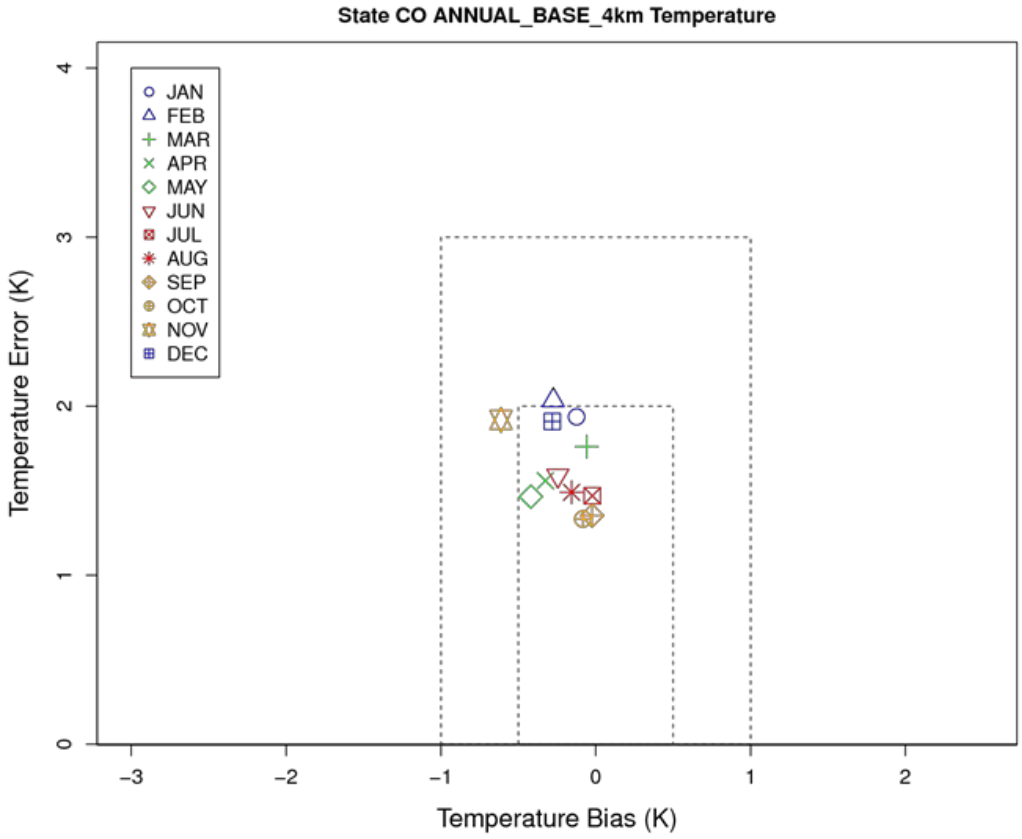

Figure 5-2. Example Soccer plot of monthly temperature error and bias (K) for 4-km domain.

5.4.3 Qualitative Evaluations Using PRISM Data

Oregon State University (OSU) publishes precipitation analysis fields based on observations that can be used to qualitatively evaluate the WRF precipitation fields. The Parameter-elevation Relationships on Independent Slopes Model (PRISM[50]) is used to generate the precipitation analysis fields (Daly et al., 2008). The PRISM interpolation method was used to develop data sets that reflected, as closely as possible, the current state of knowledge of spatial climate patterns in the United States. PRISM calculates a climate – elevation regression for each digital elevation model

[50] http://prism.oregonstate.edu/

(DEM) grid cell, and stations entering the regression are assigned weights based primarily on the physiographic similarity of the station to the grid cell. Factors considered are location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain.

Spatial plots of the WRF monthly precipitation fields will be compared with the PRISM spatial maps for the 12-km 12WUS2 and 4-km New Mexico modeling domains in a qualitative model evaluation (note that PRISM does not include any analysis fields outside of the U.S.). Daily PRISM precipitation fields will be compared against the WRF daily spatial maps within the 12WUS2 domain and the New Mexico 4-km domain. The WRF performance for daily convective precipitations will be analyzed in particular as overstated summer convective precipitation can suppress ozone formation and its correct simulation is critically important for ozone modeling in New Mexico during the summer monsoon season. In the past WRF has had difficulty in accurately predicting the spatial extent and magnitude of the summer convective precipitation in the IMW region. Note that the PRISM precipitation interpolation scheme works better for synoptic weather systems than for convective showers that can be spotty and intermittent. So even though quantitative statistics can be calculated using the PRISM and WRF precipitation data, the evaluation will still be qualitative in nature as the PRISM interpolation scheme has greater uncertainties for convective precipitation.

6. PGM BASE YEAR INPUT PREPARATION PROCEDURES

This section summarizes the procedures to be used for developing the base case meteorological, emissions, and air quality inputs for the CAMx photochemical grid model and the summer 2014 modeling period. The modeling procedures used in the NM OAI Study modeling are consistent with almost 30 years of EPA ozone modeling guidance documents (e.g., EPA, 1991; 1999; 2005a; 2007; 2014d; 2018d), past modeling studies of the western U.S. conducted by WRAP and others (see, for example, Morris et al., 2004a,b, 2005a,b; 2007; 2008a,b,c; Tesche et al., 2005a,b; Stoeckenius et al., 2009; ENVIRON, Alpine and UNC, 2013; Adelman, Shankar, Yang and Morris, 2014; 2016), Denver 8-hour ozone SIP modeling (Morris and Mansell, 2003a; Morris et al., 2004d; Morris et al., 2008a,b; Ramboll and Alpine, 2016a,b; 2017a; RAQC and CDPHE, 2017) as well as the methods used by EPA in support of their recent Transport analysis (EPA, 2010; 2015b, EPA, 2016c) and national regional haze modeling (EPA, 2019).

6.1 Meteorological Inputs

Procedures for WRF meteorological modeling for the NM OAI Study 2014 36/12/4-km applications were described in Chapter 5. The WRF meteorological model output data will be processed to provide inputs for the CAMx photochemical grid model.

6.1.1 WRFCAMx Processing of 2014 WRF Output

The WRFCAMx processor maps WRF meteorological fields to the format required by CAMx. It also calculates turbulent vertical exchange coefficients (Kz) that define the rate and depth of vertical mixing in CAMx. Steps in the WRFCAMx processing include:

- Reading in meteorological model output files;
- Extracting meteorological data for PGM domain;
- Collapsing meteorological data if coarser vertical resolution data is requested in the PGMs than used in WRF;
- Computing vertical diffusivities (Kz); and
- Output the meteorological fields in the formats used by CAMx.

Several options are available to derive vertical turbulent exchange coefficient (also known as: Kv, Kz or vertical diffusivity) fields from WRF output in WRFCAMx. When TKE (turbulent kinetic energy) is not available from the WRF output (as is the case with the YSU PBL selected WRF physics options), Kv fields are diagnosed from wind, temperature, and Planetary Boundary Layer (PBL) parameters in WRFCAMx. For this application the CMAQ-like Kv profile option was selected in WRFCAMx, although the YSU Kv profile options will also be investigated.

6.1.2 Treatment of Minimum Kv

The CAMx Kv_patch pre-processor program sets the minimum Kv value to 0.1 to 1.0 m^2/s depending on the amount urban land use category in grid cell in the lowest 100 m

of the atmosphere. This is done to account for the urban heat island effect that enhances vertical mixing through-out the day.

6.2 Emission Inputs

6.2.1 Available Emissions Inventory Datasets

The emissions inventories developed for the CAMx 2014 36/2/4-km base case modeling will be based on the WRAP/WAQS 2014v2 emissions inventory. Within the 36-km 36US North American and 12-km 12WUS2 western U.S. domains, the 2014v2 base case emissions developed by WRAP/WAQS will be used as is.

For the 4-km New Mexico domain, the WRAP/WAQS 2014v2 emissions will be reviewed by the NMED, who will provide updates as needed. For on-road mobile sources, the 4-km domain emissions will be based on MOVES2014 model, 2014 activity data and day-specific hourly gridded 2014 WRF meteorology run through SMOKE-MOVES.

6.2.2 Development of CAMx Emission Inputs

CAMx emission inputs will be generated mainly by the SMOKE and MEGAN emissions models. CAMx requires two emission input files for each day: (1) low level gridded emissions that are emitted directly into the first layer of the model from sources whose emissions are released at the surface with little or no plume rise; and (2) elevated point sources (stacks) with plume rise calculated from stack parameters and meteorological conditions. CAMx will be operated using version 6 revision 4 of the Carbon Bond chemical mechanism (CB6r4) (Yarwood et al., 2010).

A 2014 base case 4-km New Mexico domain emission inputs for CAMx and the May to August 2014 modeling period will be based on the WRAP/WAQS 2014v2 emissions that were based on the 2014NEIv2 with updates provide by the western states. The New Mexico emissions from the 2014v2 database will be reviewed by the NMED who will provide updates as needed. The 2014v2 emissions for New Mexico and portions of surrounding states within the 4-km New Mexico domain will be processed by the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system (UNC, 2015). SMOKE version 4.7 is the current version of SMOKE that was released in October 2019.[51]

6.2.2.1 Day-Specific On-Road Mobile Source Emissions

The 2014 on-road mobile source emission inputs for the 4-km New Mexico domain will be generated using the SMOKE-MOVES emissions model. SMOKE-MOVES will use a 2014 mobile source emission factor (EF) lookup table generated by the Motor Vehicle Emission Simulator (MOVES2014[52]) model (EPA, 2014a,b,c). The SMOKE-MOVES default county-level 2014 vehicle activity data for New Mexico will be reviewed by NMED and updated as needed. SMOKE-MOVES uses the 2014 MOVES EF lookup table, hourly gridded 4-km meteorological data from the 2014 WRF simulation conducted in this study and 2014 county-level activity data (e.g., vehicle miles travelled [VMT],

[51] https://www.cmascenter.org/smoke/

[52] http://www.epa.gov/oms/models/moves/#user

speed, etc.) to generate 2014 day-specific hourly gridded on-road mobile source emission inputs for CAMx and the 4-km New Mexico domain.

6.2.2.2 Point Source Emissions

2014 point source emissions will be based on the WRAP/WAQS 2014v2 emissions inventory. The 2014v2 New Mexico point source emissions will be reviewed by NMED and updated a needed. Point sources will be processed in two streams: (1) major point sources with Continuous Emissions Monitoring (CEM) devices, which are primarily fossil-fueled Electrical Generating Units (EGU) with capacity of 25 MW or greater; and (2) point sources without CEMs. For point sources with CEM data, day-specific hourly NO_X and SO_2 emissions will be used for the 2014 base case emissions scenario. The VOC, CO and PM emissions for point sources with CEM data will be based on the annual data in the 2014v2 inventory temporally allocated to each hour of the year using the CEM hourly heat input. The hourly CEM data available in the Acid Rain database on the EPA Clean Air Market Division (CAMD) website fills hours with missing CEM data with maximum potential to emit (PTE) emission rates and flags the data. This is because the purpose of the Acid Rain database is to assure that the source is not emitting higher emissions than its cap. Using PTE emissions rates is inappropriate for PGM modeling since the goal is to be accurate. Thus, a data filling program is used that uses the missing data flags to identify hours when the data filled PTE emissions occur, and they are replaced with typical emission rates.

For all point sources the locations of the point sources will be converted to the LCC coordinate system used in the modeling. Non-CEM point sources will be processed by SMOKE to generate the temporally varying (i.e., seasonal, day-of-week and hour-of-day) speciated emissions needed by CAMx. The 2014 point source emissions without CEM data will be processed using SMOKE using the default temporal (e.g., monthly, day-of-week and hourly) and speciation profiles.

6.2.2.3 Area and Non-Road Source Emissions

The 2014v2 area and non-road sources will be spatially allocated to the 4-km New Mexico grid using an appropriate surrogate distribution (e.g., population for home heating, etc.). The area sources will be temporally allocated by month and by hour of day using the SMOKE source-specific temporal allocation factors. The SMOKE source-specific CB6r4 speciation allocation profiles will also be used.

6.2.2.4 Episodic Biogenic Emissions

Biogenic emissions will be generated using Version 3.1 of the MEGAN biogenic emissions model. MEGAN uses high resolution GIS data on plant types and biomass loadings and the 2014 WRF surface temperature fields, and solar radiation to develop hourly emissions for biogenic species on the 36/12/4-km grids. MEGAN generates gridded, speciated, temporally allocated emission files. The MEGAN biogenic emissions will be used for the 36-km 36US, 12-km 12WUS2 and 4-km New Mexico modeling domains. Note that the BEIS biogenic emissions were used in the WRAP/WAQS 2014v2 modeling platform. WRAP/WAQS conducted sensitivity tests using MEGAN v3.0 and BEIS biogenic emissions and found they produced comparable ozone estimates (because the isoprene emissions were similar), but CAMx with BEIS has better Organic

Aerosol (OA) performance[53] than CAMx with MEGAN v3.0 biogenic emissions so WAQS selected BEIS. Since then MEGAN has been updated to version 3.1 and the CAMx OA performance is now similar using MEGAN v3.1 and BEIS.

6.2.2.5 Wildfires, Prescribed Burns, Agricultural Burns

2014 emissions from open-land burning including wildfires, prescribed burns and agricultural burning will be based on the WRAP/WAQS 2014v2 emissions inventory. The WRAP Fire and Smoke Work Group (FSWG[54]) processed the 2014NEIv2 Bluesky/SMARTFIRE fire emissions for the U.S. and classified them as either wildfires (WF), prescribed burns (Rx) or agricultural burning (Ag) and made other updates for the 2014v2 inventory. The 2014NEIv2 fire emissions for Mexico and Canada will be used as is.

6.2.2.6 Other Natural Emissions

Lightning NO_x (LNOx), oceanic sea salt (SSA) and dimethyl sulphide (DMS) and windblown dust (WBD) emissions will be generated using special CAMx processors and WRF 2014 meteorological data.

6.2.2.7 QA/QC and Emissions Merging

The emissions for the 4-km New Mexico domain will be processed by major source category in several different "streams", including area sources, on-road mobile sources, non-road mobile sources, biogenic sources, non-CEM point sources, CEM point sources using day-specific hourly emissions, and emissions from fires. Separate Quality Assurance (QA) and Quality Control (QC) will be performed for each stream of emissions processing and in each step following the procedures developed by WRAP (Adelman, 2004). SMOKE includes advanced quality assurance features that include error logs when emissions are dropped or added. In addition, we will generate visual displays that include:

- Spatial plots of the hourly emissions for each major species (e.g., NO_X, VOC, and CO).
- Summary tables of emissions for major species for each grid and by major source category.
- This QA information will be examined against the original point and area source data and summarized in an overall QA/QC assessment.

Scripts to perform the emissions merging of the appropriate biogenic, on-road, non-road, area and low-level point sources (i.e., point sources with little or no plume rise so they are released into the first layer of the PGM) emission files will be written to generate the CAMx-ready two-dimensional day and domain-specific hourly speciated gridded emission inputs. The point source and fire, emissions would be processed into the day-specific hourly speciated emissions in the CAMx-ready point source format.

[53] http://views.cira.colostate.edu/iwdw/docs/waqs_2014v1_shakeout_study.aspx

[54] https://www.wrapair2.org/FSWG.aspx

For the 36/12-km domains we plan on using the model-ready emissions from the WRAP/WAQS 2014v2 modeling platform, with the exception of biogenic emissions where we would replace the BEIS biogenic emissions with those from MEGAN.

The resultant CAMx model-ready emissions will be subjected to a final QA using spatial maps to: (1) assure that the emissions were merged properly and CAMx inputs contain the same total emissions; and (2) provide additional QA/QC information.

6.2.2.8 Use of the Plume-in-Grid (PiG) Subgrid-Scale Plume Treatment

CAMx includes a Plume-in-Grid (PiG) sub-model treats the early plume chemistry and dynamics of emissions from point sources and then releases the emissions into the grid model farther downwind at such time that the plume is adequately resolved by the grid. Large NO_X emissions point sources within the 4-km New Mexico domain will be selected for treatment by the subgrid-scale PiG module. The selection of which sources to be treated by the PiG module will be made after a review of the inventory.

6.2.2.9 QA/QC of Model-Ready Emissions

In addition to the CAMx-ready emission input files generated for each hour of all days modeled in the May-August 2014 modeling period, a number of quality assurance (QA) files will be prepared and used to check for gross errors in the emissions inputs. Importing the model-ready emissions into PAVE or VERDI and examine both the spatial and temporal distribution of the emission to investigate the quality and accuracy of the emissions inputs.

- Visualizing the model-ready emissions with the scale of the plots set to a very low value, we can determine whether there are areas omitted from the raw inventory or if emissions sources are erroneously located in water cells;
- Spot-checking the holiday emissions files to confirm that they are temporally allocated like Sundays;
- Producing pie charts emission summaries that highlight the contribution of each emissions source component (e.g. non-road mobile);
- Normalizing the emissions by population for each state will illustrate where the inventories may be deficient and provide a reality check of the inventories.

State inventory summaries prepared prior to the emissions processing will be used to compare against SMOKE output report totals generated after each major step of the emissions generation process. To check the chemical speciation of the emissions to CB6 species, we will compare reports generated with SMOKE to target these specific areas of the processing. For speciation, the inventory state import totals will be compared against the same state totals with the speciation matrix applied.

The quantitative QA analyses often reveal significant deficiencies in the input data or the model setup. It may become necessary to tailor these procedures to track down the source of each major problem. As such, one can only outline the basic quantitative QA steps that we will perform in an attempt to reveal the underlying problems with the inventories or processing.

6.3 Photochemical Model Inputs

6.3.1 PGM Science Configuration and Input Configuration

This section describes the CAMx configuration and science options to be used in the NM OAI Study ozone modeling. Table 6-1 summarizes the CAMx configuration to be used, with more details provided below.

6.3.1.1 PGM Model Versions

The latest version 7.0 (v7.0) of CAMx will be used in the NM OAI Study. This is the same version as used in the WRAP/WAQS 2014v2, Representative Baseline and 2028 On-the-Books (OTB) modeling as well as EPA in their national Regional Haze modeling (EPA, 2019). The model will be configured to predict both ozone and PM species.

6.3.1.2 PGM Grid Nesting Strategy

CAMx will be operated using the 36/12/4-km nested grid structure using two-way grid nesting for all simulations.

6.3.1.3 Initial and Boundary Conditions

Boundary Conditions for the CAMx most outer 36-km 36US modeling domain will be based on output from a 2014 simulation of the GEOS-Chem global chemistry conducted by WRAP for their 2014v2 modeling platform. For their 2014v1 modeling platform WRAP used BCs based on EPA's 2014 GEOS-Chem simulation. EPA's 2014 modeling platform was used in the 2014 National Air Toxics Assessment (NATA[55]). However, EPA's 2014 BCs produced a large sulfate overestimation bias in June and July and a year-round ozone overestimation bias. So, WRAP conducted their own 2014 GEOS-Chem modeling to generate new BCs that did not have those problems.

CAMx will be started on May 1, 2016 using the 36/12/4-km domains that will give it over two-weeks to initialize the model before the first high ozone day on May 17, 2014.

6.3.1.4 Other PGM Model Options

The CAMx model options and setup are defined in Table 6-1. The PPM advection solver (Colella and Woodward, 1984) will be used for horizontal transport along with the spatially varying (Smagorinsky) horizontal diffusion approach. K-theory will be used for vertical diffusion. The CB6r4 gas-phase chemical mechanism is selected because it includes the very latest chemical kinetic rates with halogen chemistry that affects ozone levels over the ocean. The latest aerosol mechanism will be used in CAMx along with the standard wet and dry deposition schemes. The Plume-in-Grid module will be used to treat the near-source chemistry and dispersion of major NO_X emissions sources in the New Mexico 4-km domain. For the future year modeling the same point sources will be selected for the plume-in-grid treatment, if they are still operating.

[55] https://www.epa.gov/national-air-toxics-assessment

Table 6-1. CAMx model configuration for the NM OAI Study.

Science Options	CAMx	Comment
Model Codes	CAMx v7.0	Latest version of CAMx used in WRAP/WAQS 2014v2 and EPA Regional Haze modeling
Horizontal Grid Mesh	36/12/4-km	
36-km grid	148 x 112 cells	36US domain
12-km grid	227 x 215 cells	12WUS2 domain. Includes buffer cells
4-km grid	245 x 227 cells	New Mexico 4-km domain. Includes buffer cells
Vertical Grid Mesh	25 vertical layers, defined by WRF	Layer 1 thickness ~20 m. Model top at 50 mb (~19 km)
Grid Interaction	36/12/4 km two-way nesting	
Initial Conditions	Start on May 1, 2014	First high ozone day is May 17, 2014
Boundary Conditions	WRAP 2014 GEOS-Chem	For 36US domain
Emissions		
Baseline Emissions Processing	SMOKE, SMOKE-MOVES2014, MEGAN	WRAP/WAQS 2014v2 emissions and EPA 2023fh for future year
Sub-grid-scale Plumes	Plume-in-Grid for major NO_X sources in New Mexico	Keep same PiG sources in 2014 and 2023 emission years
Chemistry		
Gas Phase Chemistry	CB6r4	Latest chemical reactions and kinetic rates with halogen chemistry (Yarwood et al., 2010)
Meteorological Processor	WRFCAMx	Compatible with CAMx v7.0
Horizontal Diffusion	Spatially varying	K-theory with Kh grid size dependence
Vertical Diffusion	CMAQ-like Kv	Evaluate YSU Kv scheme
Diffusivity Lower Limit	Kv-min = 0.1 to 1.0 m^2/s in lowest 100 m	Depends on urban land use fraction
Deposition Schemes		
Dry Deposition	Zhang dry deposition scheme	(Zhang et. al, 2001; 2003)
Wet Deposition	CAMx -specific formulation	rain/snow/graupel
Numerics		
Gas Phase Chemistry Solver	Euler Backward Iterative(EBI)	EBI fast and accurate solver
Vertical Advection Scheme	Implicit scheme w/ vertical velocity update	Emery et al., (2009a,b; 2011)
Horizontal Advection Scheme	Piecewise Parabolic Method (PPM) scheme	Colella and Woodward (1984)
Integration Time Step	Wind speed dependent	~0.5-1 min (4-km), 1-5 min (12-km), 5-15 min (36-km)

7. 2014 BASE CASE MODELING AND MODEL PERFORMANCE EVALUATION

This Chapter describes the CAMx 2014 base case simulations and procedures for model performance evaluation (MPE). The primary purposes of the MPE is to establish the reliability of the CAMx 2014 base case modeling for predicting maximum daily average 8-hour (MDA8) ozone and related concentrations in New Mexico to have confidence that the modeled ozone responses to changes in emissions within New Mexico are accurate enough for air quality planning. The CAMx 2014 base case model estimates are compared against the observed ambient ozone and other concentrations to establish that the model is able to reproduce the current year observed concentrations, so it is likely a reliable tool for estimating future year ozone levels. The model performance evaluation will include many types of graphical and statistical comparisons of the predicted and observed ozone concentrations including spatial plots, scatter plots and time series analysis.

7.1 2014 Base Case Modeling

A CAMx 2014 May-August 36/12/4-km base case simulation will be performed following the procedures outlined in the previous Chapters. The CAMx 2014 base case simulations will then be subjected to a model performance evaluation following the procedures outlined in this Chapter.

7.2 EPA Model Performance Evaluation Recommendations

7.2.1 Overview of EPA Model Performance Evaluation Recommendations

EPA's ozone modeling guidance (EPA, 2018d) describes a MPE framework that has four components:

- Operation Evaluation: The Operation Evaluation compares the modeled concentration estimates against concurrent observations using statistical and graphical analysis aimed at determining how well the model simulates the base year observed concentrations (i.e., does the model get the right answer).
- Diagnostic Evaluation: The Diagnostic Evaluation evaluates various components of the modeling system. It focuses on process-oriented evaluation and whether the model simulates the important processes for the air quality problem being studied (i.e., does the model get the right answer for the right reason).
- Dynamic Evaluation: The ability of the model's air quality predictions to correctly respond to changes in emissions and meteorology is part of the Dynamic Evaluation. This can include running the model for historical years to see whether the model's predictions match the changes in observations; comparison of model performance on weekdays versus weekend days can also help elucidate whether the model response to changes in emissions correctly.
- Probabilistic Evaluation: The Probabilistic Evaluation assess the level of confidence in the model predictions and estimates model uncertainty through techniques such as ensemble model simulations.

EPA's guidance recommends that "At a minimum, a model used for air quality planning should include a complete operational MPE using all available ambient monitoring data for the base case model simulations period" (EPA, 2018d, pg. 68). And goes on to say, "Where practical, the MPE should also include some level of diagnostic evaluation." EPA notes that there is no single definite test for evaluating model performance, but instead there are a series of statistical and graphical MPE elements to examine model performance in as many ways as possible while building a "weight of evidence" (WOE) that the model is performing sufficiently well for the air quality problem being studied.

7.2.2 WRAP/WAQS Companion Model Performance Evaluation

The WRAP/WAQS has conducted CAMx 2014v2 36/12-km base case modeling and MPE. The MPE of the WRAP/WAQS 2014v2 platform results will be used to help interpret the NM OAI Study MPE and put it into context.

7.3 Overview of Evaluation of CAMx 2014 Base Case Procedures

This section describes the procedures for evaluating the performance of the CAMx model focusing on ozone and related species in New Mexico.

7.3.1 Photochemical Model Evaluation Methodology

The CAMx performance evaluations will follow the procedures recommended in the EPA photochemical modeling guidance documents (EPA, 1991; 1999; 2005a; 2007; 2014d; 2018d), EPA MPE Checklist (EPA, 2015a,b), procedures discussed by Boylan and Russell (2006), Simon, Baker and Phillips (2012) and Emery and co-workers (2016). The NM OAI Study CAMx 2014 MPE will be conducted in a series of levels with each level diving more deeply into the MPE. An initial performance would focus on ozone performance at key monitors in New Mexico in 2014 to identify systematic problems that would require immediate corrective action. The MPE would then be expanded to ozone and ozone precursors across New Mexico and nearby states, especially those portions within the 4-km New Mexico domain. Finally, a broad-brush evaluation would be conducted across the western U.S. for ozone and where available its precursors.

7.3.2 Model Performance Goals and Benchmarks

EPA first proposed the use of ozone model performance goals in their 1991 ozone modeling guidance (EPA, 1991) with goals for bias (≤±15%) and error (≤35%). Since then, EPA has de-emphasized the use model performance goals as some users were focusing on achieving the model performance goals not on whether the model was accurately simulating atmospheric processes that led to the high ozone concentrations. However, model performance goals are still useful for interpreting model performance and putting the model performance into context. Since the EPA 1991 ozone guidance performance goals, Boylan and Russell (2006) extended the performance goals to PM species and visibility. Simon, Baker and Phillips (2012) summarized the model performance statistics from 69 PGM applications from 2006 to 2012 and found lots of variability but were able to isolate model performance statistical levels for the best performing models.

Emery et al., (2016) built off the work of Simon, Baker and Phillips (2012) adding additional PGM model applications and coming up with a set of PGM model performance

goals and criteria based on the variability in the past PGM model performance. "Goals" indicate statistical values that about a third of the top performance past PGM applications have met and should be viewed as the best a model can be expected to achieve. "Criteria" indicates statistics values that about two thirds of past PGM applications have met and should be viewed as what a majority of the models have achieved. We will compare the CAMx 2014 base case simulations model performance statistics for normalized mean bias (NMB), normalized mean error (NME) and correlation coefficient (r) against the model performance goals and criteria summarized by Emery et al., (2016) that are given in Table 7-1.

Table 7-1. Recommended benchmarks for photochemical model statistics (Source: Emery et al., 2016).

Species	NMB		NME		r	
	Goal	Criteria	Goal	Criteria	Goal	Criteria
1-hr & MDA8 Ozone	<±5%	<±15%	<15%	<25%	>0.75	>0.50
24-hr $PM_{2.5}$, SO_4, NH_4	<±10%	<±30%	<35%	<50%	>0.70	>0.40
24-hr NO_3	<±15%	<±65%	<65%	<115%	NA	NA
24-hr OC	<±15%	<±50%	<45%	<65%	NA	NA
24-hr EC	<±20%	<±40%	<55%	<75%	NA	NA

7.3.3 Available Aerometric Data for the Evaluations

The following monitoring networks were operating in 2014 so these data that can be used in the MPE.

EPA AQS Surface Air Quality Data: Data files containing hourly-averaged concentration measurements at a wide variety of state and EPA monitoring networks are available in the Air Quality System (AQS[56]) database throughout the U.S. Typical surface measurements at the ground level routine AIRS monitoring stations include ozone, NO_2, NO_X and CO.

IMPROVE Monitoring Network: The Interagency Monitoring of Protected Visual Environments (IMPROVE[57]) network collects 24-hour average $PM_{2.5}$ and PM_{10} mass and speciated $PM_{2.5}$ concentrations at many sites across the U.S. on a 1:3 day sampling frequency, including most Class I areas.

CSN Monitoring Network: The Chemical Speciation Network (CSN[58]) collects 24-hour average speciated $PM_{2.5}$ components on a 1:3 or 1:6-day sampling frequency. CSN monitoring sites tend to be urban oriented as compared to IMPROVE sites that are typically rural.

[56] http://www.epa.gov/ttn/airs/airsaqs/aqsweb/
[57] http://vista.cira.colostate.edu/IMPROVE/
[58] http://www.epa.gov/ttnamti1/speciepg.html

FRM Monitoring Network: 24-hour total $PM_{2.5}$ mass is collected using the federal Reference Method (FRM[59]) on a 1:3-day sampling schedule.

CASTNet Monitoring Network: The Clean Air Status and Trends Network (CASTNet[60]) operates approximately 80 monitoring sites in mainly rural areas across the U.S. CASTNet sites typically collect hourly ozone and weekly speciated $PM_{2.5}$, including HNO3. There is one CASTNet site located in the northwest corner of New Mexico (Chaco Culture NHP), although there are several more within the 4-km New Mexico modeling domain in neighboring states (i.e., Colorado and Arizona).

NADP Network: The National Acid Deposition Program (NADP[61]) collects weekly samples of SO_4, NO_3 and NH_4 in precipitation (wet deposition). There are also some sites that collect daily samples as well as mercury.

7.4 Operational Evaluation

As noted above, the Operational Evaluation compares the modeled concentrations with concurrent observations. Various tools and graphical displays and statistical methods are used as part of the Operational Evaluation as discussed below.

7.4.1 Atmospheric Model Evaluation Tool (AMET)

The Atmospheric Model Evaluation Tool (AMET[62]) (Appel et al., 2011) is a suite of software designed to facilitate the analysis and evaluation of predictions from meteorological and air quality models. AMET matches the model output for grid cells with observations from monitoring site locations from one or more networks of monitors. AMET also does species mappings to map the modeled species to the corresponding observations. These pairings of values (model and observation) are then used to statistically and graphically analyze the model's performance using a variety of techniques, many of which will be used in the CAMx 2014 base case MPE. The latest version of AMET is version 1.4, but AMET website doesn't have any information on its release date or documentation so we assume the documentation for AMET v1.3[63] is pertinent for AMET v1.4.

7.4.2 Example Operational Model Performance Evaluation Products

Below we use the results from the 2016 Denver ozone SIP (RAQC and CDPHE, 2016) modeling MPE (Ramboll and Alpine, 2017) for the 2011 CAMx ozone modeling platform to illustrate the type of MPE products that will be produced in the NM OAI Study. Summary tables of ozone statistical model performance metrics across sites in New Mexico will be produced. Such ozone performance statistics can be calculated with and without observed cut-off concentrations as illustrated in the next section. AMET comes pre-loaded with observation data from multiple networks that were described previously:

[59] http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm
[60] http://java.epa.gov/castnet/
[61] http://nadp.sws.uiuc.edu/NADP/
[62] https://www.cmascenter.org/amet/
[63] https://www.cmascenter.org/help/documentation.cfm

- Air Quality System (AQS) network
- Clean Air Status and Trends Network (CASTNET)
- Interagency Monitoring of PROtected Visual Environments (IMPROVE)
- Mercury Deposition Network (MDN)
- National Atmospheric Deposition Program (NADP)
- South-Eastern Aerosol Research and Characterization Study (SEARCH)
- Chemical Speciation Network (CSN; formerly STN)

AMET will be the primary MPE tool used in the CAMx 2014 base case simulations augmented by other MPE tools as necessary. Some example MPE displays are described in the following sections.

7.4.2.1 Soccer Plots for Comparing Performance Statistics with Goals and Criteria

Soccer Plots display ozone (or other species) model performance statistics against model performance goals and/or criteria using a scatter plot, such as bias on the x-axis and error on the y-axis. When the statistics achieves the goal, it falls within the box outlined by the goals. For example, Figure 7-1 shows ozone monthly fractional bias and error (FB and FE) performance statistics against a 15% and 35% performance goal, respectively, for the 2011 CAMx base case from the 2016 Denver ozone SIP. The Soccer Plots are for hourly (right) and MDA8 (left) ozone using no (top) and a 60 ppb (bottom) cut-off concentration. Using Soccer Plots, it is easy to determine when the performance statistics are achieving the goals and as the symbols approach the (0,0) origin that indicates better model performance. Although the example in Figure 7-1 is for monthly performance, the different symbols could be for different monitoring sites, specific modeling days with ozone exceedance days, stratified by observed ozone concentrations or stratified by any other variable that provides insight into the MPE.

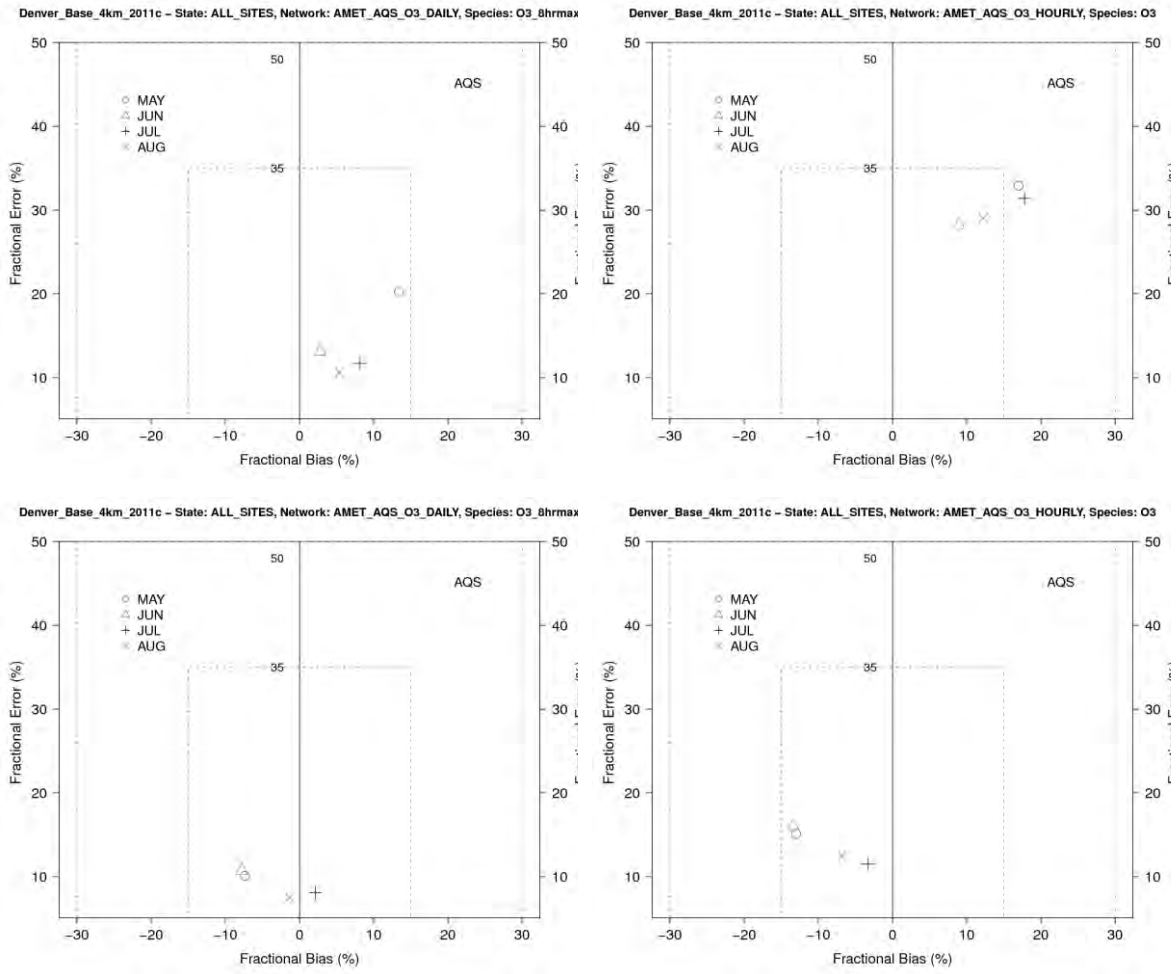

Figure 7-1. Example Soccer Plots of MDA8 (left) and hourly (right) ozone bias (FB) and error (FE) performance using no (top) and 60 ppb (bottom) observed ozone cut-off concentration (Source: Ramboll and Alpine, 2017).

7.4.2.2 Spatial Maps of Statistical Model Performance

AMET can generate spatial maps of different statistical performance metrics where the different colored symbols at the locations of monitoring sites allows an assessment of performance by geographic location. For example, Figure 7-2 displays the MDA8 ozone monthly bias (NMB) spatial plot from the CAMx 2011 base case simulation and shows an overestimation bias in May at many sites (yellow) with most of the sites achieving the <±15% performance goal for the other three months. The exception is the DMAS site in downtown Denver and the FTCO site in Fort Collins that are located close to mobile NOx emissions that titrate the ozone that is not reproduced by the model due to dilution of the local NOx emissions across a 4-km grid cell.

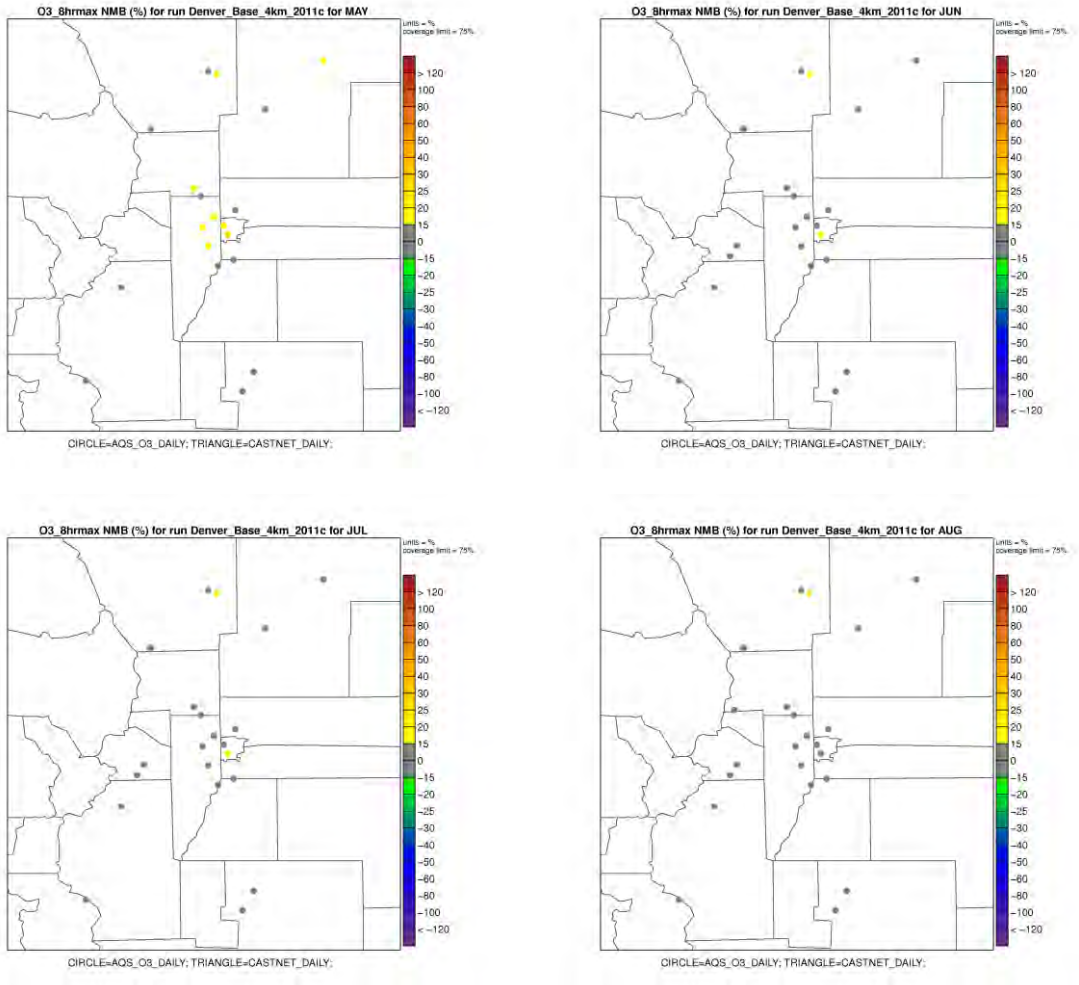

Figure 7-2. Spatial statistics plot of MDA8 monthly ozone model performance for Normalized Mean Bias (NMB), AQS sites in the Denver Metro/NFR NAA using no observed ozone cut-off concentration and May (top left), June (top right), July (bottom left) and August (bottom right) (Source: Ramboll and Alpine, 2017).

7.4.3 Scatter Plots of Model Performance

Scatter Plots are a main stay of MPE as they allow you to directly see the point-by-point comparison of predicted and observed concentrations. Figure 7-3 shows example MDA8 (left) and hourly (right) ozone scatter plots for July without (top) and with a 60 ppb observed ozone cut-off concentration from the CAMx 2011 base case simulations. In this case ozone performance for two different CAMX base cases are shown (red and blue symbols) and summary performance statistics are also displayed. The model has difficulty in predicting the lowest observed hourly ozone concentrations (see comment above on DMAS and FTCO ozone over-prediction bias), which appears to have little effect on MDA8 ozone MPE or hourly ozone performance when a 60 ppb observed ozone cut-off is used.

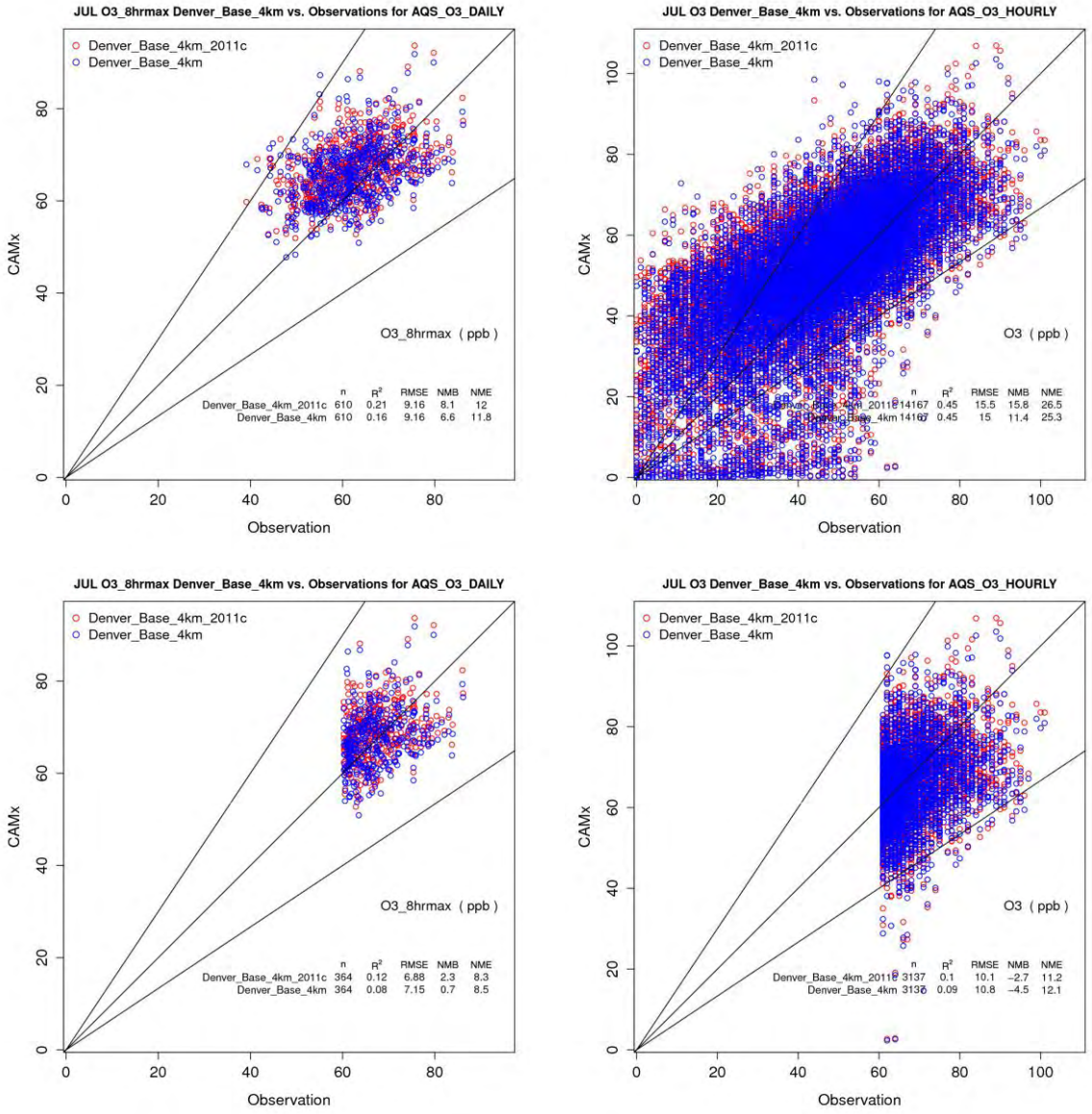

Figure 7-3. Scatter plots and model performance statistics for MDA8 (left) and hourly (right) ozone concentrations using no (top) and 60 ppb (bottom) observed ozone cut-off concentrations during the month of July (Source: Ramboll and Alpine, 2017).

7.4.4 Time Series of Predicted and Observed Concentrations

Time series of predicted and observed concentrations is another main stay of a MPE and focuses of the temporal evaluation of model performance at particular sites. For example, Figure 7-4 displays time series of predicted and observed July and August MDA8 ozone concentrations at the RFNO monitoring site for two CAMx 2011 base case simulations from 2016 Denver ozone SIP. These displays not only include the MDA8 ozone concentrations levels but the daily bias (i.e., different in the predicted and observed MDA8 ozone.

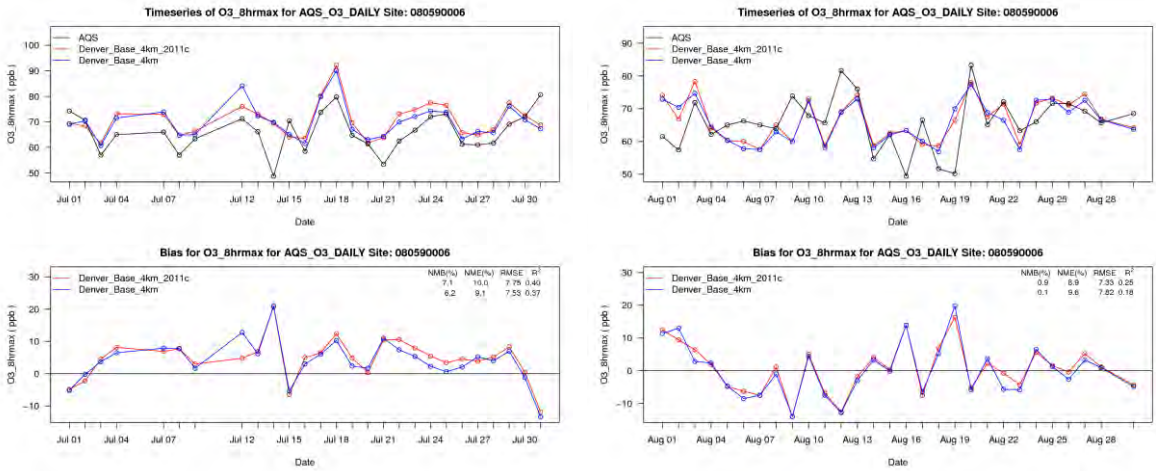

Figure 7-4. Time series of predicted and observed (black) MDA8 ozone concentrations (top panel) and bias (bottom panel) at Rocky Flats North (RFNO) for the preliminary 2011b1 (blue) and final 2011c (red) CAMx 4 km base case simulations and the months of July (left) and August (right) (Source: Ramboll and Alpine, 2017).

7.4.5 Evaluation for the Modeled MDA8 Ozone Concentrations

An important component of a PGM MPE is to evaluate the model for how well it predicts the modeled 10 highest MDA8 ozone concentrations because of the way the base and future year modeling results are used to project future year ozone DVs. The relative change in the base and future modeling results are used to project the current year observed ozone DVs to the future year. EPA's modeling guidance (EPA, 2018d) describes how to use the PGM modeling results to make the future year ozone DV projections with details presented in Chapter 8. The 10 highest base year modeled MDA8 ozone concentrations near a monitoring site are used to make the future year DV projections. It is desirable for the modeled MDA8 ozone concentrations on these 10 highest modeled base year ozone concentrations to match the observed MDA8 ozone concentrations on the same day sufficiently well. Thus, the model performance for the days used in the future year ozone DV projections are evaluated. As discussed in more detai8l in Chapter 8, alternative ozone DV projection techniques use the 10 highest modeled MDA8 ozone concentrations near a monitor just on those days in which the

modeled MDA8 ozone reproduces the observed MDA8 ozone with some performance criteria (e.g., < 10%. < 15%, < 20%).

7.5 Diagnostic Evaluation

The goal of the diagnostic evaluation is to assure that the model is simulating the correct physical and chemical processes that control the formation of ozone from the precursor emissions. Such processes include transport, dispersion, deposition and chemical transformation. The diagnostic evaluation investigates the processes that determine the ambient concentrations of ozone and related pollutants to develop confidence that the model's ozone response to changes in emissions will be accurate.

7.5.1 Base Year Base Case Diagnostic Sensitivity Tests

When developing a PGM base year base case model configuration, diagnostic sensitivity tests are frequently used to evaluate the sensitivity of the model to alternative inputs or model options in an effort to obtain a better performing base year base case simulation. For example, if two WRF base year simulations are available, the PGM could be run with both sets of WRF meteorological inputs to determine which one produces better performing PGM simulations. However, care must be taken that compensatory errors are not introduced.[64] For the NM OAI Study that is leveraging the WRAP/WAQS 2014v2 modeling platform, many diagnostic tests have already been performed so additional diagnostic sensitivity tests are likely not needed unless performance issues arise. The WRAP/WAQS modeling conducted the following diagnostic sensitivity tests that led to the 2014v2 base case CAMx configuration.

- Boundary Conditions (BC) Sensitivity: WRAP/WAQS initially used BCs based on EPA's 2014 GEOS-Chem simulation and found them inadequate so WRAP conducted their own 2014 GEOS-Chem simulation and generated BCs that greatly improved model performance.
- Vertical Mixing Sensitivity: This is a frequent sensitivity test to analyze alternative formulation of vertical mixing (Kz) formulations and the treatment of the minimum Kz near the surface that is especially important for cities where the urban heat island affects vertical mixing.
- Other Meteorological Sensitivity: The WRAP/WAQS evaluated the EPA's 2014 WRF meteorological simulations as input to CAMx and selected the WAQS 12-km data due to better precipitation model performance.
- Emissions Sensitivity: Increases or decreases in emissions (e.g., VOC and/or NO_x) from specific source categories or other emissions perturbation:
  - Top down studies have suggested oil and gas emissions may be under- or over-estimated.
  - Some studies have suggested MOVES mobile source NOx emissions may be overestimated, particularly in urban areas.
  - NO_x emissions are almost always produced by combustion so typically are hotter than ambient air so have some buoyancy and plume rise even if

[64] Compensatory errors can occur when two incorrect inputs compensate for each other so the PGM achieves seemingly good model performance, but for the wrong reason. For example, PGM modeling of Los Angeles in the late 1970s and early 1980s had a deficient VOC emissions inventory that was compensated for by overstated the Boundary Conditions.

emitted at the surface (e.g., mobile sources). By trapping them in the lowest layer (20-m in this case) it may overstate surface NO_x emissions. Emitting some of the NO_x in layer 2 may alleviate this condition, alternative the surface minimum Kz mixing parameter may also address this issue.

- Biogenic and lightning NO_x emissions are uncertain and the sensitivity to their estimates could be investigated.

- Other Sensitivity: In the development of the CAMx 2014 base case modeling platform we may find inputs or parameterizations that are uncertain how to define so warrant further investigation.

When the initial results of the CAMx 2014 base year base case MPE are obtained, they will be shared with NMED to determine a path forward and if additional sensitivity tests may be needed and as time and resource constraints allow.

7.5.2 Additional Diagnostic Evaluation Approaches

Diagnostic Evaluation of a PGM can use several different techniques to diagnose features regarding model performance, such as evaluation of how the model responds to changes in inputs or simulates specific processes important for simulating the air quality issue being studied. The CAMx is instrumented with "probing tools" that can explore attributes of the model during a simulation, including ozone and particulate source apportionment (OSAT/PSAT), Decoupled Direct Method (DDM) sensitivity and Process Analysis. The most common type of diagnostic evaluation involves using the Brute Force (BF) approach where a model base case and model perturbation case is performed, and the sensitivity of the model estimates are the differences in the output concentrations between the two BF runs.

The comparison of modeling results with observations for key indicator species can also be a useful diagnostic evaluation technique. Section 3.4.2 of EPA's PGM modeling guidance list several species indicator ratios that suggest whether the atmosphere and/or model ozone formation is more VOC-limited or NO_x-limited (EPA, 2018a, pp. 92-95). However, many of these indicator ratios involve species not routinely measured and may require more precision than typically obtained.

Although a comprehensive diagnostic sensitivity analysis may not be possible given resource and time constraints, some elements of a Diagnostic Evaluation is expected to occur.

7.6 Dynamic Evaluation

The Dynamic Evaluation evaluates a PGM for the way it is primary used in an ozone SIP as it evaluates how well the modeled ozone response to emissions changes with observed responses. The most comprehensive dynamic evaluation is to compare model responses to observed historical changes in ozone concentrations in a retrospective analysis. Because differences in meteorology between years can have as much or even more effect on observed ozone concentrations, such dynamic evaluation could include not only running with different historical years of emissions, but also running with different historical years of meteorology. Thus, this kind of retrospective analysis dynamic evaluation can be quite resource and time intensive. The WRAP/WAQS is

conducting a Dynamic Evaluation of their 2014v2/RepBase modeling platform by back casting 2014v2 emissions to 2002 and comparing the changes in observed and modeled concentrations form a past year (2002), to a current year (2014 and RepBase) that can be potentially used as a Dynamic Evaluation in the NM OAI Study.

Another dynamic evaluation approach that is not as resource intensive as a retrospective modeling analysis is to stratify the operational model performance under varying conditions, such as day-of-week (e.g., weekday vs. weekend day), by season or by region. When the model shows the same ozone response as observed across these different chemical regimes, it supports the assertion that the modeled ozone concentrations would respond correctly to changes in emissions over time.

7.6.1 Probabilistic Evaluation

The probabilistic evaluation attempts to assess the level of confidence in the model predictions through techniques such as ensemble of model simulations. At this time, there are no plans to incorporate the probabilistic evaluation as part of the NM OAI Study.

8. FUTURE YEAR MODELING

This Chapter describes the 2023 future year modeling to evaluate source contributions to ozone concentrations in New Mexico and potential control strategies designed to reduce ozone.

8.1 Future Year to be Modeled

There is no Federal regulation guiding the NM OAI Study future year modeling. Thus, we selected the 2023 future year due to the available of EPA's 2023fh emissions inventories developed as part of the EPA 2016v1 modeling platform. EPA also developed a 2028fh emissions that is too far out in the future and portions of a 2020 emissions inventory that is too current. Thus, the 2023 future year seemed an ideal choice for the NM OAI Study.

8.2 Future Year Emissions

2023 future year anthropogenic emissions will be used in the future year modeling. The following natural emission sources will be assumed to remain unchanged from 2014 base year base case levels:

- Biogenic emissions.
- Lighting NOx emissions.
- Ocean Sea Salt and DMS emissions.
- Windblown Dust.
- Open Land Fires (Wildfires, Prescribed Burns and Agricultural Burning).

8.2.1 2023 Future Year Anthropogenic Emissions

The primary source of the 2023 future year anthropogenic emissions is the 2023fh emission projections from the joint EPA/MJO 2016 emissions inventory collaborative development study. EPA's 2016v1 modeling platform included model-ready 2023 emissions for the 36/12-km domains that can be used "as is" for the NM OAI Study except for on-road mobile source emissions that were developed using SMOKE-MOVES and the 2016 meteorological conditions. For the 12-km 12WUS2 domain we will run SMOKE-MOVES using the 2023 MOVES EF Look-Up table, 2023 vehicle activity and the 2014 WRF meteorological conditions.

For the 4-km New Mexico domain, the EPA 2023fh New Mexico emissions will be reviewed and updated by NMED as needed and processed with SMOKE to generate 4-km resolution emission inputs for the 4-km New Mexico domain. The 2023 MOVES inputs and 2023 vehicle activity data will also be reviewed and updated by NMED as needed and SMOKE-MOVES run using the 2023 MOVES EF Look-Up table, 2023 vehicle activity and 4-km hourly gridded WRF data to generate 2023 on-road mobile emission inputs.

8.2.2 Future Year Emissions Quality Assurance

Similar QA/QC procedures (e.g., as described in Adelman, 2004; UNC, 2018; EPA, 2018a) will be performed on the future year model-ready emissions inventories as were utilized in checking the base year datasets described previously. Standard inventory assessment methods will be employed to generate the future year emissions data including, but not limited to: (a) visualizing the model-ready emissions graphically, (b) spot-checking the holiday emissions files to confirm that they are temporally allocated like Sundays, (c) producing pie charts emission summaries for each source category, and (d) normalizing the emissions by population for each state to reveal where the future year inventories may be suspect. Of particular importance will be the comparison of the 2014 base year and 2023 future year emissions by source category and region to make sure the expected changes occurred in the modeling inventories.

8.3 Future Year CAMx Modeling

The 2023 future year CAMx base case modeling will be performed the same way that the 2024 base year base case modeling was performed only using the 2023 future year anthropogenic emissions. The CAMx PGM will be applied on the 36/12/4-km nested grid domain structure using two-way grid nesting. Due to uncertainties in global emissions, the BCs based on the WRAP 2014 GEOS-Chem simulation will also be used for 2023.

Future year ozone DV projections will be made using the 2014 base case and 2023 future year CAMx simulation outputs following the procedures given in Chapter 9 that use EPA's latest 8-hour ozone modeling guidance (EPA, 2018d).

8.3.1 Future Year Ozone Source Apportionment Modeling

The CAMx Anthropogenic Precursor Culpability Assessment (APCA) version of the Ozone Source Apportionment Technology (OSAT) will be used to estimate 2023 future year contributions of emissions from U.S. and international anthropogenic emissions and natural emissions from different geographic regions on ozone concentrations in New Mexico. A 2023 future year CAMx 36/12/4-km nested grid simulations will be conducted using geographic source regions defined by New Mexico and other nearby state boundaries and separating anthropogenic sources from natural sources. Fires would also be treated as a separate source category. The CAMx 2023 future year ozone source apportionment modeling will also provide separate contributions by Source sector for emissions in New Mexico and outside New Mexico as follows:

- Upstream Oil and Gas.
- Midstream Oil and Gas.
- EGU Point.
- Non-EGU Point.
- On-Road Mobile.
- Non-Road Mobile.
- Other Anthropogenic.

- Fires (WF, Rx and Ag).
- Natural
- BC from International Anthropogenic Emissions.
- BC from US Anthropogenic Emissions.
- BC from Natural Sources.
- Initial Concentrations.

The exact definition of the 2023 ozone source apportionment modeling will be documented and provided to NMED for review and refinements later in the NM OAI Study.

8.3.2 Future Year Sensitivity and Control Strategy Simulations

2023 future year control strategy sensitivity simulations will be conducted. The definitions for the 2023 control strategy sensitivity scenarios will be provided by NMED at a later date,

9. FUTURE YEAR OZONE PROJECTIONS

EPA's latest ozone State Implementation Plan (SIP) modeling guidance (EPA, 2018d) contains detailed procedures for how to use base year and future year photochemical grid model (PGM) modeling results to make future year ozone Design Value (DV) projections. The EPA-recommended ozone attainment demonstration includes a model attainment test for projecting base year ozone DVs to the future year and a weight of evidence (WOE) analysis used to confirm and corroborate the modeled attainment demonstration test. EPA has developed the Speciated Modeled Attainment Test (SMAT[65]) tool that includes the EPA (2018d) recommended procedures for projecting ozone DVFs.

9.1 EPA Recommended Future Year Ozone DV Projection Procedures

The procedures for making future year ozone DV projections are outlined in Chapter 4 of EPA's latest ozone modeling guidance (EPA, 2018d, pp. 99-110). EPA recommends using PGM modeling results in a relative fashion the scale base year ozone DV (DVB) to estimate the future year ozone DV (DVF). The model derived scaling factors are called Relative Response Factors (RRF) and are the ratio of future to base year ozone modeling results.

$$DVF = DVB \times RRF$$

Below we highlight the key elements in EPA's recommended ozone DV projection approach, more details and justification for the approach are provided in EPA's modeling guidance (EPA, 2018d).

9.1.1 Base Year Ozone Design Value (DVB)

The DVB is defined as the average of three-years of ozone DVs centered on the base modeling year. As an ozone DV is defined as the three-year average of the 4th highest MDA8 ozone concentrations at a monitor, the DVB is based on 5 years of 4th highest MDA8 ozone concentrations centered on the base year so the highest weight (3x) is on the 4th highest MDA8 ozone for the base year with less weights in the 2 years before and after the base year (i.e., weighting factors of 1, 2, 3, 2, 1).

For the NM OAI Study modeling, the base year is 2014 so that the DVB at each site will be defined from three years of ozone DVs as follows:

$$DVB_{2014} = (DV_{2012\text{-}2014} + DV_{2013\text{-}2015} + DV_{2014\text{-}2016}) / 3$$

9.1.2 Calculation of Relative Response Factors (RRFs)

The RRF is defined as the ratio of the average of the PGM future year (FY) to base year (BY) MDA8 ozone concentrations near the monitor for the 10 days with the -highest base year modeled MDA8 ozone concentrations near the monitoring site.

[65] https://www.epa.gov/scram/photochemical-modeling-tools

$$RRF = \sum MDA8\ Ozone_{FY} / \sum MDA8\ Ozone_{BY}$$

Near the Monitor: By near the monitor, the highest modeled base year MDA8 ozone is selected in a 3x3 array of grid cells centered on the monitor is used. For the future year, the future year MDA8 ozone is selected from the same grid cell in the 3x3 array centered on the monitor as used in the base year.

10 Highest Base Year MDA8 Ozone Days: The RRF is based on the 10 days with the highest base year modeled MDA8 ozone concentrations near the monitor, provided the base year MDA8 ozone is greater or equal to 60 ppb. If there are less than 10 days with base year MDA8 ≥ 60 ppb, then just the days ≥ 60 ppb are used provided there are at least 5 days. If there are less than 5 days with base year MDA8 ozone ≥ 60 ppb EPA recommends that RRFs not be calculated for that site.

9.1.3 Flexibility in RRF Calculations

EPA's modeling guidance includes the flexibility to modify the recommended ozone DV projection procedure. For example, there may be a reason that grid cells in the 3x3 array centered on the monitor may not be representative of conditions at the monitor. For example, if a grid cell is dominated by water so has different mixing characteristics or the monitor is in an area with sharp terrain gradients.

There may be also reasons that one of the highest 10 base year MDA8 ozone days should not be used in the RRF. For example, if the modeled base year MDA8 ozone is highly influenced by emissions from wildfires it could be excluded and then the next highest modeled MDA8 ozone included so that 10 modeled days are still used in the RRF.

The PGM model performance on the 10 highest modeled MDA8 ozone days may also be considered in selected the top 10 modeled MDA8 ozone days to use in the RRFs.

9.2 Unmonitored Area Analysis (UAA)

An unmonitored area analysis (UAA) will be conducted using the SMAT tool. The UAA first interpolates the ozone DVB to each 4-km grid cell in the New Mexico 4-km domain. The interpolation will be done with and without accounting for modeled concentration gradients. Once a gridded field of ozone DVB is obtained, the ozone DVB are projected to the future using the same procedures as used in the modeled attainment test only the modeling results at the grid cell containing the monitor is used and there is typically some relaxation of the requirement for MDA8 ozone to be above 60 ppb since the UAA is making projections in fairly clean ozone concentrations regions. The gridded future year ozone DVFs are then analyzed to determine locations with grid cells that exceed the ozone NAAQS. Note that estimate locations of ozone DVFs above the ozone NAAQS in the UAA does not necessarily imply a failure to demonstrate attainment. For example, when modeled concentration fields are used in the UAA ozone DVB interpolation frequently at locations of wildfires the ozone DVB and DVF are above the NAAQS. But any UAA ozone DVF exceedances of the NAAQS should be identified and explained in the analysis.

9.3 Weight of Evidence (WOE) Attainment Demonstration

The Weight of Evidence (WOE) is a necessary and critically important component of the ozone attainment demonstration. As stated in EPA's modeling guidance, "By definition, models are simplistic approximations of complex phenomena" (EPA, 2018a, pp. 169). EPA guidance recommends three types of supplemental analysis to support a modeled attainment demonstration:

1. Additional modeling analysis.
2. Analysis of trends in ambient concentrations and emissions.
3. Additional emission controls.

As the NM OAI Study is not a formal regulatory SIP ozone attainment demonstration study, then a formal WOE is not needed. However, the concept of a WOE should be integrated into the NM OAI Study.

9.4 Documentation of the PGM Modeling

Results of the NM OAI Study will be documented in PowerPoint (PPT) presentations and other documents that will be presented to the NMED in monthly webinars following the schedule in Tables 1-2 and 1-3. After each webinar presentations and with approval from NMED, the documents will be posted to a webpage on the WRAP website, like we did for the Southern New Mexico Ozone Study (SNMOS[66]). Two formal reports will be generated, one on the developed of the NM OAI Study 2014 36/12/4-km CAMx modeling platform and model performance evaluation and an Air Quality Technical Support Document (AQTSD) that documents the entire study including the 2023 future year modeling, ozone design Value projections, source apportionment modeling and control strategy sensitivity modeling.

[66] https://www.wrapair2.org/SNMOS.aspx

10. QUALITY ASSURANCE PROJECT PLAN (QAPP)

This Modeling Protocol also serves as an informal Quality Assurance Project Plan (QAPP) for the NM OAI Study. A formal QAPP is a stand-alone document that discusses the Quality Assurance (QA) and Quality Control (QC) aspects of a study. QAPPs are typically required for Federal studies and are designed to assure that data are collected in the most rigorous ways possible, subjected to detailed QA/QC and have a chain of custodia review of data to preserve the quality. QAPPs are particularly important for measurement studies where the study must assure that the data collected meet a level of QA/QC as, unlike a modeling study where one can go back and rerun the model, if data collected at a certain time and place is ruled invalid there is no way to collect the measurement data under the same circumstances. This is not to say QA/QC is not important for modeling studies and, as shown below, this Modeling Protocol is full of QA/QC processes in each step of the modeling.

EPA has developed a template for developing a formal QAPP.[67] EPA has also developed a document that describes the elements of a QAPP.[68] Below we go through each of the seven elements EPA recommends be part of a QAPP and discuss where they can be found in this Modeling Protocol.

10.1 Title Page And Approval Page

As this is not a formal QAPP , there is no Approval Page. However, we have a list of Project Participants in Table 1-1 that are responsible for reviewing and accepting the Modeling Protocol/QAPP.

10.2 Quality System Components

This section of a QAPP describes the study's quality assurance program and procedures and who has responsibility for the QA/QC. Below we point to sections in this Modeling Protocol where rigorous QA/QC procedures are put in place for the NM OAI Study.

10.2.1 Roles of Personal for QA/QC of the NM OAI Study

The two Co-Principal Investigators, Tom Moore of WESTAR and Ralph Morris of Ramboll, have overall responsibility for the QA/QC of the NM OAI Study. Together they have over 50 years' experience in managing large air quality studies including instituting comprehensive QA/QC procedures. In Table 1-1 we also list the leads for each major component of the modeling study (emissions, meteorological and photochemical modeling) who will oversee the QA/QC of each component of the database development. Also listed in Table 1-1 is the NM OAI Study Project Manager and staff at NMED who will review and comment on each phase of the study. Each month during the NM OAI Study we will have a Webinar and present elements of the study to the NMED for their review and comment following the schedule in Table 1-3.

[67] https://www.epa.gov/quality/quality-assurance-project-plan-development-tool

[68] https://www.epa.gov/sites/production/files/2015-05/documents/assess4.pdf

10.2.2 QA/QC of the 2014 Base Year and 2023 Future Year Emissions Data

The QA/QC of the base and future year emissions data is described in Section 1.5.4. The 2014 base year emissions were based on the 2014NEIv2 that have gone through several rounds of review and updates by EPA and the states. The WRAP states then conducted further review and updates of the 2014NEIv2 emissions in two phases to develop the WRAP/WAQ 2014v1 and final 2014v2 emissions used in the WRAP/WAQS 2014v2 modeling platform. Finally, under the NM OAI Study, the NMED will make further review of the New Mexico emissions in the 2014v2 inventory and make updates as needed.

The 2023 future year emissions used in the study are part of EPA's 2016v1 modeling platform (2023fh inventory). They are the result of several iterations of EPA making future year emission projections and represent their current best estimate of future year emissions. The NMED will also review the 2023 emissions for New Mexico and make updates as needed.

10.2.3 QA/QC of 2014 and 2023 Emissions Processing

Section 1.5.5 describes the process that will be used in processing the 2014 and 2023 emissions into the gridded, hourly and speciated emissions inputs needed for the CAMx PGM. The NM OAI Study modeling study will perform a multistep emissions QA/QC approach as developed for the WRAP 2002 modeling (Adelman, 2004) and following the procedures in EPA's latest ozone modeling guidance (EPA, 2018a, pp. 60) and Section 2.20 of the SMOKE User's Manuel (UNC, 2018, pp. 94). These steps include making sure that the mass input to the emissions models is consistent with the output and generation numerous QA/QC visualization graphics, including spatial maps and time series plots. Sections 6.2.2.7 and 6.2.2.9 provide more details on the QA/QC process for the emissions modeling. The QA/QC of the 2023 emissions processing is discussed in Section 8.2.2.

10.2.4 QA/QC of the Meteorological Modeling

The QA/QC of the meteorological modeling is briefly discussed in Section 1.5.6 with a more detailed discussions contained in Chapter 5. The NM OAI Study has separate work elements to evaluate the performance of the current WRAP/WAQS 2014 WRF simulation in New Mexico as well as a more detailed evaluation of the 36/12/4-km WRF simulation being conducted under the NM OAI Study that is described in Section 5.4.

10.2.5 QA/QC of the Boundary Conditions

The WRAP/WAQS study did a detailed QA/QC of EPA's 2014 GEOS-Chem modeling that was used in the initial BCs in the 2014v1 platform and found the ozone BCs to be inadequate, so WRAP ended up doing their own 2014 GEOS-Chem modeling that improved the 2014 BCs. The NM OAI Study will conduct a QA/QC of the WRAP 2014 GEOS-Chem BCs for sites in New Mexico

10.2.6 QA/QC of the Air Quality Modeling

The QA/QC of the CAMx air quality modeling will included independent review of the run scripts against the Modeling Protocol to make sure that the model configuration is

correct, as discussed in Section1.5.7. The NM OAI Study CAMx 36/12/4-km base case simulation will be subjected to a model performance evaluation (MPE) to assure that the model is replicating 2014 observed ozone concentrations sufficiently well that it can be used for making future year ozone projections (Section 1.5.9). Chapter 7 goes into details on how the CAMx Operational MPE will be conducted that includes statistical performance measures that are compared against Goals and Criteria and graphical MPE products. Elements of Diagnostic MPE being conducted are discussed in Section 1.5.10 with details of the diagnostic model performance evaluation provided in Section 7.5.

10.3 Project Definition and Background

Section 1-1 provides the impetus for the NM OAI Study with an overview of the study provided in Section 1-2. The background on related studies in provided in Section 1.3.

10.4 Data Quality Objectives

The data quality objectives for the meteorological, emissions and photochemical modeling are contained in Chapters 5, 6 and 7 respectively. Of particular note are meteorological model performance benchmarks listed in Table 5-3 that the NM OAI Study WRF 22014 36/12/4-km simulation will be compared against as part of the assessment of the meteorological data quality. Similarly, Table 7-1 contains model Performance Goals and Criteria that the CAMx 2014 base case simulation model performance will be compared against as part of the assessment of the data quality of the photochemical model simulation.

10.5 Project Organization and Responsibilities of the Researchers

Table 1-2 lists the organization of the NM OAI Study by task with schedule. The responsibilities of the NM OAI Study project participants are given in Table 1-1.

10.6 Project Description, Documentation and Reporting

This Modeling Protocol has a complete description of how the NM OAI Study will be carried. A description of the documentation and how the study will be reported is given in Section 1.8. And a summary of the documentation is also provided at the end of Chapter 9.

10.7 Reconcile with Data Quality Objectives

This Modeling Protocol provides a roadmap for how the NM OAI Study will be conducted. However, it is a living document that can be modified as issues or new information comes up. During the course of the study, WESTAR/Ramboll will have regular webinars that are scheduled monthly to go over progress and results for the previous month. If issues come up or problems are encountered, the WESTAR/Ramboll team will discuss them with the NMED and develop corrective action to reconcile any issues/difficulties.

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APPENDIX A

Observed MDA8 Ozone Concentrations during 2014. Red indicates ozone ≥71 ppb and yellow indicates ozone between 67 and 71 ppb.

Observed MDA8 Ozone Concentrations during 2014. Red indicates ozone ≥71 ppb and yellow indicates ozone between 67 and 71 ppb.

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Montezuma	Bernalillo	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
1-Jan	36	28	43	38	43	39	36	32	39	36	38		37	47	42	39	32	36	37	34	32	33		47	43	47	42
2-Jan	42	34		28	32	30	35	29	37	32	37		33	47	46	31	29	26	39	36	34	35		47	35	47	46
3-Jan	47	32		26	30	28	33	23	32	30	35		30	47	48	29	31	27	41	28	29	36		48	33	47	48
4-Jan	44	42		40	44	40	40	33	42	37	43		34	51	44	41	40	40	36	37	41	31		51	44	51	44
5-Jan	45	41		38	43	42	38	33	43	36	35		35	50	42	40	38	39	34	38	39	38		50	43	50	42
6-Jan	42	35		34	38	35	35	28	37	27	34		32	50	42	38	32	33	33	34	34	35		50	38	50	42
7-Jan	34	27		19	28	24	26	21	31	26	28		28	47	39	29	26	25	30	24	26	33		47	28	47	39
8-Jan	39	23		22	28	25	30	32	39	37	40		32	49	40	27	18	10	32	27	37	24		49	30	49	40
9-Jan	43	35		24	24	22	29	28	37	33	26		27	48	43	24	28	16	31	28	34	33		48	29	48	43
10-Jan	42	39		38	42	40	38	36	43	40	44		38	52	43	39	37	40	40	36	41	43		52	42	52	43
11-Jan	41	36		35	36	36	33	31	35	35	39		36	49	39	35	29	30	39	32	29	40		49	36	49	39
12-Jan	45	42		38	44	41	38	33	42	38	42		36	50	43	41	40	43	38	35	40	36		50	44	50	43
13-Jan	41	32	44	37	42	38	37	32	40	35	41		36	48	42	39	36	34	44	31	28	41		48	42	48	42
14-Jan	42	39	46	38	44	41	38	26	43	33	44		40	51	44	41	38	37	46	28	30	40		51	44	51	44
15-Jan	40	30	47	36	40	34	37	30	40	38	41		36	49	42	39	35	32	41	32	35	38		49	40	49	42
16-Jan	40	31	47	38	43	36	38	29	44	33	40		40	53	42	40	30	34	44	32	34	41		53	43	53	42
17-Jan	44	31	45	27	16	31	35	31	44	38	43		37	53	42	36	31	29	50	37	36	37		53	35	53	42
18-Jan	41	34	42	33	36	34	36	33	41	37	41		37	51	41	37	28	33	47	34	37	43		51	36	51	41
19-Jan	39	33	42	28	31	34	32	27	43	35	44		43	53	44	34	29	27	48	37	39	40		53	34	53	44
20-Jan	36	30	43	34	38	31	36	31		34	42		38	50	42	37	21	32	44	27	34	40		50	38	50	42
21-Jan	35	33	40	30	33	32	32	32		36	42		39	52	45	34	30	31	45	38	38	39		52	33	52	45
22-Jan	31	18	39	18	25	26	28	23		29	34		27	52	40	27	23	22	42	22	3	40		52	28	52	40
23-Jan	40	36	33	32	30	32	34	29			35		31	42	37	32	35	32	35	35	32	34		42	34	42	37
24-Jan	39	30	31	17	25	23	25	22			34		33	44	42	28	25	28	35	25	27	35		44	28	44	42
25-Jan	44	25	45	26	29	30	36	23			31		25	47	44	35	21	32	36	31	30	38		47	36	47	44
26-Jan	47	30	43	37	38	39	38	29			32		26	51	44	40	28	37	35	37	40	37		51	39	51	44
27-Jan	45	38	42	26	32	30	29	20			36		33	47	41	31	30	29	35	31	30	35		47	32	47	41
28-Jan	45	50	52	43	40	32	41	21			33		31	53	50	37	47	32	33	32	31	35		53	43	53	50
29-Jan	48	35	48	35	33	37	39	18		33	32		27	49	47	35	31	32	36	32	25	37		49	39	49	47

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
30-Jan	45	29	37	30	33	30	32	29		38	39		29	52	37	33	30	33	42	33	40	35		52	33	52	37
31-Jan	45	39	44	39	37	39	36	29	36	36	43		34	48	46	38	37	35	38	35	38	28		48	39	48	46
1-Feb	45	41	43	41	45	43	38	27	35	34	42		36	48	44	41	36	45	39	35	36	31		48	45	48	44
2-Feb	46	40	42	42	42	42	39	25	37	37	32		33	56	46	41	38	38	34	34	38	38		56	42	56	46
3-Feb	47	42	39	39	43	41	39	26	39	36	27		28	53	45	42	41	40	31	41	40	35		53	43	53	45
4-Feb	48	41	42	36	42	40	37	32	44	39	44		38	54	44	40	38	45	45	40	41	29		54	45	54	44
5-Feb	48	35	41	22	27	26	23	20	28	24	33		33	46	42	29	37	27	33	29	28	38		46	27	46	42
6-Feb	44	38	43	18	22	20	24		33	24	32		33	44	44	24	38	24	31	34	33	39		44	24	44	44
7-Feb	45	35	43	31	37	35	34	44	43		38		28	53	45	37	35	39	37	38	42	33		53	39	53	45
8-Feb	47	38	44	37	36	39	37	46	45		44		40	54	46	39	32	39	43	40	43	41		54	39	54	46
9-Feb	40	34	36	34	36	36	34	40	39		40		40	47	40	36	28	35	42	35	37	28		47	36	47	40
10-Feb	46	36	41	36	40	35	35	41	39		21		24	45	39	37	33		35	34	38	35		45	40	45	39
11-Feb	47	41	44	34	38	37	36	30	32		22		33	49	43	37	35		32	30	31	35		49	38	49	43
12-Feb	46	32	46	38	42	41	38	31	47		45		33	41	46	40	34	30	40	39	41	43		47	42	47	46
13-Feb	37	32	36	27	31	33	31	34	36		37		37	32	37	32	28	32	41	29	32	41		37	33	37	37
14-Feb	35	33	35	28	33	33	31	33	35	29	25		37	34	36	31	29	34	38	31	31	44		37	34	37	36
15-Feb	39	28	35	29	27	30	28	32	32	33	22		32	33	33	28	26	31	37	27	30	32		33	31	33	33
16-Feb	45	32	45	36	40	38	36	38	40	39	25		37	38	41	37	23	40	40	34	38	41		41	40	40	41
17-Feb	45	44	45	42	42	43	41	31	38	28	28		38	38	48	42	38	43	45	32	35	43		48	43	38	48
18-Feb	48	29	46	38	42	41	41	37	40	29	28		40	40	47	31	32	44	46	33	37	49		47	44	40	47
19-Feb	52	45	45	44	48	46	44	36	42	40	32		39	40	48	45	44	48	45	32	44	41		48	48	42	48
20-Feb	49	43	43	40	44	43	39	46	45	47	34		45	34	44	41	41	44	53	42	40	44		47	44	47	44
21-Feb	47	42	42	38	41	40	40	39	46	42	31		41	46	45	39	33	38	46	33	47	44		46	41	46	45
22-Feb	50	42	45	42	44	45	42	47	53	49	38		50	51	44	40	39	43	45	43	50	44		53	45	53	44
23-Feb	54	41	46	43	44	46	44	49	53	50	32		46	51	47	42	38	43	44	46	49	43		53	46	53	47
24-Feb	53	43	49	41	46	47	45	39	42	40	35		43	42	50	41	41	36	47	38	38	44		50	47	43	50
25-Feb	45	48	51	35	37	35	38	34	38	35	26		31	38	48	37	45	37	38	31	34	35		48	38	38	48
26-Feb	47	40	45	37	41	41	41	36	41		19		31	39	49	39	39	41	26	38	37	33		49	41	41	49
27-Feb	42	37	44	38	41	40	39	36	37		25		39	38	43	38	34	41	34	33	33	40		43	41	39	43
28-Feb	40	40	40	41	43	43	43	32	35		29		45	33	46	42	39	42	39	30	31	47		46	43	45	46
1-Mar	38	34	39	33	28	32	32	26	27		22		33	25	28	34	32	28	37	25	25	37		34	33	33	34
2-Mar	49	42	45	40	46	45	43	44	45		21		33	44	45	42	44	45	35	43	44	36		46	46	45	45
3-Mar	51	43	46	43	44	45	43	32	39		21		31	44	47	42	39	44	38	34	38	39		47	45	44	47
4-Mar	38	41	43	39	42	42	41	41	42		29		38	43	48	41	37	43	38	41	43	45		48	43	43	48

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Montezuma	Bernalillo	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
5-Mar	52	35	50	43	48	46	42	46	46		35		38	46	48	44	38	47	49	43	43	35		48	48	46	48
6-Mar	49	44	50	41	41	44	41	43	51		33		47	48	52	41	40	41	51	46	48	47		52	44	51	52
7-Mar	52	44	43	43	49	48	45	50	54		40		53	51	48	45	44	50	51	47	49	49		54	50	54	48
8-Mar	48	44	43	40	40	42	38	38	39		33		40	41	46	39	44	40	42	38	37	41		46	42	41	46
9-Mar	52	41	41	44	45	46	39	42	41		33		43	42	46	44	41	47	46	42	40	44		47	47	43	46
10-Mar	51	11	47	41	42	45	38	45	47		35		46	46	47	39	35	43	42	44	45	50		47	45	47	47
11-Mar	56	29	47	46	49	49	46	51	54	52	37		49	52	54	45	48	50	50	47	49	46		54	50	54	54
12-Mar	54	50	52	44	47	47	40	42	42	42	27		41	44	46	43	46	44	45	42	41	49		47	47	44	46
13-Mar	49	49	51	43	46	45	42	42	46	44	34		43	45	47	44	48	43	47	42	43	47		48	46	46	48
14-Mar	51	44	49	43	43	43	40	47	50	49	36		44	50	47	42	46	43	50	46	46	50		50	43	50	47
15-Mar	55	55	52	46	47	47	45	48	49	49	39		48	51	48	44	52	47	53	46	45	51		52	47	51	52
16-Mar	52	46	49	50	50	51	46	50	52	52	36		42	51	52	47	46	49	47	49	48	42		52	51	52	52
17-Mar	56	50	52	49	51	46	47	46	49	48	35		46	48	53	48	50	51	48	43	48	46		53	51	49	53
18-Mar	56	44	43	44	48	50	43	52	54	52	39		48	52	47	43	43	51	54	48	49	47		54	51	54	47
19-Mar	54	51	50	47	48	47	43	43	44	45	37		45	48	53	44	44	45	46	42	42	47		53	48	48	53
20-Mar	55	52	53	46	48	50	45	41	47	43	33		46	47	55	46	50	47	50	41	41	49		55	50	47	55
21-Mar	56	51	51	50	53	51	48	48	51	50	38		52	50	54	50	48	52	51	44	47	48		54	53	52	54
22-Mar	56	54	53	44	49	49	44	43	45	44	38		44	45	56	47	55	48	45	42	41	43		56	49	45	56
23-Mar	59	52	52	50	51	51	46	44	43	45	36		42	46	53	49	52	48	41	41	41	42		53	51	46	53
24-Mar	56	45	54	50	54	52	49	48	50	51	39		50	52	56	49	50	54	43	51	47	45		56	54	52	56
25-Mar	52	53	54	46	49	51	46	44	45	45	37		48	50	52	46	52	47	43	43	43	46		52	51	50	52
26-Mar	56	50	52	46	48	45	46	44	47	46	32		44	45	52	46	52	46	42	40	43	45		52	48	47	52
27-Mar	54	49	51	47	52	50	49	43	47	45	34		44	46	49	48	47	51	50	40	45	48		52	52	47	49
28-Mar	53	49	47	44	48	47	46	46	50	48	35		48	49	51	44	47	48	49	43	44	49		51	48	50	51
29-Mar	56	53	52	50	53	54	50	52	53	54	39		53	49	51	50	50	48	54	49	49	50		54	54	54	51
30-Mar	57	51	54	51		54	51	51	55	53	35		50	54	56	51	53	53	52	47	50	54		56	54	55	56
31-Mar	54	50	49	52	53	53	49	49	52	50	38	47	51	50	52	49	50	53	55	46	46	51		53	53	52	52
1-Apr	57	54	58	46		48	47	49	47	51	39	56	50	51	52	45	54	48	51	46	48	49		56	48	56	54
2-Apr	59	54	56	53		57	53	50	53	51	39	52	50	52	57	51	55	54	53	45	50	54		57	57	53	57
3-Apr	53	54	52	49		53	50	55	58	55	46	57	57	53	54	49	51	53	53	53	53	52		58	53	58	54
4-Apr	59	57	56	53		56	52	48	51	50	40	52	52	50	55	51	55	51	51	47	47	53		56	56	52	55
5-Apr	58	60	57	55		57	53	54	56	56	39	53	50	58	56	53	59	56	53	51	54	49		59	57	58	59
6-Apr	53	53	50	49		52	50	52	54	53	41	54	50	51	54	48	51	52	58	51	50	45		54	52	54	54
7-Apr	55	47	50	52		55	51	52		52	40	51		52	55	50	51	54	52	49	41	48		55	55	52	55

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
8-Apr	50	44	48	47		49	47	50	53	53	33	48		43	54	45	46	51	53	55	49	49		54	51	53	54
9-Apr	54	51	50	49		49	48	46	50	49	35	53	49	49	53	46	48	48	54	46	44	53		53	49	53	53
10-Apr	51	54	54	53		57	52	49	54	51	37	51	48	51	57	50	53	59	56	47	47	53		59	59	54	57
11-Apr	56	55	55	51		54	52	47	52	50		55		48	58	50	50	53	53	44	45	68		58	54	55	58
12-Apr	55	56	56	46		50	46	41	44	43		45		46	54	46	54	48	47	40	42	51		54	50	46	54
13-Apr	59	56	54	54		55	53	49	52	51		55		52	53	52	54	56	56	45	49	50		56	56	55	54
14-Apr	52	54	57	44		45	43	40	41	41	36	41	44	55	49	43	48	43	45	38	38	47		55	45	55	49
15-Apr	53	51	53	48		51	47	47	53	50	36	50	49	49	53	47	46	46	50	47	47	53		53	51	53	53
16-Apr	58	50	52	50		54	49	53	57	56	40	60	51	56	53	48	49	54	52	50	54	55		60	54	60	53
17-Apr	54	57	52	56		57	53	56	54	60	40	53	50	55	59	51	51	55	56	52	50	37		60	57	60	59
18-Apr	56	59	59	55		58	54	53	54	56	34	50	51	53	58	55	57	52	47	50	50	52		58	58	56	58
19-Apr	52	59	57	47		50	43	44	45	47	26	43	41	48	54	47	60	43	44	42	42	47		60	50	48	60
20-Apr	55	55	53	50		51	48	49	54	52	33	55	54	55	55	49	52	49	47	53	48	53		55	51	55	55
21-Apr	59	64	61	59		60	56	61	55	64	38	55	57	54	64	54	60	57	51	59	54	61		64	60	64	64
22-Apr	61	60	61	56		59	56	54	59	59	36	59	68	54	59	56	58	54	59	53	52	66		68	59	68	59
23-Apr	61	60	60	54		56	55	50	55	54	38	61	56	53	59	54	58	56	53	48	51	61		61	56	61	59
24-Apr	62	55	58	55		58	52	58	60	61	37	58	56	57	62	51	53	55	58	59	55	56		62	58	61	62
25-Apr	53	65	64	52		55	52	49	55	52	35	56	56	56	60	51	60	50	59	46	48	62		60	55	56	60
26-Apr	53	46	53	50		51	50	49	51	51	38	51	52	46	56	49	51	49	52	47	47	53		56	51	52	56
27-Apr	59	55	54	52		56	51	54	57	57	42	56	55	53	55	50	53	55	50	53	52	47		57	56	57	55
28-Apr	57	59	58	54		55	55	54	57	55	41	57	55	54	59	53	57	53	52	52	50	54		59	55	57	59
29-Apr	56	53	49	57		59	54	62	63	61	44	60	55	58	53	52	52	54	58	58	56	44		63	59	63	53
30-Apr	56	56	49	54		58	49	45	48	48	34	47	45	50	50	47	47	55	48	46	44	50		58	58	50	50
1-May	56	54	55	52		53	49	47	49	51		53	51	52	53	48	51	49	56	48	46	49		53	53	53	53
2-May	51	51	51	48		51	48	49	55	52		49	52	52	54	47	49	47	59	54	48	53		55	51	55	54
3-May	52	59	59	50		52	48	48	54	52		53	51	49	55	46	53	45	54	52	48	53		55	52	54	55
4-May	59	56	56	57		59	55	53	58	57		59	55	55	57	51	54	54	56	51	50	57		59	59	59	57
5-May	59	56	55	54		56	56	46	52	50		58	58	48	59	51	52	51	54	45	46	57		59	56	58	59
6-May	55	57	56	53		56	53	40	46	43		53	53	42	59	50	53	49	47	37	40	56		59	56	53	59
7-May	60	58	58	53		56	54	47	53	51	53	57	45	52	50	51	57	54	43	46	52	46		57	56	57	57
8-May	60	48	48	51		53	51	54	56	57	61	61	55	54	49	50	47	53	49	52	52	57		61	53	61	50
9-May	59	56	58	56		58	56	54	59	58	64	63	58	55	58	55	54	55	57	53	54	55	56	64	58	64	58
10-May	56	57	56	57		60	56	52	56	56	57	56	54	51	56	58	55	51	54	51	49	62	57	60	60	57	58
11-May	65	59	61	58		61	57	50	52	53	58	57	56	50	61	57	58	58	59	48	50	57	50	61	61	58	61

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Montezuma	Bernalillo	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
12-May	50	32	40	45		46	42	55	57	58	49	47	48	56	43	44	40	42	53	55	53	43	45	58	46	58	44
13-May	55	49	51	46		46	41	42	44	45	47	44	45	42	46	43	48	42	47	42	40	42	51	48	46	47	48
14-May	58	53	51	54		55	50	50	49	53	57	54	52	52	54	51	53	54	52	49	45	57	52	57	55	57	54
15-May	55	53	50	52		52	52	57	63	59	57	57	55	51	59	52	49	51	64	56	58	57	51	63	52	63	59
16-May	56	52	51	49		52	51	54	58	57	62	58	57	53	57	49	51	53	60	54	51	56	50	62	53	62	57
17-May	68	52	55	55		55	55	58	63	62	68		60	58	57	54	56	51	62	63	56	60	54	68	55	68	57
18-May	61	68	65	61		61	62	55	59	58	70	62	61	54	66	60	62	57	62	53	51	58	61	70	62	70	66
19-May	61	62	59	58		58	59	53	56	57	64	61	58	55	63	57	57	55	55	49	53	61	58	64	59	64	63
20-May	53	58	56	55		56	56	51	55	54	62	61	60	49	61	54	53	52	54	49	48	63	56	62	56	62	61
21-May	51	47	48	51		52	52	50	56	55	62	57	52	47	57	52	44	50	49	50	49	56	51	62	52	62	57
22-May	46	49	49	46		46	48	44	48	48	45	42	34	38	49	47	45	45	47	43	42	43	48	49	48	48	49
23-May	48	43	47	43		45	44	43	51	47	52	51	47	36	42	45	40	42	55	47	47	43	49	52	45	52	45
24-May	61	50	53	44		44	46	46	50	52	55	54	47	52	48	43	56	44	53	43	44	49	60	56	46	55	56
25-May	58	58	51	56		55	56	54	58	58	59	55	57	56	59	55	51	55	48	55	51	57	47	59	56	59	59
26-May	55	60	62	62		62	59	53	55	56	56	55	55	52	63	58	59	62	51	53	49	55	60	63	62	56	63
27-May	59	54	53	63		63	58	60	61	64	67	65	65	55	55	57	55	61	61	61	55	66	53	67	63	67	57
28-May	59	59	57	62		58	62	65	63	72	75	74	68	59	58	61	52	59	65	60	58	65	59	75	62	75	61
29-May	52	61	58	63		61	64	67	66	72	72	69	65	57	57	64	59	58	60	64	62	63	55	72	64	72	64
30-May	56	47	57	56		53	57	59	66	63	69	60	69	52	55	54	58	56	65	59	60	66	50	69	57	69	58
31-May	56	57	54	56		55	56	57	63	61	72	63	73	51	55	57	51	55	65	54	55	62	55	73	56	73	57
1-Jun	51	55	56	49		49	51	45	49	49	60	53	60	44	55	48	53	50	63	44		66	67	60	51	60	55
2-Jun	46	66	61	59		55	58	53	54	55	62	56	64	40	54	55	56	47	52	57	54	52	64	64	59	64	56
3-Jun	46	41	53	53		51	54	49	57	54	54	51	53	47	49	52	39	52	38	44	46	52	69	57	54	57	52
4-Jun	57	59	64	51		52	52	49	54	53	57	49	50	46	57	46	54	54	45	56	46	60	69	57	54	57	57
5-Jun	65	71	68	60		59	59	52	53	55	60	52	56	53	64	60	66	60	41	55	51	63	65	66	60	60	66
6-Jun	71	70	67	62		62	58	52	57	57	47	42	40	57	68	60	69	63	32	54	63	47	45	69	63	57	69
7-Jun	71	67	67	51		50	47	62	67	66	51	49	40	59	56	52	61	53	31	61	63	54	61	67	53	67	61
8-Jun	67	59	57	61		63	58	52	59	56	45	43	46	58	62	59	60	65	35	52	59	59	62	65	65	59	62
9-Jun	63	61	56	62		64	57	65	65	69	58	56	51	60	67	57	52	67	53	64	65	47	59	69	67	69	67
10-Jun	67	42	61	64		65	60	72	70	76	74		66	65	63	62	60	64	60	70	71	61	64	76	65	76	63
11-Jun	54	59	61	43		44	45	44	48	47	62		61	43	53	43	54	48	52	41	44	67	65	62	48	62	54
12-Jun	55	65	58	62		61	59	41	46	44	60	59	57	43	56	60	60	61	44	45	46	50	56	62	62	60	60
13-Jun	46	46	47	41		43	41	51	42	55	58	52	58	38	42	45	42	44	46	46	54	56	60	58	44	58	45
14-Jun	69	61	63	52		52	55	39	43	43	46	43	49	42	64	54	61	52	48	38	39	61	59	64	55	49	64

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
15-Jun	66	62	63	57		57	55	35	38	38	50	43	50	37	61	56	56	53	44	34	38	58	60	61	57	50	61
16-Jun	48	53	56	41		42	40	40	44	43	52		46	42	46	40	46	44	43	37	39	45	55	52	44	52	46
17-Jun	42	45	42	40		40	40	36	40	39	47	47	49	40	47	38	43	44	42	39	39	49	41	49	44	49	47
18-Jun	44	34	47	32		32	32	35	40	38	41	40	52	28	39	32	40	35	43	36	36	43	49	52	35	52	40
19-Jun	45	57	56	48		47	46	37	40	40	44	45	55	31	57	47	55	45	43	45	41	38	50	57	48	55	57
20-Jun	49	56	51	41		42	40	48	43	53	39	42	42	39	52	43	55	44	33	41	43	39	51	55	44	53	55
21-Jun	41	50	51	47		48	45	63	53	64	42		43	44	47	45	49	49	39	52	57	36	49	64	49	64	49
22-Jun	43	54	50	41		42	40	41	43	44	50		57	38	45	41	51	42	45	42	39	46	49	57	42	57	51
23-Jun	47	53	47	47		48	47	45	46	47	53	51	54	42	47	47	50	49	41	52	46	51	42	54	49	54	50
24-Jun	47	58	55	46		46	45	42	46	45	55		72	39	55	45	55	45	50	46	43	55	45	72	46	72	55
25-Jun	49	59	53	53		50	50	42	46	46	48		46	42	54	51	52	49	42	43	44	45	51	54	53	48	54
26-Jun	51	49	48	47		46	46	41	44	45	56	60	48	40	53	46	47	45	44	41	42	48	48	60	47	60	53
27-Jun	50	47	45	50		53	49	36	42	40	42		44	43	48	51	43	53	47	35	42	50	45	53	53	44	51
28-Jun	62	60	57	56		59	54	44	54	47	51		54	48	65	54	56	59	46	42	47	51	48	65	59	54	65
29-Jun	50	56	53	60		59	56	41	48	45			51	43	55	54	57	60	43	40	43	50	59	60	60	51	57
30-Jun	49	47	44	51		51	48	37	44	41	45		44	39	51	45	45	48	37	35	38	45	51	51	51	45	51
1-Jul	47	49	46	46		45	39	41	43	44	47	51	39	45	47	50	42	47	41	42	42	46	60	51	47	51	50
2-Jul	47	49	50	51		52	46	47	49	52	47	42	43	35	45	53	49	53	34	44	48	41	41	53	53	52	53
3-Jul	49	52	50	55		55	50	46	43	51	47		44	48	45	58	51	56	35	42	43	38	41	58	56	51	58
4-Jul	50	51	52	55		53	49	43	41	47	41	41	36	40	48	54	52	53	31	39	41	37	47	55	55	47	54
5-Jul	53	48	46	60		57	55	47	50	49	43	43	40	47	44	54	50	57	36	42	51	43	49	60	60	50	54
6-Jul	54	60	53	60		61	52	39	43	43	40	45	40	48	59	54	61	57	39	37	40	44		61	61	48	61
7-Jul	56	60	63	64		59	59	58	55	63	54	56	43	52	52	63	62	59	34	50	57	52		64	64	63	63
8-Jul	54	56	59	51		49	43	55	51	61	51		53	55	47	48	56	52	33	49	51	43	46	61	52	61	56
9-Jul	56	50	56	56		57	52	50	47	55	43		41	51	44	51	54	59	34	45	48	41	52	59	59	55	54
10-Jul	56	60	59	60		58	54	51	44	57	41		40	49	52	57	58	58	40	43	47	44	38	60	60	57	58
11-Jul	55	62	55	63		64	56	42	41	44	39		39	45	57	59	59	61	35	38	40	38	39	64	64	45	59
12-Jul	58	55	52	65		60	60	41	39	46	41		37	48	55	59	57	63	39	36	40	39		65	65	48	59
13-Jul	62	56	59	43		45	40	42	39	46	48		39	46	45	43	51	49	34	38	38	49	39	51	49	48	51
14-Jul	54	51	55	60		68	52	41	45	46	47	44	43	48	45	48	54	61	36	43	47	45	45	68	68	48	54
15-Jul	53	36	50	50		51	42	67	60	72	53		50	61	42	43	49	50	38	57	62	50	52	72	51	72	49
16-Jul	47	47	47	51		54	43	48	56	54	59		58	53	44	45	47	53	43	53	53	50		59	54	59	47
17-Jul	57	55	57	60		58	54	47	52	52	52		43	47	58	56	54	59	52	58	51	42	44	60	60	52	58
18-Jul	54	57	59	61		65	57	50	68	56	56		63	44	58	57	58	63	42	57	73	47		68	65	68	58

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Montezuma	Bernalillo	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
19-Jul	49	58	57	52		64	61	46	53	52	52		56	51	57	59	59	68	49	50	50	51		68	68	56	59
20-Jul	47	52	50	55		60	48	47	55	52	58		55	48	52	47	49	56	51	52		57	31	60	60	58	52
21-Jul	41	49	41	56		53	48	48	54	53	59		59	49	54	48	39	51	48	66	55	55	34	59	56	59	54
22-Jul	51	48	45	54		55	47	67	59	71	52		52	55	48	48	51	57	45	58	62	46	38	71	57	71	51
23-Jul	58	51	57	54		54	48	45	48	51	57		58	56	52	52	48	52	47	43	45	54	46	58	54	58	52
24-Jul	55	58	59	57		55	52	56	54	51	65		64	52	52	55	51	51	54	51	56	61		65	57	65	55
25-Jul	57	51	59	62		58	53	65	67	69	61	61	58	54	62	56	52	57	52	51	63	63	40	69	62	69	62
26-Jul	61	57	58	64		64	54	59	61	61	55	48	55	56	56	55	48	60	50	53	60	54	39	64	64	61	56
27-Jul	63	59	57	56		59	50	58		61	53	53	51	54	56	51	52	61	45	51	55	66		61	61	61	56
28-Jul	60	55	60	57		56	50	52		57	53		48	55	41	58	44	55	39	47	51	51	38	58	57	57	58
29-Jul	60	58	59	58		54	50	55		59	56	52	50	57	46	56	55	53	43	59	65	45	46	59	58	59	56
30-Jul	54	56	55	66		63	54	57		59	55	51		57	59	60	45	61	48	66	54	50		66	66	59	60
31-Jul	54	48	54	53		52	48	62		67	43			55	46	54	46	50	49	53	58	56		67	53	67	54
1-Aug	56	48	54	56		54	48	49		52	46		55	52	43	54	46	55	41	49	51	56		56	56	55	54
2-Aug	54	49	53	56		52	50	54		56	57		52	57	46	50	41	53	49	50	49	56		57	56	57	50
3-Aug	51	51	56	57		58	48	54		58	63		58	57	51	58	42	58	51	51	52	56	41	63	58	63	58
4-Aug	50	52	54	57		56	49	56		60	61		60	51	45	54	51	49	57	51	55	59		61	57	61	54
5-Aug	51	56	55	59		57	50	59	63	66	64		58	60	52		51	56	59	62	70	61		66	59	66	52
6-Aug	55	53	56	55		52	51	61	74	62	62		61	58	51	47	52	55	54	56	70	55		74	55	74	52
7-Aug	59	59	55	43		43	42	53	57	58	54		59	52	45	43	53	39	48	57	59	56	32	59	43	59	53
8-Aug	57	51	52	60		57	56	58	55	61	52		48	55	50	60	52	57	44	73	58	53	38	61	60	61	60
9-Aug	58	54	56	59		56	51	48	48	53	49		43	49	57	56	54	57	42	46	49	43		59	59	53	57
10-Aug	56	53	56	53		50	47	41	41	46	48		45	47	52	51	56	52	46	43	43	51		56	53	48	56
11-Aug	52	55	56	58		55	48	44	43	48			45	50	51	51	53	57	37	42	43	57		58	58	50	53
12-Aug	48	53	57	48		60	53	42	39	45			59	46	50	46	54	57	36	36	39	55		60	60	59	54
13-Aug	47	39	47	41		41	36	48	45	50			61	47	40	45	36	42	52	40	45	58		61	42	61	45
14-Aug	52	44	48	53		51	43	41	49	47			53	50	49	52	46	51	55	41	48	56		53	53	53	52
15-Aug	52	45	51	52		52	47	52	56	54			51	50	52	53	49	49	49	57	54	54		56	52	56	53
16-Aug	55	45	46	49		54	37	51	53	54			53	53	44	49	46	58	43	61	54	57		58	58	54	49
17-Aug	51	44	49	53		54	42	52	57	55			59	51	39		49	56	44	57	65	59		59	56	59	49
18-Aug	51	51	50	59		55	53	63	57	69			61	56	43	63	51	57	45	58	57	55	38	69	59	69	63
19-Aug	42	48	52	52		50	48	46	54	51	55	42	60	50	51	55	48	54	45	49	51	48	40	60	54	60	55
20-Aug	49	52	52	47		48	42	43	47	47	49	56	47	43	55	47	48	51	42	46	45	55		56	51	56	55
21-Aug	46	49	49	54		53	51	39	45	44	40	54	47	45	48	55	44	54	50	46	43	50		55	54	54	55

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
22-Aug	46	43	48	41		40	36	46	60	50	46	56	52	43	39		41	43	43	48	58	53		60	43	60	41
23-Aug	48	53	54	51		49	47	38	42	43	49	59	59	40	54		51	48	42	44	43	52	44	59	51	59	54
24-Aug	45	61	59	56		55	49	47	53	48	43	55	50	41	52		53	55	38	45	50	48		56	56	55	53
25-Aug	42	55	52	50		50	46	43	51	45	45	42	45	43	45		45	49	40	44	52	47		51	50	51	45
26-Aug	37	43	48	41		41	40	42	45	43	47	51	51	39	34		41	42	44	49	44	39		51	42	51	41
27-Aug	40	54	53	39		41	35	56	51	59	36	46	52	46	44		46	43	50	60	52	51		59	43	59	46
28-Aug	55	48	49	52		52	38	47	46	48	47	63	51	44	55		44	55		62	46	48		63	55	63	55
29-Aug	56	54	51	62		58	57	62	54	64	51	68	59	53	49		56	57		57	56	55		68	62	68	56
30-Aug	52	54	54	54		55	49	67	67	68	54	70	55	50	51		50	55		55	67	55		70	55	70	51
31-Aug	49	49	51	55		53	51	46	50	49	51	60	52	48	56		46	54		50	48	51		60	55	60	56
1-Sep	45	47	49	52		50	46	45	47	47	45	55		46	50		43	50		46	43	58		55	52	55	50
2-Sep	47	54	48	50		51	46	48	55	50	49	56		44	49		45	53		57	56	51		56	53	56	49
3-Sep	47	51	48	51		50	48	52	51	56	39	49		43	46		43	52		41	50	40		56	52	56	46
4-Sep	42	41	41	47		44	42	36	37	39	37	39		36	44		38	46		34	35	37		47	47	39	44
5-Sep	45	47	47	51		45	44	28	34	33	37	39		43	41		49	51		30	33	32		51	51	43	49
6-Sep	45	46	48	40		36	42	31	31	32	20	24		39	38		49	41		29	30	28		49	42	39	49
7-Sep	47	47	47	45		43	40	25	26	28	35	33		31	39		44	42		27	24	35		45	45	35	44
8-Sep	33	49	42	35		32	32	39	50	41	47	42		34	38		40	35	36	34	52	46		50	35	50	40
9-Sep	35	31	37	36		36	35	33	39	36	35	50		39	36		30	39	36	34	36	47		50	39	50	36
10-Sep	55	48	48	49		50		36	39	38	38	51		35	54		42	55	40	41	36	41		55	55	51	54
11-Sep	58	58	60	55		52	56	33	40	36	40	45		38	62		56	55	34	35	35	38		62	56	45	62
12-Sep	58	52	52	28		25	38	33	36	36	21	23		44	48		54	35	31	34	34	17		54	38	44	54
13-Sep	48	48	51	33		34	37	30	30	33	25	27		32	43		46	35	22	27	30	30		46	37	33	46
14-Sep	41	49	55	34		33	38	29	28	32	32	28	17	33	42		47	33	20	27	28	27		47	38	33	47
15-Sep	44	49	51	38		35	42	24	26	25	29	32	26	34	46		50	38	25	21	25	26		50	42	34	50
16-Sep	33	48	48	28		27	32	32	26	34	38	38		24	38	29	45	29	32	32	25	32		45	32	38	45
17-Sep	30	43	44	21		25	28	38		42	44	40		31	35	27	38	31	37	32	34	37		44	31	44	38
18-Sep	34	47	52	45		39	48	24		29	32	38		29	46	48	47	42	32	25	25	35		48	48	38	48
19-Sep	44	47	43	40		41	42	28	29	31	27	27		32	42	45	47	38	33	33	28	33		47	42	32	47
20-Sep	45	48	50	41		43	41	43	31	47	28	27		42	47	41	47	44	32	56	41	29	34	47	44	47	47
21-Sep	39	41	41	34		34	37	34	30	38	27	31		33	40	35	37	34	30	30	31	39	38	40	37	38	40
22-Sep	39	38	43	30		32	35	22	27	24	37	46	34	32	31	33	35	33	48	25	27	43	42	46	35	46	35
23-Sep	44	33	46	40		42	45	52	32	55	40	45	52	36	51	46	42	44	50	38	50	51	45	55	45	55	51
24-Sep	50	49	52	51		50	52	42	40	48	47	45	49	45	44	48	48	51	47	38	40	51	46	52	52	49	48

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
25-Sep	47	50	53	48		50	50	52	48	56	59	57	52	46	45	51	49	49	50	48	49	45	50	59	50	59	51
26-Sep	51	49	48	44		47	48	59	54	63	60	53	59	50	45	50	51	47	48	51	55	57	48	63	48	63	51
27-Sep	46	50	51	47		51	51	52	46	57	42	41	41	46	46	53	46	51	37	46	46	45	48	57	51	57	53
28-Sep	42	36	40	34		38	37	36	43	37	40	41	49	28	39	39	34	38	34	43	44	46	44	49	38	49	39
29-Sep	49	41	51	38		41	47	31	39	35	42	43	47	22	42	42	40	40	37	32	36	42	51	47	47	47	42
30-Sep	54	48	51	49		36	54	29	36	33	40	54	36	41	54	53	48	52	36	30	38	46	47	54	54	54	54
1-Oct	57	45	47	47		51	53	44	54	50	53		50	54	51	52	44	54	36	43	49	52	48	54	54	54	52
2-Oct	52	47	48	45		43	51	51	48	54	45		42	53	49	50	39	54	51	50	47	45	50	54	54	54	50
3-Oct	46	30	47	44		42	48	50	50	54	47		55	50	49	46	37	52	49	48	47	44	52	55	52	55	49
4-Oct	45	39	43	41		39	44	52	57	55			52	52	45	43	36	47	47	56	54	50	43	57	47	57	45
5-Oct	46	41	45	40		39	45	47	46	49			43	50		46	36	46	48	46	43	54	44	50	46	50	46
6-Oct	47	47	51	46		40	53	39	42	42			50	43	58	52	41	50	45	40	40	54	53	58	53	50	58
7-Oct	48	52	52	45		41	51	43	37	46			49	46	55	48	38	47	46	42	41	52	52	55	51	49	55
8-Oct	38	45	51	32		27	38	42	49	45			45	35	46	38	42	36	47	45	48	53	45	49	38	49	46
9-Oct	41	34	35	28		27	36	28	32	31	30		36	32	31	35	34	33	46	27	36	44	44	36	36	36	35
10-Oct	50	33	40	30		31	35	38	40	41	35		33	41	36	33	35	37	36	41	39	29	51	41	37	41	36
11-Oct	50	41	48	42		39	49	47	46	54	40		37	42	45	47	45	43	35	40	48	42	44	54	49	54	47
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13-Oct	42	39	42	36		35	42	43	43	45	41		40	42	44	41	34	41	44	45	42	39	43	45	42	45	44
14-Oct	42	43	45	36		37	42	15	49	47	50		44	47	43	38	34	42	44	43	46	44	38	50	42	50	43
15-Oct	42	37	47	31		34	44	50	50	56	56		46	45	42	41	40	42	43	48	49	48	44	56	44	56	42
16-Oct	40	49	54	45		42	53	40	48	35	54		37	44	53	48	46	46	45	43	43	49	45	54	53	54	53
17-Oct	38	40	50	44		45	49	39	44	41	55		54	43	45	41	37	43	42	46	38	50	46	55	49	55	45
18-Oct	34	43	45	46		48	51	54	50	54	55		40	50	40	53	39	51	47	56	53	42	42	55	51	55	53
19-Oct	42	40	42	42		45	47	42	40	44	47		36	41	39	46	42	42	36	43	41	42	43	47	47	47	46
20-Oct	44	25	43	31		34	35	34	36	35	42		46	39	41	37	35	37	34	35	36	41	41	46	37	46	41
21-Oct	41	23	41			39	42	38	38	41	39		44	36	36	41	34	40	35	37	39	48	37	44	42	44	41
22-Oct	44	38	48			38	42	38	40	42	41		41	38	44	39	37	42	35	38	42	44	46	44	42	42	44
23-Oct	43	41	49			40	47	42	50	48	35		35	43	47	44	37	45	30	54	48	41	43	50	47	50	47
24-Oct	43	42	47			44	48	43	49	45	51		41	42	45	44	38	45	35	56	47	48	44	51	48	51	45
25-Oct	38	43	47			43	46	39	44	42	48		38	37	44	43	43	45	36	46	44	44	43	48	46	48	44
26-Oct	37	35	42			35	39	33	38	36	39		38	34	41	36	32	36	36	37	35		42	41	39	39	41
27-Oct	44	45	49			41	46	31	35	33	33		29	33	47	43	41	43	38	29	33		45	47	46	35	47
28-Oct	46	41	47			38	43	42	43	41	42		41	37	50	14	36	45	46	39	41		44	50	45	43	50

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
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30-Oct	46	39	42			44	50	41	42	38	44		48	43	46	45	32	46	38	40	39	45		50	50	48	46
31-Oct	45	47	51			47	48	45	47	47	48		36	50	48	49	44	47	45	46	47	39		50	48	50	49
1-Nov	38	39	42			40	41	36	40	37	43		41	36	42	40	36	40	45	37	38	41		43	41	43	42
2-Nov	46	30	50			33	35	40	41	41	39		37		33	30	31	36	46	41	42	42		41	36	41	33
3-Nov	45	44	44			49	51	28	31	29	34		31	34	48	48	40	53	41	32	31	34		53	53	34	48
4-Nov	44	41	42			38	41	33	34	33	27		26	35	45	39	30	27	33	31	32	26		45	41	35	45
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9-Nov	44	40	46	37		40	42	39	46	41	44		32	41	49	40	40	37	39	44	47	38		49	42	46	49
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11-Nov	43	45	51	30		37	41	37	42	39	35		28	39	50	36	42	39	32	37	40	36		50	41	42	50
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14-Nov	37	28	41	31		33	37	28	31	31	31		23	34	40	34	17	33	28	31	30	31		40	37	34	40
15-Nov	45	40	47	42		47	47	35	42	36	42		24	41	46	45		45	30	32	40	42		47	47	42	46
16-Nov	46	43	46	39		45	43	36	38	37	31		25	44	43	43		43	35	36	37	36		45	45	44	43
17-Nov	40	31	48	38		39	43	34	41	35	41		30	41	44	30	25	39	42	40	40	42		44	43	41	44
18-Nov	41	31	44	36		35	44	34	42	36	36		27	43	44	38	26	38	38	30	35	41		44	44	43	44
19-Nov	42	30		26		32	39	35	24	37	43		26	40	44	33	27	33	37	31	31	41		44	39	43	44
20-Nov	44	31		28		33	39	35	41	34	44		26	30	45	33	26	33	38	32	36	40		45	39	44	45
21-Nov	42	34		19		23	33	27	38	32	39		25		38	29	29	30	38	27	34	44		39	33	39	38
22-Nov	44	36		28		42	41	39	44	41	42		23		47	37	31	36	42	38	43	42		47	42	44	47
23-Nov	44	42		40		44	43	46	49	47	45		27		43	42	39	43	42	45	47	38		49	44	49	43
24-Nov	42	40		36		41	41	37	41	38	40		22		42	39	37	40	43	33	38	40		42	41	41	42
25-Nov	41	36		35		36	41	36	41	38	40		20		43	37	31	33	43	33	39	37		43	41	41	43
26-Nov	35	26		26		33	36	32	37	35	36		24		36	33	24	32	41	23	27	39		37	36	37	36
27-Nov	33	27		26		34	32	25	38	27	44		26		39	29	23	32	40	32	35	37		44	34	44	39
28-Nov	38	30		25		31	39	28	35	38	44		25		44	30	27	28	47	32	32	36		44	39	44	44
29-Nov	38	34		32		37	41	34	41	38	43		28		41	33	28	33	43	33	36	35		43	41	43	41
30-Nov	41	28		26		32	39	37	43	40	43		27		40	30	22	31	43	36	40	34		43	39	43	40
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State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Nav-ajo	La Plata	Monte-zuma	Berna-lillo	Berna-lillo	Berna-lillo	Berna-lillo	Dona Ana	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Luna	Rio Arriba	Sand-oval	San Juan	Val-encia	Brew-ster	El Paso	El Paso	Lamp-asas	San Juan	Maxi-mum	Maxi-mum	Maxi-mum	Maxi-mum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	001	013	013	013	015	015	025	029	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0027	0029	1012	0017	0020	0021	1005	3001	0008	0003	0026	1001	0009	0008	0101	0057	0058	9991	0004				
2-Dec	32	23		1		19	35	22	33	22	26		15		37	22	28	12	34	27	30	28		37	35	33	37
3-Dec	22	35		17		25	27	28	16	31	40		23		31	25	21	29	31	27	27	29		40	29	40	31
4-Dec	41	20		20		16	31	19	25	22	15		9		34	29	13	13	28	21	30	18		34	31	25	34
5-Dec	39	27		24		6	37	28	37	33	36		21		30	25	20	31	33	30	34	39		37	37	37	30
6-Dec	25	26		25		26	34	42	42	41	44		26		33	29	22	26	40	41	41	34		44	34	44	33
7-Dec	20	30		33		38	38	38	42	42	35		15		41	36	18	34	32	38	41	36		42	38	42	41
8-Dec	26	26	39	17		21	29	32	39	32	33		25		34	24	22	24	29	32	39	41		39	29	39	34
9-Dec	22	31	40	13		18	28	30	34	31	24		17		35	22	24	26	27	32	32	44		35	28	34	35
10-Dec	24	29	35	27		28	34	19	32		23		17		34	27	10	31	24	28	28	25		34	34	32	34
11-Dec	17	28	37	17		22	30	27	39	34	25		15		37	24	17	27	30	30	36	25		39	30	39	37
12-Dec	37	27	40	14		22	37	31	41	35	23		12		35	21	28	24	34	18	32	31		41	37	41	35
13-Dec	42	42	45	34		39	44	35	25	36	34		19		47	41	28	39	42	38	44	32		47	44	36	47
14-Dec	38	38	39	38		44	41	41		42	45		26		41	40	34	41	40	40	44	37		45	44	45	41
15-Dec	36	32	43	34		25	40	33	33	35	38		23		41	37	27	36	41	24	24	31		41	40	38	41
16-Dec	35	32	43	17		15	26	35	40	36	31		20		37	25	29	15	37	35	39	36		40	26	40	37
17-Dec	36	29	38	20		27	31	39	43	41	43		22		36	18	20	24	36	37	42	22		43	31	43	36
18-Dec	41	32	39	27		33	36	34	34	38	39		24		41	32	24	35	40	32	36	17		41	36	39	41
19-Dec	39	34	42	32		39	38	30	36	34	37		16		43	36	18	37	42	24	35	21		43	39	37	43
20-Dec	35	27	40	23		29	34	33	40	37	36		17		43	23	17	32	36	30	36	32		43	34	40	43
21-Dec	33	30	37	31		29	38	38	40	39	41		24		38	35	23	28	40	36	41	36		41	38	41	38
22-Dec	36	38	43	32		36	38	34	36	36	34		21		42	35	35	36	37	33	35	42		42	38	36	42
23-Dec	42	46	44	36		42	44	39	44	40	39		26		46	41	39	41	39	40	41	36		46	44	44	46
24-Dec	41	38	40	34		37	40	34	37	39	41		23		42	35	25	37	42	36	37	39		42	40	41	42
25-Dec	42	36	44	39		41	43	36	44	40	34		19		41	40	34	39	43	34	44	34		44	43	44	41
26-Dec	37	37	39	36		42	41	30	38	34	42		23		43	39	26	39	40	34	40	23		43	42	42	43
27-Dec	39	32	40	32		35	37	32	38	33	15		17		39	35	21	31	37	37	37	32		39	37	38	39
28-Dec	39	28	38	31		36	36	35	40	39	36		20		43	33	24	31	36	35	36	34		43	36	40	43
29-Dec	43	33	41	28		28	37	35	41	38	42		21		43	30	28	29	35	33	38	29		43	37	42	43
30-Dec	43	34	39	21		27	23	27	31	27	21		20		29	21	27	24	14	25	29	30		31	27	31	29
31-Dec	32	31	35	14		22	20	17	22	18	28		17		32	24	26	20	16	19	19	28		32	22	28	32

APPENDIX B

Observed MDA8 Ozone Concentrations during 2016. Red indicates ozone ≥71 ppb and yellow indicates ozone between 67 and 71 ppb.

Observed MDA8 Ozone Concentrations during 2016. Red indicates ozone ≥71 ppb and yellow indicates ozone between 67 and 71 ppb.

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
1-Jan	29	40	46	29	40	33	25	26	33		38	34	34	35	32	21	26	25	36		40	40	38	35
2-Jan	31	35	48	34	38	37	29	27	37		30	40	33	35	34	28	27	27	38		40	38	37	40
3-Jan	32	35	48	28	37	28	35	32	41		40	40	30	33	29	21	34	31	41		41	37	41	40
4-Jan	32	36	47	30	34	41	31	27	40		33	41	38	35	27	26	29	29	39		41	41	40	41
5-Jan		37	40	25	30	32	27	14	29		22	41	30	32	28	26	15	21	28		41	32	29	41
6-Jan		36	41	31	40	37	39	40	39		28	42	35	18	33	40	34	40	20		42	40	40	42
7-Jan		37	43	33	38	39	40	41	43		38	44	36	33	37	43	38	41	32		44	39	43	44
8-Jan		39	44	37	45	44	43	43	44		38	46	40	32	44	45	37	42	21		46	45	44	46
9-Jan		38	45	36	43	41	40	41	26		26	43	38	31	40	43	36	39	34		43	43	41	43
10-Jan		41	44	35	41	42	34	38	28		33	46	40	33	39	38	33	37	25		46	42	38	46
11-Jan	37	35	43		40	41	40	40	40		36	45	38	29	37	39	35	37	42		45	41	40	45
12-Jan	41	32	39	31	29	40	34	36	37		39	44	35	32	25	40	29	23	32		44	40	39	44
13-Jan	37	37	46	34	33	43	37	38	39		37	49	37	28	33	39	24	28	37		49	43	39	49
14-Jan	41	42	50	38	45	46	42	44	43		40	47	43	33	37	46	34	43	41		47	46	44	47
15-Jan	40	37	46	38	41	41	44	44	46		41	47	38	31	38	43	39	43	41		47	41	46	47
16-Jan	41	38	50	43	47	48	43	42	44		35	49	44	38	44	46	37	38	34		49	48	44	49
17-Jan	39	36	49	40	45	46	41	40	42		42	45	41	38	43	42	35	37	19		46	46	42	45
18-Jan	37	40	47	36	36	42	38	39	25		31	44	31	35	35	41	32	36	26		44	42	39	44
19-Jan	41	36	42	38	39	42	40	42	40		40	47	39	31	39	41	33	37	35		47	42	42	47
20-Jan	41	44	48	40	45	44	43	41	43		34	45	42	40	43	43	36	41	38		45	45	43	45
21-Jan	42	38	46	39	44	45	44	44	43		41	46	42	32	43	46	40	41	40		46	45	44	46
22-Jan	40	41	48	32	36	45	38	40	41		39	47	36	36	38	42	34	33	39		47	45	41	47
23-Jan	46	44	55	27	38	43	38	43	39		39	49	32	41	34	43	34	34	37		49	43	43	49
24-Jan	46	45	45	45	51	49	45	44	47		44	47	45	39	46	52	38	47	40		51	51	47	47
25-Jan	42	40	45	40	46	46	46	45	44		43	44	42	32	44	43	38	43	41		46	46	46	44
26-Jan	41	41	45	35	35	41	38	39	30		34	47	36	36	38	36	35	36	38		47	41	39	47
27-Jan	40	39	45	36	35	44	37	40	40		38	48	40	33	37	40	37		42		48	44	40	48
28-Jan	43	43	46	34	36	42	36	40	41		38	49	34	32	37	40	36		41		49	42	41	49
29-Jan	41	41	46	36	40	41	36	40	45		41	48	40	29	41	41	31	31	40		48	41	45	48
30-Jan	45	40	45	39	45	42	42	43	47		42	44	39	34	41	44	35	41	35		47	45	47	44

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
31-Jan	42	35	43	44	49	46	43	44	46		42	46	44	38	45	46	39	42	39		49	49	46	46
1-Feb	43	44	46	41	46	45	43	44	46		43	48	44	39	44	43	39	42	36		48	46	46	48
2-Feb	41	41	45	37	43	41	37	44	44		40	42	40	39	41		40	41	40		44	43	44	42
3-Feb	41	38	45	38	44	42	39	43	43		41	43	40	39	42	45	36	40	41		44	44	43	43
4-Feb	41	39	45	38	39	44	40	38	42		42	46	40	33	41	45	39	38	41		46	44	42	46
5-Feb	42	38	46	40	44	43	44	43	45		42	47	41	35	43	45	40	40	41		47	44	45	47
6-Feb	42	44	48	43	46	46	42	42	45		43	48	44	33	42	44	34	38	44		48	46	45	48
7-Feb	40	45	50	42	47	45	41	42	45		43	51	42	30	43	40	33	36	44		51	47	45	51
8-Feb	40	53	49	42	45	45	41	39	47		43	50	44	35	42	43	35	42	43		50	45	47	50
9-Feb	40	53	55	41	44	44	42	38	48		46	51	41	35	43	43	39	40	43		51	44	48	51
10-Feb	44	46	57	39	44	45	42	40	47		42	56	42	41	41	41	36	37	44		56	45	47	56
11-Feb	42	51	50	42	42	43	43	46	47		45	51	43	35	42	46	40	34	43		51	43	47	51
12-Feb	40	49	52	43	42	45	41	47	44		53	50	42	38	43	48	35	39	44		53	45	53	50
13-Feb	45	51	52	37	47	45	46	45	64		52	48	41	45	42	50	39	43	50		64	47	64	48
14-Feb	41	42	47	41	47	42	46	46	46		44	45	42	35	44	50	41	43	40		47	47	46	45
15-Feb	41	39	44	38	42	39	43	42	47		43	42	38	37	41	45	38	39	42		47	42	47	42
16-Feb	39	41	43	35	38	39	39	41	42		35	42	29	30	38	46	36	37	41		42	39	42	42
17-Feb	42		48	33	41	44	45	60	56		46	43	36	38	39	50	42	42	44		60	44	60	43
18-Feb	42	28	51	40	47	43	51	53	58		48	44	41	35	43	54	48	48	42		58	47	58	44
19-Feb	38	42	48	34	35	40	48	47	48		38	39	37	36	36	47	41	45	42		48	40	48	39
20-Feb	40	46	50	39	45	47	47	46	51		44	46	39	40	42	47	43	41	50		51	47	51	46
21-Feb	44	49	49	46	49	46	42	45	44		42	47	44	43	46	34	41	41	44		49	49	45	47
22-Feb	44	40	48	43	49	46	51	52	43		34	48	45	41	44	44	46	49	41		52	49	52	48
23-Feb	46	45	44	37	42	34	44	49	32		37	45	37	38	43	49	44	43	35		49	43	49	45
24-Feb	48	44	46	33	44	47	40	45	45		44	49	42	34	44	43	43	40	45		49	47	45	49
25-Feb	49	45	45	45	46	44	44	45	43		40	49	45	20	47	45	45	43	43		49	47	45	49
26-Feb	47	49	47	43	46	46	51	53	51		45	50	45	41	47	51	48	51	47		53	47	53	50
27-Feb	49	46	48	45	49	49	50	51	53		50	49	44	42	50	50	45	46	49		53	50	53	49
28-Feb	45	42	45	45	46	46	53	53	49		45	45	44	36	49	52	50	48	43		53	49	53	45
29-Feb	44	44	45	39	42	44	48	49	52		47	47	41	37	44	50	41	44	46		52	44	52	47
1-Mar	44	38	38	39	40	42	46	48	50		46	45	37	36	42	47	42	43	46		50	42	50	45
2-Mar	53	48	50	43	44	47	47	50	51		44	49	46	41	47	49	42	46	44		51	47	51	49
3-Mar	51	49	52	48	48	52	48	55	52		48	54	45	41	49	54	43	45	49		55	52	55	54
4-Mar	52	50	53	53	50	53	50	52	55		46	52	49	43	49	52	46	47	49		55	53	55	52

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
5-Mar	50	51	50	49	52	52	50	51	45		57	54	50	47	51	52	45	46	51		57	52	57	54
6-Mar	42	40	47	41	43	42	47	49	39		43	43	40	38	42	44	42	45	38		49	43	49	43
7-Mar	50	47	47	49	47	49	41	44	47		41	50	49	44	47	49	40	41	40		50	49	47	50
8-Mar	48	48	49	45	45	46	48	49	48		47	49	45	44	47	47	45	46	42		49	47	49	49
9-Mar	47	42	50	48	47	49	45	47	46		43	49	47	44	51	46	43	42	42		51	51	47	49
10-Mar	49	48	44	49	51	51	49	51	48		45	41	51	43	52	47	47	45	47		52	52	51	51
11-Mar	47	48	46	45	48	47	57	62	53		53	44	45	46	49	46	52	54	52		62	49	62	46
12-Mar	53	49	53	50	52	53	52	51	55		51	51	51	51	56	48	52	55	40		56	56	55	51
13-Mar	48	47	45	49	49	49	50	51	53		48	47	47	43	48	49	47	47	47		53	49	53	47
14-Mar	46	47	47	46	47	47	46	48	48		45	48	46	44	47	56	42	45	44		48	47	48	48
15-Mar	50	51	50	48	49	49	49	52	52		50	52	48	48	51	49	49	47	50		52	51	52	52
16-Mar	47	51	48	47	47	48	49	50	56		52	51	47	46	49	52	45	44	50		56	49	56	51
17-Mar	47	37	46	46	46	47	48	50	51		49	49	45	43	47	50	45	45	51		51	47	51	49
18-Mar	48	44	48	44	45	45	49	51	44		42	48	44	41	49	52	45	46	39		51	49	51	48
19-Mar	43	43	46	44	46	45	41	45	47		42	44	43	41	45	41	42	40	44		47	46	47	44
20-Mar	50	46	47	45	46	45	42	49	46		48	48	44	44	44	41	44	42	46		49	46	49	48
21-Mar	53	53	55	53	52	54	49	51	50		45	56	53	52	51	45	46	48	46		56	54	51	56
22-Mar	53	52	54	52	49	51	55	56	58		51	52	49	51	50	52	49	55	50		58	52	58	52
23-Mar	43	40	44	44	45	44	57	57	55		50	43	42	39	48	55		53	53		57	48	57	43
24-Mar	50	48	46	48	48	49	45	48	48		43	51	47	46	50	47	49	43	46		51	50	48	51
25-Mar	51	50	53	44	50		52	56	55		52	51	47	48	51	47	51	51	50		56	51	56	51
26-Mar	55	54	52	51	53		53	55	56		51	55	50	51	53	52	50	50	48		56	53	56	55
27-Mar	56	56	52	56	56	50	53	58	47		45	54	52	51	55	41	49	50	48		58	56	58	54
28-Mar	47	50	51	49	49	50	47	48	53		47	50	48	46	49	48	43	45	45		53	50	53	50
29-Mar	51	48	50	51	48	51	48	50	53		51	48	50	48	48	53	45	46	51		53	51	53	50
30-Mar	51	48	47	50	52	51	47	46	45		45	50	51	45	53	58	43	49	48		53	53	47	51
31-Mar	47	47	46	49	51	49	48	49	50		49	49	47	43	52	57	49	47	51		52	52	50	49
1-Apr	44	49	47	46	46	44	43	50	33		38	47	46	47	46	48	48	42	45		50	46	50	47
2-Apr	49	52	50	51	51	50	47	50	50		40	46	49	46	52	46	46	44	49		52	52	50	49
3-Apr	47	47	44	47	47	46	51	50	43		44	50	45	42	48	51	50	46	50		51	48	51	50
4-Apr	56	47	44	47	43	47	55	56	54		45	46	47	41	47	55	53	51	56		56	47	56	47
5-Apr	55	53	52	54	50	53	58	59	58		51	54	52	51	57	55	54	55	55		59	57	59	54
6-Apr	53	50	51	50	51	48	54	62	52		49	53	49	47	49	55	55	51	51		62	51	62	53
7-Apr	48	54	48	50	49	50	51	42	48		49	50	47	50	49	50	39	47	44		51	50	51	50

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
8-Apr	46	45	46	44	41	43	44	50	54		48	41	41	40	45	47	48	41	49		54	45	54	41
9-Apr	50	49	48	51	49	50	52	51	55		55	52	50	48	51	47	50	47	56		55	51	55	52
10-Apr	43	54	49	54	53	54	45	46	49		47	53	53	48	54	44	43	42	51		54	54	49	53
11-Apr	45	46	43	50	46	50	49	48	45		43	45	48	42	50	49	46	45	29		50	50	49	48
12-Apr	50	48	47	45	43	45	44	44	27		28	44	43	47	47	36	39	40	41		47	47	44	47
13-Apr	48	49	47	49	46	49	53	52	52		48	49	47	45	49	51	52	49	46		53	49	53	49
14-Apr	53	52	51	55	52	54	55	54	58		51	50	54	48	55	50	51	51	57		58	55	58	54
15-Apr	55	55	53	53	53	53	52	53	53	53	51	54	50	51	56	55	49	52	43		56	56	53	54
16-Apr	42	64	62	49	47	49	52	53	63	64	59	59	49	44	48	55	49	49	41		64	49	64	59
17-Apr	39	48	42	44	41	43	51	52	46	47	47	42	40	41	45	57	52	50	32		52	45	52	42
18-Apr	53	45	46	38	36	40	47	54	46	46	46	39	39	37	43	32	48	47	47		54	43	54	39
19-Apr	55	42	51	52	49	51	56	56	49	51	47	55	49	47	53	39	56	51	34		56	53	56	55
20-Apr	57	50	53	50	49	53	59	59	59	64	53	55	49	50	53	53	54	55	52		64	53	64	55
21-Apr	58	59	56	59	53	56	59	67	53	53	57	55	53	55	58	51	54	53	56		67	59	67	55
22-Apr	57	59	59	57	54	59	57	57	62	59	60	57	58	55	56	53	55	52	62		62	59	62	58
23-Apr	56	55	65	53	49	53	55	50	56	57	57	53	53	58	53	57	51	49	61		58	53	57	58
24-Apr	63	58	59	64	62	61	53	51	53	57	52	61	60	57	64	50	47	48	74		64	64	57	61
25-Apr	61	62	64	59	56	59	58	56	55	60	57	60	56	59	57	52	50	53	61		60	59	60	60
26-Apr	52	53	53	55	52	46	61	61	60	60	59	56	54	50	55	58	56	56	57		61	55	61	56
27-Apr	54	50	47	47	45	48	57	58	60	64	59	49	47	44	49	60	55	52	50		64	49	64	49
28-Apr	60	60	59	59	57	58	52	50	48	51	56	58	58	53	60	56	50	53	56		60	60	56	58
29-Apr	49	63	60	58	50	57	62	60	63	63	62	60	58	57	56	59	59	56	36		63	58	63	60
30-Apr	51	52	48	48	45	47	58	59	59	61	56	49	45	46	48	60	57	54	42		61	48	61	49
1-May	57	46	46	45	40	43	42	44	33	33	35	42	45	37	44	53	39	39	35		45	45	44	45
2-May	57	54	51	56	52	56	47	48	44	49	47	48	53	52	54	37	43	42	52		56	56	49	53
3-May	60	61	49	57	54	54	53	60	58	59	54	53	52	56	61	44	51	49	56		61	61	60	56
4-May	59	63	61	59	55	61	63	66	63	69	59	56	60	57	61	61	59	58	50		69	61	69	60
5-May	61	64	62	62	59	62	61	61	64	61	58	60	62	57	61	61	55	55	65		64	62	64	62
6-May	54	62	58	60	58	58	61	60	57	53	57	62	59	53	60	57	52	54	57		62	60	61	62
7-May	51	62	57	60	58	58	66	67	51	65	49	57	58	55	61	51	60	62	57		67	61	67	58
8-May	53	56	54	57	54	56	63	62	59	64	60	56	56	53	56	54	59	57	61		64	57	64	56
9-May	50	49	50	47	46	48	55	53	53	55	55	48	46	45	51	60	49	51	53		55	51	55	48
10-May	52	54	52	56	52	55	59	60	60	70	63	56	53	51	56	58	56	55	58		70	56	70	56
11-May	55	49	55	55	52	55	63	63	57	68	58	56	54	52	55	54	57	57	55		68	55	68	56

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
12-May	56	66	61	64	59	60	54	61	49	50	50	61	56	61	59	42	51	50	54		64	64	61	61
13-May	60	61	60	60	55	57	64	71	54	54	52	62	57	58	60	51	53	58	61		71	60	71	62
14-May	53	62	62	54	50	53	55	59	47	52	42	52	53	54	50	57	55	52	45		59	54	59	54
15-May	58	51	51	53	50	52	54	51	43	54	37	55	52	48	53	55	47	47	36		55	53	54	55
16-May	55	59	56	55	55	56	37	39	36	43	45	56	55	52	60	45	34	39	44		60	60	45	56
17-May	53	59	55	39	36	39	39	49	24	27	31	44	44	53	40	50	44	44	35		53	40	49	53
18-May	58	41	41	35	36	39	31	37	30	30	34	40	36	38	42	28	34	35	50		42	42	37	40
19-May	56	56	56	44	50	53	52	58	49	46	43	53	50	55	53	36	56	56	45		58	53	58	55
20-May	57	63	60	57	57	52	55	56	55	54	58	59	59	55	59	46	52	55	64		59	59	58	59
21-May	57	67	61	58	60	59	53	56	53	50	50	64	61	58	61	49	52	50	45		64	61	56	64
22-May	47	54	57	56	55	57	52	54	56	66	58	55	57	49	59	51	51	54			66	59	66	57
23-May	59	67	66	52	53	54	50	53	52	63	56	49	52	58	58	49	50	48			63	58	63	58
24-May	59	63	64	55	58	58	56	60	58	69	57	60	57	55	61	42	56	56	49		69	61	69	60
25-May	54	75	67	60	57	60	50	50	46	50	49	64	61	65	60	33	46	52	63		65	60	50	65
26-May	61	67	66	62	62	65	54	57	54	62	53	65	64	64	67	51	54	59	59		67	67	62	65
27-May	56	59	58	57	58	58	60	63	58	69	61	61	59	56	64	65	62	60	64		69	64	69	61
28-May	63	63	55	58	57	60	67	66	63	65	69	54	59	55	60	53	61	63	62		69	60	69	59
29-May	58	72	67	55	53	53	47	51	41	43	48	63	57	65	57	41	50	46	57		65	57	51	65
30-May	49	63	56	54	51	53	37	41	50	49	42	54	55	53	52	37	42	40	52		55	54	50	55
31-May	54	61	55	52	54	53	47	48	46	50	52	53	52	55	52	42	44	46	55		55	54	52	55
1-Jun	53	56	55	56	54	56	46	53	50	53	51	48	60	54	55	52	50	47	46	45	60	56	53	60
2-Jun	56	57	52	58	53	55	55	61	49	51	50	52	54	54	58	55	68	57	46	49	61	58	61	54
3-Jun	49	52	50	51	50	55	55	67	54	55	55	51	50	49	56	53	55	52	45	49	67	56	67	51
4-Jun	48	43	48	56	53	53	52	60	50	51	50	37	56	40	57	49	48	50	52	28	60	57	60	56
5-Jun	56	56	54	54	50	53	57	65	54	61	55	49	56	55	54	55	52	54	60	47	65	54	65	56
6-Jun	67	57	61	61	56	61	64	79	63	62	63	50	61	54	61	61	55	63	56	55	79	61	79	61
7-Jun	54	59	57	58	54	60	69	64	61	62	64	56	60	49	58	64	53	60	57	52	69	60	69	60
8-Jun	59	57	54	56	52	58	55	55	65	66	66	59	60	56	56	60	54	52	64	53	66	58	66	60
9-Jun	58	54	53	54	48	52	57	58	57	56	56	51	52	52	56	49	55	51	55	50	58	56	58	52
10-Jun	54	50	48	49	49	48	56	57	56	60	49	44	46	47	54	46	59	56	55	42	60	54	60	47
11-Jun	52	56	48	50	47	52	58	59	56	57	51	48	52	50	53	50	55	54	46	48	59	53	59	52
12-Jun	58	63	54	55	52	54	59	60	58	60	58	55	52	56	57	50	55	53	59	44	60	57	60	56
13-Jun	53	57	50	55	48	56	51	53	60	60	65	56	58	48	53	47	43	50	45	45	65	56	65	58
14-Jun	63	62	57	60	54	61	53	54	55	60	52	56	59	52	62	46	46	48	51	50	62	62	60	59

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
15-Jun	56	69	66	61	59	63	54	52	55	56	55	61	64	58	63	45	49	47	59	60	64	63	56	64
16-Jun	55	71	54	55	50	57	52	54	51	57	65	60	57	56	57	44	45	48	63	49	65	57	65	60
17-Jun	52	66	55	60	54	57	60	61	56	51	59	55	55	53	57	48	57	54	62	49	61	60	61	55
18-Jun	58	71	69	69	66	70	55	68	62	60	61	56	67	64	69	50	60	49	47	49	70	70	68	67
19-Jun	55	62	57	62	59	60	52	63	52	53	53	57	59	62	65	42	46	49	49	48	65	65	63	62
20-Jun	55	54	53	59	54	58	54	59	51	54	52	48	60	52	56	40	48	50	50	44	60	59	59	60
21-Jun	57	61	62	58	53	59	55	70	47	45	33	49	65	56	57	30	52	56	47	56	70	59	70	65
22-Jun	55	59	64	62	57	63	58	59	44	48	43	57	63	58	61	33	59	53	48	55	63	63	59	63
23-Jun	54	48	63	65	59	66	66	65	45	50	48	57	62	56	63	41	62	77	48	54	66	66	66	62
24-Jun	49	58	55	59	57	62	59	69	50	56	53	56	59	56	56	45	61	63	51	50	69	62	69	59
25-Jun	56	59	59	54	53	54	56	61	49	54	43	53	53	57	54	45	69	56	45	51	61	54	61	57
26-Jun	52	59	57	55	52	53	46	59	47	51	52	50	55	52	58	40	51	48	37	55	59	58	59	55
27-Jun	55	60	57	60	52	57	51	54	30	42	40	51	60	59	56	32	45	47		51	60	60	54	60
28-Jun	49	52	53	44	40	44	34	37	38	38	40	47	46	47	42	39	29	33		48	47	44	40	47
29-Jun	48	49	52	48	42	51	41	49	52	54	52	40	53	43	44	40	37	38		40	54	51	54	53
30-Jun	45	50	53	50	49	39	48	57	55	57	57	38	49	48	51	48	43	45		43	57	51	57	49
1-Jul	41	38	41	40	41	39	46	47	53	48	53	38	42	34	43	45	43	44		39	53	43	53	42
2-Jul	49	48	50	52	52	51	57	59	48	53	52	51	52	45	55	52	41	52		46	59	55	59	52
3-Jul	54	58	61	54	53	54	55	58	54	56	58	63	54	57	57	52	47	51		58	63	57	58	63
4-Jul	45	58	54	54	51	51	56	57	51	53	58	54	50	52	53	51	59	53		51	58	54	58	54
5-Jul	48	55	52	50	46	49	54	55	52	53	59	48	51	51	50	51	62	48		48	59	50	59	51
6-Jul	45	48	47	50	46	49	55	53	48	52	52	51	50	48	51	43	50	47	52	52	55	51	55	51
7-Jul	47	38	51	52	51	53	55	52	52	54	53	47	52	47	54	45	50	48		49	55	54	55	52
8-Jul	46	51	45	52	48	50	60	55	53	57	63	56	48	54	53	49	55	51		39	63	53	63	56
9-Jul	48	57	54	57	52	52	58	56	62	60	55	58	54	59	57	51	64	53		49	62	57	62	59
10-Jul	50	59	54	51	46	50	54	52	53	54	53	53	51	52	52	50	52	45		55	54	52	54	53
11-Jul	45	55	58	45	40	43	52	48	50	51	54	46	45	48	48	49	41	45	56	57	54	48	54	48
12-Jul	52	60	58	46	41	48	48	46	46	50	49	56	48	59	45	42	42	40	58	52	59	48	50	59
13-Jul	52	57	55	53	52	49	49	51	48	47	53	59	51	56	54	40	51	42	61	56	59	54	53	59
14-Jul	49	61	58	57	56	56	53	52	51	50	47	62	57	60	58	44	48	43	58	54	62	58	53	62
15-Jul	46	66	61	67	58	61	51	61	54	57	57	59	60	61	58	43	46	46	58	57	67	67	61	61
16-Jul	43	61	59	52	47	49	68	65	58	58	48	48	51	53	49	38	55	67	53	55	68	52	68	53
17-Jul	42	48	44	44	44	41	60	56	52	52	44	45	42	48	48	39	56	53	49	45	60	48	60	48
18-Jul	46	59	52	54	48	51	60	61	47	50	44	45	51	48	53	36	57	60	42	34	61	54	61	51

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
19-Jul	43	61	58	63	53	59	59	70	46	47	47	43	61	61	56	39	54	56	46	39	70	63	70	61
20-Jul	60	68	60	60	55	60	54	61	47	48	42	53	59	65	61	40	41	49	45	44	65	61	61	65
21-Jul	55	68	62	62	57	61	44	55	48	51	48	56	62	65	61	45	39	41	52	52	65	62	55	65
22-Jul	58	68	64	65	59	64	48	62	49	53	51	60	62	69	63	40	44	44	51	48	69	65	62	69
23-Jul	55	48	51	60	60	58	55	69	55	60	46	53	57	53	64	39	47	51	54	48	69	64	69	57
24-Jul	54	48	49	65	59	61	51	64	52	53	48	49	60	56	62	37	48	49	50	46	65	65	64	60
25-Jul	56	54	53	70	63	60	50	54	48	50	50	49	63	60	65	43	47	46	47	49	70	70	54	63
26-Jul	56	52	51	62	62	59	50	66	51		54	51	58	57	63	47	47	47	65	44	66	63	66	58
27-Jul	54	56	52	68	66	63	58	60	63		61	49	58	61	66	52	52	52	53	50	68	68	63	61
28-Jul	52	41	58	65	63	61	63	66	63		62	54	58	56	64	43	58	56	61	50	66	65	66	58
29-Jul	54	57	56	54	55	54	51	53	52		50	56	57	60	54	39	46	47	54	52	60	55	53	60
30-Jul	55	58	56	56	54	56	49	56	53		45	51	59	58	53	44	47	47	51	48	59	56	56	59
31-Jul	55	64	61	64	60	60	57	57	51		47	57	62	62	62	45	48	53	49	51	64	64	57	62
1-Aug	57	49	55	64	59	60	64	50	48		50	46	58	59	63	42	48	59	51	57	64	64	64	59
2-Aug	54	55	56	60	54	55	59	54	53	49	51	48	58	55	54	38	53	58	47	48	60	60	59	58
3-Aug	53	61	66	49	45	49	65	49	52	49	47	40	51	64	49	39	56	59	53	51	65	49	65	64
4-Aug	58	49	53	50	49	50	68	58	56	52	55	40	53	51	50	40	63	63	50	44	68	50	68	53
5-Aug	48	43	50	53	52	53	66	58	56	53	52	39	54	43	54	41	57	65	51	49	66	54	66	54
6-Aug	47	60	56	59	56	61	60	67	51	50	50	42	59	63	57	38	57	55	49	44	67	61	67	63
7-Aug	53	58	57	63	61	64	55	56	49	52	38	47	62	58	61	31	48	53	50	46	64	64	56	62
8-Aug	55	62	57	54	51	57	64	64	50	50	44	48	55	59	56	32	54	68	41	47	64	57	64	59
9-Aug	44	56	53	56	50	58	57	53	51	49	49	46	56	57	56	33	51	52	53	45	58	58	57	57
10-Aug	48	43	50	53	49	53	62	46	53	46	48	42	56	57	49	35	52	57	53	45	62	53	62	57
11-Aug	58	51	50	50	50	54	54	52	40	41	52	52	50	48	52	40	54	49	54	48	54	54	54	52
12-Aug	53	41	54	56	56	55	48	54	49	52	54	56	52	52	58	42	52	47	56	46	58	58	54	56
13-Aug	55	52	51	56	57	57	48	49	48	52	58	42	55	55	56	51	44	48	54	48	58	57	58	55
14-Aug	55	57	58	56	55	56	50	54	50	51	45	48	54	56	57	47	49	49	47	47	57	57	54	56
15-Aug	55	57	56	62	57	62	61	64	55	57	52	47	56	57	58	52	52	54	52	47	64	62	64	57
16-Aug	53	54	57	55	55	56	59	64	58	58	57	50	49	53	56	52	55	54	52	49	64	56	64	53
17-Aug	53	56	53	55	53	58	54	56	52	52	50	43	58	58	54	36	47	47	49	48	58	58	56	58
18-Aug	52	54	52	51	51	56	54	65	49	46	38	46	53	50	54	25	54	52	46	43	65	56	65	53
19-Aug	51	51	53	53	52	54	60	56	47	42	42	43	52	55	52	28	58	58	44	51	60	54	60	55
20-Aug	54	57	50	60	54	58	48	47	51	49	45	41	56	53	56	30	41	42	37	44	60	60	51	56
21-Aug	54	55	53	51	51	52	45	49	43	46	51	45	53	51	48	34	42	42	49	49	53	52	51	53

State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
22-Aug	56	52	51	53	50	54	71	61	48	44	40	48	53	50	51	34	44	66	47	45	71	54	71	53
23-Aug	47	48	51	50	44	49	57	47	40	39	41	48	51	48	51	38	46	54	45	36	57	51	57	51
24-Aug	54	32	50	51	48	52	55	51	42	40	39	41	49	47	50	45	46	47	50	44	55	52	55	49
25-Aug	50	43	55	58	52	56	56	63	39	39	41	43	52	53	53	42	47	54	47	51	63	58	63	53
26-Aug	49	61	56	49	46	51	58	63	57	47	44	49	49	53	48	40	45	53	44	46	63	51	63	53
27-Aug	45	53	50	48	47	49	60	55	51	44	45	43	49	46	48	32	42	58	48	46	60	49	60	49
28-Aug	50	54	45	48	46	49	54	59	48	44	46	43	46	48	47	35	53	49	44	45	59	49	59	48
29-Aug	50	49	47	50	44	51	46	48	50	50	38	46	47	50	47	38	41	41	39	46	51	51	50	50
30-Aug	48	50	51	42	42	42	39	37	37	36	32	44	46	51	45	36	32	35	38	44	51	45	39	51
31-Aug	48	52	49	46	42	45	39	45	35	34	34	40	46	48	44	36	35	35	38	46	48	46	45	48
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7-Sep	37	46	47	31	30	35	35	33	28	23	32	29	32	38	31	33	24	31	29	46	38	35	35	38
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State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
County	Navajo	La Plata	Monte-zuma	Bernalillo	Bernalillo	Bernalillo	Dona Ana	Dona Ana	Eddy	Eddy	Lea	Rio Arriba	Sandoval	San Juan	Valencia	Brewster	El Paso	El Paso	Lampasas	San Juan	Maximum	Maximum	Maximum	Maximum
State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
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23-Oct	45	43	45	43	37	43	45	60	54		50	43	42	40	43	39	51	44	50		60	43	60	43
24-Oct	41	39	44	34	34	40	45	49	51		46	40	38	38	37	38	45	47	51		51	40	51	40
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State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
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State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
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State	AZ	CO	CO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	TX	TX	TX	TX	UT	NM	NM	NM	NM
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State Code	04	08	08	35	35	35	35	35	35	35	35	35	35	35	35	48	48	48	48	49	Sites			
County Code	017	067	083	001	001	001	013	013	015	015	025	039	043	045	061	043	141	141	381	037				
Site ID	0119	7001	0101	0023	0029	1012	0020	0021	1005	3001	0008	0026	1001	0009	0008	0101	0057	0058	9991	0004				
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3-Dec	36	36	42	33	34	37	28	28	23		29	45	35	28	37	17	21	25	34		45	37	29	45
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31-Dec	35	22	26	26	24	33	28	26	33		31	38	26	26	25	33	23	34	35		38	33	33	38

EXHIBIT 4

NEW MEXICO
ENVIRONMENT DEPARTMENT

525 Camino de los Marquez, Suite 1
Santa Fe, New Mexico 87505
Phone (505) 476-4300 Fax (505) 476-4375
www.env.nm.gov

Michelle Lujan Grisham
Governor

Howie C. Morales
Lt. Governor

James C. Kenney
Cabinet Secretary

Jennifer J. Pruett
Deputy Secretary

Date: April 1, 2020

From: New Mexico Environment Department Air Quality Bureau

Subject: How Ozone Trends at New Mexico's Ozone Monitoring Stations are Being Addressed

This document discusses how ozone is regulated, the recent trends in monitored ozone values in New Mexico, and the steps that the New Mexico Environment Department (NMED or Department) is taking to address this issue.

How does the Department regulate ozone?

The Department's Air Quality Bureau operates a network of ambient air monitors that continually sample the air across New Mexico, with the exception of Bernalillo County and tribal lands, which are not under the Department's jurisdiction. Click here to go to the NMED Air Monitoring web site, where you can view photos of the monitoring sites, and learn more about what pollutants we monitor and their potential health effects.

The federal national ambient air quality standard (NAAQS) for ozone is currently set at 70 parts per billion (70 ppb). As discussed below, two of New Mexico's ozone monitors (Carlsbad and Hobbs) have recently monitored ozone concentrations in excess of the federal standard. However, readings from monitors showing exceedances of the NAAQS do not in themselves trigger changes to permitting or other actions on the part of NMED. Instead, the vehicle for addressing exceedances of the NAAQS is through designation of particular areas as in "attainment" or "non-attainment".

The process of determining whether an area is in attainment or in nonattainment of a NAAQS is triggered when the 'design value' (DV) for a pollutant is shown to be in excess of the standard. The DV is the three-year average of the annual fourth-highest daily monitored value. Thus, each year, for each NAAQS standard, the DV is calculated by averaging the fourth highest monitored reading for the previous year with the fourth highest reading of the two previous years. The resulting calculated value is the DV for that pollutant for that year. For ozone, this calculated value is compared to the 8-hour NAAQS ozone standard, which is 0.070 ppm. If the calculated DV is 0.0705 or above, it is rounded up to 0.071 ppm (0.0704 is rounded down to 0.070). At 0.071 the design value is in exceedance of the 8-hour NAAQS ozone standard. DVs for each monitor for each year are submitted to EPA for verification.

What areas of the state are showing exceedances of the ozone NAAQS?

The Carlsbad monitor has monitored exceedances resulting in the DV exceeding the 8-hour ozone NAAQS in the years 2017, 2018, and 2019. The Carlsbad monitored design values are 0.076, 0.083, and

0.080 ppm, for each year, respectively. Similarly, the ozone monitor in Hobbs showed a DV exceedance in 2018. However, in 2019 the Hobbs monitor's DV demonstrated compliance with the NAAQS with a design value of 0.070 ppm. The first two-year (2017 and 2018) DVs for Carlsbad and Hobbs have been submitted to and verified by EPA. The 2019 DV for Carlsbad and Hobbs have been submitted but have yet to be verified by EPA.

How is the New Mexico Environment Department responding to these monitored exceedances?

The Air Quality Control Act requires the state to develop a plan, including regulations, to reduce ozone precursors in areas of the state that are exceeding 95% of the ozone standard. The AQB has been working diligently to address the rising ozone in those areas through its Ozone Attainment Initiative (OAI), which will include proposal of new regulations for reducing ozone precursors. The OAI is the vehicle through which NMED will investigate and implement strategies to ensure the region's 8-hour ozone levels return to full attainment status.

In order to fully understand the sources of VOC and NOx and what sectors are responsible for those pollutants, it is essential to determine whether and to what extent regional transport of these pollutants and mobile sources of these pollutants are contributing to the monitored exceedances. Thus, the state is currently conducting regional ozone modeling to determine what equipment, sources, and sectors are emitting the ozone precursors, and what portion of those emissions are being transported from other states and internationally. The results of this modeling will help guide what sources should be targeted for regulatory action to reduce their contribution to the ozone exceedances. The attached Fact Sheet provides further information regarding issues specific to ozone modeling.

Given the probability of contributions from oil and gas operations in the state, the first step of what will likely be several rulemakings under the OAI will be to reduce ozone precursors from the oil and gas industry located within the Permian and San Juan Basins. The Department intends to submit proposed rules to the Environmental Improvement Board by the end of 2020. It is anticipated that other rulemakings will follow, targeting emissions reductions from other industrial sectors, as well as the transportation sector.

The Department's current strategy is to rely upon the authority under its enabling statute, the Air Quality Control Act, to develop and implement the OAI and regulations to target and reduce the contributing ozone precursors. The plan and regulations implemented under the OAI will reduce those emissions, and the Department expects those reductions to reverse the current trend of rising ozone concentrations.

Questions?
Please contact Ted Schooley, Permit Section Chief, at 476-4334 or Kerwin Singleton, Planning Section Chief, at 476-4350.

NMED Fact Sheet on Ozone Modeling

How are ozone concentrations predicted?
Ozone is a secondary pollutant, meaning that rather than being directly emitted to the atmosphere from sources, it is created from a series of chemical reactions that occur between ozone precursors in the presence of sunlight. The precursor pollutants that contribute to ozone formation are nitrogen oxides (NO_X) and volatile organic compounds (VOC). Because chemical reactions must occur between precursors to form ozone, a chemical model (photochemical modeling) is required to predict ozone concentrations. Photochemical modeling is much more complex than the dispersion modeling typically performed for directly emitted pollutants.

How is ozone modeled?
Photochemical modeling (modeling chemical reactions in the presence of light) is generally conducted using gridded cells (or volumes) over the areas under evaluation. In each cell, pollutant concentrations are calculated using a series of mathematical equations that describe the physics and chemistry of the atmosphere. These mathematical equations describe emission rates in the cells, chemical reaction rates, and rates of mixing with neighboring cells. Chemical reaction rates within a cell will depend on the concentration of pollutants, the amount of sunlight, and temperature. Mixing to and from neighboring cells is determined using meteorological data and a separate meteorological model. Pollutant concentrations are then predicted by solving the set of mathematical equations.

How does ozone modeling differ from other criteria pollutant modeling?
Ozone (photochemical) modeling is significantly different from the dispersion modeling conducted for directly emitted criteria pollutants. In the atmosphere, the direction of criteria pollutants' flow and how the concentration disperses over time is controlled by meteorological factors. Dispersion modeling assumes that emissions from surrounding sources do not chemically interact. As described above, photochemical modeling predicts the mixing of NO_X and VOCs to calculate ozone concentrations.

Why is ozone modeled differently?
Chemical reactions govern the concentrations of ozone in the atmosphere. This is not true for most other criteria pollutants. Because chemical formation is the predominant source of ozone, chemistry must be considered. Additionally, interactions between precursors emitted from different sources can be quite important. Chemical formation and removal is significantly less important for other criteria pollutants.

When do we perform ozone modeling?
Due to the complexity of photochemical modeling, regulatory ozone modeling is typically performed only for the development or revision of state implementation plans (SIPs) or when there is a compelling reason for concern. This is currently the case in seven New Mexico counties, which have sources that cause or contribute to the high ozone concentrations. As discussed above, the initial step of the OAI will be photochemical modeling, to be performed by a contractor under the direction of the Bureau. This modeling effort will identify the different source categories that contribute to ozone formation and identify control strategies that will result in reduced ozone concentration in future years.

What is the cost of typical ozone modeling?
The cost of this modeling will be approximately two hundred and seventy thousand dollars ($270,000). A similar photochemical modeling project was completed for NMED, the Southern New Mexico Ozone Study, at a cost of approximately two hundred and fifty thousand dollars ($250,000).

EXHIBIT 5

AIR RESOURCES
TECHNICAL SUPPORT DOCUMENT

Carlsbad Field Office
Oil and Gas Resource Management Plan Revision

Prepared for:

Bureau of Land Management
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April 2013

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ACRONYMS

AAQS	Ambient Air Quality Standard
AERMET	AERMOD Meteorological Preprocessor
AERMOD	AERMOD Modeling System developed by the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee
AHOMAP	Albedo/haze/ozone mapping
ANC	Acid Neutralizing Capacity
API	American Petroleum Institute
APPB	Average peak prediction bias
AQMS	Air Quality Modeling System
AQRV	Air Quality Related Value
AQS	Air Quality System
ARTSD	Air Resources Technical Support Document
BART	Best available retrofit technology
BLM	Bureau of Land Management
BPIP	Building profile input program
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CA	Conservation area
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CAMx	Comprehensive Air Quality Model with Extensions
CATR	Clean Air Transport Rule
CB6	Version 6 of the Carbon Bond Mechanism
CEM	Continuous Emissions Monitoring
CENRAP	Central Regional Air Planning Association
CFO	Carlsbad Field Office
CFR	*Code of Federal Regulations*
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CONUS	Continental United States
CRVFO	Colorado River Valley Field Office
CSAPR	Cross-State Air Pollution Rule
DAT	Deposition analysis threshold
D-J	Denver-Julesburg Basin
DOE	U.S. Department of Energy

ACRONYMS (cont.)

dv	Deciview
DV	Design values
DVB	Baseline design value
DVF	Future design value
EC	Elemental carbon
EIA	US Energy Information Administration
EIS	Environmental Impact Statement
eq	Equivalents
ERG	Eastern Research Group, Inc.
FLAG	Federal Land Managers' Air Quality Related Values Workgroup
GHG	Greenhouse gas
GNB	Greater Natural Buttes
GPO	Government Printing Office
GWP	Global warming potential
H_2S	Hydrogen sulfide
ha	Hectare
HAP	Hazardous air pollutant
HFC	Hydrofluorocarbon
HNO_3	Nitric acid
hr	Hour
IDLH	Immediately Dangerous to Life or Health
IPCC	Intergovernmental Panel on Climate Change
K	Degrees Kelvin
kg/ha/yr	Kilograms per hectare per year
km	Kilometer
LAC	Limit of Acceptable Change
LOP	Life of Project
m	Meters
MATS	Model Attainment Test Software
mb	Millibars
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MEI	Maximally exposed individual
µeq/l	Microequivalents per liter
MFB	Mean fractional bias
MFE	Mean fractional error
$\mu g/m^3$	Micrograms per cubic meter
MLE	Most likely exposure

ACRONYMS (cont.)

MM5	Mesoscale Meteorological Model
MMBtu	Million British thermal units
MMscfd	Million standard cubic feet per day
MNB	Mean normalized bias
MNGE	Mean normalized gross error
MOVES	Motor Vehicle Emission Simulator
MOZART	Model for Ozone and Related Tracers
MPE	Model performance evaluation
MST	Mountain Standard Time
mtpy	Metric tons per year
N	Nitrogen
N_2O	Nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAMS	National Air Monitoring Station
NCAR	The National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEI	National Emissions Inventory
NEPA	*National Environmental Policy Act*
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHP	National Historic Park
NHS	National Historic Site
NIOSH	National Institute for Occupational Safety and Health
NM	National Monument
NMAAQS	New Mexico Ambient Air Quality Standards
NMED	New Mexico Environment Department
NO_2	Nitrogen dioxide
NO_3	Nitrate ion
NO_x	Oxides of nitrogen
NP	National Park
NPRI	National Pollutant Release Inventory
NPS	National Park Service
NRA	National Recreation Area
NSPS	New Source Performance Standards
NSR	New Source Review
NWR	National Wildlife Refuge
NWS	National Weather Service
O&G	Oil and gas

ACRONYMS (cont.)

O_3	Ozone
PAVE	Package for Analysis and Visualization of Environmental data
Pb	Lead
PBL	Planetary boundary layer
PFC	Perfluorocarbon
PGM	Photochemical grid modeling
PM_{10}	Particulate matter less than or equal to 10 microns in diameter
$PM_{2.5}$	Particulate matter less than or equal to 2.5 microns in diameter
ppb	Parts per billion
ppm	Parts per million
Project	Carlsbad Field Office RMP Revision
Protocol	Air Quality Impact Assessment Protocol
PSD	Prevention of Significant Deterioration
PSICC	Pike and San Isabel National Forests Cimarron and Comanche National Grasslands
REL	Reference exposure level
RfC	Reference Concentrations for Chronic Inhalation
RFD	Reasonably foreseeable development
RFDOTB	RFD with On-the-Books Controls Alternative
RFDOTBX	RFD with On-the Books plus Extra Controls Alternative
RFFA	Reasonably foreseeable future actions
RH	Relative humidity
RMC	Regional Modeling Center
RMP	Resource Management Plan
ROD	Record of Decision
RPO	Regional Planning Organization
RRF	Relative response factor
S	Sulfur
SF_6	Sulfur hexafluoride
SIP	State Implementation Plan
SLAMS	State and Local Air Monitoring Stations
SMOKE	Sparse Matrix Operator Kernel Emissions
SO_2	Sulfur dioxide
SO_4	Sulfate ion
TCEQ	Texas Commission on Environmental Quality
TexAER	Texas Air Emissions Repository
TOMS	Total ozone mapping spectrometer

ACRONYMS (cont.)

tpy	Tons per year (short)
TSP	Total suspended particulate
TUV	Tropospheric Ultraviolet and Visible Radiation Model
URF	Unit risk factors
URS	URS Group Inc. or URS Corporation
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
VFO	Vernal Field Office
VOC	Volatile organic compound
WA	Wilderness Area
WRAP	Western Regional Air Partnership
WRF	Weather Research and Forecasting Model
WRF-ARW	Advanced Research WRF
WRFO	White River Field Office

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1.0 INTRODUCTION

1.1. ARTSD SCOPE AND GOALS

This Air Resources Technical Support Document (ARTSD) explains the data and methodologies used to analyze potential air quality impacts resulting from future oil and gas development in the New Mexico Bureau of Land Management (BLM) Carlsbad Field Office (CFO) Planning Area. This effort included atmospheric dispersion and photochemical grid modeling to predict concentrations of specific pollutants in and around the CFO. Specifically included in this document are descriptions of the following air resource and climate change assessment methods.

- Data-gathering efforts
- Activity and equipment assumptions
- Emissions inventory development and processing
- Meteorological data processing
- Photochemical grid model performance evaluation
- Air quality modeling methods and input data
- Climate change analysis

The goals of the study are to predict air quality impacts using appropriate models, explain the modeling results, and identify any significant differences among potential oil and gas development Alternatives. Additionally, greenhouse gas (GHG) emissions are estimated and compared to existing GHG inventories.

1.2. STUDY AREA

For air quality assessment purposes, the study area focuses on New Mexico's Permian Basin for expansion of oil and gas recovery, and the CFO for other developments of BLM-managed resources. When analyzing regional air quality impacts, the Study Area extends beyond the CFO and New Mexico borders. The New Mexico portion of the Permian Basin comprises almost 14.5 million acres and is located in the south-eastern part of New Mexico. The New Mexico CFO manages approximately 2 million acres of public land and is completely contained within the Permian Basin area (see Map 1-1). The air quality modeling assessments will focus primarily on emissions and potential air quality impacts due to oil and gas developments within the New Mexico portion of the Permian Basin and other BLM-managed resources Reasonably Foreseeable Development (RFD) within the CFO. The study will analyze activities occurring or projected to occur on BLM lands, but will also include emissions and impacts from sources not located on BLM lands.

This air quality assessment focuses on emissions and potential air quality impacts due to oil and gas RFD within the CFO. According to the *Reasonable Foreseeable Development Scenario for the BLM New Mexico Pecos District* (BLM 2012), up to 16,000 new oil and gas wells could be developed with approximately 6,400 of those wells being developed on Federal mineral estate during the next 20 years. With respect to current oil and gas wells count in the Project area, the overall net new oil and gas well counts associated with the Project oil and gas RFD are approximately 2,989 Federal and 4,011 non-Federal wells. Development of several additional natural gas plants associated with the RFD may also occur in the CFO. These numbers reflect the maximum level of development that can be expected during this time period. Emissions

from one CFO RFD mining Project are also included in this analysis for determining total CFO multiple resource RFD impacts.

As shown in Map 1-1, the CFO includes lands owned by the federal government, the state of New Mexico, local governments, and private parties. With regard to federally owned lands, the BLM, National Park Service (NPS), and the U.S. Department of Agriculture (USDA) Forest Service (USFS) manage lands within the CFO. Land management affects whether emission control actions are applied. BLM management actions apply to oil and gas emission sources only on BLM-managed land. For example, oil and gas facilities located on BLM land and oil and gas facilities withdrawing resources from BLM mineral rights would be subject to BLM management actions that may reduce emissions from individual sources. In contrast, facilities located on private land and withdrawing resources from privately owned mineral resources would not be subject to BLM jurisdiction. When analyzing air resource impacts from project impacts, this ARTSD estimates effects from BLM-managed lands only; it estimates air quality effects from Federal, State, and private oil and gas development when analyzing for cumulative effects.

Table 1-1 provides the oil and gas (O&G) well break-down for mineral ownership as air pollutant emissions were developed and modeled for this air quality assessment.

Table 1-1. RFD Oil and Gas Wells Counts for Study

Mineral Ownership & Well Type Description	Well Counts
Active BLM Oil Wells in RFD Year 20	7,891
Active BLM Gas Wells in RFD Year 20	2,226
Total Active BLM O&G Wells in RFD Year 20	**10,117**
Active Non-BLM Oil Wells in RFD Year 20	15,896
Active Non-BLM Gas Wells in RFD Year 20	4,483
Total Active Non-BLM O&G Wells in RFD Year 20	**20,379**
BLM New Well Completions in RFD Year	342
Non-BLM New Well Completions in RFD Year	458
Total New O&G Well Completions in RFD Year	**800**

Source: *Reasonable Foreseeable Development Scenario for the BLM New Mexico Pecos District* (BLM 2012).

In addition to emissions increases associated with CFO RFD, this air quality assessment considers emissions and potential impacts of expected growth in oil and gas development for nearby oil and gas Basins, including the Raton Basin, San Juan Basin, Denver-Julesburg (D-J) Basin, White River Field Office (WRFO) and Colorado River Valley Field Office (CRVFO), Utah Vernal Field Office (VFO), Oklahoma and Kansas O&G Basins and Texas Basins. The assessment includes emission increases in southeast New Mexico for most criteria pollutants associated with RFD. The overall modeling analysis includes expected emission increases / decreases across the contiguous United States.

Air quality impacts are assessed at numerous receptors / grid cells. Within the CFO high potential gas development area and other nearby oil and gas fields, air quality impacts are assessed at Class II receptors. In addition, impacts are assessed at Federal Class I areas, which

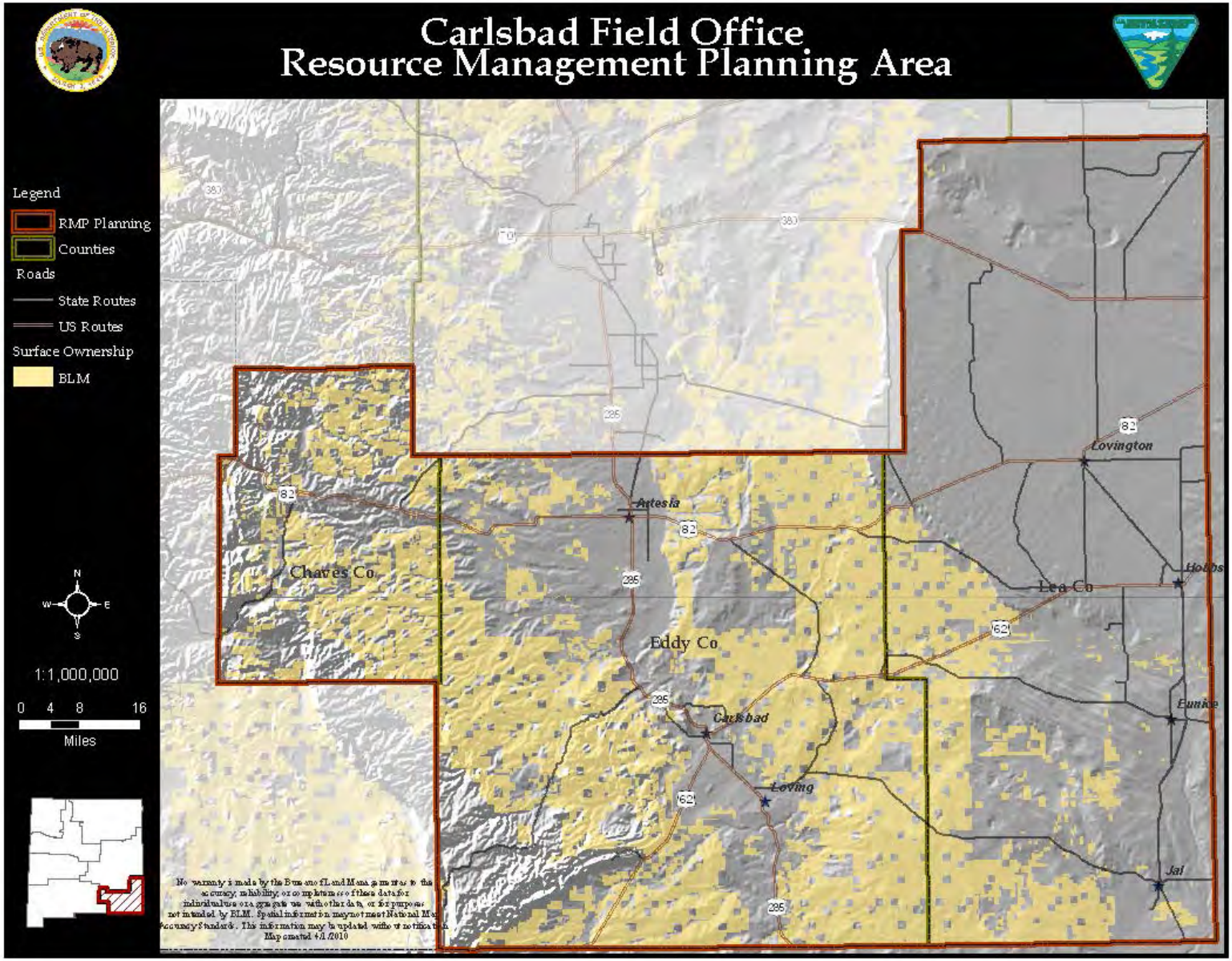
are afforded special protection under the Clean Air Act (CAA) in order to preserve good air quality and visibility. This study includes the following Class I areas, which were selected due to their close proximity to the CFO. Map 4-1 illustrates the locations of these Class I areas.

- Carlsbad Caverns National Park (NP) (NPS)
- Guadalupe Mountains NP (NPS)
- Salt Creek Wilderness (United States Fish and Wildlife Service [USFWS])
- White Mountain Wilderness (USFS)

Sensitive Class II areas do not receive special protection under the CAA, but were requested by Air Quality Stakeholders to be included in the analysis. Impacts to air quality and Air Quality Related Values (AQRVs) at sensitive Class II areas are included in the analysis for disclosure purposes only.

1.3. RELATIONSHIP TO EXISTING PLANS AND DOCUMENTS

RFD activities on BLM CFO Lands and surrounding areas are diverse and can affect a number of different resources, including air quality. The most recent documents/analyses describing current and projected activities in the area used in this analysis will be the 2012 BLM CFO RFD (BLM 2012) for the CFO and resource Study Area. BLM decisions related to resource development are guided by relevant programmatic documents generated through the National Environmental Policy Act (NEPA) actions process, including the existing Carlsbad Resource Management Plan (RMP) (BLM 1988).



Map 1-1. Carlsbad Field Office Planning Area

1.4. AIR QUALITY MODELING OVERVIEW

This air quality assessment includes comprehensive air quality modeling to predict potential ambient air quality impacts resulting from projected emissions within and beyond the CFO and New Mexico. The air quality assessment quantifies ambient concentrations of most criteria air pollutants and several hazardous air pollutants (HAPs), as well as impacts to AQRVs such as visibility, deposition, and lake chemistry. The assessment also quantifies GHG emissions, but does not model their potential impacts.

1.4.1. Pollutants and AQRVs Included in Analysis

Criteria pollutants addressed in this analysis include the following.

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Ozone (O_3)
- Particulate matter less than or equal to 10 microns in diameter (PM_{10})
- Particulate matter less than or equal to 2.5 microns in diameter ($PM_{2.5}$)
- Sulfur dioxide (SO_2)

Although lead (Pb) is a criteria pollutant, it is not included in this analysis.

HAPs and hydrogen sulfide (H_2S) near-field impacts associated with Project RFD will be modeled for this analysis. HAP analysis focused on substances emitted from the types of equipment and activities common to oil and gas development, such as engines and natural gas venting and processing. Emissions of formaldehyde and benzene, toluene, ethylbenzene, and xylenes (BTEX) were quantified and ambient concentrations were predicted for these pollutants.

Visibility was assessed by quantifying particulate and gaseous precursors that play a role in regional haze formation, including the following substances.

- Particulate matter
  - PM_{10}
  - $PM_{2.5}$
  - Elemental carbon
  - Organic carbon
  - Soils
- Gaseous precursors
  - Nitric acid (HNO_3)
  - NO_2
  - Nitrate (NO_3)
  - SO_2
  - Sulfate (SO_4)

Atmospheric deposition was assessed by quantifying deposition of total nitrogen and total sulfur, while lake chemistry impacts were determined by assessing predicted changes to acid neutralizing capacity (ANC).

GHG emissions and potential climate change impacts are also addressed in this analysis. As defined by the U.S. Environmental Protection Agency (USEPA), GHGs include the following six pollutants.

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

Of these pollutants, CO_2, CH_4, and N_2O are commonly emitted by oil and gas sources, while the remaining three GHGs are emitted in extremely small quantities or are not emitted at all. As the major component of natural gas, CH_4 emissions from oil and gas exploration, production, and transportation are considerable.

Aggregate GHG emissions are discussed in terms of carbon dioxide equivalent (CO_2e). Each GHG has a global warming potential (GWP). As defined by USEPA, the GWP provides a "ratio of the time-integrated radiative forcing from the instantaneous release of one kilogram of a trace substance relative to that of one kilogram of CO_2" (GPO 2012a). In other words, the GWP accounts for the intensity of each GHG's heat trapping effect and its longevity in the atmosphere. The GWP provides a method to quantify the cumulative effect of multiple GHGs released into the atmosphere by calculating CO_2e for the GHGs. USEPA's GWPs are provided in Table 1-2 and were determined on a 100-year basis. These GWPs are set forth in USEPA regulations within Title 40 of the *Code of Federal Regulations* (CFR), Part 98.

Table 1-2. GHGs Regulated by USEPA and Global Warming Potentials

Air Pollutant	Chemical Symbol or Acronym	Global Warming Potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons	HFCs	Varies
Perfluorocarbons	PFCs	Varies
Sulfur hexafluoride	SF6	23,900

Source: GPO 2012a, Table A-1.

This analysis quantifies emissions of CO_2, CH_4, and N_2O and describes management actions to reduce emissions of these three GHGs. In order to create a meaningful analysis of GHG emissions associated with each of the CFO oil and gas development Alternatives, these emissions are compared to state and national GHG emission inventories. Modeling to predict climate change impacts is beyond the scope of this air resource analysis.

To date, USEPA has not mandated stationary source GHG emission reductions or set National Ambient Air Quality Standards (NAAQS) for these pollutants. However, the agency requires certain GHG emission sources and some GHG suppliers to report GHG emissions. Beginning in 2011, large stationary sources of GHGs were required to obtain air quality permits from local, state, or federal air quality agencies (GPO 2010a).

1.4.2. Air Quality Models

In order to provide a comprehensive assessment of air quality impacts, air quality modeling was performed using two primary models: AERMOD and CAMx (Comprehensive Air Quality Model with Extensions). Each of these models shown in Table 1-3 is approved by USEPA and is well suited to its specific task in predicting ambient pollutant concentrations for certain types of pollutants and modeling situations. Analyzed impacts included comparisons to the NAAQS and state ambient air quality standards as well as to Prevention of Significant Deterioration (PSD) Class I and Class II increments. PSD increment demonstrations are for informational purposes only, and are not regulatory PSD increment consumption analyses.

Table 1-3. Models, Pollutants, and Assessed Impacts

Model	Model Type	Pollutants Modeled	Analyzed Impacts
AERMOD	Near-Field Gaussian	CO, NO_2, PM_{10}, $PM_{2.5}$, SO_2	NAAQS
		NO_2, PM_{10}, SO_2, $PM_{2.5}$	PSD Class I and Class II Increment Consumption (non-regulatory)
		HAPs (Formaldehyde, BTEX)	HAP Risk
CAMx	Far-Field Eulerian	O_3, NO_2, CO, PM_{10}, $PM_{2.5}$, SO_2	NAAQS
		NO_2, PM_{10}, $PM_{2.5}$, SO_2	PSD Class I and Class II Increment Consumption
		Elemental Carbon, Organic Carbon, Soils, PM_{10}, $PM_{2.5}$, HNO_3, NO_2, NO_3, SO_2, SO_4	Class I Visibility (includes sensitive Class II areas)
		Total Sulfur Total Nitrogen	Deposition
		Acid Neutralizing Capacity	Lake Chemistry

AERMOD and CAMx meteorological data and modeling methodologies are described in more detail within this ARTSD. Before discussing the modeling methodologies, a discussion of emission inventory development is included in Section 2.0.

1.4.3. Emissions Inventory Development Tasks

Emissions inventory development for the air quality assessments included estimating the following emissions.

- Project-related emissions inventories for criteria pollutants, HAPs, and GHGs
- Cumulative emissions inventories for criteria pollutants from nearby oil and gas development
- Processing cumulative emissions inventories to account for all non-oil and gas related air pollutant emissions sources

1.4.4. Air Quality Assessments

Outputs from the air quality models were used to assess the potential impacts on near- and far-field air quality and AQRVs. The following assessments were conducted.

- AERMOD modeling to predict near-field Project future air pollutant concentrations resulting from reasonably foreseeable oil and gas development emissions.
- Sparse Matrix Operator Kernel Emissions (SMOKE) and CAMx modeling to predict far-field Project and cumulative future air pollutant concentrations, including ozone, resulting from reasonably foreseeable oil and gas development emissions, as well as cumulative emissions from oil and gas and other types of stationary sources.
- Comparison of potential Project and cumulative predicted air pollutant concentrations to applicable NAAQS and to State Ambient Air Quality Standards that are more stringent than the NAAQS.
- Comparison of potential Project and cumulative air quality impact to PSD Class I and Class II increments. These demonstrations are for informational purposes only, and are not regulatory PSD increment consumption analyses.
- Prediction of future visibility changes within mandatory Federal Class I areas and sensitive Class II areas listed above.
- Prediction of future atmospheric deposition of total sulfur and nitrogen within mandatory Federal Class I areas and sensitive Class II areas.
- Prediction of future acid neutralizing capacity (ANC) changes to sensitive lakes.

1.5. DOCUMENT ORGANIZATION

The remainder of this document is organized as follows. Section 2.0 describes the data sources and methods used to develop project-specific and regional emissions inventories (Section 4.4 includes specific emissions inventory processing information for SMOKE and CAMx modeling). Sections 3.0 and 4.0 explain the modeling methodologies specific to AERMOD and SMOKE/CAMx modeling, respectively. Section 5.0 includes a discussion of climate change and GHG emissions associated with this Project. Finally, Section 6.0 summarizes air resource impacts identified during this assessment.

2.0 EMISSIONS INVENTORIES

2.1. EMISSIONS INVENTORIES INTRODUCTION

Development of the comprehensive emissions inventory was a critical first step for the CFO air quality assessment. This section describes the data sources and methods that were used to develop the multiple emission inventories needed for this analysis.

2.2. EMISSIONS INVENTORY TYPES

The following different types of emissions inventories were developed for the BLM CFO air quality modeling assessment:

- BLM CFO and cumulative base year 2008 emissions inventory — this inventory includes emissions sources and rates as existed in the year 2008, and were comprised of emissions source inventories for the entire United States (U.S.) that have been developed and are representative of year 2008. Emissions inventories and estimates including National Emissions Inventory (NEI), Western Regional Air Partnership (WRAP) and Central Regional Air Partnership (CENRAP) inventories, actual source emissions monitoring data, 2008 wildfire and biogenic inventories were processed and aggregated to develop a base year 2008 emissions inventory for the photochemical grid modeling (PGM) analysis.
- BLM CFO RFD (Project) Inventory — this emissions inventory includes Project-specific emissions associated with future development in the New Mexico portion of the Permian Basin or CFO located on BLM lands. In particular, CFO RFD emissions include (among others) emissions sources related to oil and gas development (drilling engines, well venting, gas dehydration, central treatment facilities, engines for gas compression, produced water), and fugitive dust and exhaust emissions from construction activity and land development and vehicle traffic associated with oil and gas development. Emissions estimates were also included for CFO mining RFD. BLM air quality alternatives management actions will apply to the oil and gas activities accounted for in this Project inventory.
- Non-BLM CFO RFD Inventory — this emissions inventory also focuses on emissions from future oil and gas development as well as expansions of other resources, and will account for most of the resources in the Project inventory. This inventory includes emissions from RFD sources located on lands other than the BLM.
- Reasonably Foreseeable Future Actions (RFFA) Inventory — this emissions inventory includes future projected emissions for all other sources not included in the RFD inventories. RFFA sources include emissions sources that are projected to exist concurrently with RFD sources. Emissions source inventories for the entire U.S. were included in the RFFA inventory. Future projected NEI, WRAP, CENRAP (CENRAP 2008) and other developed inventories for all areas that intersect the modeling domains were included. These datasets include emissions estimates for a wide range of source types including: large power generating and industrial, mining, livestock management, farming, on-road mobile, off-road construction, biogenic and wildfire.

For all pollutants other than ozone and $PM_{2.5}$ (far-field assessment), the modeled impacts associated with CFO BLM RFD emissions were be added to New Mexico Environment

Department (NMED) provided monitored pollutant concentrations found in the NMED air quality assessment recommendations (NMED 2010a). This dataset will cumulatively serve as a future background condition before the addition of the CFO BLM RFD related modeled emissions.

2.3. BASE YEAR 2008 EMISSIONS INVENTORY

This section provides a brief overview of the emissions data inventories and methodologies that were used in the development of a base year 2008 emissions inventory for this analysis. This inventory was developed to accurately portray the year 2008 U.S. emissions at various temporal and spatial scales. Special consideration was given to 2008 emissions inventories that have been developed, including the following:

- 2008 NEIv1.5 emissions inventories SMOKE-ready files for area (non-point), non-road mobile, and point source categories. These emissions files were downloaded from the EPA Emissions archives (USEPA 2012a).
- NEI point source emissions files were supplemented with actual day-specific Continuous Emissions Monitoring (CEM) data for year 2008 to account for major industrial point sources.
- 2008 fire emissions were processed using the fire emissions data from the Bluesky Framework. These emissions include location specific daily estimates of wildfire emissions, along with vertical distribution of the fire plumes.
- Day-specific 2008 biogenic emissions were calculated using the MEGAN2.10 biogenics model (Model of Emissions of Gases and Aerosols from Nature). These emissions used the hourly modeled meteorological data to calculate gridded hourly biogenic emissions estimates for each day of the 2008 modeling episode.
- 2008 on-road mobile emissions calculated using MOVES2010a (Motor Vehicle Emission Simulator). MOVES was run using the emissions inventory mode for each county in the US, using representative meteorological data for a weekday/weekend day pair for each month of the modeling episode.
- WRAP Phase III 2006 oil and gas inventories scaled to 2008 using development and production data for basins in Colorado (D-J, San Juan, Piceance), New Mexico (San Juan), and Utah (Uintah).
- 2008 CENRAP Study oil and gas inventories for Kansas, Oklahoma, and the Anadarko Basin in Colorado (CENRAP 2008).
- 2008 TexAER (Texas Air Emissions Repository) oil and gas produced water related emissions for Texas added to NEI oil and gas emissions inventory.
- 2008 oil and gas emissions estimates developed from 2009 (ERG 2009) and 2010 (ERG 2010) ERG Texas – Permian Basin Studies and BLM supplied information for oil and gas activities for the Permian Basin area of New Mexico.

See Appendix A for detailed emissions estimates for base year 2008 oil and gas related emissions.

2.4. FUTURE YEAR EMISSIONS INVENTORIES

The future year emissions inventories were developed in two parts. The first part is the future year base case inventory. This inventory contains all of the future year emissions estimates with the exception of the BLM Permian Basin oil and gas RFD and CFO mining RFD emissions. The BLM oil and gas RFD emissions will be a part of the future year alternatives inventories.

2.4.1. Future Year Base Case Emissions Inventory Development

The future year base case inventory consists of the RFFA inventory and the non-oil and gas RFD inventory. It also excludes BLM CFO mining RFD project.

2.4.1.1. RFFA Inventory

As discussed earlier, the RFFA emissions inventory includes emissions for all other future projected sources not included in the BLM CFO RFD inventories. RFFA sources include emissions sources that are projected to exist concurrently with RFD sources. Emissions source inventories for the entire U.S. were included in the RFFA inventory.

Future year emissions for area (non-point), nonroad, most oil and gas, and point source categories were developed using the 2005 NEIv4.3 inventory projected to 2017. MOVES2010a was used to calculate 2017 on-road mobile emissions. Biogenic and wildfire emissions will be held at 2008 levels.

Several of the oil and gas basins in the 2017 RFFA inventory were updated using newer data sources for projections beyond year 2017. The modifications to the inventories for these basins are discussed in the following section.

San Juan Basins – For the Colorado and New Mexico San Juan Basins, oil and gas emissions estimates are based on the WRAP Phase III 2012 emissions inventories controlled estimates using actual year 2011 oil and gas production values and were scaled out to future years using projected San Juan Basin RFDs. These represent unpermitted area source activities for the WRAP inventories. Most of the WRAP Phase III 2012 controlled emissions were scaled using RFD well counts (plus existing wells); other emissions values were scaled using projected oil and gas related production.

Denver-Julesburg Basin – For eastern Colorado's D-J Basin, WRAP Phase III year 2020 projected and controlled emissions inventories were used for projected oil and gas development.

Comanche National Grasslands – For eastern Colorado's Comanche National Grasslands, emissions estimates reflecting the recent USFS Pike and San Isabel National Forests Cimarron and Comanche National Grasslands (PSICC) Oil and Gas Leasing Environmental Impact Statement (EIS) 15-year projected RFD were used for projected oil and gas development.

Uinta Basin – For Utah's Uinta Basin, emissions inventories were developed based on the recent Greater Natural Buttes (GNB) EIS Project. Emissions inventories for other Uinta Basin areas were developed using the GNB Project projected RFD estimates (well counts and production) to scale the WRAP Phase III inventories.

Piceance Basin – For western Colorado's Piceance Basin, URS used BLM RFD or RMP year 2028 projected emissions inventories.

Eagle Ford Shale and Barnett Shale – Growth factors projected out to year 2030 were estimated based on the net oil and gas production increase using the Department of Energy

(DOE) Annual Energy Outlook for 2011. The growth factors were applied to baseline year 2008 for these areas.

CENRAP States (Oklahoma and Kansas) and Other Basins (not included above) – The DOE Annual Energy Outlook for 2011 was reviewed and it was determined that oil and gas development for these States should remain steady or slightly decline over the next 20 years. For this reason, the baseline year 2008 emissions estimates were modeled in the future scenarios.

See Appendix H for detailed emissions estimates for RFFA oil and gas related emissions.

In addition to updates for the projected oil and gas in the nearby States, emissions inventories were developed for local aggregate and potash mining and off-road vehicle recreation in the CFO area. These developed emissions inventories replaced estimates for these categories in the projected year 2017 datasets for the CFO counties. Off-road recreation data was provided by BLM CFO recreation management personnel and mining data was obtained from the New Mexico Mining and Minerals Division. See Appendix C for detailed CFO RFFA aggregate mining and recreation emissions estimates included in the analysis.

2.4.1.2. Non-Oil and Gas RFD Emissions Inventory Development

A non-oil and gas-related RFD emissions inventory for the CFO BLM was based on BLM estimates of projected mining RFD. BLM CFO mining personnel provided a copy of the Ochoa Mine Project EIS and projected emissions extracted directly from this EIS were modeled as part of the Project RFD emissions inventory. See Appendix F for detailed Ochoa Mine emissions estimates included in the analysis.

RFD emissions calculations for a source vary depending on the expected level of emission control as the result of air quality management actions that are applicable to the source. For all sources, the minimum level of emission control follows compliance with applicable Federal and State requirements. In addition, sources located on BLM land are subject to expected BLM air quality management actions designed to manage air quality resources. In contrast, emissions calculations for RFD sources not located on BLM land are based only on State and Federal requirements, unless explicitly defined by the BLM or USFS.

2.4.2. Future Year Alternatives Emissions Inventory Development

Two modeling scenarios (Alternatives) were performed as a part of this analysis. The first scenario (RFDOTB) includes the future year base case emissions plus the BLM oil and gas RFD emissions inventory. The RFDOTB scenario accounts for on-the-books emissions control regulations. The second scenario (RFDOTBX) includes all the sources and controls in the RFDOTB scenario plus accounts for additional BLM approved emissions controls in Project oil and gas RFD sources. See the following Table 2-1 for a more detailed description of the emissions controls for each modeling scenario. The air quality management actions included in these Alternatives would apply only to activities located on lands subject to BLM jurisdiction.

Table 2-1. Air Quality Alternative Management Actions

Source Type	Alternative RFD On-the-Books Controls (RFDOTB)	Alternative RFD On-the-Books with Extra Management (RFDOTBX)
Goals	Manage oil and gas activities to comply with all applicable local, State, Tribal, and Federal laws, regulations, standards, and implementation plans. Manage oil and gas activities to protect air quality and, within the scope of BLM's authority, minimize emissions that cause or contribute to violations of air quality standards or that negatively impact air quality-related values (AQRV) (e.g., acid deposition, visibility). Manage oil and gas activities to minimize emissions of greenhouse gases.	Manage oil and gas activities to comply with all applicable local, State, Tribal, and Federal laws, regulations, standards, and implementation plans. Manage oil and gas activities to protect air quality and, within the scope of BLM's authority, minimize emissions that cause or contribute to violations of air quality standards or that negatively impact air quality-related values (AQRV) (e.g., acid deposition, visibility). Manage oil and gas activities to minimize emissions of greenhouse gases.
Objectives	Manage oil and gas activities to meet ambient air quality standards.	Efforts taken to manage oil and gas activities to allow for minor increases in ambient air quality levels. Intensify air quality monitoring in the BLM Carlsbad Field Office (CFO).
Level of Development	Emissions would reflect development of approximately 16,000 oil and gas wells (6,400 BLM and 9,600 non-BLM).	Emissions would reflect development of approximately 16,000 oil and gas wells (6,400 BLM and 9,600 non-BLM).
Drill Rig Engines	Drill rig and frac pump engines would meet New Mexico and EPA requirements.	Within one year of the Record of Decision (ROD), all new and existing drill rig, completion rig, work-over rig and frac pump engines would meet EPA Tier 4 Nonroad Diesel Engine Emission Standards or meet equivalent emission standards, regardless of when they begin operation in the CFO.
Well Completion and Testing	Following EPA New Source Performance Standards (NSPS) Air Rules for the Oil and Gas Industry (2012), beginning, January 1st, 2015, operators will be required to capture the natural gas associated with hydraulically fractured natural gas wells completions, which can be accomplished by green completion practices. This would be required unless the need for exemption can be documented.	Green completions (includes re-completions and blow-downs activities), involving recovery and clean-up of natural gas, would be required for all natural gas and oil wells unless the need for an exemption can be documented. This management action extends the EPA NSPS Rule (2012) for capturing the natural gas associated with hydraulically fractured natural gas wells completions to oil wells, all wells re-completions and blow-downs activities.

Table 2-1. Air Quality Alternative Management Actions

Source Type	Alternative RFD On-the-Books Controls (RFDOTB)	Alternative RFD On-the-Books with Extra Management (RFDOTBX)
Construction Activities	No similar action.	During construction activities (including well drilling, completion and work-over), adequate emissions control applications (chemical dust suppressant and / or water) to construction areas and associated resource roads would be required to prevent at least 50% of fugitive dust from vehicular traffic, equipment operations, or wind events. The authorized officer may direct the operator to change the level and type of treatment if dust abatement measures are observed to be insufficient to prevent fugitive dust. In addition, fugitive dust control plans would be required.
Tanks	Oil tanks, condensate tanks, and produced water tanks would be required to meet applicable EPA NSPS (2012) emission standards such that new storage tanks with volatile organic compounds (VOC) emissions of 6 tons per year or more must reduce VOC emissions by at least 95 percent.	Emission controls would be required for oil tanks, condensate tanks, and produced water tanks, without regard to the quantity of uncontrolled VOC emissions from the equipment. VOC emissions from oil tanks, condensate tanks and produced water tanks would be reduced by at least 95 percent from uncontrolled emission levels.
Compressor Engines	New and modified centrifugal or reciprocating compressors at gas gathering and boosting stations, well sites and gas processing plants will be required to meet EPA NSPS (2012) and New Mexico Environment Department (NMED) requirements and standards.	Same as Alternative RFDOTB.
Glycol Dehydrators	Glycol dehydrators located at well sites, gathering and boosting stations, gas processing plants, and natural gas transmission stations will be required to meet applicable EPA National Emissions Standards for Hazardous Air Pollutants (NESHAP) for Oil & Natural Gas Production (2012).	In addition to EPA NESHAP for Oil & Natural Gas Production (2012) applicable to glycol dehydrators, emission controls would be required for glycol dehydrators, without regard to the location of the equipment or the quantity of uncontrolled VOC emissions from the equipment. VOC emissions from glycol dehydrators would be reduced by at least 95 percent from uncontrolled emission levels.
Air Monitoring	No similar action.	The BLM - CFO will cooperate with the NMENV in identifying air monitoring needs, as well as air monitor installation and operation.

Table 2-1. Air Quality Alternative Management Actions

Source Type	Alternative RFD On-the-Books Controls (RFDOTB)	Alternative RFD On-the-Books with Extra Management (RFDOTBX)
Fugitive Dust Control	No similar action.	During normal operations / post-development activities (including product hauling and operations maintenance), adequate emissions control applications (chemical dust suppressant, gravel and / or water) to associated resource roads would be required during dry weather periods to prevent at least 50% of fugitive dust from vehicular traffic, equipment operations, or wind events. The authorized officer may direct the operator to change the level and type of treatment if dust abatement measures are observed to be insufficient to prevent fugitive dust. In addition, fugitive dust control plans would be required.
Compressor Electrification	No similar action.	At least 70 percent of gas compression at compressor stations (gathering, boosting, transmission and gas plants) and well heads would be powered by electricity. Any new electricity transmission lines would be buried underground in existing rights-of-way.
Well Head Pump Electrification	No similar action.	At least 70 percent of CFO oil well head pumps would be powered by electricity. Any new electricity transmission lines would be buried underground in existing rights-of-way.
Water Injection Pump Electrification	No similar action.	At least 70 percent of water injection pumps would be powered by electricity. Any new electricity transmission lines would be buried underground in existing rights-of-way.
Pneumatic Controllers	Pneumatic controllers at gas gathering and boosting stations, well sites and gas processing plants will be required to meet EPA NSPS (2012) requirements. This would be required unless the need for exemption can be documented.	Same as Alternative RFDOTB.
Gas Processing Plants	New and modified natural gas sweetening units at gas processing plants will be required to meet EPA (2012) requirements.	Same as Alternative RFDOTB.

2.4.2.1. Project Oil and Gas RFD Emissions Inventory Development

This section provides a brief explanation of the oil and gas RFD emissions inventory development for the BLM CFO RMP air quality assessment.

Oil and gas-related RFD emissions inventories for the BLM CFO and New Mexico portion of the Permian Basin were based on RFD estimates of additional oil and gas development expected during the next 20 years (2012-2032). The methods used to develop estimates of future oil and gas development is described in applicable RFD documents, including the 2012 BLM CFO RFD.

The locations of emission sources were estimated following guidance and information from the Project oil and gas RFD. Factors that were considered when identifying potential emissions source locations include expected well spacing, areas of high potential development, topography and habitat-related restrictions. Because the exact locations of the emissions sources will not likely be known, the source locations that were used in the air quality models will not represent the actual locations of potential future emissions sources. The projected gas plants were modeled near expected high potential development areas of oil and gas.

This modeling analysis assesses annual average air quality impacts, as well as short-term impacts. Modeling was based on emissions estimates for one single year of activity. The RFD final year 20 was chosen for modeling oil and gas sources within the New Mexico portion of the Permian Basin.

The following sub-sections provide overview information for the oil and gas activities, assumptions and values used to develop Project oil and gas RFD emission inventories for the analysis. More detail for the values and assumptions used for developing emissions for these activities can be found in Appendix I.

2.4.2.1.1 Drilling and Completion Engine Emissions

Diesel drilling engine emissions of oxides of nitrogen (NO_x), $PM_{2.5}$, PM_{10}, volatile organic compounds (VOCs), and CO were calculated based on USEPA's non-road engine regulations (http://www.epa.gov/otaq/nonroad-diesel.htm). These regulations apply to newly manufactured engines and are structured as a tiered program by horsepower rating and year of manufacture (from 2000 forward). The Tier 1 standards were phased in from 1996 to 2000. Tier 2 standards took effect from 2001 to 2006, Tier 3 standards (for smaller engines only) applied from 2006 to 2008, and Tier 4 standards are being phased in from 2008 to 2015.

Similarly, emission estimates for SO_2 for all engines was based on emission factors contained in USEPA's AP-42. Drilling engine SO_2 emissions take into consideration USEPA's diesel fuel regulations, which require a reduction in sulfur content to 15 parts per million (ppm). For each development alternative, the number of drilling engines was based on the expected number of well pads to be drilled, anticipated engine loads, and assumptions regarding the scheduling of drilling activities over the life of the Project (LOP).

For this analysis, drilling emissions estimates for CO, NO_x, PM_{10}, $PM_{2.5}$ and VOC were derived using Tier 4 engine factors information from the ERG Texas drilling emissions Study (ERG 2009). All other values (except GHGs) were taken directly from a Table in the ERG Texas drilling Study (ERG 2009). GHG rates were determined by multiplying 2009 American Petroleum Institute (API) Compendium (API 2009) / NONROADS drill rigs emissions factors ratios (GHG/NOx) by the EPA Tier 4 Nonroad Diesel Engines Emissions Standard for NOx (175 <= hp <= 750 hp).

[illegible] [illegible] Wellhead Compressor and Oil Pump Engines

Wellhead compressor and oil pump engines emissions were developed using Permian Basin oil and gas operations information from the ERG Study (ERG 2010). Compressions requirements (per gas production level) and pumpjack engine information representative of Permian Basin were taken directly from the Report. GHG emissions factors for equivalent engines were obtained from the API Compendium (API 2009).

[illegible] [illegible] Glycol Dehydrators

Glycol dehydrator related emissions were developed using Permian Basin oil and gas operations information from the ERG Study (ERG 2010). Emissions data and information for vent and boiler exhaust as well as dehydrator representative of Permian Basin were taken directly from the Report. GHG emissions factors for equivalent engines were obtained from the EPA AP-42 (USEPA 1998). The dry gas flow rate was calculated from the annual RFD expected gas recovery for the Project area.

[illegible] [illegible] Fugitive Dust [illegible]

PM_{10} and $PM_{2.5}$ fugitive dust emissions were estimated and modeled for construction of new roads, well pads and other infrastructure. Emission rates were calculated using AP-42, Sections 13.2.3 and 13.2.4 methodologies and emission factors for heavy construction operations and material handling. Total acreage of land development and miles of new roads built per year were calculated for the New Mexico portion of the Permian Basin with BLM approved estimates and resource road dimension parameters.

Construction was expected to occur during the day, and emissions from vehicle traffic were distributed over a 24-hour period for regional PGM modeling and were released during daylight hours for the AERMOD particulate matter modeling analyses. Emissions were calculated assuming dust control for certain types of land development as provided by the BLM as part of the air quality alternatives.

Fugitive dust emissions were adjusted to account for precipitation when predicting potential annual average or number of days of impacts. Fugitive dust emissions from land development were distributed equally across area type sources within the high potential oil and gas development area for the PGM regional modeling analyses.

Fugitive dust emissions for Colorado, Kansas, New Mexico, Oklahoma, Texas, and Utah were scaled prior to modeling using the EPA Transport Factor for each county.

[illegible] [illegible] Fugitive Dust [illegible] Traveled Road

PM_{10} and $PM_{2.5}$ fugitive dust emissions were estimated and modeled for vehicle travel on unpaved roads. Emission rates were calculated using AP-42, Section 13.2.2 methodologies and emission factors for vehicle traffic on unpaved roads. Total annual miles traveled and surface silt content were estimated for the New Mexico portion of the Permian Basin with BLM provided guidance and values.

As primary road traffic was expected to occur both during day and night (particularly during well drilling), emissions from vehicle traffic were distributed over a 24-hour period. Emissions were calculated assuming dust control for certain types of roads as provided by the BLM as part of the air quality alternatives.

Fugitive dust emissions were adjusted to account for precipitation when predicting potential annual average or number of days of impacts. Fugitive dust emissions were also adjusted for

frozen and muddy roads during the colder months (if applicable). Fugitive dust emissions from roads were distributed equally across area type sources within the high potential oil and gas development area for the PGM regional modeling analyses.

Fugitive dust emissions for Colorado, Kansas, New Mexico, Oklahoma, Texas, and Utah were scaled prior to modeling using the EPA Transport Factor for each county.

[illegible] Construction and Mobile Tailpipe Related Emissions

Combustion related emissions were estimated and modeled for construction and vehicle travel activities. Emissions rates were calculated using NONROADS2008a and MOVES2010 for construction and mobile activities, respectively.

Construction was expected to occur during the day, and emissions from construction equipment and vehicle traffic were distributed over a 24-hour period for regional PGM modeling and were released during daylight hours for AERMOD analyses.

[illegible] Venting Emissions

Emissions calculations for venting from well completion, blow-down or work-over activities were estimated for Project oil and gas RFD sources. VOC and HAPs emissions related to venting were included in the air quality modeling analyses. Venting rates and temporal durations for each blow-down activities were determined using values from CENRAP and Texas Commission on Environmental Quality (TCEQ) studies and guidance. VOC, HAPs and GHG venting emissions were estimated using Permian Basin specific speciated gas analyses and information taken directly from New Mexico well completion reports (amount of gas vented for well completion). Any provisions of the oil and gas development air quality alternatives related to venting (e.g., green completions), are reflected in the emission calculations.

[illegible] Tank Related Emissions

Emissions from produced water and oil tanks were estimated for Project RFD oil and gas production. Emissions for oil tanks were estimated using Permian Basin oil and gas operations information from the ERG Study (ERG 2010), and water tank flashing emissions were calculated using emissions factors derived for nearby state Colorado oil and gas operations. Oil truck load-out emissions were estimated using EPA AP-42 Section 5.2.2.1.1 Equation 1 and factors obtained from ERG Study (ERG 2010).

[illegible] Heaters

Emissions from well pad heaters were estimated for Project oil and gas RFD. Emissions for these heaters were estimated using Permian Basin oil and gas operations information from the ERG Study (ERG 2010) and from the 2008 CENRAP Study (CENRAP 2008). Emissions factors from EPA AP-42 Section 1.4 (Natural Gas Combustion) and gas heat content taken from Permian Basin Artesia Gas Plant gas sample were used to estimate emissions associated with well pad heaters.

[illegible] Fugitives and Pneumatic Devices

Emissions associated with well pad fugitives and pneumatic devices were estimated for Project RFD oil and gas wells. Emissions factors from EPA Protocol for Equipment Leak Emissions Estimates (USEPA 1995) and wellhead component counts obtained from oil and gas operators in nearby Anadarko Basin were used to estimate emissions for well pad equipment leak fugitives. Information from CENRAP (CENRAP 2008) and ERG Study (ERG 2010) was used to develop emissions for pneumatic devices.

2.4.1.1 Gas Plants

For gas plant related emissions, Permian Basin gas plants operating permits were evaluated to determine a "model" gas plant to be used to account for future oil and gas centralized processing. Specifically, the recently permitted Linam Ranch Gas Plant (NSR Permit No:0039M6) located in the CFO was used as the model gas plant. Current permitted gas plant throughputs were scaled based on expected future net gas production to determine the potential number of additional future "model" gas plants that were needed to accommodate the future gas production. GHG emissions for engines were estimated based on API Compendium emissions factors (API 2009) using engine specific information from the permitted Facility.

2.4.1.2 Other Sources

Other Project emission sources that could be included in the RFD emissions inventory include amine units, wind erosion, well pad reclamation and road maintenance. And, where applicable, these emissions were calculated for both construction and production activities.

2.4.1.3 Gas Processing Facilities and RFD Drill Rigs

Gas processing facilities and drill rigs were treated as point sources in the model and located in areas of high potential oil and gas RFD. For Project sources, stack parameters reflect typical stack characteristics for oil and gas point sources. In contrast, emissions from producing and construction of well pads, and resource roads were evenly distributed across each clustered development area. Because the exact location of the emission sources would be determined when actual development occurs, the source locations used in the model do not represent the actual location of the emission sources in the development plans.

2.4.1.4 RFD Emissions Controlled to Meet BLM Standard

RFD emissions calculations for a source vary depending on the expected level of emission control as the result of air quality management actions that are applicable to the source. For all sources, the minimum level of emission control assumed compliance with applicable Federal and State requirements.

2.4.1.5 Greenhouse Gases

Emissions of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), were calculated from the relevant Project sources as listed above. Greenhouse gas emissions factors and guidance were obtained from the Intergovernmental Panel on Climate Change, the API (API 2009), NONROADS, MOVES, where available, and alternately from guidance provided by USEPA AP-42. Methane emissions related to venting or fugitive gas release were based on Permian Basin specific gas analyses. Greenhouse gas emissions from the Project sources were compared to state-wide totals obtained from the NMED or USEPA.

2.5. EMISSIONS INVENTORIES DEVELOPMENT QUALITY ASSURANCE / QUALITY CONTROL

Project Tasks followed the rigorous URS internal validation and quality assurance/quality control (QA/QC) procedures for developing emissions inventories. The QA/QC procedure systematically conducts checks for data entry errors, completeness checks, consistency checks, double counting, reasonableness tests and quality control checks.

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3.0 AERMOD NEAR-FIELD MODELING

A near-field ambient air quality impact assessment was performed to quantify and evaluate maximum pollutant impacts within the vicinity of the Project Area resulting from construction and production emissions. The near-field analysis predicts impacts that could occur within several kilometers of clustered oil and gas development areas. USEPA's recommended guideline model, AERMOD (version 12060), was used to assess near-field impacts. Near-field modeling followed the procedures explained in *BLM Carlsbad Field Office – Permian Basin Resource Management Plan Air Quality Impacts Analysis – Air Quality Modeling Protocol* (BLM-URS 2012), except where noted below. As outlined in the Protocol, the near-field modeling analyses followed Guidance and recommendations provided in the New Mexico Air Quality Bureau Air Dispersion Modeling Guidelines (NMED 2011).

Near-field modeling predicted long-term and short-term averaged ambient concentrations for the following criteria pollutants: CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$. HAP concentrations and potential human health risk were estimated for benzene, ethylbenzene, formaldehyde, n-hexane, toluene, and xylenes. In addition, H_2S and TSP concentrations were estimated to address New Mexico Air Quality Standards and Guidelines.

The following bulleted list highlights some of the assumptions and methodologies that were applied for the near-field modeling assessment:

- Near-field modeling was not performed for each air quality Alternative. Rather, modeling was performed based on reasonable emissions that could conceivably occur under a restrictive combination of emissions scenarios.
- Near-field modeling was completed for two "typical" near-field (~ four square mile area) clustered oil and gas layouts. These two analyses were performed because of the clustered oil and gas development that can currently be found in near-field sections (~ four square mile area) in the Basin: one with minimal natural gas operations (i.e. mostly oil wells), and then a balanced oil and gas scenario (~50% oil and ~50% gas) that can be found within the Basin.

Additional information for how the near-field modeling domains were established and setup is provided later in this report in section "Near-Field Modeling Setup and Emissions".

3.1. MODELING INPUTS AND METHODOLOGY

3.1.1. Meteorology

Meteorological surface data was collected from a National Weather Service (NWS) ASOS at Carlsbad, New Mexico Airport / Cavern City Air Terminal (WBAN: 93033) located at 32.33N, 104.26W for five years (2006 – 2010). Data collected at the surface meteorological station for the creation of the near-field modeling dataset included numerous parameters such as wind speed, wind direction, temperature, relative humidity, cloud cover, atmospheric pressure, visibility, and precipitation. Upper air radiosonde data was collected by the National Weather Service in Midland, Texas, located at 31.93N, 102.20W. The complete aggregation of raw monitored meteorological data values was processed by AERMET (version 11059) with monthly values for albedo, Bowen ratio, and surface roughness length derived specifically for the Cavern City Air Terminal to produce an AERMOD ready dataset.

The wind rose shown in Figure 3-1 illustrates the 2006-2010 five-year compilation of wind direction and speed frequencies for the Carlsbad, New Mexico Airport surface meteorological station. The average wind speed over the five year period was approximately 3.94 meters per second. For the five year period, winds most frequently blew from the southeast quadrant (approximately 25 percent of the time from southeast direction), and stronger / faster winds blew from the west to west-southwest directions.

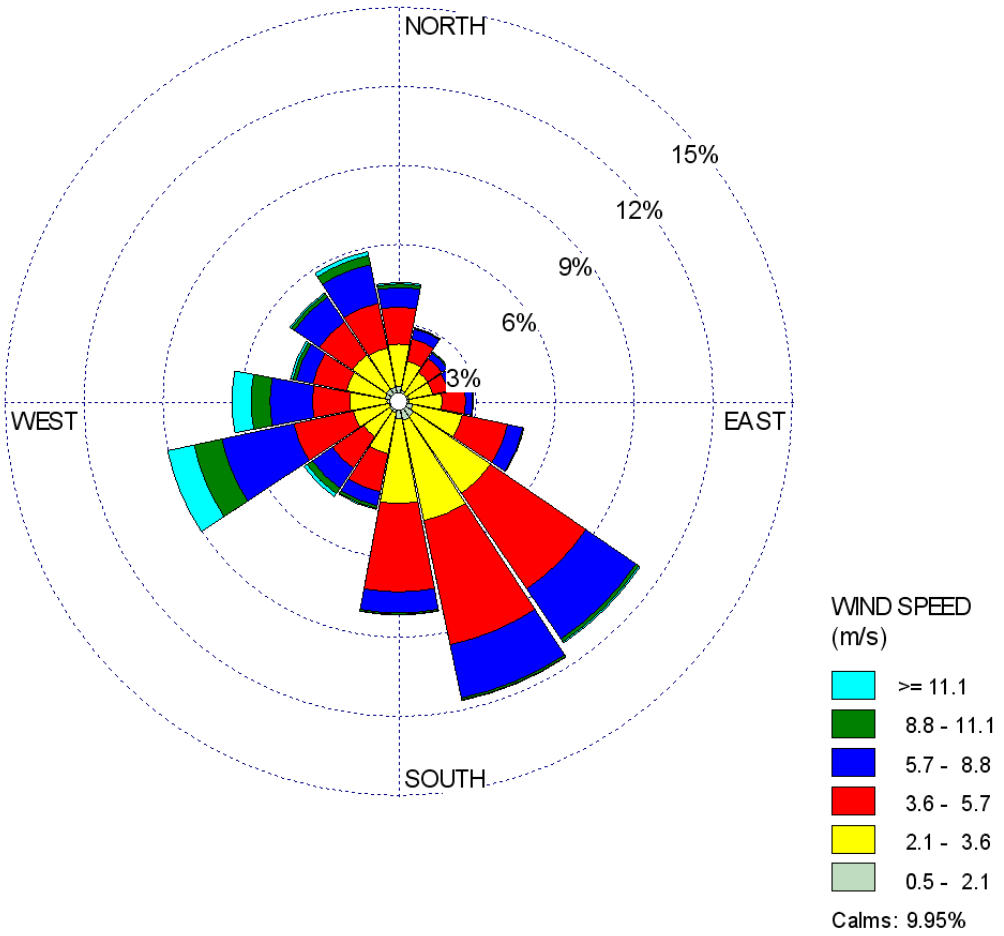

Figure 3-1. Cavern City Air Terminal Windrose

3.1.2. Terrain

A variety of terrain is found within the CFO's high potential oil and gas development areas. Using aerial photographs with ArcMAP, it was determined that the terrain is more reflective of flat terrain than complex terrain for the near-field (~ 1 mile radius) modeling scenarios. In addition to the lack of specificity regarding precise locations of future emission sources, the assumption of flat terrain in combination with the general conservative assumptions used in the near-field modeling was determined as an appropriate application for the near-field modeling analysis.

3.1.3. Ambient Air Background Concentration Data

Representative background pollutant concentration data collected at regional monitoring sites that are provided in the New Mexico Modeling Guidelines (NMED 2011) for use in New Mexico air quality permitting analyses were used for all pollutants, except for SO_2 3-hour average. Table 3-1 provides the background criteria pollutant concentrations and describes the location and data source of each concentration value. Pollutant concentrations in micrograms per cubic meter ($\mu g/m^3$) are shown for all pollutants, while gaseous pollutant concentrations are also shown in parts per million (ppm). These background concentrations represent all non-Project near-field emissions sources impacts and are added to the near-field modeled concentrations to produce cumulative predicted near-field concentrations for comparison to applicable air quality standards.

Table 3-1. Background Ambient Air Quality Concentrations

Pollutant / Units	Background Monitored Concentrations					Monitoring Station Location a
	Annual	24-Hour	8-Hour	3-Hour	1-Hour	
CO ($\mu g/m^3$)	-	-	1,667	-	2,400	2003-2006 2ZR Rio Rancho Senior Center (The rest of New Mexico)
CO (ppm)	-	-	1.5	-	2.1	
NO_2 ($\mu g/m^3$)	5.7	-	-	-	57	Eastern New Mexico, Carlsbad, ID: 5ZR. Years 2007-2009
NO_2 (ppm)	0.003	-	-	-	0.03	
TSP ($\mu g/m^3$)	28.1	61.4	-	-	-	There are currently no TSP monitors in New Mexico. Followed New Mexico Guidelines for estimating TSP background concentration using PM10 values (see footnote).
PM_{10} ($\mu g/m^3$)	-	51.9	-	-	-	Eastern New Mexico, Hobbs, ID: 5ZS. Years 2007-2009
$PM_{2.5}$ ($\mu g/m^3$)	6.2	16.9	-	-	-	Eastern New Mexico, Hobbs, ID: 5ZS. Years 2007-2009
SO_2 ($\mu g/m^3$)	-	-	-	13.8	52.8	1-hour: Average 3-year 100% maximum concentration 5ZP Artesia 6/3/2006-6/2/2009 (Eastern New Mexico) 3-hour: EPA AirData for monitor ID: 48-141-58, El Paso, Texas. First maximum 3-hour average value for year 2011.
SO_2 (ppm)	-	-	-	0.005	0.02	

$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
CO = carbon monoxide
NO_2 = nitrogen dioxide
PM_{10} / $PM_{2.5}$ = particulate matter less than or equal to 10 microns / 2.5 microns in size
SO_2 = sulfur dioxide
TSP = Total Suspended Particulate

[a] Background concentration information: CO: The rest of New Mexico, 2003-2006 2ZR Rio Rancho Senior Center (New Mexico Guidelines); NO2: Eastern New Mexico, Carlsbad, ID: 5ZR. Years 2007-2009 (New Mexico Guidelines); SO2 1-hour: Eastern New Mexico. Average 3-year 100% maximum concentration 5ZP Artesia 6/3/2006-6/2/2009 (New Mexico Guidelines); H2S: NMED has no H2S monitors. The H2S standards are generally designed to protect against noticeable changes in concentration above the background concentration for the region, and no background concentration is added (New Mexico Guidelines). PM2.5 and PM10: Eastern New Mexico, Hobbs, ID: 5ZS. Years 2007-2009 (from New Mexico Guidelines). Maximum 24-hour average values shown for PM2.5 and PM10; TSP: There are no TSP monitors in New Mexico. Estimate TSP background concentration by multiplying PM10 concentration for the same averaging period by 1.33 (New Mexico Guidelines). 2nd high 24-hour PM10 value used for TSP background concentration.

Table 3-2 provides HAP concentration data obtained from the USEPA that is used to represent existing HAP conditions in the Project area.

Table 3-2. HAP Background Concentrations

Averaging Time	Year	Concentration, ppbv (μg/m^3) [a]				
		Benzene	Ethylbenzene	Formaldehyde	Toluene	n-Hexane
Annual Mean	2011	1.91 (6.18)	0.74 (3.27)	2.66 (3.31)	3.44 (13.17)	7.17 (25.69)
1-Hour Maximum	2011	33.90 (110.05)	33.81 (149.18)	4.88 (15.23)	83.79 (320.86)	152.03 (544.52)

Source: USEPA.

μg/m^3 = micrograms per cubic meter
ppbv = parts per billion by volume

[a] Background concentrations are values for year 2011 for all pollutants, except formaldehyde; formaldehyde value is for year 2010. These values were provided to URS by EPA for the Region and all pollutants data were monitored / collected at Odessa, Texas (48-135-3) location for all pollutants, except formaldehyde; formaldehyde value is from El Paso, Texas monitor (48-141-44). Maximum 1-hour concentrations for all pollutants, except formaldehyde; formaldehyde value is maximum 24-hour concentration that is divided by 0.4 to adjust to a 1-hour average concentration. All annual values are annual arithmetic means.

3.1.4. Near-Field Modeling Setup and Emissions

Near-field ambient air models of criteria pollutants and HAPs were created with AERMOD to assess potential impacts from oil and gas related construction and production activities. To conservatively estimate potential near-field emissions due to layout of high clustered oil and gas areas, forty-nine facilities within a two mile by two mile area (four square mile) were grouped together for AERMOD modeling.

Figures 3-2 and 3-3 show the composite near-field modeling layouts. Near-field modeling was completed for two "typical" near-field clustered oil and gas scenarios because of the clustered oil development that can currently be found in near-field sections of the Basin: one for minimal natural gas operations (i.e. mostly oil wells), and then one for a balanced oil and gas wells layout (~50% oil and ~50% gas) that are found within the Basin. These modeling layouts include all possible emission sources for all pollutants modeled. However, only sources emitting relevant pollutants were modeled for individual emission scenarios. For example, when modeling SO_2, only sources of SO_2 emissions were included in the modeling run. A natural gas plant is shown at the center of the modeling layouts. Forty-eight well pads with associated roadways are clustered around the gas plant. As shown in the Figures, a well pad could represent an operating oil or natural gas well, a natural gas or oil well being drilled, a well pad being constructed or operating water well. These grouping of emissions sources and activities are conservative estimates of the quantity and close proximity of emissions and potential impacts that could occur for oil and gas activities within the CFO. Point source / well pad specific emissions associated with a particular well pad type were only released from appropriate locations within the

modeling domain. For example, water well injection pump emissions are only released from the operational water wells. All traffic related emissions are distributed among all the roadway volume sources within the modeling domain.

The following provides details about the emissions sources that were included in the near-field modeling and any additional information about how the emissions were released / modeled within the near-field domains:

- Well pad construction: accounts for heavy equipment surface disturbance and assumes 50% dust control during these activities. Includes well pad access road, pipeline and well pad development and accounts for heavy equipment exhaust. Emissions released from "pad development" volume sources located at center of well pad areas. Well pad volumes release height: 2 meters, sigma-y: 9.3 meters and sigma-z: 2.33 meters.
- Well drilling: accounts for drilling engine operations associated with drilling a well. Uses Tier 4 engines emissions factors with information from the ERG Texas drilling emissions Study (ERG 2009). Emissions released from point source at center of "drilling" well pad locations. Point source height: 9.1 meters, exhaust exit temperature: 675 K, exhaust velocity: 30 meters/second and stack tip diameter: 0.2 meters.
- Development related traffic: accounts for traffic associated with well pad access road, pipeline and well pad constructions, as well as drilling, completion and re-completion related activities. Emissions distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- New well work-overs: accounts for engine operations and traffic associated with new well work-overs. Calculations for work-over engines use same emissions factors as for well drilling engines. Emissions released from point source at center of "drilling" well pad locations.
- Routine well pad visits: accounts for traffic associated with routine well pads / facilities check-ups. Emissions distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- Well pad access road maintenance: accounts for heavy equipment operations and traffic associated with maintaining well pad access roads. Emissions distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- Produced water tanks, pumps and traffic: accounts for produced water flashing, water hauling traffic emissions, and water injection pumps. Traffic related emissions were distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters; water pumps emissions released from well pad center point source with stack height: 6 meters, exhaust temperature: 703 K, exit velocity: 26.4 meters/second and stack tip diameter: 0.3 meters.
- Oil tanks and traffic: accounts for oil tanks venting emissions, truck load-out emissions, and traffic for oil hauling. Traffic related emissions were distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- Well blow-downs: vented emissions associated with oil and gas wells blow-downs.
- Compressors and oil pumps: accounts for well-head natural gas compressor and oil pump engines at oil and gas wells. Criteria pollutant emissions factors and well head engine requirements obtained from ERG Study (ERG 2010). Engines emissions released from

well pad center point source with stack height: 6 meters, exhaust temperature: 703 K, exit velocity: 26.4 meters/second and stack tip diameter: 0.3 meters.

- Natural gas dehydrators: accounts for dehydrator flash vessel and regenerator vents, dehydrator regenerator boilers and dehydrator related flares. Emissions factors were obtained from ERG Study (ERG 2010). Emissions released from "operating" volume sources located at center of well pad areas. Well pad volumes release height: 2 meters, sigma-y: 9.3 meters and sigma-z: 2.33 meters.
- Wind erosion: wind erosions associated with initial well pad developments surface disturbance, and traffic related surface disturbance. Emissions were distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- Well pad heaters: accounts for heaters at well pads. Calculations use heater requirements and activities show in an ERG Study (ERG 2010). Emissions released from "operating" point sources located at center of well pad areas. Heaters emissions released from well pad center point source with stack height: 6 meters, exhaust temperature: 703 K, exit velocity: 26.4 meters/second and stack tip diameter: 0.3 meters.
- Wellhead fugitives and pneumatic devices: accounts for natural gas leaks associated with wellhead components and pneumatic devices. Uses input from ERG Study (ERG 2010).
- Well pad and access road reclamation: accounts for heavy equipment operations and vehicle traffic associated with new well pad and access road reclamation activities. Emissions were distributed evenly among all access roads volume sources with release height: 2 meters, sigma-y: 2.3 meters and sigma-z: 1.9 meters.
- Gas plants: accounts for centralized natural gas processing facility emissions. Information from the latest Linam Ranch Gas Plant (located in Project area) air quality permit was used to develop gas plant emissions associated increase natural gas production for the near-field layout. Gas plant emissions released from centralized facility center point source with stack height: 13.75 meters, exhaust temperature: 703 K, exit velocity: 26.4 meters/second and stack tip diameter: 0.3 meters. These parameter values derived by averaging values for 800 oil and gas facilities in New Mexico except for stack height; stack height is based on GEP equation assuming station building is ~ 18 feet tall.

More detail for the values and assumptions used for developing emissions for these activities can be found in Appendix I.

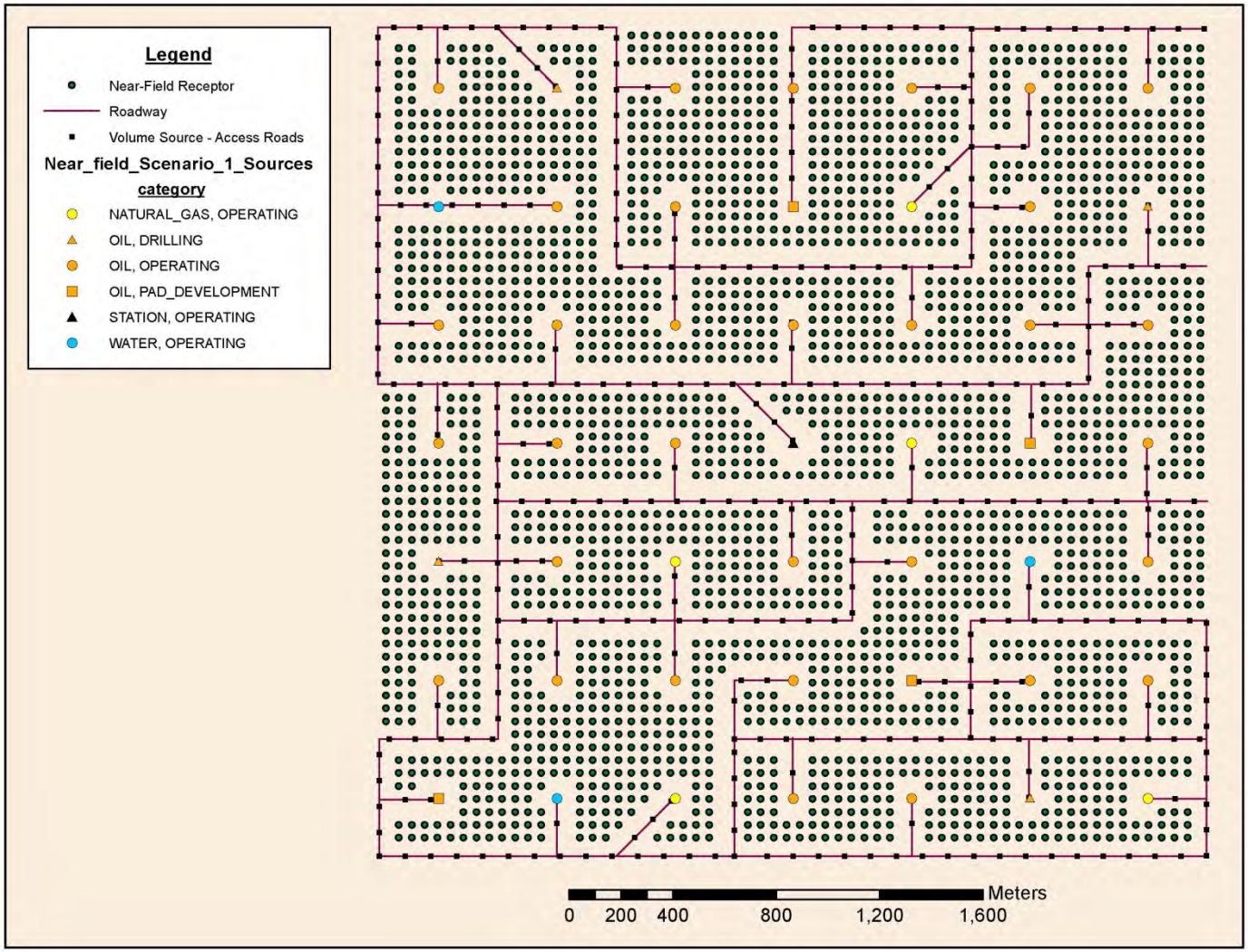

Figure 3-2. Near-Field Well Pad Cluster Layout 1

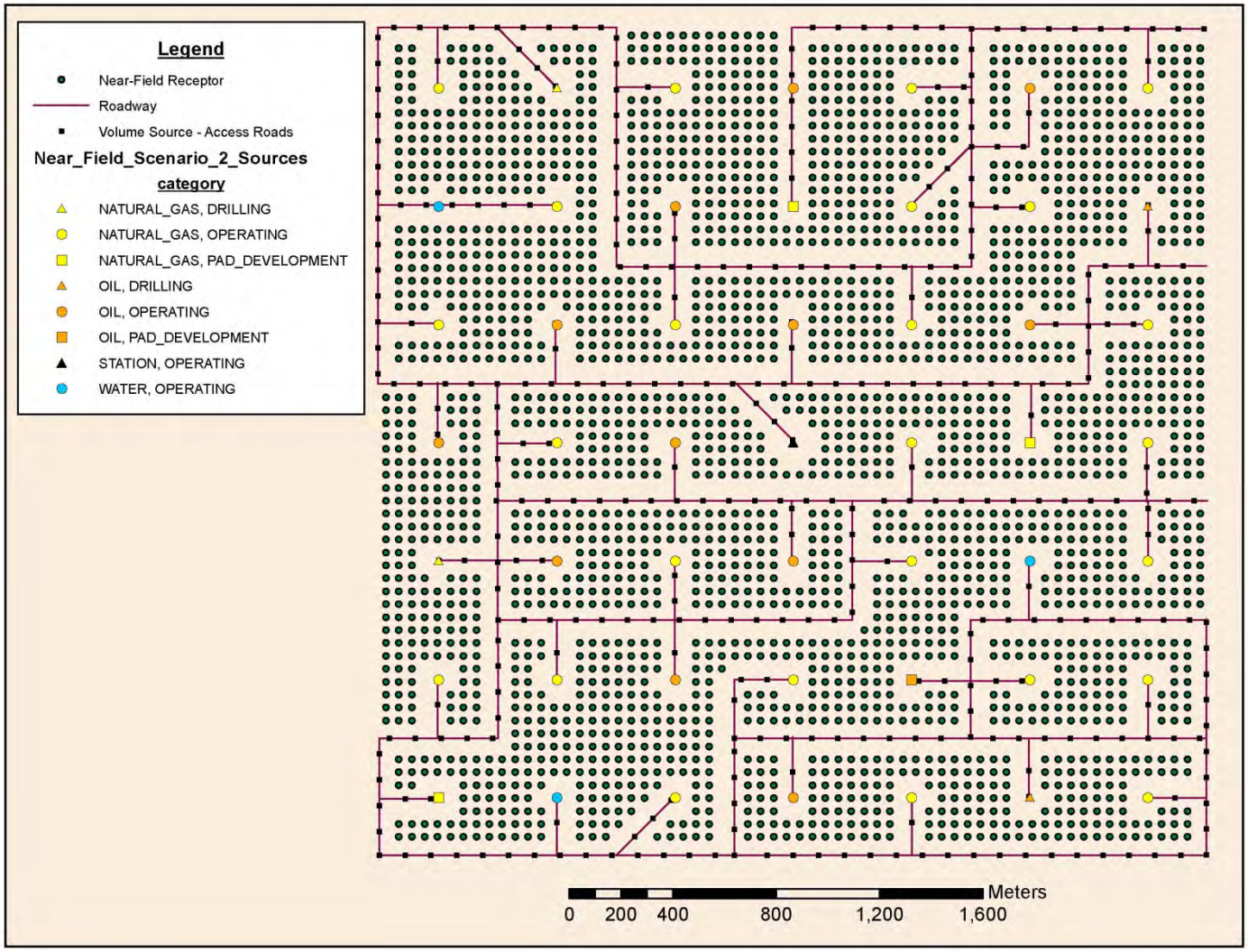

Figure 3-3. Near-Field Well Pad Cluster Layout 2

In addition to the information provided regarding oil and gas emissions sources layouts for the near-field modeling, the following provides more information regarding how the emissions were controlled and modeled for the analysis:

- Deposition was included for particulate matter modeling to better represent large particle fallout within short distances from emissions sources. Three size categories were specified for the modeling: $PM_{2.5}$ (≤2.5 micrometers [μm]), PM_{10} (>2.5 μm and less than 10 μm) and TSP (accounts for all suspended particulate matter). The ratios of emissions rates determined the mass fractions for each source. The mean particle diameters were set at 1.0 μm and 7 μm for the $PM_{2.5}$ and PM_{10} particles, respectively. The particle size distribution for TSP was modeled as follows: 10% at mean diameter 1.5 μm, 10% at mean diameter 3.7 μm, 15% at mean diameter 7.5 μm, 15% at mean diameter 12 μm, 26% at mean diameter 22 μm, and 24% at mean diameter 40 μm. Particle density was set at 1 g/cm^3 for all particle sizes. In addition to deposition, fugitive dust emissions were 50% controlled before being modeled.
- Fugitive dust emissions caused by vehicle travel on unpaved roads were modeled as being released for 12 hours per day starting at 7 am. Fugitive dust emissions associated with well pad construction surface disturbance was also modeled for 12 hours per day starting at 7 am.
- Downwash parameter values were included for drilling equipment and central gas plant. The Building Profile Input Program (BPIP) was used to develop downwash parameter values for a 5.5 meter high building and 5 meter high structure for the gas plant and drilling engines, respectively.
- For annual average modeling, emissions were divided by 8,760 hours and distributed equally over the entire year hours. For short-term average modeling, annual emissions were divided by a number of hours less than 8,760. Here are some of the assumptions that were used to determine the number of hours for each emissions activity: 36 hours total for each well pad construction and reclamation, 12 hours of natural gas venting for each new well and 5 hours of natural gas venting for each well blow-down. There is a Table in Appendix I that has more values and assumptions for the number of hours used to calculate emission rates for short-term average modeling.
- Mobile source exhaust emissions factors were derived using the EPA MOVES model for Lea County, New Mexico, representing year 2028 and average vehicle speed 30 mph. Non-road equipment exhaust emissions factors were created using the EPA NONROADS emissions model year 2028 data for all pollutants except CH_4 and N_2O and HAPs; 2009 API O&G GHG Compendium CH_4 and N_2O factors were used and EPA AP-42 HAPs emissions factors were used for non-roads equipment operations emissions calculations.
- Assumptions for routine well pad visits / check-ups include each well pad is visited weekly (52 visits per year) and multiple well pads are visited by operators for each trip out into the field.
- Green completion technology emission reduction was applied to new well completion activities for near-field H_2S short-term average modeling.

Appendix I provides more details and information regarding the near-field modeling layouts including emissions activities that were accounted for in the emissions calculations. Appendix I also provides information / data for how the emissions were calculated including details for the emissions calculation methodologies and factors.

The following outline provides details about the near-field receptor grid surrounding the emissions sources. The receptor networks are shown in Figure 3-2 and Figure 3-3.

- 50 meter receptor spacing throughout the near-field modeling domains
- Receptors were not placed within 50 meters of the resource / access roads
- Receptors were not placed within 75 meters of the well pads
- Receptors were not placed within 100 meters of the central gas plant

3.2. NEAR-FIELD ASSESSMENT OF AIR QUALITY IMPACTS

3.2.1. Criteria Pollutants

The predicted criteria pollutant concentrations were compared with applicable NAAQS and to any applicable New Mexico Ambient Air Quality Standards (NMAAQS) that are more stringent or have different averaging times than the NAAQS or for other pollutants, as shown in Table 3-3. The NAAQS include standards for NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3, CO, and lead. Given the insignificant levels of potential lead emissions, lead standards were not addressed in this analysis. Comparisons to the O_3 standard are described in Section 4.0 of this air quality assessment.

Operational impacts from near-field modeling results were compared to applicable PSD Class II increments. However, all comparisons to PSD increments are made to identify potential significance, and do not represent a Regulatory Increment Consumption analysis. Regulatory PSD increments analysis is generally required only for individual major stationary sources at the time that a specific facility applies for a PSD permit prior to facility construction. In New Mexico, PSD increment analysis is also required for minor source permitting. Under the PSD Program, a major stationary source is a source that has the potential to emit 100 tons per year (tpy) or 250 tpy of a criteria pollutant (depending on the type of facility).

Table 3-3. Applicable Ambient Air Quality Standards and PSD Increments

Pollutant	Averaging Period	NAAQS ($\mu g/m^3$)	New Mexico Ambient Air Quality Standards ($\mu g/m^3$)	PSD Increments ($\mu g/m^3$)	
				Class I	Class II
CO	1-Hour [a]	40,000	~ 14,971	---	---
	8-Hour [a]	10,000	~ 9667	---	---
PM_{10}	24-Hour [a]	150	---	8	30
	Annual [b]	---	---	4	17
$PM_{2.5}$	24-Hour [a]	35	---	2	9
	Annual [b]	12	---	1	4
SO_2	1-Hour [c]	196	---	---	---
	3-Hour [a]	1,300	---	25	512
	24-Hour [a]	365	~ 261	5	91
	Annual [b]	80	~ 53	2	20
NO_2	1-Hour [d]	189	---	---	---
	24-Hour[e]	---	~ 189	---	---
	Annual [b]	100	94	2.5	25
H_2S	½-Hour[e]	---	~ 141	---	---
TSP	24-hour	---	150	---	---
	7-day	---	110	---	---
	30-day	---	90	---	---
	Annual[f]	---	60	---	---

$\mu g/m^3$ = micrograms per cubic meter

ppm = parts per million

[a] Not to be exceeded more than once per year.

[b] Annual arithmetic mean not to be exceeded.

[c] 3-year average of the 99th percentile of the daily maximum 1-hour average at each receptor within the area must not exceed this Standard.

[d] 3-year average of the 98th percentile of the daily maximum 1-hour average at each receptor within the area must not exceed this Standard.

[e] New Mexico specific Standard (NMAAQS). H_2S Standard for Pecos-Permian Basin Intrastate AQCR. Source: NMED, 2010

[f] Annual geometric mean

'---' means no final value exists for parameter.

Table 3-4, Table 3-5, Table 3-6, and Table 3-7 provide the maximum modeled concentration for each criteria pollutant, averaging time, and modeled year using RFD emission rates for near-field layouts 1 and 2 (Figures 3-2 and 3-3 show near-field modeling layouts). With the exception of H_2S predicted total concentrations, the maximum modeled concentrations were added to the background concentration (from Table 3-1), and the total concentrations were compared to the NAAQS and / or NMAAQS. For all near-field modeled criteria pollutants and averaging times, predicted near-field concentrations are below the NAAQS and NMAAQS.

Table 3-4. Non-Particulate Criteria and other non-HAP Pollutants Predicted Concentrations – Scenario 1

Criteria Pollutant	Avg. Period	Year	Concentration (µg/m^3)			Ambient Standard (µg/m^3)		Percent of AAQS [c]
			Modeled	Background [a]	Total [b]	NAAQS	NMAAQS	
CO	1-hour	2006	1,333.87	2,400	**3,733.87**	40,000	14,971	24.94%
		2007	1,336.83	2,400	**3,736.83**	40,000	14,971	24.96%
		2008	1,295.70	2,400	**3,695.70**	40,000	14,971	24.69%
		2009	1,321.61	2,400	**3,721.61**	40,000	14,971	24.86%
		2010	1,356.08	2,400	**3,756.08**	40,000	14,971	25.09%
CO	8-hour	2006	950.63	1,667	**2,617.30**	10,000	9,667	27.07%
		2007	893.82	1,667	**2,560.48**	10,000	9,667	26.49%
		2008	959.77	1,667	**2,626.44**	10,000	9,667	27.17%
		2009	915.16	1,667	**2,581.83**	10,000	9,667	26.71%
		2010	848.90	1,667	**2,515.56**	10,000	9,667	26.02%
NO_2	1-hour	2006						
		2007						
		2008	110.37	56.60	**166.97**	189	NA	88.34%
		2009						
		2010						
NO_2	Annual	2006	11.22	5.66	**16.88**	100	NA	16.88%
		2007	12.83	5.66	**18.49**	100	NA	18.49%
		2008	11.50	5.66	**17.16**	100	NA	17.16%
		2009	10.68	5.66	**16.34**	100	NA	16.34%
		2010	12.09	5.66	**17.75**	100	NA	17.75%
SO_2	1-hour	2006						
		2007						
		2008	35.46	52.78	**88.24**	196	NA	45.02%
		2009						
		2010						
SO_2	3-hour	2006	34.78	13.78	**48.56**	1,300	NA	3.74%
		2007	29.81	13.78	**43.59**	1,300	NA	3.35%
		2008	32.81	13.78	**46.59**	1,300	NA	3.58%
		2009	31.36	13.78	**45.14**	1,300	NA	3.47%
		2010	29.56	13.78	**43.34**	1,300	NA	3.33%
H_2S	1/2-hour	2006	73.62	NA	**73.62**	NA	141	52.21%
		2007	71.18	NA	**71.18**	NA	141	50.48%
		2008	71.96	NA	**71.96**	NA	141	51.04%
		2009	74.83	NA	**74.83**	NA	141	53.07%
		2010	73.31	NA	**73.31**	NA	141	51.99%

NMAAQS = New Mexico Ambient Air Quality Standards
µg/m^3 = micrograms per cubic meter
NAAQS = National Ambient Air Quality Standards

[a] Background concentration information: CO: The rest of New Mexico, 2003-2006 2ZR Rio Ranch Senior Center (New Mexico Guidelines); NO2: Eastern New Mexico, Carlsbad, ID: 5ZR. Years 2007-2009 (New Mexico Guidelines); SO2 1-hour: Eastern New Mexico. Average 3-year 100% maximum concentration 5ZP Artesia 6/3/2006-6/2/2009 (New Mexico Guidelines); SO2 3-hour: EPA AirData for monitor ID: 48-141-58, El Paso, Texas. First maximum 3-hour average value for year 2011; H2S: NMED has no H2S monitors. The H2S standards are generally designed to protect against noticeable changes in concentration above the background concentration for the region, and no background concentration is added (New Mexico Guidelines).

[b] Compliance with the CO and SO_2 (except 1-hour) NAAQS is based on the highest-second-highest (H2H) short-term concentration. Compliance with SO2 1-hour Standard is based on maximum 5-year average of 99th percentile daily maximum 1-hour average values. Compliance with NO2 1-hour Standard is based on maximum 5-year average of 98th percentile daily maximum 1-hour average values; EPA Guidance Tier 2 80% NOx to NO2 conversion applied. Maximum 1-hour H2S concentrations are shown for short-term H2S New Mexico Standard compliance. Annual (long-term) modeled concentrations are highest concentrations which are required for an annual average NAAQS compliance demonstration. Compliance with the NO2 1-hour NAAQS also serves as compliance for the NO2 24-hour NMAAQS (New Mexico AQ Bureau Guidelines). Compliance with the SO2 1-hour NAAQS also serves as compliance for the SO2 24-hour and Annual NMAAQS (New Mexico AQ Bureau Guidelines).

[c] Percent of NMAAQS if NMAAQS exists for pollutant and averaging time, else percent of NAAQS.

Table 3-5. Particulate Matter Pollutants Predicted Concentrations – Scenario 1

Criteria Pollutant	Avg. Period	Year	Concentration (µg/m^3)			Ambient Standard (µg/m^3)		Percent of AAQS [c]
			Modeled	Background [a]	Total [b]	NAAQS	NMAAQS	
PM_{10}	24-hour	2006	45.52	51.90	**97.42**	150	NA	64.95%
		2007	40.93	51.90	**92.83**	150	NA	61.88%
		2008	42.53	51.90	**94.43**	150	NA	62.96%
		2009	44.49	51.90	**96.39**	150	NA	64.26%
		2010	41.02	51.90	**92.92**	150	NA	61.95%
$PM_{2.5}$	24-hour	2006 2007 2008 2009 2010	3.40	16.90	**20.30**	35	NA	58.00%
$PM_{2.5}$	Annual	2006 2007 2008 2009 2010	0.05	6.20	**6.25**	12	NA	52.08%
TSP	24-hour	2006	86.15	61.45	**147.60**	NA	150	98.40%
		2007	84.95	61.45	**146.40**	NA	150	97.60%
		2008	84.14	61.45	**145.58**	NA	150	97.06%
		2009	87.17	61.45	**148.62**	NA	150	99.08%
		2010	82.09	61.45	**143.53**	NA	150	95.69%
TSP	Annual	2006	0.61	28.06	**28.68**	NA	60	47.79%
		2007	0.67	28.06	**28.73**	NA	60	47.89%
		2008	0.64	28.06	**28.70**	NA	60	47.84%
		2009	0.62	28.06	**28.68**	NA	60	47.81%
		2010	0.68	28.06	**28.74**	NA	60	47.90%

NMAAQS = New Mexico Ambient Air Quality Standards

µg/m^3 = micrograms per cubic meter

NAAQS = National Ambient Air Quality Standards

[a] Background concentration information: PM2.5 and PM10: Eastern New Mexico, Hobbs, ID: 5ZS. Years 2007-2009 (from New Mexico Guidelines). Maximum 24-hour average values shown for PM2.5 and PM10; TSP: There are no TSP monitors in New Mexico. Estimate TSP background concentration by multiplying PM10 concentration for the same averaging period by 1.33 (New Mexico Guidelines). 2nd high 24-hour PM10 value used for TSP background concentration.

[b] Compliance with PM10 and TSP short-term AAQS is based on the highest-second-highest (H2H) short-term concentration, while compliance with the short-term PM2.5 NAAQS is based on the highest 5-year average eighth-highest short-term concentration. TSP annual (long-term) modeled concentrations are highest concentrations which are required for an annual average NMAAQS compliance demonstration. Compliance with the long-term PM2.5 NAAQS is based on the maximum 5-year average annual concentration. Compliance with the TSP 24-hour NMAAQS also serves as compliance for the TSP 7-day NMAAQS (New Mexico AQ Bureau Guidelines) and TSP 30-day NMAAQS.

[c] Percent of NMAAQS if NMAAQS exists for pollutant and averaging time, else percent of NAAQS.

Table 3-6. Non-Particulate Criteria and other non-HAP Pollutants Predicted Concentrations – Scenario 2

Criteria Pollutant	Avg. Period	Year	Concentration (µg/m^3)			Ambient Standard (µg/m^3)		Percent of AAQS [c]
			Modeled	Background [a]	Total [b]	NAAQS	NMAAQS	
CO	1-hour	2006	1,333.87	2,400.00	**3,733.87**	40,000	14,971	24.94%
		2007	1,336.82	2,400.00	**3,736.82**	40,000	14,971	24.96%
		2008	1,295.70	2,400.00	**3,695.70**	40,000	14,971	24.69%
		2009	1,321.61	2,400.00	**3,721.61**	40,000	14,971	24.86%
		2010	1,356.08	2,400.00	**3,756.08**	40,000	14,971	25.09%
CO	8-hour	2006	950.87	1,666.67	**2,617.53**	10,000	9,667	27.08%
		2007	894.14	1,666.67	**2,560.81**	10,000	9,667	26.49%
		2008	960.02	1,666.67	**2,626.69**	10,000	9,667	27.17%
		2009	915.30	1,666.67	**2,581.97**	10,000	9,667	26.71%
		2010	849.05	1,666.67	**2,515.71**	10,000	9,667	26.02%
NO_2	1-hour	2006 2007 2008 2009 2010	110.46	56.60	**167.06**	189	NA	88.39%
NO_2	Annual	2006	11.26	5.66	**16.92**	100	NA	16.92%
		2007	12.85	5.66	**18.51**	100	NA	18.51%
		2008	11.53	5.66	**17.19**	100	NA	17.19%
		2009	10.70	5.66	**16.36**	100	NA	16.36%
		2010	12.10	5.66	**17.76**	100	NA	17.76%
SO_2	1-hour	2006 2007 2008 2009 2010	35.47	52.78	**88.25**	196	NA	45.02%
SO_2	3-hour	2006	34.78	13.78	**48.56**	1,300	NA	3.74%
		2007	29.81	13.78	**43.59**	1,300	NA	3.35%
		2008	32.81	13.78	**46.59**	1,300	NA	3.58%
		2009	31.36	13.78	**45.14**	1,300	NA	3.47%
		2010	29.57	13.78	**43.35**	1,300	NA	3.33%
H_2S	1/2-hour	2006	42.58	NA	**42.58**	NA	141	30.20%
		2007	41.79	NA	**41.79**	NA	141	29.64%
		2008	43.61	NA	**43.61**	NA	141	30.93%
		2009	46.10	NA	**46.10**	NA	141	32.70%
		2010	44.27	NA	**44.27**	NA	141	31.40%

NMAAQS = New Mexico Ambient Air Quality Standards

$\mu g/m^3$ = micrograms per cubic meter

NAAQS = National Ambient Air Quality Standards

[a] Background concentration information: CO: The rest of New Mexico, 2003-2006 2ZR Rio Ranch Senior Center (New Mexico Guidelines); NO2: Eastern New Mexico, Carlsbad, ID: 5ZR. Years 2007-2009 (New Mexico Guidelines); SO2 1-hour: Eastern New Mexico. Average 3-year 100% maximum concentration 5ZP Artesia 6/3/2006-6/2/2009 (New Mexico Guidelines); SO2 3-hour: EPA AirData for monitor ID: 48-141-58, El Paso, Texas. First maximum 3-hour average value for year 2011; H2S: NMED has no H2S monitors. The H2S standards are generally designed to protect against noticeable changes in concentration above the background concentration for the region, and no background concentration is added (New Mexico Guidelines).

[b] Compliance with the CO and SO_2 (except 1-hour) NAAQS is based on the highest-second-highest (H2H) short-term concentration. Compliance with SO2 1-hour Standard is based on maximum 5-year average of 99th percentile daily maximum 1-hour average values. Compliance with NO2 1-hour Standard is based on maximum 5-year average of 98th percentile daily maximum 1-hour average values; EPA Guidance Tier 2 80% NOx to NO2 conversion applied. Maximum 1-hour H2S concentrations are shown for short-term H2S New Mexico Standard compliance. Annual (long-term) modeled concentrations are highest concentrations which are required for an annual average NAAQS compliance demonstration. Compliance with the NO2 1-hour NAAQS also serves as compliance for the NO2 24-hour NMAAQS (New Mexico AQ Bureau Guidelines). Compliance with the SO2 1-hour NAAQS also serves as compliance for the SO2 24-hour and Annual NMAAQS (New Mexico AQ Bureau Guidelines).

[c] Percent of NMAAQS if NMAAQS exists for pollutant and averaging time, else percent of NAAQS.

Table 3-7. Particulate Matter Pollutants Predicted Concentrations – Scenario 2

Criteria Pollutant	Avg. Period	Year	Concentration ($\mu g/m^3$)			Ambient Standard ($\mu g/m^3$)		Percent of AAQS [c]
			Modeled	Background [a]	Total [b]	NAAQS	NMAAQS	
PM_{10}	24-hour	2006	45.70	51.90	**97.60**	150	NA	65.07%
		2007	41.14	51.90	**93.04**	150	NA	62.02%
		2008	42.74	51.90	**94.64**	150	NA	63.09%
		2009	44.76	51.90	**96.66**	150	NA	64.44%
		2010	41.22	51.90	**93.12**	150	NA	62.08%
$PM_{2.5}$	24-hour	2006 2007 2008 2009 2010	3.42	16.90	**20.32**	35	NA	58.07%
$PM_{2.5}$	Annual	2006 2007 2008 2009 2010	0.12	6.20	**6.32**	12	NA	52.70%
TSP	24-hour	2006	86.63	61.45	**148.08**	NA	150	98.72%
		2007	85.43	61.45	**146.88**	NA	150	97.92%
		2008	84.57	61.45	**146.01**	NA	150	97.34%
		2009	87.76	61.45	**149.21**	NA	150	99.47%
		2010	82.49	61.45	**143.94**	NA	150	95.96%
TSP	Annual	2006	0.78	28.06	**28.84**	NA	60	48.07%
		2007	0.85	28.06	**28.91**	NA	60	48.19%
		2008	0.81	28.06	**28.87**	NA	60	48.12%
		2009	0.79	28.06	**28.85**	NA	60	48.08%
		2010	0.86	28.06	**28.92**	NA	60	48.20%

NMAAQS = New Mexico Ambient Air Quality Standards

$\mu g/m^3$ = micrograms per cubic meter

NAAQS = National Ambient Air Quality Standards

[a] Background concentration information: PM2.5 and PM10: Eastern New Mexico, Hobbs, ID: 5ZS. Years 2007-2009 (from New Mexico Guidelines). Maximum 24-hour average values shown for PM2.5 and PM10; TSP: There are no TSP monitors in New Mexico. Estimate TSP background concentration by multiplying PM10 concentration for the same averaging period by 1.33 (New Mexico Guidelines). 2nd high 24-hour PM10 value used for TSP background concentration.

[b] Compliance with PM10 and TSP short-term AAQS is based on the highest-second-highest (H2H) short-term concentration, while compliance with the short-term PM2.5 NAAQS is based on the highest 5-year average eighth-highest short-term concentration. TSP annual (long-term) modeled concentrations are highest concentrations which are required for an annual average NMAAQS compliance demonstration. Compliance with the long-term PM2.5 NAAQS is based on the maximum 5-year average annual concentration. Compliance with the TSP 24-hour NMAAQS also serves as compliance for the TSP 7-day NMAAQS (New Mexico AQ Bureau Guidelines) and TSP 30-day NMAAQS.

[c] Percent of NMAAQS if NMAAQS exists for pollutant and averaging time, else percent of NAAQS.

3.2.2. Hazardous Air Pollutants

All near-field HAP modeling was based on the same layouts as for criteria pollutants. Short-term (1-hour) average HAP concentrations were compared to acute Reference Exposure Levels (RELs), shown in Table 3-8 and Table 3-9. RELs are defined as concentrations at or below which no adverse short-term health effects are expected. No RELs are available for ethylbenzene and n-hexane; instead, the available Immediately Dangerous to Life or Health divided by 10 (IDLH/10) values are used. These IDLH values were determined by the National Institute for Occupational Safety and Health (NIOSH) and were obtained from USEPA's Air Toxics Database (USEPA 2005a). These values approximate pollutant concentrations likely to produce mild effects during 1-hour exposures.

As shown in Table 3-8 and Table 3-9, all HAP maximum 1-hour concentrations (with inclusion of background concentrations) are well below the REL or IDLH/10 reference concentrations.

Table 3-8. 1-Hour HAP Maximum Concentrations Comparison to RELs – Scenario 1

HAP	Modeled Year	Maximum 1-Hour Modeled Concentration ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$) [a]	Maximum Total Concentration ($\mu g/m^3$)	REL ($\mu g/m^3$)
Benzene	2006	15.54	110.05	125.58	1,300 [b]
	2007	15.19	110.05	125.23	
	2008	15.27	110.05	125.31	
	2009	16.17	110.05	126.22	
	2010	15.47	110.05	125.52	
Ethylbenzene	2006	1.02	149.18	150.20	350,000 [c]
	2007	1.01	149.18	150.19	
	2008	0.97	149.18	150.15	
	2009	1.01	149.18	150.19	
	2010	1.01	149.18	150.20	
Formaldehyde	2006	15.92	15.23	31.14	94 [b]
	2007	16.08	15.23	31.30	
	2008	15.76	15.23	30.98	
	2009	15.94	15.23	31.17	
	2010	16.64	15.23	31.87	
n-Hexane	2006	3009.94	544.52	3,554.46	390,000 [c]
	2007	2831.10	544.52	3,375.61	
	2008	3016.29	544.52	3,560.81	
	2009	3011.29	544.52	3,555.80	
	2010	2919.31	544.52	3,463.82	
Toluene	2006	280.13	320.86	600.99	37,000 [b]
	2007	263.35	320.86	584.21	
	2008	280.58	320.86	601.44	
	2009	280.11	320.86	600.97	
	2010	271.56	320.86	592.42	
Xylene	2006	272.90	N/A [d]	272.90	22,000 [b]
	2007	256.58	N/A [d]	256.58	
	2008	273.37	N/A [d]	273.37	
	2009	272.91	N/A [d]	272.91	
	2010	264.58	N/A [d]	264.58	

$\mu g/m^3$ = micrograms per cubic meter

REL = Reference Exposure Level

[a] Background concentrations are values for year 2011 for all pollutants, except formaldehyde; formaldehyde value is for year 2010. These values were provided to URS by EPA for the Region and all pollutants data were monitored / collected at Odessa, Texas (48-135-3) location for all pollutants, except formaldehyde; formaldehyde value is from El Paso, Texas monitor (48-141-44). All values are maximum 1-hour concentrations for all pollutants, except formaldehyde; formaldehyde value is maximum 24-hour concentration that is divided by 0.4 to adjust to a 1-hour average concentration.

[b] USEPA Air Toxics Database, Table 2 (USEPA, 2005a).

[c] No REL available for these HAPs. Values shown are from Immediately Dangerous to Life or Health (IDLH/10), USEPA Air Toxics Database, Table 2 (USEPA, 2005a).

Table 3-9. 1-Hour HAP Maximum Concentrations Comparison to RELs – Scenario 2

HAP	Modeled Year	Maximum 1-Hour Modeled Concentration ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$) [a]	Maximum Total Concentration ($\mu g/m^3$)	REL ($\mu g/m^3$)
Benzene	2006	30.02	110.05	140.06	1,300 [b]
	2007	29.60	110.05	139.65	
	2008	30.70	110.05	140.75	
	2009	32.43	110.05	142.48	
	2010	31.44	110.05	141.49	
Ethylbenzene	2006	0.72	149.18	149.91	350,000 [c]
	2007	0.69	149.18	149.88	
	2008	0.68	149.18	149.86	
	2009	0.71	149.18	149.89	
	2010	0.72	149.18	149.90	
Formaldehyde	2006	15.92	15.23	31.14	94 [b]
	2007	16.08	15.23	31.30	
	2008	15.76	15.23	30.98	
	2009	15.94	15.23	31.17	
	2010	16.64	15.23	31.87	
n-Hexane	2006	6,042.97	544.52	6,587.49	390,000 [c]
	2007	5,683.88	544.52	6,228.40	
	2008	6,055.72	544.52	6,600.24	
	2009	6,045.67	544.52	6,590.19	
	2010	5,861.00	544.52	6,405.51	
Toluene	2006	555.60	320.86	876.46	37,000 [b]
	2007	522.42	320.86	843.28	
	2008	556.60	320.86	877.46	
	2009	555.67	320.86	876.53	
	2010	538.70	320.86	859.56	
Xylene	2006	539.94	N/A [d]	539.94	22,000 [b]
	2007	507.74	N/A [d]	507.74	
	2008	540.96	N/A [d]	540.96	
	2009	540.06	N/A [d]	540.06	
	2010	523.56	N/A [d]	523.56	

$\mu g/m^3$ = micrograms per cubic meter

REL = Reference Exposure Level

[a] Background concentrations are values for year 2011 for all pollutants, except formaldehyde; formaldehyde value is for year 2010. These values were provided to URS by EPA for the Region and all pollutants data were monitored / collected at Odessa, Texas (48-135-3) location for all pollutants, except formaldehyde; formaldehyde value is from El Paso, Texas monitor (48-141-44). All values are maximum 1-hour concentrations for all pollutants, except formaldehyde; formaldehyde value is maximum 24-hour concentration that is divided by 0.4 to adjust to a 1-hour average concentration.

[b] USEPA Air Toxics Database, Table 2 (USEPA, 2005a).

[c] No REL available for these HAPs. Values shown are from Immediately Dangerous to Life or Health (IDLH/10), USEPA Air Toxics Database, Table 2 (USEPA, 2005a).

Long-term maximum potential exposure to HAPs are compared to Reference Concentrations for Chronic Inhalation (RfCs) in Table 3-10 and Table 3-11. An RfC is defined by USEPA as the daily inhalation concentration at which no long-term adverse health effects are expected. RfCs exist for both non-carcinogenic and carcinogenic effects on human health (USEPA 2005b). Annual modeled HAP concentrations for each modeled HAP are compared directly to the non-carcinogenic RfCs shown in Table 3-10 and Table 3-11.

Of the above HAPs, only benzene and formaldehyde are suspected to be carcinogenic. RfCs for these HAPs are expressed as unit risk factors (URFs) and are shown in Table 3-12 and Table 3-13. Accepted methods for risk assessment were used to evaluate the incremental cancer risk for these pollutants. Based on the Superfund National Oil and Hazardous Substances Pollution Contingency Plan, a cancer risk range of 1 in a million to 100 in a million (10^{-6} to 10^{-4} risk) is generally acceptable (USEPA 1990). Cancer risks for each individual HAP and for combined exposure to both HAPs for both most likely exposure (MLE) and maximally exposed individual (MEI) are within or below this range. A detailed explanation of this determination follows.

Annual total concentrations (modeled plus background) were multiplied by USEPA's URF (based on 70-year exposure) for those pollutants, and then the product was multiplied by an adjustment factor that represents the ratio of projected exposure time to 70 years. The adjustment factors represent two scenarios: an MLE scenario and one reflective of the MEI.

The MLE duration was assumed to be 9 years, which corresponds to the mean duration that a family remains at a residence (USEPA 1993). This duration corresponds to an adjustment factor of 9/70 = 0.13. The duration of exposure for the MEI was assumed to be 20 years (i.e., the LOP), corresponding to an adjustment factor of 20/70 = 0.29.

Table 3-10. Annual Average Predicted HAP Concentrations Compared to RfCs

Pollutant	Year	Annual Average Modeled Concentration ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$) [a]	Maximum Total Concentration ($\mu g/m^3$)	RfC [b] ($\mu g/m^3$)
Benzene	2006	0.48	6.18	6.67	30
	2007	0.51	6.18	6.70	
	2008	0.47	6.18	6.66	
	2009	0.47	6.18	6.66	
	2010	0.55	6.18	6.73	
Ethylbenzene	2006	0.05	3.27	3.32	1,000
	2007	0.06	3.27	3.33	
	2008	0.05	3.27	3.32	
	2009	0.05	3.27	3.32	
	2010	0.06	3.27	3.32	
Formaldehyde	2006	1.09	3.31	4.40	9.8
	2007	1.25	3.31	4.57	
	2008	1.11	3.31	4.43	
	2009	1.03	3.31	4.34	
	2010	1.17	3.31	4.49	
n-Hexane	2006	82.49	25.69	108.18	200
	2007	91.23	25.69	116.92	
	2008	77.16	25.69	102.85	
	2009	73.54	25.69	99.23	
	2010	88.27	25.69	113.96	
Toluene	2006	7.79	13.17	20.96	400
	2007	8.62	13.17	21.79	
	2008	7.23	13.17	20.41	
	2009	6.90	13.17	20.07	
	2010	8.34	13.17	21.51	
Xylene	2006	7.58	N/A [c]	7.58	100
	2007	8.38	N/A [c]	8.38	
	2008	7.04	N/A [c]	7.04	
	2009	6.72	N/A [c]	6.72	
	2010	8.11	N/A [c]	8.11	

$\mu g/m^3$ = micrograms per cubic meter

RfC = Reference Concentration for Chronic Inhalation

[a] Background concentrations are values for year 2011 for all pollutants, except formaldehyde; formaldehyde value is for year 2010. These values were provided to URS by EPA for the Region and all pollutants data were monitored / collected at Odessa, Texas (48-135-3) location for all pollutants, except formaldehyde; formaldehyde value is from El Paso, Texas monitor (48-141-44). All values are annual arithmetic means.

[b] USEPA Air Toxics Database, Table 1 (USEPA, 2005b).

[c] Monitored data was not available for this pollutant.

Table 3-11. Annual Average Predicted HAP Concentrations Compared to RfCs

Pollutant	Year	Annual Average Modeled Concentration ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$) [a]	Maximum Total Concentration ($\mu g/m^3$)	RfC [b] ($\mu g/m^3$)
Benzene	2006	1.02	6.18	7.20	30
	2007	1.13	6.18	7.32	
	2008	1.04	6.18	7.23	
	2009	1.04	6.18	7.22	
	2010	1.14	6.18	7.33	
Ethylbenzene	2006	0.04	3.27	3.31	1,000
	2007	0.05	3.27	3.32	
	2008	0.04	3.27	3.31	
	2009	0.04	3.27	3.31	
	2010	0.05	3.27	3.31	
Formaldehyde	2006	1.07	3.31	4.38	9.8
	2007	1.26	3.31	4.57	
	2008	1.12	3.31	4.43	
	2009	1.04	3.31	4.35	
	2010	1.17	3.31	4.48	
n-Hexane	2006	161.43	25.69	187.12	200
	2007	182.74	25.69	208.43	
	2008	148.05	25.69	173.74	
	2009	135.85	25.69	161.55	
	2010	175.62	25.69	201.31	
Toluene	2006	15.25	13.17	28.43	400
	2007	16.90	13.17	30.07	
	2008	13.69	13.17	26.87	
	2009	12.56	13.17	25.73	
	2010	16.34	13.17	29.51	
Xylene	2006	14.49	N/A [c]	14.49	100
	2007	16.41	N/A [c]	16.41	
	2008	13.30	N/A [c]	13.30	
	2009	12.20	N/A [c]	12.20	
	2010	15.77	N/A [c]	15.77	

$\mu g/m^3$ = micrograms per cubic meter

RfC = Reference Concentration for Chronic Inhalation

[a] Background concentrations are values for year 2011 for all pollutants, except formaldehyde; formaldehyde value is for year 2010. These values were provided to URS by EPA for the Region and all pollutants data were monitored / collected at Odessa, Texas (48-135-3) location for all pollutants, except formaldehyde; formaldehyde value is from El Paso, Texas monitor (48-141-44). All values are annual arithmetic means.

[b] USEPA Air Toxics Database, Table 1 (USEPA, 2005b).

[c] Monitored data was not available for this pollutant.

A second adjustment was made for time spent at home versus time spent elsewhere. For the MLE scenario, the at-home time fraction is 0.64 (USEPA 1993), and it was assumed that during the rest of the day the individual would remain in an area where annual HAP concentrations would be one-quarter as large as the maximum annual average concentration.

Therefore, the MLE adjustment factor was $(0.13) \times [(0.64 \times 1.0) + (0.36 \times 0.25)] = 0.095$. The MEI scenario assumed that the individual is at home 100 percent of the time, for a final adjustment factor of $(0.29 \times 1.0) = 0.29$. USEPA URFs and adjustment factors are shown in Table 3-12 and Table 3-13.

Cancer risk from benzene, formaldehyde, and the combined HAPs are shown in Table 3-12 and Table 3-13. For the MLE, an individual could encounter a maximum cumulative cancer risk due to both pollutants of up to 0.85 in one million associated with Scenario 2.

Table 3-12. Cancer Risk From Long-Term Exposure – Scenario 1

HAP	Year	Analysis	Carcinogenic RfC URF 1/(μg/m^3)	Exposure Adjustment Factor	Cancer Risk (in a million)
Benzene	2006	MLE	7.80E-06	0.095	0.36
		MEI	7.80E-06	0.29	1.09
	2007	MLE	7.80E-06	0.095	0.38
		MEI	7.80E-06	0.29	1.16
	2008	MLE	7.80E-06	0.095	0.35
		MEI	7.80E-06	0.29	1.07
	2009	MLE	7.80E-06	0.095	0.35
		MEI	7.80E-06	0.29	1.07
	2010	MLE	7.80E-06	0.095	0.41
		MEI	7.80E-06	0.29	1.24
Formaldehyde	2006	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2007	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2008	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2009	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2010	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
Total Combined	2006 - 2010	MLE			0.41
		MEI			1.24

μg/m^3 = micrograms per cubic meter

MEI = maximally exposed individual

MLE = most likely exposure

URF = unit risk factor

[a] USEPA Air Toxics Database, Table 1 (USEPA, 2005b).

Table 3-13. Cancer Risk From Long-Term Exposure – Scenario 2

HAP	Year	Analysis	Carcinogenic RfC URF 1/(µg/m^3)	Exposure Adjustment Factor	Cancer Risk (in a million)
Benzene	2006	MLE	7.80E-06	0.095	0.75
		MEI	7.80E-06	0.29	2.30
	2007	MLE	7.80E-06	0.095	0.84
		MEI	7.80E-06	0.29	2.56
	2008	MLE	7.80E-06	0.095	0.77
		MEI	7.80E-06	0.29	2.36
	2009	MLE	7.80E-06	0.095	0.77
		MEI	7.80E-06	0.29	2.34
	2010	MLE	7.80E-06	0.095	0.85
		MEI	7.80E-06	0.29	2.58
Formaldehyde	2006	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2007	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2008	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2009	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
	2010	MLE	5.5E-09	0.095	0.00
		MEI	5.5E-09	0.29	0.00
Total Combined	2006 - 2010	MLE			0.85
		MEI			2.58

µg/m^3 = micrograms per cubic meter

MEI = maximally exposed individual

MLE = most likely exposure

URF = unit risk factor

[a] USEPA Air Toxics Database, Table 1 (USEPA, 2005b).

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4.0 PHOTOCHEMICAL GRID MODELING ANALYSIS

4.1. PGM OVERVIEW

Photochemical grid modeling (PGM) programs were used to assess impacts to ambient ground-level pollutants resulting from air emissions associated with the CFO RMP. Pollutant impacts were quantified and compared to the NAAQS, including the newly revised PM NAAQS. Modeling was performed using a 2008 base case year and emissions growth projections with data reflecting 2017 emissions inventories. The pollutant assessment focuses on impacts throughout the state of New Mexico and nearby surrounding states, although pollutant concentrations were predicted for the contiguous United States.

4.1.1. PGM MODEL SELECTION

Three models were used in the CFO RMP assessment. The CAMx photochemical grid model predicted ambient pollutant concentrations based on meteorological data inputs prepared using the Weather Research and Forecasting Model (WRF) and emissions data prepared using the SMOKE emissions processing system. Each of these programs is discussed below.

4.1.2. CAMx Regional Photochemical Model Description

The CAMx modeling system is a state-of-science 'One-Atmosphere' photochemical grid model capable of addressing ozone, particulate matter (PM), visibility and acid deposition at regional scale for periods up to one year (ENVIRON 2011). CAMx is a publicly available open-source computer modeling system for the integrated assessment of gaseous and particulate air pollution. Built on today's understanding that air quality issues are complex, interrelated, and reach beyond the urban scale, CAMx is designed to (a) simulate air quality over many geographic scales, (b) treat a wide variety of inert and chemically active pollutants including ozone, inorganic and organic $PM_{2.5}$ and PM_{10} and mercury and toxics, (c) provide source-receptor, sensitivity, and process analyses and (d) be computationally efficient and easy to use. The USEPA has approved the use of CAMx for numerous Ozone and PM State Implementation Plans (SIPs) throughout the U.S, and has used this model to evaluate regional mitigation strategies including those for recent regional rules (e.g., Cross-State Air Pollution Rule [CSAPR], Clean Air Transport Rule [CATR], Clean Air Interstate Rule [CAIR], NO_x State Implementation Plan [SIP] Call, etc.).

4.1.3. WRF Model Description

The non-hydrostatic version of the WRF model (WRF-ARW; Skamarock et al. 2005; Mickalakes et al. 2001) is a three-dimensional, limited-area, primitive equation, prognostic model that has been used widely in regional air quality model applications. The basic model has been under continuous development, improvement, testing and open peer-review for more than 10 years and has been used world-wide by hundreds of scientists for a variety of mesoscale studies, including cyclogenesis, polar lows, cold-air damming, coastal fronts, severe thunderstorms, tropical storms, subtropical easterly jets, mesoscale convective complexes, desert mixed layers, urban-scale modeling, air quality studies, frontal weather, lake-effect snows, sea-breezes, orographically induced flows, and operational mesoscale forecasting. WRF is a next-generation mesoscale prognostic meteorological model routinely used for urban- and regional-scale photochemical, fine particulate and regional haze regulatory modeling studies. Developed jointly by the National Center for Atmospheric Research (NCAR) and the National Centers for

Environmental Prediction (NCEP), WRF is maintained and supported as a community model by researchers and practitioners around the globe. The code supports two modes: the Advanced Research WRF (ARW) version and the Non-hydrostatic Mesoscale Model version. WRF-ARW has become the new standard model used in place of the older Mesoscale Meteorological Model (MM5) for regulatory air quality applications in the U.S. It is suitable for use in a broad spectrum of applications across scales ranging from meters to thousands of kilometers (WestJumpAQMS 2011).

4.1.4. SMOKE Emissions Processing System Description

The SMOKE processing system is a set of programs that is used by the USEPA, Regional Planning Organizations (RPOs), and state environmental agencies to prepare emissions inventory data for input to air quality models such as CAMx (Coats 1995). SMOKE converts annual or daily estimates of emissions at the state or county level to hourly emissions fluxes on a uniform spatial grid that are formatted for input to an air quality model. SMOKE integrates annual county-level emissions inventories with source-based temporal, spatial, and chemical allocation profiles to create hourly emissions fluxes on a predefined model grid. For elevated sources that require allocation of the emissions to the vertical model layers, SMOKE integrates meteorology data to derive dynamic vertical profiles. In addition to its capacity to simulate emissions from stationary area, stationary point, and on-road mobile sectors, SMOKE can also receive inputs from the Model of Emissions of Gases and Aerosols from Nature (MEGAN) biogenics modeling system, as well as outputs from the MOVES motor vehicle emissions model. SMOKE can additionally be used to calculate future-year emissions estimates, if the user provides data about how the emissions will change in the future.

4.2. MODELING DOMAIN AND VERTICAL LAYERS

The CFO pollutant assessment modeling included the three nested domains shown in Map 4-1 (CFO 4 km, CFO 12 km, and continental U.S. [CONUS]). The domains were defined using projection information included in Table 4-1. The CFO modeling domains are based in part on the domains used in the WestJump Air Quality Modeling Study (AQMS) (WestJumpAQMS 2011).

Table 4-1. CAMx Domain Projection and Coordinates

Lambert-Conformal Projection Information	Grid	Domain[a]		
		D01	D02[b]	D03[b]
Alpha: 33°	Dx Dy (km)	36	12	4
Beta: 45°	Xorig (km)	-2,736	-2388	-1084
Gamma: -97°	Yorig (km)	-2,088	-1236	-904
Central longitude: -97°	# Columns	148	227	209
Central latitude: 40°	# Rows	112	119	155

[a]Domain D01 is the same as the WestJumpAQMS 36 km domain, while the 12 km domain (D02) and the 4 km domain (D03) are a subset of the WestJumpAQMS 12 km and 4 km domains.

[b]Buffer cells are included for the D02 and D03 domains.

The three nested PGM domains are based on the Lambert-Conformal projection used by the WestJumpAQMS and are 3:1 nested grids of 36:12:4 km resolution. The 4 km domain, which will be the focus of the ozone modeling assessment, encompasses the CFO area and the entire New Mexico portion of the Permian Basin. To ensure consistency in meteorological parameters, the horizontal projection of the CAMx modeling domain will match that of the WRF meteorological modeling domains.

Map 4-1. CAMx Model Domains

The vertical structure of the WRF modeling domain includes 37 vertical layers, with 20 layers approximately within the planetary boundary layer (PBL) (below ~2500 m) and 17 layers above the PBL. The top of the modeling domain was set at the 50 millibar (mb) level (~19,000 meters). The WRF layer structure was collapsed to 25 layers for the CAMx modeling (see Table 5-2). This vertical structure is the same as that used for the WestJumpAQMS modeling.

Table 4-2. Vertical Layer Structure for WRF Modeling (Left) and CAMx Modeling (Right)

WRF					CAMx		
WRF Layer	Sigma	Pressure (mb)	Height (m)	Thickness (m)	CAMx Layer	Height (m)	Thickness (m)
37	0	50	19260	2055	25	19260	3904.9
36	0.027	75.65	17205	1850			
35	0.06	107	15355	1725	24	15355.1	3425.4
34	0.1	145	13630	1701			
33	0.15	192.5	11930	1389	23	11929.7	2569.6
32	0.2	240	10541	1181			
31	0.25	287.5	9360	1032	22	9360.1	1952.2
30	0.3	335	8328	920			
29	0.35	382.5	7408	832	21	7407.9	1591.8
28	0.4	430	6576	760			
27	0.45	477.5	5816	701	20	5816.1	1352.9
26	0.5	525	5115	652			
25	0.55	572.5	4463	609	19	4463.3	609.2
24	0.6	620	3854	461	18	3854.1	460.7
23	0.64	658	3393	440	17	3393.4	439.6
22	0.68	696	2954	421	16	2953.7	420.6
21	0.72	734	2533	403	15	2533.1	403.3
20	0.76	772	2130	388	14	2129.7	387.6
19	0.8	810	1742	373	13	1742.2	373.1
18	0.84	848	1369	271	12	1369.1	271.1
17	0.87	876.5	1098	177	11	1098	176.8
16	0.89	895.5	921	174	10	921.2	173.8
15	0.91	914.5	747	171	9	747.5	170.9
14	0.93	933.5	577	84	8	576.6	168.1
13	0.94	943	492	84			
12	0.95	952.5	409	83	7	408.6	83
11	0.96	962	326	82	6	325.6	82.4
10	0.97	971.5	243	82	5	243.2	81.7
9	0.98	981	162	41	4	161.5	64.9
8	0.985	985.75	121	24			
7	0.988	988.6	97	24	3	96.6	40.4
6	0.991	991.45	72	16			
5	0.993	993.35	56	16	2	56.2	32.2
4	0.995	995.25	40	16			
3	0.997	997.15	24	12	1	24.1	24.1
2	0.9985	998.58	12	12			
1	1	1000	0				

4.3. CAMx PERFORMANCE EVALUATION

A model performance evaluation (MPE) was performed to determine how well the CAMx model is able to replicate observed concentrations of pollutants in the troposphere. Model performance was limited to an assessment of ozone and $PM_{2.5}$ performance.

The following represents a summary of the MPE and is presented here to provide context for the remainder of this document.

4.3.1. Ozone Evaluation

4.3.1.1. Ozone Monitor Locations and Data

Ozone monitor locations and their data play two crucial roles in this air quality assessment, as follows.

- For the MPE, the monitors' data are used to determine how well the 2008 base case CAMx runs replicate monitored ozone concentrations.
- For the ozone impacts analysis, ozone design values (DVs) from these monitors were used to calculate future design values (DVFs) for use in determining compliance with the NAAQS.

Observational data used for the MPE included data from ozone monitors in several monitoring networks (described below). Of the 32 ozone monitors operating in the 4 km domain during 2008, the majority were State and Local Air Monitoring Stations (SLAMS). There were also several monitors in the National Air Monitoring Station (NAMS) network. Additional monitors within the 4 km domain were operated by the National Park Service (NPS), and the Jemez Pueblo. Map 4-2 shows the location of the monitors in the 4 km domain.

SLAMS – This network is a collection of monitors run by State and local governments; each monitor must meet USEPA measurement and siting requirements. Data from this network is reported to USEPA's Air Quality System (AQS). SLAMS monitors are typically located in urban areas. All monitors in the SLAMS network are continuous monitors that meet strict performance and quality assurance requirements. SLAMS monitors are used to determine whether an area should be designated attainment or nonattainment for the ozone NAAQS. SLAMS monitors are identified by unique 9-digit numbers, as shown in Map 4-2.

NAMS – This network is a collection of monitors operated by USEPA and is similar to the SLAMS network. These monitors are also used to determine the attainment status of an area and are also identified by unique 9-digit numbers.

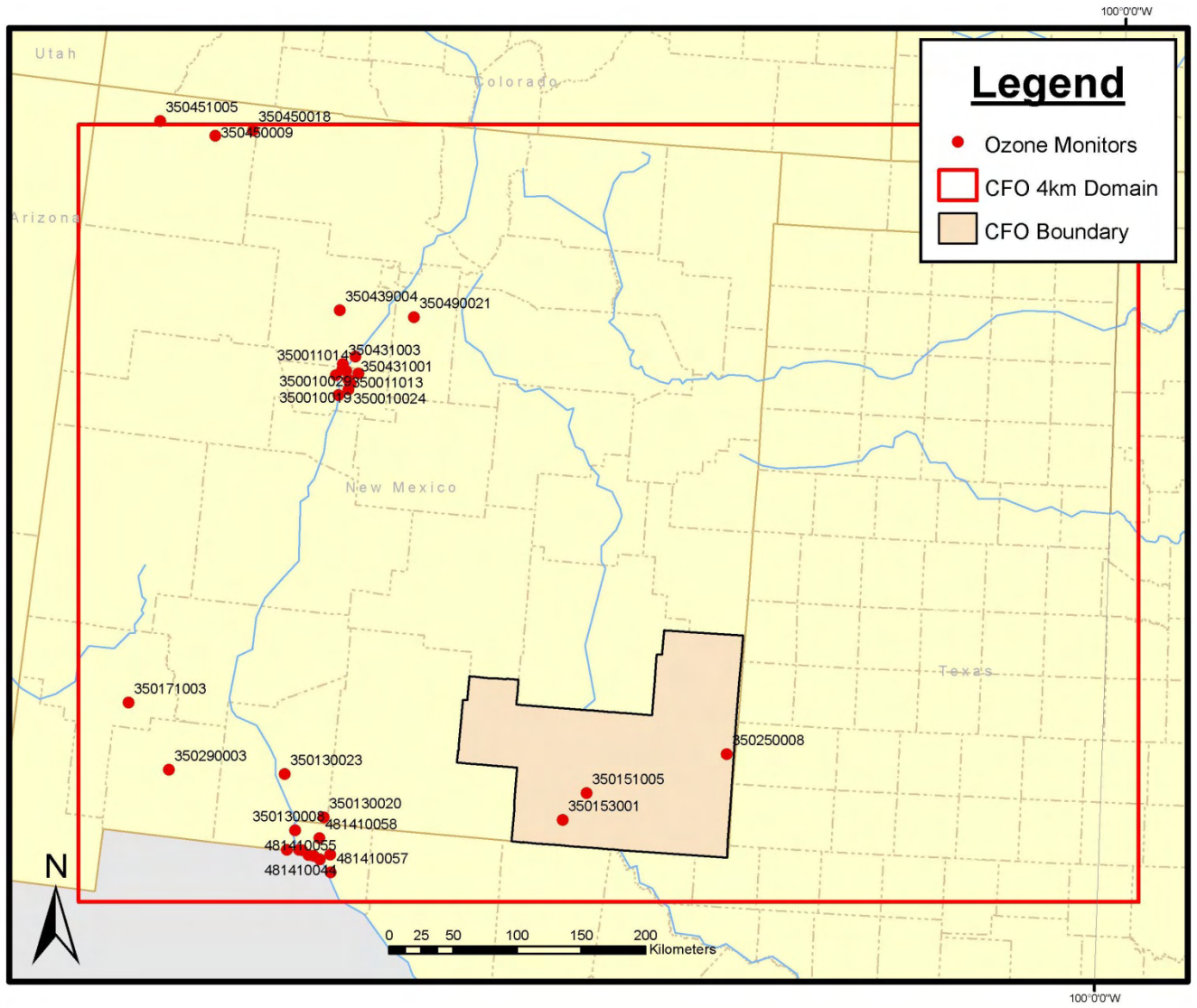
Special purpose monitors – These monitors are not part of a network, but do report data to the AQS. These monitors are usually used by State or local governments for a variety of reasons. Some are used to help determine siting for a permanent monitor, while others are used to investigate certain areas of importance within an agency's domain. Special purpose monitors are categorized as "other" monitors in Map 4-2.

NPS – The NPS operates one ozone monitor in the 4 km domain at Carlsbad Caverns National Park.

A full list of ozone monitors that operated during 2008 in the 4 km domain is provided in Table 4-3.

Table 4-3. 2008 Active Ozone Monitors in the 4 km Domain

Monitor ID	Location Description	Monitor Type
CFO		
350151005	Holland St., Carlsbad	SLAMS
350153001	Carlsbad Caverns National Park	NPS
350250008	Hobbs-Jefferson	SLAMS
Doña Ana County		
350130020	Chaparral	SLAMS
350130008	St. Lukes Episcopal Church	SLAMS
350130017	Sunland Park City Yard	SLAMS
350130021	Sunland Park	SLAMS
350130022	Santa Teresa Intl. Blvd.	SLAMS
350130023	NM Hwy. Dept. Yard, Las Cruces	SLAMS
El Paso, TX		
481410058	Skyline Park	SLAMS
481410029	Ivanhoe Fire Station	Special Purpose
481410055	Ascarate Park SE	PAMS
481410044	Chamizal	SLAMS
481410037	University of Texas at El Paso (UTEP)	SLAMS
481410057	Socorro	SLAMS
Southwest New Mexico		
350290003	Airport Road, Deming	SLAMS
350171003	Hurley Park	SLAMS
Albuquerque, New Mexico		
350010029	South Valley Mountain View	SLAMS
350010024	South East Heights	Other
350010019	Uptown Zuni Park	SLAMS
350010023	Del Norte High School	SLAMS
350010027	Westside Taylor Ranch	SLAMS
350011012	Far North East Heights	SLAMS
350011013	North Valley	SLAMS
350011014	Westside Corrales	SLAMS
350431001	NM Hwy. Dept. Yard, Sandoval County	SLAMS
350431003	Rio Rancho Senior Center	SLAMS
350439004	Pueblo of Jemez Tribal Trust Lands	Tribal
Santa Fe, New Mexico		
350490021	Aviation Dr., Santa Fe	SLAMS
Four Corners Area Monitors		
350450018	Navajo Dam	SLAMS
350450009	NM Hwy. Dept. Yard, Bloomfield	SLAMS
350451005	USBR Shiprock Substation	SLAMS



Map 4-2. Ozone Monitors in the 4 km Domain

4.3.1.2. Ozone Model Performance Evaluation Methodology

There are no set standards for performing an MPE, however, the EPA has provided guidelines in its document, Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze (USEPA 2007).

USEPA's guidance recommends that the following statistical measures be calculated for 8-hour daily maximum ozone:

- Mean Normalized Bias (MNB),
- Mean Normalized Gross Error (MNGE),
- Average Peak Prediction Bias (APPB).

The guidelines from the guidance document are shown in Table 4-4.

Table 4-4. USEPA Ozone Modeling Performance Goals

Statistical Measure	Goal
Mean Normalized Bias (MNB)	≤ ±15%
Mean Normalized Gross Error (MNGE)	< 35%
Average Peak Prediction Bias (APPB)	(no EPA guideline)

MNB and MNGE were calculated using 8-hour ozone observed values greater than or equal to 60 ppb. APPB was calculated using 8-hour daily maximum ozone observed values greater than or equal to 60 ppb. The MNB, MNGE, and APPB values were computed using model values from the grid cell in which the monitor is located.

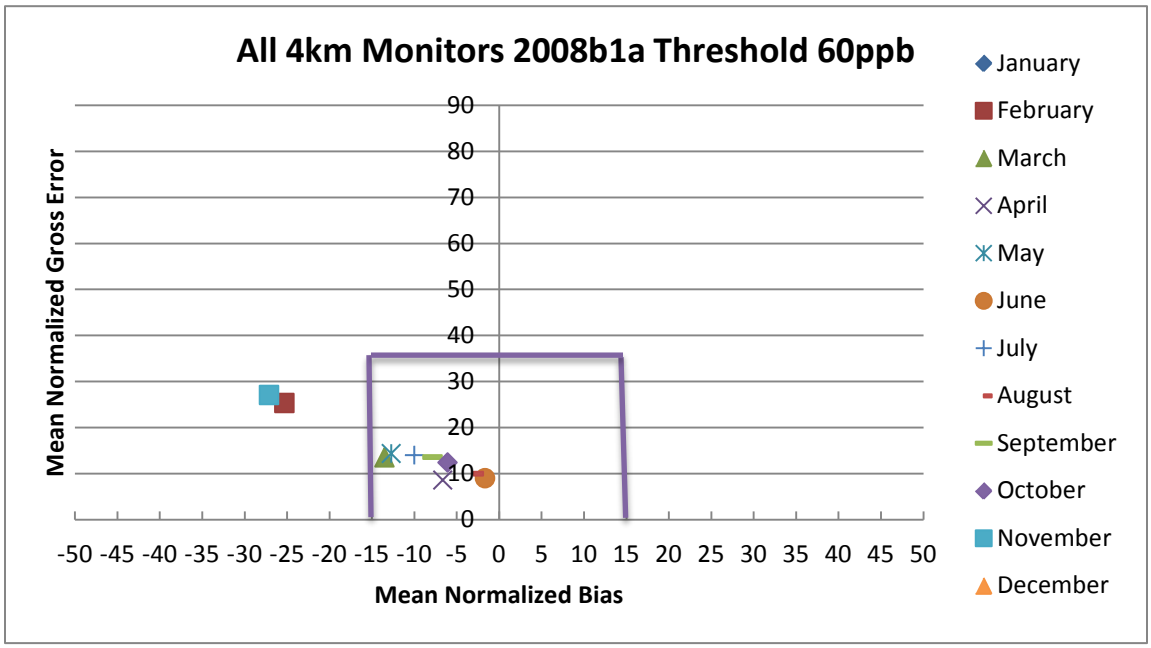
Average Peak Prediction Bias is simply the mean normalized bias of the 8-hour daily maxima ozone values. Table 4-5 below shows APPB values averaged over a month for all the monitors in the 4 km domain and for each of the three monitors in the CFO. For the months of February and November, there was only one day at one site for each month that had observed values greater than 60ppb.

Table 4-5. Average Peak Prediction Bias for Ozone

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
All monitors in 4km domain		-19	-11	-3	-10	0	-8	-1	-6	-5	-25	
350151005			-10	1	-4	-4	-1	2	-7			
350153001				-10	-11	-4	-2	0	3			
350250008				-2	-9	3	-7	1				

MNB and MNGE were calculated for all observation/model pairs when the observed value was greater than 60ppb. Figure 4-1 shows two soccer plots, one for all the monitors in the 4km domain and one for just the three monitors in the CFO. Each point on the plot represents the MNB and MNGE for each month. The purple box outlines the goal for these metrics. These plots show the model performing very well with only two months outside the goal when looking at all the monitors. The two months outside the goal, February and November, had only one day each that had observational values above 60ppb. Soccer plots for the individual monitors also show most months within the goal box. The vast majority of the months outside the goal are for

low MNB. This means that the model tends to under predict 8-hour daily maximum when the observed values are above 60ppb.



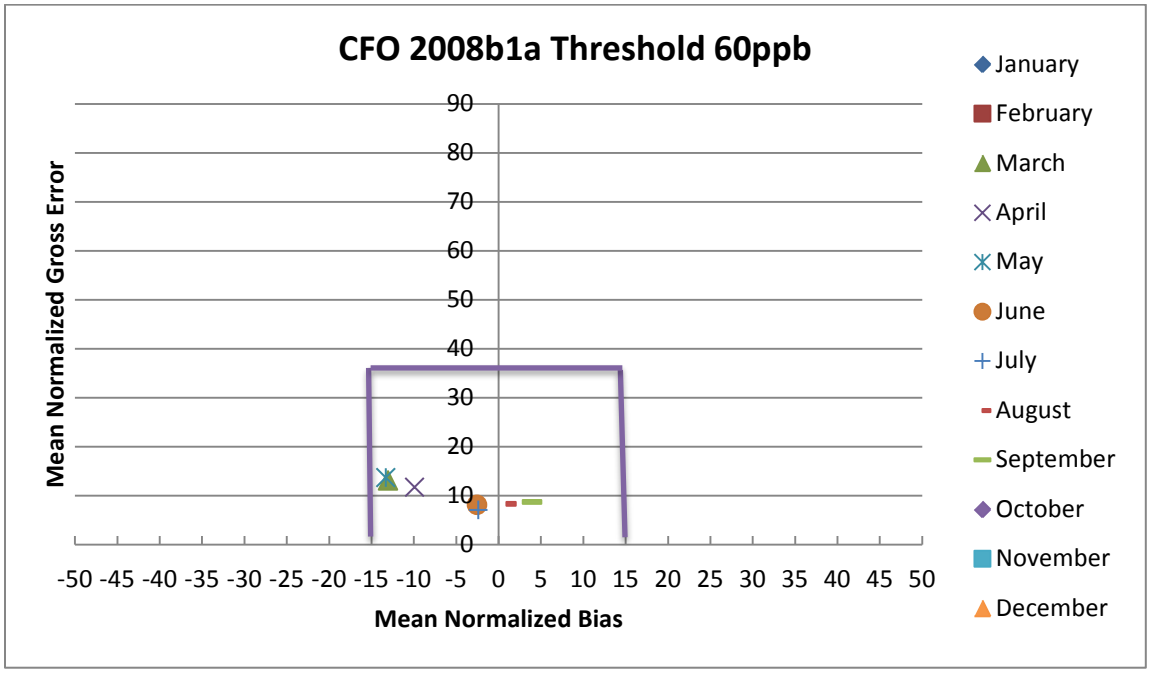


Figure 4-1. 8-hour Daily Maximum Ozone Soccer Plots

In addition to USEPA's modeling performance goals shown in Table 4-4, the agency also issued draft guidance that allows for a less stringent performance goal based on most days demonstrating nearby daily 8-hour maximum ozone values within ±20 percent of observed values (USEPA 1991). USEPA defines nearby as within an approximate 15 km radius from the center of the grid cell containing the monitor. Therefore, in the 4 km domain, the modeled value

or values were selected from a 7×7 grid of cells centered on the cell containing the monitor (USEPA 2007).

For some analyses, model performance is assessed by reviewing three different types of "nearby" predicted values: co-located value, closest value, and the maximum value. Figure 4-2 provides an illustration of these values. In this example, the observed (monitored) value is 65 ppb ozone as shown in green text at the center of the 7×7 grid. The co-located predicted value is shown in blue; it is the modeled value for the grid cell that contains the monitor. The "closest" predicted value is the numerical value within the 7x7 grid that most closely approximates the monitored value. In this case, three values of 66 ppb (shown in orange) are closest to the observed value of 65 ppb. Finally, the maximum value is the greatest numerical value within the grid. In this case, two maximum values of 67 ppb are shown in red.

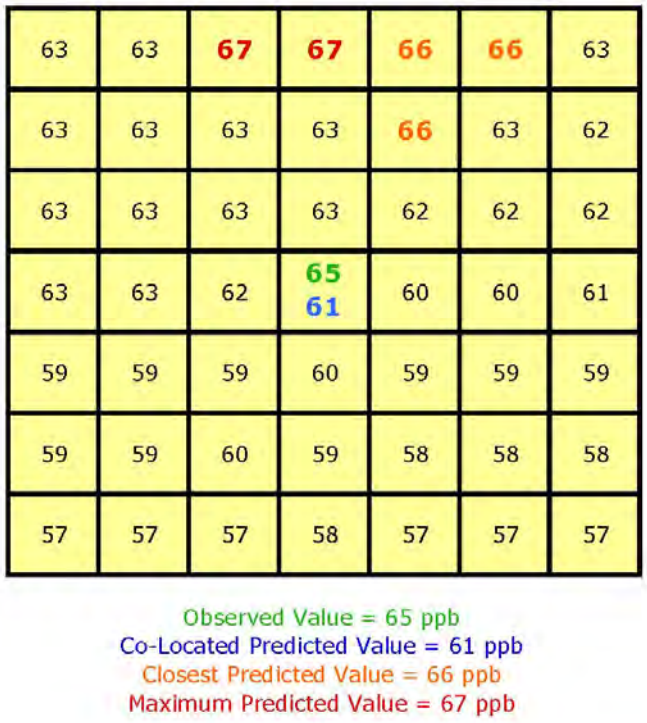


Figure 4-2. Example of Nearby Values Used in Model Performance Analysis

Table 4-6 provides a summary of the percentage of days for which predicted ozone concentrations are within 20 percent of monitored values for all monitors in the 4 km domain.

The modeled values "near" the monitor will be used to project 8-hour ozone design values into the future using EPA's relative response factors (RRFs) approach. Performance is better in the spring and early summer.

Table 4-6. Percentage of Days 2008 Nearby 8-hr Daily Maximum Predicted Concentrations Within ±20% of Observed Values

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Spatially Paired Values	68	71	90	88	77	71	70	59	49	55	63	51
Maximum Values	50	63	86	83	74	60	63	41	34	33	42	40

Another important comparison of daily maximum 8-hour ozone predicted values relates to the form of the ozone NAAQS. Violations of the standard are based on a three-year average of the fourth highest daily maximum 8-hour monitored value in each year. The first, second, third, and fourth highest absolute predicted values during 2008 base case modeling were compared to observed values.

First through fourth highest predicted ozone concentrations differences are below 10 percent for the monitors in the CFO (Carlsbad and Hobbs), as shown in Table 4-7. The first through fourth highest predicted ozone concentrations indicate a tendency toward over prediction at all monitors in New Mexico and under prediction at all monitors in El Paso County, Texas. The largest difference (21%) occurred at the Las Cruces monitor for the highest value. Performance improved to 9% for the fourth highest value.

Table 4-7. 2008 1st Through 4th Highest Daily Maximum 8-hour Ozone Concentration Differences

Ozone Concentration (ppb)	Carlsbad (350151005)	Hobbs (350250008)	Albuquerque (350010023)	Four Corners (350450009)	Las Cruces (350130023)	El Paso (481410044)
1st High						
Observed	72	69	68	65	70	84
Predicted	78	75	77	76	84	79
Difference	9%	8%	13%	17%	21%	-6%
2nd High						
Observed	69	68	66	65	68	84
Predicted	73	72	75	76	75	72
Difference	6%	6%	15%	17%	9%	-15%
3rd High						
Observed	68	67	65	64	67	80
Predicted	71	72	73	75	74	69
Difference	4%	6%	12%	17%	11%	-13%
4th High						
Observed	67	67	65	63	65	74
Predicted	71	71	72	73	71	69
Difference	5%	6%	11%	16%	9%	-6%

4.3.2. $PM_{2.5}$ Evaluation

4.3.2.1. $PM_{2.5}$ Monitor Locations and Data

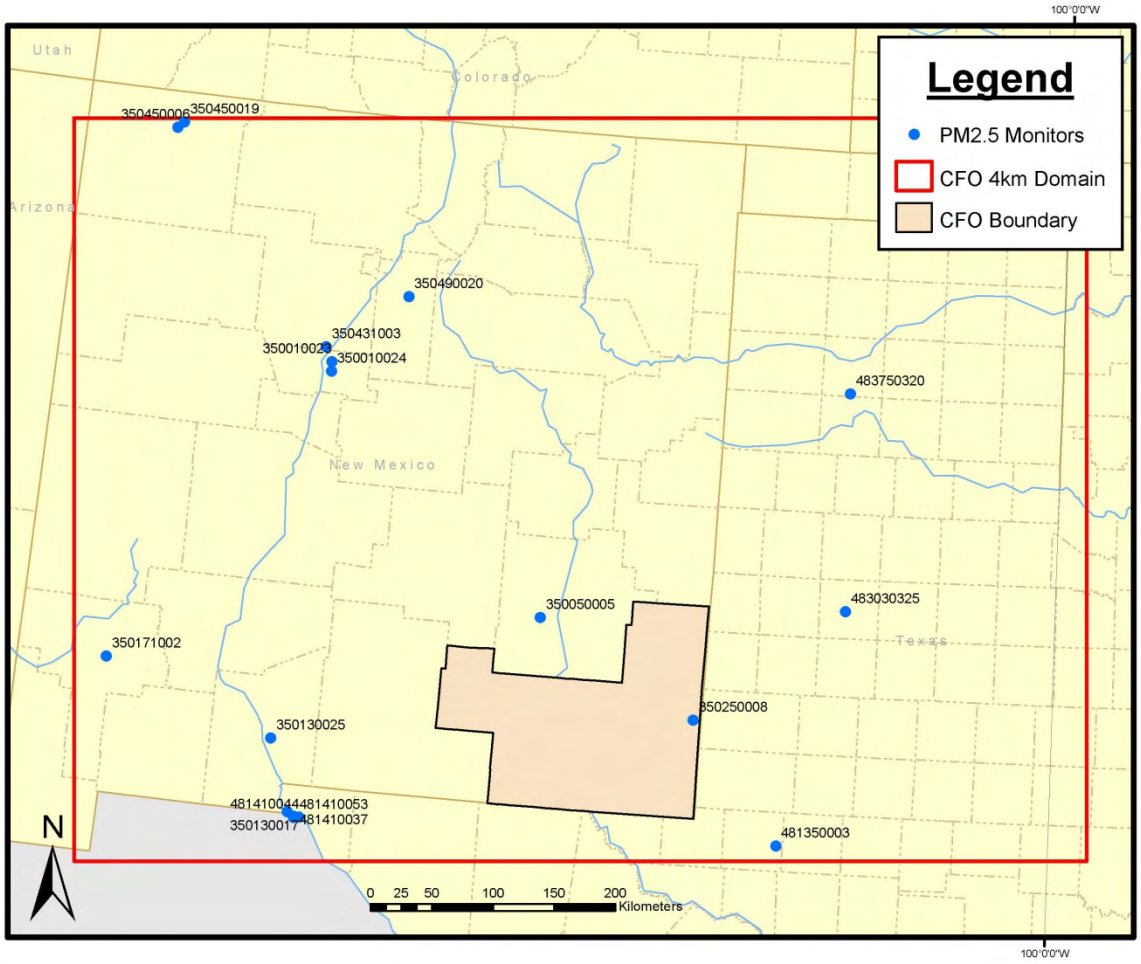
Similar to ozone, $PM_{2.5}$ monitor locations and their data play two crucial roles in this air quality assessment, as follows.

- For the MPE, the monitors' data are used to determine how well the 2008 base case CAMx runs replicate monitored $PM_{2.5}$ concentrations.
- For the $PM_{2.5}$ impacts analysis, $PM_{2.5}$ design values (DVs) from these monitors were used to calculate future design values (DVFs) for use in determining compliance with the NAAQS.

Of the 17 $PM_{2.5}$ monitors operating in the 4 km domain during 2008, the majority were State and Local Air Monitoring Stations (SLAMS). Map 4-3 shows the location of the monitors in the 4 km domain. A full list of $PM_{2.5}$ monitors that operated during 2008 in the 4 km domain is provided in Table 4-8.

Table 4-8. 2008 Active $PM_{2.5}$ Monitors in the 4 km Domain

Monitor ID	Location Description	Monitor Type
CFO		
350250008	Hobbs-Jefferson	SLAMS
Near CFO		
350050005	Roswell City Offices	SLAMS
Southwest New Mexico		
350130017	Sunland Park City Yard	SLAMS
350130025	NM Environmental Dept. District Office	SLAMS
350171002	Western New Mexico University	SLAMS
Odessa, Texas		
481350003	Odessa-Hays Elementary School	SLAMS
Lubbock, Texas		
483030325	Lubbock	Supplemental Speciation
El Paso, Texas		
481410037	University of Texas at El Paso (UTEP)	SLAMS
481410044	Chamizal	SLAMS
481410053	Sun Metro	Supplemental Speciation
Albuquerque, New Mexico		
350010023	Del Norte High School	SLAMS
350010024	South East Heights	SLAMS
350431003	Rio Rancho Senior Center	SLAMS
Santa Fe, New Mexico		
350490020	Runnels Building	SLAMS
Amarillo, Texas		
483750320	Texas A&M AgriLife Research and Extension Center	SLAMS
Four Corners Area		
350450006	EIA Office	SLAMS
350450019	Farmington Environmental Department Office	SLAMS



Map 4-3. PM2.5 Monitors in the 4 km Domain

4.3.2.2. $PM_{2.5}$ Model Performance Evaluation Methodology

EPA guidance suggests calculating the mean fractional bias (MFB) and the mean fractional error (MFE) for PM. These metrics are better to use because of the very small values that PM can reach. Model performance goals that have been developed are broken into three categories (Table 4-9).

Table 4-9. USEPA PM Modeling Performance Goals

Statistical Measure	Goal		
	Excellent	Good	Average
Mean Fractional Bias (MFB)	≤ ±15%	≤ ±30%	≤ ±60%
Mean Fractional Error (MFE)	< 35%	< 50%	< 75%

Soccer plots were created for all the 4 km monitors as well as each individual monitor. Only one $PM_{2.5}$ monitor exists inside the CFO. However, there is a monitor in Roswell which is approximately 50 km from the CFO boundary. Another soccer plot was created using the CFO monitor and the Roswell monitor. The soccer plot for all 4 km monitors shows eight months

meeting the average performance goal, the months of February, March and August just outside of all goals, and the month of June showing good performance (Figure 4-3). The performance is much improved for the Texas monitors. Most monitors show that the model tends to over predict $PM_{2.5}$.

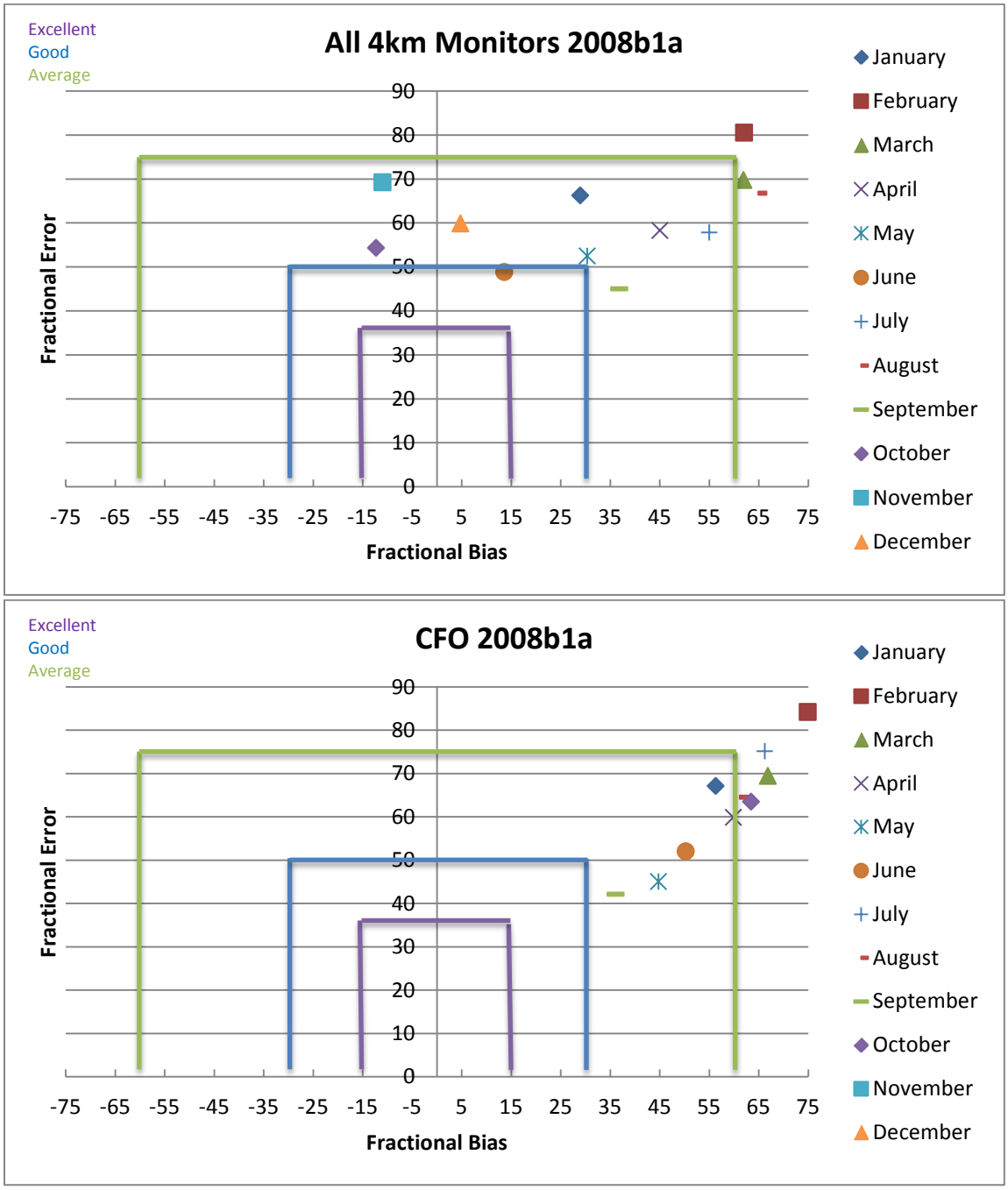


Figure 4-3. PM2.5 Soccer Plots

4.3.3. Model Performance Evaluation Conclusion

The MPE indicated that the model is performing within USEPA's modeling guidelines most of the time, and particularly during the high ozone months.

Ozone statistics showed that on most high ozone days during the year, the 8 hour daily maximum model results fall within USEPA statistical guidelines. This is important since these values are compared to the ozone NAAQS when determining potential future-year impacts from CFO alternatives. Overall, the model tended to under predict ozone when the observed values were greater than 60 pbb.

The $PM_{2.5}$ statistics show that the model tends to over predict $PM_{2.5}$, sometimes by a large margin. This will be taken into account when looking at the model impact results from CFO Project emissions.

The MPE demonstrated that the model performs adequately to predict future year ozone and $PM_{2.5}$ concentrations within a reasonable margin of error, in accordance with USEPA guidelines and performance goals.

4.4. EMISSIONS INVENTORY DEVELOPMENT AND PROCESSING

Emissions inventory development involved development and processing of multiple emissions sets. One set of emissions represented year 2008 base case emissions. Three additional emissions sets represented year 2017 future year emissions scenarios. The three future year emissions sets included a future year base case emissions scenario, which excluded CFO Project emissions and included year 2017 and 2028 cumulative emissions, and one future year emissions scenario for each of two CFO Alternatives. The future year base case inventory enables assessment of the incremental pollutant concentrations associated with each Alternative by comparing these concentrations to future year base case concentrations without CFO oil and gas development.

Most PGM emissions inventories input into the SMOKE emissions processing system were built from the WRAP Regional Modeling Center (WRAP-RMC), other regional planning organization emission sets, and USEPA emissions databases. Emissions inventories representing years 2008 and 2017 were used to represent current (base case) emissions and future year emissions, respectively. The 2017 future year PGM emissions inventories do not align with the 20-year time frame of the CFO LOP. However, the 2017 emissions inventories provide the best available estimates of future year emissions for many source categories. Year 2017 emissions sets were increased to include year 2028 emissions for the CFO.

The following sections provide a brief description of emissions sets included in the 2008 and 2017 emissions inventories. More detailed information on these emissions sets is included Section 2 of this report.

4.4.1. 2008 Base Case Emissions Inventory

Six main types of sources were included in the 2008 base case emissions inventory: stationary area sources (non-point), non-road mobile, mobile sources, point sources (including fires), biogenic sources, and oil and gas sources. Emissions inventory sources for these general source types are listed in Table 4-10. Note that oil and gas sources are a combination of point and area sources.

Table 4-10. 2008 Base Case Emissions Inventory Sources

Inventory Type	Spatial Coverage	Description
Stationary area (non-point)	U.S., Canada, Mexico	2008 NEI v1.5 2006 NPRI Canadian Emissions 1999 Mexico National Emissions Inventory Ver2.2
Non-road mobile	U.S., Canada, Mexico	2008 NEI v1.5 2006 NPRI Canadian Emissions 1999 Mexico National Emissions Inventory Ver2.2
On-road mobile	U.S.	Emissions calculated using MOVES2010a
Point	U.S., Canada, Mexico	2008 NEI v1.5 CEM data for major industrial point sources Fire emissions data from the BlueSky Framework 2006 NPRI Canadian Emissions 1999 Mexico National Emissions Inventory Ver2.2
Biogenic	North America and Caribbean	Emissions calculated using MEGAN2.10
Oil and Gas	U.S.	WRAP Phase III 2008 CENRAP Study 2008 TexAER ERG Texas – Permian Basin Studies

NEI = National Emissions Inventory
NPRI = National Pollutant Release Inventory
MOVES = Motor Vehicle Emission Simulator
CEM = Continuous Emissions Monitoring
MEGAN = Model of Emissions of Gases and Aerosols from Nature
WRAP = Western Regional Air Partnership
CENRAP = Central Regional Air Planning Association
TexAER = Texas Air Emissions Repository
ERG = Eastern Research Group, Inc.

4.4.2. 2017 Base Case Non-Oil and Gas Emissions Inventory

The 2017 future year emissions inventory includes emissions growth due to projected population increases and other emissions-producing activity growth. The 2017 emissions inventory also accounts for emissions decreases due to implementation of "on the books" emissions standards and replacement of older high-emitting equipment with newer equipment incorporating better emissions controls. Appendices C and F provide detailed information describing the data sets used for the 2017 base case non-oil and gas emissions inventory.

4.4.3. Integrating BLM Oil and Gas Emissions Growth with Future Year Inventories

Each of the two future year CFO Alternative emissions sets required combination of the following types of emissions.

- Year 2017 non-oil and gas RFFA emissions sets (e.g., mobile, biogenic, etc.)
- Year 2017 non-oil and gas RFD emissions sets
- Year 2028 CFO Project emissions (oil and gas RFD)

4.4.3.1. CFO BLM Oil and Gas Emissions Summary

The 2028 CFO Alternative emissions inventories used in the PGM assessment are derived from the emissions inventory included in Appendix D and E. The emissions were processed using SMOKE to speciate VOCs and also to geographically distribute emissions among the CAMx grid cells. Table 4-11 summarizes emissions for CO, NO_x, and VOC for CFO Project sources associated with each Alternative during 2028. For the analysis, Project sources are defined to include emissions from sources located on BLM mineral estate. Emissions calculation spreadsheets for these source groups are included in Appendix D and E.

Table 4-11. 2028 CFO Project Emissions

Pollutant	Emissions (tpy)	
	Alt. RFDOTB	Alt. RFDOTBX
CO	6,072	5,205
NO_x	8,885	7,208
VOC	35,797	7,391

tpy = short tons per year

4.4.3.2. Cumulative Oil and Gas Emissions Summary

Oil and gas emissions for CFO non-Project sources (those on non-BLM land) were also estimated for the year 2028 modeling. Emissions for these source groups are shown in Table 4-12 and were estimated using methods consistent with those used for the CFO, based on available data. Emissions calculation spreadsheets for CFO non-Project (non-BLM) emissions are included in Appendix G.

Table 4-12. 2028 Oil and Gas Cumulative Emissions

Pollutant	Emissions (tpy)	
	Alt. RFDOTB	Alt. RFDOTBX
CO	5,809	5,809
NO_x	7,625	7,625
VOC	26,475	26,475

tpy = short tons per year

The Project oil and gas emissions and cumulative oil and gas emissions shown in Table 4-11 and Table 4-12, respectively, were processed with SMOKE to prepare CAMx-ready inputs reflecting future oil and gas activity. Table 4-13 shows emissions totals for the future year cases.

Table 4-13. 2028 CFO Oil and Gas Emissions for Future Year Modeling

Emissions Scenario	Emissions (tpy)					
	CO	NO_X	VOC	SO_2	PM_{10}	$PM_{2.5}$
Future Year Base Case	5,809	7,625	26,475	89	1,603	306
Alternative RFDOTB	11,881	16,510	62,271	163	3,380	630
Alternative RFDOTBX	11,014	14,833	33,865	163	2,605	515

tpy = short tons per year

4.5. PHOTOCHEMICAL GRID MODELING METHODOLOGY

4.5.1. Modeling Parameters

In addition to the emissions and meteorological inputs to a PGM, other inputs are required to drive the modeling system. Prior to executing the model, several switches or options must be identified regarding the model chemistry, the numerical diffusion scheme, and the type of grid nesting. As a dynamic system, PGMs also require information that can affect concentration predictions; these are items external to what is happening within the modeling domain, but are required in accounting for pollution production. These external, existing parameters are the initial conditions, boundary conditions, photolysis rates, and albedo/haze/ozone column data. These model switches and external conditions are discussed in detail below.

Table 4-14 summarizes the parameters for the CAMx model that were used for this modeling exercise. Version 5.4.0 of the CAMx model was used, with Carbon Bond version 6 (CB6) as the chemical mechanism. The chemical species, reactions, and rate constants are determined by CB6.

Horizontal transport was handled by the Piecewise Parabolic Method advection solver, and horizontal diffusion was handled with the spatially varying (Smagorinsky) approach. CAMx used K-theory for vertical diffusion using vertical diffusivities from the WRFCAMx meteorological preprocessor.

Table 4-14. CAMx Modeling Parameters

Parameter	Value
Version	5.40
Chemical Mechanism	CB6, Mechanism 7
Chemistry Solver	Euler Backward Iterative -- Fast Solver
Vertical Advection Scheme	Implicit scheme w/ vertical velocity update
Horizontal Advection Scheme	Piecewise Parabolic Method scheme
Horizontal Nesting	36/12/4 km two-way nesting for CAMx
Horizontal Diffusion	Spatially varying
Vertical Diffusion	Kz
Dry Deposition Scheme	Zhang dry deposition scheme
Wet Deposition Scheme	CAMx-specific formulation

4.5.2. External Model Inputs

Table 4-15 summarizes datasets used for input into CAMx. The remainder of this Section provides additional details about some of these CAMx inputs.

Table 4-15. Summary of CAMx Input Data

File Type		Source
Albedo/Haze/Ozone Column Files		Created by the AHOMAP program from daily TOMS data files. [a]
Photolysis Rates Files		Created by the TUV program from the albedo/haze/ozone column files.
Meteorological Files	Landuse File	Created by WRFCAMx program from WestJumpAQMS WRF modeling files.
	Height/Pressure File	
	Wind File	
	Temperature File	
	Water Vapor File	
	Cloud/Rain File	
	Vertical Diffusivity File	
Initial Conditions File		Initial conditions derived from the MOZART global chemistry model, with a 10 day spin-up.
Boundary Conditions Files		36 km boundary conditions derived from the MOZART global chemistry model.
Elevated Emissions Files		Created by the SMOKE emissions processor.
Low-level Emissions Files		Created by the SMOKE emissions processor along with MOVES and MEGAN.

AHOMAP = Albedo/Haze/Ozone Mapping
MOZART = The Model for Ozone and Related Chemical Tracers
MOVES = Motor Vehicle Emission Simulator
MEGAN = Model of Emissions of Gases and Aerosols from Nature
TOMS = Total ozone mapping spectrometer
TUV = Tropospheric Ultraviolet and Visible Radiation Model

[a] http://ozoneaq.gsfc.nasa.gov/datadis.md?year=2008&instr=omi&prod=ozone&patt=L3e_ozone_omi

4.5.2.1. Initial and Boundary Conditions

CAMx requires specification of initial conditions for model species in each grid cell in the model domain (in all layers) and boundary conditions for all grid cells along each of the boundaries (in all layers). Generation of initial and boundary conditions for individual model species includes gas-phase mechanism species, non-reactive species, and tracer species.

Boundary conditions represent pollution inflow into the model and initial conditions provide an estimate of pollution that already exists. The initial conditions are usually considered to be background concentrations of pollutants. Both initial and boundary conditions may vary in time and in vertical space.

The boundary conditions for the 36 km CONUS domain simulation were extracted from the MOZART (The Model for Ozone and Related Chemical Tracers) global chemistry model. Existing programs were used to interpolate the boundary conditions data to the CAMx coordinate system and vertical layer structure and to map the MOZART chemical species to the CB6 chemical mechanism.

The CAMx modeling began with initial conditions derived from the same global chemistry model outputs as the boundary conditions. The CAMx model was executed in quarters (January-March, April-June, July-September and October-December). A spin-up period of ten days preceding the quarter was run for all domains.

4.5.2.2. Photolysis Rates

For chemical reactions in CB6 that are dependent on solar irradiation, photolysis rates must be provided for each grid cell. Photolysis rates are dependent on solar zenith angle, altitude, total ozone column, surface albedo, and atmospheric turbidity. The photolysis rates were calculated using the "TUV" (Tropospheric Ultraviolet and Visible Radiation Model) program from ENVIRON/NCAR. CAMx was configured to use the new in-line TUV to adjust for cloud cover.

4.5.2.3. Albedo/Haze/Ozone

The photolysis rates depend upon the surface ultraviolet albedo, atmospheric haze, and the stratospheric ozone column. The albedo/haze/ozone file specifies how these parameters vary in time and space for the CAMx simulation. The surface albedo was determined from gridded land use data. Total Ozone Mapping Spectrometer (TOMS) satellite data was used to determine the stratospheric ozone column. Finally, atmospheric turbidity (i.e., haze) was assumed to be constant throughout the domain. The albedo/haze/ozone inputs were calculated using the "AHOMAP" (Albedo/Haze/Ozone Mapping) program from ENVIRON.

4.5.2.4. Land Cover and Land Use

CAMx requires gridded land use data to characterize surface boundary conditions, such as roughness, deposition parameters, albedo, vegetative distribution, and water/land boundaries. Gridded geographic data was developed from United States Geological Survey land use/land cover and topographic databases. The land use/land cover data is identical to that used in the WestJumpAQMS.

4.6. ASSESSMENT OF PREDICTED OZONE AND $PM_{2.5}$ IMPACTS

4.6.1. Analysis Approach

Predicted ozone and $PM_{2.5}$ concentrations from the CAMx model were analyzed to determine ozone and $PM_{2.5}$ -related air quality impacts to the CFO and surrounding areas. The analysis focused on ozone and $PM_{2.5}$ impacts in the CFO and within the 4 km domain, which does not include any current ozone or $PM_{2.5}$ nonattainment areas. Several ozone nonattainment areas exist within the 12 km domain, such as, Dallas-Fort Worth, Texas; Houston, Texas; Denver, Colorado; Phoenix, Arizona; and multiple areas in California. There are also several $PM_{2.5}$ nonattainment areas within the 12 km domain, such as, Salt Lake City, Utah; Provo, Utah; West Central Pinal County, Arizona; Nogales, Arizona; and multiple areas in California. As described in later sections, ozone and $PM_{2.5}$ impacts from oil and gas development in the CFO have a limited geographic extent.

Ozone and $PM_{2.5}$ impacts were analyzed in terms of relative changes compared to existing air quality and in terms of absolute predicted concentrations for each of the two CFO Alternatives combined with cumulative emissions. Background information and data analysis methods are explained in this Section, along with descriptions of predicted ozone and $PM_{2.5}$ impacts.

4.6.1.1. USEPA Guidance

Analysis of predicted ozone and $PM_{2.5}$ impacts for the CFO RMP revision followed USEPA guidance to the extent practical. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze (USEPA

2007) plus the memorandum, Update to the 24 Hour $PM_{2.5}$ NAAQS Modeled Attainment Test (USEPA 2011), provide the most recent USEPA guidance on using PGMs to predict ozone and $PM_{2.5}$ concentrations and assess ozone and $PM_{2.5}$ attainment status. With regard to ozone and $PM_{2.5}$ analyses, this guidance primarily sets forth state implementation plan (SIP) modeling procedures used to demonstrate that additional emissions reductions will bring nonattainment areas into compliance with the NAAQS.

However, several factors specific to the CFO analysis prompted departures from USEPA guidance, as described below.

- *Revisions to reflect new standards* — USEPA's guidance is currently based on the 0.08 ppm 8-hour ozone NAAQS, although the ozone NAAQS was revised to 0.075 ppm on March 27, 2008 (GPO 2008). USEPA guidance is also currently based on the 15.0 µg/m3 annual average PM2.5 NAAQS, which was revised to 12 µg/m3 on December 14, 2012 (GPO 2013). This analysis compares predicted data with the most current NAAQS.
- *Lack of nearby monitors with sufficient data* — The CFO is located in a rural area that is currently designated unclassifiable/attainment for both ozone and $PM_{2.5}$. The Carlsbad and Hobbs monitors are the only ozone monitors located in the CFO that have complete ozone monitoring data to calculate 2008 design values in accordance with USEPA guidance. Note that the NPS Carlsbad Caverns NP ozone monitor began collecting data in 2007. There are no monitors located in the CFO that have all the data required to calculate future year design values in accordance with USEPA guidance.
- *Less-defined study area* — The geographical extent of the study area is less well defined for the CFO analysis than would be true for SIP modeling, which generally focuses the air quality assessment on predicted concentrations at monitors within the nonattainment area of interest.
- *Threshold values* — Due to the fact that the CFO includes many rural areas with lower ozone concentrations, a threshold of 60 ppb was used for calculating relative response factors (RRF) instead of the 85 ppb threshold from the guidance.

In-depth ozone and $PM_{2.5}$ impact assessment is relatively new to NEPA analysis and best practices for NEPA PGM analysis are currently being developed by the modeling community. NEPA allows flexibility to determine technically defensible methods for conducting natural resource impact assessments. This modeling analysis is based on existing SIP guidance, which has been adapted for NEPA purposes.

4.6.1.2. Terminology

The PGM results presented in the following sections refer to multiple emissions sets when describing pollutant impacts. Descriptions of each emissions set are provided below.

- "RFDOTB" refers to the RFD on-the-books Alternative modeled scenario for the CFO. This scenario includes the following:
  - CFO RFD Project emissions for year 2028 with on-the-books controls
  - National and regional emissions inventories for year 2017
- "RFDOTBX" refers to the RFD on-the-books Alternative modeled scenario for the CFO with extra controls. This scenario includes the following:
  - CFO RFD Project emissions for year 2028 with on-the-books plus extra controls
  - National and regional emissions inventories for year 2017

- "2008b1" refers to the 2008 emissions base case. This emissions set reflects existing emissions, and is described in more detail in Section 2.3 and Appendix A.
- "2017a1" refers to the future year base case, which includes all future year emissions sets except for the CFO Project emissions associated with Alternative RFDOTB or RFDOTBX. This emissions set is described in more detail in Section 2.4 and Appendices B and C.

When "Alternative RFDOTB" (or Alternative RFDOTBX) is used in the text within this Chapter, it refers to emissions associated with the specific Alternative plus cumulative emissions.

4.6.1.3. Visual Tools

Many visual Package for Analysis and Visualization of Environmental data (PAVE) plots are provided in this analysis. Each plot includes identifying information in the header and footer. The header information always includes the emissions set that is represented (e.g., RFDOTB) and the modeling domain that is shown. The type of pollutant concentration is also shown (e.g., daily maximum 8-hour ozone) in the header. Footer information includes the date and time in Mountain Standard Time (MST), which is usually zero for this analysis, indicating that the entire day is represented. Also included in the footer are the minimum and maximum pollutant concentrations (plus the units) included in the plotted area and the grid coordinates indicating the locations for the maximum and minimum predicted concentrations.

Some PAVE plots show absolute concentrations while others show the concentration difference between two modeled scenarios. Absolute concentrations indicate raw predicted pollutant concentrations. An absolute concentration that appears to exceed the NAAQS is not deterministic due to the following reasons.

- A NAAQS exceedance is determined based on multiple 8-hour daily maximum ozone, 24-hour average $PM_{2.5}$, or annual average $PM_{2.5}$ concentrations occurring over three years. An individual predicted concentration above the NAAQS does not indicate a violation of the NAAQS.
- Nonattainment can only be determined based on monitoring data at a monitoring site that meets USEPA criteria for data quality and completeness.
- Predicted concentrations are not necessarily accurate and must be interpreted in the context of the MPE and other data (such as the relative response factor [RRF]) to determine whether the data indicates potential attainment or nonattainment.
- The emissions sets used in the modeling are estimates created by different entities and the accuracy of these estimates can vary.

Difference plots were used to isolate predicted impacts. For example, a difference plot labeled RFDOTBX – 2017a1 indicates the difference in pollutant concentrations when 2017a1 modeled concentrations are subtracted from RFDOTBX modeled concentrations. This difference in concentrations illustrates the incremental impact attributable to RFDOTBX Project emissions compared to future year cumulative emissions without RFDOTBX Project emissions.

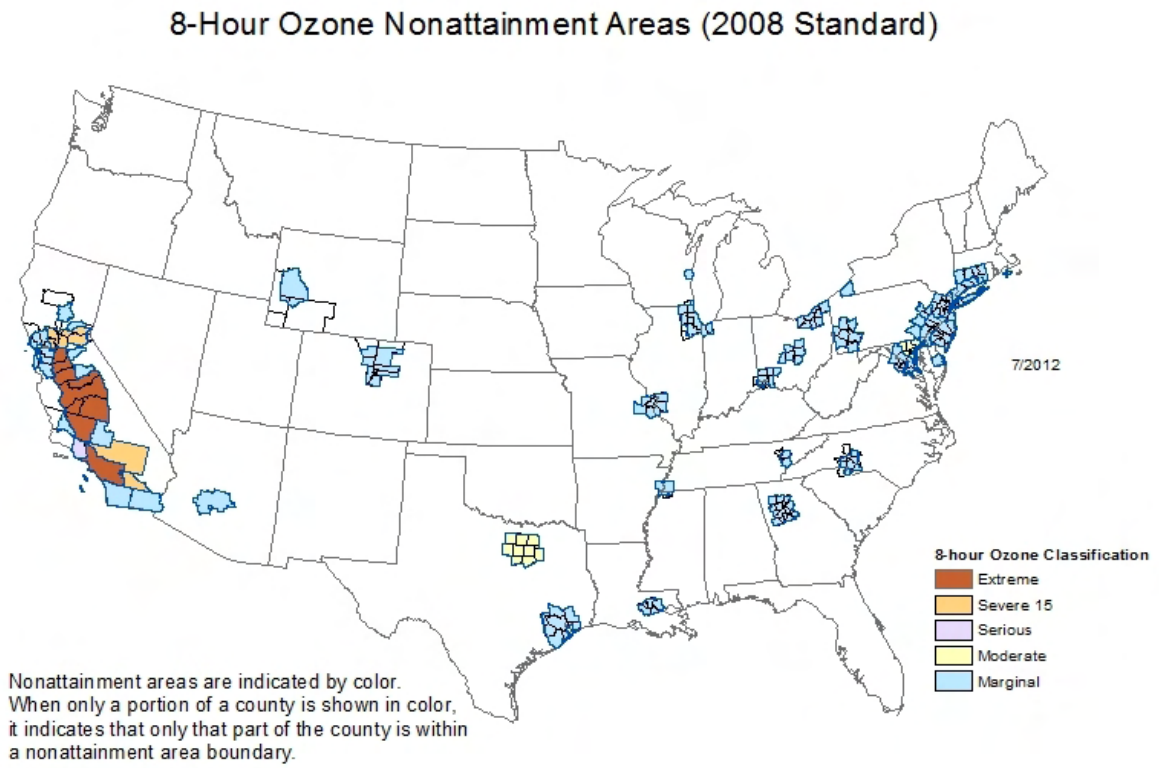
4.6.2. Assessment of Predicted Ozone Impacts

4.6.2.1. Existing Regional Ozone Levels

The current ozone primary and secondary NAAQS of 0.075 ppm (GPO 2008) are being reconsidered. Promulgation of new ozone NAAQS will require USEPA to identify ozone

nonattainment areas based on the new standards. Current ozone nonattainment area designations are based on the 0.075 ppm NAAQS.

Map 4-4 shows the locations of areas throughout the nation that are currently designated ozone nonattainment under the 0.075 ppm standard (USEPA 2012b). Within the 12 km modeling domain, Dallas-Fort Worth, Texas; Houston, Texas; Denver, Colorado; Phoenix, Arizona; and multiple areas in California are designated ozone nonattainment. The CFO and nearby oil and gas development areas are located in an ozone unclassifiable/ attainment area.



Map 4-4. Current Ozone Nonattainment and Maintenance Areas (0.075 ppm Standard)

4.6.2.2. Predicted CFO Project Ozone Impacts

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On most modeled days, the geographic extent of CFO Project impacts is generally limited to the CFO and nearby counties in New Mexico and Texas.

Project emissions for Alternative RFDOTB have the greatest geographic extent. Alternative RFDOTB difference plots (RFDOTB – 2017a1) illustrate the extent of ozone due to the Project emissions increases associated with Alternative RFDOTB. In these difference plots, negative (bluer) values indicate ozone decreases, while positive (redder) values indicate ozone increases. Figure 4-4 illustrates the maximum northern extent of ozone increases associated with Alternative RFDOTB Project impacts, while Figure 4-5 illustrates the extent to the east. Figure 4-6 illustrates the maximum western extents, while Figure 4-7 illustrates the extent south.

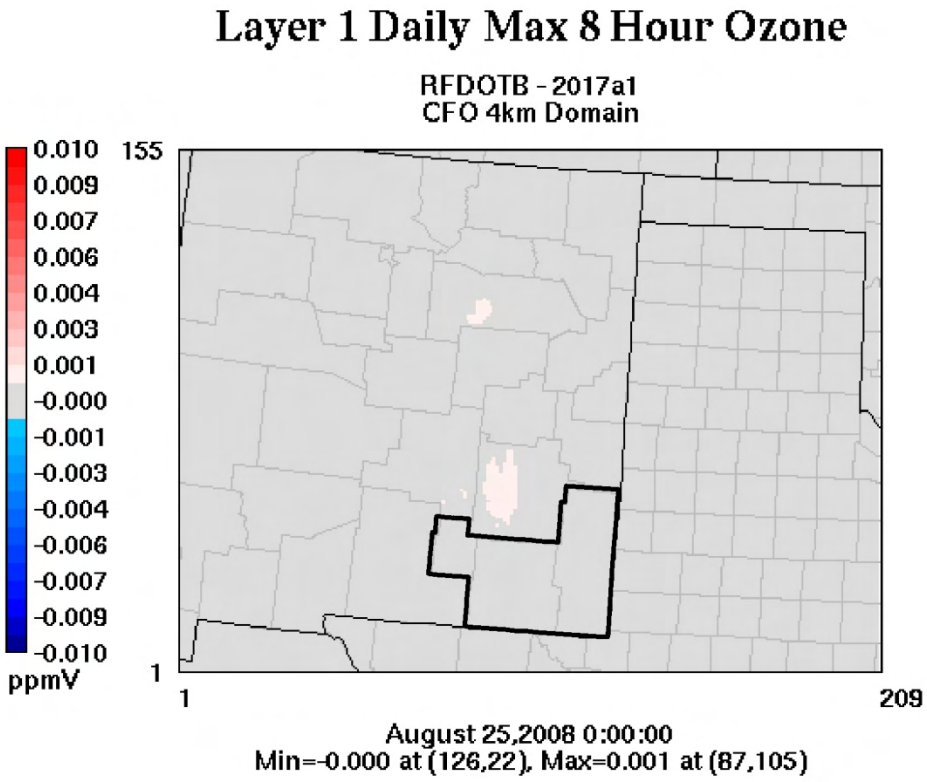

Figure 4-4. Northern Geographic Extent of Alternative RFDOTB Project Impacts (8-hour daily max)

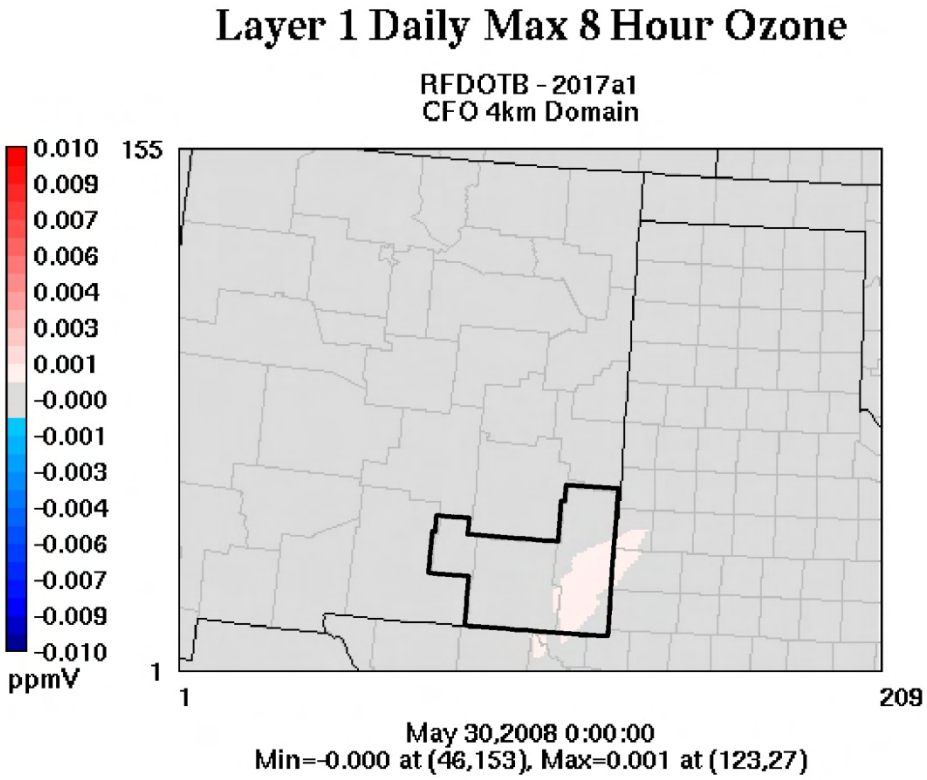

Figure 4-5. Eastern Geographic Extent of Alternative RFDOTB Project Impacts (8-hour daily max)

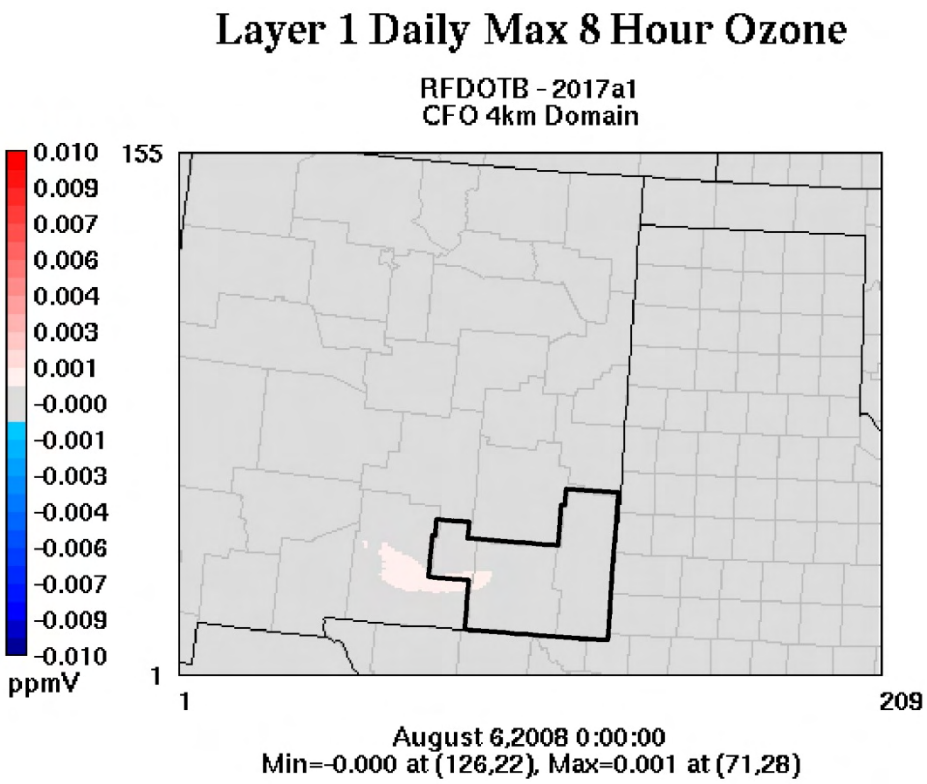

Figure 4-6. Western Geographic Extent of Alternative RFDOTB Project Impacts (8-hour daily max)

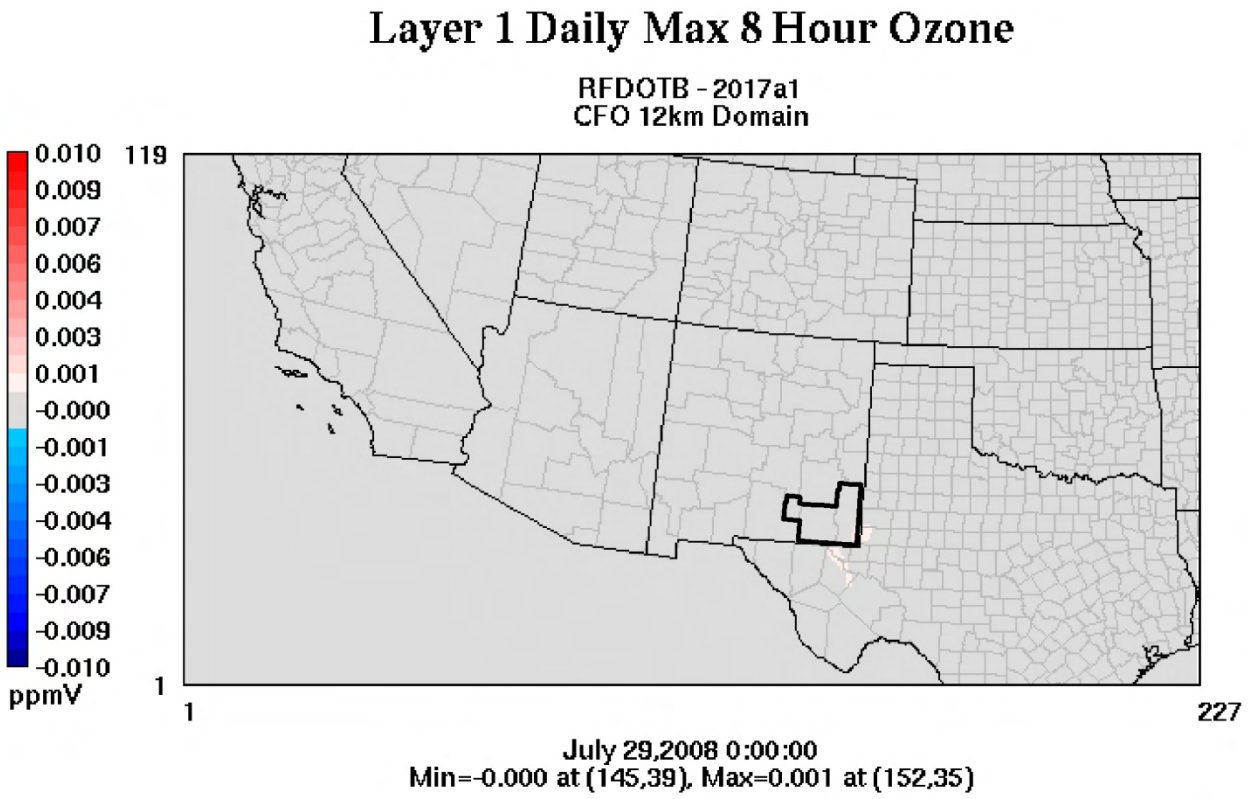

Figure 4-7. Southern Geographic Extent of Alternative RFDOTB Project Impacts (8-hour daily max)

□□□□□□□□□□□ I□□r□□ □□□□□□ □□□□ I□□r□□□□ D□□ □□ □ □□ □r□□□□

The greatest ozone concentration increases due to Project emissions is 2.5 ppb occurring on August 10 (Figure 4-8). The maximum increase occurs within the CFO area. The average daily maximum ozone increase attributable to CFO Project emissions is 0.02 ppb for Alternative RFDOTB.

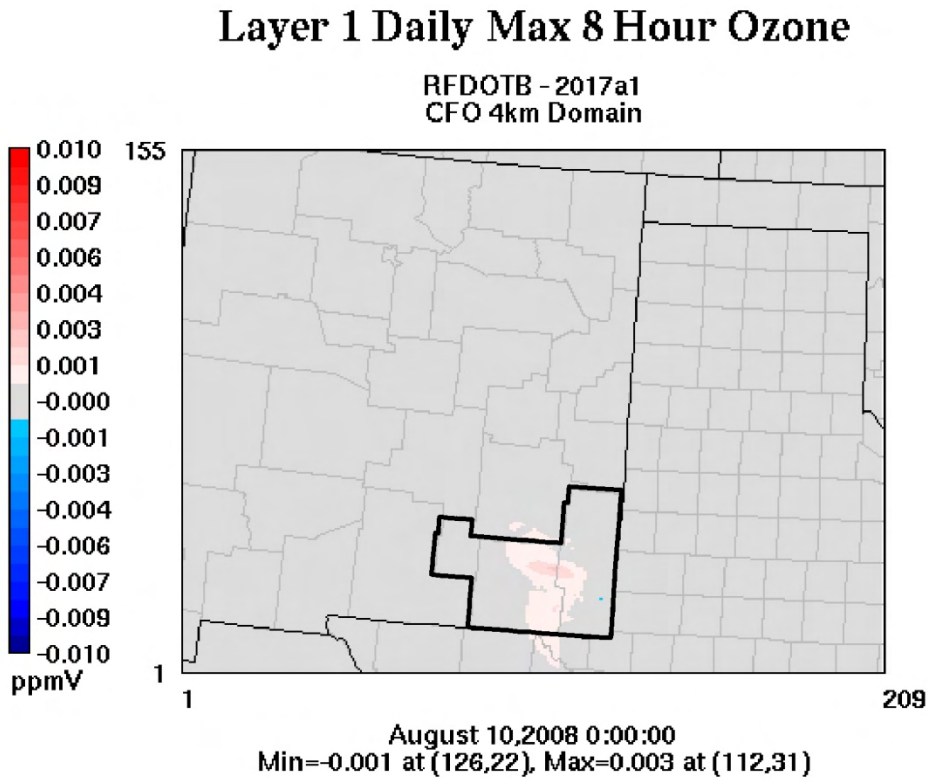

Figure 4-8. Greatest 8-hour Daily Max Ozone Concentrations Due to CFO Project Emissions

With regard to the geographic extent of each modeled day's 8-hour maximum ozone concentration attributable to CFO Project emissions, maximum concentration changes occur in the CFO for all except one day of the year. The greatest impact due the CFO Project emissions always occurs within New Mexico or the counties in Texas that border the CFO.

In terms of maximum predicted absolute ozone concentrations, the highest ozone day within the 4 km domain is August 22, with the maximum occurring in the Los Alamos/Santa Fe area (see Figure 4-9 for a plot showing absolute concentrations). On August 22, the incremental ozone impact due to Alternative RFDOTB Project emissions compared to future year base case emissions is predicted to be 1 ppb, as shown in Figure 4-10. Based on these modeling predictions, CFO Project emissions do not contribute to high ozone concentrations predicted on August 22.

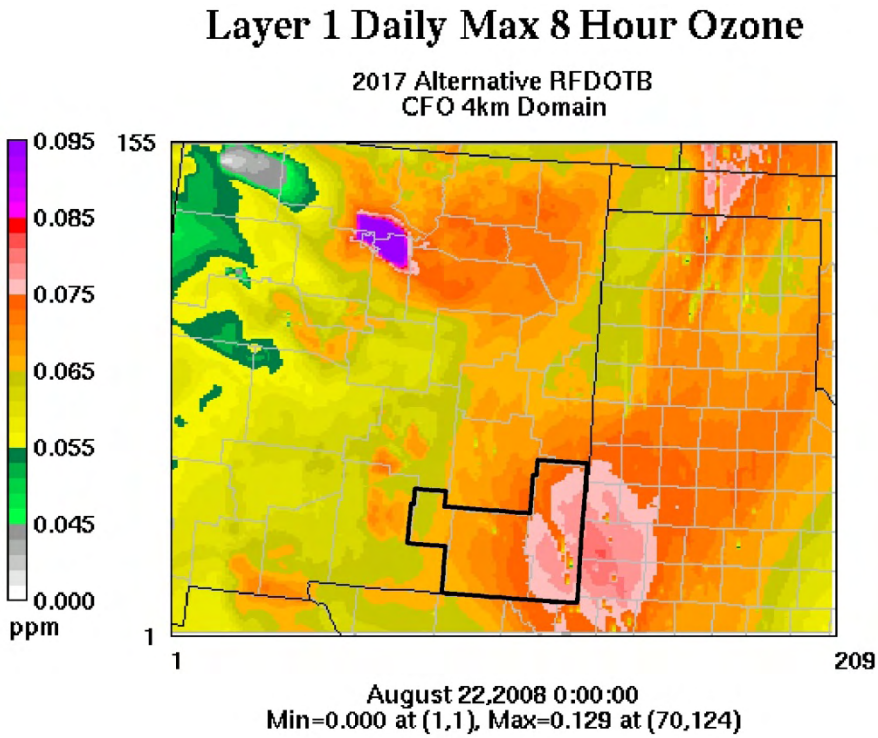

Figure 4-9. 8-hour Daily Max Ozone Concentrations on August 22 from RFDOTB

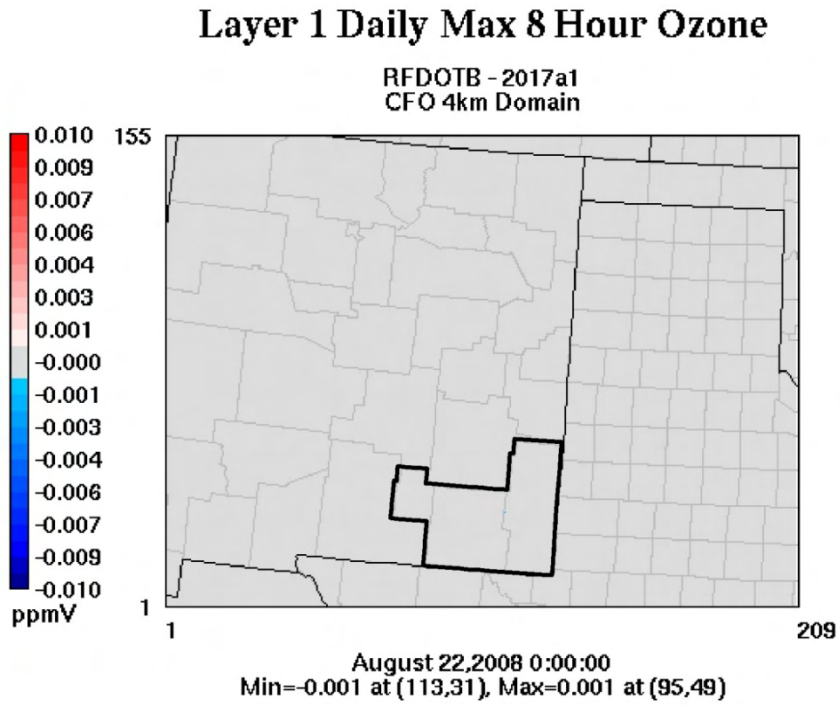

Figure 4-10. Ozone Impacts Due to CFO Project Emissions on Highest Ozone Day in the 4km Domain

□□□□□□□□□□ D□□□r□□□□□ B□□□ □□□ □□r□□□□□□

Predicted ozone concentration differences among the Alternatives occur, but are very small and infrequent. Table 4-16 summarizes the ozone concentration differences between Alternative RFDOTB and Alternative RFDOTBX by providing the number of days with a maximum difference of 0 ppb, the number of days with a maximum difference greater than 0 ppb, and the maximum difference that was identified. The modeling results indicate only 7 days throughout the year with the difference greater than 0 ppb when subtracting Alternative RFDOTBX predicted concentrations from Alternative RFDOTB predicted concentrations.

The maximum of the daily maximum concentration differences is shown in the third row of the table. This number indicates the magnitude of ozone concentration increases between Alternative RFDOTB and Alternative RFDOTBX, which is 1 ppb. Finally, the average maximum ozone concentration differences are shown in the last row of the table.

Table 4-16. Summary of Maximum Differences between Alternatives in 4 km Domain

Difference Criteria	RFDOTB - RFDOTBX
Number of Days < 1 ppb	359
Number of Days ≥ 1 ppb	7
Maximum Difference (ppb)	1.0
Average Maximum Difference (ppb)	0.0

4.6.2.3. Predicted Cumulative Ozone Impacts

Cumulative impacts were determined for each of the Alternatives, and reflect predicted impacts from each of the Alternatives combined with oil and gas RFD and growth in regional and national emissions databases to 2017 emissions levels. Ozone impacts were assessed using the following two separate methods.

- Ozone design value (DV) predictions for future years based on USEPA guidance using the Model Attainment Test Software (MATS) (Abt 2012)
- Ozone concentration predictions using absolute modeled results

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Ozone DVs (both baseline and future DVs) have the same format as the 8-hour ozone NAAQS and can be compared directly to the ozone NAAQS to assess compliance. Ozone NAAQS compliance occurs when the DV (based on three full years of data) is less than or equal to 0.075 ppm, which is the ozone NAAQS as of April 22, 2013. USEPA is in the process of reconsidering the ozone NAAQS and proposed to revise the standard within the range of 0.060 to 0.070 ppm (GPO 2010b). Because a revised ozone NAAQS has not been set, and the 0.075-ppm standard remains effective, this analysis compares modeled results to the current standard of 0.075 ppm.

The baseline DV (DVB) is the current value, which is determined at each individual ozone monitor and is defined as the 3-year average of the 4th highest daily maximum 8-hour ozone concentration measured at the monitor. The future DV (DVF) is predicted based on future-year ozone modeling.

USEPA guidance (USEPA 2007) provides a method to predict the DVF at each monitor. In this approach, modeled ozone concentrations are used in a relative rather than an absolute sense. This method involves two steps: calculating the relative response factor (RRF) and then using the

RRF to calculate the DVF from the DVB. The DVF for each monitor is then compared to the ozone NAAQS to determine whether the standard is likely to be met at that monitoring site.

RRF Calculation

The RRF is the ratio of the future (e.g., RFDOTB) 8-hour daily maximum concentration predicted near a monitor (averaged over multiple days within one episode) to the baseline 8-hour daily maximum concentration predicted near the monitor (averaged over the same days). RRFs were calculated for each monitor in the 4 km domain and for each Alternative. Equation 4.1 provides the equation used to calculate RRFs.

$$\mathbf{RRF_i = CF_i \div CB_i} \qquad \textbf{(Equation 4.1)}$$

Where:

RRF_i = the relative response factor calculated near site *i* (unitless) for each episode

CF_i = the mean 8-hour daily maximum future concentration predicted by the model at site *i* (ppb) averaged over each day in the episode

CB_i = the mean 8-hour daily maximum baseline concentration predicted by the model at site *i* (ppb) averaged over each day the episode

As recommended by USEPA guidance (USEPA 2007b), future and baseline modeled ozone concentrations at cells "near" each monitor were considered when determining which 8-hour daily maximum ozone concentrations were used in the RRF calculation. Cells near each monitor are those within an approximate radius of 15km from the monitor. For the 4 km domain, this is a 7×7 array of cells centered on the cell containing the monitor.

Specific steps followed in the calculation approach included the following.

- Determine mean 8-hour daily maximum baseline concentration (CB*i*) at each monitor:
  - For the base case modeling scenario (2008b1), the grid cell with the highest 8-hour daily maximum ozone concentration within each monitor's 7×7 array was identified for each day of the episode.
  - Days with base case predicted ozone concentrations less than 60 ppb were excluded.
  - The mean base case 8-hour daily maximum ozone concentration was calculated for each monitor.
- Determine mean 8-hour daily maximum future concentration (CF*i*) at each monitor:
  - For each Alternative's future year modeling scenario, the grid cell with the highest 8-hour daily maximum ozone concentration within each monitor's 7×7 array was identified for each day of each episode. This may or may not be the same grid cell that was chosen when determining CB*i*.
  - Days with base case predicted ozone concentrations less than 60 ppb were excluded.
  - The mean future year 8-hour daily maximum ozone concentration was calculated for each monitor.
- For each Alternative and at each monitor, the RRF was calculated according to Equation 4-1.

According to USEPA guidance for implementing the 0.080 ppm 8-hour ozone standard, only days with modeled 8-hour maxima values above 85 ppb (the effective standard when rounding is taken into account) should be used to compute the RRF (USEPA 2007). This guidance does not yet reflect the March 2008 revision to the 8-hour ozone standard, which set the ozone NAAQS to 0.075 ppm. Consequently, a threshold of 75 ppb would reflect the new standard. However, because the CFO analysis includes many rural areas with lower ozone concentrations, a threshold of 60 ppb was used. This value allows the analysis to focus on "high" ozone days in the rural areas, without excluding a large number of days.

Future Design Value Calculation

DVFs were calculated for the future year base case (2017a1) and for each of the Alternative modeling scenarios (RFDOTB and RFDOTBX) at each monitor in the 4 km domain. Each DVF was calculated by multiplying the RRF for each monitor by the DVB for that monitor. Equation 4.2 describes the approach used to calculate future year design values.

$$\mathbf{DVF}_i = \mathbf{RRF}_i \times \mathbf{DVB}i \qquad \textbf{(Equation 4.2)}$$

Where:

DVF_i = the estimated future design value at monitor *i* (ppb) for the episode

RRF*i* = the relative response factor for monitor *i* (unitless)

DVB*i* = the baseline concentration monitored at site *i* (ppb)

DVBs were calculated using the maximum available data from years 2006–2010. USEPA recommends using the average of three DVBs that straddle the baseline inventory year (USEPA 2007). When sufficient data were available, DVBs were calculated for the years 2006–2008, 2007–2009, and 2008–2010. However, for some monitors, only one or two DVBs could be calculated. When more than one DVB was available, the DVB used in Equation 4.2 represented the average of all DVBs for that monitor.

Comparison to Ozone NAAQS

After DVFs were determined, they were compared to the ozone standard. DVFs less than or equal to 75 ppb (equivalent to the 0.075 ppm standard) indicate expected future compliance with the ozone NAAQS that is currently effective on the date of publication of this ARTSD. Although USEPA plans to promulgate a more stringent ozone NAAQS, a specific standard has not yet been proposed.

Table 4-17 provides predicted RRFs, DVBs, and DVFs for all monitors in the 4 km domain with sufficient data to calculate DVBs (see Map 4-2 for locations). Values over the 75 ppb standard are shown in bold. Two of the three monitors in the CFO show predicted values over the standard in the future base case (2017a1) and both Alternatives. Predicted values for the RFDOTB Alternative at the Carlsbad, New Mexico monitor show an increase of 1 pbb over the future year base case (2017a1), all other Alternatives' values for all other monitors, have a DVF equal to that of the future year base case. MATS output files are included in Appendix J.

Table 4-17. Future Design Values for Monitors in 4 km Domain

Monitor ID	Location Description	2008b1	2017a1		RFDOTB		RFDOTBX	
		DVB (ppb)	RRF	DVF (ppb)	RRF	DVF (ppb)	RRF	DVF (ppb)
CFO								
350151005	Holland St., Carlsbad	67	1.14	**76**	1.14	**77**	1.14	**76**
350153001	Carlsbad Caverns NP	66	1.14	**75**	1/14	**75**	1.14	**75**
350250008	Hobbs-Jefferson	63	1.15	72	1.15	72	1.15	72
Southwest New Mexico								
350130008	St. Luke's Episcopal Church	67	1.07	71	1.07	71	1.07	71
350130017	Sunland Park City Yard	66	1.07	70	1.07	70	1.07	70
350130020	Chaparral	67	1.08	72	1.08	72	1.08	72
350130021	Sunland Park	72	1.07	**77**	1.07	**77**	1.07	**77**
350130022	Santa Teresa Intl. Blvd.	69	1.07	74	1.07	74	1.07	74
350130023	NM Highway Dept. Yard, Las Cruces	63	1.08	68	1.08	68	1.08	68
350171003	Hurley Park	62	1.07	67	1.07	67	1.07	67
350290003	Deming	58	1.08	62	1.08	62	1.08	62
El Paso Co., Texas								
481410029	Ivanhoe Fire Station	73	1.07	**78**	1.07	**78**	1.07	**78**
481410037	UTEP	73	1.07	**78**	1.07	**78**	1.07	**78**
481410044	Chamizal	72	1.07	**76**	1.07	**76**	1.07	**76**
481410055	Ascarate Park SE	70	1.07	74	1.07	74	1.07	74
481410057	Socorro	70	1.07	**75**	1.07	**75**	1.07	**75**
481410058	Skyline Park	71	1.07	**76**	1.07	**76**	1.07	**76**
Albuquerque								
350010019	Uptown Zuni Park	70	1.07	74	1.07	74	1.07	74
350010023	Del Norte High School	66	1.07	70	1.07	70	1.07	70
350010024	South East Heights	67	1.07	72	1.07	72	1.07	72
350010027	Westside Taylor Ranch	68	1.07	73	1.07	73	1.07	73
350010029	South Valley Mountain View	67	1.08	72	1.08	72	1.08	72
350011012	Far North East Heights	67	1.07	71	1.07	71	1.07	71
350011013	North Valley	68	1.07	73	1.07	73	1.07	73
350011014	Westside Corrales	66	1.07	70	1.07	70	1.07	70
350431001	Highway Dept. Yard, Sandoval County	60	1.07	64	1.07	64	1.07	64
350431003	Rio Rancho Senior Center	70	1.07	**75**	1.07	**75**	1.07	**75**
350439004	Pueblo of Jemez	68	1.08	73	1.08	73	1.08	73
Four Corners								
350450009	Hwy. Dept. Yard, Bloomfield	62	1.02	63	1.02	63	1.02	63
350450018	Navajo Dam	**75**	1.05	**79**	1.05	**79**	1.05	**79**
350451005	USBR Shiprock Substation	67	1.05	70	1.05	70	1.05	70

DVB = Baseline design value
DVF = Future design value
NP = National Park
ppb = parts per billion
RRF = Relative response factor

As shown in Table 4-17, the 0.075 ppm ozone NAAQS is expected to be attained at 21 of the 31 monitors in the 4 km domain for both Alternatives including cumulative emissions. Two of the three monitors in the CFO (Carlsbad, NM and Carlsbad Caverns NP) show an expected exceedance. The greatest DVF for all monitors (79 ppb) occurs at the Navajo Dam monitor in the Four Corners region.

[illegible]

Predicted absolute ozone concentrations should be interpreted carefully for the following reasons.

- *Daily maximum ozone concentrations do not compare directly to the NAAQS* — An absolute ozone concentration above 0.075 ppm at a specific grid cell on an individual day does not indicate an ozone violation. This is due to the fact that compliance with the ozone NAAQS is determined by comparing the three-year average of the 4th highest daily maximum 8-hour average monitored concentration to the NAAQS. The format of the ozone NAAQS is intentionally designed to allow multiple high ozone days over a three-year period.
- *Spatial consistency of high ozone concentrations is needed* — Ozone concentrations exceeding 0.075 ppm must occur repeatedly at the same location in order for a violation to occur.
- *PGM predictions are not exact* — PGMs cannot achieve complete accuracy in their predictions. These models incorporate huge quantities of data, particularly meteorological and emissions data, for the contiguous United States. Data input into the CAMx, SMOKE, and WRF models come from many sources and includes some assumptions and data gaps. Even if perfectly accurate data inputs could be obtained, PGMs cannot accurately predict every chemical transformation under all atmospheric conditions. Model predictions can be off by ±20 percent in terms of unpaired peak accuracy and still be within USEPA model performance goals.
- *2028 inventory versus 2017 inventory* — Although the emissions inventory for the Alternatives and for nearby oil and gas development within the Permian Basin were based on estimated year 2028 emissions, regional and national emissions inventories were available for the year 2017. Therefore, emission increases or decreases that may occur between 2017 and 2028 are not reflected in the modeling of other emissions sets, due to the unavailability of 2028 inventories beyond the CFO oil and gas emissions inventories. Predicted future year ozone concentrations may be greater or less than actual future ozone concentrations depending on how actual future 2028 emissions vary from the 2017 estimated emissions for emission sets beyond the CFO oil and gas emissions inventories.

Maximum Ozone Concentrations in the CFO

Absolute ozone predictions within the CFO are provided in Appendix K plots. As discussed above, absolute ozone concentrations above the ozone NAAQS on any individual day do not indicate a predicted violation of the ozone NAAQS. The Appendix K plots have been zoomed in

to show predicted ozone concentrations in the CFO based on Alternative RFDOTB emissions. All grid cells outside the CFO have been masked out.

In addition to providing absolute ozone concentrations within the CFO, Appendix K also provides difference plots showing ozone concentration changes between the Alternative RFDOTB modeling results and the future base case year (2017a1) modeling results. Review of Appendix K plots indicates that high absolute ozone concentrations are most likely not associated with oil and gas development in the CFO. Specific examples are discussed below.

The greatest predicted 8-hour ozone daily maximum concentration within the CFO is 103 ppb and occurs on August 6 for both Alternatives. Figure 4-11 illustrates the modeled concentrations for RFDOTB.

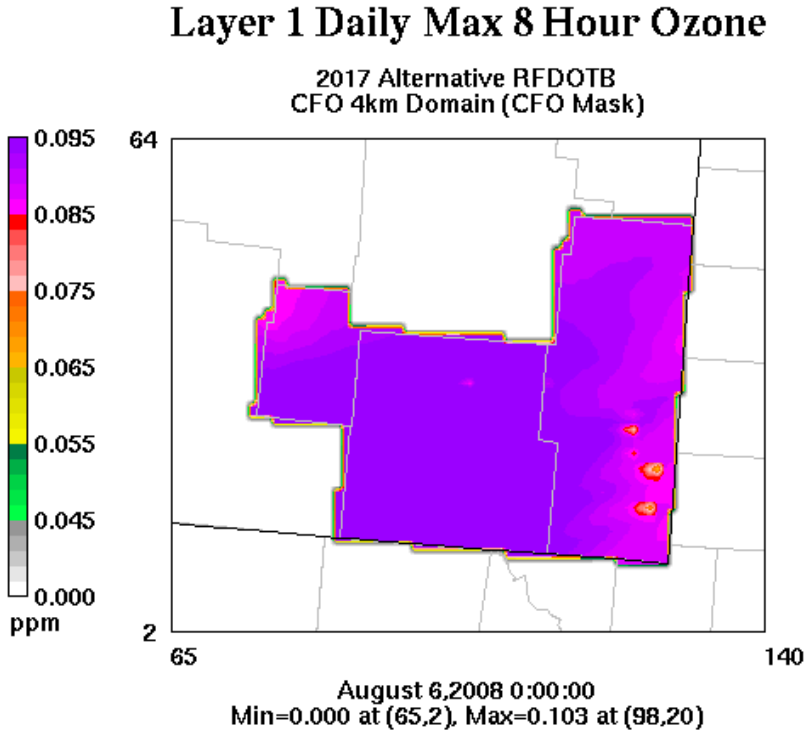


Figure 4-11. 8-hour Daily Max Ozone Concentrations In CFO on August 6 From RFDOTB

The difference plot in Figure 4-12 illustrates a small area of modeled ozone increase in the western portion of the CFO when future year base case (2017a1) concentrations are subtracted from future year Project and cumulative concentrations for Alternative RFDOTB.

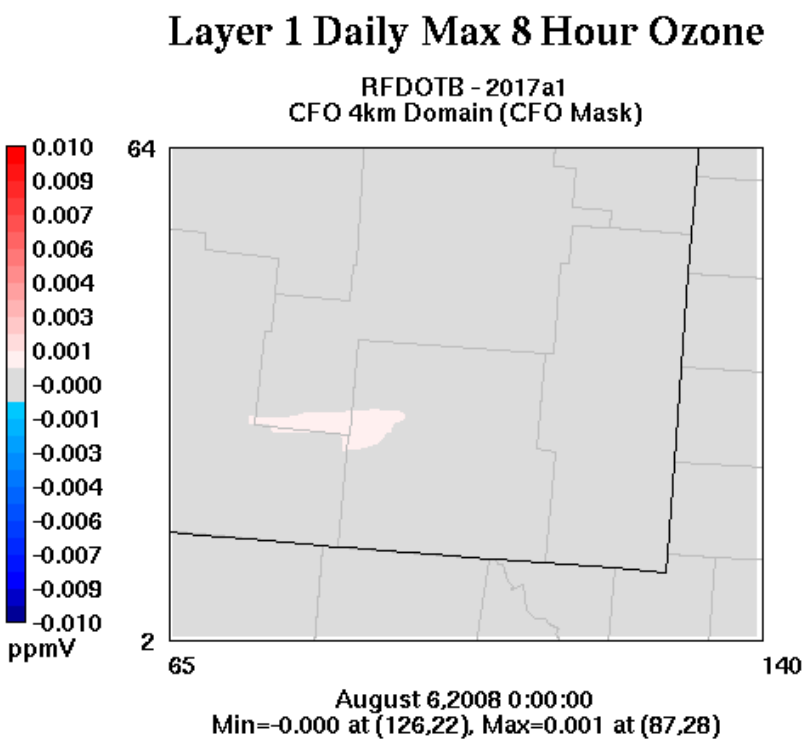


Figure 4-12. Difference Plot Showing August 6 Project and Cumulative Ozone Impacts Compared to 2017a1

Predicted Maximum Ozone Concentrations in the 4 km Domain

Table 4-18 provides the two highest absolute predicted 8-hour daily maximum peak ozone concentrations in the 4 km domain during the year. These predicted ozone concentrations do not vary among the Alternatives and the future year base case (2017a1) and consequently may not be tied directly to emissions associated with future year CFO Project and cumulative emissions. As shown in Table 4-18, the two highest maximum predicted concentrations are located outside of the CFO.

Table 4-18. Summary of Predicted Absolute 8-hour Daily Maximum Concentrations in 4 km Domain

Criteria	2017a1, RFDOTB and RFDOTBX		
	Concentration (ppb)	General Location	Peak Day in 4 km Domain
1st Highest Day	**129**	Los Alamos/Santa Fe	Aug. 22
2nd Highest Day	**117**	Eastern portion of Texas panhandle	Aug. 5

Figure 4-13 and Figure 4-14 illustrate ozone concentrations for August 22, and August 5, respectively. For each of the two days, two plots are presented. The first plot illustrates predicted ozone concentrations throughout the 4 km domain for Alternative RFDOTB, while the second plot illustrates the difference in ozone concentration when subtracting 2017a1 concentrations from RFDOTB concentrations.

In Figure 4-13, the maximum ozone concentrations predicted on August 22 are shown in the Los Alamos and Santa Fe areas, with concentrations as high as 129 ppb. A second area of high ozone is also located in western Texas panhandle and extending into the eastern part of the CFO. Although high absolute concentrations occur in the CFO, review of the difference plot indicates that RFDOTB ozone concentrations changes from 2017a1 concentrations were predicted in only two grid cells in the 4 km domain. Consequently, oil and gas emissions from the CFO do not appear to cause the high ozone concentrations on August 22.

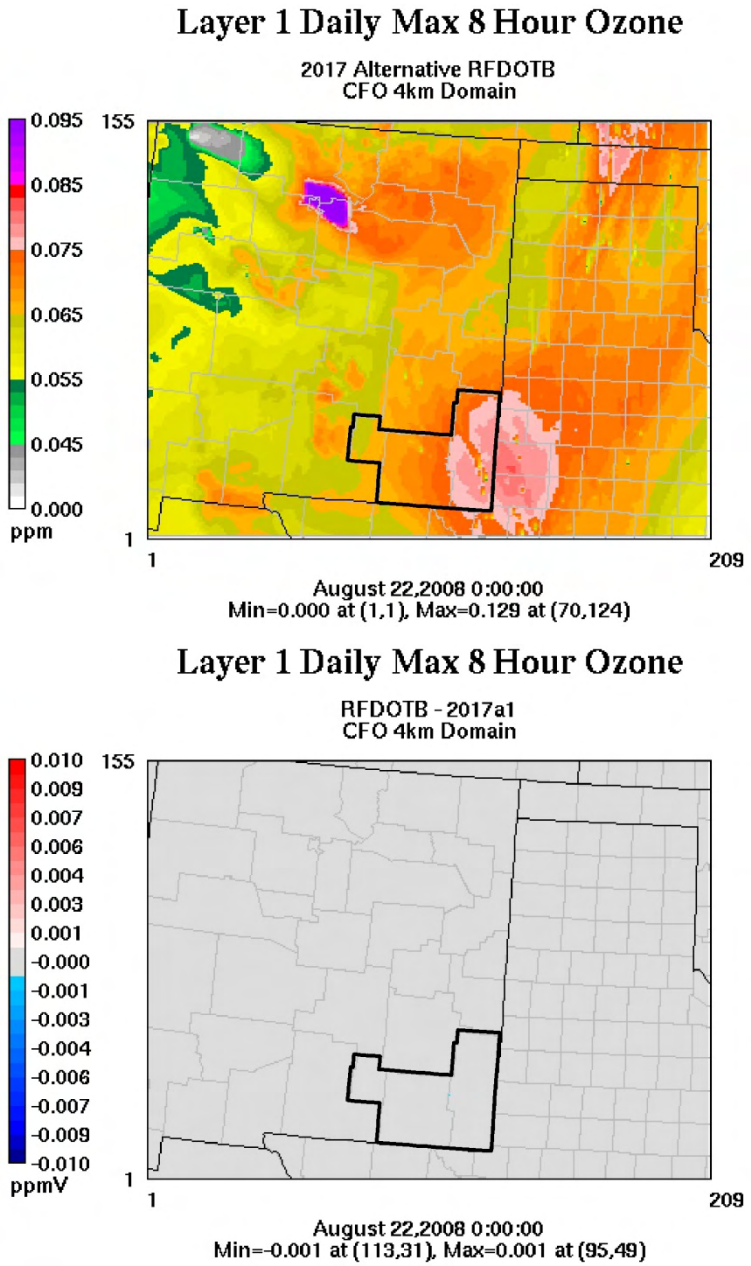


Figure 4-13. August 22 Predicted 8-hour Daily Maximum Ozone and Difference Plots

Figure 4-14 shows maximum ozone concentration and a difference plot for August 5, which had the second-highest predicted ozone concentration (117 ppb) during the year. High absolute ozone concentrations on this date occurred throughout the eastern half of the 4 km domain, with

maximum concentrations occurring in the eastern Texas panhandle and extending through southwest New Mexico. With regard to CFO oil and gas emissions, future year Alternative RFDOTB Project and cumulative emissions cause essentially no change in ozone concentrations throughout the 4 km domain when Alternative RFDOTB ozone concentrations are compared to future year baseline concentrations.

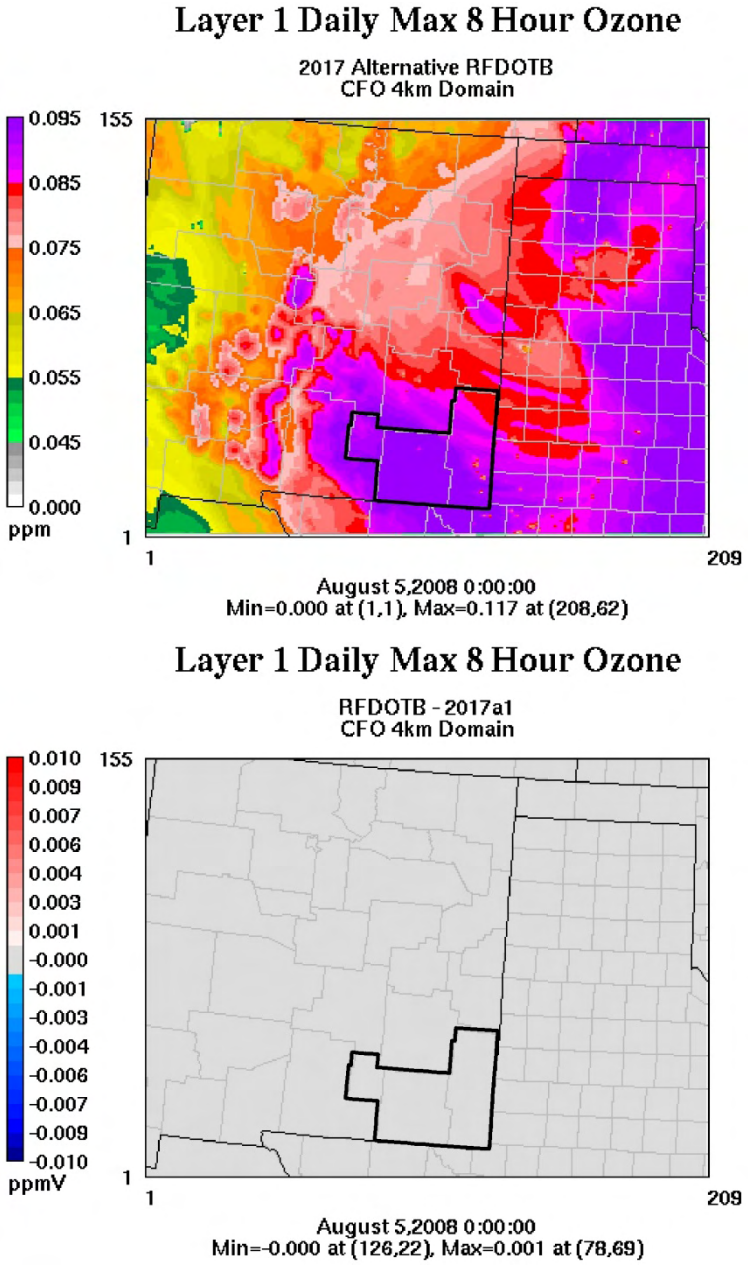


Figure 4-14. August 5 Predicted 8-hour Daily Maximum Ozone and Difference Plots

The above ozone concentration and difference plots indicate that peak-day modeled ozone concentrations do not occur in areas with increased modeled ozone concentrations associated with CFO Project and cumulative emissions.

Metrics for Evaluating Ozone Concentrations

Statistical metrics are used as another means of assessing predicted ozone concentrations. As explained earlier, DVFs predict compliance with the 75 ppb ozone standard at 21 of the 31 ozone monitors in the 4 km domain. However, DVFs are limited because they do not provide an indication of ozone concentrations at non-monitor grid cells, nor do they provide an indication of daily ozone concentration variations. The following statistical metrics provide additional insight into day-to-day absolute ozone concentrations and the spatial extent of ozone impacts. In addition, the metrics provide a focused statistical assessment to evaluate ozone changes at all grid cells within the CFO. A broader metrics assessment also provides statistics on all grid cells in the 4 km domain.

The following metrics analysis provides a tabular, rather than graphic, view of the data. The following four metrics were calculated based on all grid cells in the 4 km domain.

- **Metric 1:** Percent change in modeled ozone concentration greater than 75 ppb (based on 8-hour daily maximum)
- **Metric 2:** Percent change in the *number* of grid cells with modeled concentrations greater than 75 ppb (based on 8-hour daily maximum)
- **Metric 3:** Percent change in the number of modeled grid cell-hours greater than 75 ppb-hr (based on 8-hour daily rolling average)
- **Metric 4**: Percent change in maximum modeled 8-hour ozone (with no ozone concentration threshold)

For each of the above metrics, each of the 2017 CFO Alternative scenarios were compared to the 2017 future base case year (2017a1) scenario.

The process for calculating Metric 1 values involves iterating through each cell and determining if its 2017a1 8-hour daily maximum concentration was greater than 75 ppb. If it was, the increment above 75 ppb was calculated and saved. At the end of the iterative process, a sum of the "excess ozone" was determined for the 2017a1 scenario. A similar process was completed for each of the Alternatives (RFDOTB and RFDOTBX). The percent change from 2017a1 to RFDOTB was calculated by subtracting the sum of excess ozone for 2017a1 from the sum of excess ozone for RFDOTB. This difference was then divided by the 2017a1 excess ozone sum and multiplied by 100 to determine the percent change.

Metric 2 evaluates changes in the number of grid cells whose 8-hour daily maximum concentration exceeds 75 ppb. This metric is calculated using an approach similar to that used for Metric 1. The percent change for each of the Alternatives compared to 2017a1 was calculated. The resulting percentages represent the geographical extent of excess ozone changes.

Metric 3 combines the number of grid cells calculated for Metric 2 with a time exposure component. The total number of hours that each grid cell exceeds 75 ppb (8-hour average) was summed and percentages were calculated for each of the Alternatives compared to the 2017a1 future base case.

Metric 4 is a simple comparison between the modeled 8-hour daily maximum concentrations for each of the Alternatives compared to 2017a1. All modeled 8-hour daily maximum values were included in this calculation, regardless of whether the values exceeded 75 ppb.

Table 4-19 summarizes the results of Metrics 1–4. Each of the metrics is calculated twice for each future year scenario. The first set of metrics includes all grid cells within the CFO. The second set includes all grid cells within the 4 km domain.

Within the CFO, the metrics can be summarized as follows.

- **Metric 1:** Compared to the 2017 future base case modeling scenario, excess ozone increased by 2% to 3% for the Alternatives. This indicates that the Project emissions contribute approximately 2% to 3% to this increase in ozone.
- **Metric 2:** The number of grid cells with excess ozone increased by approximately 2% to 3% for the Alternatives. Consequently, a 2% to 3% larger geographic area within the CFO would experience ozone concentrations above 75 ppb compared to the 2017 future base case.
- **Metric 3:** Grid cell-hours with excess ozone increased approximately 1 to 2 percent.
- **Metric 4:** The 8-hour daily maximum ozone does not change between the 2017a1 case and both Alternatives.

When the metrics are calculated for all cells within the 4 km grid, ozone concentration increases for all Metrics are approximately half of those for the CFO grid cells.

Table 4-19. Absolute Concentration Metrics

Modeled Scenario	Percent Change			
	Metric 1	Metric 2	Metric 3	Metric 4
	Max 8-hour ozone ≥ 75ppb	Number of grid cells ≥ 75ppb	Number of grid cell-hours ≥ 75ppb	Max 8-hour ozone
CFO Grid Cells				
RFDOTB	3.0%	2.9%	2.0%	0.0%
RFDOTBX	1.9%	1.8%	1.1%	0.0%
All 4 km Grid Cells				
RFDOTB	1.1%	1.1%	1.0%	0.0%
RFDOTBX	0.7%	0.7%	0.7%	0.0%

[illegible]

For all future year Alternative modeling scenarios (which include cumulative emissions), modeled absolute 8-hour daily maximum ozone concentrations are consistently greater than concentrations predicted for 2008b1 at all monitors. This is consistent with the RRF calculations presented earlier. As was stated previously, care must be taken when interpreting absolute model concentrations.

The future year base case (2017a1), RFDOTB, and RFDOTBX 8-hour daily maximum ozone concentration results are illustrated in the following figures. In order to conform to the methods used for the RRF calculation, the absolute concentrations shown are the maximum concentrations predicted at nearby cells (within the 7×7 grid surrounding the monitor). Figure 4-15, Figure 4-16, and Figure 4-17 compare concentrations at the Carlsbad, New Mexico; Carlsbad Caverns NP; and the Hobbs, New Mexico monitors. As shown in the graphs, there is essentially no change between the future year base case and Alternative concentrations. Time series plots at all monitors in the 4 km domain are included in Appendix L.

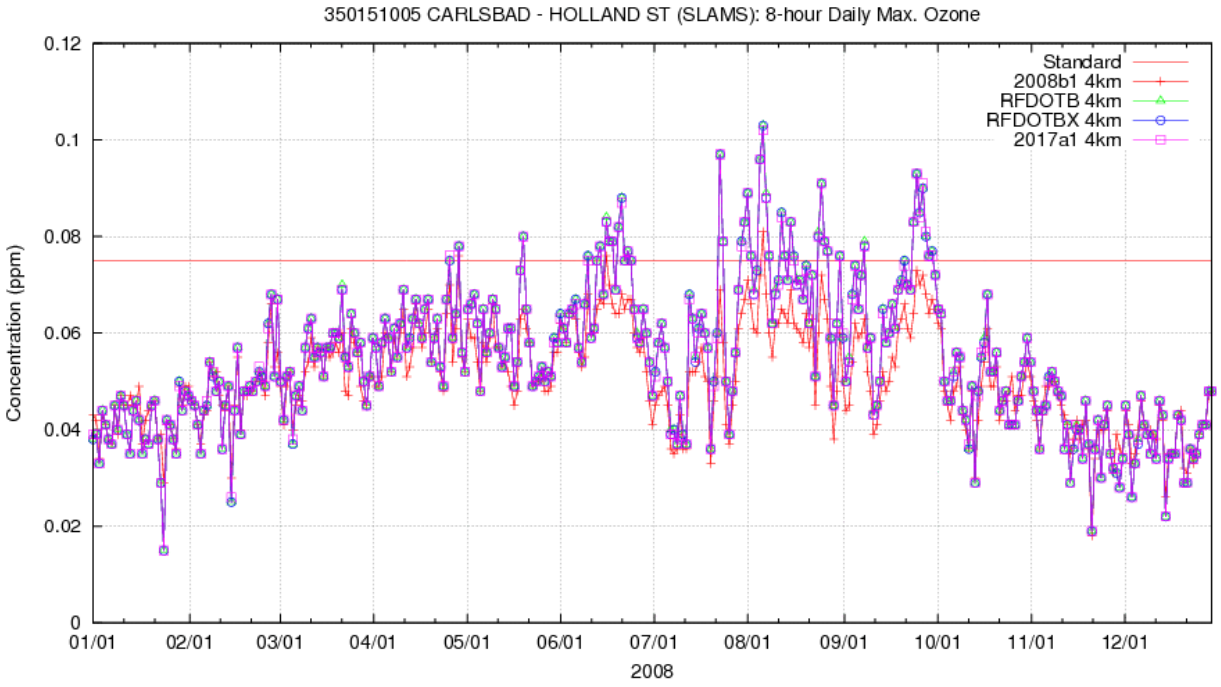


Figure 4-15. Time Series Plots Comparing Alternatives and 2008b1 Predicted Concentrations at the Carlsbad, New Mexico Monitor

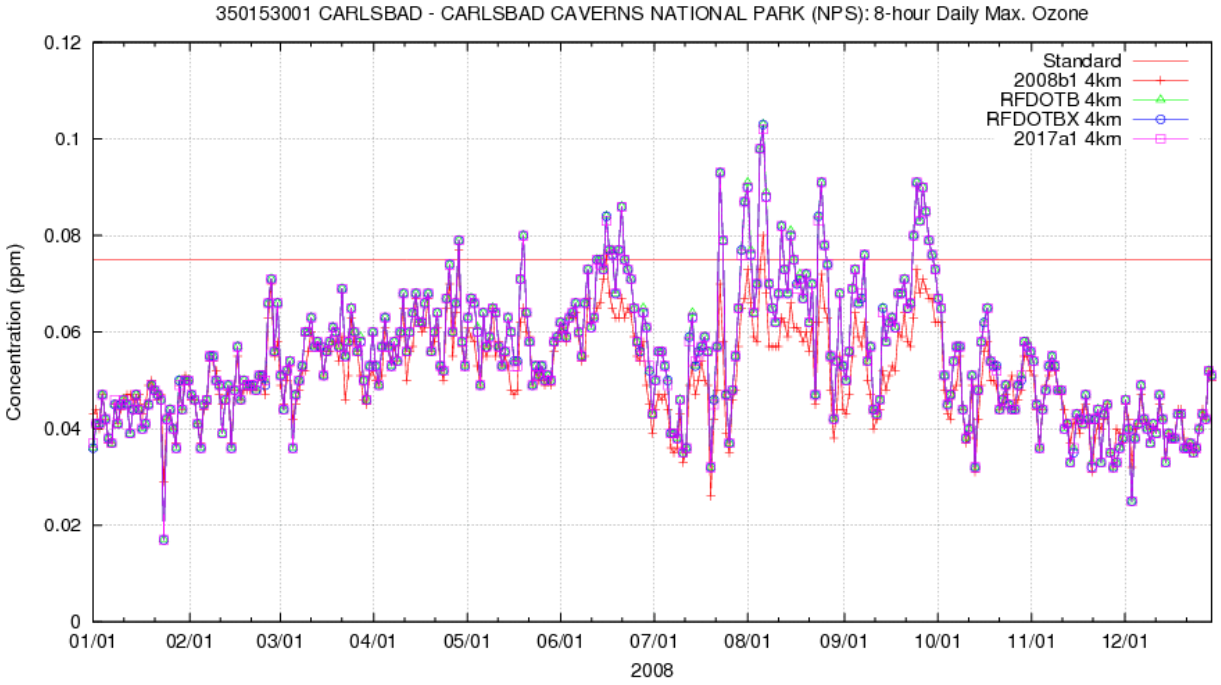


Figure 4-16. Time Series Plots Comparing Alternatives and 2008b1 Predicted Concentrations at the Carlsbad Caverns NP Monitor

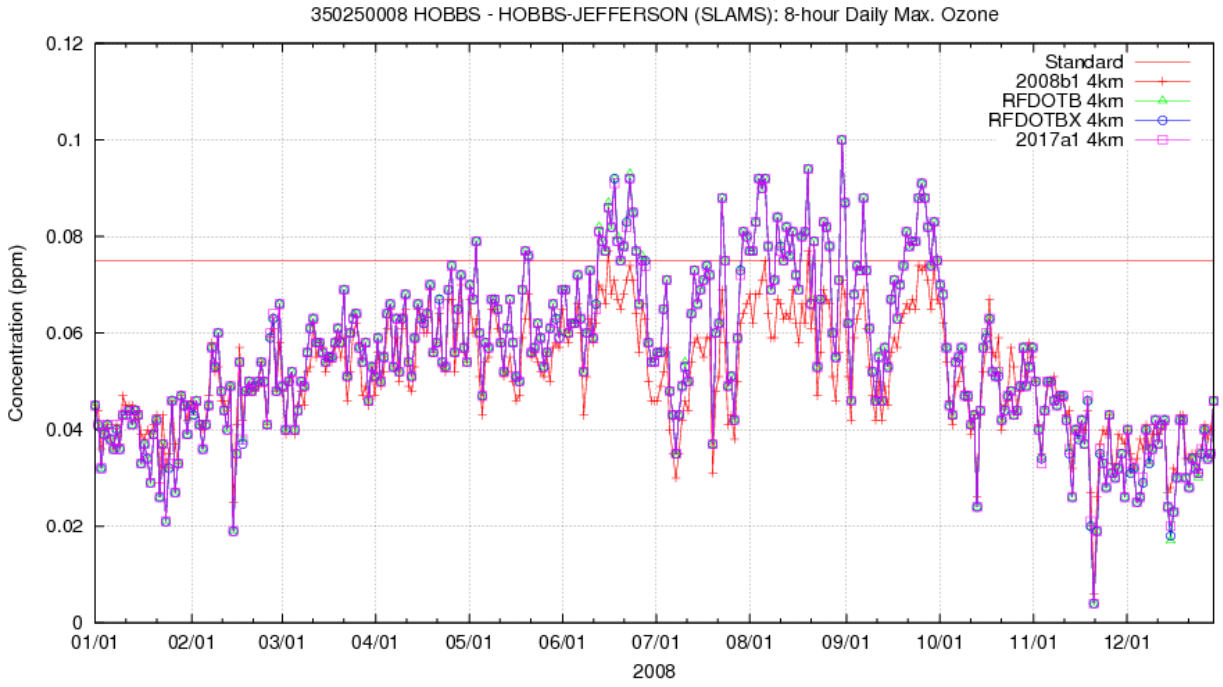


Figure 4-17. Time Series Plots Comparing Alternatives and 2008b1 Predicted Concentrations at the Hobbs, New Mexico Monitor

4.6.2.4. Ozone Conclusions

Ozone impacts attributable to CFO Project and cumulative emissions are not expected to cause or contribute to violations of the ozone NAAQS. For each Alternative (including cumulative oil and gas emissions), one third of the projected DVs in the 4 km domain are above the 75 ppb ozone NAAQS; however, the projected DVs for the two Alternatives show little to no change from the future year base case. In addition, modeled ozone impacts attributable to CFO Project emissions do not extend to any nonattainment areas when comparing future year modeling results with and without Project emissions.

4.6.3. Assessment of Predicted $PM_{2.5}$ Impacts

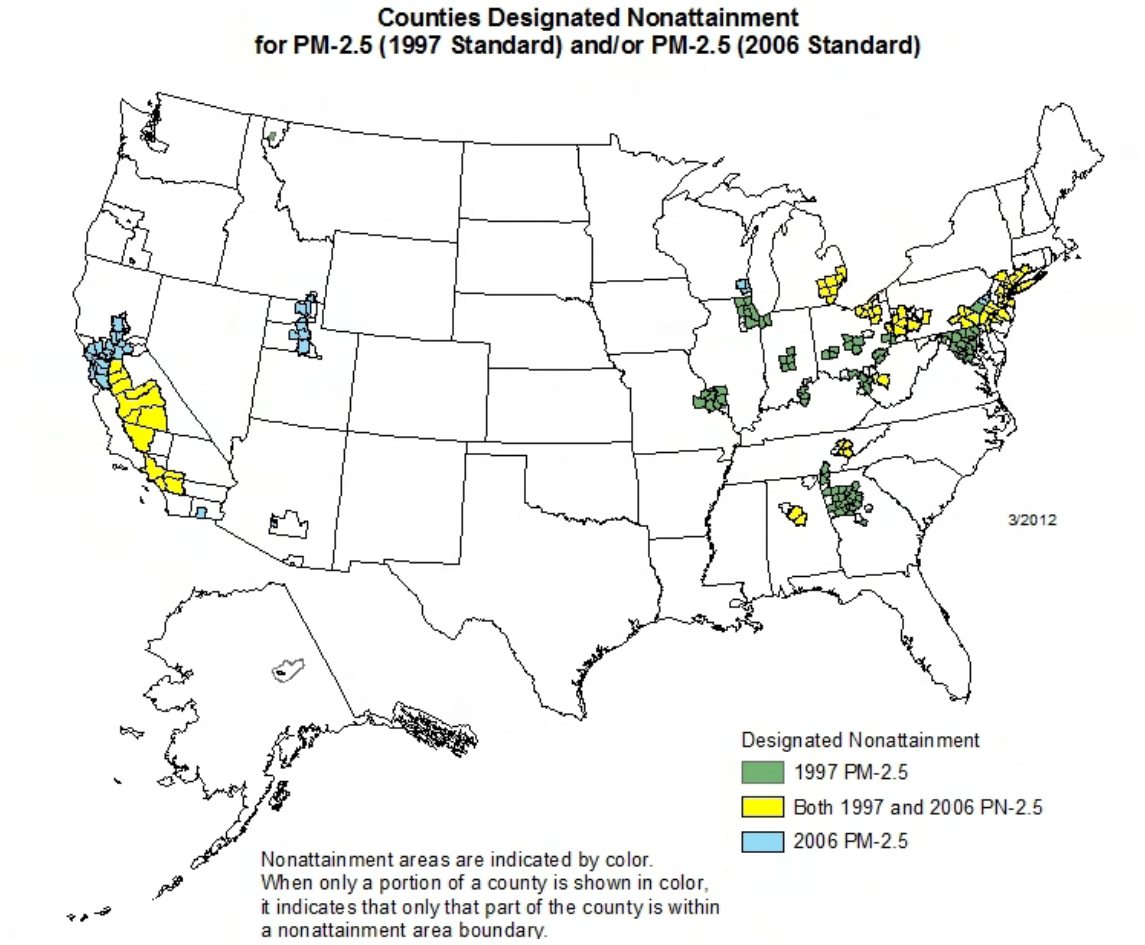
4.6.3.1. Existing Regional $PM_{2.5}$ Levels

Current nonattainment area designations for the 24-hour average $PM_{2.5}$ primary and secondary NAAQS of 35 µg/m^3 were established in 2006. The following are nonattainment areas within the 12 km domain, Salt Lake City, Utah; Provo, Utah; West Central Pinal County, Arizona; Nogales, Arizona; and multiple areas in California. Current nonattainment area designations for the annual average $PM_{2.5}$ primary NAAQS of 15 µg/m^3 were established in 1997. The following are nonattainment areas within the 12 km domain, Los Angeles-South Coast Air Basin, California; and the San Joaquin Valley, California.

Although the 12 µg/m^3 standard became effective on December 12, 2012, USEPA has not designated any areas nonattainment under this standard.

Map 4-5 shows the locations of areas throughout the nation that are currently designated $PM_{2.5}$ nonattainment under the 24-hour standard (35 µg/m^3) and the annual standard (15 µg/m^3)

(USEPA 2012c). The CFO and nearby oil and gas development areas are located in an ozone unclassifiable/ attainment area.



Map 4-5. Current $PM_{2.5}$ Nonattainment Areas (1997 and 2006 Standards)

4.6.3.2. Predicted CFO Project $PM_{2.5}$ Impacts

□□□□□□□1□ □ □□□r□□□□□E□□□□□□□□□□ I□ □□□□□

On most modeled days, the geographic extent of CFO Project impacts is generally limited to the CFO and nearby counties in New Mexico and Texas.

Project emissions for Alternative RFDOTB have the greatest geographic extent. Alternative RFDOTB difference plots (RFDOTB – 2017a1) illustrate the extent of $PM_{2.5}$ due to the Project emissions increases associated with Alternative RFDOTB. In these difference plots, negative (bluer) values indicate decreases, while positive (redder) values indicate increases. Figure 4-18 illustrates the maximum geographic extent of 24-hour average $PM_{2.5}$ increases associated with Alternative RFDOTB Project impacts, while Figure 4-19 illustrates the same for the annual average. While the 24-hour impacts do reach into the eastern panhandle of Texas, the values are less than or equal to 0.3 $\mu g/m^3$. The annual average impacts are completely within the CFO.

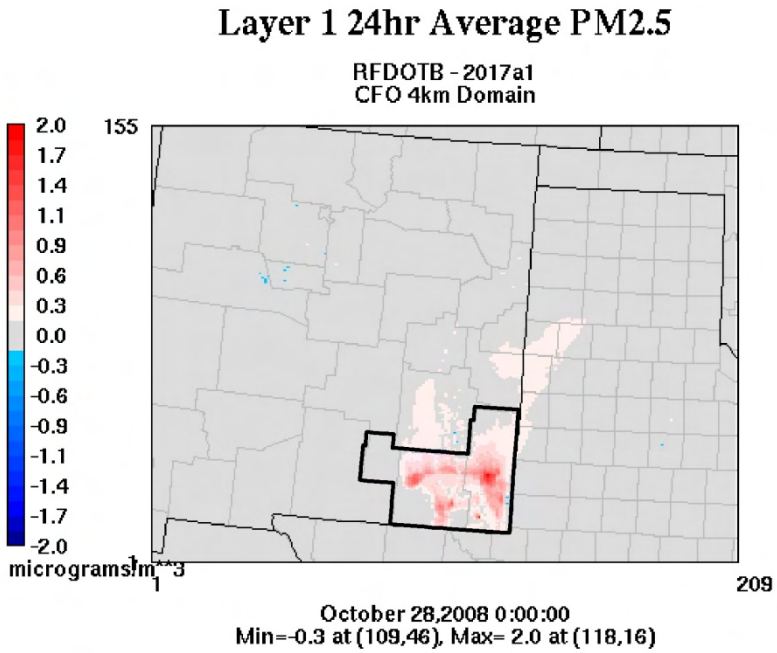


Figure 4-18. Maximum Geographic Extent of Alternative RFDOTB Project Impacts (24-hour average)

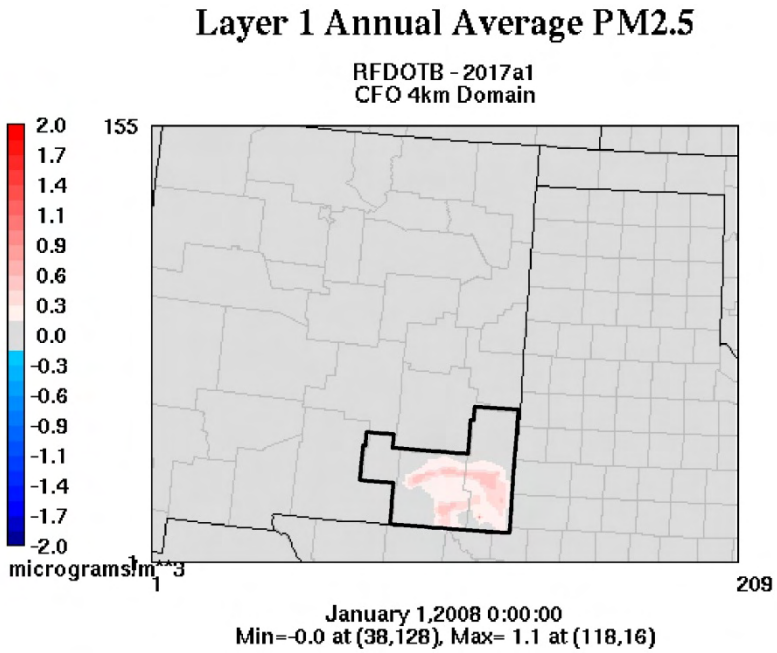


Figure 4-19. Alternative RFDOTB Project Impacts (Annual average)

[illegible]

The greatest 24-hour average $PM_{2.5}$ concentration increases due to Project emissions is 3.8 µg/m^3 occurring on October 17 (Figure 4-20). The maximum increase occurs within the CFO area. The annual average $PM_{2.5}$ increase of 1.1 µg/m^3 also occurs within the CFO (Figure 4-19). The average 24-hour average $PM_{2.5}$ increase attributable to CFO Project emissions is 0.01 µg/m^3 for Alternative RFDOTB.

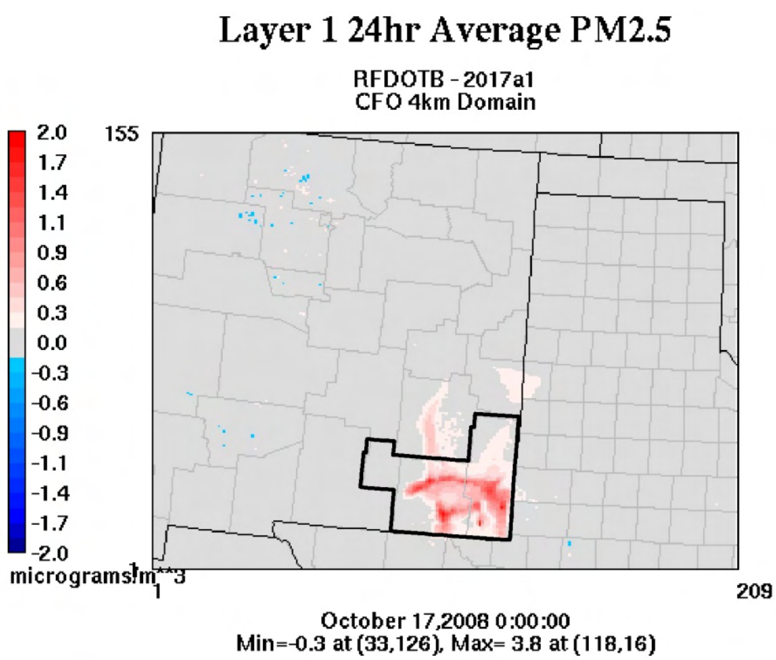


Figure 4-20. Greatest 24-hour Average $PM_{2.5}$ Concentrations Due to CFO Project Emissions

In terms of maximum predicted absolute $PM_{2.5}$ concentrations, the highest day within the 4 km domain is October 17, with the maximum occurring in the Odessa, Texas area (Figure 4-21). On October 17, the incremental $PM_{2.5}$ impact due to Alternative RFDOTB Project emissions compared to future year base case emissions is predicted to be 3.8 µg/m^3, as shown in Figure 4-20. Based on these modeling predictions, CFO Project emissions do not appear to contribute to high concentrations predicted on October 17.

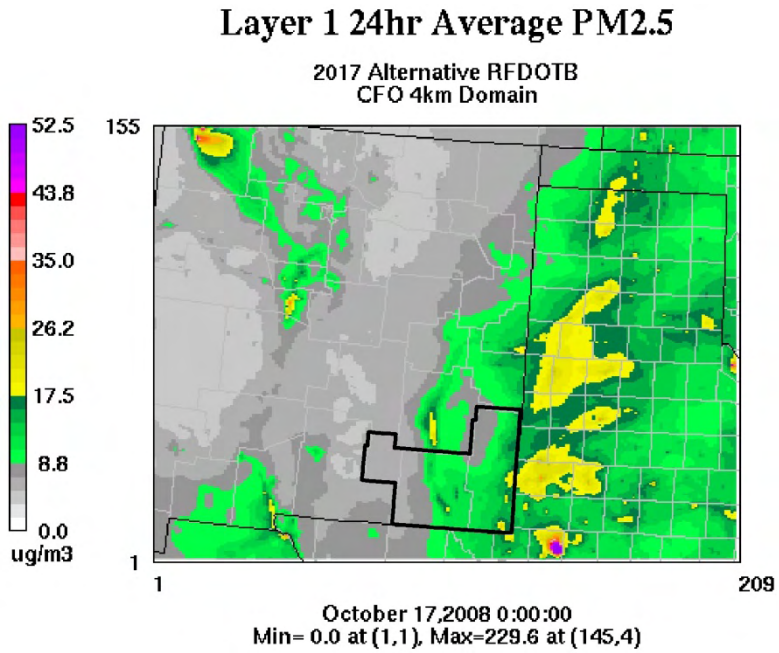


Figure 4-21. 24-hour Average $PM_{2.5}$ Concentrations on October 17 From RFDOTB

[illegible] [illegible] [illegible] [illegible]

Predicted $PM_{2.5}$ concentration differences among the Alternatives occur, but are very small in magnitude. Table 4-20 summarizes the $PM_{2.5}$ concentration differences between Alternative RFDOTB and Alternative RFDOTBX by providing the maximum, minimum, and average differences that were identified. The modeling results indicate that at most the Alternatives differ by 1.11 µg/m^3 and have an average difference of 0.005 µg/m^3 for the 24-hour average. With respect to the annual average, the maximum difference is 0.3 µg/m^3.

Table 4-20. Summary of Differences between Alternatives in 4 km Domain

Difference Criteria	RFDOTB - RFDOTBX
24-Hour Average, Maximum Difference (µg/m^3)	1.110
24-Hour Average, Minimum Difference (µg/m^3)	-0.034
24-Hour Average, Average Difference (µg/m^3)	0.005
Annual Average, Maximum Difference (µg/m^3)	0.300
Annual Average, Minimum Difference (µg/m^3)	0.000

4.6.3.3. Predicted Cumulative $PM_{2.5}$ Impacts

Cumulative impacts were determined for each of the Alternatives, and reflect predicted impacts from each of the Alternatives combined with oil and gas RFD and growth in regional and national emissions databases to 2017 emissions levels. $PM_{2.5}$ impacts were assessed using the following two separate methods.

- $PM_{2.5}$ DV predictions for future years based on USEPA guidance using the Model Attainment Test Software (MATS) (Abt 2012)
- $PM_{2.5}$ concentration predictions using absolute modeled results

4.6.3.4. $PM_{2.5}$ Future Year DV Projections

$PM_{2.5}$ DVs (both baseline and future DVs) have the same format as the 24-hour or annual average NAAQS and can be compared directly to the NAAQS to assess compliance. $PM_{2.5}$ NAAQS compliance occurs when the DV (based on three full years of data) is less than or equal to 35 µg/m^3 for the 24-hour average or 12 µg/m^3 for the annual average, which are the NAAQS as of April 2013.

The DVB is the current value, which is determined at each individual monitor and is defined as the 3-year average of the 98th percentile of the 24-hour averages or the 3-year average of the annual means measured at the monitor. The DVF is predicted based on future-year modeling.

USEPA guidance (USEPA 2007 and 2011) provides a method to predict the DVF at each monitor for both 24-hour average and annual average $PM_{2.5}$. In this approach, modeled $PM_{2.5}$ concentrations are used, as well as, individual $PM_{2.5}$ component species. The sections below summarize the steps for each of the averages.

Annual Average $PM_{2.5}$

The calculation of future year DV values for annual average $PM_{2.5}$ has four basic steps which are described below.

- **Step 1**
  The first step is to compute observed quarterly mean $PM_{2.5}$, as well as, quarterly mean values for $PM_{2.5}$ component species at each monitor.
- **Step 2**
  The second step is to calculate the $PM_{2.5}$ component RRFs at each monitor for each quarter of the year. Equation 4.3 provides the equation used to calculate component specific RRFs.

  $$\mathbf{RRF_{ij} = CF_{ij} \div CB_{ij}} \qquad \textbf{(Equation 4.3)}$$

  Where:

  RRF_{ij} = the relative response factor calculated near site *i* (unitless) for each component *j*

  CF_{ij} = the annual average future concentration predicted by the model at site *i* (µg/m^3) for each component *j*

  CB_{ij} = the annual average baseline concentration predicted by the model at site *i* (µg/m^3) for each component *j*

As recommended by USEPA guidance (USEPA 2007), future and baseline modeled concentrations at cells "near" each monitor were considered when determining which annual average concentrations were used in the RRF calculation. Cells near each monitor are those within an approximate radius of 15km from the monitor. For the 4 km domain, this is a 7×7 array of cells centered on the cell containing the monitor.

- **Step 3**
  The third step is to obtain projected quarterly species estimates. This is done by multiplying the observed quarterly mean component values (from Step 1) by the component specific RRF from Step 2.

- **Step 4**
  The last step is to calculate the estimated future year annual average $PM_{2.5}$ concentration. This is accomplished by summing the quarterly mean component values from Step 3 to get a quarterly mean $PM_{2.5}$ value. These quarterly mean values are then averaged to get a future year annual average $PM_{2.5}$ estimate for each monitor (DVF). This value can then be compared to the NAAQS.

Comparison to the Annual Average $PM_{2.5}$ NAAQS

After DVFs were determined, they were compared to the annual average standard. DVFs less than or equal to 12 µg/m^3 (revised standard from 2012) indicate expected future compliance with the annual average $PM_{2.5}$ NAAQS that is currently effective on the date of publication of this ARTSD.

Table 4-21 provides predicted annual average $PM_{2.5}$ RRFs, DVBs, and DVFs for all monitors in the 4 km domain with sufficient data to calculate DVFs. Values over the 12 µg/m^3 standard are shown in bold. The monitor closest to the CFO shows future values under the standard. Predicted values for the RFDOTB and RFDOTBX Alternatives at the Roswell, New Mexico monitor show an increase of 0.01 µg/m^3 over the future year base case (2017a1), all other Alternatives values for all other monitors, have a DVF equal to that of the future year base case. MATS output files are included in Appendix J.

Table 4-21. Annual Average Future Design Values for Monitors in 4 km Domain

Monitor ID	Location Description	2008b1	2017a1		RFDOTB		RFDOTBX	
		DVB (µg/m^3)	RRF	DVF (µg/m^3)	RRF	DVF (µg/m^3)	RRF	DVF (µg/m^3)
Near CFO								
350050005	Roswell City Offices	6.39	1.64	10.51	1.65	10.52	1.65	10.52
Southwest New Mexico								
350130017	Sunland Park City Yard	10.85	1.27	**13.77**	1.27	**13.77**	1.27	**13.77**
350130025	NMED District Office	5.86	1.33	7.80	1.33	7.80	1.33	7.80
350171002	Western New Mexico Unv.	4.92	1.28	6.31	1.28	6.31	1.28	6.31
El Paso Co., Texas								
481410037	UTEP	8.70	1.32	11.51	1.32	11.51	1.32	11.51
481410044	Chamizal	10.63	1.31	**13.92**	1.31	**13.92**	1.31	**13.92**
Odessa, Texas								
481350003	Odessa-Hays Elementary School	8.20	2.09	**17.15**	2.09	**17.15**	2.09	**17.15**
Albuquerque								
350010023	Del Norte High School	6.10	1.27	7.74	1.27	7.74	1.27	7.74
350010024	South East Heights	5.84	1.29	7.56	1.29	7.56	1.29	7.56
350431003	Rio Rancho Senior Center	4.84	1.29	6.23	1.29	6.23	1.29	6.23
Amarillo, Texas								
483750320	Texas A&M AgriLife Research and Extension Center	6.17	1.95	**12.02**	1.95	**12.02**	1.95	**12.02**

DVB = Baseline design value
DVF = Future design value
NP = National Park
$\mu g/m^3$ = micrograms per meter cubed
RRF = Relative response factor

As shown in Table 4-21, the annual average $PM_{2.5}$ NAAQS is expected to be attained at 7 of the 11 monitors in the 4 km domain for both Alternatives including cumulative emissions. The greatest DVF for all monitors (17.15 $\mu g/m^3$) occurs at the Odessa-Hays Elementary School monitor in Odessa, Texas.

24-Hour Average $PM_{2.5}$

The calculation of future year DV values for 24-hour average $PM_{2.5}$ has nine basic steps which are described below.

- **Step 1**
  The first step is to identify the eight highest observed 24-hour $PM_{2.5}$ concentration days ("high" days) in each quarter for each year for each FRM site. Then identify the day rank of the observed 98th percentile value for each year. The USEPA guidance recommends using five years of data.
- **Step 2**
  The second step is to calculate the quarterly observed species fractions for $PM_{2.5}$ components on the "high" days from Step 1.
- **Step 3**
  The third step is to calculate the species concentrations for each of the "high" days. This is accomplished by multiplying the quarterly "high" day species fractions from Step 2 by the $PM_{2.5}$ concentrations from Step 1.
- **Step 4**
  The fourth step is to calculate the $PM_{2.5}$ component RRFs at each monitor for each of the "high" days. Equation 5.2 provides the equation used to calculate component specific RRFs.
- **Step 5**
  The fifth step is to obtain projected quarterly species estimates. This is done by multiplying the observed "high" day component values (from Step 3) by the component specific RRF from Step 4.
- **Step 6**
  The sixth step uses the calculations in Step 5 to calculate the future year concentrations for other species, such as, ammonium and particle bound water.
- **Step 7**
  The seventh step involves summing the species concentrations for each day to get total $PM_{2.5}$ values.
- **Step 8**
  In the eighth step, the 98th percentile concentrations for each site are determined.
- **Step 9**
  The last step is to calculate the estimated future five year weighted average 24-hour design values (DVF) for each monitor. This value can then be compared to the NAAQS.

Comparison to the 24-Hour Average $PM_{2.5}$ NAAQS

After DVFs were determined, they were compared to the 24-hour average standard. DVFs less than or equal to 35 µg/m^3 indicate expected future compliance with the 24-hour average $PM_{2.5}$ NAAQS that is currently effective on the date of publication of this ARTSD.

Table 4-22 provides predicted 24-hour average $PM_{2.5}$ RRFs, DVBs, and DVFs for all monitors in the 4 km domain with sufficient data to calculate DVFs. Values over the 35 µg/m^3 standard are shown in bold. The monitor closest to the CFO shows future values under the standard. Predicted values for the RFDOTB and RFDOTBX Alternatives for all monitors have a DVF equal to that of the future year base case. MATS output files are included in Appendix J.

Table 4-22. 24-Hour Average Future Design Values for Monitors in 4 km Domain

Monitor ID	Location Description	2008b1	2017a1		RFDOTB		RFDOTBX	
		DVB (µg/m^3)	RRF	DVF (µg/m^3)	RRF	DVF (µg/m^3)	RRF	DVF (µg/m^3)
Near CFO								
350050005	Roswell City Offices	15.9	1.27	20.2	1.27	20.2	1.27	20.2
Southwest New Mexico								
350130017	Sunland Park City Yard	34.5	1.08	**37.1**	1.08	**37.1**	1.08	**37.1**
350130025	NMED District Office	12.8	1.33	17.0	1.33	17.0	1.33	17.0
350171002	Western New Mexico Unv.	10.3	1.29	13.3	1.29	13.3	1.29	13.3
El Paso Co., Texas								
481410037	UTEP	19.9	1.17	23.3	1.17	23.3	1.17	23.3
481410044	Chamizal	26.2	1.22	31.9	1.22	31.9	1.22	31.9
Odessa, Texas								
481350003	Odessa-Hays Elementary School	17.3	2.51	**43.4**	2.51	**43.4**	2.51	**43.4**
Albuquerque								
350010023	Del Norte High School	15.4	1.10	16.9	1.10	16.9	1.10	16.9
350010024	South East Heights	15.9	1.12	17.8	1.12	17.8	1.12	17.8
350431003	Rio Rancho Senior Center	9.6	1.36	13.1	1.36	13.1	1.36	13.1
Amarillo, Texas								
483750320	Texas A&M AgriLife Research and Extension Center	14.8	2.01	29.7	2.01	29.7	2.01	29.7

DVB = Baseline design value
DVF = Future design value
NP = National Park
µg/m^3 = micrograms per meter cubed
RRF = Relative response factor

As shown in Table 4-22, the 24-hour average $PM_{2.5}$ NAAQS is expected to be attained at 9 of the 11 monitors in the 4 km domain for both Alternatives including cumulative emissions. The greatest DVF for all monitors (43.4 µg/m^3) occurs at the Odessa-Hays Elementary School monitor in Odessa, Texas.

□□□□□□□□1□ □□□□□□□□ □M□□□ □r□□□□□□□□□

Predicted absolute $PM_{2.5}$ concentrations should be interpreted carefully for the following reasons.

- *Annual and 24-hour average $PM_{2.5}$ concentrations do not compare directly to the NAAQS* — An absolute annual average $PM_{2.5}$ concentration above 12 µg/m^3, or a 24-hour average $PM_{2.5}$ concentration above 35 µg/m^3 at a specific grid cell on an individual day does not indicate a violation. This is due to the fact that compliance with the NAAQS is determined by comparing the three-year average of the annual averages or the 8th highest 24-hour average monitored concentration to the NAAQS. The format of the NAAQS is intentionally designed to allow multiple high $PM_{2.5}$ days over a three-year period.
- *Spatial consistency of high $PM_{2.5}$ concentrations is needed* — $PM_{2.5}$ concentrations exceeding the standards must occur repeatedly at the same location in order for a violation to occur.
- *PGM predictions are not exact* — PGMs cannot achieve complete accuracy in their predictions. These models incorporate huge quantities of data, particularly meteorological and emissions data, for the contiguous United States. Data input into the CAMx, SMOKE, and WRF models come from many sources and includes some assumptions and data gaps. Even if perfectly accurate data inputs could be obtained, PGMs cannot accurately predict every chemical transformation under all atmospheric conditions. Model predictions can be off by ±20 percent in terms of unpaired peak accuracy and still be within USEPA model performance goals.
- *2028 inventory versus 2017 inventory* — Although the emissions inventory for the Alternatives and for nearby oil and gas development within the Permian Basin were based on estimated year 2028 emissions, regional and national emissions inventories were available for the year 2017. Therefore, emission increases or decreases that may occur between 2017 and 2028 are not reflected in the modeling of other emissions sets, due to the unavailability of 2028 inventories beyond the CFO oil and gas emissions inventories. Predicted future year ozone concentrations may be greater or less than actual future ozone concentrations depending on how actual future 2028 emissions vary from the 2017 estimated emissions for emission sets beyond the CFO oil and gas emissions inventories.

Maximum $PM_{2.5}$ Concentrations in the CFO

Absolute $PM_{2.5}$ predictions within the CFO are provided in Appendix M plots. As discussed above, absolute $PM_{2.5}$ concentrations above the NAAQS on any individual day do not indicate a predicted violation of the NAAQS. The Appendix M plots have been zoomed in to show predicted $PM_{2.5}$ concentrations in the CFO based on Alternative RFDOTB emissions. All grid cells outside the CFO have been masked out.

In addition to providing absolute $PM_{2.5}$ concentrations within the CFO, Appendix M also provides difference plots showing $PM_{2.5}$ concentration changes between the Alternative RFDOTB modeling results and the future base case year (2017a1) modeling results. Review of Appendix M plots indicates that high absolute $PM_{2.5}$ concentrations do not appear to be associated with oil and gas development in the CFO. Specific examples are discussed below.

The greatest predicted 24-hour average $PM_{2.5}$ concentration within the CFO is 55.8 µg/m^3 and occurs on August 20 for both Alternatives. Figure 4-22 illustrates the modeled concentrations for RFDOTB.

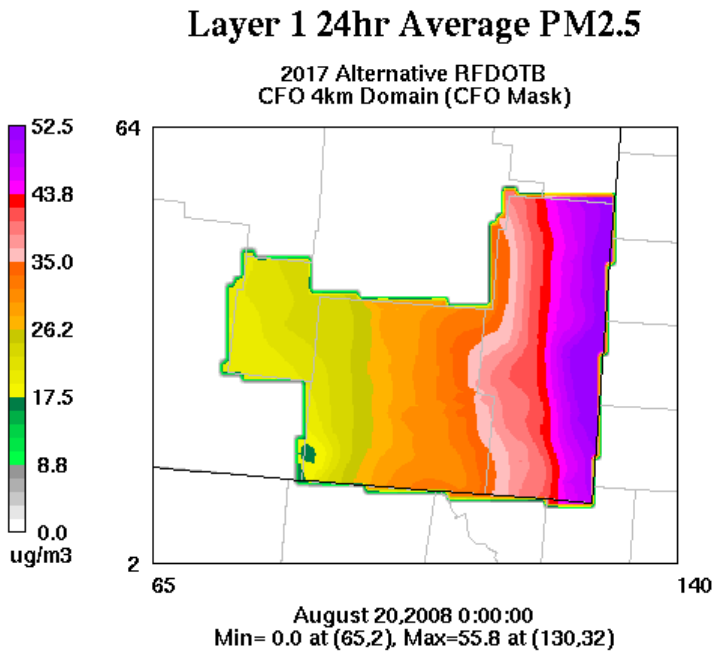


Figure 4-22. 24-hour Average $PM_{2.5}$ Concentrations in CFO on August 20 from RFDOTB

The difference plot in Figure 4-23 illustrates a small area of $PM_{2.5}$ increase across the middle portion of the CFO when future year base case (2017a1) concentrations are subtracted from future year Project and cumulative concentrations.

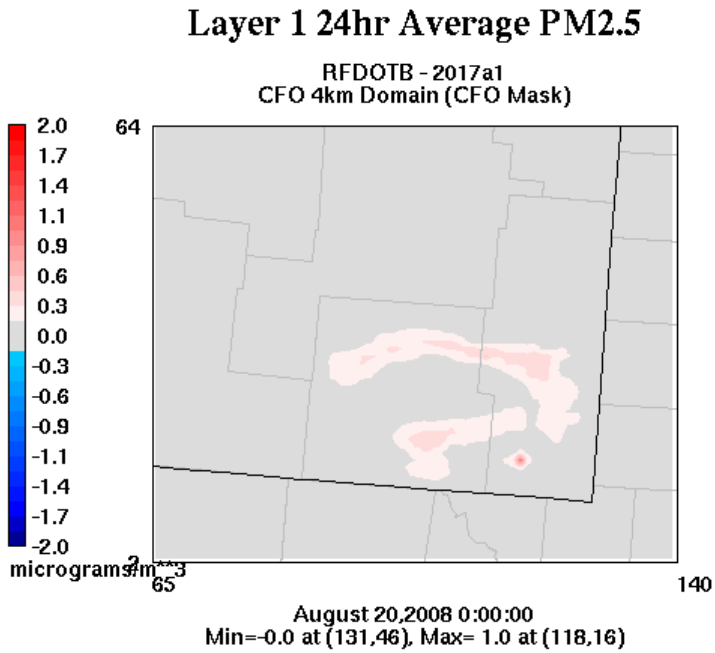


Figure 4-23. Difference Plot Showing August 20 Project and Cumulative Ozone Impacts Compared to 2017a1

Metrics for Assessing Absolute $PM_{2.5}$ Concentrations

Statistical metrics are used as another means of assessing predicted $PM_{2.5}$ concentrations. The following statistical metrics provide additional insight into day-to-day absolute $PM_{2.5}$ concentrations and the spatial extent of $PM_{2.5}$ impacts. In addition, the metrics provide a focused statistical assessment to evaluate $PM_{2.5}$ changes at all grid cells within the CFO. A broader metrics assessment also provides statistics on all grid cells in the 4 km domain.

The following metrics analysis provides a tabular, rather than graphic, view of the data. The following three metrics were calculated based on all grid cells in the 4 km domain.

- **Metric 1:** Percent change in modeled $PM_{2.5}$ concentration greater than 12 µg/m^3 (based on annual average), or greater than 35 µg/m^3 (based on 24-hour average).
- **Metric 2:** Percent change in the *number* of modeled grid cells with concentrations greater than the NAAQS.
- **Metric 3**: Percent change in maximum modeled 24-hour and annual average $PM_{2.5}$.

For each of the above metrics, each of the 2017 CFO Alternative scenarios were compared to the 2017 future case year (2017a1) scenario to illustrate the impacts of the Project emissions.

The process for calculating these metric is similar to that for ozone described in Section 4.6.2.3.3.

Table 4-23 summarizes the results of Metrics 1–3 for the annual average. Each of the metrics is calculated twice for each future year Alternative. The first set of metrics includes all grid cells within the CFO. The second set includes all grid cells within the 4 km domain.

Within the CFO, the metrics can be summarized as follows.

- **Metric 1:** Compared to the 2017 future base case modeling scenario, excess $PM_{2.5}$ increased by about 36% for the RFDOTB Alternative.
- **Metric 2:** The number of grid cells with excess $PM_{2.5}$ increased by approximately 43% percent for the RFDOTB Alternative. Consequently, a larger geographic area within the CFO would experience $PM_{2.5}$ concentrations above 12 µg/m^3 compared to the 2017 future base case.
- **Metric 3:** The maximum annual average increases by only 1.8% for the RFDOTB Alternative.

When the metrics are calculated for all cells within the 4 km grid, $PM_{2.5}$ concentration increases for all Metrics are lower than those for the CFO grid cells.

Table 4-23. Annual Average Absolute Concentration Metrics

Modeled Scenario	Percent Change		
	Metric 1	Metric 2	Metric 3
	Max Annual $PM_{2.5}$ ≥ 12µg/m^3	Number of Grid Cells ≥ 12µg/m^3	Max Annual Average $PM_{2.5}$
CFO Grid Cells			
RFDOTB	36.3%	43.3%	1.8%
RFDOTBX	18.4%	20.8%	1.0%
All 4 km Grid Cells			
RFDOTB	0.6%	1.7%	0.0%
RFDOTBX	0.4%	0.8%	0.0%

Table 4-24 summarizes the results of Metrics 1–3 for the 24-hour average. Each of the metrics is calculated twice for each future year Alternative. The first set of metrics includes all grid cells within the CFO. The second set includes all grid cells within the 4 km domain.

Within the CFO, the metrics can be summarized as follows.

- **Metric 1:** Compared to the 2017 future base case modeling scenario, excess $PM_{2.5}$ increased by about 3% for the RFDOTB Alternative.
- **Metric 2:** The number of grid cells with excess $PM_{2.5}$ increased by approximately 6% percent for the RFDOTB Alternative. Consequently, a six percent larger geographic area within the CFO would experience $PM_{2.5}$ concentrations above 12 µg/m^3 compared to the 2017 future base case.
- **Metric 3:** The maximum annual average does not increase for either Alternative.

When the metrics are calculated for all cells within the 4 km grid, $PM_{2.5}$ concentration increases for all Metrics are lower than those for the CFO grid cells.

Table 4-24. 24-Hour Average Absolute Concentration Metrics

Modeled Scenario	Percent Change		
	Metric 1	Metric 2	Metric 3
	Max Annual $PM_{2.5}$ ≥ 12µg/m^3	Number of Grid Cells ≥ 12µg/m^3	Max Annual Average $PM_{2.5}$
CFO Grid Cells			
RFDOTB	2.6%	5.6%	0.0%
RFDOTBX	1.6%	3.3%	0.0%
All 4 km Grid Cells			
RFDOTB	0.1%	0.1%	0.0%
RFDOTBX	0.0%	0.1%	0.0%

4.6.3.5. $PM_{2.5}$ Conclusions

Annual average and 24-hour average $PM_{2.5}$ impacts attributable to CFO Project and cumulative emissions are not expected to cause or contribute to violations of the $PM_{2.5}$ NAAQS. For each Alternative (including cumulative oil and gas emissions), almost one fourth of the projected DVs in the 4 km domain are above the NAAQS; however, the projected DVs for the two Alternatives show no change from the future year base case. In addition, modeled $PM_{2.5}$ impacts attributable to CFO Project emissions do not extend to any nonattainment areas when comparing future year modeling results with and without Project emissions.

4.7. FAR-FIELD ASSESSMENT OF AIR QUALITY IMPACTS

Far-field assessments of air quality impacts included assessments of NO_2, CO, PM_{10}, and SO_2, as well as assessments of AQRVs. Criteria pollutant assessments are described first, followed by the following AQRVs: visibility, deposition, and lake chemistry.

Air quality impacts from CFO BLM sources are provided for the future year base case (2017a1) and both Alternatives (RFDOTB and RFDOTBX). A summary of the RFD well counts is provided in Table 1-1, while air quality management actions applied to the BLM portion are presented in Table 2-1.

CAMx output concentrations from the multiple modeling runs were post-processed to determine concentrations for comparison to the NAAQS, PSD increments, and AQRVs.

4.7.1. Criteria Pollutant Analysis Approach

Predicted criteria pollutant concentrations were compared with applicable NAAQS and with NMAAQS when the New Mexico standards are more stringent or have different averaging times than the NAAQS, as shown in Table 3-3.

Far-field modeling results were also compared to applicable PSD Class I or Class II increments. However, all comparisons to PSD increments were made to identify potential significance, and do not represent a Regulatory Increment Consumption analysis.

Cumulative impacts were calculated by subtracting the maximum modeled value applicable to the NAAQS in the grid cells covering each Class I and sensitive Class II area for the 2008 base case from the maximum modeled value applicable to the NAAQS over the same grid cells for the 2017 base case and the 2017 Alternatives. Project impacts were calculated by subtracting the maximum modeled value applicable to the NAAQS in the grid cells covering each Class I and sensitive Class II area for the 2017 base case from the maximum modeled value applicable to the NAAQS over the same grid cells for each of the 2017 Alternatives. These impacts were then compared to the PSD increments.

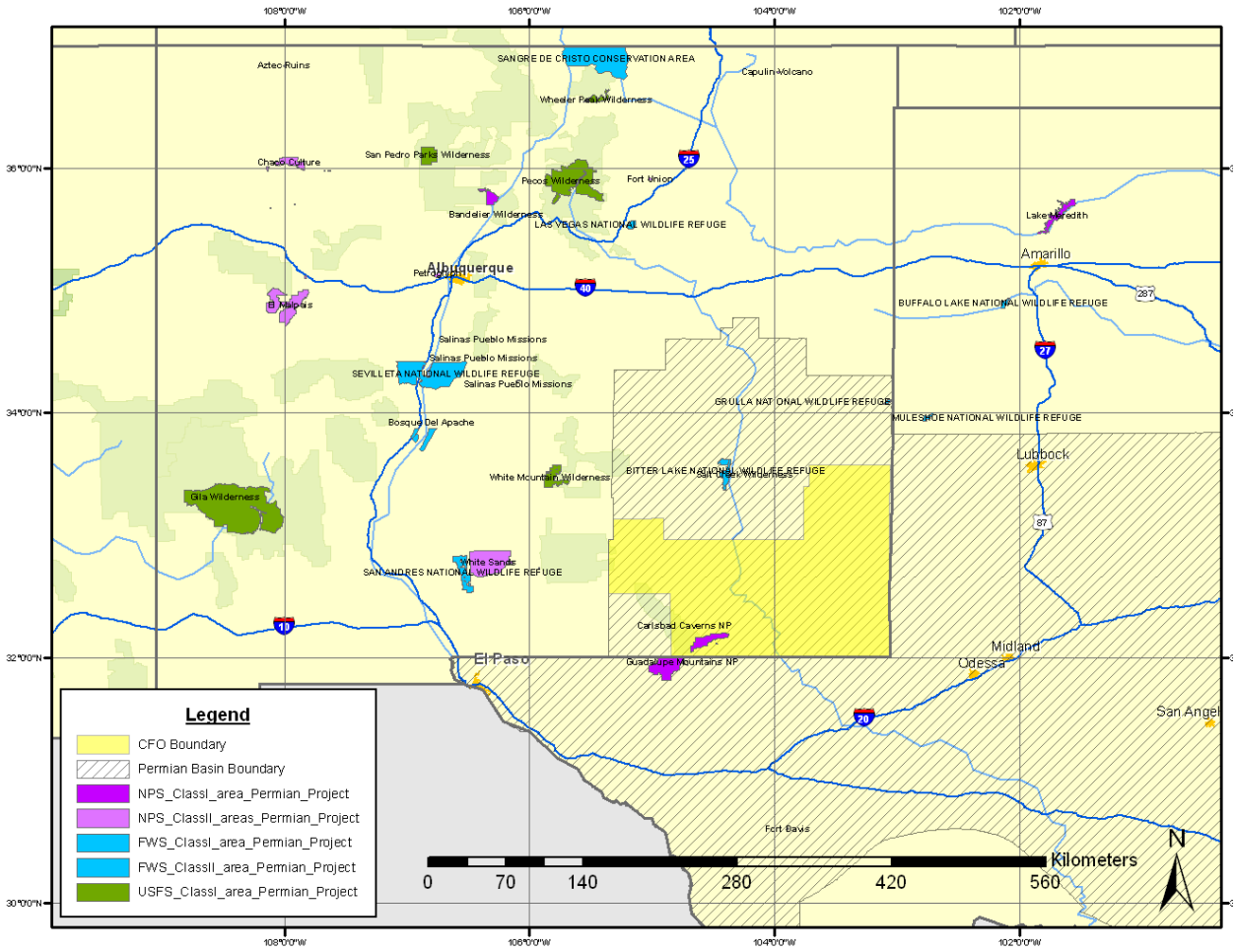
The values from above were then added to the background values for each Class I and sensitive Class II area and then were compared to the NAAQS and/or NMAAQS. Project impact tables are included in Appendix O, while the cumulative impact tables are included in Appendix P.

Table 4-25 and Map 4-6 include a list and locations of the Class I and sensitive Class II areas included in this analysis. Background values for each Class I and sensitive Class II area in this analysis were taken from New Mexico and Texas modeling guidance documents (NMED 2011 and TCEQ 2010a and 2010b).

In addition, predicted concentrations are also provided for the entire 4 km domain shown in Map 4-1. The 4 km grid cell grouping shown at the bottom of each table includes all grid cells within the CFO area where CFO oil and gas drilling, construction, and production sources will be located.

Table 4-25. Class I and Sensitive Class II Areas

Class I Areas	Sensitive Class II Areas
Bandelier Wilderness (NPS)	Aztec Ruins National Monument (NM) (NPS)
Bosque del Apache (USFWS)	Bitter Lake National Wildlife Refuge (USFWS)
Carlsbad Caverns National Park (NP) (NPS)	Buffalo Lake National Wildlife Refuge (USFWS)
Gila Wilderness (USFS)	Capulin Volcano NM (NPS)
Guadalupe Mountains NP (NPS)	Chaco Culture National Historic Park (NHP) (NPS)
Pecos Wilderness (USFS)	El Malpais NM (NPS)
Salt Creek Wilderness (USFWS)	Fort Davis National Historic Site (NPS)
San Pedro Parks Wilderness (USFS)	Fort Union NM (NPS)
Wheeler Peak Wilderness (USFS)	Grulla National Wildlife Refuge (USFWS)
White Mountain Wilderness (USFS)	Lake Meredith National Recreation Area (NPS)
	Las Vegas National Wildlife Refuge (USFWS)
	Muleshoe National Wildlife Refuge (USFWS)
	Petroglyph NM (NPS)
	Salinas Pueblo Missions NM (NPS)
	San Andres National Wildlife Refuge (USFWS)
	Sangre De Cristo Conservation Area (USFWS)
	Sevilleta National Wildlife Refuge (USFWS)
	White Sands NM (NPS)



Map 4-6. Class I and Sensitive Class II Areas in the 4 km Modeling Domain

In order to provide a brief summary of air quality impacts due to Project sources within the main text of this ARTSD, the two highest Class I and sensitive Class II, as well as, the gridded Class II air quality impacts are summarized below. This maximum is the maximum impact over the future year base case and both Alternatives for each area (Class I, sensitive Class II, and gridded Class II). Typical air quality impacts are lower. Readers are encouraged to review the referenced tables in the Appendices O and P to see the range of estimated air quality impacts.

4.7.2. NO_2

1-Hour Impacts

Table 4-26 provides a summary of the maximum predicted 1-hour NO_2 air quality impacts. The following 1-hour NO_2 concentrations represent the highest of the eighth-highest modeled concentrations over the grid cells covering a Class I or sensitive Class II area. The Project modeled value is difference between the Alternative and the 2017 base case. The "total" Project modeled value is the Project value added to the background concentration.

All total Project 1-hour NO_2 predicted concentrations at Class I and sensitive Class II areas are less than 50% of the NAAQS. The future year base case and both Alternatives have nearly identical predicted 1-hour concentrations for grid cells in all Class I and sensitive Class II areas. The lack of variation between the Alternatives and the future year base case indicates that Project

source impacts are relatively insignificant compared to other sources in the cumulative analysis. The eighth-highest predicted total cumulative concentration is approximately 828 $\mu g/m^3$ and occurs in the Four Corners region of New Mexico; this concentration and other high predicted concentrations are largely attributable to RFFA sources. Figure 4-24 shows a contour plot for Alternative RFDOTB as an example; this Alternative is similar to contour plots for the future year base case and Alternative RFDOTBX scenarios. Figure 4-25 shows the impacts from the Project emission sources. Nearly all Project impacts are in the CFO area, with the maximum impact being approximately 13 $\mu g/m^3$.

Table 4-26. Project Maximum 1-Hour NO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***N/A***		***189 [100]***
Carlsbad Caverns NP	RFDOTB	56.70 [30]	1.45 [0.8]	N/A	58.15 [31]	31%
Bosque del Apache	RFDOTBX	71.82 [38]	0.001 [5E-4]	N/A	71.82 [38]	38%
Sensitive Class II						***189 [100]***
Muleshoe NWR	RFDOTB	70.00 [37]	1.59 [0.8]	N/A	71.59 [38]	38%
Grulla NWR	RFDOTB	69.93 [37]	0.73 [0.4]	N/A	70.66 [37]	37%
Gridded Class II						***189 [100]***
All 4 km Grid Cells	RFDOTBX	87.16 [46]	0.0002 [1E-4]	N/A	87.16 [46]	46%

Conc. = concentration$\mu g/m^3$ = micrograms per cubic meter
ppb = parts per billion
WA = Wilderness Area
NHP = National Historic Park
NM = National Monument
[a] No PSD increments have been set for the 1-hour NO_2 NAAQS.
[b] The NAAQS is the same for all areas and is shown in italics.

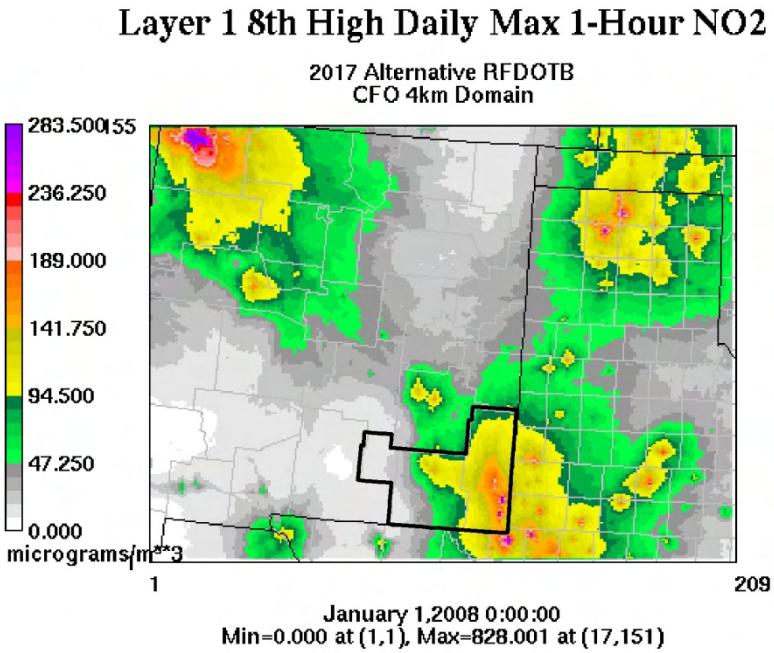


Figure 4-24. CFO Cumulative Alternative RFDOTB 8th High 1-Hour Daily Maximum NO_2 Concentration (NAAQS = 189 μg/m^3)

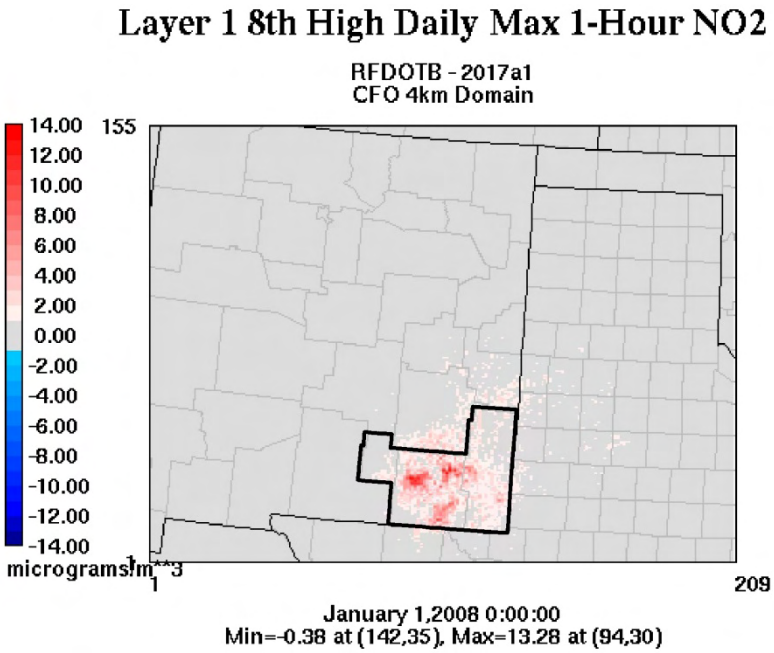


Figure 4-25. CFO RFDOTB Project Impacts for 8th High 1-Hour Daily Maximum NO_2

24-Hour Impacts

The EPA has not set a NAAQS for the 24-hour average; however, New Mexico has set a standard. According to NMED guidance (NMED 2011), demonstration of compliance with the 1-hour standard is a demonstration of compliance with the 24-hour New Mexico standard. Since the Project impacts are well below the 1-hour standard, 24-hour compliance has been demonstrated. Project and cumulative impacts for the 24-hour standard are shown in Appendix O and P respectively.

Annual Impacts

Project annual NO_2 impacts at Class I and sensitive Class II areas are well below the NAAQS (Table 4-27). The maximum in the 4 km domain occurs in only one grid cell in the Four Corners region of New Mexico (Figure 4-26). The Project impacts are almost completely within the CFO area with a maximum Project impact of approximately 11 $\mu g/m^3$ (Figure 4-27).

Table 4-27 Project Maximum Annual NO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NAAQS [b] ($\mu g/m^3$ [ppb], %)	NMAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***2.5 [1.3]***		***100 [53]***	***94 [50]***
Carlsbad Caverns NP	RFDOTB	5.66 [3]	0.14 [0.07]	6%	5.80 [3.1]	6%	6%
Salt Creek WA	RFDOTB	9.43 [5]	0.11 [0.06]	4%	9.54 [5]	10%	10%
Sensitive Class II				***25 [13.3]***		***100 [53]***	***94 [50]***
Bitter Lake NWR	RFDOTB	9.43 [5]	0.11 [0.06]	<1%	9.58 [5.1]	10%	10%
Muleshoe NWR	RFDOTB	20.0 [11]	0.03 [0.02]	<1%	20.03 [11]	20%	21%
Gridded Class II				***25 [13.3]***		***100 [53]***	***94 [50]***
All 4 km Grid Cells	RFDOTB	20.35 [11]	0.006 [0.003]	<1%	20.36 [11]	20%	22%
All New Mexico 4 km Grid Cells	RFDOTB	20.35 [11]	0.006 [0.003]	<1%	20.36 [11]	20%	22%

Conc. = concentration$\mu g/m^3$ = micrograms per cubic meter
ppb = parts per billion
WA = Wilderness Area
NP = National Park
NM = National Monument
NRA = National Recreation Area
[a] The PSD increments are provided in italics for each type of area. Predicted concentrations for sensitive Class II areas are compared to the PSD increment for a Class I area.
[b] The NAAQS/NMAAQS is the same for all areas and is shown in italics.

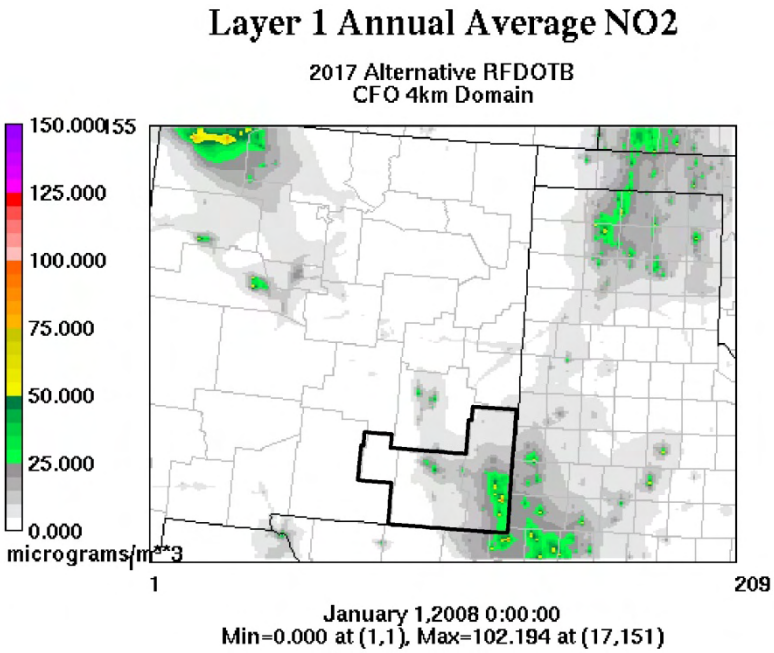


Figure 4-26. CFO Cumulative Alternative RFDOTB Annual Average NO_2 Concentration (NAAQS = 100 μg/m^3)

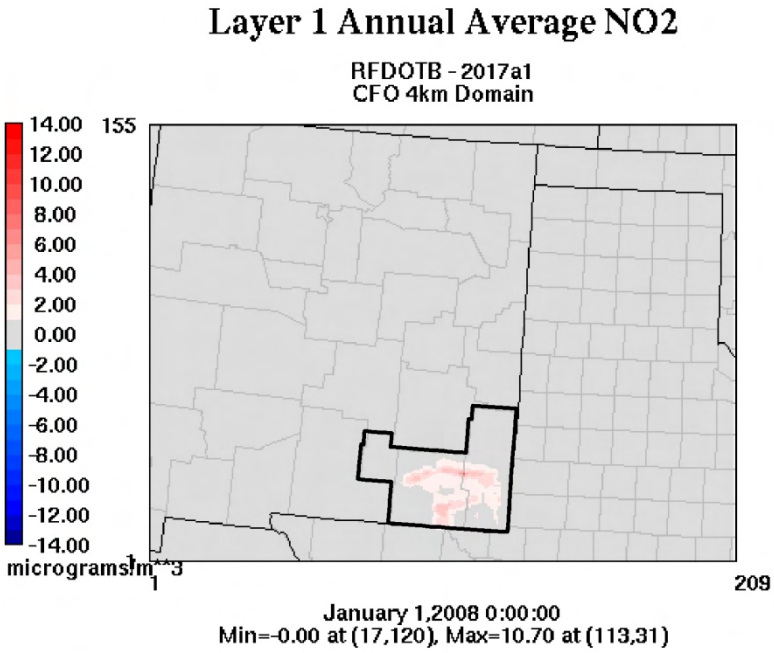


Figure 4-27. CFO RFDOTB Project Impacts for Annual Average NO_2

4.7.3. PM_{10}

24-Hour Impacts

Table 4-28 provides a summary of the maximum 24-hour PM_{10} air quality impacts. The maximum values were determined using the 2nd highest value over the year for the grid cells in the Class I or sensitive Class II area.

All of the 2nd highest values for the Class I and sensitive Class II areas are well below the NAAQS of 150 µg/m^3. The maximum occurs just to the south of Albuquerque, New Mexico. The future year base case and both Alternatives have nearly identical predicted 24-hour concentrations for grid cells in all Class I and sensitive Class II areas. The lack of variation between the Alternatives and the future year base case indicates that Project source impacts are relatively insignificant compared to other sources in the cumulative analysis.

Table 4-28. Project Maximum 24-Hour PM_{10} Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. (µg/m^3)	Project Max. Modeled Conc. (µg/m^3)	PSD Increment (µg/m^3)	Total Project Max. Modeled Conc. (µg/m^3)	NAAQS [b] (µg/m^3, %)
Class I				***8***		***150***
Salt Creek WA	RFDOTB	52.5	0.25	3%	52.75	35%
Carlsbad Caverns NP	RFDOTB	46.2	0.04	<1%	46.24	31%
Sensitive Class II				***30***		***150***
Bitter Lake NWR	RFDOTB	52.5	0.46	2%	52.96	35%
Sangre De Cristo CA	RFDOTB	52.1	0.005	<1%	52.10	35%
Gridded Class II				***30***		***150***
All 4 km Grid Cells	RFDOTBX	46.9	0.009	<1%	46.91	31%

Conc. = concentration

µg/m^3 = micrograms per cubic meter

NP = National Park

NWR = National Wildlife Refuge

NRA = National Recreation Area

WA = Wilderness Area

[a] The PSD increments are provided in italics for each type of area. Predicted concentrations for sensitive Class II areas are compared to the PSD increment for a Class I area.

[b] The NAAQS is the same for all areas and is shown in italics. Compliance with the 24-hour PM_{10} NAAQS is based on the second-highest annual maximum.

Figure 4-28 provides an illustration of high predicted PM_{10} areas, which are shown in purple, for Alternative RFDOTB emissions. Within the modeling domain, 24-hour PM_{10} concentrations at several grid cells south of Albuquerque are predicted to exceed the NAAQS. The Project impacts are almost completely within the CFO area with a maximum Project impact of approximately 4 µg/m^3 (Figure 4-29).

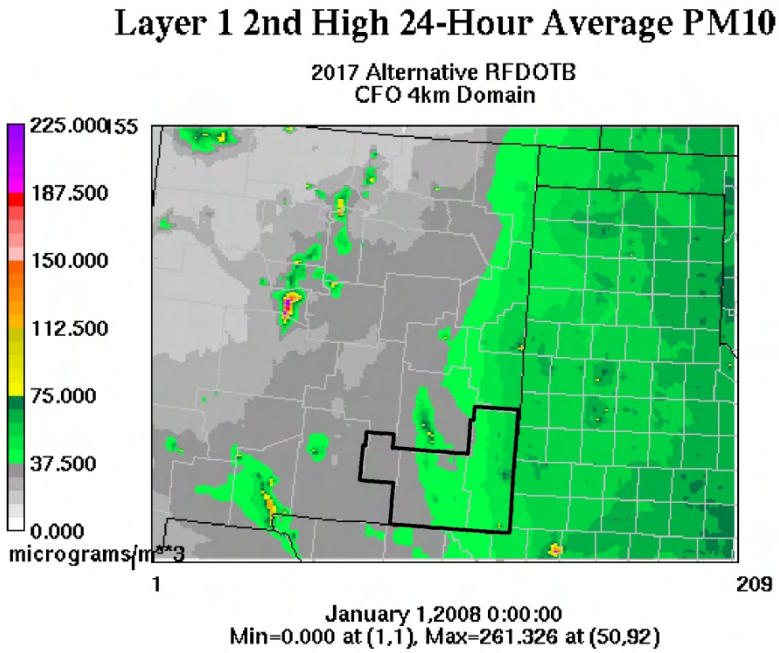


Figure 4-28. CFO Cumulative Alternative RFDOTB 2nd High 24-Hour PM_{10} Concentration (NAAQS = 150 μg/m^3)

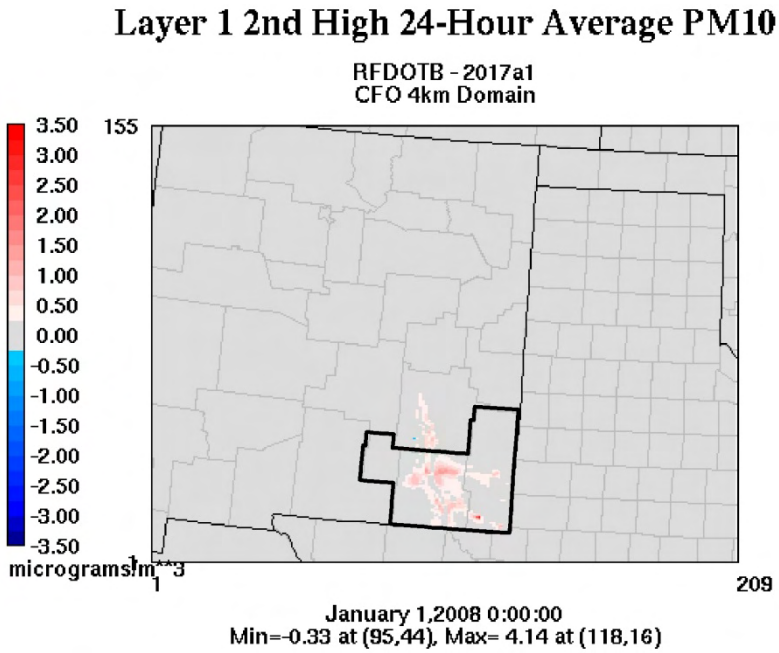


Figure 4-29. CFO RFDOTB Project Impacts for 24-Hour Average PM_{10}

4.7.4. SO_2

Four averaging times were analyzed when determining SO_2 air quality impacts: 1-hour, 3-hour, 24-hour, and annual averages. The SO_2 NAAQS is in transition due to the new 1-hour SO_2 standard, which became effective on August 23, 2010 (GPO 2010c). The 1-hour standard replaces the 3-hour, 24-hour, and annual primary SO_2 standards. However, the 3-hour standard remains effective at the federal level as a secondary NAAQS. The 1-hour standard is set at 75 ppb, which is equivalent to 195.5 $\mu g/m^3$. Compliance with the 1-hour standard is determined using the three-year average of the 99th percentile of 1-hour daily maximum SO_2 concentrations. The 3-hour, 24-hour, and annual primary standards remain in effect until USEPA promulgates attainment/nonattainment designations for the new 1-hour SO_2 standard. Consequently, modeling results are shown for these older standards. Furthermore, the NMED has set NMAAQS for 24-hour and annual averages.

For all averaging times the future year base case and both Alternatives have nearly identical predicted 24-hour concentrations for grid cells in all Class I and sensitive Class II areas. The lack of variation between the Alternatives and the future year base case indicates that Project source impacts are relatively insignificant compared to other sources in the cumulative analysis.

1-hour Impacts

Maximum 1-hour SO_2 values are well below the standard for all Class I and sensitive Class II areas (Table 4-29). Figure 4-30 is a contour plot of the fourth highest 1-hour daily maximum SO_2 concentrations. There are several areas of very high concentrations, especially in the Amarillo, Texas area. Figure 4-31 shows the Project impacts for Alternative RFDOTB, which are mostly within the CFO area.

Table 4-29. Project Maximum 1-Hour SO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***N/A***		***196 [75]***
Salt Creek WA	RFDOTBX	53.05 [20]	0.02 [8E-3]	N/A	53.07 [20]	27%
Carlsbad Caverns NP	RFDOTB	53.05 [20]	0.01 [4E-3]	N/A	53.06 [20]	27%
Sensitive Class II				***N/A***		***196 [75]***
Muleshoe NWR	RFDOTB	50.0 [19]	6E-3 [2E-3]	N/A	50.01 [19]	26%
Sangre De Cristo CA	RFDOTBX	19.08 [7]	3E-3 [1E-3]	N/A	19.08 [7]	10%
Gridded Class II				***N/A***		***196 [75]***
All 4 km Grid Cells	RFDOTB	27.29 [10]	-0.02 [-0.01]	N/A	27.27 [10]	14%

Conc. = concentration
$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
WA = Wilderness Area
NP = National Park
NWR = National Wildlife Refuge
CA = Conservation Area

[a] No PSD increment has been promulgated for the 1-hour SO_2 standard. However, the 24-hour and annual SO_2 PSD increments are still effective.

[b] The NAAQS is the same for all areas and is shown in italics. Compliance with the 1-hour SO_2 NAAQS is based on the three-year average of the 99th percentile of 1-hour daily maximum SO_2 concentrations.

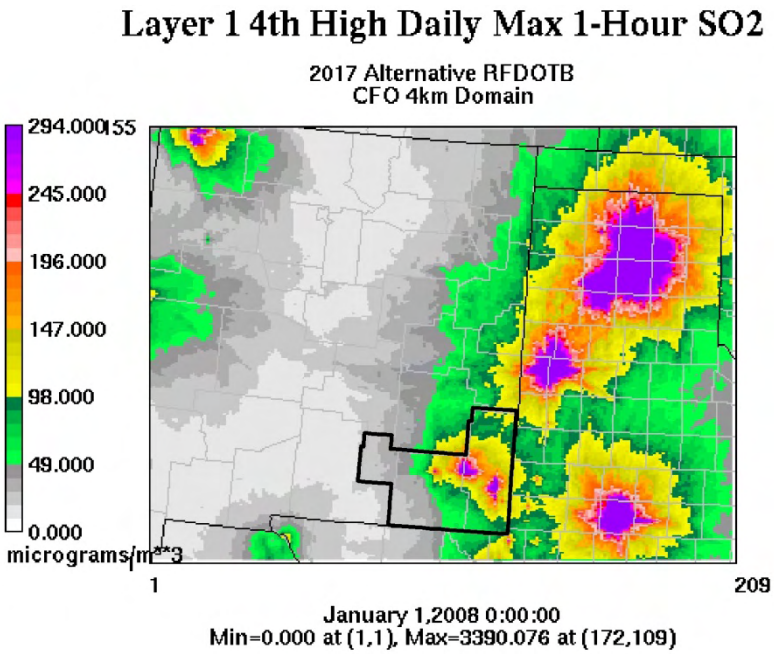


Figure 4-30. CFO Cumulative Alternative RFDOTB 4th High 1-Hour Daily Maximum SO_2 Concentration (NAAQS = 196 $\mu g/m^3$)

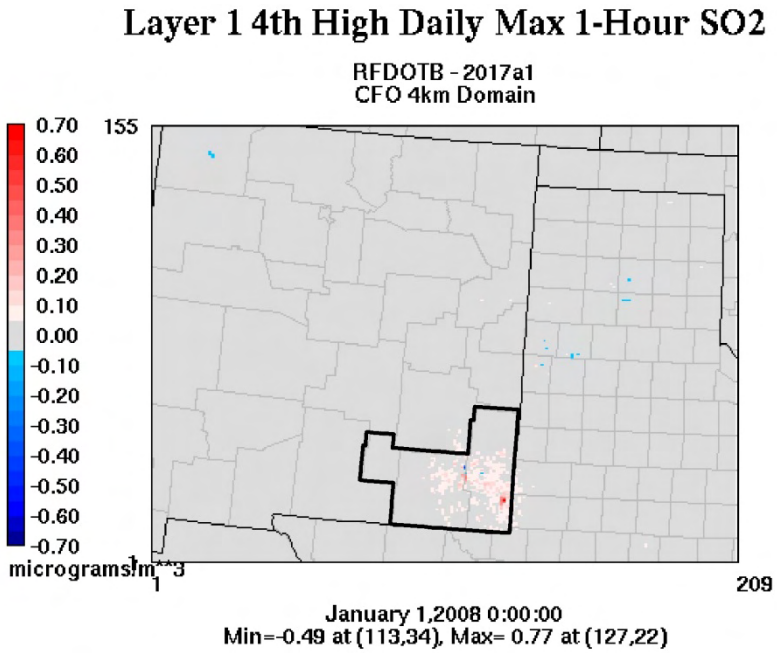


Figure 4-31 CFO RFDOTB Project Impacts for 1-Hour Daily Maximum SO_2

3-hour Impacts

Maximum 3-hour SO_2 Project impacts are below the PSD increment for all Class I and sensitive Class II areas in New Mexico and Texas (Table 4-30). NMED does not provide background values for the 3-hour average, therefore, the impacts are not compared to the NAAQS.

Table 4-30. Project Maximum 3-Hour SO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***25 [10]***		***1309 [500]***
Carlsbad Caverns NP	RFDOTBX	N/A	7E-3 [3E-3]	<1%	N/A	N/A
Guadalupe Mountains NP	RFDOTBX	N/A	4E-3 [2E-3]	<1%	N/A	N/A
Sensitive Class II				***512 [196]***		***1309 [500]***
Buffalo Lake NWR	RFDOTBX	N/A	0.03 [0.01]	<1%	N/A	N/A
Fort Davis NHS	RFDOTBX	N/A	9E-3 [3E-3]	<1%	N/A	N/A
Gridded Class II				***512 [196]***		***1309 [500]***
All 4 km Grid Cells	RFDOTB/ RFDOTBX	N/A	-3E-4 [-1E-4]	<1%	N/A	N/A

Conc. = concentration
$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
NP = National Park
NWR = National Wildlife Refuge
NHS = National Historic Site
[a] The PSD increments are provided in italics for each type of area. Predicted concentrations for sensitive Class II areas are compared to the PSD increment for a Class I area.
[b] The NAAQS is the same for all areas and is shown in italics. Compliance with the 3-hour SO_2 NAAQS is based on the second-highest annual maximum.

24-hour Impacts

Maximum 24-hour SO_2 Project impacts are below the PSD increment for all Class I and sensitive Class II areas in New Mexico (Table 4-31). NMED does not provide background values for the 24-hour average, therefore, the impacts are not compared to the NMAAQS.

Table 4-31. Project Maximum 24-Hour SO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NMAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***5 [2]***		***261 [100]***
Salt Creek WA	RFDOTB	N/A	0.02 [8E-3]	<1%	N/A	N/A
Guadalupe Mountains NP	RFDOTB	N/A	0.01 [4E-3]	<1%	N/A	N/A
Sensitive Class II				***91 [35]***		***261 [100]***
Bitter Lake NWR	RFDOTB	N/A	0.02 [8E-3]	<1%	N/A	N/A
White Sands NM	RFDOTB	N/A	0.01 [4E-3]	<1%	N/A	N/A
Gridded Class II				***91 [35]***		***261 [100]***
All 4 km Grid Cells within New Mexico	RFDOTBX	N/A	8E-3 [3E-3]	<1%	N/A	N/A

Conc. = concentration
$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
WA = Wilderness Area
NP = National Park
NM = National Monument
NWR = National Wildlife Refuge
[a] The PSD increments are provided in italics for each type of area. Predicted concentrations for sensitive Class II areas are compared to the PSD increment for a Class I area.
[b] The NMAAQS is the same for all areas and is shown in italics. Compliance with the 24-hour SO_2 NMAAQS is based on the second-highest annual maximum.

Annual Impacts

Maximum annual SO_2 Project impacts are below the PSD increment for all Class I and sensitive Class II areas in New Mexico (Table 4-32). NMED does not provide background values for the annual average, therefore, the impacts are not compared to the NMAAQS.

Table 4-32. Project Maximum Annual SO_2 Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppb])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	PSD Increment ($\mu g/m^3$ [ppb])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppb])	NMAAQS [b] ($\mu g/m^3$ [ppb], %)
Class I				***2 [1]***		***53 [20]***
Salt Creek WA	RFDOTB	N/A	3E-3 [1E-3]	<1%	N/A	N/A
Carlsbad Caverns NP	RFDOTB	N/A	2E-3 [8E-4]	<1%	N/A	N/A
Sensitive Class II				***20 [8]***		***53 [20]***
Bitter Lake NWR	RFDOTB	N/A	3E-3 [1E-3]	<1%	N/A	N/A
Muleshoe NWR	RFDOTB	N/A	1E-3 [4E-4]	<1%	N/A	N/A
Gridded Class II				***20 [8]***		***53 [20]***
All 4 km Grid Cells within New Mexico	RFDOTB	N/A	0.02 [8E-3]	<1%	N/A	N/A

Conc. = concentration

$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million

WA = Wilderness Area

NP = National Park

NWR = National Wildlife Refuge

[a] The PSD increments are provided in italics for each type of area. Predicted concentrations for sensitive Class II areas are compared to the PSD increment for a Class I area.
[b] The NMAAQS is the same for all areas and is shown in italics.

4.7.5. CO

1-Hour Impacts

Table 4-33 provides a summary of the maximum 1-hour CO air quality Project impacts. All Project impacts are well under the NAAQS and NMAAQS.

Table 4-33. Project Maximum 1-Hour CO Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppm])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppm])	PSD Increment ($\mu g/m^3$ [ppm])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppm])	NAAQS [b] ($\mu g/m^3$ [ppm], %)	NMAAQS [b] ($\mu g/m^3$ [ppm], %)
Class I				***N/A***		***40,000 [35]***	***14,971 [13.1]***
Salt Creek WA	RFDOTB	2400.0 [2.1]	0.46 [9E-5]	N/A	2400.5 [2.1]	6%	16%
Bandelier WA	RFDOTB	2400.0 [2.1]	0.04 [4E-5]	N/A	2400.0 [2.1]	6%	16%
Sensitive Class II				***N/A***		***40,000 [35]***	***14,971 [13.1]***
Sangre De Cristo CA	RFDOTB	2400.0 [2.1]	0.07 [6E-5]	N/A	2400.1 [2.1]	6%	16%
Fort Davis NHS	RFDOTB	2400.0 [2.1]	0.04 [4E-5]	N/A	2400.0 [2.1]	6%	16%
Gridded Class II				***N/A***		***40,000 [35]***	***14,971 [13.1]***
All 4 km Grid Cells	RFDOTB/ RFDOTBX	2400.0 [2.1]	0 [0]	N/A	2400.0 [2.1]	6%	16%
All New Mexico 4 km Grid Cells	RFDOTB	2400.0 [2.1]	2E-3 [2E-6]	N/A	2400.0 [2.1]	6%	16%

Conc. = concentration$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
WA = Wilderness Area
CA = Conservation Area
NHS = National Historic Site
[a] No PSD increments have been set for the 1-hour CO NAAQS.
[b] The NAAQS is the same for all areas and is shown in italics.

8-Hour Impacts

Table 4-34 provides a summary of the maximum 8-hour CO air quality Project impacts. All Project impacts are well under the NAAQS and NMAAQS.

Table 4-34. Project Maximum 8-Hour CO Air Quality Impacts

Area with Greatest Predicted Impact	Alternative with Greatest Predicted Impact	Back-ground Conc. ($\mu g/m^3$ [ppm])	Project Max. Modeled Conc. ($\mu g/m^3$ [ppm])	PSD Increment ($\mu g/m^3$ [ppm])	Total Project Max. Modeled Conc. ($\mu g/m^3$ [ppm])	NAAQS [b] ($\mu g/m^3$ [ppm], %)	NMAAQS [b] ($\mu g/m^3$ [ppm], %)
Class I				***N/A***		***10,000 [9]***	***9,667 [8.7]***
Salt Creek WA	RFDOTB	1666.7 [1.5]	0.34 [3E-4]	N/A	1667.0 [1.5]	17%	17%
White Mountain WA	RFDOTB	1666.7 [1.5]	0.17 [2E-4]	N/A	1666.8 [1.5]	17%	17%
Sensitive Class II				***N/A***		***10,000 [9]***	***9,667 [8.7]***
Bitter Lake NWR	RFDOTB	1666.7 [1.5]	0.34 [3E-4]	N/A	1667.0 [1.5]	17%	17%
Sangre De Cristo CA	RFDOTB	1666.7 [1.5]	0.10 [9E-5]	N/A	1666.8 [1.5]	17%	17%
Gridded Class II				***N/A***		***10,000 [9]***	***9,667 [8.7]***
All 4 km Grid Cells	RFDOTB/ RFDOTBX	1666.7 [1.5]	0 [0]	N/A	1666.7 [1.5]	17%	17%
All New Mexico 4 km Grid Cells	RFDOTB	1666.7 [1.5]	3E-4 [3E-7]	N/A	1666.7 [1.5]	17%	17%

Conc. = concentration$\mu g/m^3$ = micrograms per cubic meter
ppm = parts per million
WA = Wilderness Area
CA = Conservation Area
NWR = National Wildlife Refuge
[a] No PSD increments have been set for the 8-hour CO NAAQS.
[b] The NAAQS is the same for all areas and is shown in italics.

4.7.6. Visibility

Visibility is affected by plume impairment (heterogeneous) or regional haze (homogeneous). Because potential air pollutant emission sources include many small sources spread over a large area, discrete visible plumes are not likely to impact distant sensitive areas. At this preliminary resource planning stage, the RFD emission sources in this analysis consist of sources that do not have a defined location. The U.S. Congress has delegated implementation of the Clean Air Act to applicable local, state and tribal air quality regulatory agencies (with USEPA oversight). These agencies are able to determine the visual impact of the plume from individual emission sources during the NSR air quality permitting process. Therefore, this analysis focuses on visibility impairment due to regional haze. Visibility changes are assessed at Class I and sensitive Class II Areas. Map 4-6 illustrates the locations of the Class I and sensitive Class II Areas.

Regional haze is caused by fine particles and gases scattering and absorbing light. For this modeling analysis, potential changes to regional haze were calculated in terms of the level of perceptible change in visibility when compared to background conditions. A 1.0 deciview (dv) change is considered potentially significant in mandatory Federal PSD Class I areas as described in the USEPA Regional Haze Regulations (40 CFR §51.300 et seq.), and originally presented in Pitchford and Malm Study (Pitchford and Malm 1994). A 1.0-dv change is defined as approximately a 10 percent change in the extinction coefficient (corresponding to a 2 to 5 percent change in contrast, for a black target against a clear sky, at the most optically sensitive distance from an observer), which is a small but noticeable change in haziness under most circumstances when viewing scenes in mandatory Federal Class I areas.

As part of its Best Available Retrofit Technology (BART) implementation program, the USEPA established recommended procedures for identifying and evaluating potential visibility impairment primarily in mandatory Federal PSD Class I Areas (USEPA 2006). According to this procedure, predicted changes in visibility are calculated in terms of percent change in extinction (or change in dv). The Federal Land Managers' Air Quality Related Values Work Group (FLAG) 2010 Revision adopts similar criteria as outlined by the USEPA BART guidelines (FLAG 2010). The visibility screening analysis for this modeling analysis followed the recommendations in the FLAG Phase I Report - Revised guidelines (FLAG 2010). Specifically, this analysis compared daily modeled primary ($PM_{2.5}$ and PM_{10}) and secondary (sulfate and nitrate) particulate matter concentrations, as well as NO_2 concentrations, to calculated "natural" background conditions utilizing monthly relative humidity (RH) adjustment values. Background conditions for sensitive Class II areas were determined using FLAG background conditions data for the nearest Class I areas. The RH adjustment factor was based on monthly average relative humidity, capped at 95 percent. The analysis utilized the most recent USEPA estimates to determine annual average conditions using the new USEPA-approved visibility algorithm that accounts for multiple size background and monthly RH values for sulfates, nitrates and organics. Predicted visibility impacts were also estimated for FLAG 20% Best Natural Conditions values for each Class I or sensitive Class II Area.

For this analysis, Excel Workbooks were set up with unique Class I Area values following FLAG 2010 Guidance and include the new USEPA-approved visibility algorithm for estimating visibility changes from FLAG 2010 baseline conditions. The calculated visibility changes values are then compared to the 5 and 10 percent changes in extinction threshold for each Class I or sensitive Class II area.

The absolute total number of days of significant visibility changes (greater than 0.5 delta-dv and greater than 1.0 delta-dv) calculated in the Excel Workbooks for base year 2008, base case 2017 and future RFD alternatives is 366 days (every day of the year). Therefore, to show relative impacts among the Alternatives with respect to the base case emissions scenarios, the calculated delta-dv (change in visibility) was divided by 15 for each day before counting and reporting the number of days above the thresholds. This essentially equates to evaluating impacts for thresholds of 7.5 delta-dv and 15 delta-dv. The number of days per year with visibility changes greater than 0.5 dv (~ 5%) and greater than 1.0 dv (~ 10%) after dividing each day visibility change (delta-dv) by 15 are reported in Appendix Q.

Table 4-35 provides a summary of the Project-only contribution to visibility air quality impacts for each Class I area and sensitive Class II area based on a 1.0 delta-dv threshold (after dividing each day visibility change (delta-dv) by 15). The Project-only day count values are determined by subtracting out the number of days of "significant" visibility changes associated with the future base case modeling scenario (contains all cumulative emissions except Project-emissions)

from the number of days of "significant" visibility changes associated with each Project Alternative (RFDOTB and RFDOTBX). For example, if the number of days calculated for RFDOTB emissions for a specific Class I area and FLAG conditions is 10 and the number of days for the future base case emissions scenario and same Class I area (and FLAG conditions) is 5, the difference is 5 that would be reported in the Table below for the Class I area, Alternative and FLAG conditions. These calculated values give a perspective of the number of additional days above significant visibility change levels associated with Project-only emissions. These values are reported for the FLAG 2010 Annual and 20% Best Natural Conditions for both Project Alternatives (RFDOTB and RFDOTBX).

Table 4-35. Visibility Impacts at Class I and Sensitive Class II Areas Associated with Project Emissions

Class I or Sensitive Class II Areas	Number of Days in Modeled Year (normalized)			
	RFDOTB – 1.0 dv		RFDOTBX – 1.0 dv	
	Annual	20%	Annual	20%
Bandelier WA	0	0	0	0
Bosque del Apache	0	0	0	0
Carlsbad Caverns NP	0	0	0	0
Gilla Wilderness	1	0	1	0
Guadalupe Mountains NP	0	0	0	0
Pecos WA	0	0	0	0
Salt Creek WA	1	0	0	0
San Pedro Parks WA	0	0	0	0
Wheeler Peak WA	0	0	0	0
White Mountain WA	0	0	0	0
Aztec Ruins NM	0	0	0	0
Bitter Lake NWR	0	0	0	0
Buffalo Lake NWR	0	0	0	0
Capulin Volcano NM	1	0	1	0
Chaco Culture NHP	0	0	0	0
El Malpais NM	1	0	1	0
Fort Davis NHS	0	0	0	0
Fort Union NM	0	0	0	0
Grulla NWR	1	0	1	0
Lake Meredith NRA	0	0	0	0
Las Vegas NWR	0	0	0	0
Muleshoe NWR	2	0	2	0
Petroglyph NM	0	0	0	0
Salinas Pueblo Missions NM	1	0	1	0
San Andres NWR	0	0	0	0
Sangre De Cristo CA	0	1	0	0
Sevilleta NWR	0	0	0	0
White Sands NM	1	0	1	0

dv = deciview
WA = Wilderness Area
NP = National Park
NM = National Monument
NHP = National Historic Park
NWR = National Wildlife Refuge
NHS = National Historic Site
NRA = National Recreation Area
CA = Conservation Area
20% = FLAG 20% Best Conditions

For the Table above, Project visibility impact contributions associated with the projected future Alternatives (RFDOTB and RFDOTBX) are minimal. As shown, there are only several instances where "significant" impacts are predicted to occur at Class I or Sensitive Class II areas. The highest number of days associated with Project emissions occurs at Muleshoe National Wildlife Refuge which is just down wind (predominant direction) of projected Project O&G development.

Tables in Appendix Q provide detailed data for the modeled year and provide the number of days per year exceeding both 0.5 delta-dv and 1.0 delta-dv visibility change thresholds (after dividing each day visibility change (delta-dv) by 15) due to base case and future RFD Alternatives sources emissions. These thresholds are not regulatory requirements. Instead, they are thresholds used for disclosure purposes only.

Non-Project cumulative emissions (base case inventories) induced visibility impacts are driving the overall visibility impacts. These overall visibility impacts are conservatively estimated by PGM using the U.S. and Regional emissions inventories primarily due to the over-estimations of particulate matter and other pollutant concentrations for the base year 2008 emissions inventory that were ultimately used to build the future base case (non-Project) emissions inventories. As shown in the impacts Tables (above and Appendix Q), the Project visibility impact contributions are minimal, while the high values of total cumulative impacts are likely too conservative due to the over-estimation of emissions in the cumulative inventories. A refinement of the non-Project cumulative emissions estimates would reduce the number of days of total visibility impacts that would be likely closer to matching actual base and future visibility impacts / baseline conditions. In addition, it is possible that additional regulatory controls (beyond that currently accounted for cumulative sources) on NO_x emissions from engines and diesel particulate from non-road engines will significantly decrease emissions of these pollutants over the next 20 years. Use of ultra-low sulfur fuel will also substantially decrease ambient concentrations of sulfates that contribute to visibility impairment.

USEPA's Regional Haze Rule implements the "national goal of preventing any future, and remedying any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution . . . " (40 CFR §51.300). Air quality regulations designed to achieve this goal require: (1) emission reductions at certain older stationary sources, (2) review of predicted visibility impacts from certain new stationary sources under the NSR Program, and (3) development of long-term State Implementation Plans (SIPs) to reduce emissions of haze-producing pollutants. Federal agencies such as the NPS and USFS monitor visibility and review New Source Review (NSR) air quality permit applications to determine potential visibility impacts. State air quality agencies identify and implement emission reductions within their jurisdictions that are needed to reduce visibility impairment. USEPA set a goal of attaining natural visibility in Class I areas by the year 2064.

4.7.7. Deposition

The maximum annual nitrogen (N) and sulfur (S) deposition rates were estimated for one year of CAMx model outputs using Project and cumulative emissions. For disclosure purposes only, Project impacts were compared to the NPS screening deposition analysis thresholds (DATs), which are defined as 0.005 kilogram per hectare per year (kg/ha/yr) in the western United States for both N and S (FLAG 2008). Project impacts were determined by subtracting the annual deposition for the future year base case from the Alternative annual deposition value. A DAT is the additional amount of N or S deposition within a Class I area, below which estimated impacts from a proposed new or modified source are considered to be insignificant. The DAT is a screening threshold that was developed primarily to assess impacts from a single stationary

source. If a DAT is exceeded, cumulative modeling is required to demonstrate that cumulative deposition is below the level of concern. Modeling results showing deposition greater than a DAT do not indicate the need for mitigation.

Full cumulative modeling was performed as part of this analysis. Project and cumulative impacts were compared to the level of concern, which is defined by the NPS and USFS as 3 kg/ha/yr for N and 5 kg/ha/yr for S (Fox 1989). Deposition rates that are below the level of concern are believed to cause no adverse impacts.

At all areas and for both Alternatives, the N DAT is exceeded at all Class I and sensitive Class II areas (Table 4-36). For a large aggregate project that includes thousands of sources (such as oil and gas development in the CFO), deposition greater than the DAT is typical. Appendix R and S provide detailed N deposition results for Project and cumulative impacts respectively.

Table 4-36. Maximum Annual N Deposition

Area with Greatest Predicted Impact	Area with Greatest Predicted Impact	Max. Modeled Project Deposition (kg/ha/yr)	DAT [a] (kg/ha/yr, %)	Back-ground Deposition (kg/ha/yr)	Total Project Deposition (kg/ha/yr)	Level of Concern [b] (kg/ha/yr, %)
Class I			***0.005***			***3.0***
Salt Creek WA	RFDOTB	0.29	5800%	2.59	2.88	93%
Carlsbad Caverns NP	RFDOTB	0.19	3800%	2.59	2.77	92%
Sensitive Class II			***0.005***			***3.0***
Bitter Lake NWR	RFDOTB	0.29	5800%	2.59	2.88	93%
Grulla NWR	RFDOTB	0.11	2200%	2.59	2.70	90%

DAT = deposition analysis threshold
kg/ha/yr = kilogram per hectare per year
N = nitrogen
WA = Wilderness Area
NP = National Park
NWR = National Wildlife Refuge
[a] The DAT is shown in italics, while the maximum modeled deposition is provided as a percentage of the DAT.
[b] The Level of Concern is shown in italics, while the maximum total deposition is shown as a percentage of the Level of Concern.

At all areas and for both Alternatives, the S DAT is greater than the Project impacts at all Class I and sensitive Class II areas (Table 4-37). Project S deposition is less than the level of concern at all Class I and sensitive Class II areas. Appendix R and S provide detailed S deposition results for Project and cumulative impacts respectively.

Table 4-37. Maximum Annual S Deposition

Area with Greatest Predicted Impact	Area with Greatest Predicted Impact	Max. Modeled Project Deposition (kg/ha/yr)	DAT [a] (kg/ha/yr, %)	Back-ground Deposition (kg/ha/yr)	Total Project Deposition (kg/ha/yr)	Level of Concern [b] (kg/ha/yr, %)
Class I			***0.005***			***5.0***
Wheeler Peak WA	RFDOTBX	0.0014	28%	1.27	1.27	25%
Pecos WA	RFDOTBX	0.0006	12%	1.27	1.27	25%
Sensitive Class II			***0.005***			***5.0***
Sangre De Cristo CA	RFDOTBX	0.0008	16%	1.27	1.27	25%
Muleshoe NWR	RFDOTBX	0.0006	12%	1.27	1.27	25%

DAT = deposition analysis threshold

kg/ha/yr = kilogram per hectare per year

S = sulfur

WA = Wilderness Area

CA = Conservation Area

NWR = National Wildlife Refuge

[a] The DAT is shown in italics, while the maximum modeled deposition is provided as a percentage of the DAT.

[b] The Level of Concern is shown in italics, while the maximum total deposition is shown as a percentage of the Level of Concern.

[c] Cumulative impacts are not compared to DATs.

4.7.8. Lake Chemistry

An analysis of potential changes to lake ANC was performed. Annual deposition fluxes of S and N predicted by CAMx at sensitive lake receptors were used in conjunction with baseline ANC values to estimate the change in ANC. Lake chemistry baseline ANC data were obtained from the USFS for each sensitive lake included in the analysis and are included in Table 4-38. All five lakes in this analysis fall within the Pecos Wilderness Area.

The maximum ANC change values were calculated in accordance with procedures included in the USFS Rocky Mountain Region's *Screening Methodology for Calculating ANC Change to High Elevation Lakes, User's Guide* (USFS 2000). Table 4-38 provides a summary of the calculated changes in ANC; additional data is provided in Appendices I and J. Potential lake chemistry impacts were calculated for combined CFO Project and cumulative emissions.

The USFS considers lake chemistry changes to be potentially significant if the screening methodology predicts decreases in ANC of more than the Limit of Acceptable Change (LAC). A lake's LAC depends on its baseline ANC value. The LAC is 10 percent change in ANC for lakes with baseline ANC values greater than or equal to 25 microequivalents per liter (μeq/l) and "no more than 1 ueq/L cumulative loss in Acid Neutralizing Capacity is acceptable" for lakes with ANC baseline values less than 25 μeq/l (USFS 2012). For this Analysis, all lakes have a baseline ANC value greater than 25 μeq/l. Consequently, a decrease of 10 percent in ANC at any of the lakes is considered to be a significant impact.

Maximum changes to each lake's ANC are shown in Table 4-38. Values for each Alternative are included in Appendix R and S. For all lakes the Project impacts, determined by subtracting the 2017a1 values from the Alternatives values, are less than 1 percent ANC change.

Table 4-38. Maximum Changes to Lake ANC

Lake	Alternative with Greatest Impact	Baseline ANC [a] (eq)	LAC [b] (eq)	Max. H Deposition (eq)	Max. ANC Change (%)	Max. Percent of LAC (%)
Upper Truchas Lake	RFDOTBX	169,931,501	16,993,150	1,092,260	0.64	6.4
Stewart Lake	RFDOTBX	1,028,085,579	102,808,558	1,092,260	0.11	1.1
Lake Katherine	RFDOTBX	1,338,210,567	133,821,057	1,092,260	0.08	0.8
Spirit Lake	RFDOTBX	981,354,416	98,135,442	1,092,260	0.11	1.1
Lake Johnson	RFDOTBX	1,384,941,730	138,494,173	1,092,260	0.08	0.8

ANC = acid neutralizing capacity
eq = equivalents
H deposition = acid deposition
LAC = limit of acceptable change
N/A = not applicable

[a] Baseline ANC values were calculated by URS using USFS provided information.

[b] The LAC change is 10 percent change for lakes with baseline ANC values greater than or equal to 25 μeq/l. For lakes with lower baseline ANC values (less than 25 μeq/l), the LAC is no more than 1 ueq/L cumulative loss in Acid Neutralizing Capacity (ANC), USFS, http://www.fs.fed.us/air/technical/class_1/wilds.php?recordID=53).

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5.0 CLIMATE CHANGE ANALYSIS

Climate is both a driving force and a limiting factor for biological, ecological, and hydrological processes, and has great potential to influence resource management. Climate change is a phenomenon that could alter natural resource and ecologic conditions on spatial and temporal scales we have not yet experienced. The Intergovernmental Panel on Climate Change (IPCC) has stated, "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." The general consensus is that as atmospheric concentrations of GHGs continue to rise, average global temperatures and sea levels will rise, precipitation patterns will change, and climatic trends will change and influence earth's natural resources in a variety of ways. Therefore, to the extent possible and appropriate, incorporation of climate and climate change information to assist in making informed decisions regarding BLM planning and program activities is an integral element of effective program management.

When conducting long-range planning; when making major decisions regarding BLM activities, projects, and programs; and when authorizing uses of the public lands, the BLM must include consideration of climate change (USDOI 2009, BLM 2009). The depth and the scale of climate change analysis should be in accordance with the extent to which the climate change information is needed in order to make planning decisions and reflective of the information that is available. Varying degrees of information on climate change impacts on resources are available on different geographical scales and at different geographical locations, and the degree and type of this information is changing rapidly. When little information is available, it is inappropriate to overanalyze the issue. This climate change assessment for the CFO is qualitative as necessary and quantitative as available data allows, and as is appropriate. CO_2, CH_4, and N_2O are the three major anthropogenic greenhouse gases the BLM considers in addition to climate change impacts related to land management activities (URS 2010).

5.1. Climate Change Science

Substantial scientific evidence demonstrates that increased atmospheric concentrations of GHGs and land-use changes are contributing to an increase in average global temperature, often referred to as global warming (USEPA 2010). GHGs in the atmosphere moderate the planet's temperature, allowing the planet to sustain life. Due in large part to human activities, there has been a marked increase in the atmospheric concentration of these and other gases since the start of the industrial age, which has contributed to observed climate variability beyond the historic norm. Though the average global temperature has increased by 1.4°F from 1880–2012 (NASA 2013), temperature change and climatic variability are not evenly distributed across the globe. Observed temperature increases in northern latitudes have been greater than those in other areas, and seasonal low temperatures are generally increasing faster than seasonal high temperatures. Other unevenly distributed effects of climate change include altered weather patterns and precipitation rates, increased sea levels, increased wildfire occurrences, length of seasons, desert expansion, vegetation distribution, and plant and animal distribution.

Ongoing scientific research has identified the potential impacts of anthropogenic (man-made) GHG emissions, changes in biological carbon sequestration, and other changes due to land management activities on the global climate. Through complex interactions on a regional and global scale, these changes cause a net warming effect of the atmosphere, primarily by decreasing the amount of heat energy radiated by the earth back into space. Although natural

GHG levels have varied for millennia, recent industrialization and burning of fossil carbon sources have caused CO_2e concentrations to increase dramatically, and are likely to contribute to overall global climatic changes. The IPCC recently concluded that "warming of the climate system is unequivocal" and "most of the observed increase in globally average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC 2007). Models indicate that average temperature changes are likely to be greater in the Northern Hemisphere. Northern latitudes (above 24° N) have exhibited temperature increases of nearly 2.1°F since 1900, with nearly a 1.8°F increase since 1970 alone. Without additional meteorological monitoring systems, it is difficult to determine the spatial and temporal variability and change of climatic conditions, but increasing concentrations of GHGs are likely to accelerate the rate of climate change.

In 2001, the IPCC indicated that by the year 2100, global average surface temperatures would increase between 2.5°F and 10.4°F above 1990 levels, depending on the assumptions made in the predictive model. The National Academy of Sciences has confirmed these findings, but also has indicated there are uncertainties regarding how climate change may affect different regions. Computer model predictions indicate that increases in temperature will not be equally distributed, but are likely to be accentuated at higher latitudes. Warming during the winter months is expected to be greater than during the summer, and increases in daily minimum temperatures are more likely than increases in daily maximum temperatures. Increases in temperatures would increase water vapor retention in the atmosphere, and reduce soil moisture, increasing generalized drought conditions, while at the same time enhancing heavy storm events. Although large scale spatial shifts in precipitation distribution may occur, these changes are more uncertain and difficult to predict.

There are uncertainties associated with the science of climate change. This does not imply that scientists do not have confidence in many aspects of climate change science. Some aspects of the science are known with virtual certainty because they are based on well-known physical laws and documented trends. Several activities contribute to the phenomena of climate change, including emissions of GHGs (especially CO_2, CH_4, and N_2O) from fossil fuel development, large wildland fires and activities using combustion engines; changes to the natural carbon cycle; and changes to radiative forces and reflectivity (albedo). It is important to note that GHGs will have a sustained climatic impact over different temporal scales. For example, recent emissions of CO_2 can influence climate for 100 years. It may be difficult in some cases to discern whether global climate change is already affecting resources in the analysis area. However in most cases there is information about potential or projected effects of global climate change on resources. It is important to note that projected changes are likely to occur over several decades to a century. Therefore, many of the projected changes associated with climate change described below may not be measurable within the reasonably foreseeable future. Existing climate prediction models are not at a scale sufficient to estimate potential impacts of climate change within the analysis area.

5.2. CFO Climate Change Assessment

As stated above, climate change analyses are comprised of several factors, including GHGs, land use management practices, and the albedo effect. While it is possible in many cases to quantify potential quantities of GHG emissions or the amount of carbon sequestered from particular activities, the tools necessary to quantify the incremental climatic impacts of those specific activities are presently unavailable. For example, a certain quantity of GHG emissions associated with gas production cannot be linked with a specific, measured impact of a global

increase in temperature. As a consequence, impact assessment of effects of specific authorized activities (such as oil and gas development) in the CFO cannot be performed at this time. While calculating GHG oil and gas production emissions is relatively straightforward, predicting the effect of these emissions on climate change requires modeling on a global scale. Climate change is a global phenomenon; potential impacts may occur thousands of miles from GHG emission sources, such as those included in the CFO Alternatives.

Therefore, climate change analysis for the purpose of this document is limited to accounting and disclosing factors that contribute to climate change, followed by a brief comparison of GHG emissions, in order to put the emissions in some context. Additional emissions comparisons and a qualitative discussion of potential climate change impacts will be provided in the Air Quality Impacts Analysis portion of the EIS.

Natural gas is a valuable commodity that meets U.S. and international energy needs. Due to its low CO_2 combustion emissions, natural gas is replacing other fuels with greater carbon footprints. Consequently, GHG emission increases from CFO oil and gas development may be offset by CO_2 emission reductions realized from replacing other high CO_2-emitting fuels consumed in the United States. CFO Project GHG emissions may also be offset if natural gas produced using stringent GHG emission reduction strategies (such as green completions) replaces higher GHG-emitting natural gas production within the CFO or elsewhere in New Mexico or other states.

This analysis addresses the following main topics.

- Current and future regulation of GHGs
- Quantity of GHGs emitted on BLM lands from oil and gas activities
- GHG efficiency of CFO BLM natural gas production
- Natural gas displacement of other fuels

5.3. Current and Future GHG Regulation

USEPA is in the early stages of regulating GHGs as air pollutants under the Clean Air Act (CAA). In its "Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act," the USEPA determined that the six GHGs listed in Table 1-2 are air pollutants subject to regulation under the CAA. Generally, these pollutants are regulated as a group, although emission standards may be set for the group of six GHGs or for a subset of these GHGs (e.g., CO_2 only or CO_2 and methane) at USEPA's discretion.

CO_2e emissions are calculated by summing, for each GHG, the product of the quantity of GHG released and the GWP for that GHG. GHG emissions are typically reported in terms of metric tons. An example calculation of CO_2e for combined emissions of CO_2, CH_4, and N_2O is provided below. This calculation could be extended to include additional GHGs; however, CO_2, CH_4, and N_2O are the three that are relevant to this analysis. The units of CO_2e are the same as the units used to represent the quantity of CO_2, CH_4, and N_2O emissions.

$$CO_2e = [CO_2 \times 1] + [CH_4 \times 21] + [NO_2 \times 310]$$

It is important to note that the Intergovernmental Panel on Climate Change (IPCC), the international scientific body created by the United Nations to evaluate the risk of climate change, has published more recent GWPs in its Fourth Assessment Report. They are: 1.0 for CO_2, 25 for CH_4, and 298 for N_2O. While the IPCC GWPs are more universal and more recent than USEPA-published GWPs, the USEPA-published numbers are being used by companies that

must report GHG emissions to USEPA, including certain sectors of the oil and gas industry. Because many U.S. companies are using USEPA-published GWPs, and for consistency in sectoral comparisons, BLM New Mexico has chosen to use USEPA GWPs. In the event that USEPA revises their published GWPs, BLM New Mexico will follow suit.

The first USEPA regulation to limit emissions of GHGs affects light-duty vehicles, including passenger cars and light trucks. The rule sets vehicle manufacturer emission limits for CO_2 and became effective on July 6, 2010 (GPO 2010a).

As of April 2013, USEPA had not set GHG emission limits for stationary sources. However, USEPA is gathering detailed GHG emission data from thousands of facilities throughout the United States. Data gathered during this effort will be used by USEPA to develop an improved national GHG inventory and to inform future GHG emission control regulations. Beginning in 2010, many facilities across the United States estimated or measured GHG emissions in accordance with USEPA's GHG Mandatory Reporting Rule [40 *Code of Federal Regulations* (*CFR*) Part 98, GPO 2010d]. These emissions were reported by March 31, 2011. Many oil and gas facilities began determining GHG emissions in 2011 and submitted their first annual GHG emission reports by March 31, 2012 in accordance with Subpart W of 40 *CFR* Part 98 (GPO 2010e). USEPA will then be able to compile much more complete GHG emissions inventories for the oil and gas production sector.

Beginning in 2011, GHG emissions from some facilities became subject to federal air quality permitting programs, such as the Title V Operating Permit Program and the PSD Program. Historically, GHG emissions were not measured by facilities under these programs and air quality permits did not address GHGs. However, USEPA and state and local air quality permitting agencies will begin reviewing GHG emissions under these programs in accordance with USEPA's "Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule" (GPO 2010a). This review may lead to more accurate estimates of GHG emissions from these facilities and may prompt GHG emission monitoring in some cases.

Based largely on GHG emission data submitted under the GHG Mandatory Reporting Rule, USEPA plans to develop stationary source GHG emission reduction rules that could mandate substantial reductions in U.S. GHG emission reductions. Alternatively, the U.S. Congress may develop cap-and-trade legislation as another means to reduce GHG emissions.

5.4. Quantity of GHG Emissions from BLM Project Activity

Table 5-1 provides maximum annual Project GHG emission for each Alternative and each of the three estimated GHGs, as well as CO_2e emissions in metric tons per year (mtpy) for year 2028. GHG emissions calculated for this analysis include GHGs that would be emitted from oil and gas equipment (combustion sources and equipment leaks), gas venting, and motor vehicle emissions. Upstream and downstream GHG emissions are not included in the inventory. Two examples of excluded emissions are (1) GHG emissions associated with electricity produced by other entities and transmitted to oil and gas operators, and (2) GHG emissions associated with combustion of natural gas by end users.

In Table 5-1, Project GHG emissions are compared to statewide annual 2007 New Mexico emissions (NMED 2010b). Actual annual estimated 2007 New Mexico GHG emissions were 76.2 million metric tons of CO_2e. Due to greater emissions controls, Alternative RFDOTBX produces the least quantity of CO_2e emissions. Maximum Project GHG emissions are estimated to be approximately 17 percent of 2007 New Mexico GHG emissions. The maximum estimated

Project GHG emissions are approximately 0.2 percent of total U.S. 2008 CO_2e emissions of 6,821E+06 mtpy (USEPA 2012d).

Table 5-1. 2028 Project GHG Emissions as Percentage of Colorado Annual Inventory

CFO Alternative	Emissions (mtpy)			CO_2e Emissions (10^6 mtpy)	Percentage of New Mexico Inventory [a]
	CO_2	CH_4	N_2O		
RFDOTB	**11,547,017**	**46,191**	**208**	**13**	**17%**
RFDOTBX	11,512,402	13,235	208	12	16%

mtpy = metric tons per year

[a] Based on *Inventory of New Mexico Greenhouse Gas Emissions: 2000 - 2007* (NMED 2010b).

5.5. Potential Displacement of Other Fuels

As mentioned earlier, combustion of natural gas produces lower GHG emissions than combustion of most other fossil fuels. Consequently, natural gas may displace coal and oil as the fossil fuel of choice as companies modify operations to reduce GHG emissions from power generation, heaters, boilers, vehicles, and other combustion sources. Table 5-2 provides a comparison of natural gas and other fossil fuel combustion emissions. In terms of GHG emissions per MMBtu of heat input, natural gas replacement would reduce GHG emissions from coal by approximately 44 percent and would reduce GHG emissions from petroleum by approximately 25 to 28 percent.

Table 5-2. Comparison of GHG Emissions From Fossil Fuel Combustion

Fuel	Emissions (kg/MMBtu)			
	CO_2	CH_4	N_2O	CO_2e
Natural Gas	53.02	0.001	0.0001	53.07
Coal [a]	94.38	0.011	0.0016	95.11
Diesel Fuel	73.25	0.003	0.0006	73.50
Gasoline	70.22	0.003	0.0006	70.47

Source: 40 CFR Part 98, Subpart C, Tables C-1 and C-2 (GPO 2010d).
kg = kilogram
MMBtu = Million British thermal units

[a] The coal CO_2 emission factor is based on a mixture of coal types and represents coal used in electricity generation. The range of coal CO_2 emissions factors is 93.4 to 103.54 kg/MMBtu.

To the extent that economics, availability, and regulatory requirements encourage existing fossil fuel replacement by natural gas, global GHG emissions can be reduced by increased production of natural gas. For example, the U.S. Energy Information Administration (EIA) predicts that fuel switching will prompt an 83 percent increase in electric power sector natural gas consumption from 2009 to 2030 (EIA 2009).

While natural gas will displace some fossil fuels, renewable energy is expected to replace some natural gas usage in a variety of applications, such as home heating and electric power generation. The EIA predicts that total natural gas consumption in the United States will fall by 14 percent from 2009 to 2030 (EIA 2009). If natural gas consumption decreases, natural gas production in the CFO may be less than the levels of development included in some of the Alternatives within this analysis.

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6.0 SUMMARY

The results of this analysis indicate that air quality impacts, while noticeable, are generally acceptable. Most predicted criteria pollutant concentrations are well below the NAAQS throughout the extensive modeling domains included in this analysis. In a few cases and in limited locations, criteria pollutant concentrations are predicted to be greater than the NAAQS when assessing cumulative impacts, as shown in Table 6-1. Due to the many assumptions included in the analysis and the conservative nature of the modeling, these predictions may or may not indicate future exceedances of the NAAQS. Predictions of pollutant concentrations approaching or exceeding the NAAQS indicate the need for additional ambient monitoring data, refined modeling, and consideration of additional mitigation measures. As the air quality permitting agency, NMED-AQB will closely track future air quality changes and require facility-specific modeling for high-emitting sources before issuing air quality permits.

Table 6-1. Summary of Far-field Potential NAAQS Impacts

Pollutant	Averaging Time	Potential Project Impacts Above NAAQS?	Potential Cumulative Impacts Above NAAQS?	Comments on Potential Cumulative Impacts
CO	1 hour	No	No	
	8 hour	No	No	
NO_2	1 hour	No	No	
	Annual	No	No	
Ozone	8 hour	No [a]	Yes [a]	Ten of the 31 monitors in the 4 km domain have DVFs above the NAAQS.
PM_{10}	24 hour	No	No	
$PM_{2.5}$	24 hour	No [a]	Yes [a]	Two of the eleven monitors in the 4 km domain have DVFs above the NAAQS.
	Annual	No [a]	Yes [a]	Four of the eleven monitors in the 4 km domain have DVFs above the NAAQS.
SO_2	1 hour	No	Yes	Potential impacts above the NAAQS may occur for both Alternatives at some Class II receptors. Differences among Alternatives are slight.
	3 hour	No	No	
	24 hour	No	No	
	Annual	No	No	

[a] Based on DVFs.

Far-field potential AQRV impacts are summarized in Table 6-2 and described below.

Table 6-2. Summary of Far-field Potential AQRV Impacts

AQRV	Potential Project Impacts	Potential Cumulative Impacts
Visibility at Class I Areas	~ (See Visibility Section 4.7.6)	366 days (see Visibility Section 4.7.6)
Visibility at Sensitive Class II Areas	~ (See Visibility Section 4.7.6)	366 days (see Visibility Section 4.7.6)
N Deposition	Above the DAT at most Class I and sensitive Class II areas, but below the LOC at all receptors.	Above the LOC at all receptors.
S Deposition	Below the DAT and LOC at all receptors.	Above the LOC at most receptors.
Lake ANC	Below the LACs for all Lakes.	Above the LACs for all Lakes.

ANC = Acid neutralizing capacity
DAT = Deposition analysis threshold
LAC = Limit of acceptable change
LOC = Level of concern
N = Nitrogen
S = Sulfur

6.1. Emissions and Alternative Comparisons

Air quality impacts differed among the Alternatives, with Alternative RFDOTB generally having the greatest air quality impacts when emissions from Project sources are modeled. Alternative RFDOTB includes management actions required by State and National "on the books" regulations has the greater emissions of pollutants than other Alternative RFDOTBX that includes additional emissions controls applied to Project oil and gas RFD sources.

6.2. Near-Field Results

With regard to criteria pollutants subject to NAAQS or NMAAQS, seven pollutants were modeled. Near-field modeling predicted concentrations are below the AAQS for each non-ozone (and non-lead) criteria (State and National) pollutant and averaging time. HAP emissions were also modeled, though there is no ambient standard for these pollutants. Risks associated with six modeled HAPs were predicted to be much less than RELs and RfCs. Cancer risk was estimated to be below one in one million for the most likely exposed (MLE) individual scenario.

6.3. Far-Field Criteria Pollutant Results

Far-field criteria pollutant modeling results are briefly summarized, as follows.

- Project impacts are predicted to be below the NAAQS for each Alternative and at each modeled receptor for the following pollutants and averaging times.
  - Ozone (8-hour)
  - NO_2 (1-hour and annual)
  - PM_{10} (24-hour and annual)
  - $PM_{2.5}$ (24-hour and annual)
  - SO_2 (1-hour, 3-hour, 24-hour, and annual)

  - CO (1-hour and 8-hour)
- Cumulative impacts are predicted to be below the NAAQS for each Alternative and at each modeled receptor for the following pollutants and averaging times.
  - PM_{10} (24-hour)
  - NO_2 (1-hour and annual)
  - SO_2 (3-hour, 24-hour, and annual)
  - CO (1-hour and 8-hour)
- Cumulative 8-hour ozone total concentrations greater than the NAAQS are predicted for each Alternative at approximately one-third of the monitors in the 4 km domain. The majority of the monitors lie in the El Paso, Texas area.
- Cumulative 1-hour SO_2 total concentrations greater than the NAAQS are predicted for each Alternative at two areas near Amarillo, Texas and at another area in the lower panhandle of Texas.
- Cumulative 24-hour and annual $PM_{2.5}$ total concentrations greater than the NAAQS are predicted for each Alternative at a few monitors not in the CFO.

6.4. AQRV Results

AQRV assessments lead to the following conclusions.

- **Visibility** — Visibility impacts are not evaluated against an enforceable standard. Instead, they are assessed in terms of the number of days in which visibility changes may equal or exceed a 0.5 dv (single source) or 1.0 dv (multiple sources) change from estimated natural visibility conditions.
- The absolute total number of days of significant visibility changes (greater than 0.5 delta-dv and greater than 1.0 delta-dv) calculated in the Excel Workbooks for base year 2008, base case 2017 and future RFD alternatives is 366 days (every day of the year). Therefore, to show relative impacts among the Alternatives with respect to the base case emissions scenarios, the calculated delta-dv (change in visibility) was divided by 15 for each day before counting and reporting the number of days above the thresholds. Baseline conditions were subtracted from Alternatives impacts to determine Project contributions and there are only several instances where “significant” Project-related impacts are predicted to occur at Class I or Sensitive Class II areas. The highest number of days associated with Project emissions occurs at Muleshoe National Wildlife Refuge which is just down wind (predominant direction) of projected Project O&G development
- **Deposition** — Project S and N deposition are below the Level of Concern at all modeled Class I and Sensitive Class II areas.
- **Lake Chemistry** — At the five modeled sensitive lakes, ANC changes due to Project emissions are predicted to be less than one percent while ANC changes due to cumulative emissions are predicted to be more than 200 percent. The greatest ANC changes are predicted to occur at Upper Truchas Lake.

6.5. Climate Change

Potential climate change impacts were assessed in terms of GHG emissions, levels of GHG emission control, comparisons of natural gas combustion to combustion of other fossil fuels, and comparisons to New Mexico and federal GHG emission inventories. While GHGs will be

emitted during oil and gas production, total maximum Project GHG emissions would be approximately 17 percent of total New Mexico 2007 GHG emissions and 0.2 percent of U.S. 2010 GHG emissions.

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Assessing Human Health $PM_{2.5}$ and Ozone Impacts from U.S. Oil and Natural Gas Sector Emissions in 2025

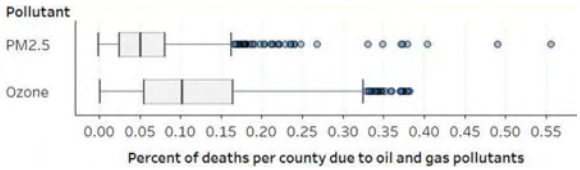
Neal Fann*, **Kirk R. Baker**, **Elizabeth A. W. Chan**, **Alison Eyth**, **Alexander Macpherson**, **Elizabeth Miller**, **Jennifer Snyder**

Office of Air Quality Planning and Standards U.S. Environmental Protection Agency, 109 T.W. Alexander Drive, Research Triangle Park, North Carolina 27711, United States

Abstract

Incomplete information regarding emissions from oil and natural gas production has historically made it challenging to characterize the air quality or air pollution-related health impacts for this sector in the United States. Using an emissions inventory for the oil and natural gas sector that reflects information regarding the level and distribution of $PM_{2.5}$ and ozone precursor emissions, we simulate annual mean $PM_{2.5}$ and summer season average daily 8 h maximum ozone concentrations with the Comprehensive Air-Quality Model with extensions (CAMx). We quantify the incidence and economic value of $PM_{2.5}$ and ozone health related effects using the environmental Benefits Mapping and Analysis Program (BenMAP). We find that ambient concentrations of $PM_{2.5}$ and ozone, and associated health impacts, are highest in a handful of states including Colorado, Pennsylvania, Texas and West Virginia. On a per-ton basis, the benefits of reducing $PM_{2.5}$ precursor emissions from this sector vary by pollutant species, and range from between $6,300 and $320,000, while the value of reducing ozone precursors ranges from $500 to $8,200 in the year 2025 (2015$).

Graphical Abstract



INTRODUCTION

Air pollution health burden assessments often characterize the ambient levels of pollution and enumerate the adverse health outcomes associated with emissions from total anthropogenic sources or certain classes of industrial and mobile sectors.[1–4] Studies

*Corresponding Author: Fann.neal@epa.gov.

Supporting Information
The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.8b02050.
Additional details regarding: our approach for estimating population exposure and the health impact functions we applied(PDF)

The authors declare no competing financial interest.

quantifying the economic value of these impacts have also reported estimates of the monetized benefits of reducing emissions that are precursors to fine particles (particulate matter sized 2.5 μm and smaller, that is, $PM_{2.5}$) from a given sector; these are often referred to as a "benefit per-ton."[5–7] This literature provides insight regarding the size, distribution, and economic value of the air pollution impacts associated with emissions from a broad array of industrial activities including industrial boilers, cement kilns and refineries among other sectors.[8]

While there is a growing literature examining air quality and human health impacts attributable to the oil and natural gas sector in the United States, we were unable to identify any studies employing a national emissions inventory coupled with a photochemical grid model to simulate the nonlinear formation of pollutants including ozone and $PM_{2.5}$ attributable to this sector.[9] Some studies have assessed the risks attributable to this sector within discrete geographic areas and employed less computationally complex air quality modeling approaches to monetize health impacts from oil and natural gas production nationwide.[10,11]

This work has been encumbered in part by limited data regarding the level and geographic distribution of emissions associated with oil and natural gas production across the U.S. As we describe below, emissions from this sector tend to originate from a large number of small but geographically diffuse sources located throughout several basins, making it challenging to estimate both the level and location of emissions accurately. These uncertainties, in turn, have made it difficult to simulate $PM_{2.5}$ and ozone air quality with confidence. In this paper, we apply an emissions inventory for the oil and natural gas sector that reflects a spatially detailed nationwide estimate of the level and distribution of emissions from this sector. This version of the U.S. Environmental Protection Agency's (EPA) National Emissions Inventory (NEI) for the year 2011 includes data that States provided as part of the process for developing the NEI; these data substantially improve our ability to characterize oil and natural gas emissions over space and time as compared to previous versions of the emissions inventory for these sources.

This improved inventory permits us to simulate of air quality impacts from this sector's emissions, with the goal of answering three key questions:

- What are the annual average $PM_{2.5}$ concentrations and summer season average daily 8-h maximum ozone concentrations associated with this sector?
- What is the human health burden—in terms of $PM_{2.5}$ and ozone-related premature deaths and illnesses—attributable to the oil and natural gas sector and how is this burden distributed over the U.S?
- What are the health benefits—in terms of avoided deaths and illnesses—of reducing $PM_{2.5}$ and ozone precursor emissions on a per ton basis and how does the benefit per ton (BPT) vary across pollutant precursor?

Below we describe our approach to modeling emissions and air quality before detailing our methodology for estimating the incidence and economic value of air pollution-attributable

premature deaths and illnesses and calculating BPT values. We then present the results of this analysis before discussing the implications of this research.

MATERIALS AND METHODS

Estimating Emissions.

This analysis of the oil and natural gas sector draws upon estimates of pollutant emissions reported in the U.S. EPA NEI, which incorporates national activity, emission factors and basin-specific information submitted by State and Local agencies for this sector. Activity data are specific to each county for the year 2011. For the purposes of this analysis, we define the oil and natural gas sector as comprising an array of processes and equipment, including: drill rigs, workover rigs, well completions, well hydraulic fracturing, heaters, storage tanks, mud degassing, dehydration, pneumatics, well venting, fugitives, truck loading, wellhead engines, pipeline compressor engines, flaring, artificial lifts, and gas actuated pumps. These sources reflect the production and transportation of crude oil and natural gas and distribution of natural gas but exclude refineries and the distribution of refined products. The U.S. EPA defined the sector to reflect those activities covered by the New Source Performance Standards. Previous U.S. EPA analyses have assessed the air quality and health impacts associated with pollutants emitted during the refining process and so we exclude this sector here.[12]

Most oil and natural gas emissions data are estimated by county and spatially allocated to the model grid using surrogates that are based on year 2011 well locations and attributes related to the production of oil and natural gas and their byproducts. This procedure is described in the technical support document “Preparation of Emission Inventories for the Version 6.2, 2011 Emissions Modeling Platform”; the “platform” in this context describes the baseline inventory, meteorological model and air quality model used to simulate air quality.[13,14]

Beginning with this inventory, the U.S. EPA developed a method for estimating nonpoint emissions for the oil and natural gas production sector. In April of 2012, the Agency began collaborating with an extensive national workgroup comprised of state and regional emissions developers. This effort yielded a substantially improved Nonpoint Oil and Gas Emission Estimation Tool, which produces county-level emissions for calendar year 2011 for criteria pollutants and their precursors including volatile organic compounds and ammonia.[15] Both states and the U.S. EPA applied this tool to estimate emissions, either using the default tool inputs, or by providing their own basin- and/or county-specific inputs.

In brief, as part of a national outreach effort, U.S. EPA received data from two Regional Planning Organizations—the Lake Michigan Air Directors Consortium (representing Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin) and the Mid-Atlantic Regional Air Management Association (representing 10 state and local agencies including the Allegheny County Air Quality Program, the Pennsylvania Department of Environmental Protection, the North Carolina Department of Natural Resources, the Virginia Department of Environmental Quality and the West Virginia Department of Environmental Protection). In total, the states submitting data included CA, CT, DC, DE, IA, ME, MI, NC, NE, NY, PA,

OK, TX, UT, VA, WA. Each organization provided information including the location, emission rate and controls. VOC and $PM_{2.5}$ emissions are speciated based on basin-specific speciation factors provided by the Western Regional Air Partnership.[13,14] National VOC and $PM_{2.5}$ speciation profiles were used for this assessment where location speciation profiles were unavailable. Annual total emissions for this sector are evenly distributed across each hour of each day using temporal allocation factors that account for units operating continuously throughout the year.

To account for the expected change in the size and distribution of this sector over time, we projected the 2011 sector emissions to the year 2025 using economic growth factors based on product and consumption indicators derived from the Annual Energy Outlook (AEO) 2014 (Table 1).[13,14] We selected a future year of 2025 because it was most relevant for U.S. EPA air quality planning purposes. The AEO projected growth rates for each U.S. Census Division, which were then assigned to each basin. Projected levels of emissions from the sector can be useful to policy makers as they seek to understand the future air quality and health impacts attributable to the sector. However, as we note below, this procedure also introduces uncertainty to the analysis. Aside from the growth factors, emission reductions are reflected for some oil and natural gas categories including reductions of criteria air pollutants due to stationary reciprocating internal combustion engine regulations that reduce emissions of hazardous air pollutants and New Source Performance Standards. Additional details regarding our approach are available in the Version 6.2, 2011 Emissions Modeling Platform TSD.

Air Quality Modeling Simulations.

The Comprehensive Air-Quality Model with extensions (CAMx) version 6.20[16,17] was applied for the entire year of 2011 with a 10 day “spin-up” period at the end of 2010 to minimize the influence of initial conditions. The model domain covered the contiguous United States with 12 km by 12 km sized grid cells. The surface to model top (~15 km) was resolved with 25 layers with most in the boundary layer to best capture the diurnal variation in the surface mixing layer. CAMx has treatment of gas-phase chemistry based on Carbon Bond 6, inorganic particulate matter thermodynamics based on ISORROPIA, aqueous phase chemistry, and semivolatile partitioning of VOC to secondary organic aerosol.[16,18,19] In this assessment, CAMx was not modified to capture wintertime ozone formation that is associated with production activities in certain oil and natural gas basins, meaning the ozone air quality and health impacts provided here are entirely associated with traditional warm season (May 1 to September 30) ozone formation.[20,21] Moreover, the risk coefficients we used to quantify ozone effects were drawn from studies assessing the health risks associated with warm season ozone exposure; modeling ozone in this way ensures that the exposure estimates are consistent with the health impact assessment described below.

CAMx was applied with source apportionment to differentiate the contribution of the oil and natural gas sector from all other emissions. The contribution of oil and natural gas emissions was tracked to model estimated primary ($PM_{2.5}$ elemental carbon, $PM_{2.5}$ organic carbon, and crustal compounds) and secondary (e.g., ozone contributions from NO_x, ozone contributions from VOC, $PM_{2.5}$ sulfate ion, $PM_{2.5}$ nitrate ion, and $PM_{2.5}$ ammonium ion)

pollutants.[16,22–24] The contribution of VOC emissions to secondary organic aerosol (SOA) were not tracked because the model estimates a very small amount of anthropogenic SOA (from all sources) and while this sector emits a large amount of VOC, the bulk of the species contributing to the emissions mass (e.g., methane, ethane, propane) are not known to yield large amounts of SOA. Year 2011 meteorological inputs were generated using the Weather Research and Forecasting model.[25] WRF was applied with a domain consistent with the photochemical grid model and has been shown to compare well with surface, upper air, and mixing layer height measurements.[26] Further details about the WRF configuration are provided in the Supporting Information. Initial chemical conditions and boundary inflow were extracted from a global model simulation using a database tool developed jointly by the University of Florida and the U.S. EPA, and subsequently translated to match the domain and chemical species employed for this assessment.[27] Both biogenic and anthropogenic emissions were incorporated into the air quality modeling. Biogenic emissions were estimated using the Biogenic Emission Inventory System version 3.6.1.[13,28,29] Anthropogenic emissions were based on the 2011 National Emission Inventory version 2 as described in the associated technical support document.[14,30] Wildland fire emissions were also included in the 2011 NEI version 2 and are based on known fires in 2011.[31]

Estimating Counts of Air Pollution-Related Deaths and Illnesses Attributable to the Oil and Natural Gas Sector.

We calculate a health impact function to quantify counts of premature deaths and illnesses attributable to the model-predicted $PM_{2.5}$ and ozone from the oil and natural gas sector. For each $PM_{2.5}$ and ozone human health end point we calculate a separate health impact function. Each function specifies four input parameters: (1) an effect coefficient (or, beta parameter) from a published air pollution epidemiology study; (2) a count of the number of people affected in each 12 km by 12 km air quality grid from the U.S. census; (3) the air quality concentration to which the population is exposed from the photochemical model; (4) a baseline rate of death or disease among this population from Centers for Disease Control and Prevention and the Agency for Healthcare Research and Quality.

To automate the procedure for calculating health impacts we used the open-source environmental Benefits Mapping and Analysis Program—Community Edition software program.[32] The $PM_{2.5}$-related health outcomes we quantify include premature death, respiratory hospital admissions, cardiovascular hospital admissions, emergency department visits for asthma, upper respiratory symptoms, lower respiratory symptoms, days of work lost, days of school lost, cases of aggravated asthma, and cases of acute respiratory symptoms. We quantify ozone-related end points including premature death, respiratory hospital admissions, respiratory emergency department visits, exacerbated asthma, and days of school missed.

Using the health impact function for $PM_{2.5}$-related deaths as an example, we specify the input parameters below. In eq 1, we estimated the number of $PM_{2.5}$-related total deaths (y_{ij}) for adults in each county j ($j = 1,\ldots,J$ where J is the total number of counties) as

$$y_j = \sum_a y_{ja} \quad (1)$$
$$y_{ija} = m0_{ja} \times \left(e^{\beta \cdot C_k} - 1\right) \times P_{ika},$$

where β is a beta coefficient for all-cause mortality in adults associated with annual average exposure to $PM_{2.5}$, $m0_{ja}$ is the baseline all-cause death rate for adults in county j stratified in 10-year age bins, C_k is the annual mean $PM_{2.5}$ concentration in air quality grid cell k, and P_{ka} is the number of adult residents in air quality grid cell k stratified into 5-year age bins. The program assigns the all-cause death rates for adults in county j to grid cell k using an area-weighting algorithm described in the BenMAP-CE user manual.[33] This health impact function returns a count of the number of $PM_{2.5}$-related deaths occurring in each county due to annual mean $PM_{2.5}$ concentrations. The function above can be generalized to the remaining $PM_{2.5}$ morbidity and ozone mortality and morbidity end points; when quantifying ozone-attributable premature deaths, we substituted a daily average mortality rate for the annual mortality rate noted above.

Our approach for specifying the health impact functions above is consistent with the methodology the U.S. EPA employed in the Regulatory Impact Analyses (RIAs) supporting the $PM_{2.5}$ and Ozone National Ambient Air Quality Standards (NAAQS).[34,35] These two RIAs considered evidence the Agency evaluated in the Integrated Science Assessments (ISAs) for Particulate Matter and Ozone. The ISAs systematically reviews the toxicological, epidemiological, and clinical evidence for each pollutant, carefully assessing the evidence before determining whether each pollutant is causally associated with a given health outcome. After identifying the human health end points as being either causally, or likely to be causally, associated with each pollutant, the RIA next evaluates the epidemiological studies quantifying these end points. As noted in the PM NAAQS RIA, the Agency "··· follow[s] a weight of evidence approach, based on the biological plausibility of effects, availability of concentration-response functions from well conducted peer-reviewed studies, cohesiveness of results across studies, and a focus on end points reflecting public health impacts···rather than physiological responses."[34] That RIA further specifies a host of criteria the Agency considers when selecting effect coefficients, including the study type, population attributes, pollutant measures, and other attributes.

To quantify PM-related premature deaths, we derived a long-term mortality β coefficient from a Hazard Ratio reported in the most recent extended analysis of the American Cancer Society (ACS) cohort (ages 30 and older) (β = 0.0058; SE =0.000962) (Supporting Information Table S-1).[36] To estimate ozone-related premature deaths, we derive a short-term mortality β coefficient from an estimate of the percentage increase in the risk of ozone-related death from a multicity analysis (ages 0–99) (β = 0.00051; SE = 0.00012) (Supporting Information Table S-2).[37]

As noted below, the dollar value associated with the incidence of air pollution-related deaths is considerable, and so we searched the literature to identify alternative concentration-response parameters from more recently published epidemiological studies. We were unable

to identify a long-term epidemiological study of $PM_{2.5}$ all-cause mortality for a representative U.S. cohort of both adult males and females that was more current than Krewski et al. (2009).[36] However, as a sensitivity analysis, we also quantify risks using the hazard ratio from the extended analysis of the Harvard Six Cities study Lepuele et al. (2012); these results may be found in the Supporting Information (Table S-6).[38] We found that the Zanobetti & Schwartz (2008) ozone multicity study exhibited a number of strengths, including its evaluation of multiple exposure lags and its pooling of the single-city risk coefficients to derive a single national risk coefficient.[39] As a sensitivity analysis, we also report ozone-attributable premature deaths using the results of other broadly cited ozone mortality studies, including a multicity study (Table S-6).[40]

We performed a Monte Carlo-based simulation to construct an error distribution of estimated $PM_{2.5}$ and ozone-related effects. To inform the Monte Carlo simulation, we constructed a distribution around each effect (or, beta) coefficient using the standard error reported in each study; these resulting distributions are normally distributed (Table S-1). We calculated total numbers of premature deaths and illnesses in the contiguous U.S. for each year by summing the county-specific estimates, and report the sums of the 2.5th and 97.5th percentiles of the Monte Carlo distributions as 95% confidence intervals. As we note below, this distribution became an input to the Monte Carlo simulation we performed when quantifying a distribution of economic values. We use information regarding the distribution around each of the other input parameters (i.e., air quality, baseline incidence and population) and thus treated these parameters deterministically.

We defined m_{0ja} as the county-level age-stratified all-cause death rates from the Centers for Disease Control Wide-ranging Online Data for Epidemiologic Research database.[41] To account for the improved longevity of the population over time, we projected these death rates to future years using a life table reported by the U.S. Census Bureau (Supporting Information Tables S-3 and S-4). We defined the baseline incidence rates for the morbidity end points using rates of hospital admissions, emergency department visits and other outcomes for the year 2014 from the Healthcare Cost and Utilization Program (Supporting Information Table S-5). We defined P_{ka} using age-stratified population data from the U.S. Census Bureau. We projected population to year 2025 using an economic and demographic forecast from the Woods & Poole company.[42]

We calculated the fraction of all deaths due to $PM_{2.5}$ and ozone in each county and year using the following function:

$$\mathrm{AF}_j = \frac{y_j}{\sum_a m0_{ja} \times P_{ja}} \quad (2)$$

where y_j is the estimated number of air pollution deaths, $m0_{ja}$ is the age-stratified baseline death rate, and, P_{ja} is the age-stratified population, respectively, in county j.

We calculated the population-weighted annual mean concentration for all counties combined (C) as

$$C = \frac{\sum_j C_j \times P_j}{P} \quad (3)$$

where C_j is the county-average $PM_{2.5}$ concentrations in county j, P_j is the population in county j, and P is the total population over all counties combined.

Estimating Economic Values of Air Pollution Effects.

We estimate the economic value of the $PM_{2.5}$ and ozone-attributable premature deaths and illnesses on a per-ton of emissions basis using an approach that is consistent with the approaches used in the U.S. EPA's Ozone and PM NAAQS RIAs.[34] Those analyses applied a suite of willingness to pay (WTP) and cost of illness (COI) unit values built into the BenMAP-CE software that relate counts of adverse health outcomes to an estimated dollar value. A WTP measure describes the value that society places on avoiding some adverse health outcome. By contrast, COI reflects the direct costs associated with an adverse event; this can include medical expenses associated with a hospital visit and the value of lost productivity.

Because the value associated with air pollution-related premature deaths tends to account for as much as 99% of the total dollar value of a given air pollution health benefits assessment, it is worth detailing our method for valuing this end point. We apply a value of statistical life (VSL) to estimate the value of air pollution-related deaths. The VSL reflects the amount of money that a large number of people are willing to pay to reduce their risk of death by a small amount. As an example, 10 000 people might be willing to pay $500 to reduce their risk of death by 1-in-10 000; this yields a VSL of $5M. In this analysis, we apply a base VSL of $6.3 M in year 2000$ that is constant for all adult populations. This value is derived from a meta-analysis of 26 value of life studies published over a two-decade period.[43] While the number of publications reporting VSLs in the U.S. is quite large, we selected a value from this study because it has been applied extensively in the literature, making it easier to compare values in this manuscript to those published elsewhere.[2,6,44] The uncertainty around this mean value is represented by a Weibull distribution. We adjust this value in two ways. First, we inflate the VSL to year 2015$. Next, we account for the role of income growth in increasing future willingness to pay to reduce the risk of death by projecting the VSL to the year 2025. Adjusting the base VSL for these two factors yields a VSL of $10.4 M for the year 2025 in 2015$.

Benefit Per-Ton Calculation. We calculated the dollar per-ton for the contiguous United States BPT_i as

$$\mathrm{BPT}_p = \frac{\sum_{bp}}{\mathrm{emissions}_p} \quad (4)$$

where BPT_p is the dollar benefit per ton for a given $PM_{2.5}$ or ozone precursor, b is the total dollar benefits summed across all health end points for precursor p and $emissions_p$ is the national sum of emissions for precursor p.

RESULTS

The CAMx model predicted annual mean $PM_{2.5}$ concentrations attributable to the sector ranging from a maximum of 5.27 $\mu g/m^3$ (located in western Colorado) to less than 0.001 μg/m3, with a median value of 0.04 $\mu g/m^3$ (Figure 1 and Table 2). States including Illinois, Ohio, and Pennsylvania in the east; Alabama, Louisiana, Oklahoma, and Texas in the south; North Dakota in the midwest; and Colorado and Wyoming in the west, experience the greatest $PM_{2.5}$ concentrations from the oil and natural sector (Figure 1). The predicted summer season average 8-h maximum ozone value ranges from a high of 8.12 ppb (located in Western Texas) to a low of 0.003 ppb, with a median value of 0.57 ppb (Figure 1 and Table 2). West Virginia in the east and Alabama, Louisiana, Nebraska, Oklahoma, and Texas in the south experience the greatest summer season ozone levels from this sector (Figure 1). The national population-weighted annual mean $PM_{2.5}$ value is about 0.05 $\mu g/m^3$ while the population-weighted summer season average 8 h maximum ozone value is1.34 ppb (Table 2).

For the year 2025, we estimate 970 (95% confidence interval 670–1300) ozone-related premature deaths and 1000 (95% confidence interval 520–1400) $PM_{2.5}$-related deaths nationwide (Table 2). We also estimate about 1000 respiratory and cardiovascular hospital admissions, 3600 emergency department visits, tens of thousands of upper and lower respiratory symptoms, approximately 100 000 lost work days, and over a million cases of exacerbated asthma and acute respiratory symptoms (Table S-6). Because the air quality impacts from this sector are spatially heterogeneous, we also report state-by-state estimates of PM and ozone-related premature deaths. The PM and ozone-related mortality burden is the in Texas, Pennsylvania, Ohio, Oklahoma, Illinois, California, Michigan, Colorado, Indiana, and Louisiana (Table 3). To account for the role of population size in influencing these values, we also report the number of PM and ozone-related deaths per 100 000 people, finding that Oklahoma, Louisiana, Colorado, Pennsylvania and Indiana experience the largest number of deaths on a population-normalized basis (Figure 2). Estimated dollar values for these cases of premature death range from $13 to $28 billion and cases of illnesses range from $1 to $200 million depending on the end point; full results may be found in Supporting Information Table S-7.

We also estimate the national BPT values for PM and ozone precursors by dividing the total estimated benefits associated with each ozone precursor or PM species by the tons emitted of that precursor. Modeled precursors of PM elemental and primarily emitted organic carbon (EC/OC), SO_2, and oxides of nitrogen (NO_x), and NO_x and VOC precursors were modeled for ozone. For the purposes of estimating the incidence attributable to each PM species, we assume that each specie is as detrimental to health as total PM mass. The two largest BPT estimate ranges were for the PM precursors to EC/OC and sulfate, at $140,000–$320,000 and $27,000–$62,000, respectively (2015$ for all estimates); this range reflects the sum of the value of the morbidity end points and the long-term PM mortality coefficients from

Krewski et al. 2009 at the low end and Lepeule et al. 2012 at the high end. The BPT ranges for the PM precursor to nitrate and the ozone precursor NO_X were of similar magnitudes, at $2,800–$6,300 and $4,600–$8,200, respectively. The range of economic value per ton of ozone-related VOC from the oil and natural gas sector was $300–$500; this range reflects the sum of the value of morbidity impacts and the Smith et al. 2009 ozone mortality risk coefficient at the low end and the Zanobetti & Schwartz 2008 risk coefficient at the high end.

DISCUSSION

The oil and natural gas sector emits pollutants that contribute to forming ozone and fine particles in the atmosphere, degrading air quality and ultimately adversely affecting public health in the form of premature deaths, hospital admissions, emergency department visits, cases of aggravated asthma, and lost days of school and work, among other outcomes.

While we were unable to identify other national-scale estimates of the air pollution impacts for this sector in the literature, we can place the estimates above in the context of analyses assessing the overall burden of $PM_{2.5}$ and ozone on health. The Global Burden of Disease study estimates about 100 000 $PM_{2.5}$ and ozone-related deaths in the United States for the year 2016.[4] A separate analysis of the U.S. reported about 130 000 $PM_{2.5}$ and ozone-related deaths for the year 2005.[45] The total number of oil- and natural gas-attributable $PM_{2.5}$ and ozone premature deaths represents a small fraction of the national burden these two analyses estimates. Because both the national burden analyses retrospectively estimate $PM_{2.5}$ and ozone-attributable deaths for 2010 and 2005, it is difficult to compare directly against these 2025-projected estimates. Moreover, neither national burden analyses reported state-by-state estimates of air pollution burden, which would arguably be a more relevant geographic unit of comparison for this sector, given the spatially heterogeneous air quality impacts from oil and natural gas facilities.

The results above indicate that the air quality and health impact associated with this sector correspond closely with the location of oil and natural gas facilities. Six states—Texas, Oklahoma, Colorado, North Dakota, West Virginia, and Pennsylvania—contributed almost 70% of the onshore natural gas production and over 74% of the onshore crude oil production in the lower 48 states in 2016.[46,47] These states also experience the highest levels of ground-level ozone and fine particle levels attributable to this sector. While the modeled ambient levels of fine particles are more spatially heterogeneous, ozone concentrations appear to be more spatially homogeneous across states including Nebraska, Oklahoma and Texas, suggesting a role for interstate transport. The estimated premature ozone and $PM_{2.5}$-related mortality corresponds well with the location of the air quality impacts. Indeed, in the western U.S., the sector tends to contribute $PM_{2.5}$ among locations in which fine particle levels are projected to be quite low—generally below about 6 $\mu g/m^3$. While we expect these areas to experience projected $PM_{2.5}$ levels well below the annual NAAQS of 12 $\mu g/m^3$, we quantify cases of excess $PM_{2.5}$-related premature deaths and illnesses in these locations because evidence suggests that there is no population-level concentration threshold for fine particles.

To our knowledge, this manuscript is the first reported benefit per-ton estimates for precursor emissions to $PM_{2.5}$ or ozone for the oil and natural gas sector derived from full-form photochemical grid modeling.[10] The $PM_{2.5}$-related health benefits of direct PM, sulfur dioxide (SO_2), and NO_X have previously been characterized for emission reductions from 17 industrial, area, and mobile emission sectors in the U.S. for the year 2016.[48] That manuscript published in 2012 did not quantify impacts from the oil and natural gas sector because of uncertainties associated with the 2005 emissions inventory for that sector. Direct PM BPT estimates for these 17 sectors range from $45,000–$490,000, which is comparable with our EC/OC BPT estimate of $140,000–$320,000. Similarly, our sulfate and nitrate BPT values ($27,000–$62,000 and $2,800– $6,300, respectively) fell within the range of SO_2 and NO_X BPT estimates for the 17 sectors ($12,000–$97,000 [with one exception: $400,000 for the iron and steel sector] and $1800– $16,000, respectively). As the BPT estimates presented here are comparable with previously published BPT values, we believe them to be reasonable.

Among all species and precursors considered in this study, the lowest BPT estimates were for VOC contributions to ozone formation (fewer than 100 deaths in 2025) than for NO_X (over 900 deaths each in 2025). In addition, there were considerably fewer restricted activity days, the health outcome with the second highest value, associated with VOC (under 170 000) than with NO_X (over 2 million). Another reason for less impact from VOC compared to NO_X is that most source areas tend to be located in places that are VOC-rich (also referred to as NO_X-sensitive) meaning that additional VOC has less impact than NO_X. This heterogeneity in ozone formation regime is reflected in the contribution results which is a strength of using a photochemical model to support ozone impact assessments.

Loomis and colleagues apply a suite of benefit per-ton values reported in the literature to quantify the air pollution impacts attributable to hydraulic fracturing in 14 states.[5,7,8] The authors calculate an average of these values, weighted according to whether the wells are located in urban or rural locations. The authors estimate the economic value of emissions from hydraulic fracturing of between $14 and $48B (2015$). Litovitz and colleagues quantify the economic value of air pollution impacts shale gas production in Pennsylvania, by employing the Air Pollution Experiments and Policy Analysis (APEEP) model.[7,11] This study estimates total damages of between $7.2 M and $32 M for Pennsylvania. While the present analysis did not report the total national economic value for the sector, multiplying the BPT values reported above against the sector emissions yields an estimate of between $13B to $29B, which is comparable to the value reported by Loomis et al.

Analyses of this scope and complexity are subject to important uncertainties and limitations. First, quantifying the air quality and health impacts for this sector is especially challenging because of uncertainties in the emission inventory for oil and natural gas production and transmission. These uncertainties can vary from basin to basin meaning that impacts in some areas may be better characterized than others depending on the level of effort provided by state and local agencies toward generating emissions and activity data for their particular area. The projected level of oil and natural gas production in 2025 is also sensitive to the price of oil in that year, which we cannot account for completely in this analysis. Further, uncertainties in the assumed composition of VOC emissions can be important, especially if

the currently assumed composition is biased low for highly reactive VOC meaning less potential to facilitate ozone formation. We modeled an emissions inventory that was the best available at the time of the analysis and itself represented substantial improvements over previous inventories. Another uncertainty associated with quantifying an ozone-related BPT value in particular is that ozone-related impacts are sensitive to baseline levels of VOC and NO_x. These levels differ by location and are not assumed to change over time as these baseline pollutant levels change. Similarly, $PM_{2.5}$ impacts are sensitive to baseline levels of ammonia and in the case of nitrate ion also to favorable weather conditions (e.g., cool temperatures and higher relative humidity). $PM_{2.5}$ impacts from this sector are likely under-represented to some degree since impacts on SOA were not quantified. VOC emissions from this sector (e.g., aromatics) are known to form SOA and the NO_x emissions in proximity to biogenic VOC may also contribution to SOA formation.[49,50]

To the extent that future populations are healthier and more resilient to air pollution than we have forecast in this analysis, and thus more resilient to air pollution, then the BPT values may be overstated. The Monte Carlo analysis described above accounts only for the statistical uncertainty associated with the pollutant effect coefficients and economic unit values; it does not account for a host of other uncertainties associated with the emissions inventory, air quality modeling, baseline health or demographic information. Finally, the estimates of economic value are sensitive to the VSL that we applied; management policies affecting this sector.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABBREVIATIONS

BenMAP	environmental Benefits Mapping and Analysis Program
CAMx	Comprehensive Air Quality Model with extensions
EPA	Environmental Protection Agency
ICD	International Classification of Disease
MATS	Mercury and Air Toxics Standards
NAAQS	National Ambient Air Quality Standards
O_3	Ground-level ozone
$PM_{2.5}$	Particulate matter, 2.5 μm or less in diameter
RRF	Relative Response Factor

WHO World Health Organization

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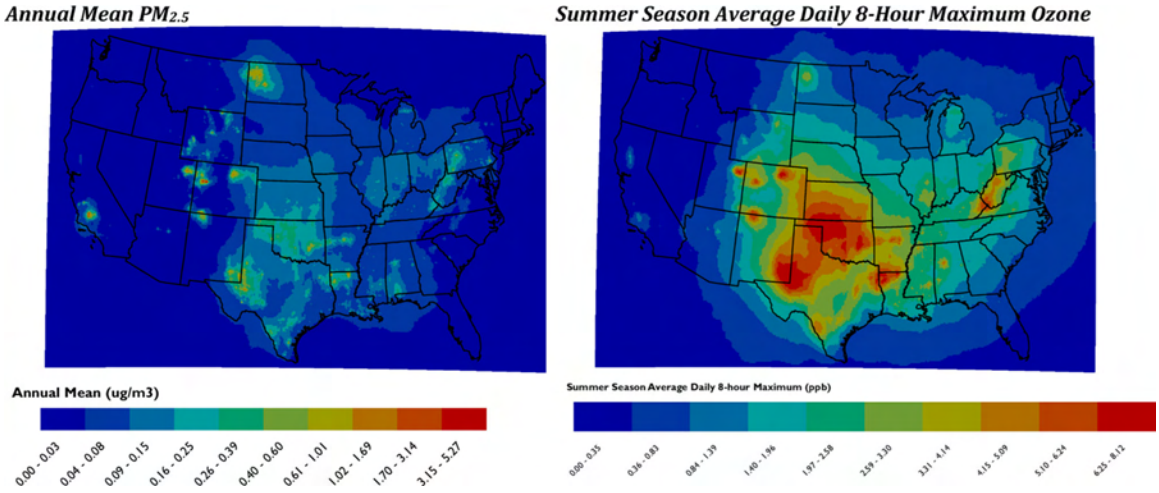

Figure 1.

Annual Mean $PM_{2.5}$ and Summer Season Daily 8 h Maximum Ozone Attributable to the Oil and Natural Gas Sector in 2025. State and county boundaries drawn according to Census Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line files in the ArcGIS software.

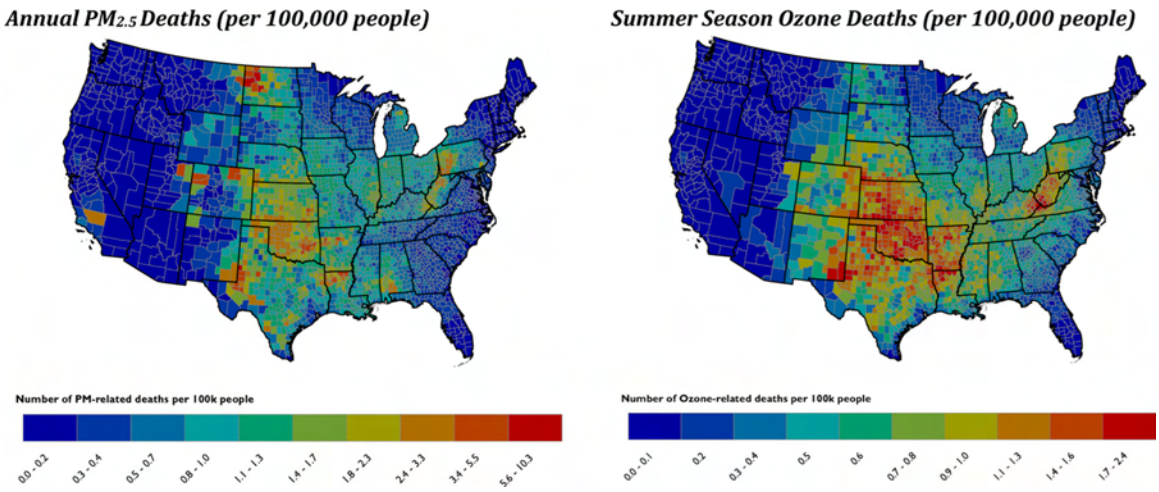

Figure 2.

Premature Deaths (per 100 000 people) attributable to annual mean $PM_{2.5}$ and Summer season daily 8 h maximum ozone from the oil and natural gas sector in 2025. State and county boundaries drawn according to Census Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line files in the ArcGIS software.

Table 1.

Emission Levels for the Oil and Natural Gas and All Other Sectors in 2025 (tons/year)

	pollutant					
	NO_x	**SO_2**	**NH_3**	**CO**	**VOC**	**elemental and organic carbon**
oil and gas	1 190 846	108 619	5927	978 765	3 671 787	10 451
biogenics	1 020 456			6 749 945	44 712 816	
fugitive dusts						51 370
residential wood combustion	34 805	7619	18211	2 328 506	408 910	208 118
industrial point sources	1 021 969	783 630	66 612	1 884 412	786 950	69 062
electricity generating units	2 021 937	2 089 206	46 238	907 624	42 253	23 149
area sources	75 462	95 102	94 938	278	3 426 185	212 672
wildland fires[a]	333 404	165 790	329 398	20 566 821	4 689 022	1 075 975

[a]Assumed constant from the 2011 baseline.

Table 2.

Distribution of CAMx Model Predicted Annual Mean $PM_{2.5}$ and Summer Season 8-h Maximum Ozone Concentrations and Population-Weighted Levels for the Oil and Natural Gas Sector in 2025[a]

	percentile									
pollutant	**min**	**10%**	**25%**	**50%**	**75%**	**90%**	**max**	**mean**	**SD**	**national population-weighted value**
$PM_{2.5}$ (ug/m^3)	<0.01	0.0034	0.009	0.02	0.06	0.1	5.27	0.04	0.07	0.0557
SO_4	<0.01	0.001	0.004	0.008	0.016	0.03	0.55	0.013	0.015	0.02
NO_3	<0.01	<0.01	<0.01	<0.01	0.01	0.04	0.25	0.01	0.2	0.02
directly emitted $PM_{2.5}$	<0.01	<0.01	<0.01	<0.01	0.01	0.01	2	<0.01	0.02	<0.01
ozone (ppb)	<0.01	0.068	0.19	0.57	1.59	2.91	8.12	1.12	1.36	1.34
NO_x	<0.01	0.05	0.2	0.6	1.7	3	7.6	1.16	1.36	1.24
VOC	<0.01	<0.01	0.02	0.04	0.08	0.16	3.2	0.07	0.09	0.1

[a]Calculated from 12 × 12 km model predicted concentrations.

Table 3.

National-Total and Selected State $PM_{2.5}$-and Ozone-Related Premature Deaths Attributable to Emissions from the Oil and Natural Gas Sector in 2025

	estimated numbers of premature deaths (95% confidence interval)[b]			
state[a]	**attributable to $PM_{2.5}$**	**attributable to ozone**	**total deaths attributable to $PM_{2.5}$ and ozone**	**total deaths per 100 000 people**
Texas	130 (88—170)	130 (70—190)	260 (160—370)	1.4
Pennsylvania	85 (57—110)	55 (30—80)	140 (87—190)	1.6
Ohio	65 (44—86)	48 (26—70)	110 (69—160)	1.5
Oklahoma	48 (32—63)	55 (29—81)	100 (62—140)	4.1
Illinois	55 (37—73)	38 (20—55)	92 (57—130)	1.1
California	59 (40—77)	14 (7.4—20)	72 (47—97)	0.27
Michigan	39 (26—52)	32 (17—47)	71 (44—98)	1.1
Colorado	37 (25—49)	34 (18—49)	70 (43—98)	1.9
Indiana	38 (26—50)	29 (15—42)	66 (41—92)	1.6
Louisiana	34 (23—45)	28 (15—40)	61 (38—85)	2
national total	1000 (670—1300)	970 (520—1400)	1900 (1100—2700)	0.9

[a]These states comprise the largest health impacts for the sector. States listed by descending order of total $PM_{2.5}$ and ozone-attributable deaths.

[b]All values rounded to two significant figures.

EXHIBIT 7

Southern New Mexico Ozone Study
Technical Support Document

Prepared by:

S. Kemball-Cook, J. Johnson, A. Wentland, Z. Liu, and R. Morris
Ramboll Environ US Corporation
773 San Marin Drive, Suite 2115
Novato, California, 94945

Z. Adelman
University of North Carolina
Institute for the Environment
Chapel Hill, NC 27599-6116

October 19, 2016

UNC INSTITUTE FOR THE ENVIRONMENT

RAMBOLL ENVIRON

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ACRONYMS AND ABBREVIATIONS

3SAQS	Three-State Air Quality Study
AIRS	Aerometric Information Retrieval System
AMET	Atmospheric Model Evaluation Tool
APCA	Anthropogenic Precursor Culpability Assessment
AQ	Air Quality
AQS	Air Quality System
BC	Boundary Condition
CAMx	Comprehensive Air-quality Model with extensions
CARB	California Air Resources Board
CASTNet	Clean Air Status and Trends Network
CB6r2	Carbon Bond mechanism version 6, revision 2
CMAQ	Community Multiscale Air Quality modeling system
CONUS	Continental United States
CPC	Center for Prediction of Climate
CSAPR	Cross State Air Pollution Rule
CSN	Chemical Speciation Network
EC	Elemental Carbon Fine Particulate Matter
ECMWF	European Center for Medium Range Weather Forecasting
EGU	Electrical Generating Units
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FB	Fractional Bias
FE	Fractional Error
FRM	Federal Reference Method
GCM	Global Chemistry Model
GEOS-Chem	Goddard Earth Observing System (GEOS) global chemistry model
GIRAS	Geographic Information Retrieval and Analysis System
IMPROVE	Interagency Monitoring of Protected Visual Environments
IWDW	Intermountain West Data Warehouse
LCP	Lambert Conformal Projection
LSM	Land Surface Model
MADIS	Meteorological Assimilation Data Ingest System
MATS	Modeled Attainment Test Software
MCIP	Meteorology-Chemistry Interface Processor
MEGAN	Model of Emissions of Gases and Aerosols in Nature
MNGE	Mean Normalized Gross Error
MNB	Mean Normalized Bias
MNE	Mean Normalized Error
MOVES	Motor Vehicle Emissions Simulator
MOZART	Model for OZone And Related chemical Tracers
MPE	Model Performance Evaluation
MSKF	Multi-Scale Kain-Fritsch Cumulus Parameterization

NAAQS	National Ambient Air Quality Standard
NAM	North American Mesoscale Forecast System
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCDC	National Climatic Data Center
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NH_4	Ammonium Fine Particulate Matter
NMB	Normalized Mean Bias
NME	Normalized Mean Error
NO_2	Nitrogen Dioxide
NO_3	Nitrate Fine Particulate Matter
NOAA	National Oceanic and Atmospheric Administration
OA	Organic Aerosol Fine Particulate Matter
OC	Organic Carbon Fine Particulate Matter
OSAT	Ozone Source Apportionment Technology
PAVE	Package for Analysis and Visualization
PBL	Planetary Boundary Layer
PGM	Photochemical Grid Model
PM	Particulate Matter
PPM	Piecewise Parabolic Method
QA	Quality Assurance
QC	Quality Control
RMP	Resource Management Plan
RRF	Relative Reduction Factor
SCC	Source Classification Code
SIP	State Implementation Plan
SMOKE	Sparse Matrix Kernel Emissions modeling system
SNMOS	Southern New Mexico Ozone Study
SOA	Secondary Organic Aerosol
SO_2	Sulfur Dioxide
SO_4	Sulfate Fine Particulate Matter
TCEQ	Texas Commission on Environmental Quality
UNC-IE	University of North Carolina Institute for the Environment
USFS	United States Forest Service
VERDI	Visualization Environment for Rich Data Interpretation
VMT	Vehicle Miles Traveled
WBD	Wind Blown Dust model
WAQS	Western Air Quality Study
WESTAR	Western States Air Resources Council
WESTUS	Western United States
WRAP	Western Regional Air Partnership
WGA	Western Governors' Association
WRF	Weather Research Forecasting model

1.0 EXECUTIVE SUMMARY

The Southern New Mexico Ozone Study (SNMOS) studied the factors contributing to high ozone in Doña Ana County. Photochemical modeling was carried out for May 1 – September 30, 2011 using emissions scenarios for a 2011 base year and a 2025 future year. The SNMOS modeling platform was derived from the Western Air Quality Study (WAQS) regional modeling platform that was available through the Intermountain West Data Warehouse (IWDW) with adjustments and updates to the meteorology and modeling domains to optimize the platform for application to Southern New Mexico and surrounding regions.

The Weather Research Forecasting (WRF) model was used to provide meteorology data for use in the photochemical modeling. Emissions processing was primarily conducted using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system using emissions data from the EPA 2011-based modeling platform (2011v6) version 2 and the WAQS (2011b) inventories. Photochemical grid modeling was done with the Comprehensive Air-quality Model with extensions (CAMx) version 6.20. A model performance evaluation was carried out for the meteorological and photochemical models; performance was determined to be acceptable through comparison with EPA Modeling Guidance (EPA, 2014) and to be consistent with performance in similar regional modeling studies. The major findings of the SNMOS are listed below:

- 2025 future year design value projections indicate that all Doña Ana County ozone monitors are expected to attain the 70 ppb National Ambient Air Quality Standard for ozone (NAAQS) in 2025.
- The modeled decreases in Doña Ana County ozone design values between 2011 and 2025 are mainly driven by projected reductions in emissions from cars, trucks and other on-road mobile sources
- All Doña Ana County ozone monitors would have attained the 70 ppb ozone NAAQS in 2011 but for the ozone contribution due to anthropogenic emissions from Mexico
- Regional emissions sources contributing the most ozone to 2011 Doña Ana County ozone were: (1) on-road mobile emissions from Texas, Mexico and New Mexico; (2) power plant emissions from Mexico; and (3) natural emissions (mainly from plants as well as lightning and fires) from Mexico.
- Regional emissions sources contributing the most ozone to Doña Ana County ozone monitors in 2025 were: (1) on-road mobile emissions from Texas and Mexico; (2) power plant and non-power plant point source emissions from Mexico; and (3) natural emissions from Mexico.
- Ozone transport plays an important role in determining ozone levels in Doña Ana County. Ozone from emissions sources outside the region was the largest contributor of ozone; this is a typical result for a regional modeling study. For all Doña Ana County monitors except Solano, the individual ozone contribution from Texas and Mexico was larger than that of New Mexico.

- New Mexico anthropogenic emission sources that contributed the most ozone to Southern New Mexico monitors were: (1) on-road mobile; (2) offroad mobile; (3) oil and gas; and (4) power plants.

We provide recommendations for model improvement and further study at the end of this report.

2.0 INTRODUCTION

2.1 Project Background

Doña Ana County in Southern New Mexico experiences some of the highest observed ground-level ozone concentrations in the state. The Sunland Park Ozone Nonattainment Area (NAA) which lies within Doña Ana County was designated as marginal nonattainment for the 1-hour ozone standard on June 12, 1995 (60 FR 30789). With the revocation of the 1-hour ozone standard in 2004, the Sunland Park NAA was designated a maintenance area for 8-hour ozone (NMED, 2007). Lowering of the 8-hour ozone standard by EPA in 2008 to 0.75 ppm (75 ppb) and again in 2015 to 0.70 ppm (70 ppb) will likely lead to the Sunland Park NAA receiving a nonattainment designation for 8-hour ozone. In addition, the New Mexico Air Quality Control Act (NMAQCA) requires the New Mexico Environment Department (NMED) to develop a plan for reducing ozone levels in areas that are within 95% of the ozone standard (NMSA 1978, § 74-2-5.3). Table 2-1 shows the 1st through 4th highest daily maximum 8-hour average ozone (MDA8) concentrations measured from 2011 to 2014 at the EPA Air Quality System (AQS) monitors in Doña Ana County. This table shows that all but a handful of the measurements at these monitors exceeded either the 2015 NAAQS for ozone (orange) or the NMAQCA 95% threshold (yellow).

Table 2-1. Daily maximum 8-hour average ozone measurements from 2011-2014 at AQS sites in Doña Ana County, NM.

Station	1st Highest		2nd Highest		3rd Highest		4th Highest	
	Date	ppmV	Date	ppmV	Date	ppmV	Date	ppmV
La Union	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPCY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chaparral	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Desert V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sta Teresa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Solano	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
La Union	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPCY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chaparral	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Desert V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sta Teresa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Solano	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
La Union	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPCY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chaparral	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Desert V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sta Teresa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Solano	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
La Union	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPCY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chaparral	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Desert V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Station	1st Highest		2nd Highest		3rd Highest		4th Highest	
	Date	ppmV	Date	ppmV	Date	ppmV	Date	ppmV
Sta Teresa	□□1 □□□□1 □	□□□□1	□□1 □□□□1 □	□□□□	□□□1 □□□1 □	□□□□□	□□1 □□□□1 □	□□□□□
Solano	□□1 □□□□1 □	□□□□□	□□□□□1 □	□□□□□	□□□□□□1 □	□□□□□	□□□□□1 □	□□□□□

The statutory requirements of both the NAAQS and the NMAQCA include the development of a plan to control the emissions of sources pursuant to attainment and maintenance of the NAAQS. In the case of a NAAQS NAA State Implementation Plan (SIP), air quality modeling is required to identify the causes of high pollution and to propose emissions control strategies that will bring the area into attainment.

The Southern New Mexico Ozone Study (SNMOS) studied the factors contributing to high ozone in Doña Ana County and investigated future emissions scenarios that will produce NAAQS attainment. The SNMOS is a collaborative project between NMED, the Western Regional Air Partnership (WRAP), the Western Air Resources Council (WESTAR), Ramboll Environ US Corporation (RE), and the University of North Carolina Institute for the Environment (UNC-IE). This Study built off of the Western Air Quality Study (WAQS), a cooperative project that is intended to facilitate air resource analyses for federal and state agencies in the intermountain western U.S. toward improved information for the public and stakeholders as a part of air quality planning. The Intermountain West Data Warehouse (IWDW) at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University was the source for the regional air quality modeling data and software resources from the WAQS. The SNMOS leveraged the WAQS 2011 version B (WAQS_2011b) modeling platform to conduct base and future year air quality modeling for Doña Ana County.

2.2 Organization of the Technical Support Document

This Technical Support Document (TSD) summarizes the objectives, methods and results of the SNMOS. In the remainder of Section 2, we provide a summary of the SNMOS modeling approach. In Section 3, we present an overview of the results of the study. The organization of Section 3 of the TSD follows that of the SNMOS, which was broken into 13 separate Tasks:

- **Task 1**: 2011 WRF 36/12/4-km modeling with 4-km grid focused on Dona Ana/El Paso/Juárez and Data Analysis/Modeling Work Plan
- **Task 2**: 2011 update of Permian Basin oil and gas emission inventory
- **Task 3**: 2011 update of emissions inventories for Juárez and nearby Mexico and 2025 Mexico emissions
- **Task 4**: SMOKE modeling of current 2011 National Emission Inventory for 4-km domain
- **Task 5**: Gridded 2011 biogenic, fires, wind-blown dust, lightning emissions for 4-km domain
- **Task 6**: Develop 2011 4-km CAMx database and perform base case modeling
- **Task 7**: 2011 CAMx model performance evaluation and sensitivity modeling for Doña Ana County
- **Task 8**: SMOKE current 2025 US emission inventory and Mexico emissions update

- **Task 9**: Future year (2025) 12/4-km CAMx simulation
- **Task 10**: FY (2025) ozone design value projections (MATS)
- **Task 11**: 2025 emissions sensitivity tests/controls
- **Task 12:** Ozone source apportionment modeling of 2011 and 2025
- **Task 13**: Technical Support Document (TSD)

For each Task, we outline the methods, data used and results. Then we summarize the major findings of the Task. Finally, we list the Task deliverables and their completion dates. A PowerPoint presentation and/or written documentation describing each Task in more detail are available on the WRAP SNMOS website.

In Section 4, we provide a summary of results and conclusions of the SNMOS and make recommendations for future work.

2.3 Overview of the SNMOS Modeling Approach

The SNMOS modeling platform was derived from the WAQS_2011b regional modeling platform. A regional modeling platform is the suite of data and software required for conducting a regional-scale air quality modeling study. The procedures for the SNMOS 2011 modeling followed those performed for the 2011 WAQS with adjustments to the meteorology and modeling domains to optimize the modeling platform for application to southern New Mexico. The SNMOS 2011 modeling platform included nested 36, 12 and 4-km resolution meteorology modeling domains. The regional air quality modeling was conducted at 12 and 4-km resolution.

The SNMOS modeling domains were selected to facilitate high resolution modeling for sources around Doña Ana County and to enable regional source apportionment modeling among all of the surrounding Western states. The SNMOS 12 and 4-km domains, shown in Figure 2-1, were designed to encompass the meteorology and emissions features that are most important to ground-level ozone formation in southern New Mexico. Also shown in Figure 2-1 are the locations of EPA's Air Quality System (AQS) ozone monitors (green) and point sources of nitrogen oxide (NOx) emissions (blue).

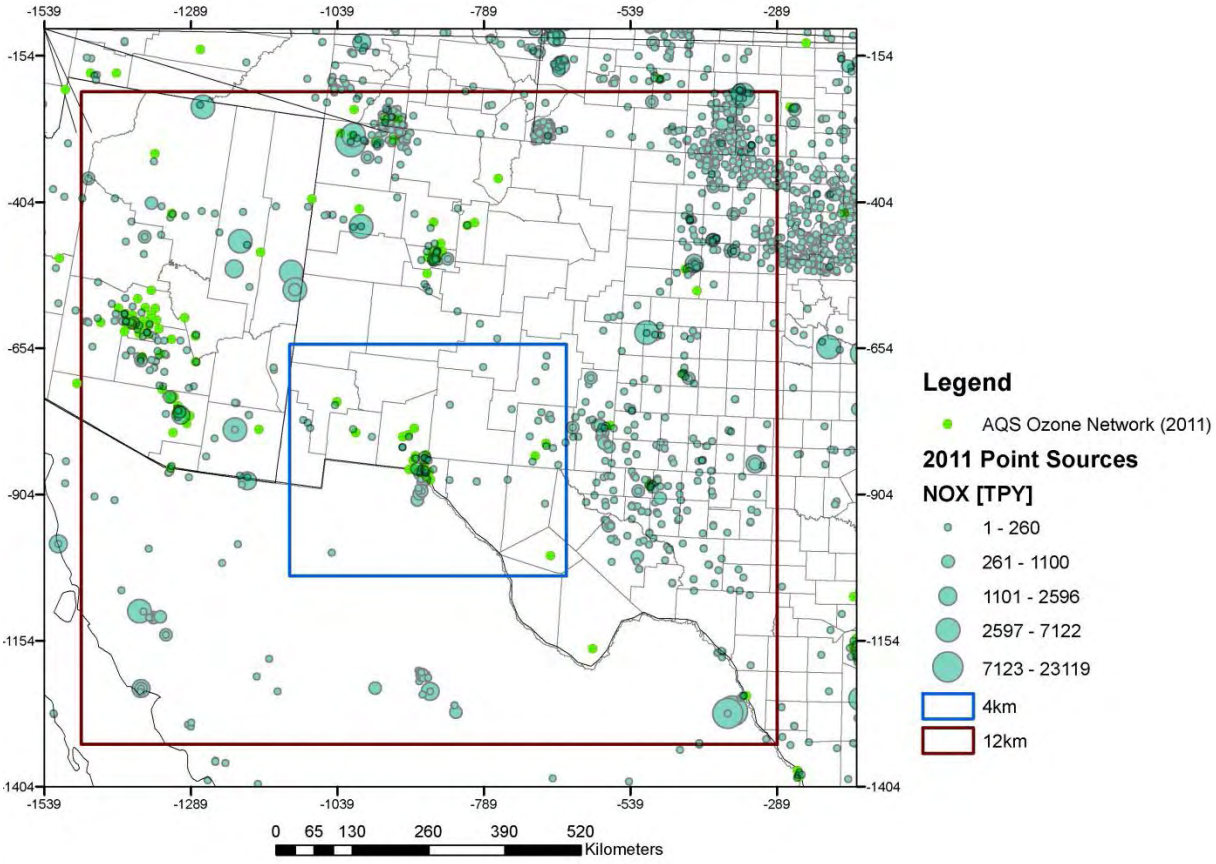


Figure 2-1. SNMOS 2011 CAMx 12/4-km modeling domains.

The CAMx and emissions domains for modeling of 2011 were chosen for the following reasons:

- New continental-scale coarse grid modeling was not needed for the SNMOS because we were able to extract BCs for the 12-km domain from the WAQS 2011 CAMx modeling results. The WAQS modeling used the 36-km RPO grid and a 12-km modeling domain that encompassed much of the western U.S. As we used the same emissions data and CAMx configuration for the SNMOS as were used for the WAQS, there was consistency between these simulations enabling the use of the WAQS modeling as lateral boundary conditions (BCs) for the SNMOS domains.
- The SNMOS 12-km CAMx domain encompasses all of New Mexico, extends west to include the metropolitan area of Phoenix, east to include East Texas, and south to include the Carbon II power plant in Coahuila, Mexico. This facility is a large source of NOx emissions and lies in a region that was sometimes upwind of Doña Ana County on high ozone days during 2011. The SNMOS 12-km domain was designed to balance computational efficiency and the need to model transport from sources likely to influence Doña Ana County at 12-km resolution.
- The SNMOS 4-km Doña Ana County domain focuses on Southern New Mexico and the major emissions source regions in the immediate vicinity, including Ciudad Juárez, Mexico and El Paso, TX.

We simulated the 2011 ozone season and evaluated the meteorology and air quality model performance against surface and aloft monitors that operated in the modeling domains during the study period. Following the base year model performance evaluation, we used projected emissions data to simulate air quality in the year 2025. Along with future year attainment tests, the future year modeling included emissions sensitivity testing and ozone source apportionment modeling of emissions source region and source category contributions to ozone concentrations and ozone design values at ozone monitoring sites in Doña Ana County (and elsewhere in the region). A summary of the SNMOS modeling approach is given below.

- The 2011 ozone season for New Mexico (May 1 – September 30) was selected for the modeling period.
- Year 2011 and 2025 inventories were used to estimate base and future year emissions.
- The Weather Research Forecasting (WRF) version 3.7.1 was used to simulate meteorology data for this study.
- Emissions processing was primarily conducted using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system version 3.7 using emissions data from the EPA 2011-based modeling platform (2011v6) version 2 and the WAQS (2011b).
- Photochemical grid modeling (PGM) was done with the Comprehensive Air-quality Model with extensions (CAMx) version 6.20. The Carbon Bond 6 revision 2 (CB6r2) photochemical mechanism was used for the SNMOS modeling.
- For the SNMOS 2011 modeling, hourly BCs for the portion of the lateral boundaries of the SNMOS 12-km PGM domain that lies within the larger WAQS 12-km domain were extracted from the WAQS 36-km continental U.S. CAMx modeling.

- Model performance evaluation was conducted for meteorology, ozone, and ozone precursor and product species.
- Diagnostic sensitivity testing was conducted to determine sensitivity of the PGM model estimates to the WRF model configuration and to improve the 2011 base year model performance in simulating ground-level ozone in Southern New Mexico and the surrounding region.
- Future year modeling was used to estimate air quality in 2025 and to conduct attainment tests for Doña Ana County.
- Future year emissions sensitivity modeling was used to evaluate the impacts of emissions reductions on future attainment of the ozone NAAQS.
- Future year CAMx source apportionment modeling was used to quantify the source region and source category contributions to ozone concentrations and ozone design values at ozone monitoring in Dona Ana County.

2.4 Project Participants

The SNMOS was facilitated and managed by the Western States Air Resources Council (WESTAR). RE and UNC-IE conducted the meteorology, emissions, and air quality modeling and analysis. Key contacts and their roles in the SNMOS are listed in Table 2-2.

Table 2-2. SNMOS key contacts.

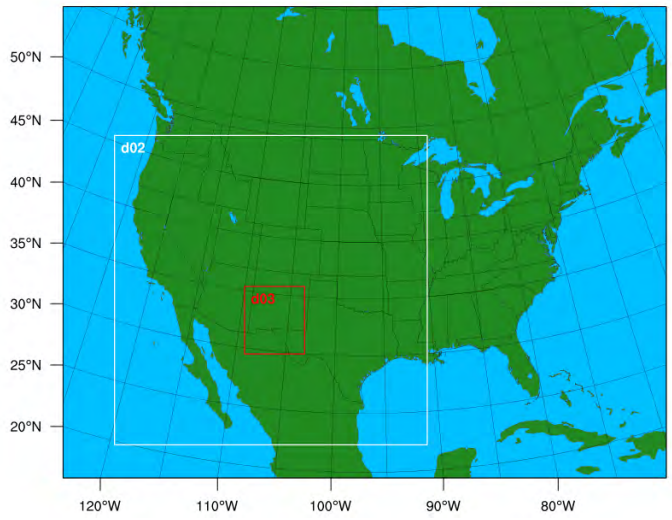
Name	Role	Organization/Contact
Tom Moore	Project Manager	WESTAR c/o CSU/CIRA 1375 Campus Delivery Fort Collins, CO 80523 (970) 491-8837 tmoore@westar.org
Zac Adelman	UNC-IE Lead	University of North Carolina Institute for the Environment 100 Europa Dr., Suite 490, CB 1105 Chapel Hill, NC 27517 (919) 962-8510 zac@unc.edu
Ralph Morris	Ramboll Environ Lead	Ramboll Environ 773 San Marin Drive, Suite 2115 Novato, CA 94998 (415) 899-0708 rmorris@environcorp.com

3.0 SNMOS TASK SUMMARIES

3.1 Task 1: Weather Research Forecast (WRF) Meteorological Modeling

3.1.1 Task Summary

The objective of this task was to simulate and evaluate WRF meteorology for modeling 2011 summer season ozone in Doña Ana County, New Mexico. We coordinated with WRF modelers in the western U.S. to find a candidate model configuration for best simulating ozone in the southwestern U.S. We used the most recent version of WRF (v3.7.1) available at the time of the study to test four different WRF configurations in simulating summer season (April 15-August 30, 2012) meteorology on 33 vertical layer (Table 3-1) 36-km U.S. EPA Continental U.S. (CONUS), 12-km Western U.S. and 4-km SNMOS modeling domains (Figure 3-1). After conducting an operational model performance evaluation on all of the WRF simulations and selecting the best performing configuration, we converted the WRF output to CAMx inputs using the WRFCAMx software. Additional details of the WRF sensitivities, evaluation, and final configuration are provided below.



Parameter	Value
Projection	Lambert-Conformal
1st True Lat	33 degrees N
2nd True Latitude	45 degrees N
Central Lon	97 degrees W
Central Lat	40 degrees N
dX (km)	d01 = 36, d02 = 12, d03 = 4
dY (km)	d01 = 36, d02 = 12, d03 = 4
X-orig (km)	d01 = -2736, d02 = -2196, d03 = -912
Y-orig (km)	d01 = -2088, d02 = -1728, d03 = -828
# cols	d01 = 165, d02 = 256, d03 = 148
# rows	d01 = 129, d02 = 253, d03 = 166

Figure 3-1. WRF modeling domains.

Table 3-1. Vertical layer interfaces for the WRF and CAMx simulations

WRF and CAMx Levels				
WRF Level	Sigma	Pressure (mb)	Height (m)	Thickness (m)
33	0.0000	50.00	19260	2055
32	0.0270	75.65	17205	1850
31	0.0600	107.00	15355	1725
30	0.1000	145.00	13630	1701
29	0.1500	192.50	11930	1389
28	0.2000	240.00	10541	1181
27	0.2500	287.50	9360	1032
26	0.3000	335.00	8328	920

WRF and CAMx Levels				
WRF Level	Sigma	Pressure (mb)	Height (m)	Thickness (m)
25	0.3500	382.50	7408	832
24	0.4000	430.00	6576	760
23	0.4500	477.50	5816	701
22	0.5000	525.00	5115	652
21	0.5500	572.50	4463	609
20	0.6000	620.00	3854	461
19	0.6400	658.00	3393	440
18	0.6800	696.00	2954	421
17	0.7200	734.00	2533	403
16	0.7600	772.00	2130	388
15	0.8000	810.00	1742	373
14	0.8400	848.00	1369	271
13	0.8700	876.50	1098	177
12	0.8900	895.50	921	174
11	0.9100	914.50	747	171
10	0.9300	933.50	577	84
9	0.9400	943.00	492	84
8	0.9500	952.50	409	83
7	0.9600	962.00	326	83
6	0.9700	971.50	243	81
5	0.9800	981.00	162	65
4	0.9880	988.60	97	41
3	0.9930	993.35	56	32
2	0.9970	997.15	24	24
1	1.0000	1000	0	

The WRF configuration sensitivity tests that we ran were based on previous WRF modeling studies of the region. Our objective for these tests was to maximize the skill of the model in simulating conditions conducive to surface ozone build up in southern New Mexico. One key issue that we wanted to address was the known performance problem that WRF has in simulating precipitation in the Western U.S. Accurately capturing the timing and location of both convective precipitation events and events driven by the North American monsoon is important in developing a reliable model of ozone formation in the region. The prior WRF modeling studies that we considered in our design for the SNMOS included,

- The Bureau of Land Management's Montana-Dakotas (BLM-MT/DK) Study examined the sensitivity of WRF model performance in the Montana/Dakotas region for different WRF model configurations used in recent studies (McAlpine et al., 2014). In the initial Montana-Dakotas modeling, WRF overstated precipitation over the 4-km modeling domain during the summer months. The initial WRF run used surface temperature and humidity observation nudging in the 4-km domain. The temperature and humidity observation nudging introduced instabilities in the WRF simulation that resulted in increased convective activity and rainfall. BLM-MT/DK Study sensitivity testing

demonstrated that removing temperature and humidity observation nudging and using the Grell-Freitas cumulus parameterization on the 4-km domain for the final WRF simulation improved rainfall, wind speed, and wind direction model performance. The reduction in explicit convective activity allowed WRF to more accurately simulate the observed winds.

- In the San Juan Mercury Modeling (Ramboll Environ and Systech Water Resources, 2015), WRF overpredicted precipitation in a 12-km domain focused on the Four Corners region, but was much more accurate at the 4-km resolution. Observational nudging was applied to the 12-km and 4-km domains for winds, but not for temperature or humidity. Several cumulus parameterizations were evaluated to determine their effect on modeled precipitation.
- The 2011 WRF evaluation for the 3-State Air Quality Study (3SAQS) compared WRF 3.6.1 estimates to monthly PRISM observations (UNC and ENVIRON, 2014). While summertime WRF precipitation was generally too high relative to PRISM and the model did not resolve the local convective features well, there were questions about the PRISM analysis fields and their reliability at capturing isolated convective cells.

In consideration of these studies, we conducted a series of WRF simulations and selected the best performer (lowest bias and error for surface temperature, winds, humidity, and precipitation at sites in the 4-km SNMOS domain) for the operational simulations. The sensitivities were based off of the WAQS (UNC and ENVIRON, 2014) and San Juan Mercury Modeling (Ramboll Environ and Systech Water Resources, 2015) studies. Table 3-2 summarizes the base configuration that we used for the SNMOS WRF sensitivities and compares this configuration to the WAQS WRF modeling. The WRF version 3.7.1 sensitivity simulations that we ran included the following:

- Configuration 1 (NAM KF Mods): Base WRF configuration using settings from the 3SAQS/WAQS 2011 configuration. The key parameters here for the WRF sensitivity tests are the North American Model (NAM) Initial and Boundary Conditions (ICBCs) and the modified Kain-Fritsch (KF) cumulus scheme (Alapaty et al., 2012). The modified convective parameterization scheme provides subgrid-scale cloud fraction and condensate feedback to the shortwave and longwave radiation schemes. The impact of including the subgrid-scale cloud fraction is a reduction in the shortwave radiation, leading to less buoyant energy, thereby alleviating the overly energetic convection and reducing precipitation.
- Configuration 2 (NAM MSKF): Same as Configuration 1 with the multi-scale (grid-aware) Kain-Fritsch (MSKF) cumulus scheme (Alapaty et al., 2014). Additional changes were made to the modified KF scheme to improve the accuracy of precipitation at grey zone resolutions (<10 km). These include scale dependent features of convection such as scale dependent consumption of the convective available potential energy and entrainment of environmental air.
- Configuration 3 (ERA MSKF): Same as Configuration 2 but using the European Centre for Medium-range Weather Forecasts (ECMWF) ERA-Interim analysis as the ICBC fields.

Experience from the San Juan Hg WRF tests indicate that the ERA-Interim ICBC fields may improve simulated precipitation associated with the North American Monsoon.

- Configuration 4 (ERA MSKF No AN): Same as Configuration 3 but based on prior experiences from the San Juan Hg study, analysis nudging was not applied in domain 2.

Table 3-2. Base configuration for the SNMOS WRF sensitivity modeling.

WRF Treatment	3SAQS/WAQS	SNMOS
Mic·ophysics	Thompson	Thompson
Longwave R□diation	RRTM□	RRTM□
S□or□wave Radi□tion	RRTM□	RRTM□
Minutes between radiation physics ca□ls	20	20
Lan□ Su□face M□d□□(LS M)	NOA H	NOA H
P□aneta□y Boun□ary Laye□ (P BL) scheme	YSU	YSU
Cumul□s □aramet□rization	Kain □Fritsch □ the 36- □□ □□d 12-km □omains only □	Multiscale (□rd- □□□r□) Kain-Fritsch.
Analysis nu□ging	Applie□ to win□s (uv), temp □ratu□e □t) an□ moistu□e (q) in the 36-km an□ 12-km □omains	Applie□ to win□s (uv), tempe□atu□e ( ) □□d moistu□e □q) in □□□ 36-km an□ 12-km □omains
Analysis nu□ging coefficients	uv: 5e-4 □d01), 3e-4 □d02) □: 5e- □ □d01), 3e-4 □d02) q: 1e-5 □d01 an□ d02)	uv: 5e-4 □d01), 3e-4 □d02) t: 5e- □ □d01□, 3e-4 □d02) q: 1e-5 □d01 an□ d02)
Obse□vation Nu□ging	Applie□ to su□face win□ an□ □emp □atu□e in □□□ 4-km □om □in	None
Obse□vation nu□ging coefficien□	uv: 1.2e-3 □d03) □: 6e- □ □d03)	N/A
Initializa□ion Dat□set	12-km No□t□ Ame□ican M□d□□ (NA M)	12-km (NA M)
Top (mb)	50	50
Ve□tical Levels (La□e□s)	37 (36)	33 (32)

We ran the WRF model in 5-day blocks initialized at 12Z every 5 days with a 90-second integration time step. Model results were output every 60 minutes and output files split at 24-hour intervals. Twelve hours of spin-up were included in each 5-day block before the data were used in the subsequent evaluation. The model was run at 36-km, 12-km and 4-km grid resolution from May 15 through September 1, 2011 using one-way grid nesting with no feedback (i.e., the meteorological conditions are allowed to propagate from the coarser grid to the finer grid but not vice versa).

The evaluation for these simulations focused on simulating the North American Monsoon with an emphasis on the timing, location, and magnitude of precipitation in southern New Mexico. The model evaluation approach was based on a combination of qualitative and quantitative analyses. The quantitative analyses were divided into monthly summaries of 2-m temperature, 2-m mixing ratio, and 10-m wind speed using the boreal seasons to help generalize the model

bias and error relative to a standard benchmark. We supplemented the WRF evaluation with select diurnal and time series analyses at specific sites in the 4-km SNMOS modeling domain. Additional analysis included a qualitative evaluation of the daily total WRF precipitation fields against PRISM fields. The PRISM data were mapped to the WRF domains and grid resolution. The observed database for winds, temperature, and water mixing ratio used in this analysis were the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) Meteorological Assimilation Data Ingest System (MADIS).

Table 3-3 shows the 4-km domain average performance statistics for temperature, moisture, and winds. The performance trends illustrate that initializing WRF with the North American Model (NAM) produces a WRF model that has a warm and dry bias with underestimated wind speeds. The ERA initialization produces a WRF model with a warm and wet bias that also underestimates the wind speeds. Including the MSKF convective cloud module slightly improved the moisture bias in the model and we found that the performance of this option was sensitive to the initialization dataset that we selected.

Table 3-3. 4-km domain average model performance statistics

	Temperature (deg K)		**Mixing Ratio (g/kg)**		**Wind Speed (m/s)**		**Wind Direction (degrees)**	
	Bias	Error	Bias	Error	Bias	RMSE	Bias	Error
Benchmark: Simple	≤ ±0.5	≤ 2.0	≤ ±0.5	≤ 1.0	≤ ±0.5	≤ 2.0	≤ ±5	≤ 40
Benchmark: Complex	≤ ±1.0	≤ 3.0	≤ ±1.0	≤ 2.0	≤ ±1.0	≤ 3.0	≤ ±10	≤ 80
NAM KFmods	**0.21**	**1.77**	-0.53	1.05	**-0.30**	2.12	5.46	43.6
NAM MSKF	0.22	**1.77**	-0.46	**1.03**	-0.34	2.12	5.02	43.9
ERA MSKF	0.24	1.87	**0.14**	1.12	-0.43	**2.08**	**3.95**	**42.8**
ERA MSKF no AN	0.40	2.05	-0.39	1.18	-0.34	2.28	4.73	49.1

Figure 3-2 shows August 2011 wind roses, indicating the mean monthly wind direction and speeds, for all sites in the 4-km SNMOS modeling domain. The figures in this plot compare the wind data for observations relative to the four WRF configurations that we tested. Figure 3-3 is a plot of PRISM precipitation observations compared to the WRF modeling results. We generated and evaluated many of these types of plots for all simulation months, for days during high ozone episodes, and where applicable, for each meteorological observation site in southern Doña Ana County. Additional evaluation plots included time series plots, bias-error (soccer) plots, temperature spatial plots with wind vector overlays, and scatter plots.

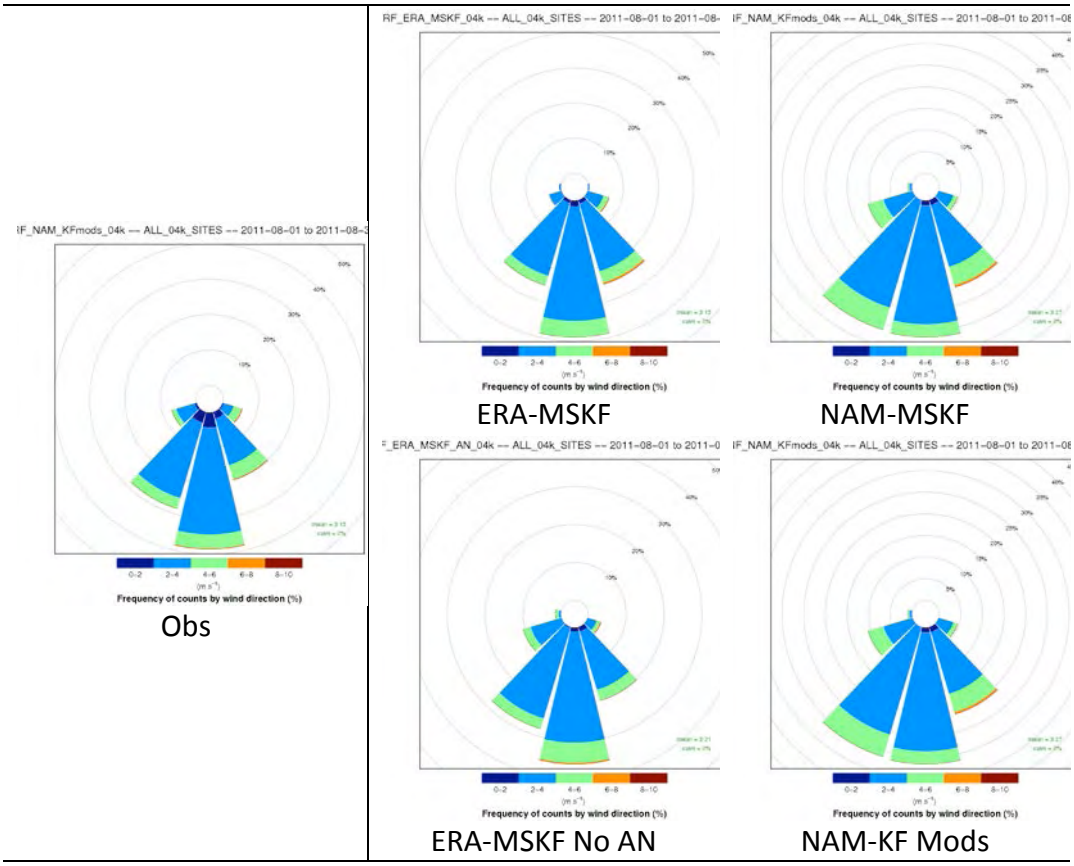


Figure 3-2. August 2011 wind roses, all sites in the 4-km domain

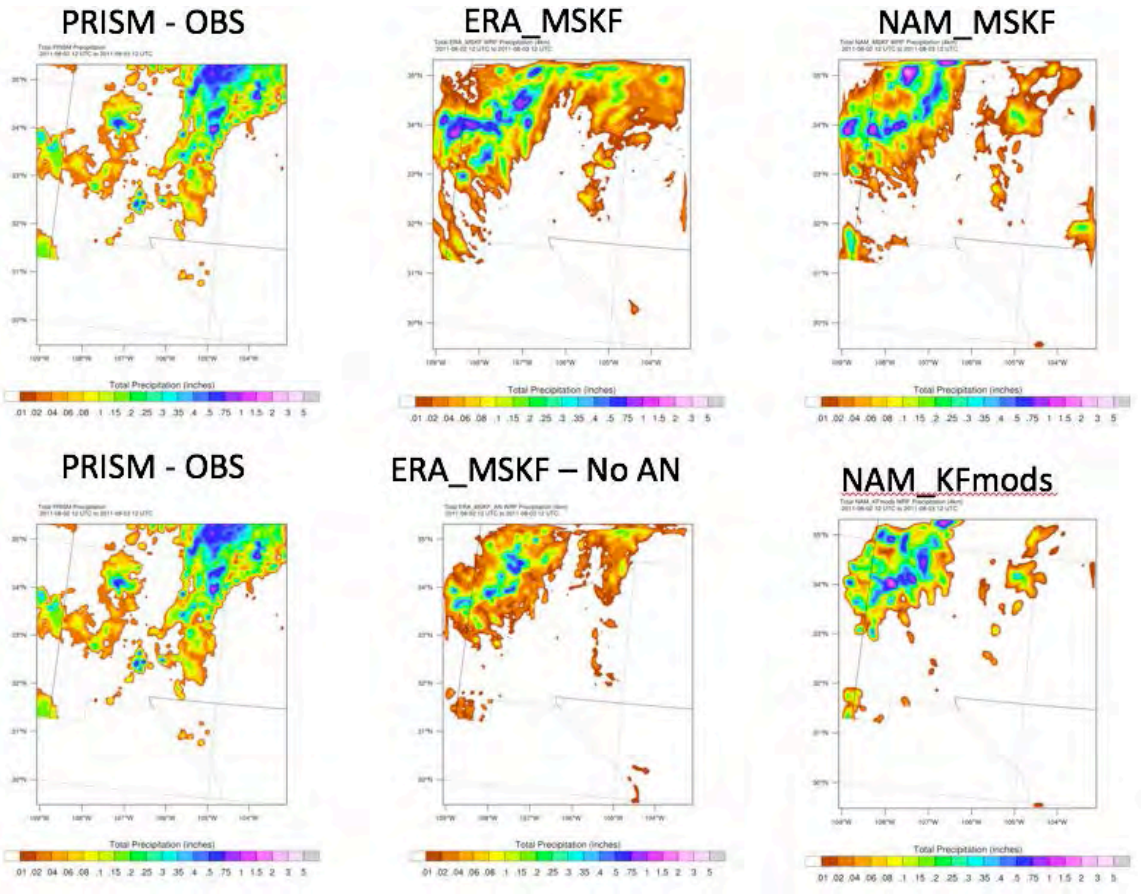


Figure 3-3. August 3, 2011 PRISM precipitation plots.

We ultimately selected NAM as the initialization dataset for the SNMOS WRF modeling. While NAM and ERA had comparable performance in simulating winds, we selected the NAM configuration with the MSKF convection cloud option because it tended to be dryer than ERA and exhibited better skill at simulating temperature. We judged that for ozone simulations, it was better to have simulated meteorology with a dry rather than wet bias in order to allow more solar insolation for ozone production.

Additional details about the WRF evaluation and configurations are available in the final Power Point deliverable for this task (UNC-IE and Ramboll Environ, 2015).

3.1.2 Significant Findings

The North American Model (NAM) and the European Centre for Medium Range Weather Forecasts model (ERA) initialization datasets provided comparable performance for WRF simulations of warm season meteorology in Southern New Mexico. While WRF performance was improved using the Multiscale (grid-aware) Kain-Fritsch cumulative cloud scheme, the model was still unable to consistently simulate precipitation patterns related to the North American monsoon. With the focus of the SNMOS on warm season ozone, we selected the NAM configuration with the multiscale Kain-Fritsch option because it tended to be dryer than ERA and exhibited better skill at simulating temperature. We judged that for ozone

simulations, it was better to have simulated meteorology with a dry rather than wet bias in order to allow more solar insolation for ozone production.

3.1.3 Milestones and Deliverables

- Prepare a work plan for the WRF modeling and other aspects of study. (Completed 11/30/2015)
- Power Point Presentation of WRF Results/Recommendations (Completed 11/30/2015)

3.2 Task 2: Permian Basin Oil & Gas Inventory

3.2.1 Task Summary

Ramboll Environ reviewed available Permian Basin oil and gas (O&G) inventories and recommended 2011 and future year inventories for the SNMOS. Figure 3-4 shows Permian Basin active O&G well locations circa-2014 in New Mexico and Texas. The Doña Ana study base and future year Permian Basin emission inventories were based on the 2011NEIv2-based Platform (2011v6.2). The 2011NEIv2-based Platform base year emission inventory is for 2011, the base year of the Doña Ana County study; it includes the 2011 TCEQ well site emission inventory for Texas, and is consistent with the latest available well site emission inventory inputs for the Permian Basin in New Mexico. 2011 base year emissions from the 2011NEIv2-based Platform and 2025 2011NEIv2-based Platform emission inventories were used as is.

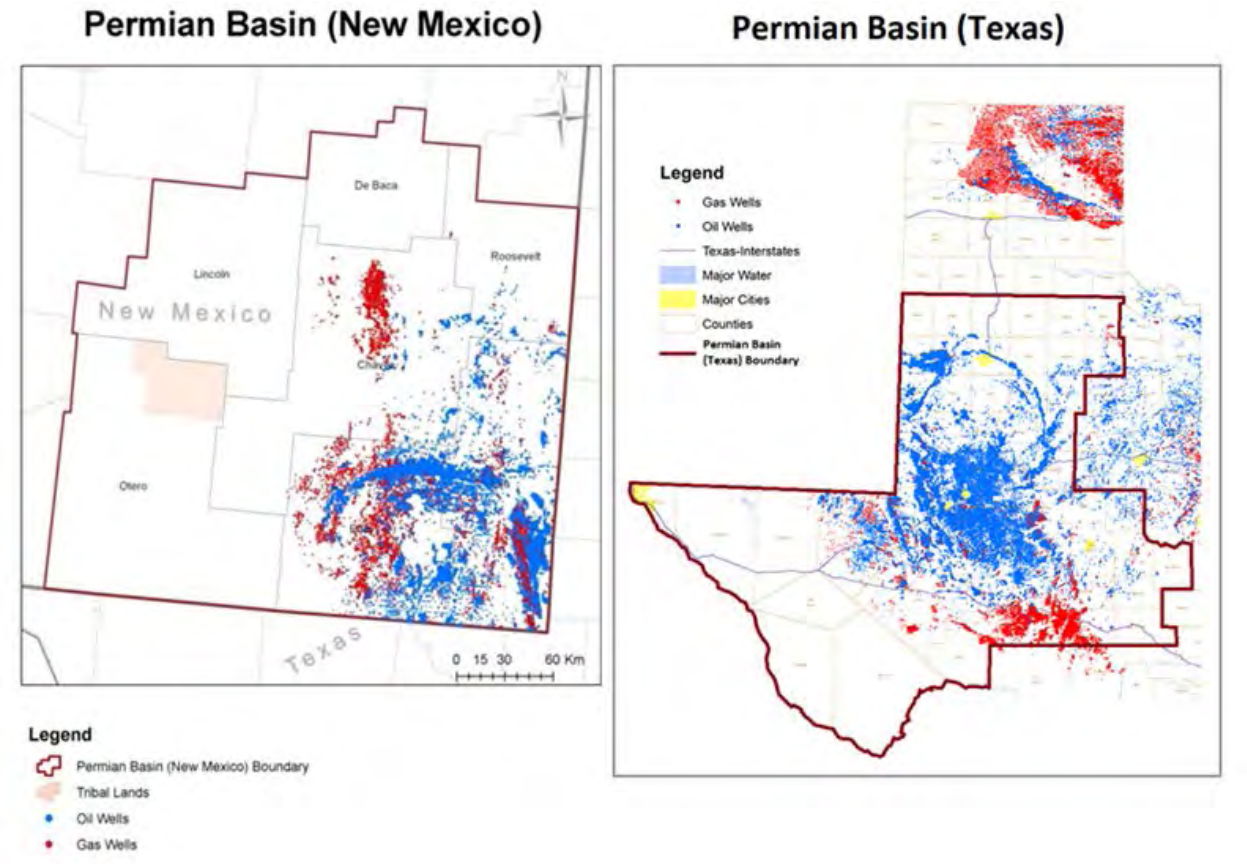


Figure 3-4. Permian Basin Well Locations (circa 2014). Source: Adapted from TCEQ Texas Oil and Gas Wells Map[1].

Figure 3-5 shows 2011 Permian Basin NOx and VOC Emissions broken down by state. NOx emissions totalled 99,577 tpy; 60% of the NOx emissions were from area sources and 40% were from point sources. Of the area source emissions (59,275 tpy), 50% were from compressor engines, 26% from artificial lift engines, 15% from heaters, and 7% from drill rigs (Figure 3-6). The sum of the other remaining categories was <3% of the emissions total. Texas was the source of 71% of the NOx emissions, and 29% of NOx emissions were from New Mexico (Figure 3-5).

Permian Basin 2011 VOC emissions were 507,813 tpy, and nearly all (99 %) emissions were from area sources, and 1% were from point sources. The largest category of VOC area sources (498,889 tpy) was oil tanks (55%) followed by wellhead venting (18%). Pneumatic devices, truck loading, and produced water each contributed 4% of area source VOC emissions and the remaining categories total <11%. Like NOx emissions, VOC emissions were heavily concentrated in Texas (83%) with New Mexico contributing the other 17% of emissions.

[1] http://www.tceq.state.tx.us/assets/public/implementation/barnett_shale/bs_images/txOilGasWells.png

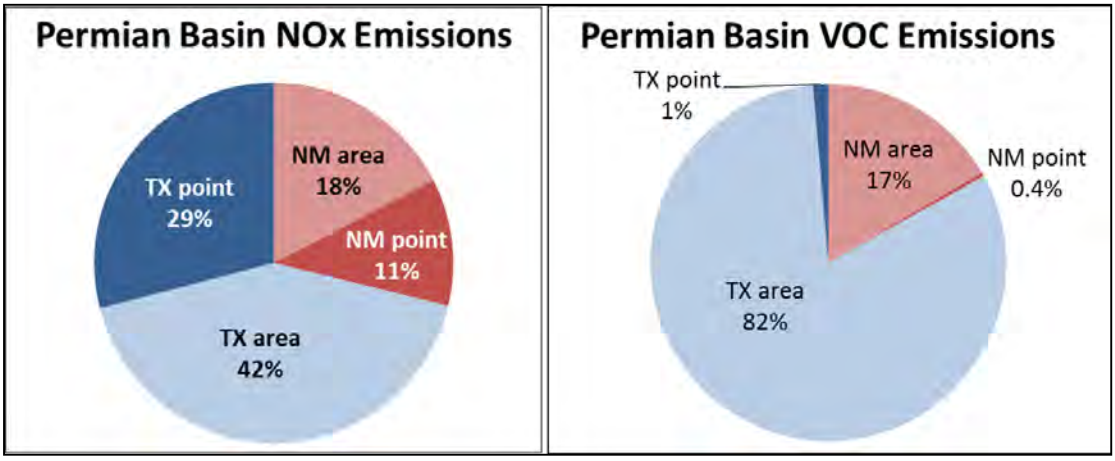


Figure 3-5. Permian Basin 2011 NOx and VOC emissions breakdown by state.

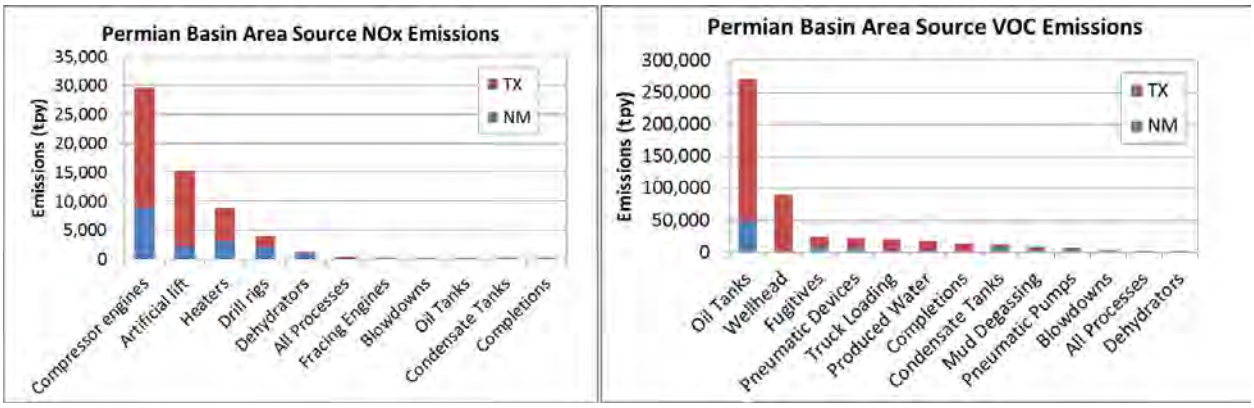


Figure 3-6. Permian Basin 2011 NOx and VOC emissions breakdown by emissions source category.

2011 point source emissions sources (40,302 tpy) were comprised of emissions from gas plants (59%), compressor stations (39%) and other sources such as tank batteries (3%) (Figure 3-7). A summary of Permian Basin-wide emissions for 2011 is given in Table 3-4.

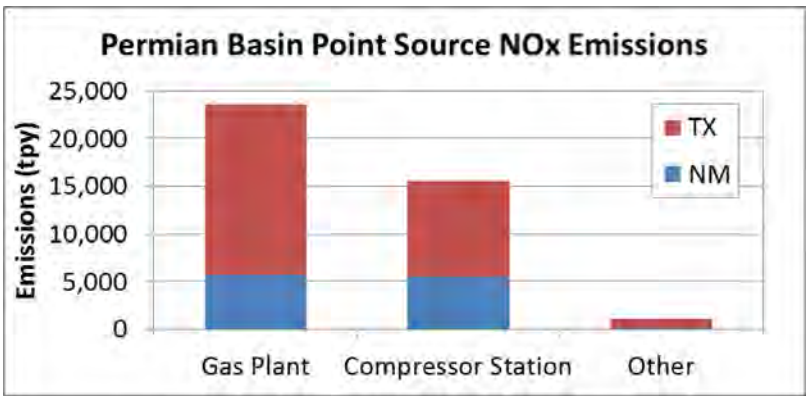


Figure 3-7. Permian Basin 2011 NOx point source emissions breakdown by state and emissions source category.

Table 3-4. Permian Basin 2011 inventory criteria pollutant emissions summary.

State	Type	2011 Permian Basin O&G Emissions (tpy)					
		NOX	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$
NM	area	17,354	84,140	20,694	190	518	516
	point	11,367	1,887	5,428	12,340	171	170
NM Total		***28,721***	***86,027***	***26,123***	***12,530***	***689***	***686***
TX	area	41,921	414,749	36,820	2,728	707	705
	point	28,935	7,036	16,699	5,136	935	920
TX Total		***70,856***	***421,786***	***53,519***	***7,864***	***1,642***	***1,626***
Grand Total		**99,577**	**507,813**	**79,642**	**20,395**	**2,331**	**2,312**

For the SNMOS future year emissions modeling, activity growth for the Permian Basin was forecast. O&G activity growth factors for each play within the Permian Basin were based on the U.S. Energy Information Administration's Annual Energy Outlook (AEO) for 2014[2] (Figure 3-8). Southwest region growth factors were used outside of the specified plays. Table 3-5 shows the ratio of 2025:2011 sources for oil, gas and oil/gas wells. For all three defined plays within the Permian Basin and the Southwest Region, the number of oil, gas and oil/gas wells is forecast to increase.

AEO 2014 forecasts were released in April 2014, when the Cushing, Oklahoma (OK) West Texas Intermediate (WTI) crude oil price was about $100 per barrel. In August 2014, crude oil prices began to decline sharply and since November 2014, the Cushing, OK WTI crude oil price has

[2] http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

remained between $40 and $60 per barrel[3]. The AEO 2015 forecast for the Cushing, OK WTI crude oil price for calendar year 2025 is 12% lower than the AEO 2014 estimate; AEO 2015 forecasts overall Southwest Region oil production to be 21% higher than the AEO 2014. While any oil and gas production forecasts are uncertain, the consistency in forecast crude oil production increases for the AEO 2014 and AEO 2015 indicate that the sharp increases in EPA's forecasts based on the AEO 2014 are reasonable, even with marked decreases in crude oil prices since August 2014.

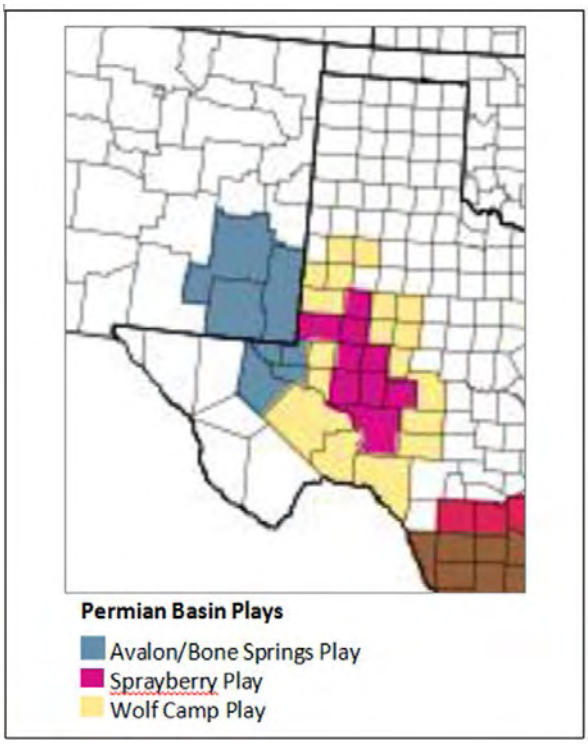


Figure 3-8. Permian Basin plays. Source: 2011v6.2 Modeling Platform TSD, excerpt from Figure 4-1.

Table 3-5. Permian Basin growth forecast by play.

Play / US Region	Oil Well Sources	Gas Well Sources	Oil and Gas Well Sources
Ratio 2025:2011			
Sprayberry Play	2.500	2.500	2.500
Wolfcamp Play	2.500	2.500	2.500
Avalon/Bone Springs Play	1.862	1.571	1.841
Southwest Region	1.448	1.384	1.006

In addition to the effects of activity growth, EPA considers the control effects of on-the-books regulations for the O&G sector (EPA, 2015) when developing emissions forecasts. The control

[3] Spot Prices for Crude Oil and Petroleum Products, http://www.eia.gov/dnav/pet/PET_PRI_SPT_S1_M.htm

effects of the following rulemakings are considered in the 2011NEIv2-based Platform 2017 and 2018 forecasts:

- New Source Performance Standards (NSPS) Subpart OOOO (area and point sources)
- Reciprocating internal combustion engine (RICE) NSPS Subparts JJJJ and IIII and NESHAP Subpart ZZZZ (area and point sources)
- Industrial/Commercial/Institutional Boilers and Process Heaters Maximum Achievable Control Technology (MACT) Rule (point sources)
- Standards of Performance for Turbines 40 CFR Part 60 - Subpart KKKK (point sources)
- Process Heaters NSPS (point sources)

3.2.2 Significant Findings

Emissions for the Permian Basin for 2011 and 2025 were developed using 2011NEIv2-based platform, growth based on the U.S. EIA AEO for 2014 and controls from pertinent rulemakings. Growth in activity is projected for the Permian Basin between 2011 and 2025; therefore, emissions of ozone precursors are projected to increase in 2025 relative to 2011.

3.2.3 Milestones and Deliverables

- Power Point Presentation on Permian Basin oil and gas 2011 and future year emission update (Completed 11/30/2015)
- Memo on available Permian Basin oil and gas 2011 and future year emissions data (Completed 11/10/2015)

3.3 Task 3: Juárez and Mexico Border Inventory (Current and Future Years)

3.3.1 Task Summary

The objective of this task was to recommend 2011 and future year emission inventory data covering the Mexico Border States and Ciudad Juárez for use in the SNMOS. We coordinated with NMED and the U.S. EPA to gather the best available data. We reviewed the available emissions data for these regions, including both inventories and ancillary data, and determined that the 2008-based Mexico National Emission Inventory (MNEI) were the best available data and the most appropriate of the available data to use for the SNMOS. These data were available as part of the U.S. EPA 2011v6.2 National Emissions Inventory (NEI) Emissions Modeling Platform (EMP).

The U.S. EPA distributed Mexico emissions data as part of the 2011v6.0 and 2011v6.2 EMPs. The 2011v6.0 EMP included a 1999-based version of the MNEI with projections to 2008, 2012, and 2030 (USEPA, 2014; Wolf et al., 2009). The 2011v6.2 EMP included a 2008-based version of the MNEI with projections to 2018 and 2025 (ERG, 2014). Figure 3-9 shows state total comparisons of the two Mexico inventories for the three major inventory sectors: on-road mobile, nonpoint, and point sources.

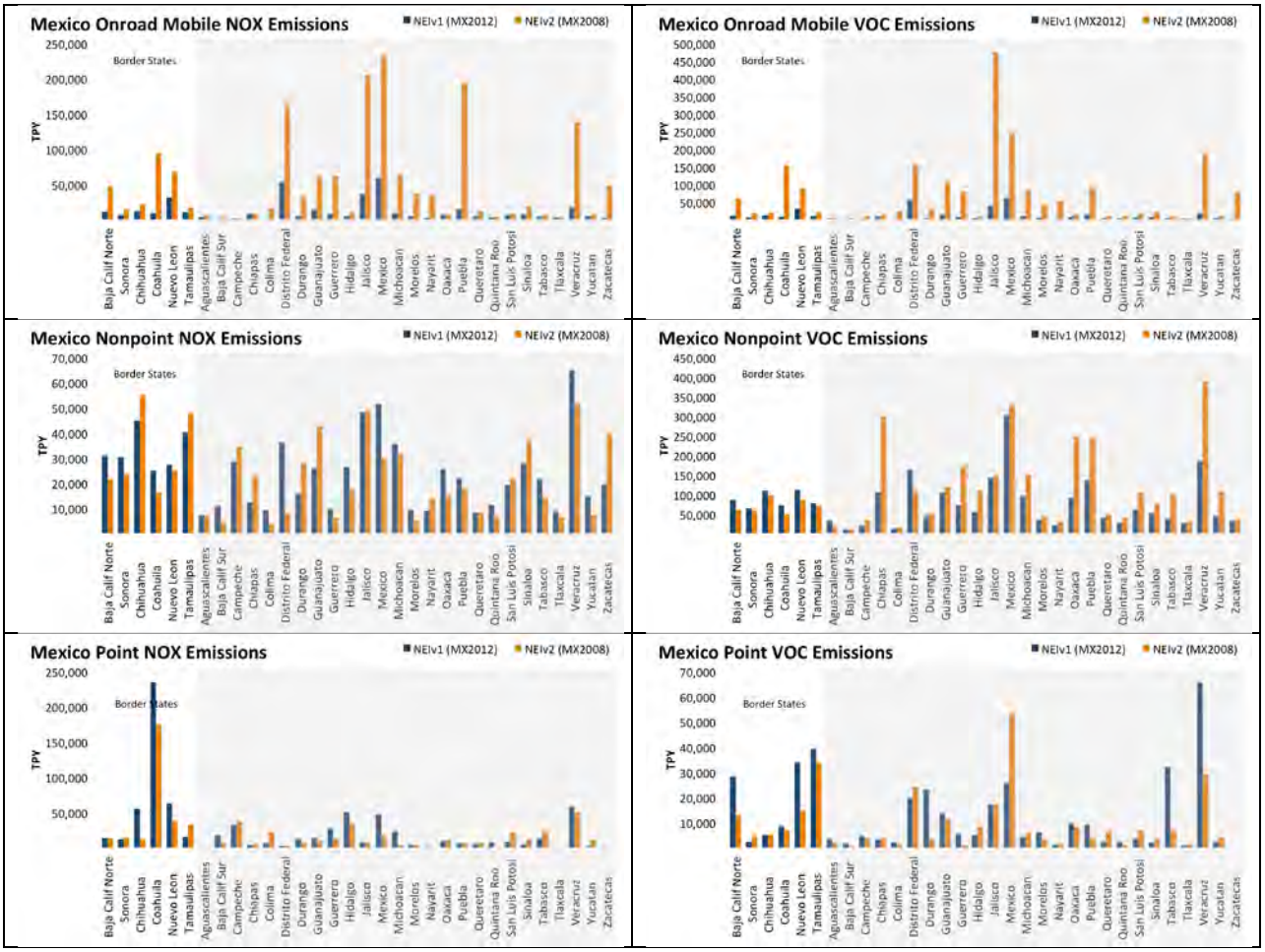


Figure 3-9. Mexico state inventory comparisons

As the 2008-based MNEI uses the most recent activity data that are publically available for Mexico, we decided with NMED that we would use these data for the SNMOS ozone modeling. We determined that this version of the MNEI, which is distributed with the U.S. EPA 2011v6.2 EMP, is the best available anthropogenic emissions data for Mexico. We used the 2008 MNEI as is for the 2011 SNMOS modeling and the 2025 projections for the future year SNMOS modeling. Natural emissions sources in Mexico were estimated using the same data and approaches used to estimate these emissions for the U.S. (see Task 5).

Our analyses of the MNEI anthropogenic emissions data included comparisons of the emissions totals between 2008 and 2025 at the state level (Figure 3-10) and for the municipalities in the immediate vicinity of Doña Ana County.

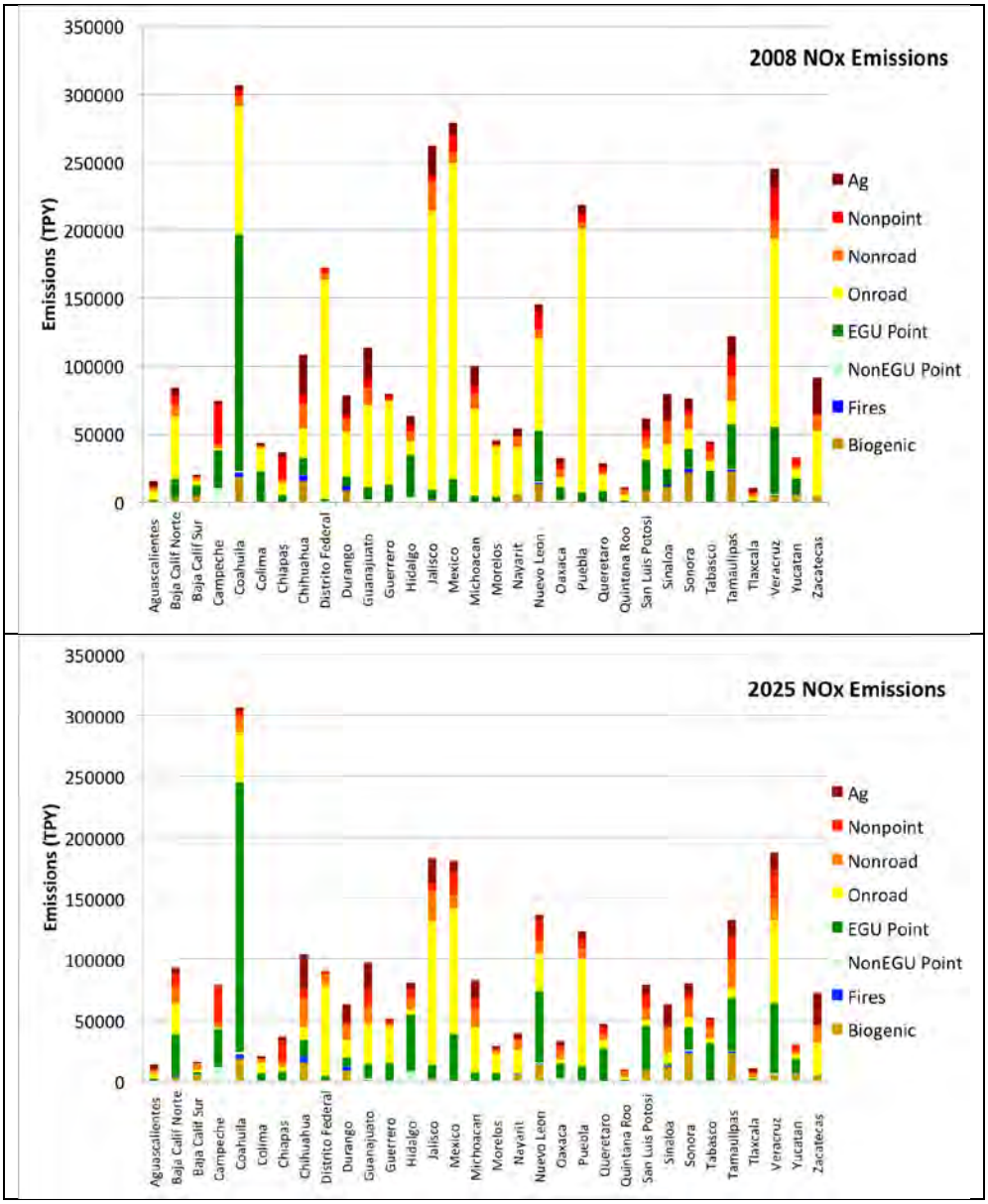


Figure 3-10. 2008 (top) and 2025 (bottom) Mexico state total NOx emissions

Additional details about the Mexico emissions data evaluation are available in the final Power Point deliverable for this task (UNC-IE and Ramboll Environ, 2015).

3.3.2 Significant Findings

The 2008-based Mexico NEI, which is distributed with the U.S. EPA 2011v6.2 emissions modeling platform, is the best available database of current and future year emissions estimates for Mexico. The 2008 base year emissions and 2025 emissions projections for Mexico were selected for the SNMOS.

3.3.3 Milestones and Deliverables

- Power Point presentation on Mexico emissions to be used in 2011 base and future year modeling (Completed 11/30/2015).

3.4 Task 4: Prepare Base Year Emissions with SMOKE

3.4.1 Task Summary

We developed anthropogenic emissions estimates for the SNMOS from the WAQS 2011 version B (2011b) emissions modeling platform available from the IWDW[4]. The data sources for the WAQS 2011b emissions estimates included the U.S. EPA, Ramboll Environ, and the states of Colorado, Utah, and Wyoming. As part of the WAQS, UNC-IE formatted the data for input to the Sparse Matrix Operator Kernel Emissions (SMOKE[5]) system, processed the data into CAMx input files with SMOKE, and performed quality assurance and quality control (QA/QC) on the emissions data and modeling.

We used all of the anthropogenic emissions data (e.g., non-road mobile, nonpoint, electricity generating units) collected and prepared for the WAQS 2011b simulation to generate CAMx-ready emissions for the SNMOS. The significant effort invested in the WAQS in collating and quality assuring these data was inherited by the SNMOS through adaptation of the WAQS 2011b modeling platform. As the modeling domains and meteorology data are different between the studies, adapting the WAQS data involved generating emissions for the SNMOS modeling domains and time period.

The SNMOS used 12-km and 4-km modeling domains focused on southern New Mexico. The standard continental U.S. (CONUS) Lambert Conformal Conic Projection (LCP) was used in the SNMOS for the domains shown in Figure 3-11 and described below.

- The SNMOS WESTUS12 CAMx domain encompasses all of New Mexico, extends west to include the metropolitan area of Phoenix, east to include West Texas, and South to include the Carbon II power plant in Coahuila, Mexico. This facility is a large source of NOx emissions and lies in a region that was sometimes upwind of Doña County on high ozone days during 2011. The SNMOS WESTUS12 domain was designed as a trade-off between computational efficiency and the need to model transport from sources likely to influence Doña Ana County at 12-km resolution.
- The SNMOS 4-km Doña Ana County domain focuses on Southern New Mexico and the major source regions in the immediate vicinity, including Ciudad Juárez, Mexico and El Paso, TX.

[4] http://views.cira.colostate.edu/tsdw
[5] http://www.smoke-model.org

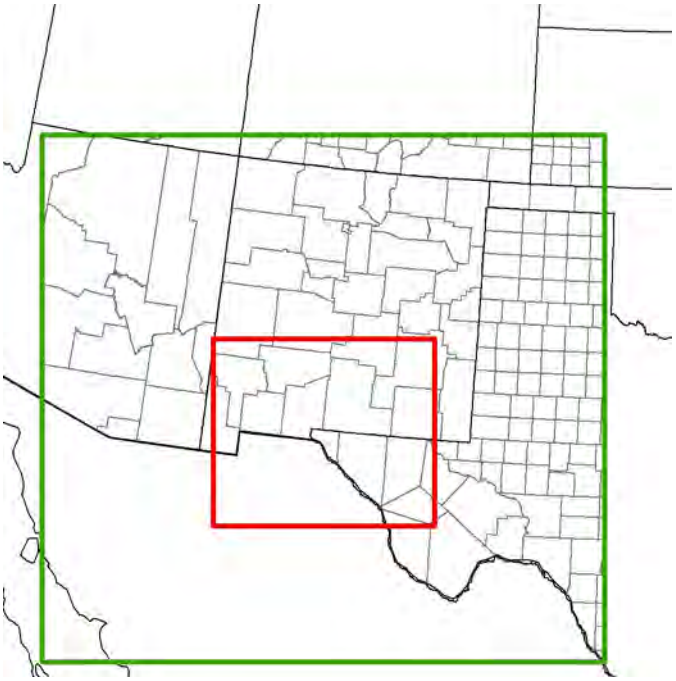


Figure 3-11. SNMOS 12-km (green) and 4-km (red) nested CAMx modeling domains.

We prepared emissions on these domains for April 15 through August 30, 2011 using SMOKE version 3.7. The first 15 days of emissions (April 15-30) were prepared to initialize the CAMx simulation for the air quality analysis period beginning on May 1.

Consistent with the WAQS 2011b emissions modeling platform, all of the non-O&G anthropogenic emission inventories for the SNMOS base year 2011 simulations were taken from the U.S. EPA National Emission Inventory (NEI). EPA publically released the 2011v6 platform in February 2014 and updated it twice, version 6.2 being the most recent. Details of the inventory, sectors, and preparation procedures for these data are available in the NEI2011v6.2 Technical Support Document (US EPA, 2015). The exception was the O&G inventories for most of the basins in Northern New Mexico, Colorado, Utah, and Wyoming, which were provided by Ramboll Environ. Ramboll Environ also developed emissions estimates for natural emissions sources for the SNMOS, including fires, biogenics and lightning (see Task 5 summary).

In coordination with NMED, we determined that the 2008 Mexico National Emission Inventory (MNEI), which is packaged with the NEI2011v6.2, was the most appropriate publically available Mexico inventory to use for the SNMOS (see Task 3 summary).

Ramboll Environ also conducted a review of the available Permian Basin O&G inventories and determined that the inventory and ancillary emissions data that are part of the NEI2011v6.2 are the best available data for these sources (Grant and Kemball-Cook, 2015; and see Task 2 summary).

The SNMOS project used MOVES to estimate on-road mobile emissions for U.S. sources. The U.S. EPA provided MOVES input emission-factors for 2011. The SMOKE-ready on-road mobile inventory data are a combination of county-level activity data and emissions factor look-up tables output from MOVES for representative counties. The on-road mobile activity data included county-level vehicle miles travelled (VMT), vehicle population (VPOP), and averaged speed profiles by vehicle type and road class. The look-up tables for representative counties, which are output from MOVES emissions rate mode simulations, contained county-level emissions factors as a function of temperature, relative humidity, and speeds. Land cover data and biogenic emissions factors by land cover type were used to estimate biogenic emissions fluxes. We used non-inventory, or ancillary emissions data provided by the U.S. EPA, to convert the inventories into the format required by CAMx.

Part of the preparation process for the inventory data included splitting the inventories into detailed subsectors. We split up many of the U.S. EPA NEI inventories to support the application of source-specific parameterizations of temporal and spatial patterns, to facilitate source-based emissions sensitivities, and to support targeted quality assurance of important inventory sectors. Although anthropogenic inventories can be generally classified as point, non-point, or mobile sources, we used over 20 individual anthropogenic inventory sectors in the SNMOS modeling. Table 3-6 is a listing of the inventory processing sectors used for the SNMOS. The table lists the inventory processing sectors, the source of the inventory data, the type of inventory (i.e., point, nonpoint, or gridded), the inventory year, and brief descriptions of the inventory sources included in the sector.

Table 3-6.SNMOS emissions processing sectors

Sector	Source	Type	Inventory Period and Year	Description
Locomotive/ marine	NEI 2011v6.2	Point and Nonpoint	Annual 2011 and 2025	The locomotive/marine sector is a subset of the non-point/area sector. It includes county-level emissions for line haul locomotives (nonpoint), train yards (point), and class 1 and 2 in- and near-shore commercial marine.
Off-road mobile	NEI 2011v6.2	Nonpoint	Monthly 2011 and 2025	NMIM county-level inventories for recreational vehicles, logging equipment, agricultural equipment, construction equipment, industrial equipment, lawn and garden equipment, leaf and snow blowers, and recreational marine. The CA and TX NONROAD estimates were normalized to emissions values provided by these states.
On-road mobile (US)	NEI 2011v6.2	MOVES	Annual and Daily 2011 and 2025	EPA ran MOVES2014 for 2011 in emissions factor mode. The MOVES lookup tables include on-network (RPD), on-network for CA (RPD_CA), off-network starts/stops (RPV), off-network starts/stops for CA (RPV_CA), off-network vapor venting (RPP), off-network vapor venting sources for CA (RPP_CAT, off-network hotelling (RPH). These data include the reference county and reference fuel month assignments that EPA used for the MOVES

Sector	Source	Type	Inventory Period and Year	Description
				simulations. The CA MOVES estimates were normalized to emissions values provided by these states.
Non-point/ Area	NEI 2011v6.2	Nonpoint	Annual 2011 and 2025	County-level emissions for sources that individually are too small in magnitude or too numerous to inventory as individual point sources. Includes small industrial, residential, and commercial sources; broken out into nonpoint, residential wood combustion, livestock, and fertilizer processor sectors.
Refueling	NEI 2011v6.2	Nonpoint	Annual 2011 and 2025	Nonpoint, gasoline stage 2 refueling.
Area Oil & Gas	WAQS 2011 and NEI 2011v6.2	Nonpoint	Annual 2011 and 2020	Non-point oil and gas sources are survey-based and typically unpermitted sources of emissions from up-stream oil and gas exploration, development, and operations. The non-point O&G sector consists of the WAQS Phase II and the NEI 2011v6.2 inventory for all basins outside of the WAQS inventory coverage area.
Point Oil & Gas	WAQS 2011 and NEI 2011v6.2	Point	Annual 2011 and 2020	Point oil and gas sources are permitted sources of emission from up-stream oil and gas exploration, development, and operations. The point O&G sector consists of the WAQS Phase II and the NEI 2011v6.2 inventory for all areas outside of the WAQS inventory coverage area.
CEM Point	2011v6.2 and CAMD	Point	Hourly 2011 and 2025	2011 Clean Air Markets Division (CAMD) hourly Continuous Emissions Monitor (CEM) data and Integrated Planning Model (IPM) projections to 2025.
non-CEM Point	2011v6.2	Point	Annual 2011 and 2025	Elevated and low-level combustion and industrial sources, airports, and offshore drilling platforms.
Offshore Shipping	2011v6.2	Point	Annual 2011 and 2025	Elevated point C3 commercial marine sources in offshore commercial shipping lanes.
Fires	□MDET□I□	Point	Daily 2011	PMDETAIL version 2 wildfire, prescribed burns and agricultural burning open land fires.
Canada Sources	NPRI 2010	Nonpoint and Point	Annual 2010	Canadian 2010 National Pollutant Release Inventory; there are no future year projections from the 2010 NPRI.
Mexico Sources	MNEI 2012	Nonpoint and Point	Annual 2008 and 2025	Mexican NEI 2008 and projections to 2025.
Biogenic	MEGAN v2.10	Gridded	Hourly 2011	MEGANv2.10 estimated with 2011 meteorology.
Lightning	Ramboll Environ	Gridded	Daily 2011	Lightning NOx emissions estimated with 2011 meteorology.

Several gridded emissions datasets were used for either directly estimating air emissions or as ancillary data for processing/adjusting the emissions data. The following datasets are key gridded data used in the SNMOS. We included neither sea salt nor windblown dust emissions in the SNMOS because of the study emphasis on O_3.

In addition to the inventory and gridded emissions data, ancillary datasets provide temporal, chemical, and spatial allocation specifications to the emissions. The ancillary data for SNMOS were taken directly from the WAQS 2011b modeling, which was derived primarily from the EPA 2011v6.2 modeling platform.

Additional details about the U.S. emissions data used for the SNMOS is available in the final emissions modeling memo for this task (Adelman and Baek, 2016).

3.4.2 Significant Findings

The Western Air Quality Study 2011b emissions modeling platform was used to develop summer season 2011 emissions for the SNMOS. On an annual basis, on-road mobile sources were the largest source of NOx and biogenic sources the largest source of VOC in Doña Ana County in 2011. In the immediate vicinity of Doña County, El Paso County, TX was the largest source NOx and Ahumada Municipality the largest source of VOC in 2011.

3.4.3 Milestones and Deliverables

- Technical memo for 2011 base year emission modeling with SMOKE (Completed 2/29/2016)

- CAMx-ready 2011 base year emissions on the project 12-km and 4-km modeling domains (Completed 2/29/2016)

3.5 Task 5: Prepare Natural Emissions for the Project Modeling

3.5.1 Task Summary

Ramboll Environ prepared natural emissions for the SNMOS 2011 Base Case 12/4 km domain CAMx modeling. Natural emissions are unrelated to human activities and for SNMOS, the natural emission inventory consisted of biogenic emissions and emissions from fires and lightning.

3.5.1.1 Biogenic Emissions Modeling

The Model of Emissions of Gases and Aerosols in Nature (MEGAN) is a modeling system for estimating the net emission of gases and aerosols from terrestrial ecosystems into the atmosphere (Guenther et al., 2006; Guenther et al., 2012). Driving variables include land cover, weather, and atmospheric chemical composition. MEGAN is a global model with a base resolution of ~1 km and so is suitable for regional and global models. A FORTRAN code is available for generating emission estimates for the CAMx regional air quality model. WRAP has recently updated the MEGAN biogenic emissions model using western U.S. data and higher resolution inputs (Sakulyanontvittaya et al., 2012). MEGAN v2.1 was used for the SNMOS biogenic emissions modeling

MEGAN generates hourly, gridded biogenic emissions and requires gridded inputs. Land cover data specify the type of plants present in each model grid box as well as the density of the foliage. Global distributions of land cover variables (Emission Factors, Leaf Area Index, and Plant

Functional Types) are available for spatial resolutions ranging from ~ 1 to 100 km. Leaf Area Index (LAI) quantifies the amount of foliage at a given location and the age of the foliage and is derived from satellite measurements. Satellite-observed radiances at several wavelengths are related to chlorophyll activity and leaf area. The LAI variable defines the number of equivalent layers of leaves relative to a unit of ground area. The data are composited every 8 days at 1-kilometer resolution. Plant functional type data are developed from high resolution satellite land cover/crop data and species composition is averaged over ecoregion. The National Land Cover Database (NLCD) includes three products that are used in the development of the MEGAN land cover: tree-cover fraction impervious cover fraction, and a land cover dataset.

Weather determines how active the plants are. MEGAN requires gridded hourly temperature, solar radiation and soil moisture data, which were supplied by the SNMOS 2011 WRF MSKF NAM meteorological model run outputs. The final input data for MEGAN are emission factor maps which are based on vegetation species composition.

Ramboll Environ ran MEGAN for the SNMOS 2011 episode and performed quality assurance of the MEGAN emissions. We prepared county-level emission summaries for NOx, CO and VOC and reviewed spatial maps of the biogenic emissions. The review focused on whether the pattern of emissions appeared reasonable. For example, we expect to see higher biogenic emissions over heavily vegetated regions and that urban areas and deserts should have lower biogenic emissions. Figure 3-12 is an example of the spatial quality assurance of the biogenic emission inventory and shows the episode average isoprene emissions on the 4-km grid. The isoprene emissions show minima in emissions where there is little vegetation (urban areas, deserts) and maxima in emissions in forested areas such as the Lincoln National Forest. Overall, isoprene emissions are larger in Mexico than in the U.S. There is a discontinuity in emissions at the U.S.-Mexico border (white arrow) that is not apparent in the vegetation distribution in the Google Earth satellite imagery. This suggests that there is uncertainty in biogenic emission inventory related to differences in MEGAN inputs for the U.S. and Mexico.

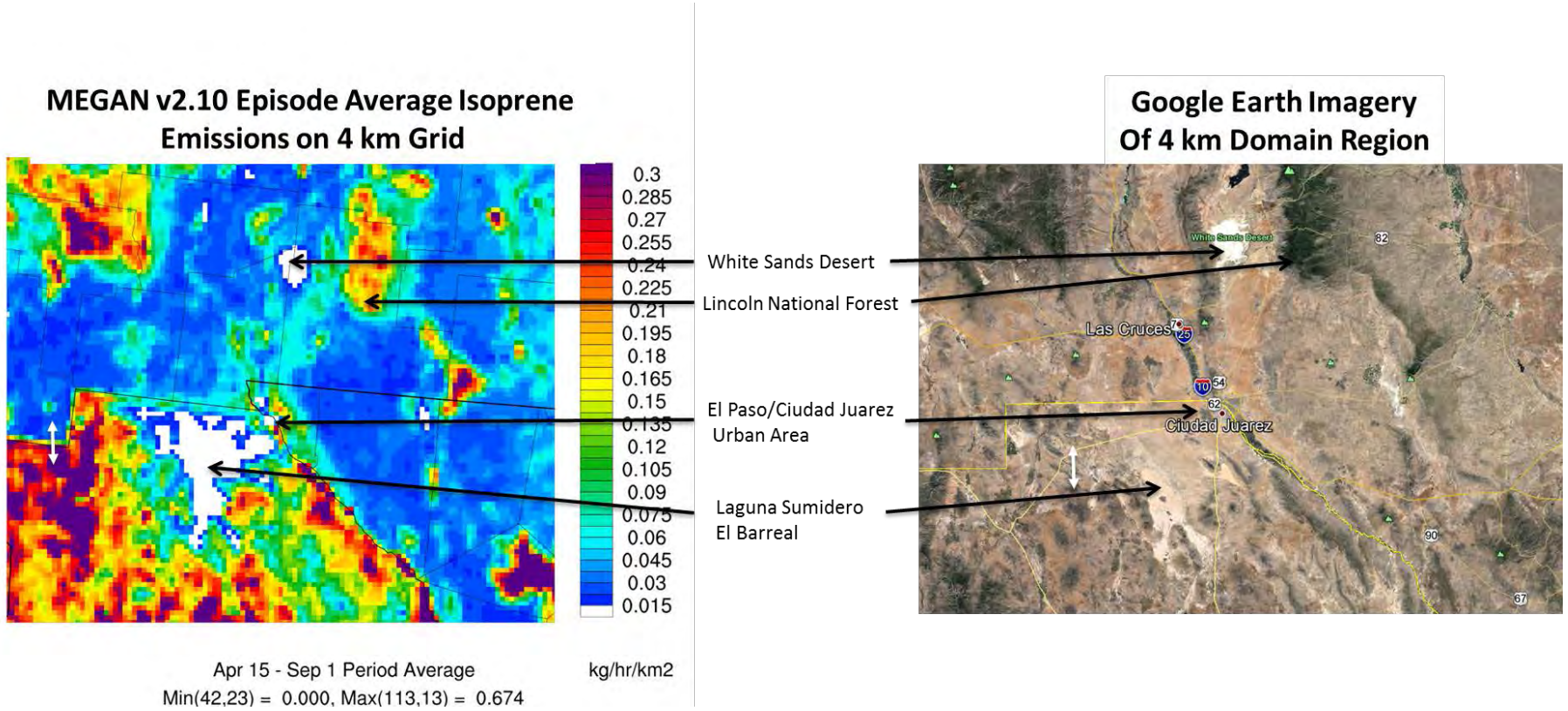


Figure 3-12. Example of biogenic emissions quality assurance. Left panel: SNMOS MEGAN v2.10 2011 episode average isoprene emissions on the 4-km grid. Right panel: Google Earth visible imagery of the region shown in the left panel.

3.5.1.2 Fire Emissions Modeling

Open biomass burning makes up an important part of the total global emissions of greenhouse gases, reactive trace gases, and particulate matter. Although episodic in nature and highly variable, open biomass burning emissions can contribute to local, regional, and global air quality problems and climate forcing. The SNMOS used fire emissions for 2011 that were generated by the Particulate Matter Deterministic and Empirical Tagging and Assessment of Impacts on Levels (PMDETAIL) study. PMDETAIL developed 2011 fire emission using satellite data and ground detect and burn scar, in addition to other data, with a slight modification (Mavko, 2014) to the methodology used in the Deterministic and Empirical Assessment of Smoke's Contribution to Ozone Project (DEASCO3) study for the 2008 modeling year (DEASCO3, 2013). We used a similar plume rise approach as PMDETAIL/DEASCO3 where plume rise depends on fire size and type (Mavko and Morris, 2013). The PMDETAIL 2011 fire inventory was selected over the 2011 Fire INventory from NCAR (FINN) and Smartfire 2011 inventory because it uses a more complete satellite and surface fire dataset.

Day-specific FETS fire activity data was used for all wildfire, agricultural, and prescribed fires within the 12/4 km modeling domain. FETS data included size, location, timing, fuel loading, moisture, and emission fluxes and chemical parameters. Fire emissions were gridded to the SNMOS modeling domains and speciated for the CAMx CB6r2 chemical mechanism. The plume characteristics for each fire event were prescribed based on the fire type and size. Plume rise is weather-dependent is and is characterized by smoldering fraction, plume bottom and plume top. Once PMDETAIL fire emissions were developed for the SNMOS Base Case 2011 modeling period, we developed separate county-level emissions summaries for agricultural burns, wildfires, and prescribed fires. We also made spatial plots of the daily fire emissions and performed spot checks to ensure that the PMDETAIL fire locations matched satellite fire detections from NOAA's Hazard Mapping System (HMS) Fire and Smoke Analysis Product. The HMS product uses data from the GOES Imager, the AVHRR (Advanced Very High Resolution Radiometer) instrument, and MODIS (Moderate Resolution Imaging Spectroradiometer). Fire locations derived by thee algorithms based on different satellite retrievals reviewed by an analyst, who removes false detections and reconciles the three fire location data sets. The analyst outlines the locations of smoke plumes inferred from satellite aerosol optical depth retrievals.

Figure 3-13 shows an example of the fire emissions quality assurance for June 5, 2011. On this day, there were several large fire complexes burning in the 4-km domain. The Wallow Fire in eastern Arizona, the Horseshoe 2 fire in southeastern Arizona and the Monument Fire on the U.S.-Mexico border are shown in the fire emissions plot in the left hand panel and match the satellite fire detections shown in the HMS product.

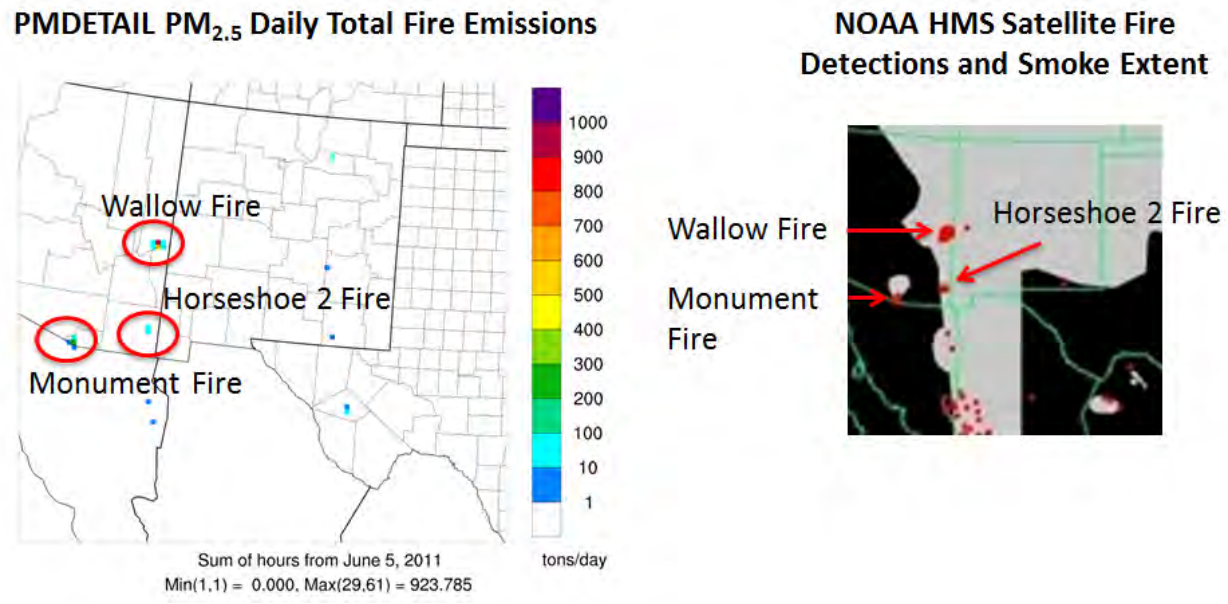


Figure 3-13. Example of fire emissions quality assurance. Left panel: June 5, 2011 PMDETAIL daily total $PM_{2.5}$ emissions HMS product showing fire locations (red dots) and smoke plume (gray area).

3.5.1.3 Lightning Emissions Modeling

NO_X is formed in lightning channels as the heat released by the electrical discharge causes the conversion of N_2 and O_2 to NO. Lightning NOx emissions (LNOx) can be estimated directly based on the number of lightning flashes, the intensity of each flash, the lightning type (cloud-to-ground vs. cloud-to-cloud), and the amount of NOx emitted per flash. Because formation of LNOx is associated with deep convection in the atmosphere, LNOx production is typically parameterized in terms of the modeled convective activity. LNOx production is often assumed to be related to cloud top height or convective rainfall. The modified lightning NOx emissions model of Koo et al. (2010) was used to estimate lightning NOx emissions for the SNMOS. Koo et al. use a hybrid approach that preserves the consistency of the WRF modeled convection and the location of LNOx emissions, but also attempts to constrain the LNOx emissions to match observed distributions of lightning or an estimate of total emissions. Additional details on the development and evaluation of the lightning emissions processor used in the SNMOS are available in the WestJumpAQMS Sea Salt and Lightning memo (Morris et al., 2012) [6]. LNOx emissions were allocated to WRF grid columns where modeled convection occurred using WRF convective precipitation as a proxy for lightning activity. LNOx emissions were distributed in the vertical using profiles derived from aircraft measurements and cloud-resolving models. LNOx emissions were modeled as point sources with zero plume rise in appropriate layer.

Once the LNOx emissions had been generated, we performed quality assurance of the emissions by comparing maps of vertically integrated LNOx emissions with WRF modeled precipitation. An example of this quality assurance is shown in Figure 3-14, which compared

[6] http://www.wrapair2.org/pdf/memo_12_seasalt_lightning_june25_2012_final.pdf

the daily total precipitation from WRF (left panel) with the column-integrated LNOx emissions for a 24-hour period in July 2011. The locations of locally intense (convective) rainfall align well with the maxima in the LNOx emissions, which indicates that the LNOx emissions have been correctly allocated in space.

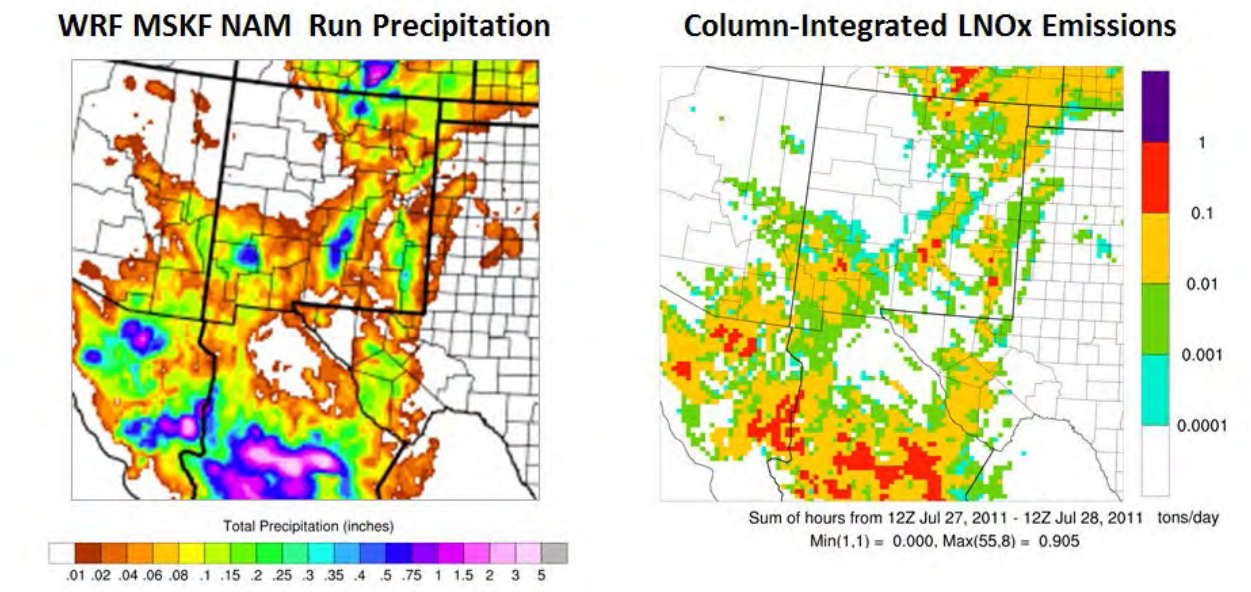


Figure 3-14. LNOx emissions quality assurance for July 27-28, 2011. Left panel: daily total precipitation from the WRF MSKF NAM model run. Right panel: column-integrated LNOx emissions for the July 27-28 period matched in time to the precipitation total shown in the left panel.

3.5.2 Significant Findings

The results of the quality assurance for the natural emissions suggest that the emissions modeling was correctly executed. However, there are significant uncertainties in all three components of the natural emission inventory. For the biogenic inventory, there is a discontinuity in emissions at the U.S.-Mexico border and emissions are larger over Mexico than the U.S. for environments that appear from Google Earth imagery to have comparable vegetation cover. Further investigation of differences in MEGAN inputs for the U.S. and Mexico should be undertaken to understand these differences and to ensure that the most accurate inventories possible are used on both sides of the border. Modeling of fire and lightning emissions are active areas of scientific research, and the SNMOS emission inventories should be considered to have considerable uncertainty associated with them.

3.5.3 Milestones and Deliverables

- Prepared gridded, CAMx ready MEGAN version 2.10 biogenic emissions. (Completed 1/12/2016)
- Prepared gridded, CAMx ready lightning NOx emissions. (Completed 1/15/2016)
- Prepared gridded, CAMx ready PMDETAIL fire emissions. (Completed 1/18/2016)

- Provided natural emissions on the 12/4 km grids to UNC for SMOKE emissions modeling/merge (Completed 1/18/2016)
- PowerPoint presentation on results of natural emissions modeling. (Completed 2/16/2016)

3.6 Task 6: Base Year Air Quality Modeling

3.6.1 Task Summary

The SNMOS performed photochemical grid modeling for the year 2011 using the Comprehensive Air Quality Model with Extensions (CAMx) version 6.20. The SNMOS Work Plan for the 2011 Modeling Year (Adelman et al., 2015a) details the CAMx configuration and justification for the model's selection for the SNMOS. CAMx was run for April–October, 2011 and configured as in the WAQS 2011b study. The model configuration is summarized in Table 3-7.

The SNMOS CAMx modeling grids are shown in Figure 3-15. The 3SAQS 36-km grid 3D CAMx output fields were used as BCs for the SNMOS 12-km grid. While the SNMOS modeling leveraged the WAQS/3SAQS modeling platforms, some changes to the WAQS/3SAQS modeling grids were required simulate ozone in Southern New Mexico as accurately as possible. The brown rectangle in Figure 3-15 shows the extent of the 3SAQS 12-km modeling grid. The SNMOS 12-km modeling domain, shown in green, is smaller than the 3SAQS 12-km grid and is focused on the region surrounding southern New Mexico. The southern boundary of the SNMOS 12-km grid was extended southward beyond the southern boundary of the 3SAQS 12-km grid in order to encompass the NOx emissions sources that are most important to ground-level ozone formation in southern New Mexico (Figure 2-1). The SNMOS 12-km grid boundary lies south of the Carbon II power plant in Coahuila, Mexico. This facility is a large source of NOx emissions and lies in a region that was sometimes upwind of Doña Ana County on high ozone days during 2011. The spatial extent of the SNMOS 12-km domain strikes a balance between computational efficiency and the need to model transport from sources likely to influence Doña Ana County at 12-km resolution. The SNMOS 4-km Doña Ana County domain (shown in red in Figure 3-15) focuses on Southern New Mexico and the major emissions source regions in the immediate vicinity, including Ciudad Juárez, Mexico and El Paso, TX. The 12-km domain provided the BCs for the 4-km domain.

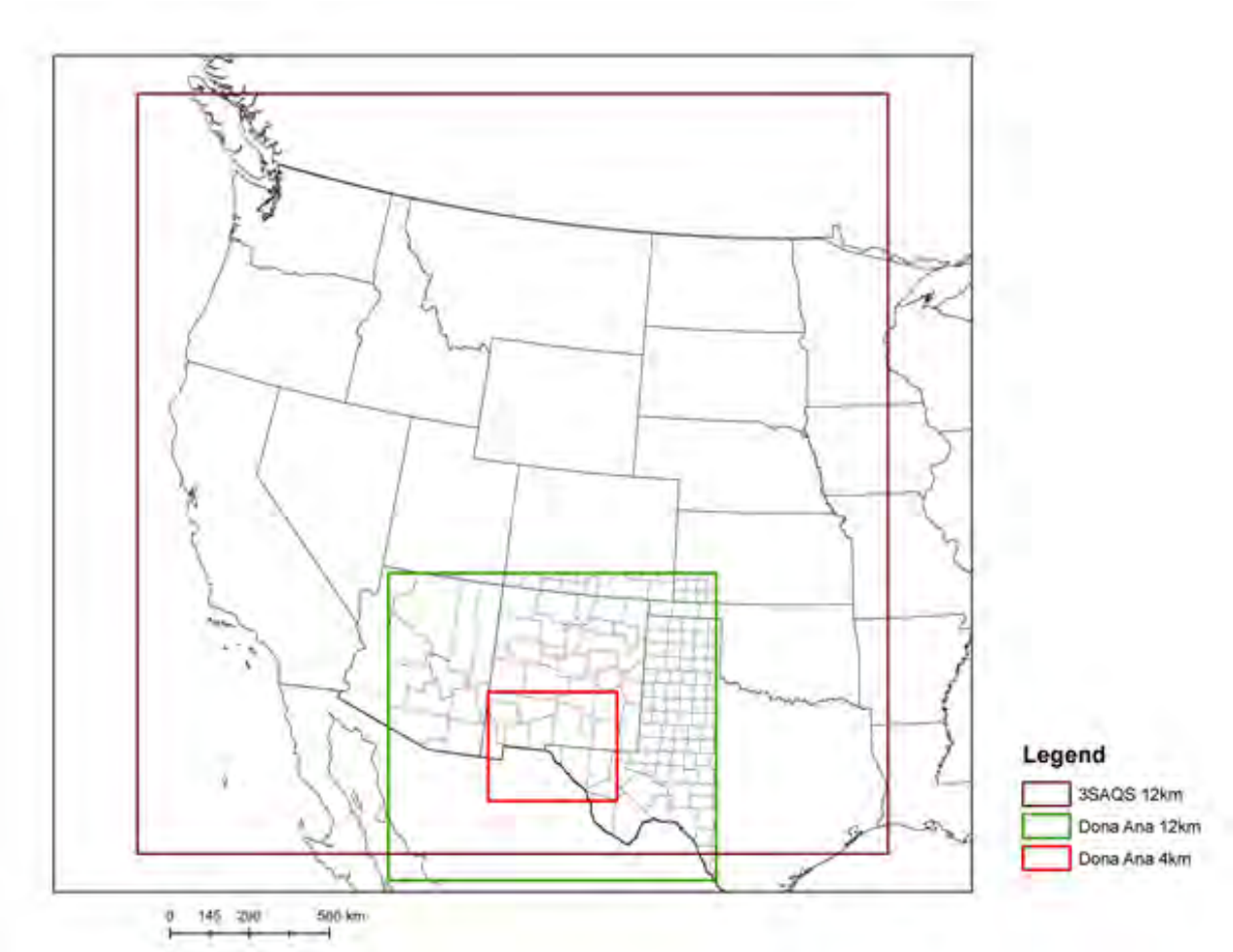


Figure 3-15. CAMx Modeling Domains and Boundary Conditions.

Table 3-7. SNMOS CAMx version 6.20 configuration.

Science Options	Configuration	Details
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3.6.2 Significant Findings

The CAMx modeling of 2011 was completed successfully.

3.6.3 Milestones and Deliverables

- 2011 base year air quality modeling presentation (Completed 2/22/2016)
- Carry out SNMOS 2011 Base Case CAMx modeling (Completed 3/25/2016)

3.7 Task 7: Model Performance Evaluation and Sensitivity Modeling

3.7.1 Task Summary

Following the completion of the SNMOS 2011 base case modeling, we performed a CAMx model performance evaluation (MPE) for the entire modeling episode. In this section, we present the evaluation of CAMx model performance against concurrent measured ambient concentrations using graphical displays of model performance and statistical model performance measures. We compared these measures against established model performance goals and criteria following the procedures recommended in EPA's photochemical modeling guidance documents (EPA, 2014).

Model performance was evaluated in New Mexico and surrounding regions for two CAMx runs that used different meteorological inputs, but were otherwise identical. UNC-IE carried out a series of Weather Research and Forecasting Model (WRF; Skamarock et al., 2005) meteorological model simulations of the SNMOS modeling episode and compared model performance in each run against observed weather data (Section 3.1; UNC-IE and Ramboll Environ, 2015). The WRF model runs differed in their cumulus parameterizations and the datasets used for initial conditions and analysis nudging. The two WRF runs that produced the best model performance over the SNMOS WRF 12/4 km modeling domains used the MSKF cumulus scheme (Alapaty et al., 2014; Herwehe et al., 2014). One of the MSKF WRF runs used the NCEP NAM analysis for initial conditions and analysis nudging, while the other MSKF run used the ECMWF ERA-Interim analysis. We refer to the two WRF simulations hereafter as the WRF ERA and WRF NAM runs and the two CAMx runs that used these WRF runs as the CAMx ERA and CAMx NAM runs.

For both CAMx runs, model performance was acceptable for daily maximum 8-hour average (MDA8) ozone based on comparison with EPA statistical performance benchmarks (Figure 3-16). Both CAMx runs had an overall high bias when all episode days were considered, but underestimated ozone on high ozone days, which were defined to be days with observed MDA8 ozone > 60 ppb. The CAMx run using ERA WRF meteorology performed slightly better than CAMx with NAM WRF meteorology on days when MDA8 > 60 ppb (Figure 3-16). The CAMx NAM run performed slightly better when all days were considered (i.e., on lower MDA8 ozone days) (Figure 3-16; Figure 3-17).

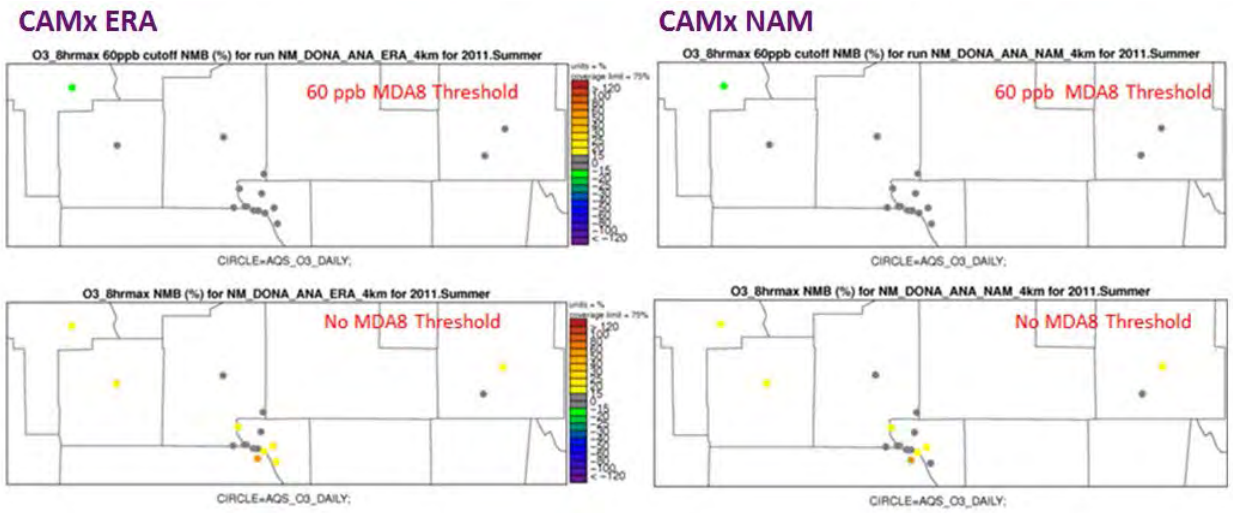


Figure 3-16. Comparison of NMB for the CAMx ERA (left) and CAMx NAM (right) model runs. Upper figures have 60 ppb MDA8 threshold and no threshold was used for the lower figures.

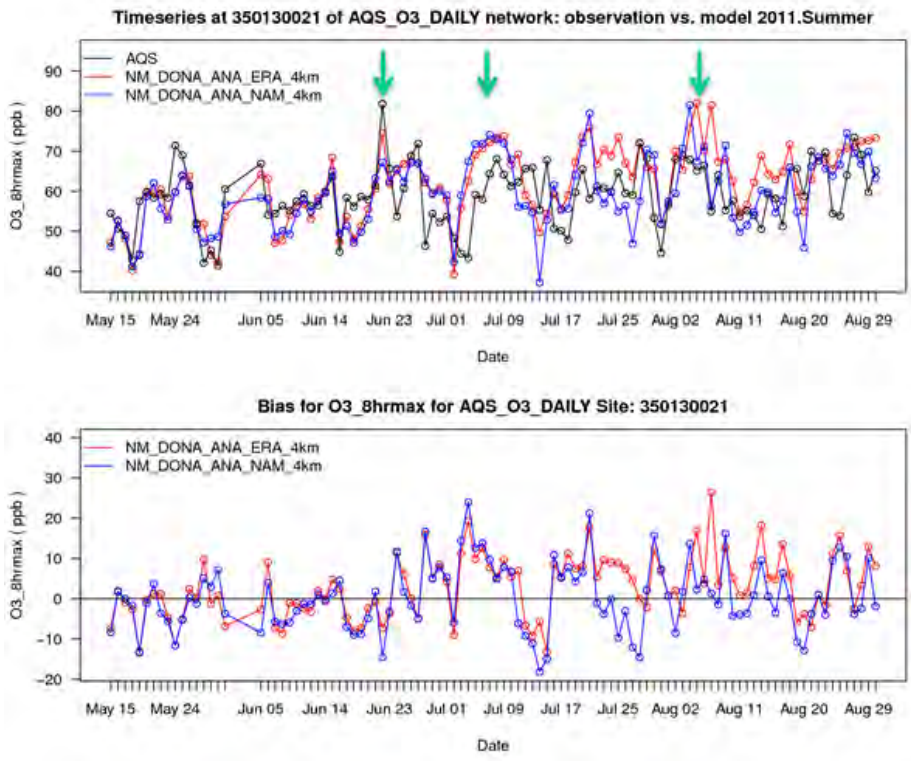


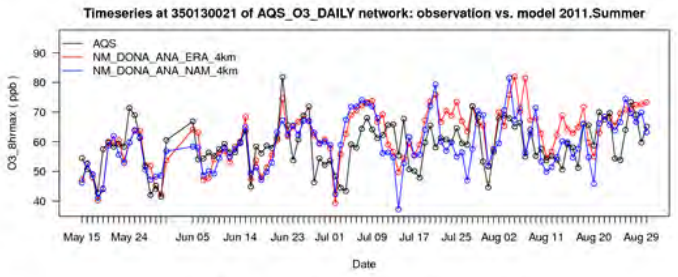
Figure 3-17. Upper panel: time series of observed (black) and modeled MDA8 ozone for the CAMx ERA (red) and CAMx NAM (blue) runs at the Desert View monitor. Lower panel: Model bias in MDA8 ozone for the CAMx ERA (red) and CAMx NAM (blue) runs at the Desert View monitor. Left green arrow shows a day when the model underestimated high values of observed ozone (June 22). Center and right green arrows show examples of July and August periods when the model had a persistent regional high bias for ozone.

We examined performance at the ground level ozone monitors within Doña Ana County in light of the form of the NAAQS for ozone and the EPA's recommended method for performing modeled attainment demonstrations (EPA, 2014) using the Modeled Attainment Test Software (MATS). The MPE focused on the MDA8 ozone on the highest modeled days because the modeling plan called for a modeled attainment demonstration for Doña Ana County using the 2011 base case model and the 2025 future year model. In carrying out the base case model performance, we considered how CAMx performance in the 2011 base year runs would affect the modeled attainment demonstration and selected the CAMx model run that would provide the more reliable future year ozone projection.

Figure 3-18 presents ranked lists of the 10 days with the highest modeled values of modeled MDA8 ozone at the Desert View, NM monitor for the CAMx ERA and CAMx NAM runs. The highest modeled MDA8 ozone days do not correspond well to high observed MDA8 ozone in either CAMx run. In general, the highest modeled days are days on which the model greatly overestimates the observed MDA8 ozone. For example, on the highest modeled MDA8 ozone day in the CAMx ERA run, the modeled MDA8 ozone was 82 ppb, while the observed MDA8 ozone was 65 ppb, corresponding to a model bias of 17 ppb in the MDA8. There was only one day out of the 10 highest modeled days in the CAMx ERA run that corresponded to a day when the observed MDA8 ozone exceeded 70 ppb: June 22. The CAMx ERA bias on June 22 was -7 ppb, consistent with the MPE statistical analysis that showed that CAMx ERA tended to underestimate observed ozone on high observed ozone days.

NM_DONA_ANA_ERA_4km				
Rank	Date	Obs_Average	Model_Average	Bias_Average
1	8/5/2011	65.13	81.97	16.84
2	8/7/2011	55.00	81.43	26.43
3	7/21/2011	58.13	75.84	17.71
4	8/4/2011	67.88	75.79	7.91
5	6/22/2011	81.75	74.45	-7.30
6	7/9/2011	64.13	73.71	9.58
7	7/20/2011	65.50	73.57	8.07
8	7/25/2011	64.63	73.44	8.82
9	7/8/2011	68.00	73.34	5.34
10	8/30/2011	65.13	73.31	8.18

NM_DONA_ANA_NAM_4km				
Rank	Date	Obs_Average	Model_Average	Bias_Average
1	8/4/2011	67.88	81.49	13.62
2	7/21/2011	58.13	79.34	21.22
3	8/26/2011	64.00	74.45	10.45
4	7/7/2011	64.38	74.05	9.67
5	7/8/2011	68.00	72.93	4.93
6	7/20/2011	65.50	72.03	6.53
7	7/9/2011	64.13	71.94	7.81
8	7/6/2011	58.00	71.82	13.82
9	7/5/2011	59.13	71.76	12.64
10	8/9/2011	55.25	71.40	16.15



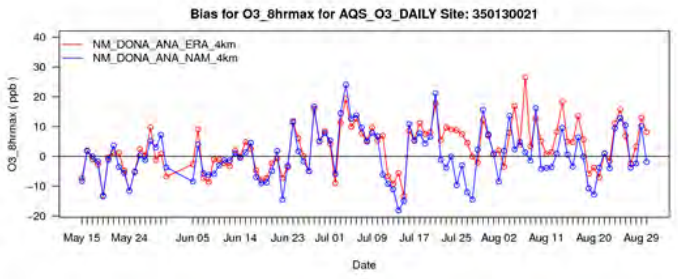


Figure 3-18. Upper (lower) left panel: Ranked list of the 10 days with the highest modeled values of modeled MDA8 ozone (ppb) at the Desert View, NM monitor for the CAMx ERA (NAM) run. Also shown are date, observed MDA8 (ppb) and the model bias (ppb). Upper right panel: time series of observed (black) and modeled MDA8 ozone for the CAMx ERA (red) and CAMx NAM (blue) runs at the Desert View monitor. Lower right panel: Model bias in MDA8 ozone for the CAMx ERA (red) and CAMx NAM (blue) runs at the Desert View monitor.

In the CAMx NAM run, none of the 10 highest modeled days corresponded to a day with observed MDA8 exceeding 70 ppb. The CAMx NAM run bias was positive on all 10 of the highest modeled days. For both the CAMx ERA and CAMx NAM runs, the 10 highest modeled days occurred mainly during July and August, which are periods when both runs saw persistent overestimates of MDA8 ozone at the Desert View monitor.

For both CAMx runs, the 10 highest MDA8 ozone days that would form the relative reduction factor (RRF) in the design value calculation for Doña Ana County monitors had significant regional overestimates of ozone, and most of the 10 highest modeled MDA8 ozone days did not have high observed ozone. It is therefore uncertain whether either model run could provide useful results for analyzing local emissions control strategies for Doña Ana County using the EPA MATS default RRF method. Local controls would not be predicted to reduce Doña Ana County ozone if the RRF is formed from days when modeled ozone is driven by an overestimated regional background.

Therefore, we evaluated use of an ozone model performance criterion in selecting days for making RRFs and future year design value projections and using this procedure to determine whether the CAMx NAM or CAMx ERA run should be used as the 2011 base case in the SNMOS. We used only modeled days in which the observed and modeled MDA8 ozone are within a specified % bias of each other. We therefore formed RRFs based on more days with observed high ozone and better model performance. Days on which the model performed poorly would not be used in the RRF. There are precedents for using an MPE filter in selecting days for use in RRFs in making future year ozone projections including modeling done in California (e.g., SCAQMD AQMP[7]).

To illustrate the procedure, we apply a ±10% bias criterion to the 10 highest modeled MDA8 ozone days at the Desert View monitor. If we were to apply the default MATS method to calculate the RRF, the days shaded in blue in Figure 3-19 would be selected. Only one of the top 10 observed MDA8 ozone days (shaded yellow) at the Desert View monitor would be included using this method.

[7] http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2012-air-quality-management-plan/final-2012-aqmp-(february-2013)/appendix-v-final-2012.pdf

		MDA8 (ppb)		Bias	
Rank	Date	Observed	Modeled	(ppb)	(%)
1	8/5/2011	65.125	81.966	16.841	25.86%
2	8/7/2011	55	81.433	26.433	48.06%
3	7/21/2011	58.125	75.839	17.714	30.48%
4	8/4/2011	67.875	75.785	7.91	11.65%
5	6/22/2011	81.75	74.447	-7.303	-8.93%
6	7/9/2011	64.125	73.708	9.583	14.94%
7	7/20/2011	65.5	73.573	8.073	12.33%
8	7/25/2011	64.625	73.442	8.817	13.64%
9	7/8/2011	68	73.339	5.339	7.85%
10	8/30/2011	65.125	73.307	8.182	12.56%

Top 10 observed MDA8 days

Top 10 modeled MDA8 days

Figure 3-19. Desert View monitor: default MATS method for selecting 10 highest modeled days for the RRF.

		MDA8 (ppb)		Bias	
Rank	Date	Observed	Modeled	(ppb)	(%)
1	6/22/2011	81.75	74.447	-7.303	-8.93%
2	7/8/2011	68	73.339	5.339	7.85%
3	8/28/2011	69.125	72.483	3.358	4.86%
4	7/28/2011	72	71.9	-0.1	-0.14%
5	8/18/2011	66	71.665	5.665	8.58%
6	8/27/2011	73.375	70.966	-2.409	-3.28%
7	8/6/2011	66.375	70.191	3.816	5.75%
8	8/2/2011	68	69.984	1.984	2.92%
9	6/26/2011	68.75	68.794	0.044	0.06%
10	8/22/2011	67.5	68.517	1.017	1.51%

Top 10 observed MDA8 days

Top 10 modeled MDA8 days

Figure 3-20. Desert View monitor: alternate method for selecting 10 highest modeled days for the RRF.

If we select only the top 10 modeled MDA8 ozone days on which the bias was < ±10%, we obtain a different population of days (Figure 3-20). The 10 days to be used in the RRF now include 4 of the 10 highest observed days at Desert View, and model performance is reasonably good on all days that would go into the RRF. Observed and modeled MDA8 values are now closer to the observed base year design value than would be the case using the default MATS method shown in Figure 3-19.

We tested this procedure using bias thresholds ranging from 5% to 20% for the CAMx ERA and CAMx NAM runs. For each bias threshold, we determined the number of modeled MDA8 ozone days in the RRF (top 10 days) that were also among the 10 highest observed MDA8 ozone days. For all values of the bias threshold, using the CAMx ERA run produced a higher number of days in the ranked list of the 10 highest modeled MDA8 ozone days that also corresponded to days that were among the top 10 observed MDA8 ozone days at the Doña Ana County monitors. Therefore, the CAMx ERA run was better suited for making future year ozone projections and for emissions control strategy development. The bias threshold that produced the highest number of top 10 observed MDA8 ozone days in the list of 10 highest modeled MDA8 ozone days was the 10% threshold, and we recommended that this threshold be used in making future year ozone projections in the SNMOS in addition to the default method outlined in the EPA Modeling Guidance (EPA, 2014).

Once the ozone MPE was completed, we conducted a model performance evaluation for the CAMx ERA run for ozone precursors and fine particulate matter ($PM_{2.5}$) and its component species with a focus on the modeling results for Doña Ana County. We evaluated the ozone precursors carbon monoxide (CO) and nitrogen dioxide (NO_2), but did not include volatile organic compound (VOC) species due to lack of observed data. Although the main focus of this study was ozone, the $PM_{2.5}$ evaluation included total $PM_{2.5}$ along with the component species sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), elemental carbon (EC), and organic carbon (OC).

NO_2 and CO performance are typical of photochemical model simulations of the Western U.S. and are comparable to performance noted in the WAQS 2011b modeling (Adelman et al., 2016) and the Three State Air Quality Study (3SAQS; Adelman et al., 2015b). The SNMOS PM performance evaluation showed that $PM_{2.5}$ was underestimated across the New Mexico and the surrounding region and that the underestimate of total $PM_{2.5}$ was consistent with modeled underestimates of several of its component species including NH_4, NO_3, and SO_4. While there were shortcomings in model performance for the CAMx ERA simulation of $PM_{2.5}$ and its component species, performance was roughly comparable to that of other similar studies in the western U.S. such as the WAQS and 3SAQS. PM performance was not the main focus of the SNMOS, and so no effort was expended to try to diagnose and improve model performance for PM. We noted the reasonable model performance and concluded that the CAMx 2011 SNMOS model was functioning as expected.

3.7.2 Significant Findings

CAMx base year 2011 model performance was evaluated on the 12/4 km SNMOS domains for two CAMx runs that used different meteorological inputs. For both CAMx runs, model performance for MDA8 ozone was acceptable based on comparison with EPA statistical performance benchmarks.

In both runs, CAMx had an overall high bias when all days were considered, but underestimated ozone on days with observed MDA8 ozone > 60 ppb. The CAMx run using ERA WRF meteorology performed slightly better than CAMx with NAM WRF meteorology when MDA8 ozone > 60 ppb. The CAMx NAM run performed slightly better when all days were considered.

For both CAMx runs, many of the 10 highest MDA8 ozone days that would be used to form an RRF for future year design value projections for Doña Ana County monitors had significant region-wide overestimates of ozone. Most of the 10 highest modeled MDA8 days did not have high observed MDA8 ozone. We proposed an alternate method of making future year projections using a model performance criterion that selects only days when modeled ozone is high and model performance is within acceptable bias limits. When this alternate procedure was used, the CAMx ERA run used more of 10 highest observed days corresponding to high modeled MDA8 ozone days in the projection calculation. In a perfect model run, the 10 highest model days would correspond to the 10 highest observed days, so we selected the run that came closer to this ideal.

We therefore selected the CAMx ERA run as the SNMOS 2011 base year run due to its better performance within the 4-km and 12-km domain on days where observed MDA8 ozone > 60 ppb as well as the fact that RRFs formed with this run had a better correspondence between high modeled and high observed MDA8 days.

In summary, we conclude that model performance for ozone, ozone precursors NO_2 and CO and PM was adequate for the SNMOS in the CAMx ERA run.

3.7.3 Milestones and Deliverables

- Base case modeling and model performance evaluation report. (Completed 4/17/2016)

3.8 Task 8: Prepare Future Year Emissions with SMOKE

3.8.1 Task Summary

The objective of this task was to combine the U.S. EPA 2011v2 modeling platform 2025 projection inventory, WAQS future year O&G inventories, and future year Mexico inventories to estimate future year emissions for the SNMOS. For this task we collected the 2025 emissions inventory and ancillary data from the US EPA 2011v6.2 modeling platform (US EPA, 2015). We applied the same version and configuration of SMOKE used for the SNMOS base year modeling to prepare future year, CAMx-ready emissions on the project 12-km and 4-km modeling domains. All of the natural source emissions and ancillary data were held constant with the 2011 base year modeling. Table 3-8 lists the emissions data used for the SNMOS future year modeling. We summarized the future year emissions inventories and processing results in a series of plots and developed a Power Point presentation on future year emissions modeling.

Table 3-8. SNMOS future year emissions data summary

Category	Data Source	Projection Year	Notes
Non-oil and gas	EPA 2011NEIv6.2	2025	Same categories as base year.
Oil and gas	Ramboll Environ and WAQS	2020 (Phase 2)	Permian basin projections for 2025 from NEI2011v6.2.
Mexico	ERG and EPA	2025	

	2011NEIv6.2		
Biogenic	SNMOS	Same as base year	No projection.
Fires	PMDETAIL version 2	Same as base year	No projection.
Lightning	SNMOS	Same as base year	No projection.
Ancillary Data	WAQS	Same as base year	No projection.

Figure 3-21 through Figure 3-26 summarize the New Mexico county base and future year NOx and VOC emissions. Figure 3-22 illustrates that Doña Ana County is projected to experience a 59.6% decrease in NOx emissions from 2011 to 2025, the majority of which will come from reductions in on-road mobile source emissions. Figure 3-25 shows that Doña Ana County is projected to experience a 42.1% decrease in VOC emissions, also primarily from decreases in on-road mobile emissions.

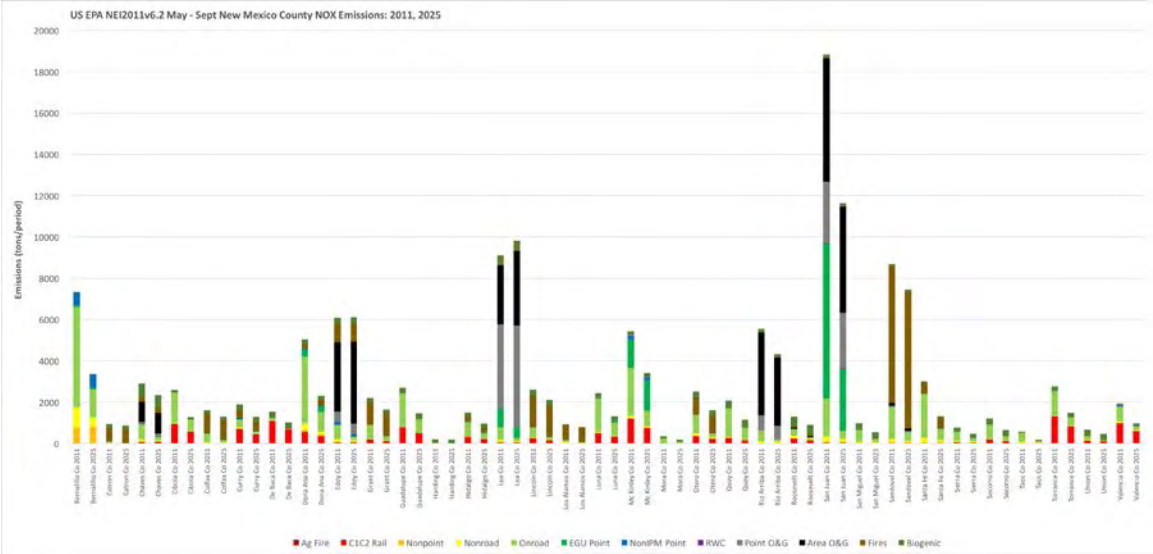


Figure 3-21.New Mexico county 2011 and 2025 NOx emissions.

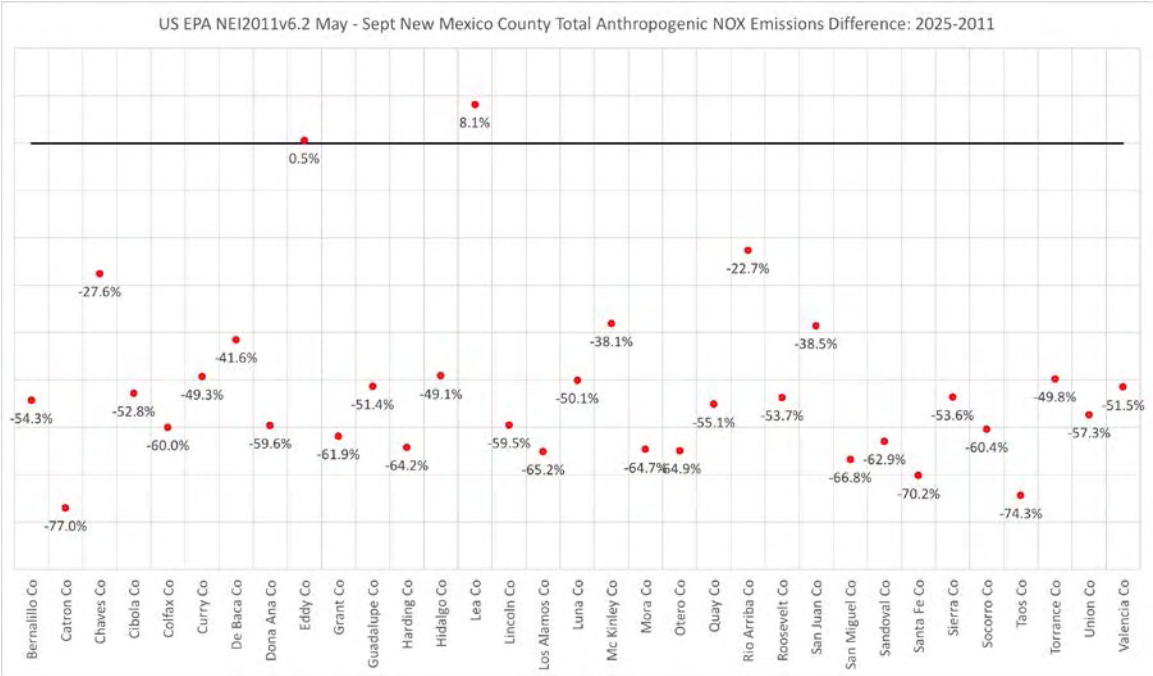


Figure 3-22. New Mexico county total anthropogenic NOx emissions change.

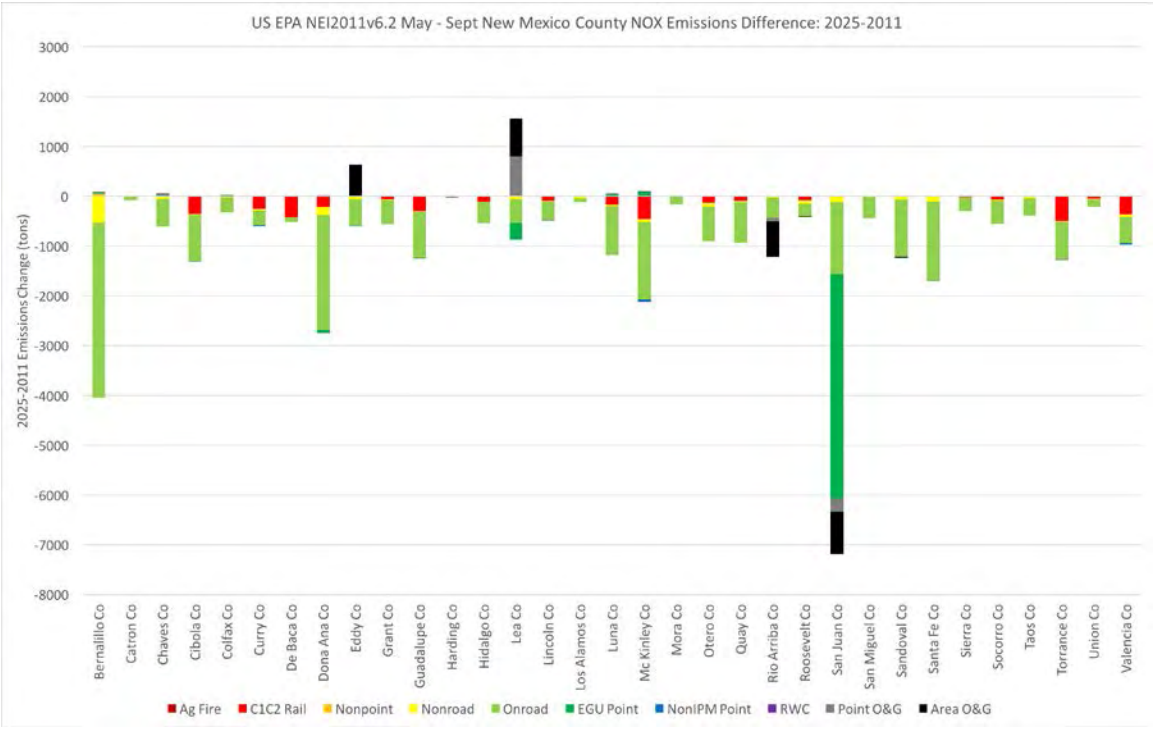


Figure 3-23. New Mexico 2011 and 2025 NOx emissions differences.

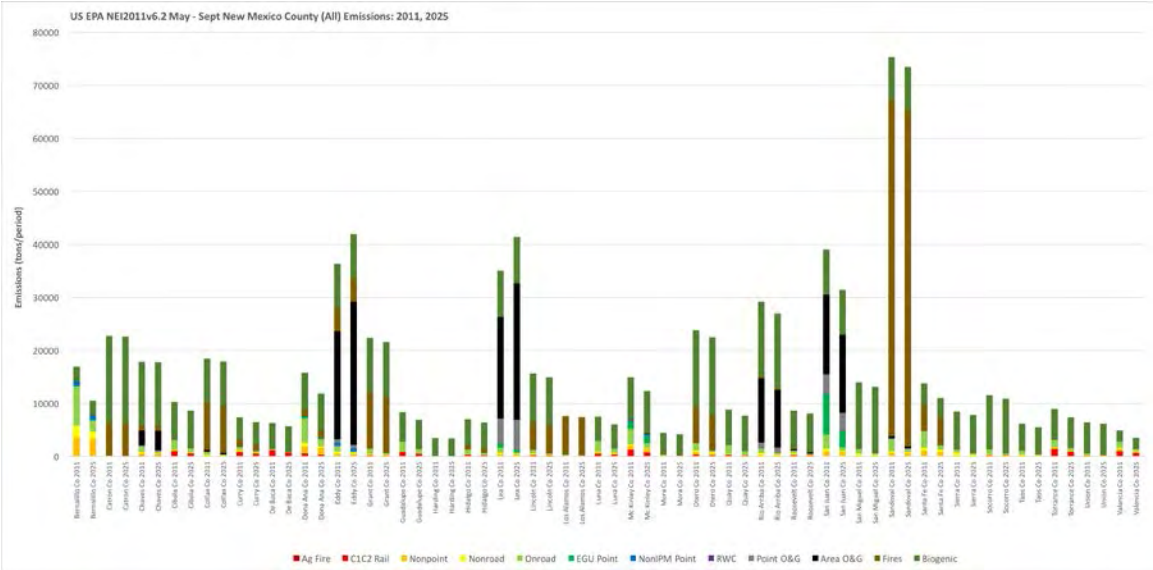


Figure 3-24. New Mexico county 2011 and 2025 VOC emissions.

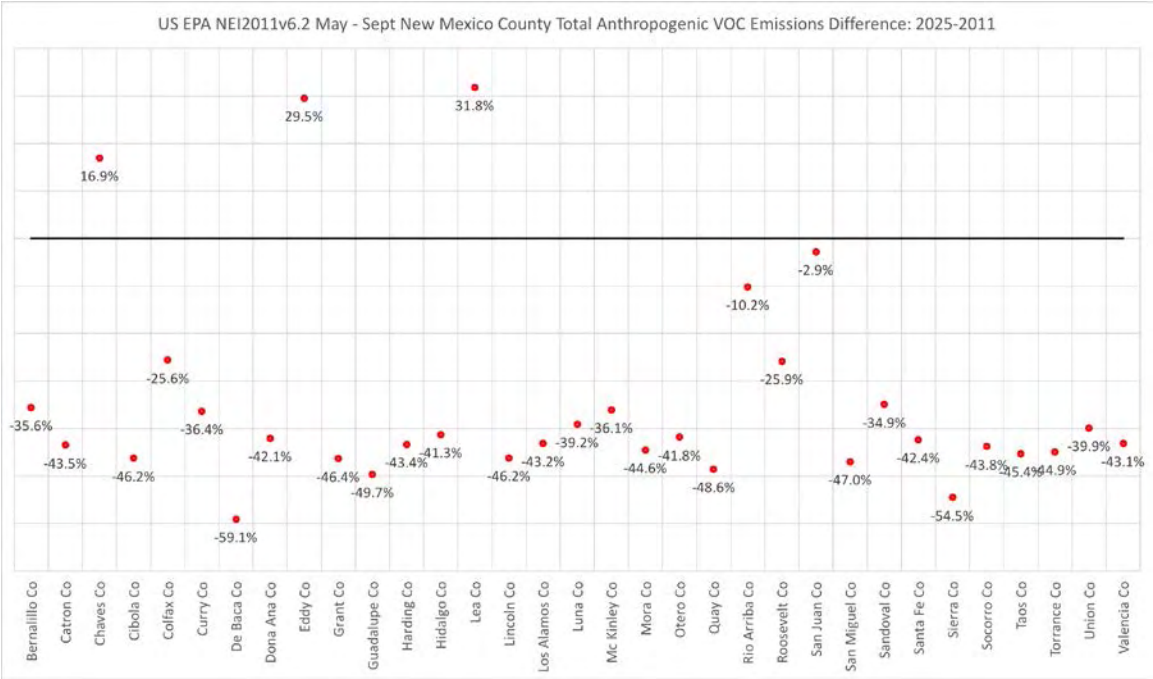


Figure 3-25. New Mexico county total anthropogenic VOC emissions change.

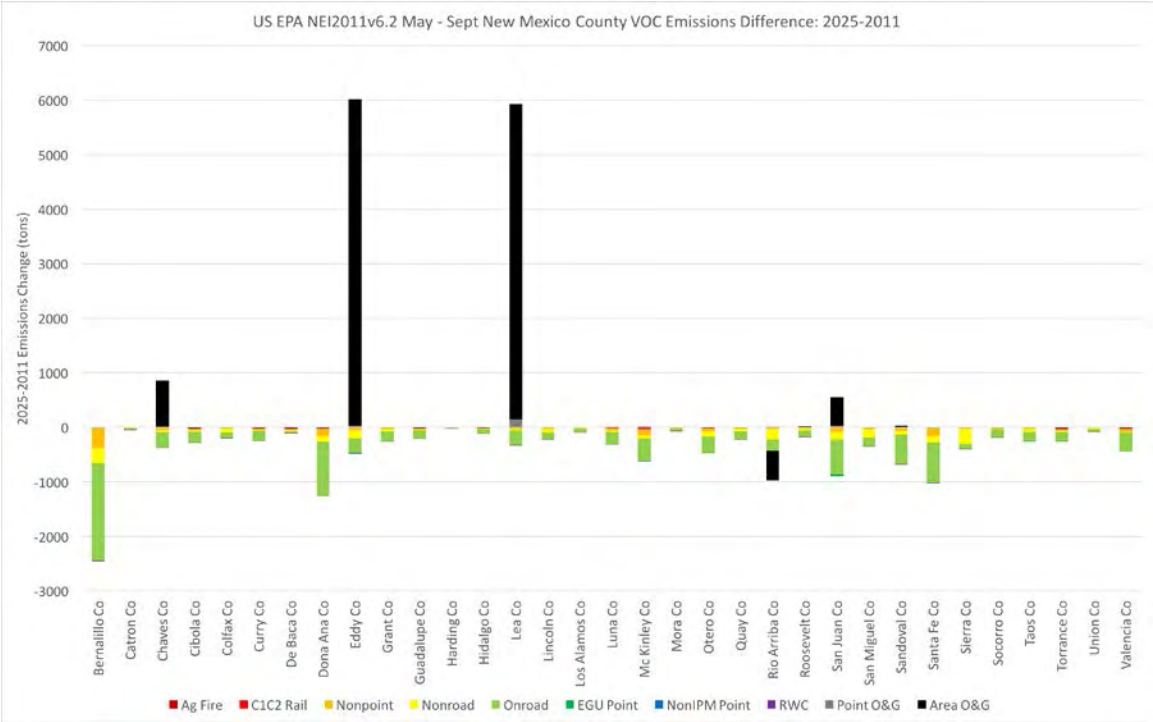


Figure 3-26. New Mexico 2011 and 2025 VOC emissions differences.

Additional details about the future year emissions data used for the SNMOS is available in the final Power Point presentation for this task (UNC-IE and Ramboll Environ, 2016a).

3.8.2 Significant Findings

In most of the New Mexico counties, ozone precursor (NOx and VOC) emissions are projected to decrease in 2025 relative to 2011. The exceptions are the oil and gas counties in the Permian Basin, which are projected to experience increases in both NOx and VOC emissions. Doña Ana County ozone precursor emissions are projected to decrease in 2025 relative to 2011, primarily as a result of ~70% reductions in on-road mobile NOx and VOC emissions.

3.8.3 Milestones and Deliverables

- Summarize the future year emissions inventories and processing results (Completed 4/30/2016)
- Power Point Presentation on future year emissions modeling (Completed 4/30/2016)
- CAMx-ready 2025 base year emissions on the project 12-km and 4-km modeling domains (Completed 4/30/2016)

3.9 Task 9: Future Year Air Quality Modeling

3.9.1 Task Summary

The objective of this task was to simulate future year summer season air quality using CAMx. In coordination with NMED we selected 2025 as the future year. We ran CAMx using the same configuration and, with the exception of the emissions, input data as the SNMOS 2011 CAMx simulation (see Task 6). We prepared the 2025 future year emissions estimates in Task 8. Upon completion of the CAMx simulation, we compared the 2025 ozone air quality projections with the 2011 estimates at the locations of ozone air quality monitors in Doña Ana County. The results of the simulation and the comparison to the base year were summarized in a final PowerPoint presentation.

Figure 3-27 compares differences between the CAMx estimates of 2025 and 2011 air quality. This figure also shows differences in the corresponding primary emissions (NOx and VOC) that drive ozone formation. As seen in this figure, CAMx predicted that ozone concentrations will generally decrease across the modeling domain in the entire summer season in 2025 relative to 2011. Large projected decreases in NOx and VOC emissions from on-road mobile sources appeared to be the factor driving the ozone reductions in 2025. Projected increases in oil and gas source emissions in the Permian basin were not predicted to impact future year air quality in Doña Ana County.

Additional details about the future year air quality modeling are available in the final Power Point presentation for this task (UNC-IE and Ramboll Environ, 2016b).

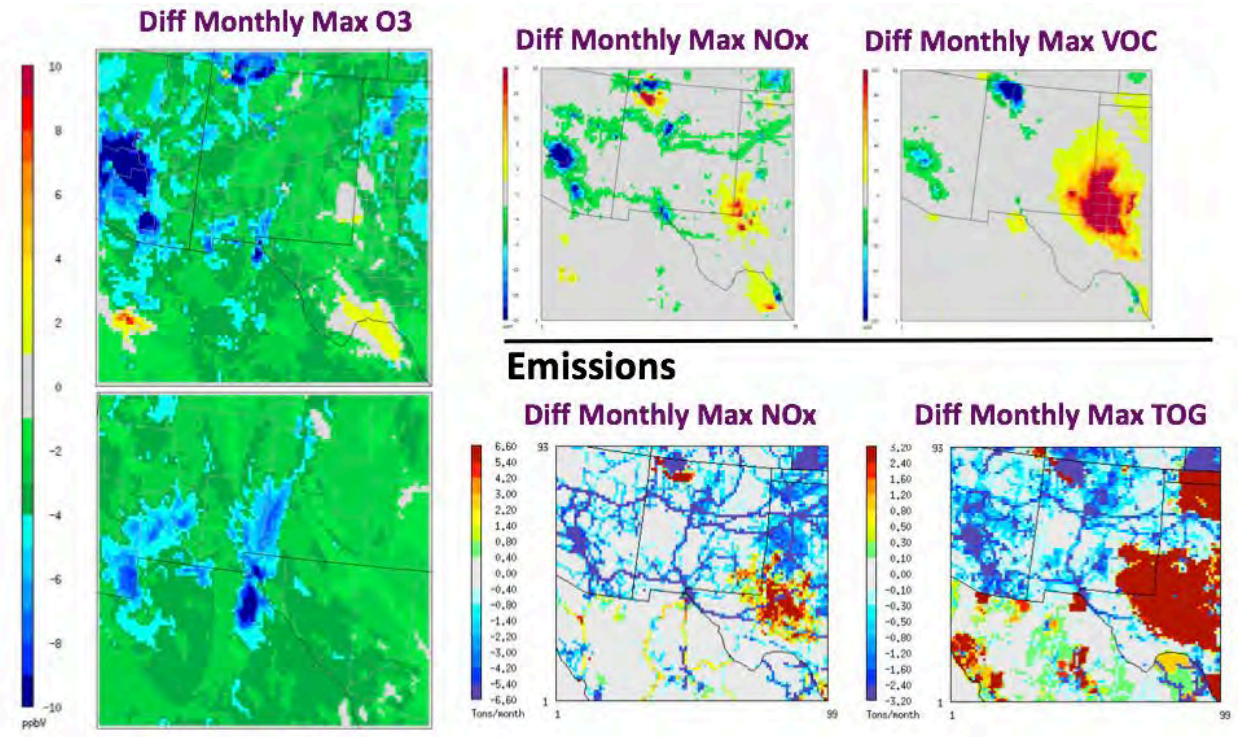


Figure 3-27. July 2011 differences (2025-2011) in CAMx monthly maximum O_3, NOx, VOC and corresponding emissions differences.

3.9.2 Significant Findings

CAMx predicted future year ozone reductions on most days of the summer season in Doña Ana County. The ozone reductions are consistent with significant reductions in ozone precursor emissions (NOx and VOC) in the area around Doña Ana County, particularly from the on-road mobile sector.

3.9.3 Milestones and Deliverables

- Power Point Presentation on future year air quality modeling (Completed 5/31/2016)

3.10 Task 10: Modeled Attainment Test

3.10.1 Task Summary

The objective of this task was to conduct a model attainment test using the U.S. EPA Model Attainment Test Software (MATS)[8] to estimate future design values (DVFs), relative response factors (RRFs), and unmonitored area analysis (UAA) for the SNMOS 12 and 4-km modeling domains. We used MATS version 2.6.1. to estimate DVFs and RRFs with the EPA default MATS configuration. In addition to the EPA defaults, we tested two different MATS configuration options to quantify how they impacted the attainment test results. Based on analysis conducted in Task 6, we also conducted an alternative MATS analysis that used the top 10 modeled 8-hour ozone days for days in which CAMx had a normalized mean bias < 10%. We

[8] https://www3.epa.gov/scram001/modelingapps_mats.htm

created plots of all the MATS simulations and prepared a Power Point presentation of the results.

Under this task we compared ten years of design values at the Doña Ana County monitors and recent projections from the EPA to the SNMOS 2025 design values. Figure 3-28 compares the official ozone design values at each of the Doña Ana County monitors from 2006 to 2015. This plot illustrates that 2011 was the lowest reported year for several of the sites. The plot also compares the 2011 DVCs, EPA modeling 2017 DVFs, and SNMOS 2025 DVFs for the Doña Ana County monitors. While the 2025 DVFs appear consistent with the EPA 2017 modeling, it is important to note that as the SNMOS projections were made from 2011, they may be biased low because they are based off of an historically low concentration base year.

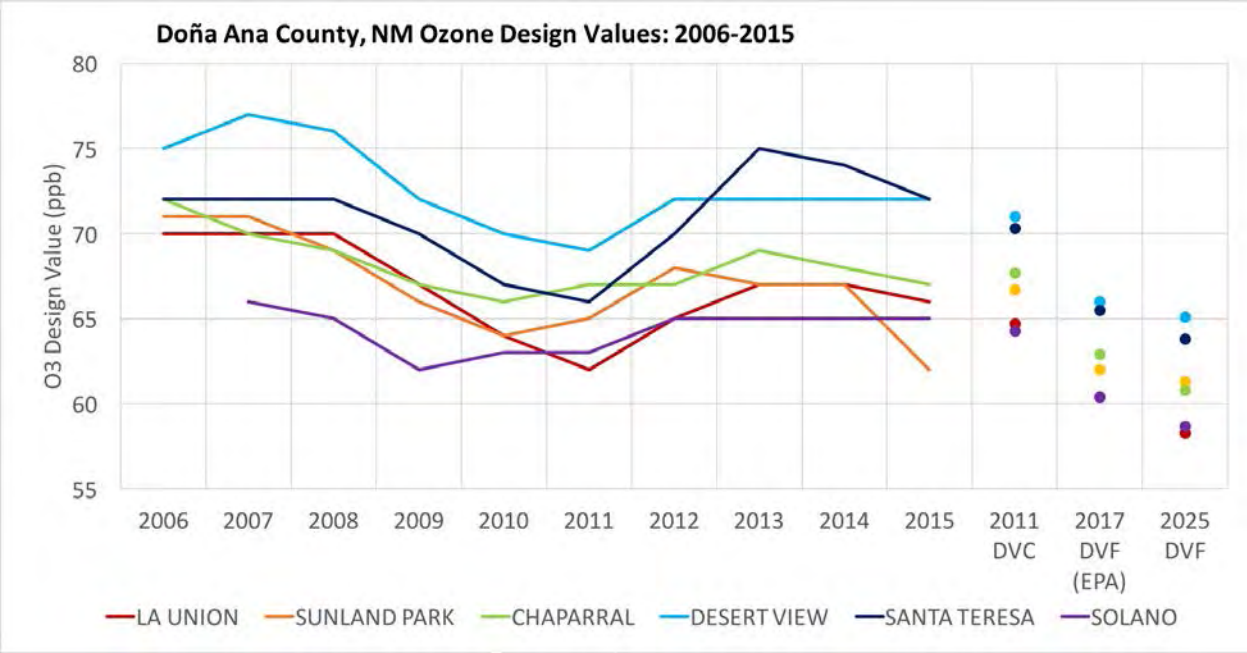


Figure 3-28. Annual ozone design values and a comparison of DVFs for EPA 2017 and SNMOS 2025 modeling.

Using the EPA default MATS configuration, we demonstrated that all of the monitors in the SNMOS 12-km domain, including all of the sites in Doña Ana County, are projected to be in attainment of the 2015 NAAQS for 8-hour ozone (70 ppb) in 2025 (Figure 3-29).

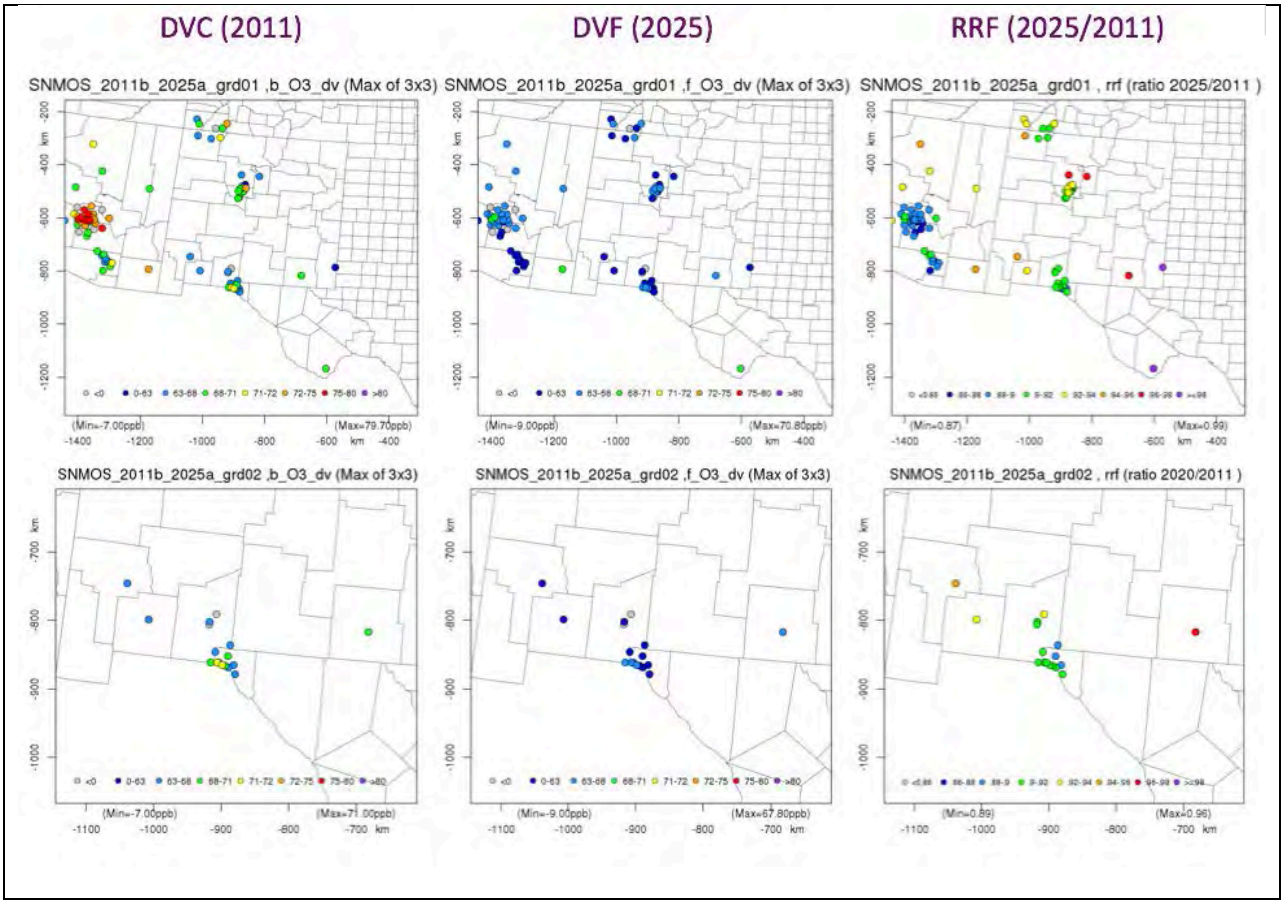


Figure 3-29. SNMOS 12-km (top) 4-km (bottom) domain MATS results.

In order to evaluate the sensitivity of the calculated DVFs to the MATS configuration and to biases in the CAMx ozone model, we conducted the following MATS sensitivity experiments:

- Spatial Matrix Experiment: test the impact of the size of the spatial matrix surrounding each monitor. MATS finds the maximum concentration from a matrix of modeled grid cells surrounding a monitor in the RRF calculation. We changed the EPA default from a 3x3 matrix to a 7x7 matrix.

- Temporal Averaging Experiment: test the impact of using fewer averaging days. Current EPA guidance uses the top 10 modeled daily maximum 8-hour average ozone in the RRF calculation. We tested the impact of using the top 5 modeled days.

- Model Performance Filter Experiment: test the impact of using only model days where the bias < 10%. We filtered the base year CAMx results to select the top 10 modeled days from only those days in which the Normalized Mean Bias was <= 10%. As this experiment required a separate MATS run for each monitor, we only used it for the Doña Ana County monitors in the 4-km modeling domain.

All of the experiments that we tested had little impact on the future year attainment status for the Doña Ana County monitors; they all continued to project attainment of the NAAQS. While the ozone bias filtering changed the DVF predictions by up to a few percent and resulted in a mix of higher and lower DVFs at the Doña Ana County monitors relative to the EPA default MATS configuration, none of the DVFs were greater than 65 ppb (Table 3-9).

Table 3-9. Low model bias MATS configuration 4-km domain results

Site ID	DVC	DVF (Base)	DVF (Bias < 10%)	RRF (Base)	RRF (Bias < 10%)	Site Name
350130008	64.7	58.3	60.2	0.9026	0.9306	LA UNION
350130017	66.7	61.3	60.9	0.9195	0.9136	SUNLAND PARK
350130020	67.7	60.8	62.9	0.8985	0.9293	CHAPARRAL
350130021	71	65.1	64.5	0.9183	0.9092	DESERT VIEW
350130022	70.3	63.8	64.3	0.9086	0.9158	SANTA TERESA
350130023	64.3	58.7	59.5	0.9136	0.9263	750 N.SOLANO DRIVE

The unmonitored area analysis that we conducted showed that all but a few cells in the 4-km domain will be in attainment in 2025 (Figure 3-30). The nonattainment cells in northern Grant County resulted from poor model performance related to a wildfire plume.

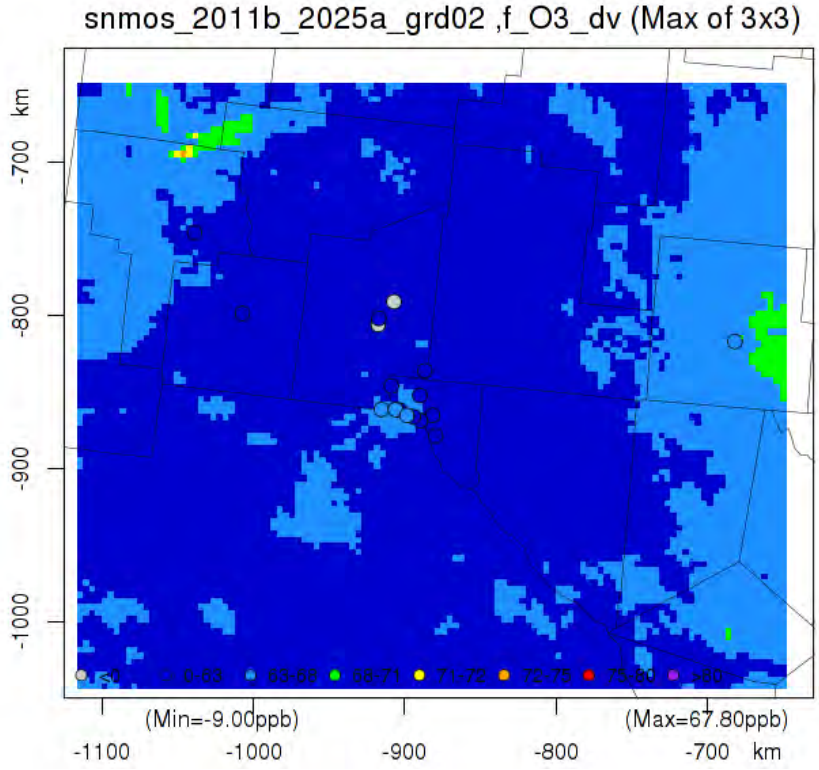


Figure 3-30. MATS unmonitored area analysis for 2025.

Additional details about the future year ozone projections using MATS is available in the final Power Point presentation for this task (UNC-IE and Ramboll Environ, 2016b).

3.10.2 Significant Findings

All of the Doña Ana County monitors are projected to be in attainment of the 2015 ozone NAAQS in 2025 (Table 3-10). We ran a series of experiments that showed despite fairly large changes to the EPA default MATS configuration, the projections of the future year attainment status did not significantly change.

Table 3-10. SNMOS 4-km CAMx modeling DVFs and RRFs

Site ID	DVC	DVF	RRF	County	Site Name
350130008	64.7	58.3	0.9026	Dona Ana	LA UNION
350130017	66.7	61.3	0.9195	Dona Ana	SUNLAND PARK
350130019	-7	-9	0.9239	Dona Ana	LAS CRUCES WELL STATION #41;HOLMAN ROAD
350130020	67.7	60.8	0.8985	Dona Ana	CHAPARRAL
350130021	71	65.1	0.9183	Dona Ana	DESERT VIEW
350130022	70.3	63.8	0.9086	Dona Ana	SANTA TERESA
350130023	64.3	58.7	0.9136	Dona Ana	750 N.SOLANO DRIVE
350131012	-7	-9	0.9198	Dona Ana	HOLIDAY INN
350151005	70.3	67.8	0.9646	Eddy	HOLLAND ST;SE OF WATER TANK;CARLSBAD;NM
350171003	65	62	0.955	Grant	CHINO BLVD NR HURLEY PARK; HURLEY;NM
350290003	63	58.6	0.9311	Luna	310 AIRPORT ROAD; DEMING; NM 88030
481410029	65	58.4	0.8996	El Paso	10834 IVANHOE; IVANHOE FIRE STATION
481410037	71	65.2	0.9186	El Paso	RIM RD. NEAR HAWTHORNE NEXT TO UT POLICE
481410044	69	62.7	0.9098	El Paso	800 S. SAN MARCIAL STREET
481410055	66.3	60.1	0.9069	El Paso	650 R.E. THOMASON LOOP
481410057	66	59.8	0.9071	El Paso	201 S. NEVAREZ RD.
481410058	69.3	61.7	0.8917	El Paso	5050 A YVETTE DRIVE

3.10.3 Milestones and Deliverables

- Power Point Presentation on future year ozone projections (5/31/2016)

3.11 Task 11: Future Year Emissions Sensitivity/Control Modeling

3.11.1 Task Summary

The objective of this task was to conduct CAMx sensitivity modeling to evaluate the impacts of emissions reductions on attainment of the ozone NAAQS. We ran two CAMx sensitivity simulations to quantify the impacts of emissions from anthropogenic sources in Mexico and from U.S. on-road mobile sources on ozone concentrations at monitors in Doña Ana County. We used MATS to estimate the changes in the design values and RRFs resulting from the sensitivity simulations. We created model evaluation plots comparing the base CAMx and sensitivity results and bubble plots of the results from the MATS simulations. We summarized this task and presented some of the key figures in a Power Point presentation.

We prepared the emissions and ran CAMx for two sensitivity simulations to test the impacts of key emissions sources on ozone concentrations in Doña Ana County. With the exception of the emissions changes in the designed sensitivity, all of the other CAMx inputs and configuration

remained the same as the base CAMx simulation. We ran the sensitivities for the full SNMOS modeling period (April 15 – August 31, 2011) and for both the 12-km and 4-km modeling domains.

In the first sensitivity simulation we evaluated the impact of Mexico emissions sources on 2011 air quality by removing ("zero out") all of the anthropogenic emissions in Mexico (SNMOS simulation ID: NoMex). The concept of this simulation was to estimate the ozone levels in Doña Ana County minus the influence of sources in Mexico. In the second sensitivity simulation we evaluated the sensitivity of 2025 projected U.S. air quality to the magnitude of the future year on-road mobile emissions estimates. We doubled the 2025 U.S. on-road mobile emissions (SNMOS simulation ID: 2xUSOR) to determine the sensitivity of the future year design values to this emissions source category. The concept of this simulation was to consider if a less conservative on-road mobile source projection scenario would still lead to ozone NAAQS attainment for the Doña Ana County monitors.

The NoMex simulation estimated that 2011 MDA8 ozone reduced by an average of 5.1 ppb (range -3.7 to -6.3 ppb) for the modeling period across all Doña Ana County monitors (Figure 3-31). The same figure shows a time series of observed (black) and modeled MDA8 at the Desert View monitor. The time series also shows the systematic ozone reductions in the NoMex simulation (blue) relative to the base 2011 CAMx simulation (red). The MATS results in Table 3-11 show that all of the monitors in the 4-km modeling domain reach NAAQS attainment in 2011 in the NoMex simulation. The design value at the Desert View monitor (2011 design value: 71 ppb) decreased by 6.2 ppb to 64.8 ppb. The results of the NoMex simulation provide evidence that in 2011 the monitors in Doña Ana County would have been in attainment of the ozone NAAQS but for the influence of anthropogenic emissions in Mexico.

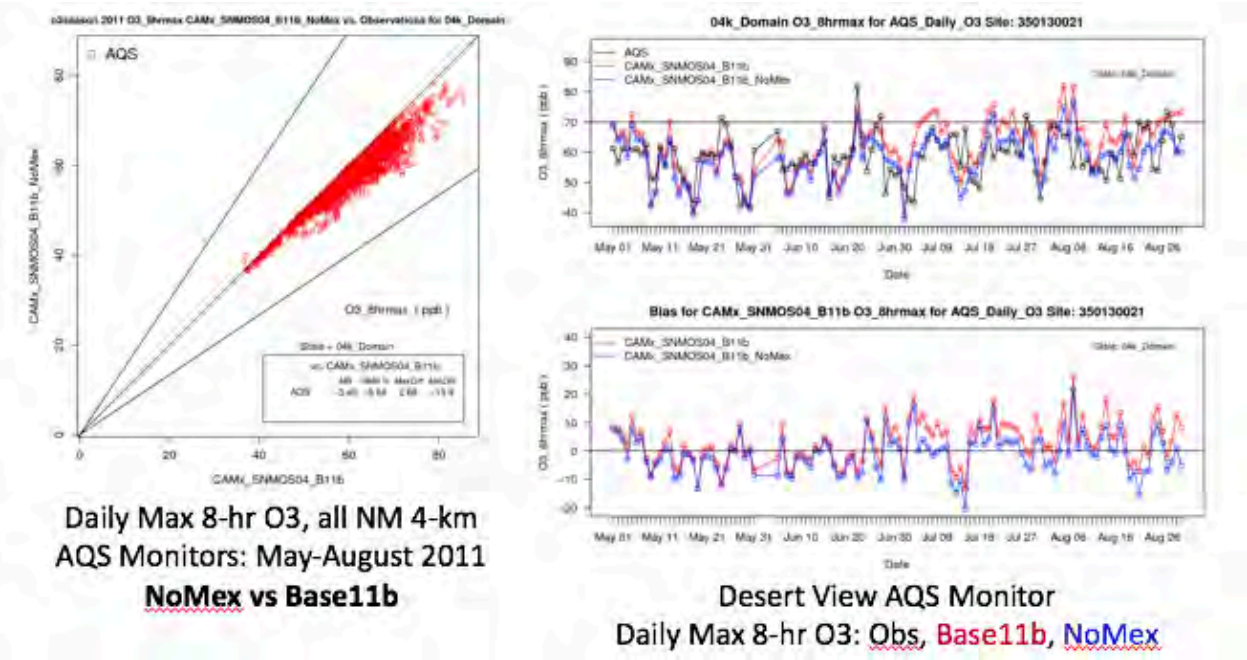


Figure 3-31. SNMOS 4-km domain 2011 zero out Mexico CAMx performance summary.

Table 3-11. SNMOS 4-km domain 2011 zero out Mexico MATS results

Site ID	DVC (2011)	DV No Mex (2011)	DV Diff	Site Name
350130008	64.7	59.6	-5.1	LA UNION
350130017	66.7	60.4	-6.3	SUNLAND PARK
350130020	67.7	63.3	-4.4	CHAPARRAL
350130021	71	64.8	-6.2	DESERT VIEW
350130022	70.3	65.2	-5.1	SANTA TERESA
350130023	64.3	60.6	-3.7	750 N.SOLANO DRIVE

The 2xUSOR simulation estimated that 2025 MDA8 ozone would increase by an average of 1.5 ppb (range: +1.3 to +1.6 ppb) for the modeling period across all Doña Ana County monitors. Despite doubling the 2025 emissions from on-road mobile sources (which contributed 70% of the anthropogenic NOx emissions in Doña Ana County), the projected air quality impacts were small. Table 3-12 shows that the DVFs for the Doña Ana County monitors were projected to increase by an average of 1.47 ppb and none of the monitors were predicted to be close to nonattainment of the 2015 ozone NAAQS (maximum 65.1 ppb at Desert View). The results of the 2xUSOR simulation demonstrate that a less conservative 2025 future year emissions scenario for U.S. on-road mobile sources than is currently estimated by MOVES will still lead to attainment of the 2015 ozone NAAQS for all monitors in Doña Ana County.

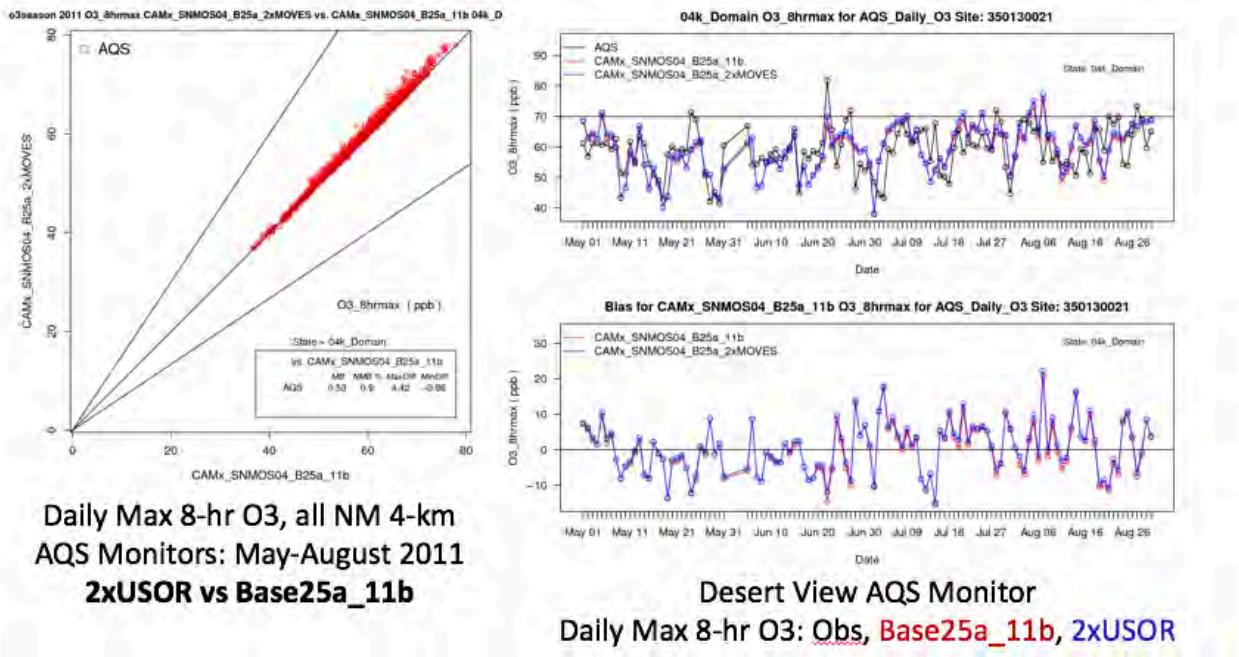


Figure 3-32. SNMOS 4-km domain 2025 double U.S. on-road emissions CAMx performance summary.

Table 3-12. SNMOS 4-km domain 2025 double U.S. on-road emissions MATS results

Site ID	DVC (2011)	DVF (2025)	DV 2xUSOR (2025)	DV Diff	RRF (2025)	RRF 2xUSOR (2025)	RRF % Change	Site Name
350130008	64.7	58.3	66.0	1.6	0.9026	0.9271	+2.71%	LA UNION
350130017	66.7	61.3	67.7	1.4	0.9195	0.9403	+2.26%	SUNLAND PARK
350130020	67.7	60.8	68.7	1.5	0.8985	0.9210	+2.50%	CHAPARRAL
350130021	71	65.1	71.9	1.5	0.9183	0.9388	+2.23%	DESERT VIEW
350130022	70.3	63.8	71.2	1.5	0.9086	0.9297	+2.32%	SANTA TERESA
350130023	64.3	58.7	65.2	1.3	0.9136	0.9341	+2.24%	750 N.SOLANO DRIVE

Additional details about the future year ozone projections using MATS are available in the final Power Point presentation for this task (UNC-IE and Ramboll Environ, 2016c).

3.11.2 Significant Findings

The results of the NoMex simulation provide evidence that in 2011 the monitors in Doña Ana County would have been in attainment of the ozone NAAQS but for the contribution of emissions from anthropogenic sources in Mexico. Despite doubling the 2025 emissions projections for U.S. on-road mobile sources, all of the monitors in Doña Ana County are projected to be well in attainment of the ozone NAAQS.

3.11.3 Milestones and Deliverables

- Power Point Presentation on future year air quality modeling (Completed 8/15/2016)

3.12 Task 12: Future Year Source Apportionment Modeling

3.12.1 Task Summary

The purpose of Task 12 was to conduct CAMx source apportionment simulations to better understand the source regions and source categories that contribute to elevated ozone concentrations in Doña Ana County and vicinity. These simulations will help set the ground work for the development of a potential State Implementation Plan (SIP) to demonstrate attainment of the ozone NAAQS. CAMx source apportionment modeling will be used to provide a complete accounting of the contributions of all sources delineated by the defined Source Groups that contribute to ozone concentrations at the Doña Ana monitoring sites and throughout the 12/4 km modeling domain.

Ozone is formed in the atmosphere by reactions of NOx and VOC in the presence of sunlight. Once formed, ozone persists and can be transported by prevailing winds. The Ozone Source Apportionment Tool (OSAT) in CAMx uses tracers to keep track of ozone production and transport (Yarwood et al., 1996; Ramboll Environ, 2015). The OSAT algorithm performs source attribution of ozone within a CAMx simulation, i.e., it provides a quantitative accounting of where ozone originated for any and all locations in the CAMx simulation. Within photochemical models like CAMx, ozone can originate from the initial conditions, the boundary conditions and emissions of ozone precursors (NOx and VOC). The OSAT method allows the emission inventory to be disaggregated to geographic regions and/or source categories for purposes of source apportionment. This allows an assessment of the role of transported ozone and precursors in

contributing to ozone episodes in Doña Ana County. The methodology is designed so that all ozone and precursor concentrations are attributed among the selected source groupings at all times. Thus, for all receptor locations and times, ozone (or ozone precursor concentrations) predicted by CAMx is attributed among the source groupings.

Source Groups are typically defined as the intersection between source regions (e.g., states) and source categories (e.g., on-road mobile sources). For the CAMx 12/4 source apportionment simulation defined four Source Regions and seven Source Categories as follows (Figure 3-33):

Source Regions (4):

- New Mexico
- Texas
- Mexico
- Arizona and remainder of other states in the 12-km domain

Source Categories (8):

- Natural (biogenics and lighting NOx)
- On-Road Mobile
- Non-Road Mobile
- Oil and Gas (point and non-point)
- Electrical Generating Unit (EGU) Point
- Non-EGU Point
- Open Land Fires (wildfire, prescribed, and agricultural burning)
- Remainder Anthropogenic.

Initial concentrations (IC) and boundary condition (BC) are always included as Source Groups, so that there were a total of 30 Source Groups (30 = 4 x 7 + 2) for the source apportionment modeling. The BCs represent the contribution from transport from outside of the 12/4 km SNMOS domain. This includes transport from sources in the remainder of U.S. outside the 12/4 km domain, international transport, and the natural global ozone background including stratospheric ozone intrusions. The boundary conditions as defined for the SNMOS includes contributions from additional sources of emissions relative to the North American background (NAB)[9] or the U.S. background (USB)[10].

[9] North American Background Ozone (NAB) is defined by the U.S. EPA to be as the ozone levels that would exist in the absence of continental North American (i.e., Canadian, U.S., and Mexican) anthropogenic emissions

[10] U.S. background (USB) ozone is defined by the U.S. EPA to be any ozone formed from sources or processes other than U.S. manmade emissions of NOx, VOC, methane and CO. USB ozone does not include intrastate or interstate transport of manmade ozone or ozone precursors.

Figure 3-33. 12/4 km domain source regions used in source apportionment modeling.

We performed the source apportionment simulation using both the 2011 and 2025 emissions in order to:

- Obtain the contributions of Mexico to 2011 ozone design values and demonstrate that, without anthropogenic emissions from Mexico, Doña Ana County would have attained the ozone NAAQS;
- Calculate 2025 ozone projections removing the contributions of fires that have high uncertainties as well as year-to-year variations.
- Determine changes in contributions between 2011 and 2025 to explain the reductions in Doña Ana County design values and provide a rough estimate of ozone levels if the emission reductions are not as large as projected.
  - For example, the reductions in ozone due to on-road mobile sources were examined to determine what the 2025 ozone design values would be if we obtained a lower level of emission reductions.
- Provide an accounting of ozone contributions in 2025 that can be used to identify those sources that contribute the most to ozone levels in Doña Ana County.

We ran the CAMx model on the SNMOS 12/4 km grids using ozone source apportionment for April–August 2011 and 2025. CAMx was configured as in the SNMOS 2011 Base Case modeling (Table 3-7). 2011 calendar dates were used for the 2025 run. The modeling setup was identical

to that used in the Task 11 Sensitivity Modeling except for the use of the use of the CAMx source apportionment tools and the unperturbed Base Case emission inventory for 2025. The 2025 Base Case emission inventory is described in Section 3.8.

We used EPA's MATS together with the CAMx OSAT results for 2011 and 2025 to calculate design values for 2025 and carry out the following analyses:

- Determine the source regions and source categories that contribute to elevated ozone concentrations in Doña Ana County and vicinity
- Obtain the contributions of Mexico emissions to 2011 ozone design values (DVs)
- Calculate 2025 ozone DVs without the contributions of fire emissions

We followed current EPA guidance on the use of MATS. The DVF calculation used the maximum concentration from a matrix 3 x 3 matrix (9 cells) of modeled grid cells surrounding each monitor. In the RRF calculation for each monitor in the 4-km grid, we used the top 10 modeled days (10 days with the highest modeled MDA8 ozone). We used a 70 ppb threshold and set the minimum number of days at or above the threshold to one day.

To calculate the contribution of each source group to each monitor's ozone design value, we first ran MATS with the full CAMx output for the base year ($CAMx\_total_{2011}$) and the future year ($CAMx\_total_{2025}$) and calculated the future year design value (DVF_{2025}) for each monitor using following EPA Guidance:

$$DVF_{2025} = \frac{CAMx\_total_{2025}}{CAMx\_total_{2011}} \times DVC_{2011}$$

where DVC_{2011} is the base year design value based on observed ozone. Next, we subtracted the ozone contribution from the i^{th} source group (for example, New Mexico on-road mobile emissions) ($SrcGrpContrib^{i}_{2025}$) from the full model output ($CAMx\_total_{2025}$) and reran MATS without contribution from the i^{th} source group.

$$DVF^{i}_{2025} = \frac{CAMx\_total_{2025} - SrcGrpContrib^{i}_{2025}}{CAMx\_total_{2011}} \times DVC_{2011}$$

The incremental contribution to the 2025 DVF from the i^{th} source group is

$$\Delta DVF^{i}_{2025} = DVF_{2025} - DVF^{i}_{2025}.$$

We define the DVF for the year 2011 to be:

$$DVF^{i}_{2011} = \frac{CAMx\_total_{2011} - SrcGrpContrib^{i}_{2011}}{CAMx\_total_{2011}} \times DVC_{2011}$$

so that the contribution to the 2011 current year design value from source group i is

$$\Delta DVC^{i}_{2011} = DVC_{2011} - DVF^{i}_{2011}.$$

3.12.1.1 OSAT Results

In this section, we present results of the OSAT analysis. We begin with detailed source apportionment results for the Desert View monitor. Results for this monitor were similar to those for the other Doña Ana monitors, so we focus on Desert View only for the sake of brevity and because it is the only Doña Ana County monitor with a DVC_{2011} that exceeds the 2015 NAAQS of 70 ppb. Results for the other Doña Ana County monitors may be found in the Task 12 Summary PowerPoint presentation.

We used the source apportionment results to assess the importance of transport in determining ozone design values at Doña Ana monitors. We reviewed the effect of boundary conditions and transport from within the 12-km domain, but outside New Mexico. The results for the Desert View monitor are shown in Figure 3-34 and Figure 3-35. The DVC_{2011} for Desert View is 71.0 ppb and the DVF_{2025} is 65.1 ppb. The contribution from each of the 12/4 km domain source regions for both years is shown in the stacked bar charts.

The BC contribution includes the effects of sources within the U.S. (e.g., Los Angeles and Phoenix) as well as sources outside the US (Asia, regions of Mexico outside the 12/4 km grid) and the stratospheric contribution. The contribution to the Desert View DVC_{2011} and DVF_{2025} from the12-km BC contribution is far larger than those of regions within the 12-km domain and decreases from 54 ppb in 2011 to 50 ppb in 2025. The total contribution from transport is indicated by the red brackets in Figure 3-34 and includes the BC contribution as well as contributions from Mexico, Texas and the Other 12 km region that includes parts of Colorado, Oklahoma, Kansas, Utah and Arizona. In 2011, transport contributed 68.6 ppb to the Desert View design value of 71.0 ppb, while New Mexico emissions sources contributed 2.4 ppb. In 2025, transport contributed 63.5 ppb to the design value of 65.1 ppb and New Mexico sources contributed 1.6 ppb.

The New Mexico contribution to the Desert View DVC_{2011} and DVF_{2025} is smaller than the Texas and Mexico contributions in both 2011 and 2025. In 2011, New Mexico emissions sources contributed 2.4 ppb to the Desert View design value while Texas contributed 6.9 ppb and Mexico contributed 7.6 ppb. In 2025, New Mexico emissions sources contributed 1.6 ppb to the Desert View design value while Texas contributed 5.0 ppb and Mexico contributed 7.8 ppb.

The reduction in the Desert View DVF_{2025} is driven by the decrease in BCs from 54 ppb to 50 ppb and in reductions contributions from New Mexico (2.4 ppb to 1.6 ppb), Texas (6.9 ppb to 5.0 ppb). The contribution from Mexico, on the other hand, increases slightly from 7.6 ppb to 7.8 ppb.

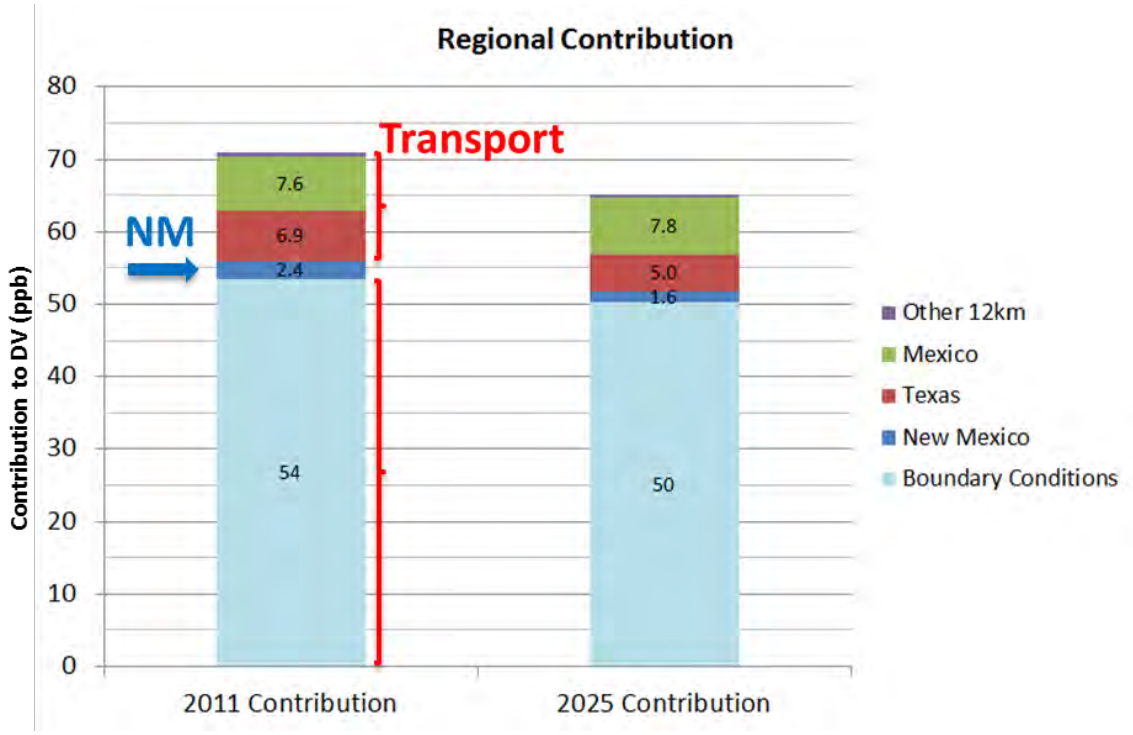


Figure 3-34. Contribution from source regions shown in Figure 3-33 and 12-km grid boundary conditions to 2011 and 2025 design values at the Desert View monitor. The contribution from New Mexico is shown in darker blue and the contribution from all sources outside New Mexico ("Transport") is indicated by the red bracket.

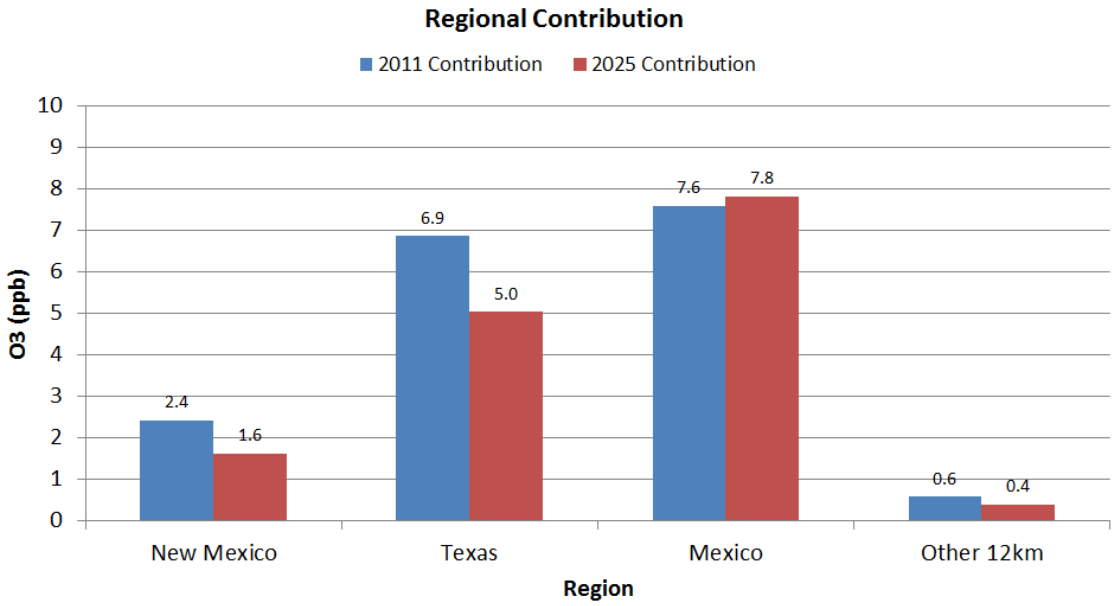


Figure 3-35. Contribution from source regions shown in Figure 3-33 to 2011 and 2025 design values at the Desert View monitor.

Figure 3-36 shows the contributions to the Desert View design values from the different emissions source categories. The largest contributions to the Desert View DVC_{2011} are from on-road mobile sources, natural sources, EGUs and non-road mobiles emissions. By 2025, the contribution of on-road mobile emissions decreases, but on-road mobile still contributes the most of any emissions source category to the Desert View design value. Natural emissions are the next largest contributor in 2025, followed by EGU and non-EGU point sources.

Figure 3-37 shows the top five contributing source groups to the DVC_{2011} at Desert View ranked by the value of their 2011 contribution alongside their 2025 contribution. The largest contributions to the Desert View DVC_{2011} are from Texas and Mexico on-road emissions and Mexico EGU and natural emissions. The largest 2025 contributions are from Mexico EGU and non-EGU point sources and on-road emissions from Texas and Mexico. Reductions in Texas, New Mexico and Mexico on-road contributions are responsible for much of the ozone decrease in the Desert View design value from 2011 to 2025.

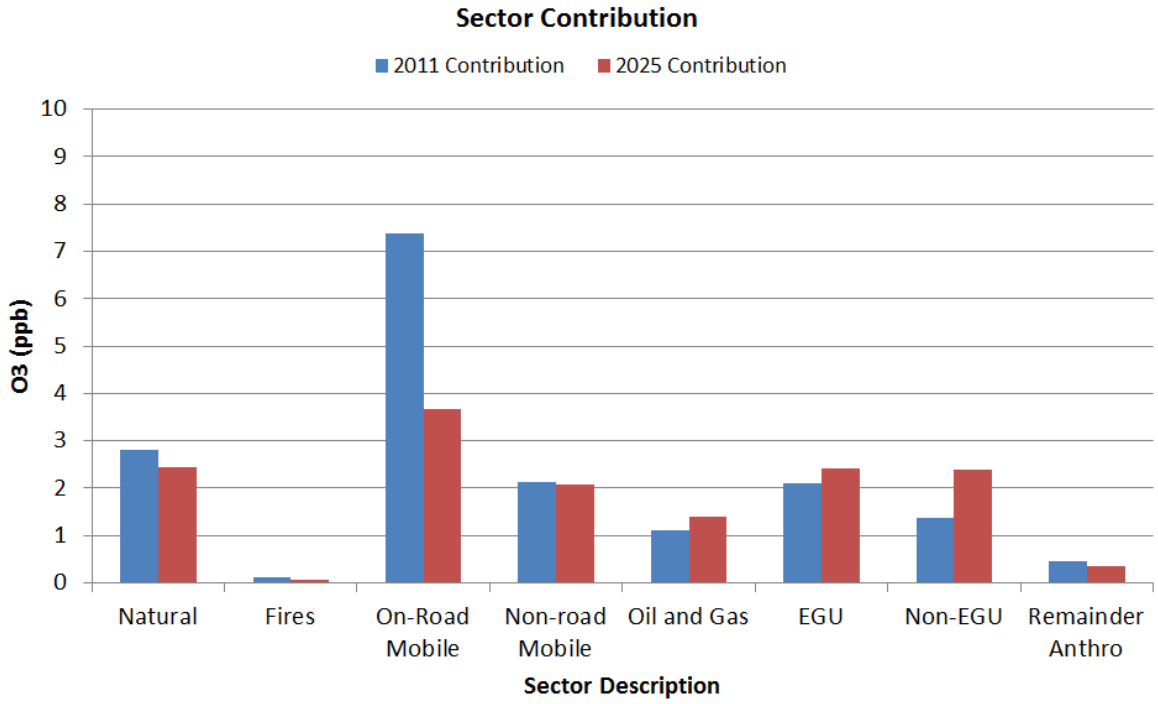


Figure 3-36. Contribution from emissions source categories to 2011 and 2025 design values at the Desert View monitor.

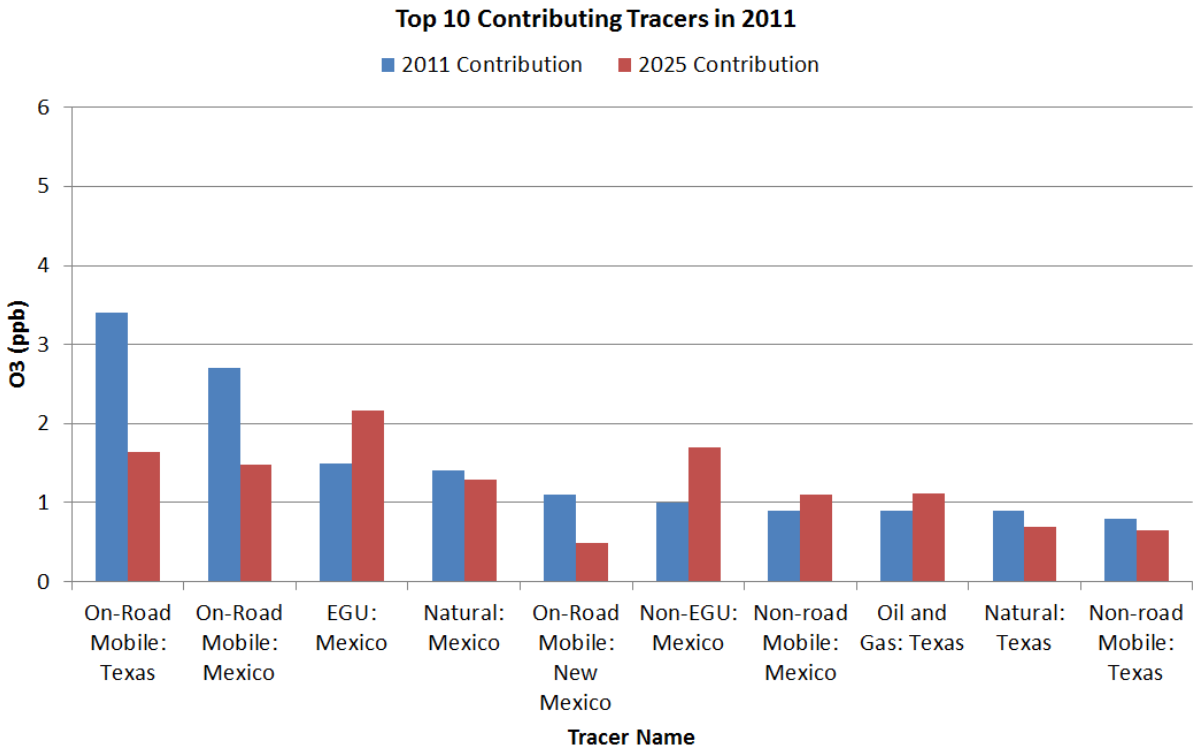


Figure 3-37. Contributions to the 2011 (blue) and 2025 (red) design values for the top ten contributing source groups in 2011 for the Desert View monitor. Source groups are ranked from left to right based on their contribution to the 2011 design values.

As noted above, results for the other Doña Ana County monitors are similar to those of Desert View and are available in the Task 12 PowerPoint. Next, we identify source groups that had the largest impact on Doña Ana County monitors. Figure 3-38 shows the frequency (as a count) with which each source group appears in the list of top five contributing source groups for the Doña Ana County monitors. We selected the top five source groups because contributions to design values tended to drop below 1 ppb for source groups outside the top five, so that focusing on the top five isolates the most important source groups. There were six Doña Ana County monitors active during this modeling episode (Figure 3-39), so that when the count for a source group is six (such as for natural emissions in Mexico in 2025) that source group was in the top five contributing source groups for all Doña Ana County monitors in that year.

Figure 3-37 shows that on-road, natural (Mexico) and EGU (Mexico) emissions appeared most frequently in the list of top five contributors to Doña Ana County monitor design values. All six Doña Ana County monitors had Texas on-road mobile sources appearing in the list of top five contributors in 2011. While New Mexico on-road mobile sources appeared in the list of the top five sources for five Doña Ana County monitors in 2011, reductions in on-road mobile emissions by 2025 meant that on-road mobile emissions from New Mexico appeared in the list of top five contributors for only one monitor (Solano) in 2025. Oil and gas emissions growth in the

Permian Basin is the cause of the increased frequency of appearance of Texas oil and gas sources in the list of top five contributors in 2025.

Mexico is the most frequently appearing source region, with emissions from Mexican natural sources, on-road mobile and EGU point sources appearing the most frequently in 2011 and Mexican natural emissions, on-road mobile sources and EGU and non-EGU point sources appearing most frequently in 2025. Next, we focus on the contribution from Mexico.

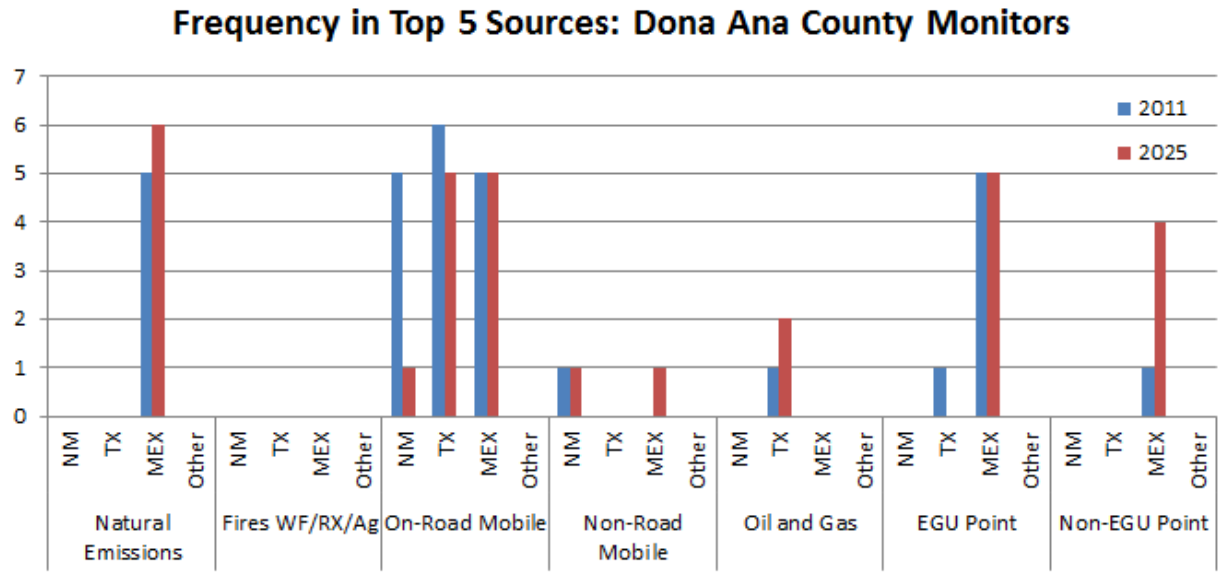


Figure 3-38. Frequency with which each source group appeared in the list of top five contributing source groups for the Doña Ana County monitors in 2011 and 2025.

Figure 3-40 shows the contributions to monitors within the 4-km domain due to emissions from Mexico along with a map of the monitors within and nearby Doña Ana County. The full map of monitors within the 4-km domain is shown in Figure 3-39. Contributions from Mexico emissions to 2011 and 2025 design values range from ~2-6 ppb at Doña Ana monitors and are similar in magnitude in 2011 and 2025. Monitors in New Mexico that are located near the U.S.-Mexico border (Desert View, Sunland Park) and El Paso monitors have larger contributions from Mexico emissions than monitors located further from the border (Carlsbad, Hurley). The contribution from Mexico emissions is significant and in 2011 is sufficiently large to affect the attainment status of the monitors. (See additional discussion below). The contribution from Mexico does not change substantially from 2011 to 2025; the contribution increases for some monitors (Sunland Park, El Paso UTEP) and decreases for other monitors (Santa Teresa, Ascarate Park).

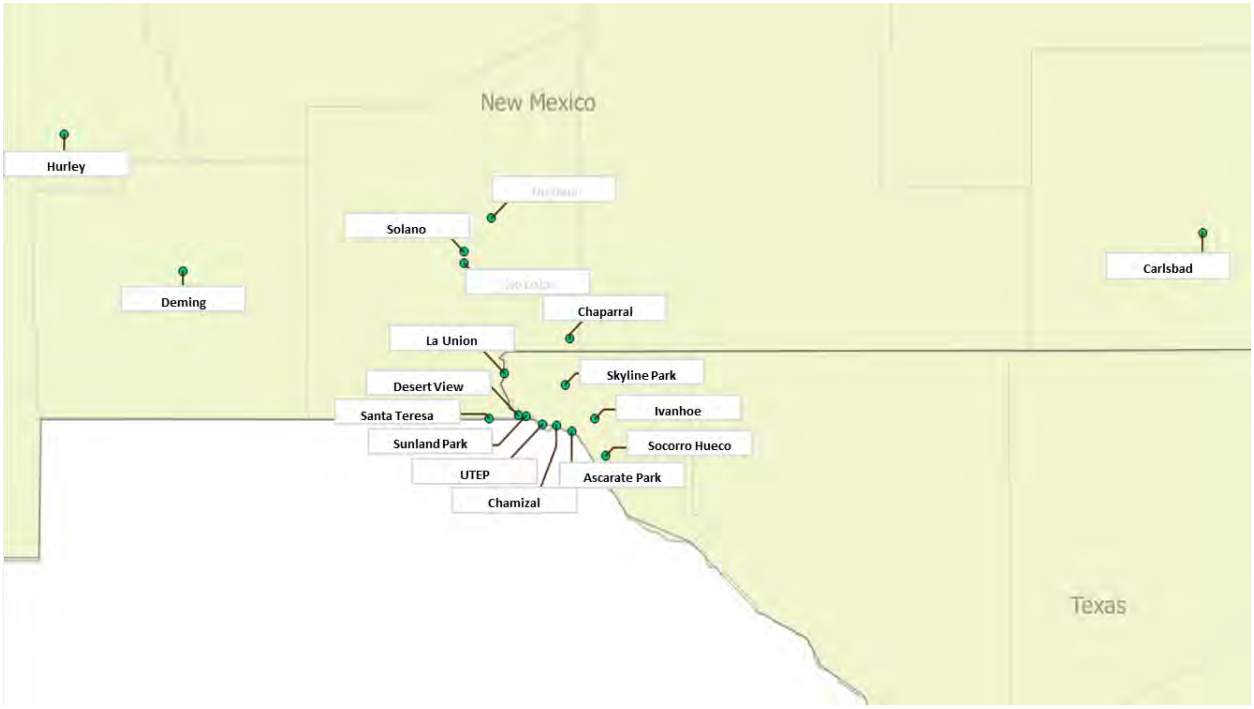


Figure 3-39. Map of ozone monitors within the SNMOS 4-km domain. Sites that were not active during the 2011 SNMOS modeling episode are indicated by "No Data".

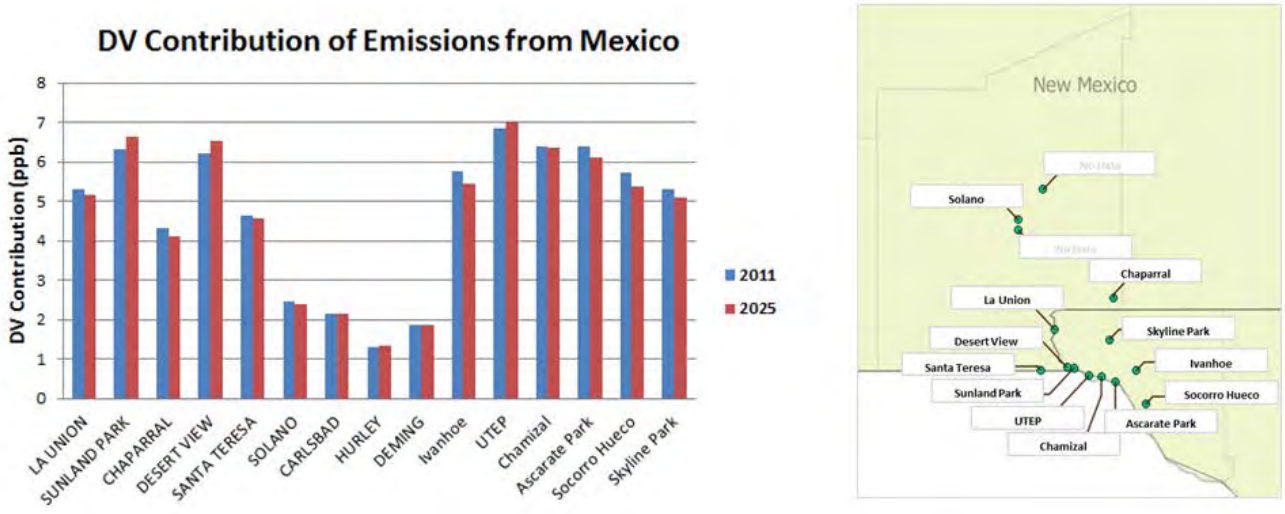


Figure 3-40. Left: contribution of Mexico anthropogenic emissions to 2011 and 2025 DVs for monitors in the 4-km grid. Right: map of ozone monitors within and nearby Doña Ana County.

The contribution to 4-km grid monitors from on-road mobile sources is shown in Figure 3-41. There are large (>7 ppb) 2011 contributions from on-road emissions to design values at Doña Ana and El Paso monitors. Decreases in U.S. and Mexico 2025 on-road mobile emissions relative to 2011 cause large decreases in the on-road mobile contribution in 2025 for all sites.

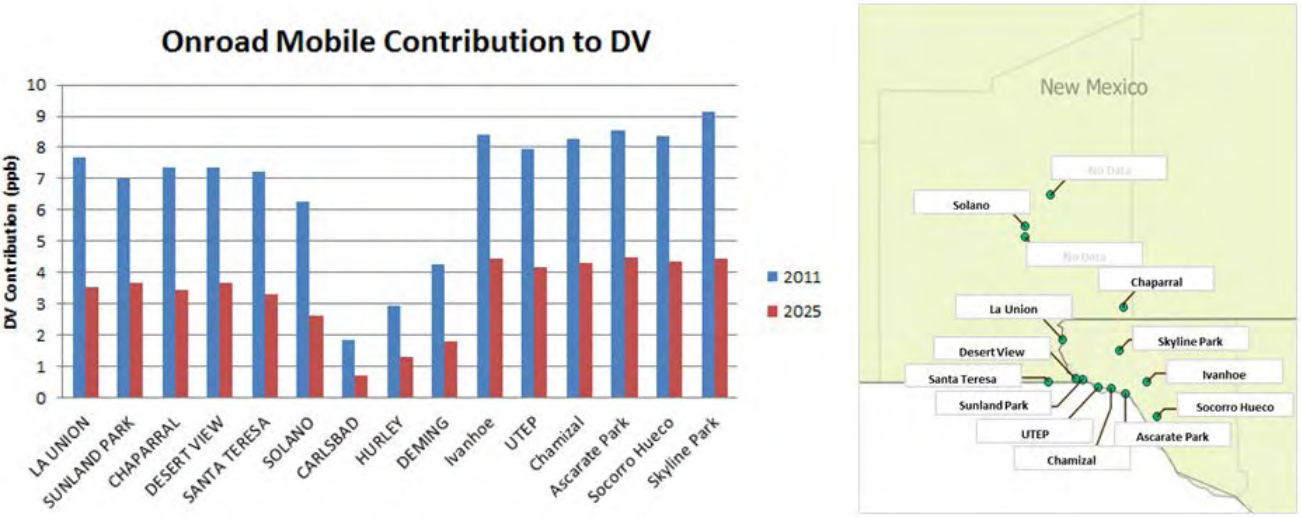


Figure 3-41. Left: contribution of on-road mobile emissions to 2011 and 2025 DVs for monitors in the 4-km grid. Right: map of ozone monitors within and nearby Doña Ana County.

Figure 3-42 shows the contribution of New Mexico anthropogenic emissions to design values of monitors in New Mexico. This represents the portion of the design values that are subject to

local control. On-road mobile emissions make the largest anthropogenic contribution to design values at most New Mexico monitors. The Solano monitor has the largest contribution from on-road mobile sources. This monitor is located within the Las Cruces urban area and is also close to Interstate I-15. The contribution from on-road mobile sources decreases in 2025 for all New Mexico monitors, consistent with the decrease in New Mexico on-road mobile emissions in 2025 relative to 2011.

Non-road mobile and oil and gas sources make next largest contributions, followed by EGU point sources. Oil and gas sources make the largest contribution at the Carlsbad monitor, which is the monitor located closest to the Permian Basin (Figure 3-39). The magnitude of the oil and gas impact increases in 2025 consistent with projected growth in emissions in the Permian Basin in 2025 relative to 2011 (Section 3.2.1).

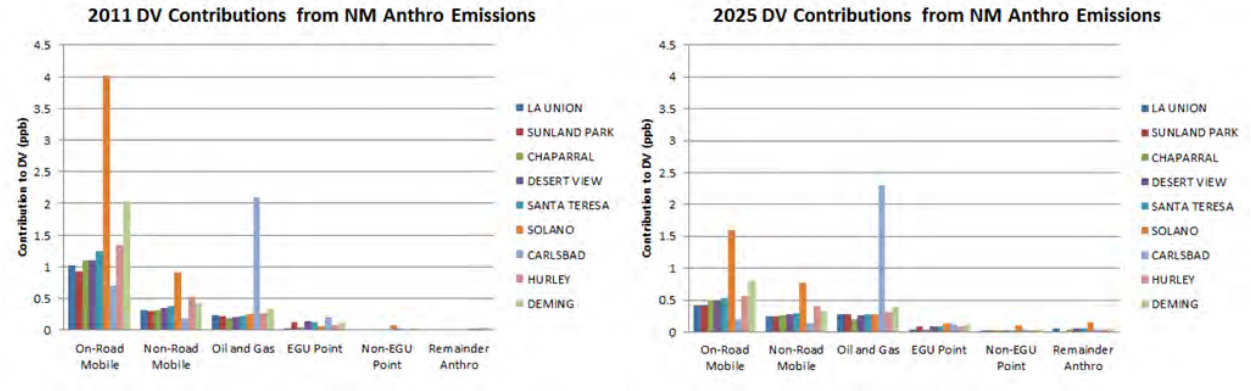


Figure 3-42. Contribution of New Mexico anthropogenic emissions to 2011 and 2025 design values for New Mexico monitors within the 4-km grid.

3.12.1.2 Contribution of Emissions from Mexico to Doña Ana County Ozone

We assessed the contribution of Mexico emissions to design values at Doña Ana monitors in 2011 and 2025 and compared the results with those of the Task 11 Sensitivity Test in which the ozone impacts of zeroing out Mexico anthropogenic emissions were quantified. This assessment is aimed at assessing whether a Section 179B "But For" test would be appropriate for Doña Ana monitors.

Section 179B of the Clean Air Act addresses impacts on U.S. air quality due to transport of pollution from outside the U.S. Section 179B provides relief from some requirements for areas that would be able to meet the NAAQS "but for" ozone impacts of emissions from another country. In preparing a Section 179B demonstration, an air agency must show that the area would attain the NAAQS but for the ozone contribution from outside the U.S. In Table 3-13, the contributions from Mexico anthropogenic emissions ("Mexico Anthro Contribution") to 2011 design values from the Task 12 source apportionment modeling as well as the Task 11 sensitivity modeling are shown. For the source apportionment results, the Mexico Anthro Contribution ranges between 1.3-6.8 ppb for monitors in the 4-km grid. Contributions to Dona Ana monitor design values from Mexico emissions range from ~2-6 ppb at Doña Ana monitors

and are similar in 2011 and 2025. Subtracting the Mexico Anthro Contribution from the 2011 DVC yields the 2011 DV NoMexAnthro, the value of the 2011 DVC at the monitor when the contribution from Mexico anthropogenic emissions is removed. When the ozone contribution from Mexico anthropogenic emissions is subtracted, the Desert View 2011 DVC drops from 71 ppb, which exceeds the 70 ppb NAAQS, to 64.8 ppb, which attains the 70 ppb NAAQS. Table 3-13 indicates that but for the contribution of emissions from Mexico, the Desert View monitor would have attained the 70 ppb NAAQS in 2011. The same is true for the UTEP monitor in El Paso; the UTEP monitor's 2011 design value drops from 71 ppb to 64.2 ppb when the contribution from Mexican anthropogenic emissions is removed.Table 3-13 indicates that monitors closer to the U.S.-Mexico border have a larger Mexico contribution (e.g., El Paso monitors) than monitors which are more distant from the border (Carlsbad, Deming).

Table 3-13. Ozone contribution to 2011 DVs from Mexico anthropogenic emissions (Mexico Anthro Contribution) for all monitors in the 4-km grid. Results are shown for the sensitivity test (Task 11) and source apportionment (Task 12) analyses. Orange shading of the 2011 DVC indicates that the DVC exceeds the 2015 ozone NAAQS of 70 ppb. Yellow shading indicates 70 ppb < DVC < 71 ppb.

Site ID	Observed	CAMx Source Apportionment		CAMx Sensitivity Test		County	Site Name
	2011 DVC	2011 DV NoMexAnthro	Mexico Anthro Contribution	2011 DV NoMexAnthro	Mexico Anthro Contribution		
350130008	64.7	59.4	5.3	59.6	5.1	Dona Ana	LA UNION
350130017	66.7	60.4	6.3	60.4	6.3	Dona Ana	SUNLAND PARK
350130020	67.7	63.4	4.3	63.3	4.4	Dona Ana	CHAPARRAL
350130021	71	64.8	6.2	64.8	6.2	Dona Ana	DESERT VIEW
350130022	70.3	65.7	4.6	65.2	5.1	Dona Ana	SANTA TERESA
350130023	64.3	61.8	2.5	60.6	3.7	Dona Ana	750 N.SOLANO DRIVE
350151005	70.3	68.2	2.1	65.2	5.1	Eddy	CARLSBAD
350171003	65	63.7	1.3	62.2	2.8	Grant	HURLEY
350290003	63	61.1	1.9	59.2	3.8	Luna	DEMING
481410029	65	59.3	5.7	59.5	5.5	El Paso	Ivanhoe
481410037	71	64.2	6.8	64.5	6.5	El Paso	UTEP
481410044	69	62.6	6.4	63.1	5.9	El Paso	Chamizal
481410055	66.3	59.9	6.4	60.4	5.9	El Paso	Ascarate Park
481410057	66	60.3	5.7	60.7	5.3	El Paso	Socorro Hueco
481410058	69.3	64	5.3	64.4	4.9	El Paso	Skyline Park

We compared the sensitivity and source apportionment results to see whether they are consistent in their estimates of the importance of the ozone contribution from Mexico. The Mexico Anthro Contribution is similar in magnitude in the source apportionment and the sensitivity testing results (Table 3-14).

Table 3-14. Contribution of Mexico emissions to 2011 DVs for Doña Ana County monitors (4-km grid results): comparison of CAMx zero out sensitivity test (Task 11) and source apportionment (Task 12) results.

	Average (ppb)	Maximum (ppb)	Minimum (ppb)
Sensitivity Test Results	5.1	6.3	3.7
Source Apportionment Results	4.9	6.3	2.5

The source apportionment and sensitivity test results are consistent in showing that Mexico emissions had a significant impact on Doña Ana County design values in 2011 and that the Desert View monitor would have attained the 70 ppb NAAQS but for the contribution of anthropogenic emissions from Mexico. The source apportionment results and the sensitivity test show similar maximum and average impacts and the sensitivity test has a higher minimum impact.

3.12.1.3 Contribution of Fire Emissions to Doña Ana County Ozone

In 2011, the southwestern U.S. had an active fire season, with a number of large fires occurring in the SNMOS 12-km domain. The CAMx modeling of 2011 showed intermittent large impacts from fire emissions. For example, on June 5, 2011, there were several large wildfires burning within the 12-km domain. In the left panel of Figure 3-43, there are areas of $PM_{2.5}$ emissions at the location of these fires, which were also apparent in satellite imagery for June 5 (Figure 3-13). The right hand panel of Figure 3-43 shows CAMx modeled 1-hour ozone for 0Z on June 5, and the plumes from the wildfire emissions in the left panel are apparent as regions of enhanced ozone. The Wallow Fire plume has modeled 1-hour ozone values exceeding 160 ppb, while ozone outside the plume ranges from ~50-70 ppb. The Wallow Fire plume passes over several ozone monitors in northern New Mexico and southern Colorado, but the monitors do not show enhanced ozone concentrations comparable to the modeled plume. The model overestimates ground level ozone impacts from the Wallow Fire plume as well as the other fires in the 12-km domain on June 5. This overestimate of fire plume ozone impacts was typical of SNMOS CAMx model performance.

The modeled ozone impacts of fires depend on accurate characterization of fire emissions and simulation of the transport, chemical transformation, and fate of emitted ozone precursors and the ozone that forms from them. Fire emissions contain uncertainties in both their magnitude and their chemical composition (e.g,. Wiedinmyer et al. 2011; Jaffe and Wigder, 2012). The chemical composition of the emissions plays a role in the photochemistry of the resulting fire plume and therefore the resulting ozone impact.

The chemistry of ozone production in fire plumes is an area of active research. Measurement campaigns in which aircraft made transects through fire plumes and measured ozone and other trace gases have produced a range of results regarding the magnitude of ozone production in fire plumes (e.g., Bertschi et al., 2004; Alvarado et al; 2010). Jaffe and Wigder (2012) note that there is not a clear relationship between the quantity of ozone precursor emissions released into the atmosphere and the ozone produced in the plume downwind of the fire. Wigder et al. (2013) hypothesize that plume rise and the altitude of subsequent plume transport can affect ozone production in the plume because temperatures are lower at higher altitudes. The interaction of fire plumes with anthropogenic emissions is not well understood. Singh et al. (2012) and Wigder et al. (2013) found enhanced ozone in fire plumes that mixed with air containing urban emissions. The presence of aerosols (smoke) in the fire plume can reduce the amount of sunlight available to initiate photochemistry, inhibiting ozone formation (e.g. Parrington et al., 2013).

Finally, in order to simulate the transport of ozone and precursors away from a fire, the meteorological model must successfully reproduce the true wind field and accurately represent vertical transport of emitted and secondary pollutants. Even if the photochemical accurately represents the amount of ozone and precursors in the fire plume, there will be bias in the modeled ground level ozone if transport and vertical mixing are not accurately simulated. In the SNMOS modeling, for example, it is possible that the modeled Wallow Fire plume affected the surface while in the real world, the fire plume passed over the monitor aloft without mixing down to the surface.

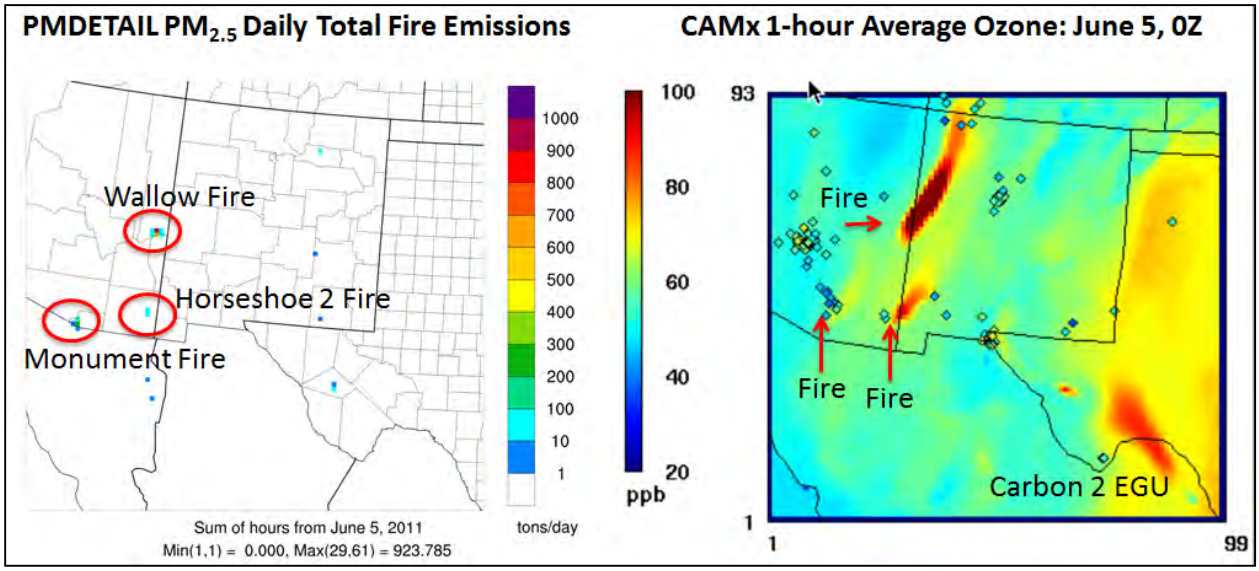


Figure 3-43. Fire emission ozone impacts on June 5, 2011. Left panel: PMDETAIL $PM_{2.5}$ emissions indicating the location of fires on June 5. Larger fires within the 12-km domain are circled in red. Right panel: CAMx 1-hour average modeled ozone for 0Z on June 5. Monitor locations are indicted by diamonds and the observed value for 0Z June 5 is indicated by the color within the diamond. The location of large fires and the ozone plume from the Carbon II Power Plant in Mexico are shown.

In the SNMOS source apportionment modeling, we treated fires separately from the rest of the natural emission inventory so their impacts could be tracked. We used source apportionment to quantify the effect of fire emissions on Doña Ana DVs in order to assess the uncertainty introduced into the design value analysis by the fire emissions modeling. Table 3-15 shows the future year 2025 design values (DVF) with and without the contribution from fire emissions for all monitors in the 4-km domain. The difference between these two DVFs is the impact of fire emissions on each monitor's design value. The impact of fire emissions on the 4-km grid monitor 2025 DVFs was < |0.5| ppb for all monitors. This indicates that fire emissions did not have a substantial effect on the design value results for monitors in the 4-km grid.

Table 3-15. Impact of fire emissions on 4-km grid monitor 2025 design value results.

Site ID	State	County	2011 DVC (ppb)	2025 Design Values (ppb)		Fire Impact on 2025 DVF (ppb)	Site Name
				DVF (without fires)	DVF (with fires)		
350130008	New Mexico	Dona Ana	64.7	58.3	58.3	0.006	LA UNION
350130017	New Mexico	Dona Ana	66.7	61.4	61.3	-0.007	SUNLAND PARK
350130020	New Mexico	Dona Ana	67.7	61.3	60.8	-0.439	CHAPARRAL
350130021	New Mexico	Dona Ana	71.0	65.1	65.1	-0.007	DESERT VIEW
350130022	New Mexico	Dona Ana	70.3	63.8	63.8	-0.007	SANTA TERESA
350130023	New Mexico	Dona Ana	64.3	58.6	58.7	0.108	SOLANO
350151005	New Mexico	Eddy	70.3	67.6	67.9	0.295	CARLSBAD
350171003	New Mexico	Grant	65.0	62.0	62.0	0.013	HURLEY
350290003	New Mexico	Luna	63.0	58.6	58.6	-0.038	DEMING
481410029	Texas	El Paso	65.0	58.4	58.4	0.006	Ivanhoe
481410037	Texas	El Paso	71.0	65.3	65.2	-0.163	UTEP
481410044	Texas	El Paso	69.0	62.5	62.7	0.158	Chamizal
481410055	Texas	El Paso	66.3	60.1	60.1	0.007	Ascarate Park
481410057	Texas	El Paso	58.7	59.8	59.8	0.000	Socorro Hueco
481410058	Texas	El Paso	69.3	62.1	61.7	-0.380	Skyline Park

The MATS design value analysis presented in Table 3-15 applies only to the monitoring sites within the 4-km domain. To determine whether fire emissions influenced ozone design values away from the monitoring sites, we performed a MATS Unmonitored Area Analysis (UAA). The UAA was performed by interpolating DVCs from monitoring sites to each grid cell in the modeling domain using the Voronoi Neighbor Averaging interpolation technique. The modeled ozone gradients are taken into account in the interpolation in order to reflect modeled higher and lower ozone areas in the interpolated DVC field. An unmonitored area analysis was performed that interpolated the 2011 DVCs across the modeling domain and performed ozone projections using the modeling results within each grid cell only. Figure 3-44 shows the results of the UAA for 2011 with the impacts of fire emissions included (left panel) and excluded (right panel). The difference of these two fields is shown in Figure 3-45. Figure 3-45 shows that larger fire impacts on design values (> 5 ppb) occurred away from monitoring sites within the 4-km domain downwind of 2011 fires. For example, the plume from the Horseshoe 2 Fire (Figure 3-43) in eastern Arizona extends into southwestern New Mexico and the ozone impacts of a number of other fires are apparent within the 4-km grid. Impacts away from the monitors exceeded 5 ppb in some of these plumes. Given the high bias seen in the CAMx simulated ozone downwind of fires in the 2011 model performance evaluation, these impacts may be overestimated and must be considered highly uncertain. However, because of the location of the fires in 2011 and wind patterns that caused plumes to miss the monitors in the 4-km domain, this uncertainty does not affect the design value results at the monitors. Results for the future year 2025 modeling are shown in Figure 3-46 and Figure 3-47and are similar to those of 2011.

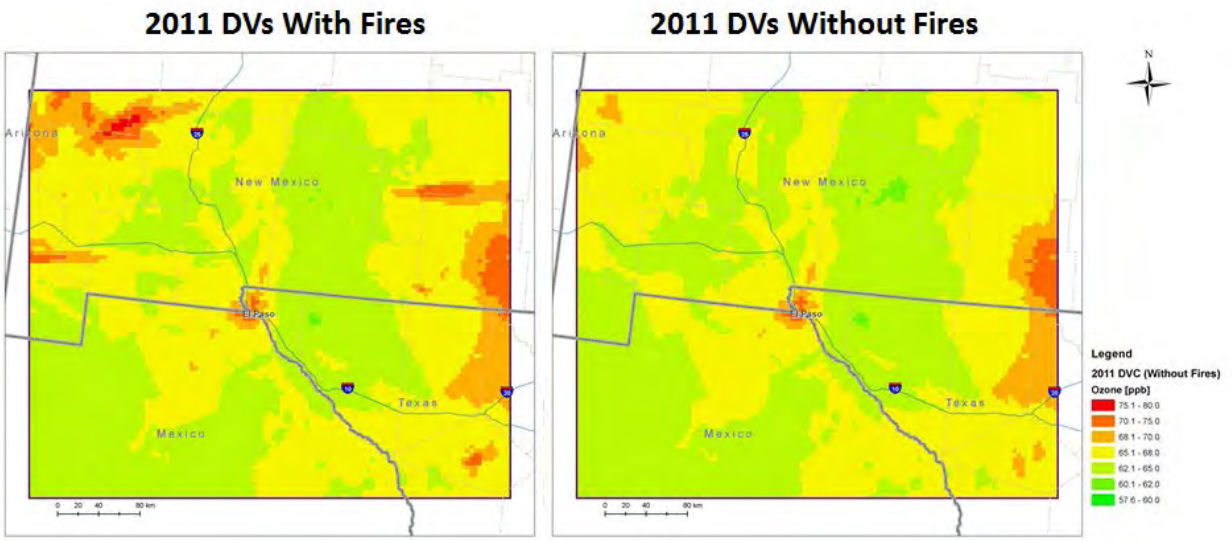


Figure 3-44. Impact of fire emissions on 4-km grid design value results: 2011 MATS Unmonitored Area Analysis.

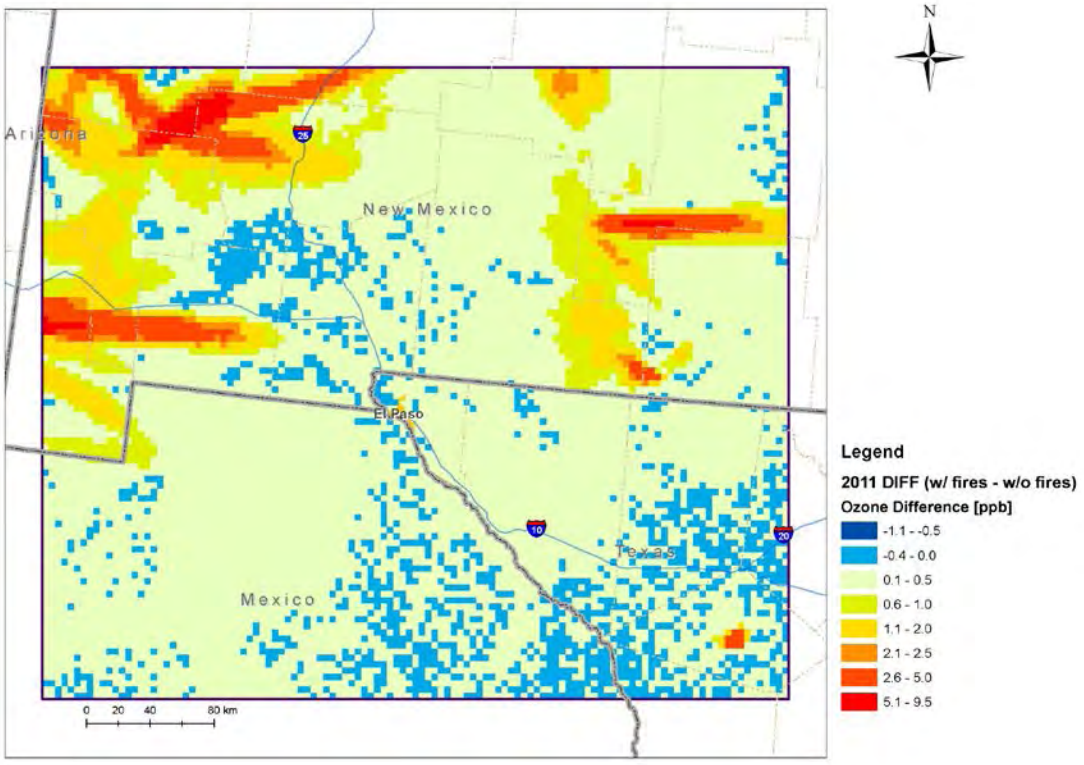


Figure 3-45. Impact of fire emissions on 4-km grid design value results: 2011 MATS Unmonitored Area Analysis: DVC(with fire contribution) - DVC(without fire contribution).

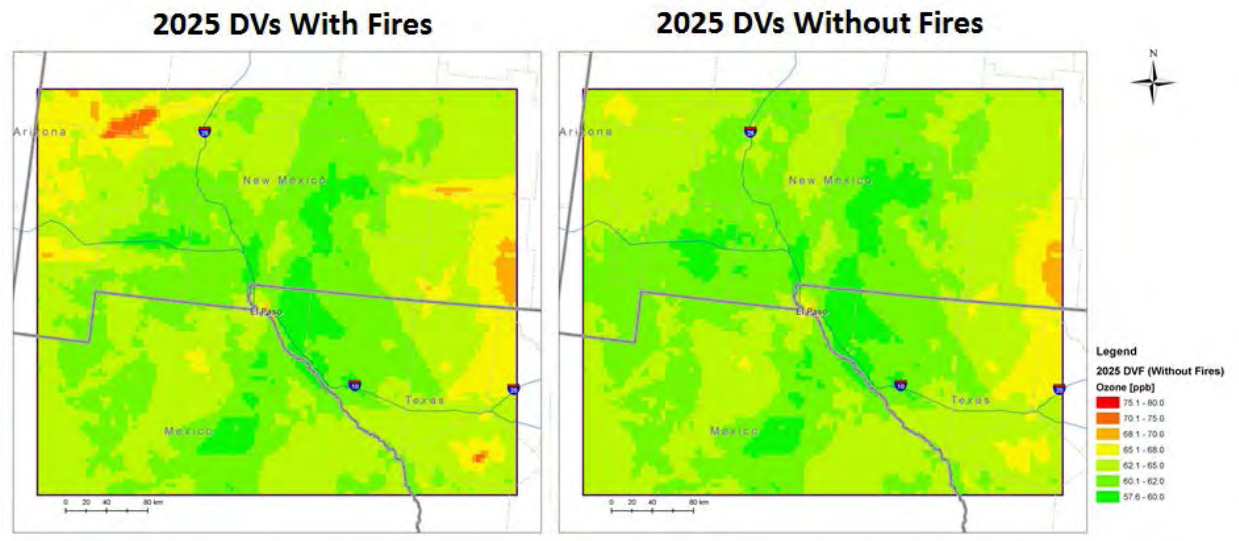


Figure 3-46. Impact of fire emissions on 4-km grid design value results: 2025 MATS Unmonitored Area Analysis.

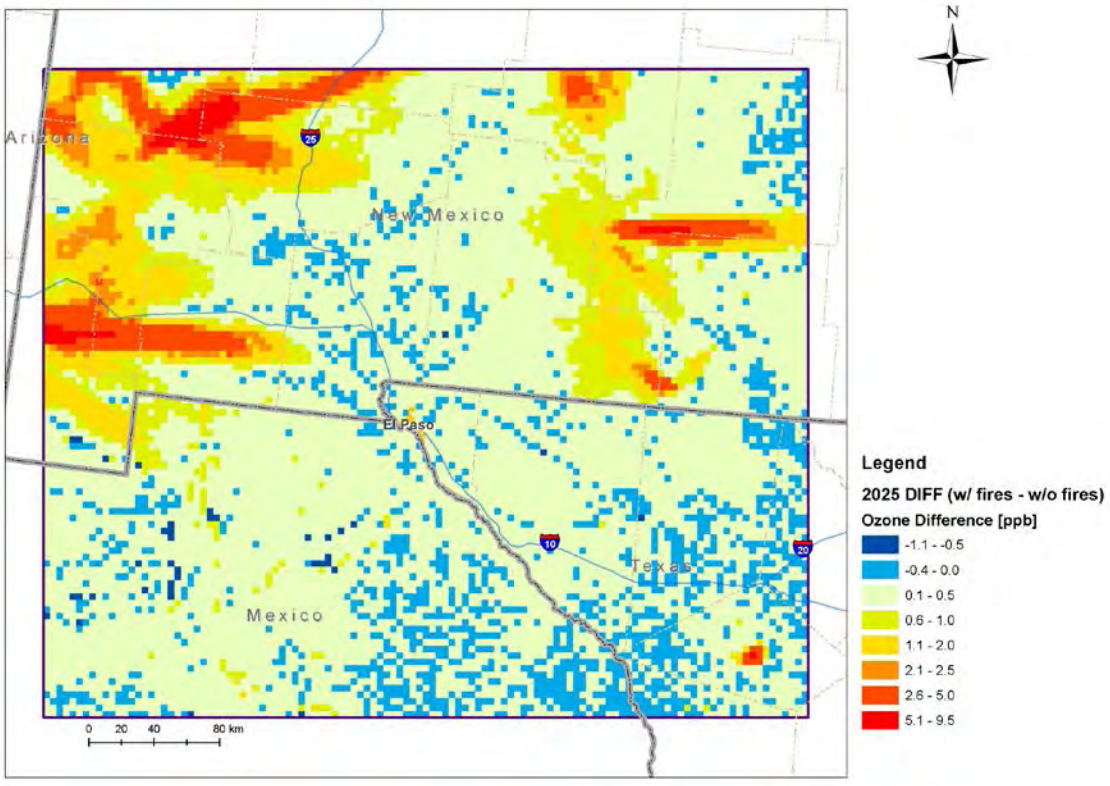


Figure 3-47. Impact of fire emissions on 4-km grid design value results: 2011 MATS Unmonitored Area Analysis: DVF(with fire contribution) - DVF(without fire contribution).

3.12.1.4 Source Apportionment Visualization Tools Overview

The SNMOS modeling results were loaded into a web-based Source Apportionment Visualization Tool (SA Vis Tool) on the Intermountain West Data Warehouse website (**http://views.cira.colostate.edu/tsdw/**). Documentation of the source apportionment results may be found in the SNMOS wiki on the IWDW website[11] (Figure 3-48).

Figure 3-48. IWDW web page.

The SNMOS ozone design value source apportionment modeling analysis is available in an interactive Excel spreadsheet that can be accessed through a link in the SNMOS wiki page. To display the Source Group contributions to 2011 and 2025 MDA8 ozone concentrations, the user can access the SNMOS 2011 and 2025 SA Vis Tool through the SNMOS wiki. The SA Vis Tools generate pie charts of 2011 and 2025 ozone contributions by Source Region, Source Category or both (i.e., Source Groups) for monitoring sites within the SNMOS 4-km modeling domain. The SA Vis Tools can be used to display base (2011) and future (2025) year MDA8 SA results. The SA Vis Tools provide source apportionment results as well as information on CAMx model performance by monitor and by date.

[11] http://vibe.cira.colostate.edu/wiki/wiki/9131/southern-new-mexico-ozone-study-snmos-2011-and-2025-ozone-source-apportionm

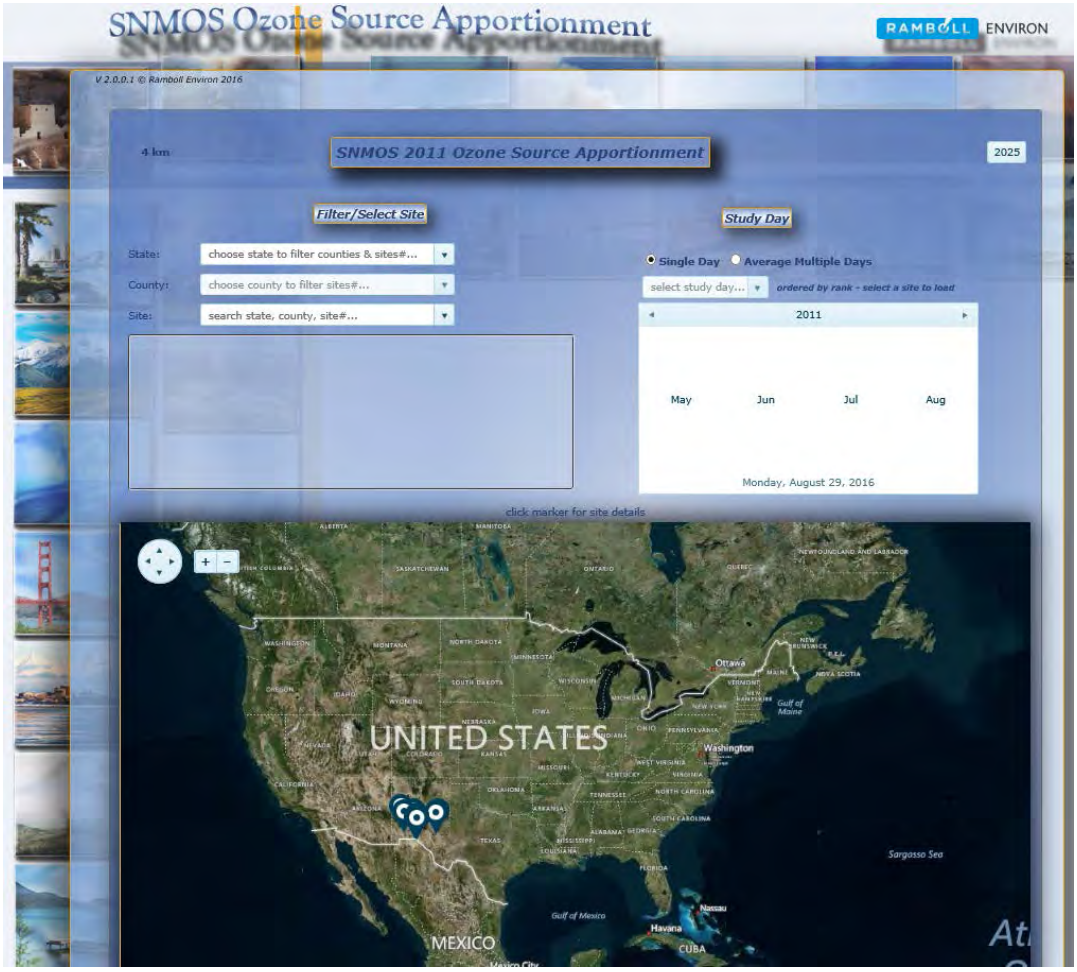


Figure 3-49. SNMOS SA Vis Tools website.

3.12.2 Significant Findings

Transport plays an important role in determining ozone levels in Doña Ana County. For Doña Ana County monitors, the 12-km grid boundary conditions were the largest contributor of ozone; this is a typical result for a regional modeling study. The contribution of New Mexico emissions to Doña Ana County monitor design values is smaller than the contributions of Texas and Mexico for all Doña Ana monitors except Solano, which has a large on-road mobile contribution from New Mexico on-road mobile emissions.

The source apportionment results indicate that the contribution of Mexico anthropogenic emissions to Doña Ana monitor 2011 design values ranges from 2.5 – 6.3 ppb with an average of 4.9 ppb. The source apportionment results confirm that all Doña Ana County ozone monitors, including Desert View, would have attained the 70 ppb ozone NAAQS in 2011 but for the ozone contribution due to anthropogenic emissions from Mexico.The source apportionment (Task 12) and Sensitivity Test (Task 11) model analyses are consistent in showing this result.

The emissions sources within the 12/4 km modeling domains that contributed the most ozone to Doña Ana County ozone monitors in 2011 were: (1) on-road mobile emissions from Texas, Mexico and New Mexico; (2) power plant emissions from Mexico; and (3) natural emissions from Mexico. In 2025, the emissions sources within the 12/4 km modeling domains that contributed the most ozone to Doña Ana County ozone monitors were: (1) on-road mobile emissions from Texas and Mexico; (2) power plant non-power plant point source emissions from Mexico; and (3) natural emissions from Mexico.

Of all New Mexico anthropogenic emissions sources, on-road mobile emissions make the largest contribution to design values at Doña Ana monitors. New Mexico anthropogenic emission sources that contributed the most ozone to New Mexico monitors in the SNMOS 4-km grid were: (1) on-road mobile; (2) offroad mobile; (3) oil and gas; and (4) power plants. Oil and gas emissions made the largest New Mexico anthropogenic contribution at the Carlsbad monitor due to its closer proximity to the Permian Basin. The impact of oil and gas sources increases in 2025 due to projected growth in Permian Basin emissions.

Fire emissions had a small (≤ |0.5| ppb) effect on 2011 and 2025 DVs at Doña Ana County monitors. These impacts are too small to affect the attainment status results for 2011 and 2025. The small magnitude of the impacts is due to location of monitors relative to 2011 fires and 2011 winds. Fire emissions had a larger effect on 2011 and 2025 DVs at grid cells elsewhere in the 4-km domain with the UAA showing design value impacts exceeding 5 ppb downwind of the fire locations.

3.12.3 Milestones and Deliverables

- Carry out SNMOS ozone source apportionment CAMx modeling of 2011 and 2025 (Completed July 18, 2016)
- PowerPoint presentation on ozone source apportionment modeling (Completed September 8, 2016)
- Wiki and SA Vis Tools Provide interactive spreadsheet source apportionment results on ozone DVs(Completed September 8, 2016)
- Provide SA Visualization Tool for 2011 and 2025 ozone contributions to MDA8 ozone at monitors (hosted on IWDW and available through wiki) (Completed September 8, 2016)

3.13 Task 13: Technical Support Document

3.13.1 Task Summary

A Technical Support Document that (TSD) that summarizes the SNMOS (this document) was prepared and submitted to the NMED.

3.13.2 Significant Findings

UNC-IE and Ramboll Environ prepared a draft TSD documenting Tasks 1-12 and submitted the draft TSD for review. The draft TSD will be updated to reflect comments received and a Response to Comments (RtC) document will be prepared and submitted along with the final AQTSD.

3.13.3 Milestones and Deliverables

- Draft Technical Support Document (TSD) (completed September 30, 2016)
- Final TSD (to completed by November 18, 2016)
- Response to Comments (RtC) document for NMED (to completed by November 18, 2016)
- Modeling data, RtC document, and final TSD posted on WAQS data warehouse (to completed by November 18, 2016)

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

In this section, we summarize the main findings of the SNMOS. We discuss the major sources of uncertainty noted during the study and provide recommendations for future work to reduce these uncertainties.

4.1 SNMOS Major Findings

- 2025 future year design value projections indicate that all Doña Ana County ozone monitors are expected to attain the 70 ppb ozone NAAQS in 2025.
  - The finding of attainment was not sensitive to the method used in the MATS design value projection procedure, the model's bias in simulating ozone, or to the modeling of fire emissions
  - The finding of attainment was robust under a sensitivity test in which projected reductions in on-road mobile emissions by 2025 were smaller than EPA MOVES model estimates
- The projected decreases in Doña Ana County ozone design values between 2011 and 2025 are mainly driven by projected reductions in on-road mobile source emissions.
- All Doña Ana County ozone monitors would have attained the 70 ppb ozone NAAQS in 2011 but for the ozone contribution due to anthropogenic emissions from Mexico.
- Emissions sources within the 12/4 km modeling domains that contributed the most ozone to Doña Ana County ozone monitors in 2011 were: (1) on-road mobile emissions from Texas, Mexico and New Mexico; (2) power plant emissions from Mexico; and (3) natural emissions from Mexico.
- Emissions sources within the 12/4 km modeling domains that contributed the most ozone to Doña Ana County ozone monitors in 2025 were: (1) on-road mobile emissions from Texas and Mexico; (2) power plant non-power plant point source emissions from Mexico; and (3) natural emissions from Mexico.
- Ozone transport plays an important role in determining ozone levels in Doña Ana County. For Doña Ana County monitors, the 12-km grid boundary conditions were the largest contributor of ozone; this is a typical result for a regional modeling study. For all Doña Ana County monitors except Solano, the ozone contribution from Texas and Mexico was larger than that of New Mexico.
- New Mexico anthropogenic emission sources that contributed the most ozone to New Mexico monitors in the SNMOS 4-km grid were: (1) on-road mobile; (2) offroad mobile; (3) oil and gas; and (4) power plants.
- Oil and gas emissions are the largest New Mexico anthropogenic contribution at the Carlsbad monitor due to its closer proximity to the Permian Basin. The impact of oil and gas sources increases in 2025 due to projected growth in Permian Basin emissions.

4.2 Recommendations for Future Work

Based on our evaluation of model performance and the major uncertainties in the SNMOS, we make the following recommendations for future work.

4.2.1 WRF Meteorological Modeling

WRF meteorological model performance is a source of uncertainty in the SNMOS. While WRF performance was improved using the Multiscale (grid-aware) Kain-Fritsch cumulative cloud scheme, the model was still unable to consistently simulate precipitation, temperature and wind patterns related to the North American monsoon. This likely degraded the CAMx model's simulation of ozone in southern New Mexico.

Recommendation: Perform additional sensitivity testing to refine the WRF configuration with the aim of improving model performance in simulating temperatures, winds and precipitation improves during the months when the North American Monsoon is active.

4.2.2 Natural Emissions

Modeling of natural emissions (biogenics, fire and lightning) is an active area of scientific research, and the SNMOS emission inventories should be considered to have considerable uncertainty associated with them. In order to understand and possibly reduce this uncertainty, additional study of these emissions and their effect on Doña Ana County ozone should be undertaken.

In the MEGAN v2.1 biogenic inventory, there is a discontinuity in isoprene and monoterpene emissions at the U.S.-Mexico border with emissions larger in Mexico than in the U.S. for environments that appear from Google Earth imagery to have comparable vegetation cover.

Recommendation: Further investigation of differences in U.S. and Mexico MEGAN inputs should be undertaken to understand their origin and to ensure that the most accurate and consistent input data available are used as well as using the most up-to-date calculation methods to develop emissions on both sides of the border.

While modeling of fire emissions did not have a substantial effect on the design value analysis at Doña Ana County monitors, fires had impacts exceeding 5 ppb on design values for grid cells elsewhere in the modeling domain. In an episode in which fires are in different locations and wind patterns are different, fire emissions may have a large influence on Doña Ana County monitors and may introduce significant uncertainty, complicating air quality planning efforts.

Recommendation: Perform a detailed analysis of the fire emissions, their modeling, and the resulting CAMx air quality model simulation of the fire plume in order to better understand the reasons for CAMx overestimates of ozone at ground level monitoring sites during 2011.

LNOx emissions are intermittent, but can contribute to regional background ozone. In the SNMOS model performance evaluation, CAMx had a high bias during July and August and better

performance earlier in the episode, before the onset of the monsoon, when intense convection and associated lightning occur across the region.

Recommendation: Investigate the effect of LNOx emissions on modeled ozone by zeroing out the SNMOS LNOx emissions and comparing the resulting ozone with the 2011 model base case. If there is a significant effect on model performance (such as a reduction in model high bias in July and August), efforts should be made to improve the treatment of LNOx emissions in the Southern New Mexico ozone modeling. We recommend a review of current parameterizations for specifying LNOx emissions to determine whether an alternate approach would be beneficial and whether satellite data can be used to constrain LNOx emissions over Southern New Mexico and the surrounding region, including Mexico.

4.2.3 Anthropogenic Emissions

The SNMOS used the best available anthropogenic emission inventories for the region. However, uncertainties in these inventories may affect the SNMOS modeling results as well as future air quality planning efforts for Doña Ana County.

Much of the reduction in Doña Ana County design values between 2011 and 2025 is driven by reductions in on-road mobile emissions. Therefore, the projection of attainment of the NAAQS by 2025 for Doña Ana monitors depends on the accuracy of these estimates of on-road mobile emissions. In the SNMOS, we used EPA's NEI on-road mobile emission estimates, which were calculated using the MOVES model. Given the importance of on-road mobile emissions for air quality planning in Doña Ana County, we recommend further evaluation of the inventory.

Recommendation: Review the MOVES inputs and model configuration for the emissions modeling in the 2011 NEI platform with the goal of evaluating the likelihood of the modeled reductions in regional on-road mobile emissions between 2011 and 2025.

Anthropogenic emissions from Mexico are a source of uncertainty in the SNMOS modeling. The data used in the SNMOS were determined to be the most complete and accurate available information, but are based on 2008 data.

Recommendation: We recommend that the NMED continue to work with air quality planning partners in Mexico to ensure that the most complete and recent available emissions data available for Mexico are integrated into modeling efforts for Southern New Mexico.

New Mexico and Texas Counties within the Permian Basin showed increases in oil and gas emissions between 2011 and 2025, and the increased emissions were reflected in the increased ozone contribution from oil and gas sources in 2025. Oil and gas emissions in these counties were among the few U.S. source groups to show an increase in projected emissions in 2025 relative to 2011. Permian Basin emissions are based on 2014 AEO activity projections. Because the oil and gas industry undergoes rapid changes in response to fluctuations in pricing and domestic and foreign production, we recommend that the Permian Basin projections be revisited before any future modeling effort is carried out.

Recommendation: Update activity projections for the Permian Basin in advance of future ozone modeling efforts.

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