Denver Metro/North Front Range
2017 8-Hour Ozone State Implementation Plan:
2017 Attainment Demonstration Modeling

Final Report

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1.0 INTRODUCTION

1.1 OVERVIEW

This report presents the 2017 attainment demonstration modeling for the Denver Metropolitan Area and North Front Range (Denver Metro/NFR) ozone nonattainment area (NAA) in support of the development of a 2017 8-hour ozone State Implementation Plan (SIP). The 2017 ozone SIP needs to demonstrate that the Denver Metro/NFR ozone NAA will attain the March 2008 0.075 ppm (75 ppb) ozone National Ambient Air Quality Standard (NAAQS) by 2017. Addressing attainment of the new October 2015 0.070 ppm (70 ppb) ozone NAAQS will occur in the future after EPA designated ozone nonattainment areas by October 2017. The March 2008 8-hour ozone NAAQS is expressed as the three year average of the fourth highest daily maximum 8-hour (MDA8) ozone concentrations with a threshold not to exceed 0.075 ppm.

The procedures for conducting the 2017 ozone attainment demonstration modeling for the Denver Metro/NFR NAA were contained in an August 2015 Modeling Protocol (Ramboll Environ and Alpine, 2015). The Modeling Protocol described the overall modeling activities to be performed in order to demonstrate attainment of the 8-hour ozone NAAQS in the Denver Metro/NFR NAA by 2017. The Denver Metro/NFR ozone attainment demonstration modeling is being carried out by a contracting team consisting of Ramboll Environ US Corporation and Alpine Geophysics, LLC under contract to the Denver Regional Air Quality Council (RAQC). Working closely with the RAQC are the Colorado Department of Public Health and Environment (CDPHE) Air Pollution Control Division (APCD), Denver Regional Council of Governments (DRCOG), Colorado Department of Transportation (CDOT), the Northern Front Range Metropolitan Planning Organization (NFRMPO), U.S. Environmental Protection Agency (EPA) Region 8 (R8) and other local agencies.

1.2 STUDY BACKGROUND

Based on 2005-2007 observed air quality observations, the Denver Metro/NFR NAA failed to attain the 1997 ozone NAAQS due to an 85.0 ppb ozone Design Value at the Rocky Flats North (RFNO) monitoring site resulting in the area being designated nonattainment of the ozone NAAQS in the fall of 2007. The Denver RAQC, in conjunction with the CDPHE/APCD and local agencies, prepared a 2008 Denver 8-hour ozone SIP[1] that demonstrated the Denver Metro/NFR would achieve the 0.08 ppm 1997 ozone NAAQS by 2010 (Morris et al., 2008; 2009).

In March 2008, EPA lowered the ozone NAAQS to 0.075 ppm. In January 2010, EPA announced they were reconsidering the 2008 ozone NAAQS and intend to lower the ozone NAAQS to somewhere in the 0.060-0.070 ppm range with the final announcement expected in mid-2011. However, EPA ultimately elected not to lower the ozone NAAQS at that time.

On July 20, 2012, EPA's designations for the 2008 8-hour ozone standard were effective, with the Denver Metro/NFR region classified as a Marginal NAA. In the Implementation Rule, published May 21, 2012, the attainment date for a Marginal area was set as December 31, 2015

[1] http://www.colorado.gov/airquality/documents/deno308/

(based on 2013-2015 observations) and for a Moderate area was December 31, 2018 (based on 2016-2018 observations). However, based on court challenge, on December 23, 2014 the DC Circuit revoked portions of the 2012 ozone SIP implementation rule. This resulted in the attainment deadline being set a specific number of years from the effective date of designation, which meant a revised attainment date of July 20, 2015 for a Marginal Area and July 20, 2018 for a Moderate Area. This resulted in the following requirements for ozone NAAs under the March 2008 ozone NAAQS:

- Marginal ozone NAAs must achieve attainment of the ozone NAAQS by July 2015 based on 2012-2014 observed ozone data.
- Moderate NAAs must achieve attainment of the ozone NAAQS by July 2018 based on 2015-2017 observed ozone data.

These dates were confirmed in the ozone SIP requirements rule that was finalized in March 2015.

1.2.1 Current Ozone Air Quality in the DMA/NFR NAA

Figure 1-1 displays 8-hour ozone Monitored Design Values from 1998 to 2014 for key monitoring sites in the Denver Metro/NFR NAA as well as the 2008 (75 ppb) ozone NAAQS. The ozone Design Values in the Denver Metro/NFR NAA exhibits a high degree of year-to-year variability that is primarily due to meteorological variations that can cause the values to change as much as 20 ppb within just a few years. There appears to be a trend toward lower ozone Design Values in more recent years. The Rocky Flats North (RFNO) and Chatfield (CHAT) monitoring sites typically have the highest ozone concentrations in the Denver Metro/NFR NAA, although high ozone has also been observed at the National Renewable Energy Laboratory (NREL), Fort Collins West (FTCW) and other monitoring sites.

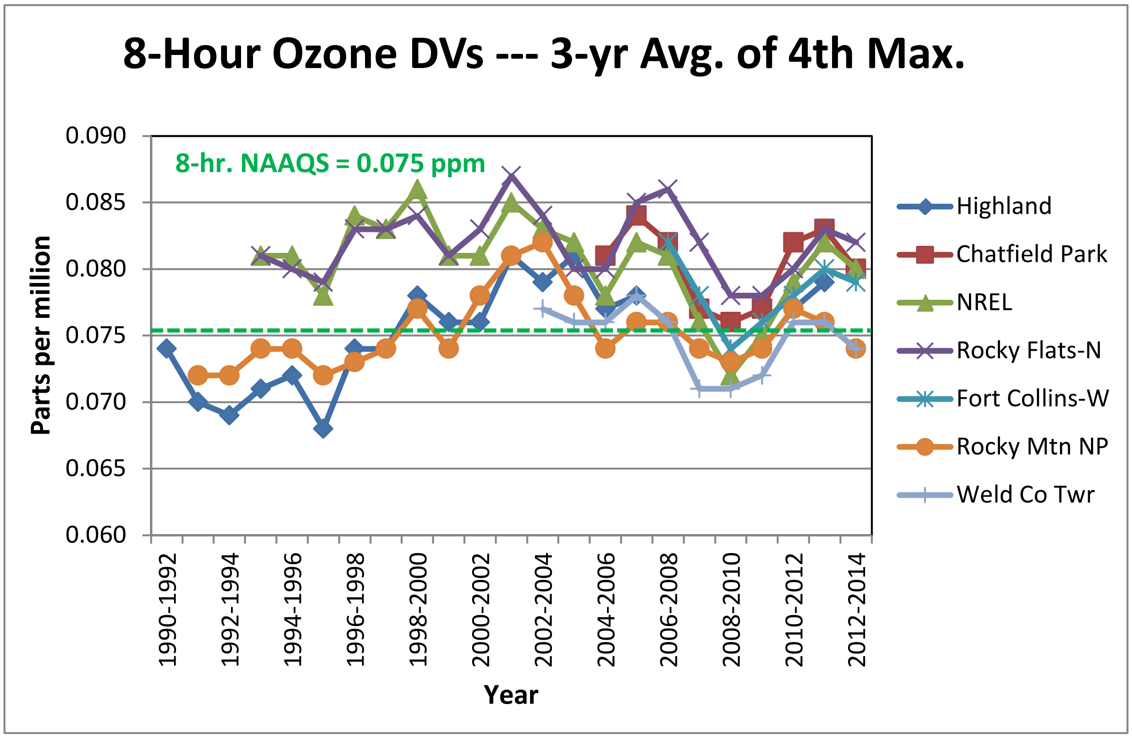

Figure 1-1. Trend in ozone Design Value concentrations at key monitoring sites in the Denver Metro/NFR NAA between 1998 and 2014.

The Denver Metro/NFR NAA was originally designated a Marginal NAA under the March 2008 ozone NAAQS that required the area to attain the 75 ppb ozone NAAQs based on 2012-2014 observed ozone air quality data. Figure 1-2 displays the 2012-2014 ozone Design Values in the Denver Metro/NFR NAA. There were four monitoring sites in the Denver Metro/NFR NAA whose 2012-2014 ozone Design Values failed to achieve the 2008 ozone NAAQS: RFNO, CHAT, NREL and FTCW. Consequently, the Denver Metro/NFR NAA was “bumped up” to a Moderate NAA that is required to attain the ozone NAAQS by July 2018, which requires the maximum 2015-2017 8-hour ozone Design Value in the region to be 75.9 ppb or less. As a Moderate NAA, the Denver Metro/NFR NAA attainment year is 2017 and an ozone SIP must be submitted within 12-24 months after EPA’s rulemaking redesignating the region to Moderate nonattainment. The new Denver Metro/NFR ozone SIP is expected to be submitted to EPA in summer 2017; for the purposes of this document we are calling this the 2017 Denver Metro/NFR Moderate Area SIP for the 2008 Ozone NAAQS.

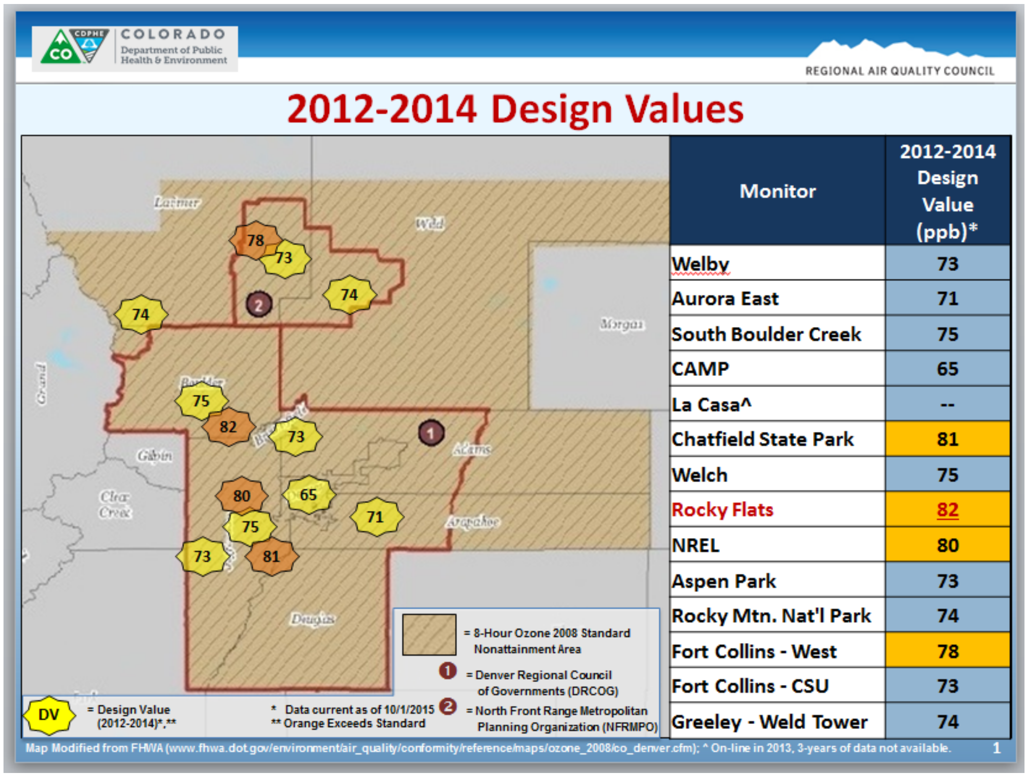

Figure 1-2. Observed 2012-2014 ozone Design Value concentrations (ppb) in the Denver Metro/NFR NAA.

1.2.2 Purpose

This document presents the future year 2017 ozone attainment demonstration modeling for the Denver 2017 ozone SIP. The document also contains modeled Weight of Evidence in support of the attainment demonstration modeling.

1.3 Lead Agency and Principal Participants

The RAQC and CDPHE/APCD are the lead agencies in the development of the Denver 8-hour ozone SIP. Additional participants include the Denver Regional Council of Governments (DRCOG), the Colorado Department of Transportation (CDOT), Northern Front Range Metropolitan Planning Organization (NFRMPO), the Colorado Air Quality Control Commission (AQCC), EPA R8 and other local agencies. EPA Region 8 in Denver is the local regional EPA office that will take the lead in the review and approval process for the Denver 8-hour ozone SIP.

1.4 WESTERN AIR QUALITY STUDY AND INTERMOUNTAIN WEST DATA WAREHOUSE

The Intermountain West Data Warehouse (IWDW[2]) was developed to be a repository and source of ambient air quality and modeling data that can be used by agencies and others in the western states for air quality planning and research. The Western Air Quality Study (WAQS) is a companion study to the IWDW that has developed air quality modeling databases to populate the IWDW. The WAQS started by enhancing the West-wide Jump-Start Air Quality Study (WestJumpAQMS[3]) 2008 WRF/SMOKE/CAMx/CMAQ 36/12 km database and making it available through the IWDW. WAQS then developed new 2011a and 2011b WRF/SMOKE/CAMx/CMAQ databases (Adelman, Shanker, Yang and Morris, 2014; 2015) that is also available through the IWDW. The WAQS 2011b modeling platform formed the basis for the 2011 CAMx database used in the 2017 Denver ozone SIP attainment demonstration modeling.

1.5 OVERVIEW OF DENVER OZONE SIP MODELING APPROACH

The 2017 Denver Metro/NFR 8-Hour ozone SIP modeling includes emissions, meteorological and ozone model simulations using a nested 36/12/4 km grid with the 4 km grid focused on the state of Colorado, including the Denver Metro/NFR NAA and vicinity.

1.5.1 Episode Selection

Episode selection is an important component of an 8-hour ozone attainment demonstration. EPA guidance recommends that 10 days be used to project 8-hour ozone Design Values at each critical monitor (EPA, 2014d). The Denver ozone season of May through August 2011 period was selected for the Denver ozone SIP for the reasons outlined in Chapter 3 of the Denver ozone SIP Modeling Protocol (Ramboll Environ and Alpine, 2015).

1.5.2 Model Selection

The Weather Research Forecast (WRF) meteorological model was used to generate meteorological inputs for the Denver ozone modeling. Emissions modeling was performed using the SMOKE emissions model for most source categories. The exceptions are the MEGAN model was used for biogenic emissions and special processors were used for emissions from fires, lightning and sea salt emissions. The MOVES2014 on-road mobile source emissions model was used with SMOKE-MOVES to generate on-road mobile source emissions. Within the Denver Metro/NFR NAA, link-based activity data were used based on Traffic Demand Model (TDM) output were used for on-road mobile source emissions. The CAMx photochemical grid model was used to simulate ozone levels in the base (2011) and future (2017) years. The model configuration was based on a similar WRF/SMOKE/MEGAN/CAMx modeling system used in the WRAP WestJumpAQMS and WAQS studies with enhancements using link-based vehicle activity data within the Denver Metro/NFR NAA, updates to the Colorado anthropogenic emission and updates to newer versions of some of the models.

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[2] http://views.cira.colostate.edu/tsdw/
[3] http://www.wrapair2.org/WestJumpAQMS.aspx

1.5.3 Base and Future Year Emissions Data

The 2017 future year was used for the attainment demonstration modeling as that is the attainment year for Moderate ozone NAA. For Colorado, the 2011 base case and 2017 future year emissions were provided by the CDPHE/APCD. For outside Colorado, the 2011 base case emissions were based on version 2 of the 2011 National Emissions Inventory (NEIv2[4]) and the 2017 future year emissions were developed by EPA as part of the 2011 Version 6.2 modeling platform that was based on the 2011 NEIv2.

1.5.4 Development of 2011 Base Case Modeling Database

The CAMx 2011c modeling database was developed for a 36 km grid resolution continental U.S. (CONUS) domain, a 12 km grid resolution western U.S. (WESTUS) domain and a 4 km grid resolution domain covering Colorado and small portions ("slivers") of neighboring states. Figure 1-3a displays the 36/12/4 km CAMx modeling domains with Figure 1-3b showing the 4 km Colorado domain and ozone monitoring sites that were operating during 2011. CAMx was run with 25 vertical layers from the surface to 50 millibar (mb) pressure height (approximately 19 km above sea level). The 36 km CONUS and 12 km WESTUS domains are the same as used in the WestJumpAQMS and WAQS studies. The projections and exact definitions of the domains are provided in the Denver 2017 Modeling Protocol and 2011 Base Case modeling reports (Ramboll Environ and Alpine 2015; 2016).

1.5.4.1 <u>Meteorology Input Preparation and QA/QC</u>

The CAMx 2011 36/12/4 km meteorological inputs were based on WRF meteorological modeling conducted by the WAQS. Details on the WAQS 2011 WRF application and evaluation are provided in UNC and ENVIRON (2015[5]). The WAQS WRF meteorological model 36/12/4 km output was re-processed using the current version of the WRFCAMx processor for the Denver ozone attainment demonstration modeling database, so the CAMx meteorological inputs for the Denver ozone modeling differed slightly from the those used by the WAQS (for details see Ramboll Environ and Alpine, 2016).

1.5.4.2 <u>Initial and Boundary Conditions Development</u>

Boundary Condition (BC) inputs for the 36 km CONUS domain were based on output from a 2011 simulation the MOZART Global Chemistry Model (GCM) and were the same as used in the WAQS. The CONUS BC inputs were day-specific and diurnally varying with 3-hour updates. The MOZART dust concentrations were capped because they are not day-specific and produced poor dust PM performance in the WAQS CAMx simulations. However, the dust BCs do not affect the Denver ozone modeling results. The CAMx model was run with 9 days of model spin-up on the 4 km domain (i.e., May 1-9, 2011) before the first high ozone day (May 10, 2015) to eliminate any influence of the initial concentrations (ICs).

[4] http://www.epa.gov/ttnchie1/net/2011inventory.html
[5] http://vibe.cira.colostate.edu/wiki/Attachments/Modeling/3SAQS_2011_WRF_MPE_v05Mar2015.pdf

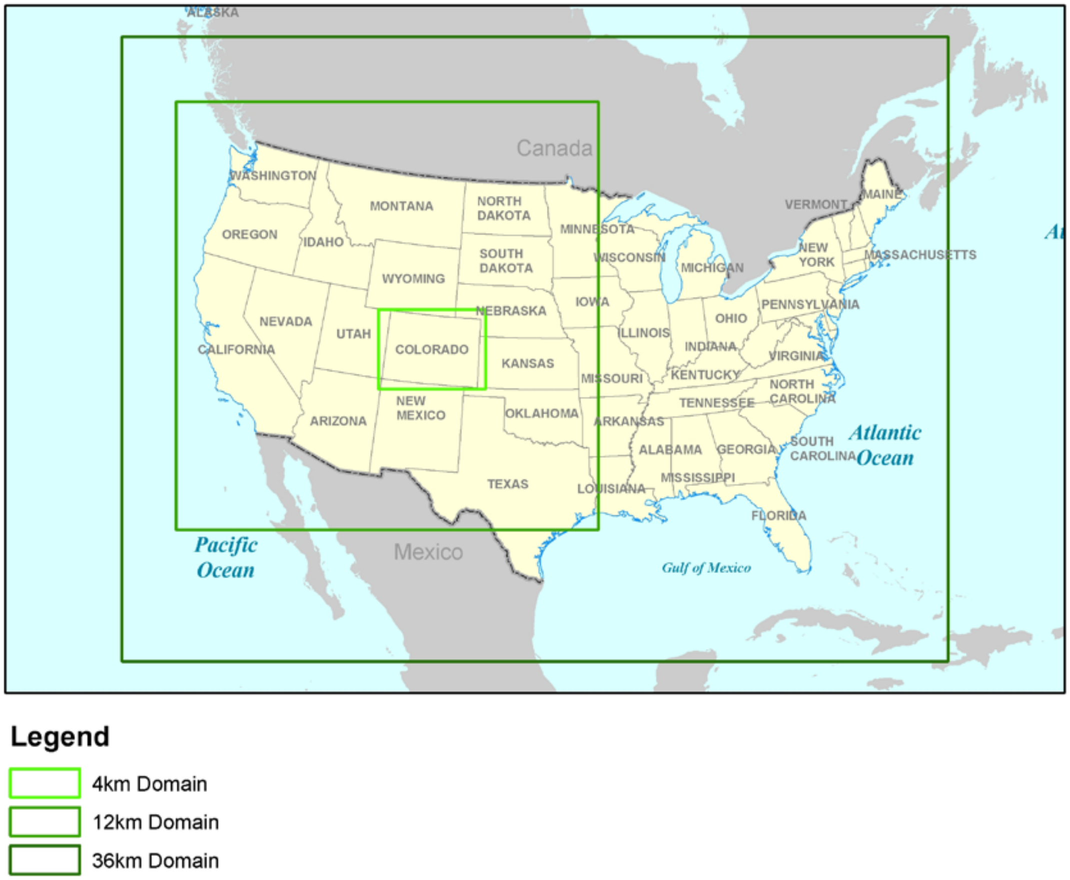

Figure 1-3a. Denver 36/12/4 km CAMx modeling domains.

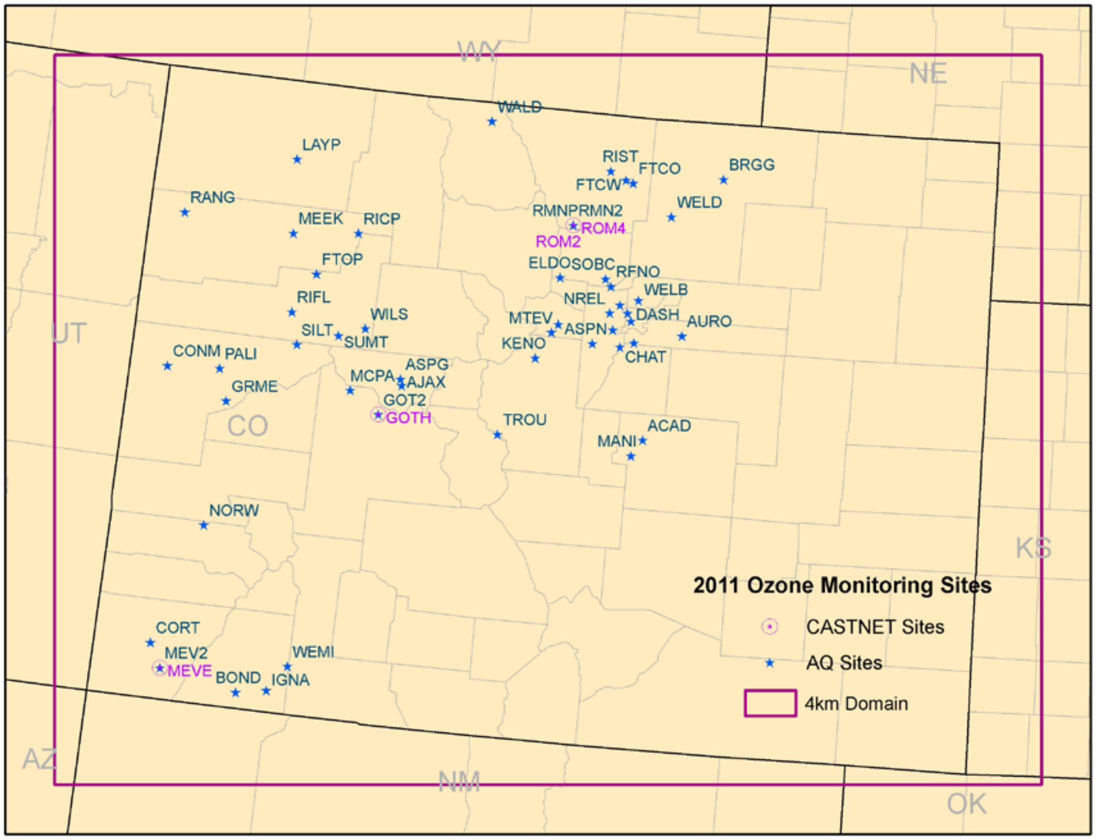

Figure 1-3b. Denver 4 km Colorado modeling domain with ozone monitors that were operating during some portion of 2011.

1.5.4.3 Model Performance Evaluation

This section presents a brief summary of the model performance evaluation. The full model performance evaluation is presented in the Denver Metro/North Front Range 2017 8-Hour Ozone State Implementation Plan: 2011 Base Case Modeling and Model Performance Evaluation (Ramboll Environ and Alpine, 2016).

The Model Performance Evaluation (MPE) relied in part on the CAMx MPE from the WAQS and followed EPA's MPE recommendations in their ozone modeling guidance documents (EPA, 1991; 2007; 2014d). EPA Region 8 (R8) has developed a MPE checklist (EPA, 2015a) that served as a reference for the Denver ozone modeling MPE. However, many of the recommendations in EPA's checklist pertain to particulate matter, visibility and deposition model performance that is not the primary focus of the Denver ozone SIP. In addition, many of EPA's MPE procedures were previously performed as part of the WAQS CAMx MPE. The relevant MPE from EPA's checklist related to ozone modeling were used in the MPE.

The Denver ozone SIP modeling conducted a detailed ozone model performance evaluation (MPE) within the Denver Metro/NFR NAA and vicinity (Ramboll Environ and Alpine, 2016). Figure 1-4 displays the locations of the ozone monitoring sites within the NAA and vicinity used in the Denver ozone MPE. The ozone MPE examined model performance across the NAA and at each individual monitoring site with particular focus on the four key monitoring sites within the NAA (i.e., RFNO, CHAT, NREL and FTCW) and on the modeling days used in the future year 2017 ozone Design Value projections. Detailed on the ozone MPE within the Denver Metro/NAA can be found in Ramboll Environ and Alpine (2016) with details on the CAMx 2011 MPE throughout the western states and for other parameters found in Adelman, Shanker, Yang and Morris (2014; 2016).

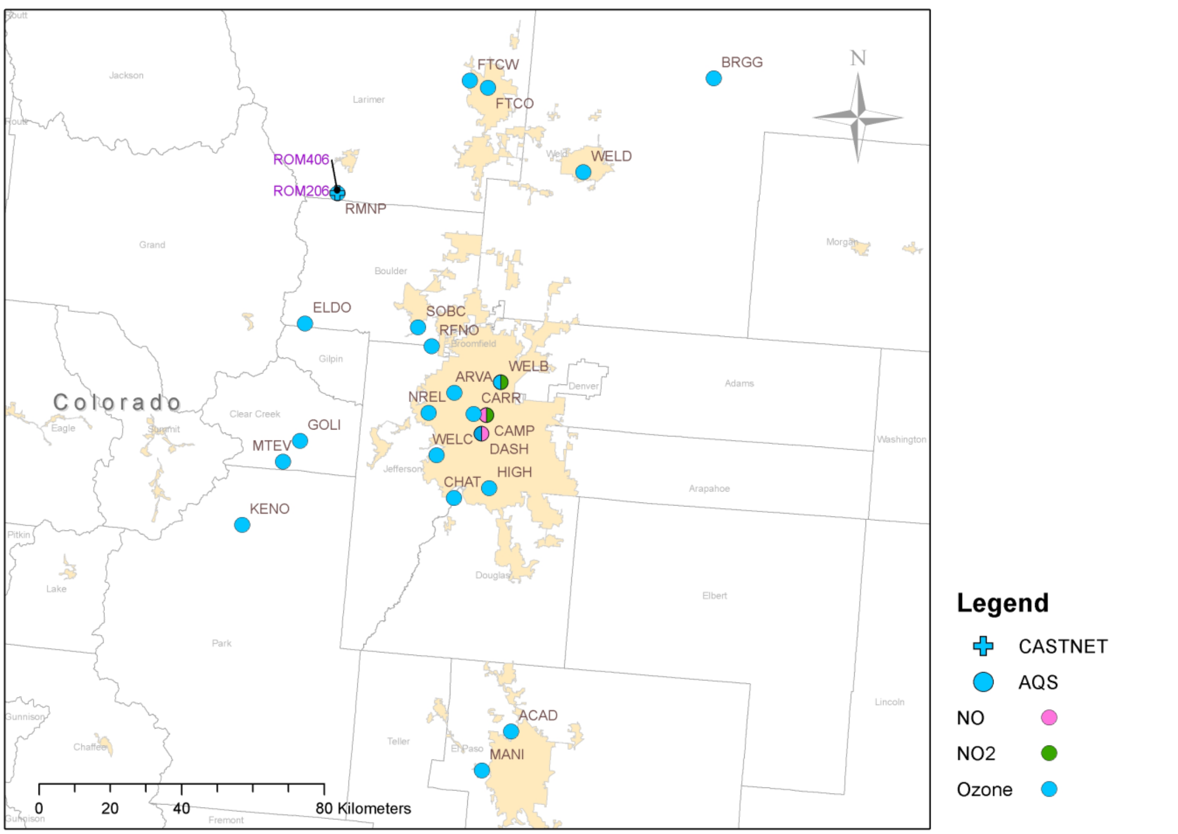

Figure 1-4. Locations of ozone and NO_X monitoring sites operating in 2011 from the AQS and CASTNet networks within the Denver Metro/NFR NAA and vicinity.

1.5.4.4 Diagnostic Sensitivity Analyses

Numerous diagnostic sensitivity tests were conducted to examine model performance and the sensitivity of model inputs to ozone projections in the Denver Metro/NFR NAA. As part of the WRAP WAQS, many additional sensitivity tests of the CAMx 2011 modeling platform were also performed and are documented on the IWDW website.

1.5.5 Future Year Modeling

Future-year modeling for ozone was performed for the Denver 2017 future year attainment date. The future year modeling application used the same modeling platform (model version, options, meteorology, boundary conditions) as the 2011 base year modeling. The only difference in the future year modeling were the emission inputs as described in Section 2.2

1.5.5.1 2017 Ozone attainment Demonstration Modeling

The Denver modeling results were used to demonstrate attainment of the 8-hour ozone NAAQS. The procedures used to demonstrate attainment of the ozone NAAQS followed EPA's latest draft guidance (EPA, 2014d). These procedures use the modeling results in a relative fashion to scale the base year observed 8-hour ozone Design Values (DVBs) using Relative Response Factors (RRFs). RRFs are the ratio of the future-year to base year modeling results and are used to scale the current year DVBs to project future-year Design Values (DVFs) that are compared against the ozone NAAQS to determine whether attainment has been demonstrated. EPA has developed the Modeled Attainment Test Software (MATS[6]; Abt, 2014) tool that includes the recommended procedures in the latest EPA guidance for projecting ozone DVFs. Note that EPA's current recommended ozone projection technique (EPA, 2014d) differs slightly from the previous procedures (EPA, 2007) used in the Denver 2008 ozone SIP attainment demonstration (Morris et al., 2008; 2009). Detailed on the 2017 future year attainment demonstration modeling are contained in Chapter 3.

1.5.5.2 Weight of Evidence Analyses

EPA's guidance recommends three general types of "weight of evidence" (WOE) analyses in support of the attainment demonstration: (a) additional modeling analysis; (b) analysis of trends in ambient air quality and emissions; and (c) additional emission controls/reductions. The Denver ozone SIP attainment demonstration includes supporting evidence from each of these three types of WOE analysis. Information on the modeling components of the 2017 ozone attainment demonstration WOE is contained in Chapter 4.

[6] http://www.epa.gov/scram001/modelingapps_mats.htm

2.0 DEVELOPMENT OF THE 2011 AND 2017 EMISSIONS

The 2017 emissions were based on data provided by the CDPHE/APCD for Colorado and EPA's 2017 emission projections for other states that were based on version 2 of the 2011 National Emissions Inventory (NEIv2) that is part of EPA's 2011 version 6.2 modeling platform. The 2017 attainment demonstration modeling uses the CAMx 2011 and 2017 simulations to project the base year observed ozone Design Values to the future years. Thus, the 2011 and 2017 emission inventories need to be developed using consistent procedures. In this Chapter we describe the development of the 2011c and 2017c base case emissions used in the 2017 ozone attainment demonstration modeling.

2.1 2011 EMISSIONS

This section presents a summary of the data sources and processing methodology for the 2011 emissions. The information is presented in this document to provide a comparison with the 2017 emissions inventory presented in Section 2.2. More details on the development of the 2011 emissions inventory and summary of results are presented in the Denver Metro/NFR 2011 Base Case Modeling and Model Performance Evaluation report (Ramboll Environ and Alpine, 2016).

2.1.1 Overview of 2011 Emission Inputs

With the exception of on-road mobile source emissions, the 2011 base year anthropogenic emissions inventory for Colorado were based on emissions provided by the CDPHE/APCD. For states outside of Colorado, version 2 of the 2011 NEI[7] was used with the following enhancements.

- Major point source SO_2 and NO_X emissions were based off measured Continuous Emissions Monitor (CEM) data that are available online from the EPA Clean Air Markets Division (CAMD[8]) website.
- For 2011, emissions from oil and gas (O&G) production and exploration sources were based on the 2011 emission inventories developed under the WAQS using the WRAP Phase III methodology. The WAQS 2011 O&G emissions are described in Section 3.1.2 of the WAQS emission report (Adelman and Baek, 2015[9]) and cover the following O&G basins:
    - Piceance (CO)
    - Denver-Julesburg (CO)
    - North San Juan (CO)
    - South San Juan (NM)
    - Uinta (UT)
    - Southwest Wyoming (WY)

7 https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data
8 http://www.epa.gov/AIRMARKETS/
9 http://vibe.cira.colostate.edu/wiki/Attachments/Emissions/3SAQS_Emissions_Modeling_Report_v18Feb2015.pdf

- Powder River (WY)
- Wind River (WY)
- Big Horn (WY)
- Paradox (UT-CO)
- Raton (CO)

The 2011 O&G emissions for the Colorado Basins (Piceance, Denver-Julesburg, North San Juan, Raton and eastern portion of Paradox) were provided by the CDPHE/APCD. But since WRAP WAQS 2011 O&G uses the same APEN O&G emissions data as CDPHE/APCD and CDPHE/APCD used the WRAP WAQS 2011 O&G data for non-APEN data, they are identical.

For 2011 O&G emissions for the Williston and Great Plains Basins in Montana-North Dakota, the results from a recent study by WRAP for the BLM Montana/Dakotas State Office were used[10]. For 2011 O&G emissions outside of the WRAP Basins, the 2011 NEI O&G emissions were used.

On-road mobile source emissions were based on the EPA's MOVES2014 on-road emissions model (EPA, 2014a,b,c). Three different procedures were used for generating on-road mobile source emission inputs for: (1) within the Denver Metro/NFR NAA; (2) within Colorado outside of the NAA; and (3) outside Colorado as follows.

- Within Denver Metro/NFR NAA, MOVES2014/CB6 was run in emissions rates mode with Colorado specific fleet characteristics and inspection and maintenance (I/M) program inputs to generate an Emissions Factor (EF) look-up table. The SMOKE-MOVES processor was used with the Colorado-specific MOVES2014 EF look-up table, Traffic Demand Model (TDM) link-based vehicle activity data and hourly gridded 4 km WRF meteorological data to generate the hourly gridded CB6r2 speciated emissions for the Denver Metro/NFR NAA.
- Within Colorado outside of the Denver Metro/NFR NAA, SMOKE-MOVES was used with MOVES2014/CB6 EF table using Colorado-specific fleet data, county-level vehicle activity data, hourly gridded 4 km WRF meteorology data and 4 km spatial surrogates for spatial distribution.
- Outside of Colorado, the SMOKE-MOVES modeling system was used with hourly WRF gridded meteorological data and EPA's 2011 Version 6.2 modeling platform 2011 EF tables that were based on MOVES2014 run with national defaults.

The 2011 fire emissions developed by the Joint Fire Sciences Program (JFSP) PMDETAIL[11] project were used. These are the same open land fire emissions as were used in the WAQS.

[10] http://www.wrapair2.org/ND-SD-MT.aspx
[11] https://pmdetail.wraptools.org/

Biogenic emissions were generated using the Model of Emissions of Gases and Aerosols in Nature (MEGAN[12]) version 2.10 (Guenther et al., 2014) that was updated by WRAP[13] to include western U.S. plant types.

Mexico emissions were based on the 2012 projections from the 1999 Mexico national emissions inventory that is provided with the 2011 NEIv2.

The Environment Canada 2010 emissions inventory that is based on the National Pollutant Release Inventory (NPRI) was used for Canada. This inventory is provided with the 2011 NEIv2.

2.1.2 Development of CAMx-Ready 2011 Emission Inventories

CAMx-ready emission inputs were generated mainly using the Sparse Matrix Operator Kernel Emissions (SMOKE) version 3.6.5 modeling system (Coats, 1995; UNC, 2015). The MEGAN biogenic and separate fire emissions models were also used for those two source categories. CAMx requires two hourly emission input files for each day: (1) low level hourly gridded emissions that are emitted directly into the first layer of the model from sources at the surface with little or no plume rise; and (2) elevated point sources (stacks) hourly emissions where CAMx calculates plume rise internally using stack parameters and hourly meteorological conditions for the grid cell containing the stack. For the 2017 Denver ozone SIP modeling, CAMx used version 6 revision 2 of the Carbon Bond chemical mechanism (CB6r2) that has newer chemical kinetic and reaction data including a new NO_2 + OH rate constant (Yarwood et al., 2010). It also includes updated aromatic chemistry that should improve the CAMx model's ability to simulate ozone formation in the NAA. As part of the emissions processing, the emissions are speciated into the chemical species used in CB6r2.

The 2011 base case 4 km emission inputs for CAMx and the May to August, 2011 modeling period were based on 2011 emissions provided by the CDPHE/APCD for Colorado that were processed by SMOKE. For slivers of other non-Colorado states within the 4 km domain (Figure 1-4b), the 2011 NEIv2 was used. Boundary conditions (BCs) for the 4 km Colorado domain were based on processing hourly three-dimensional output file concentrations from CAMx simulations of the 36 km CONUS and 12 km WESTUS domains.

2.1.2.1 Day-Specific On-Road Mobile Source Emissions

The on-road mobile source emission inputs for the 4 km Colorado domain were generated using the SMOKE-MOVES emissions model. SMOKE-MOVES uses a mobile source emission factor (EF) lookup table generated by the Motor Vehicle Emission Simulator (MOVES2014[14]) model (EPA, 2014a,b,c). SMOKE-MOVES used vehicle activity specific for Colorado provided by CDPHE/APCD, rather than use of MOVES2014 default or 2011 NEI vehicle activity data. SMOKE-MOVES uses the EF lookup table, hourly gridded meteorological data from WRF and activity data (e.g., vehicle miles travelled [VMT], speed, etc.) to generate day-specific hourly gridded on-road mobile source emission inputs for CAMx. SMOKE-MOVES was applied using two

[12] http://acd.ucar.edu/~guenther/MEGAN/MEGAN.htm
[13] http://www.wrapair2.org/pdf/WGA_BiogEmisInv_FinalReport_March20_2012.pdf
[14] http://www.epa.gov/oms/models/moves/#user

different sets of activity data: (1) use of link-based activity from Traffic Demand Models (TDMs) within the Denver Metro/NFR NAA; and (2) use of county-level activity data in Colorado outside of the Denver Metro/NFR NAA.

2.1.2.2 Colorado-Specific Vehicle Activity Data

The CDPHE/APCD provided vehicle fleet characteristics, fuel, I/M program and activity data specific to Colorado that was used with MOVES2014 to produce the EF lookup table used with SMOKE-MOVES. The CDPHE/APCD was concerned that the MOVES2014 default and 2011 NEI vehicle activity data for Colorado fails to account for several of the unique aspects of the fleet age distribution in Colorado that has a significantly higher fraction of older vehicles than assumed in the MOVES2014 and 2011 NEI fleet age distributions. EPA's 2011 version 6.2 modeling platform MOVES2014 EF lookup table also did not include the effects of Colorado's I/M Program on mobile source emissions, which is in effect in the 7-county Denver Metro nonattainment area in 2011 and the full 9-county nonattainment area in 2017.

The version of MOVES2014 uses in the Denver EF lookup table development was an interim version of MOVES2014 that was based on the October 2014 MOVES2014 release whose only difference was the addition of CB6 speciation. All other aspects of the interim MOVES2014/CB6 used were the same as the October 2014 release version.

2.1.2.3 On-Road Mobile Emissions for 4 km Colorado Domain

The SMOKE-MOVES emissions model was used to generate on-road mobile source emissions for the 4 km Colorado domain outside of the Denver Metro/NFR NAA using the 2011 county-level VMT data, 2011 MOVES2014 EF lookup table (using CDPHE/APCD vehicle distribution data), hourly gridded WRF meteorology and spatial surrogate distributions.

2.1.2.4 On-Road Emissions for the Denver Metro/NFR NAA

For the Denver Metro/NFR NAA region, 2011 on-road mobile source emissions were generated using the SMOKE-MOVES model with link-based on-road mobile source activity data, MOVES2014 EF lookup table using the CDPHE/APCD vehicle age distributions and I/M assumptions and hourly gridded WRF meteorological conditions. The link-based vehicle activity data were gridded to the 4 km grid cells retaining unique vehicle types and speeds using the new Open Data Base Connectivity (ODBC) Transportation Inventory System (OTIS) model developed by CDPHE/APCD.

The Denver Regional Council of Governments (DRCOG) and North Front Range Metropolitan Planning Organization (NFRMPO) provided 2010 and 2012 TransCAD TDM output for the Denver Metro and NFR regions, respectively. These data included link-specific capacities, volumes, and speeds for a typical weekday for 10 time periods in each day in the TransCAD TDM model (3 morning peak, 3 afternoon peak, and 4 off-peak times).

The OTIS model is a MS Access database application that links MOVES2014 emissions rate lookup tables using the ODBC connection. ODBC is a standard programming language middleware Application Program Interface (API) for accessing database management systems, which is aimed to make it independent of database systems and operating systems. OTIS uses Weekday, Saturday and Sunday-specific link-level volume and speed data by time period from the TDM model and VMT mix to calculate hourly gridded VMT by vehicle type. The lookup tables are queried to retrieve appropriate emissions factors and combined with gridded hourly VMT estimate emissions. The OTIS gridded link-based activity data was interfaced with SMOKE-MOVES, the Colorado-specific MOVES2014 EF lookup table and WRF gridded hourly meteorological data to generate day-specific gridded speciated hourly on-road mobile source emission inputs for PGM modeling.

The link-level TDM gridding capability of OTIS was used with DRCOG/NFRMPO link-based activity data to generate 4 km gridded vehicle activity data representing all links that intersect with a 4 km grid cell. The OTIS model calculates hourly gridded VMT using the link-level volume, speed and vehicle mix data for each combination of following fields:

- Grid cell
- Hour (corresponding to 10 periods in the TDM)
- Speed Class
- Vehicle Type
- Road Type

The hourly gridded VMT data was provided to a new SMOKE-MOVES2014 integration tool. SMOKE-MOVES is typically applied using county-level VMT, vehicle population and speeds that are allocated to grid cells using an appropriate spatial surrogate and then applies MOVES emission factors from a lookup table using hourly gridded meteorological data (temperature and humidity). In order to use the OTIS gridded link-based data from the TDM models, we “tricked” SMOKE-MOVES to treat each 4 km grid cell and speed class as a pseudo-county. The spatial surrogate was a one-to-one mapping of a 4 km grid cell pseudo-county to the respective 4 km grid cell. We provided daily grid cell level VMT to SMOKE calculated from the OTIS model. If there is more than one speed class for a given grid cell, vehicle type, and road type, they are treated as separate pseudo-county so that we can use the correct average speed emissions factors. We developed a diurnal temporal profile for each pseudo-county (i.e. grid cell intersecting the network) using the OTIS data and applied them on a pseudo-county basis in the temporal processing using the day-specific hourly gridded WRF meteorological data to select the appropriate MOVES2014 emissions factors from the MOVES2014 lookup table. SMOKE-MOVES tool performed the chemical speciation to the CB6 species and emissions calculation. Figure 1-5 shows the steps involved in preparing model-ready emissions using this approach. Separate SMOKE-MOVES runs were performed for each modeling day using hourly gridded WRF meteorological data for that day and Weekday, Saturday and Sunday activity data from OTIS.

The off-network emissions (e.g., diurnal) were modeled using a more standard application of SMOKE-MOVES with spatially allocated using surrogates developed from trip starts (start exhaust) and trip ends (for evaporative processes) by Traffic Analysis Zone (TAZ). These surrogates were used in SMOKE-MOVES "rate per vehicle" (RPV) and "rate per profile" (RPP) processing. We used this approach for the DRCOG and NFR networks to generate day-specific gridded hourly on-road mobile source PGM emission inputs for the Denver Metro/NFR region for off-network emissions.

For start emissions, four separate SMOKE-MOVES simulations were performed using four separate spatial surrogate distributions of start locations based on time of day: (1) morning commute; (2) mid-day; (3) afternoon commute; and (4) over night. SMOKE only allows the input of a single spatial surrogate distribution for each source category and by breaking out the SMOKE modeling of the start emissions into four time periods allows for better representation of the differences in locations for the morning (suburbs) versus afternoon (Denver Metro) start emissions.

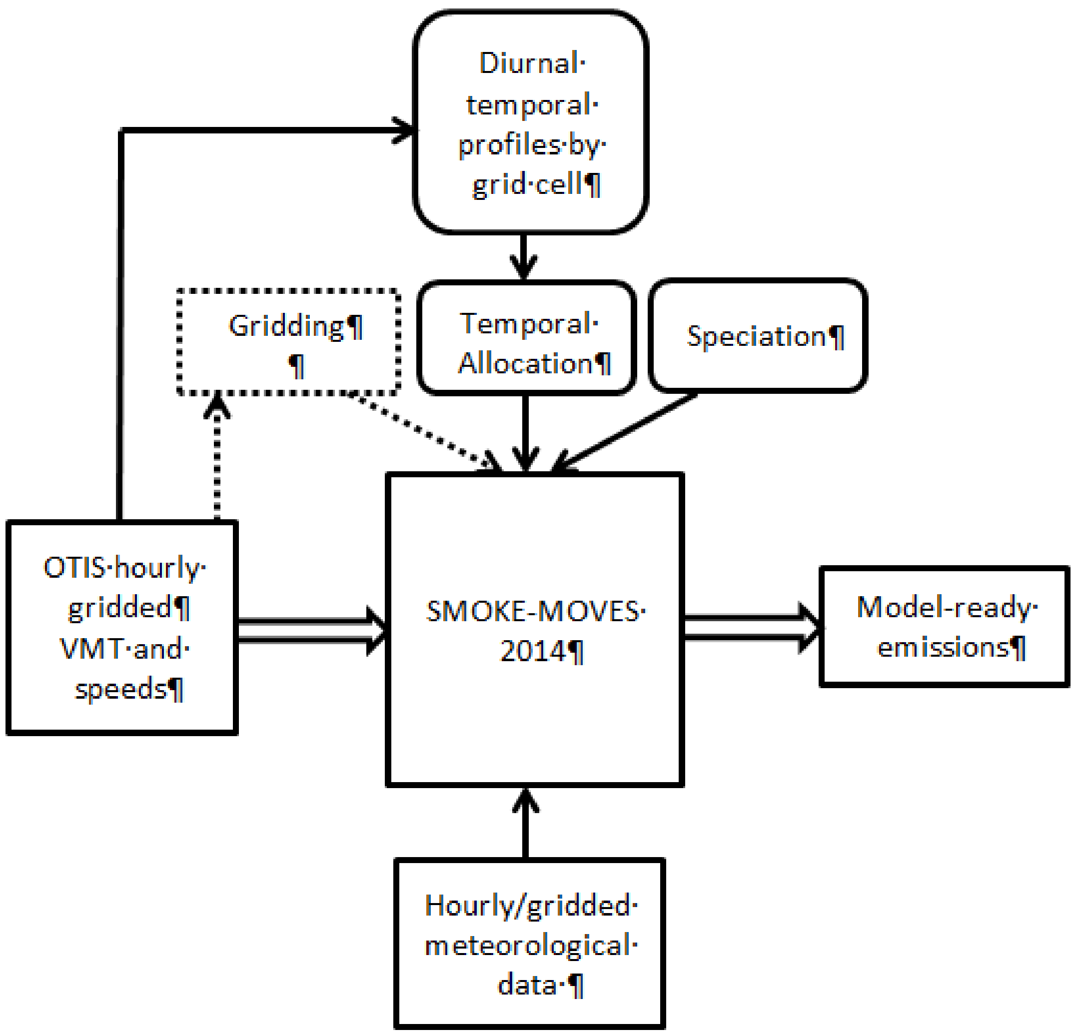

Figure 1-5. Steps involved in preparing model-ready emissions interfacing the OTIS model with SMOKE-MOVES2014.

2.1.2.5 Oil and Gas Emissions

The 2011 oil and gas (O&G) gas emissions for exploration and production sources were based on the CDPHE 2011 Air Pollutant Emissions Notice (APEN) permit database that includes sources down to 1 ton per year (TPY) within the Denver Metro/NFR NAA and 2 TPY throughout the rest of the state. Thus, APEN includes all major condensate tank VOC emissions in the Denver-Julesburg (D-J) Basin that makes up the vast majority of the VOC emissions. APEN also includes most of the major NO_X emitters associated with O&G (e.g., compressors). For sources not in the APEN database, the WRAP Phase III surveyed the Operators to obtain accounting of sources not captured by APEN (i.e., surveyed sources) that were projected to 2011 using 2011 activity data (e.g., from IHS and/or COGA databases). In recent years, O&G development in the D-J Basin is switching from vertical to horizontal drilling raising questions whether the WRAP Phase III 2006 surveys are appropriate for characterizing current and future year emissions. For 2011 emissions these are considered the best information available. However as described in Section 2.2.2.2, for the 2017 O&G emissions new information was obtained from the operators to better characterize emissions.

2.1.2.6 Episodic Biogenic Source Emissions

Biogenic emissions were generated using a version of the MEGAN biogenic emissions model (Guenther and Wiedinmyer, 2004; Guenther et al., 2014) that was enhanced by WRAP to better treat biogenic emission from plan species in the western U.S. (Sakulyanontvittaya et al., 2012). MEGAN uses high resolution GIS data on plant types and biomass loadings and the WRF surface temperature fields, and solar radiation (modeled or satellite-derived) to develop hourly emissions for biogenic species on the 36/12/4 km grids. MEGAN generates gridded, speciated, temporally allocated emission files. One feature that is included in MEGAN is that it generates biogenic VOC precursor emission species for the secondary organic aerosol (SOA) module in CAMx.

2.1.2.7 Point Source Emissions

2011 point source emissions for Colorado were provided by the CDPHE/APCD. Point source emissions inputs were developed in two categories: (1) major point sources with Continuous Emissions Monitoring (CEM) devices; and (2) point sources without CEMs. For point sources with CEM data, day-specific hourly NO_X and SO_2 emissions were used for the 2011 base case emissions scenario. The VOC, CO and PM emissions for point sources with CEM data were based on the annual emissions provided by the CDPHE that were temporally allocated to each hour of the year using the CEM hourly heat input.

2.1.2.8 Area and Non-Road Source Emissions

CDPHE/APCD provided 2011 area and non-road emissions for Colorado. Area and non-road emissions for portions of the 4 km domain not covered by Colorado (i.e. the sliver states) were based on the 2011 NEIv1 inventory. The area and non-road sources were spatially allocated to the grid using an appropriate surrogate distribution (e.g., population for home heating, etc.). The area sources were temporally allocated by month and by hour of day using the WAQS source-specific temporal allocation factors. The SMOKE source-specific CB6 speciation allocation profiles were used.

2.1.2.9 Wildfires, Prescribed Burns, Agricultural Burns

2011 emissions from open-land burning, including wildfires, prescribed burns and agricultural burning, were based on the Joint Fire Sciences Program PMDETAIL[15] project that was an extension of the DEASCO3 project (Moore et al., 2011). The PMDETAIL 2011 fires were processed for the 36, 12 and 4 km domains using the PMDETAIL fire emissions processor that accounts for plume rise and chemical speciation.

2.1.2.10 QA/QC and Emissions Merging

The 2011 emissions were 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) procedures were used for each stream of emissions processing and in each step following the procedures developed by WRAP (Adelman, 2004).

2.2 2017 EMISSIONS

The procedures for developing the 2017 emission inputs were the same as used for the 2011 emissions, only using 2017 anthropogenic emissions from CDPHE/APCD for Colorado and EPA's 2017 emissions projections for anthropogenic emissions outside of Colorado.

2.2.1 Emissions Held Constant at 2011 Levels

Natural and emissions from Mexico and Canada were held constant at 2011 emission levels. More specifically, the following emission source categories were held constant at the same levels used in the 2011 base case modeling:

- MEGAN biogenic 2011 emissions;
- Lightning NO_X emissions (LNOx);
- Wildfire, agricultural and prescribed fires;
- Seasalt;
- Emissions from Mexico (2012); and
- Emissions from Canada (2010).

2.2.2 Colorado 2017 Anthropogenic Emissions

Within Colorado, most of the 2017 emissions were provided by the CDPHE/APCD. The exceptions to this were on-road mobile sources and natural sources. Special considerations were also taken with the hourly temporal variations in the emissions from Electrical Generating Units (EGUS) using the annual emissions provided by CDPHE/APCD.

[15] https://pmdetail.wraptools.org/

2.2.2.1 Colorado 2017 On-Road Mobile Source Emissions

The same procedures as used for generating 2011 on-road mobile source emissions within the Denver Metro/NFR NAA and within Colorado outside of the NAA as described in Section 2.1.2 were used for the 2017 on-road mobile source emissions. The exceptions were as follows:

- The interim CB6 version of MOVES2014 was used to generate an EF lookup table for use with SMOKE-MOVES that account for the 2017 fleet using vehicle age distribution provided by CDPHE/APCD and the I/M program in the Denver Metro/NFR NAA.
- The 2017 link based activity data were obtained from DRCOG and NFRMPO that were gridded to the 4 km resolution using OTIS from which day-specific hourly gridded speciated emissions were generated using SMOKE-MOVES as described in Section 2.1.2.4.
- Outside of Colorado, SMOKE-MOVES was used with 2017 activity data and the MOVES2014 2017 EF lookup table that EPA developed as part of the 2011 NEI version 6.2 modeling platform using the same procedures as used in 2011 that is described in Section 2.1.2.3.

2.2.2.2 2017 Oil and Gas Emissions

The 2017 oil and gas (O&G) emissions for Colorado were provided by the CDPHE. The 2014 APEN O&G emissions and 2011 survey O&G emissions were projected to 2017 based on expected changes in production. Particular attention was paid to the O&G emissions from the Denver-Julesburg (D-J) Basin and are documented in the 2011 and 2017 Oil and Gas Emissions Inventory Development Technical Support Document (CDPHE and RAQC, 2016). The 2011 O&G emissions were based on 2011 Air Pollutant Emission Notice (APEN) data for permitted sources and WRAP Phase III 2006 surveyed sources data projected to 2011. The 2017 O&G emissions were based on 2014 APEN data projected to 2017 based on growth with controls applied. The controls were based on discussions with the six O&G Operators who operate in the D-J Basin. Oil (condensate) production is projected to grow 77% in the D-J Basin between 2014 and 2017 due to increased horizontal drilling; oil production from vertical drilling is expected to decrease between 2014 and 2017 such that by 2017 only 6% of the oil production is projected to be from vertical drilling. The Operators have or are installing VOC controls on condensate tanks that range from 100% controls for tankless operations to 75%-77% for the three stages of separation controls (1, 2 or 3 stage). Thus, despite the projected large growth in oil production between 2011 and 2017, condensate VOC emissions are projected to go down by 64%.

2.2.2.3 2017 EGU Emissions

The development of the 2017 EGU emissions were based on the 2014 APEN EGU emissions data projected to 2017 and accounting for changes in activity and controls, including any shut downs. The Colorado Clean Air Clean Jobs Act of 2010 resulted in reductions in NO_X emissions from the EGU sector that was accounted for in the 2017 EGU emissions projections. Within the Denver Metro/NFR NAA, the Cherokee Units 1-3 and Arapahoe Units 3-4 were assumed to shut down between 2011 and 2017. In addition, by the end of 2017 Cherokee Unit 4 will switch from coal to natural gas and Valmont Unit 5 will shut down, however these two sources were assumed to still be operating in the 2017 emissions scenario.

The 2017 EGU NO_X emissions were assumed to have the same hourly operating schedule as used in 2011 that was based on the measured hourly CEM data. That is, EGU Unit-specific hourly temporal profiles were developed using the CEM data and applied to the 2017 annual emissions rates provided by RAQC and CDPHE/APCD.

2.2.2.4 2017 Non-Road Mobile Emissions

The 2017 non-road mobile source emissions for Colorado were generated using EPA's NONROAD[16] emissions model that accounts for growth and controls, including new engine standards. Non-road mobile categories not included in EPA's NONROAD model include aircraft, locomotives and commercial marine. Within Colorado there are no commercial marine sources.

For aircraft, the Denver International Airport (DIA) provides data on fleet type and usage. The DIA 2014 emissions were projected to 2017 based on forecast data. For locomotives, switchers (i.e., rail yard) emissions are grown to 2017 using population growth surrogate and line haul locomotives were grown to 2017 based on track mileage within the NAA.

2.2.2.5 2017 Remaining Point and Area (Non-Point) Source Emissions

The other point sources include external combustion boilers, industrial processes, internal combustion sources and petroleum/solvent evaporation that are not EGUs or associated with the O&G industry. The 2017 other point source emissions were based on the 2014 APEN data grown to 2017 using population as the growth surrogate with controls applied as appropriate.

The non-O&G other area sources consist mainly of VOC emissions from a wide range of diverse categories including coatings, household and personal care products, pesticides, coatings, sealants, etc. The 2011 other area sources emissions were based on the 2011 NEI that was provided to EPA by CDPHE/APCD. The 2017 other area source emissions were grown from the 2011 emissions using county-level population growth as a surrogate. There are a few national regulations that impact these source categories.

2.2.3 2017 Non-Colorado Emissions

With the exception of on-road mobile source emissions, the 2017 emissions for the 36 km CONUS and 12 km WESTUS domains were taken from EPA's 2011 NEI Version 6.2 modeling platform 2017 emission projections. The development of the 2017 emissions is described in the Technical Support Document for the development of the 2011 Version 6.2 modeling platform (EPA, 2015e[17]). The EPA 2017 projection data were processed using the SMOKE emissions modeling system using default assumptions to generate the hourly gridded speciated emission inputs for the 36 km CONUS and 12 km WESTUS domains.

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[16] https://www3.epa.gov/otaq/nonrdmdl.htm
[17] https://www.epa.gov/sites/production/files/2015-10/documents/2011v6_2_2017_2025_emismod_tsd_aug2015.pdf

For on-road mobile source emissions, the MOVES2014 Emission Factor (EF) lookup table for 2017 and vehicle activity data for 2017 from the Version 6.2 modeling platform (EPA, 2015) was used with SMOKE-MOVES. The study's WRF 2011 36 km CONUS and 12 km WESTUS domains hourly gridded meteorological data to generate day-specific hourly speciated emission inputs for CAMx modeling. The final step in the 2017 emissions modeling was the merging of the files into a point source and low-level gridded emission input files for CAMx.

2.3 SUMMARY OF 2017 EMISSIONS

Table 2-1 display the planning emissions inventories within the Denver Metro/NFR NAA for the 2011 and 2017 base case with Table 2-2 showing their percent differences. Several source categories use day-specific hourly varying emissions in the photochemical modeling, so the day-specific modeling inventories differ slightly from the planning inventories given in Table 2-1. Most notably, the following source categories have daily variations in the photochemical chemical modeling so will have differences with the 2011 and 2017 planning inventories:

- Biogenic emissions for the modeling were generated using the MEGAN model and have daily variations depending on temperature and solar radiation (e.g., affected by clouds). For the planning inventories given in Table 2-1, the Denver Metro/NFR NAA biogenic emissions from MEGAN were based on the average across the May-August 2011 modeling period.
- On-road mobile source emissions in the modeling vary by day-of-week (e.g., weekday, Saturday and Sunday) and are dependent on the day-specific hourly meteorological conditions (i.e., temperature and humidity) from the WRF 2011 4 km simulation. For the planning inventories, the on-road mobile source emissions were calculated for a weekday using constant temperature conditions representative of higher temperatures of an ozone exceedance day.
- Open land fire emissions (wildfires, prescribed burns and agricultural burning) were day-specific and developed by the JFSP PMDETAIL study. There were few fires within the Denver Metro/NFR NAA during the May-August 2011 modeling period. The planning inventories in Table 2-1 do not include fire emissions.
- Lightning NO_X (LNOx) are day-specific and depend on the amount of convective clouds from the WRF 2011 4 km simulation and were the same in 2011 and 2017. LNOx emissions are not included in the 2011 and 2017 planning inventories.

Total VOC emissions in the NAA are projected to go down by approximately 170 tons per day (TPD) (-25% total emissions and -33% anthropogenic emissions only) between 2011 and 2017. Most (74%) of these VOC emission reductions come from the O&G sector (126 TPD). On-road mobile source VOC reductions are the next most important sector (-39 TPD or 23% of the reduction) followed by non-road mobile (-14 TPD or 8% of the reduction).

Total NO_X emissions in the NAA are projected to go down 86 TPD (-26%) between 2011 and 2017 despite the fact that O&G NO_X emissions are projected to increase by 24 TPD. Large reductions in on-road mobile (69 TPD), non-road mobile (21 TPD) and point source (20 TPD)

NO_X emissions more than compensate for the increase in O&G NO_X to result in a net -26% reduction in total NO_X emissions across the NAA between 2011 and 2017.

CO emissions are reduced 298 TPD (-18%) in the NAA between 2011 and 2017, which is primarily due to reductions in on-road mobile sources (278 TPD) whose reductions are over 90% of the total reduction in CO emission across the NAA.

Table 2-1. Summary of 2011 and 2017 planning emissions (tons per day) in the Denver Metro/NFR NAA.

Description	2017			2011		
	VOC	NO_X	CO	VOC	NO_X	CO
Oil and Gas Sources						
Point Sources Subtotal	16.3	20.6	19.7	14.8	18.1	17.0
Condensate Tanks Subtotal	78.7	0.6	2.3	216.0	1.1	2.3
Area Sources Subtotal	59.0	44.6	31.4	48.9	22.2	12.9
TOTAL	154.0	65.8	53.4	279.7	41.4	32.2
Point Sources (EGU and Non-Oil and Gas)						
Electric Generating Units (EGU)	0.4	19.2	2.9	0.7	39.7	3.6
Point (Non-Oil and Gas)	28.0	20.9	14.4	25.9	21.0	14.1
TOTAL	28.4	40.1	17.3	26.5	60.7	17.7
Area Sources (Non-Oil and Gas)						
TOTAL	67.5	-	1.6	60.6	-	1.4
Non-Road Mobile Sources						
TOTAL	44.3	54.9	759.7	58.2	75.9	800.2
On-Road Mobile Sources						
Light-Duty Vehicles	52.4	50.3	538.6	90.0	102.5	812.2
Medium/Heavy-Duty Vehicles	2.6	23.0	16.2	3.7	39.6	20.6
TOTAL	55.0	73.3	554.7	93.7	142.0	832.8
Total Anthropogenic Emissions	349.2	234.0	1,386.6	518.8	320.0	1,684.4
Total Biogenic Sources	170.5	6.1	21.6	170.5	6.1	21.6
Total Nonattainment Area Emissions	**519.7**	**240.1**	**1,408.2**	**689.3**	**326.1**	**1,706.0**

Table 2-2. Percent reduction in 2017 emissions from 2011 levels.

Description	2017-2011 (%)		
	VOC	NO_X	CO
Oil and Gas Sources			
Point Sources Subtotal	10.4%	14.2%	15.6%
Condensate Tanks Subtotal	-63.6%	-47.7%	-2.1%
Area Sources Subtotal	20.5%	100.4%	143.8%
TOTAL	-45.0%	58.9%	65.5%
Point Sources (EGU and Non-Oil and Gas)			
Electric Generating Units (EGU)	-37.1%	-51.8%	-20.8%
Point (Non-Oil and Gas)	8.3%	-0.4%	2.0%
TOTAL	7.1%	-34.0%	-2.7%
Area Sources (Non-Oil and Gas)			
TOTAL	11.4%		11.0%
Non-Road Mobile Sources			
TOTAL	-23.8%	-27.7%	-5.1%
On-Road Mobile Sources			
Light-Duty Vehicles	-41.8%	-50.9%	-33.7%
Medium/Heavy-Duty Vehicles	-31.2%	-41.8%	-21.5%
TOTAL	-41.4%	-48.4%	-33.4%
Total Anthropogenic Emissions	-32.7%	-26.9%	-17.7%
Total Biogenic Sources	0.0%	0.0%	0.0%
Total Nonattainment Area Emissions	**-24.6%**	**-26.4%**	**-17.5%**

3.0 2017 OZONE ATTAINMENT DEMONSTRATION MODELING

3.1 INTRODUCTION

This section presents the 2017 ozone Design Value projections for the 2017 Future Case. The future year ozone projections demonstrate that the Denver area will achieve the 0.075 ppm 8-hour ozone NAAQS by 2017. The 8-hour ozone projections are made using the CAMx modeling results for the 2011 Base Case (Ramboll Environ and Alpine Geophysics, 2016) and the 2017 Future Case. These ozone projections are made using EPA's Modeled Attainment Test Software (MATS[18]; Abt, 2014). Below we provide a brief overview of the ozone projection procedures used by MATS, whose results for the 2017 Future Case are presented later in this Chapter.

3.2 OZONE PROJECTION PROCEDURES

The Denver 2017 8-hour ozone projections were made using procedures in EPA's latest draft modeling guidance (EPA, 2014d), with one exception as described below. These procedures use the model in a relative sense to scale the observed base year 8-hour ozone Design Value (DVB) to obtain a future year projected 8-hour ozone Design Value (DVF). The model derived scaling factors are referred to as relative response factors (RRF) and are defined as the ratio of daily maximum 8-hour ozone concentrations *near a monitor* averaged over *several days* of modeling results for the 2017 emissions scenario to the 2011 base case:

$$RRF = [\Sigma \text{ 2017 scenario}] / [\Sigma \text{ 2011 base case}]$$

$$DVF = DVB \times RRF$$

The basic steps in performing the 2017 8-hour ozone DVF projections can be summarized as follows:

1. Develop an observed base year 8-hour ozone Design Value (DVB) at each monitoring site that serves as the starting point for the ozone projections.

    a. EPA guidance (EPA, 2007; 2014d) recommends using an average of three years of 8-hour ozone Design Values centered on the modeling year, which for the Denver May-August 2011 episode modeling would mean averaging 8-hour ozone Design Values from the 2009-2011, 2010-2012 and 2011-2013 periods. This results in averaging the fourth highest daily maximum 8-hour ozone concentration at a monitor across five years of data centered on 2011 using weighting factors of 1, 2, 3, 2, and 1 for the years 2009-2013, respectively.

2. Select the maximum modeled 8-hour ozone concentrations *near a monitor* for *several days* from the 2011 base and 2017 emission scenarios and take the ratio of their averages to construct the monitor-specific RRFs:

[18] http://www.epa.gov/scram001/modelingapps_mats.htm

   a. By *near a monitor* EPA's current final guidance (EPA, 2007) suggests using an array of 7 x 7 grid cells centered on the monitoring location for the Denver modeling that uses a 4 km grid resolution. EPA's draft guidance (EPA, 2014d) suggests using an array of 3 x 3 grid cells centered on the monitoring location irrespective of the grid resolution used. The attainment demonstration used both the 3 x 3 and the 7 x 7 grid cell approaches. We note that more weight should be given to the 7x7 rather than the 3x3 ozone projections since the CAMx model performance was better for the 7x7 grid cell definition (Ramboll Environ and Alpine Geophysics, 2016).

   b. By *several days* EPA's current guidance (EPA, 2007) recommends using at least 10 modeling days for the RRFs, whereas EPA's draft guidance (EPA, 2014d) recommends RRFs based on the top 10 modeled days in the 2011 base case near a monitor. Thus, the top 10 modeled days were used in the Denver ozone attainment demonstration modeling.

3. The RRF is applied to the DVB to obtain the projected DVF for the 2017 emission scenarios. The projected DVF is truncated to the nearest ppb.

4. If the DVFs at all monitoring sites are less than 76 ppb (i.e., 75 ppb or lower when truncated), then the modeled attainment demonstration test is passed. If a DVF at any monitor is 76 ppb or higher, the modeled attainment test is not passed.

5. An unmonitored area analysis is also performed that interpolates the DVBs across the modeling domain and performs the ozone projections in each grid cell using the procedures given above, except using the modeling results within each individual grid cell rather than near the grid cell are used.

   a. EPA believes that the unmonitored area analysis is more uncertain than the monitor based ozone projections. Whereas additional emissions reductions are likely required to eliminate any projected monitored ozone exceedances, the same is not true in the unmonitored area test.

   b. EPA recommends that the reasons behind any unmonitored area test exceedances be understood and explained.

3.3 OZONE ATTAINMENT DEMONSTRATION FOR THE 2017 FUTURE CASE

The 2017 Future Case ozone attainment demonstration was performed following EPA guidance both at monitoring sites and at unmonitored areas away from the monitoring sites.

3.3.1 Attainment Demonstration at the Monitoring Sites

Table 3-1 summarizes the RRFs and resulting design values at all monitors in the nonattainment area based on using both the 3x3 and 7x7 grid cell arrays. As shown, using the 7x7 grid cell array shows slightly greater response from changes in emissions between 2011 and 2017. The

7x7 grid cell array demonstrates modeled attainment at all monitors, while the 3x3 array shows modeled attainment at all monitors except at Chatfield and Rocky Flats North, which are just slightly (0.4% or 0.3 ppb) above (76.2 ppb) the standard threshold (76.0 ppb). It is anticipated that the modeled concentration under either grid array scenario could be lower, which is further demonstrated in subsequent supplemental analyses provided in the weight of evidence analysis in Section 4.

Table 3-1. Current year observed 8-hour ozone Design Values (DVB), Relative Response Factors (RRFs) and projected 8-hour ozone2017 Future Case Design Values (DVFs).

Monitor	County	Base Year (2011) DVB (ppb)	3x3 Grid Array (4 km)			7x7 Grid Array (4 km)		
			RRF	Future Year (2017) DVF (ppb)**	Final 2017 DVB (ppb)**	RRF	Future Year (2017) DVF (ppb)**	Final 2017 DVF (ppb)**
Chatfield	Douglas	80.7	0.9453	76.2	76	0.9391	75.7	75
Rocky Flats North	Jefferson	80.3	0.9493	76.2	76	0.9441	75.8	75
NREL	Jefferson	78.7	0.9591	75.4	75	0.9442	74.3	74
Fort Collins West	Larimer	78.0	0.9179	71.5	71	0.9098	70.9	70
Highland	Arapahoe	76.7	0.9517	72.9	72	0.9431	72.3	72
Welby	Adams	76.0	0.9512	72.2	72	0.9712	73.8	73
Welch	Jefferson	75.7	0.9538	72.2	72	0.9428	71.3	71
Rocky Mountain NP	Larimer	75.7	0.9464	71.6	71	0.9385	71.0	71
South Boulder Creek	Boulder	74.7	0.9477	70.7	70	0.9445	70.5	70
Greeley/Weld Co. Tower	Weld	74.7	0.9422	70.3	70	0.9226	68.9	68
Aspen Park	Jefferson	74.5	0.9389	69.9	69	0.9370	69.8	69
Arvada	Jefferson	74.0	0.9723	71.9	71	0.9495	70.2	70
Aurora East	Arapahoe	73.5	0.9373	68.8	68	0.9367	68.8	68
Carriage	Denver	71.0	0.9695	68.8	68	0.9595	68.1	68
Rist Canyon	Larimer	71.0	0.9248	65.6	65	0.9161	65.0	65
Fort Collins CSU	Larimer	68.7	0.9217	63.3	63	0.9096	62.4	62
DMAS NCore	Denver	65.0	0.9697	63.0	63	0.9522	61.8	61

3.3.2 Unmonitored Area Analysis

EPA's 8-hour ozone projection procedure also includes an unmonitored area analysis (EPA, 2007; EPA 2014d) that has been codified in MATS. The unmonitored area analysis uses the future-year 8-hour ozone Design Value projection procedure applied to each grid cell in the modeling domain. In this procedure, the current-year Design Values (DVB) are interpolated to each grid cell in the modeling domain. This interpolation scheme uses the modeled concentration gradients so that the gridded DVBs may have some locations that are higher or lower than any of the observed DVBs at the monitoring sites. RRFs are then obtained for each grid cell in the modeling domain using essentially the same approach as used for the monitored ozone projections, only RRFs are based on the model estimates within each grid cell rather than near a grid cell as done for the projections at the monitor.

Figure 3-1 displays the interpolated 2009-2013 8-hour ozone Design Values (DVB) using the MATS unmonitored area analysis. Interpolated current year ozone DVBs in excess of 76 ppb are estimated to the south, west and northwest of Denver stretching to Fort Collins and then west of Fort Collins.

The projected DVFs for the 2017 Future Case (Figure 3-2) shows all areas have values below 76 ppb. The peak value is 75.9 ppb near the Jefferson/Boulder County border.

Figure 3-3 displays the differences in the unmonitored area analysis Design Values between the 2011 Base Case and 2017 Future Base simulations. The largest ozone decreases are in Eastern Larimer and Western Weld Counties and West and South of Denver, with relatively small ozone changes in the core Denver Metro area. The relatively larger ozone reductions in western Weld and eastern Larimer Counties are likely due in part to the large reductions in oil and gas VOC emissions in this region. The reductions in ozone in the Denver Metro area are most likely mainly due to the reductions in mobile source NO_X and VOC emissions due to use of cleaner vehicles, although reductions in emissions from non-road engines and point sources also likely contributed to the ozone reductions. However, in the core of the Denver Metro area the NO_X emission reductions have competing effects on ozone concentrations with ozone reductions due to less precursors participating in photochemistry and ozone increases due to less ozone titration from the fresh NO emissions and a reduction in the inhibition effect NO_X has on ozone formation under higher NO_X concentration conditions as can occur in an urban core area.

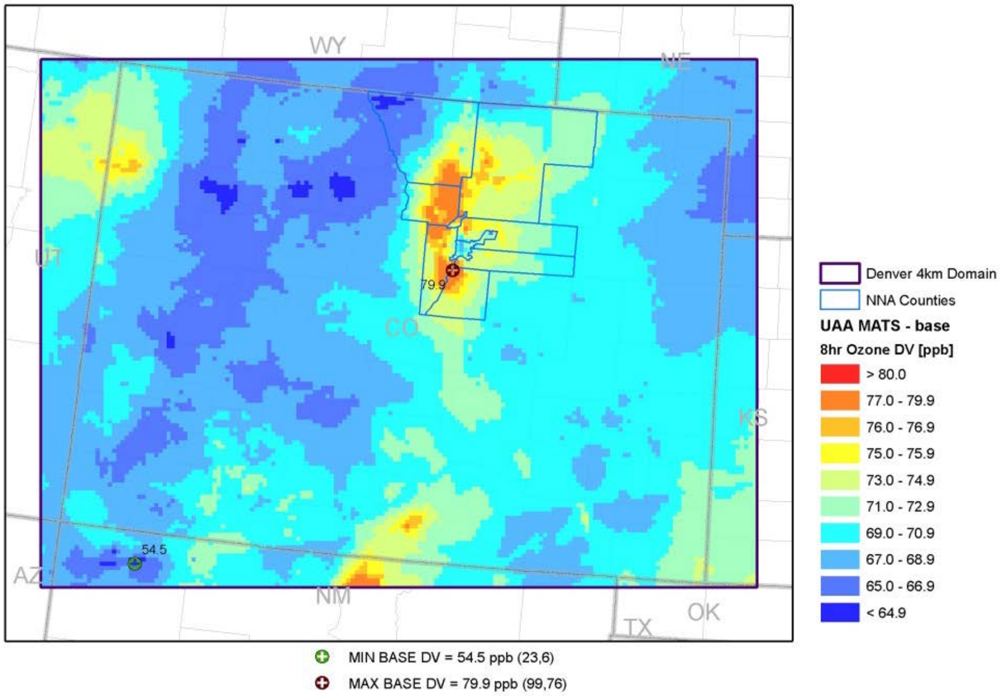

Figure 3-1. Interpolated 2009-2013 observed 8-hour ozone Design Values (DVBs) using the MATS tool with using modeled concentration gradients in the interpolation (ppb).

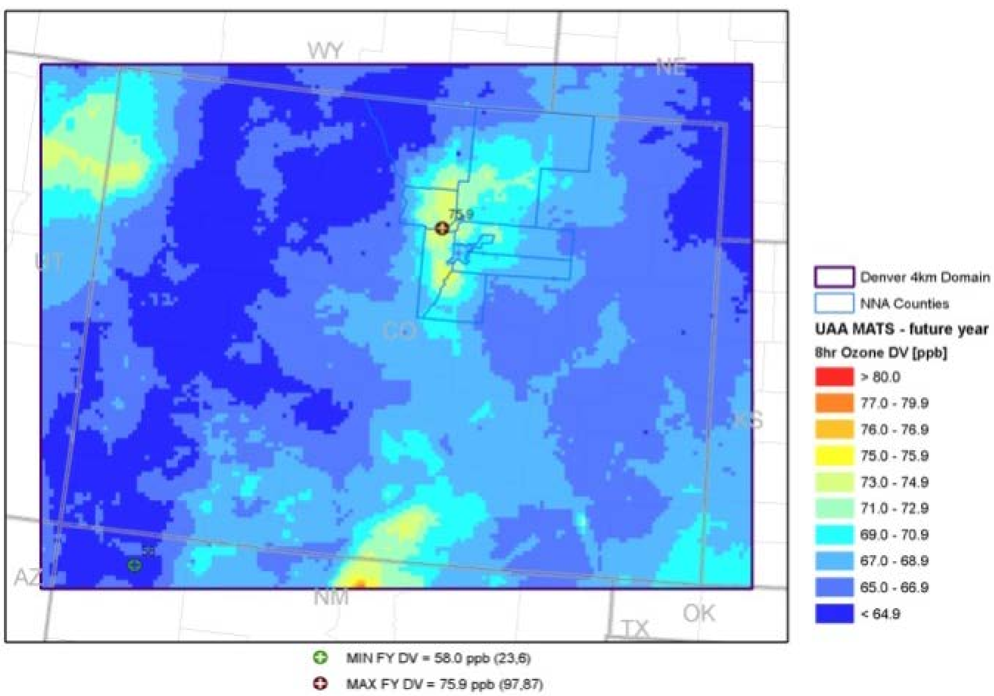

Figure 3-2. Projected 2017 8-hour ozone Design Values (DVFs) using the MATS tool (ppb).

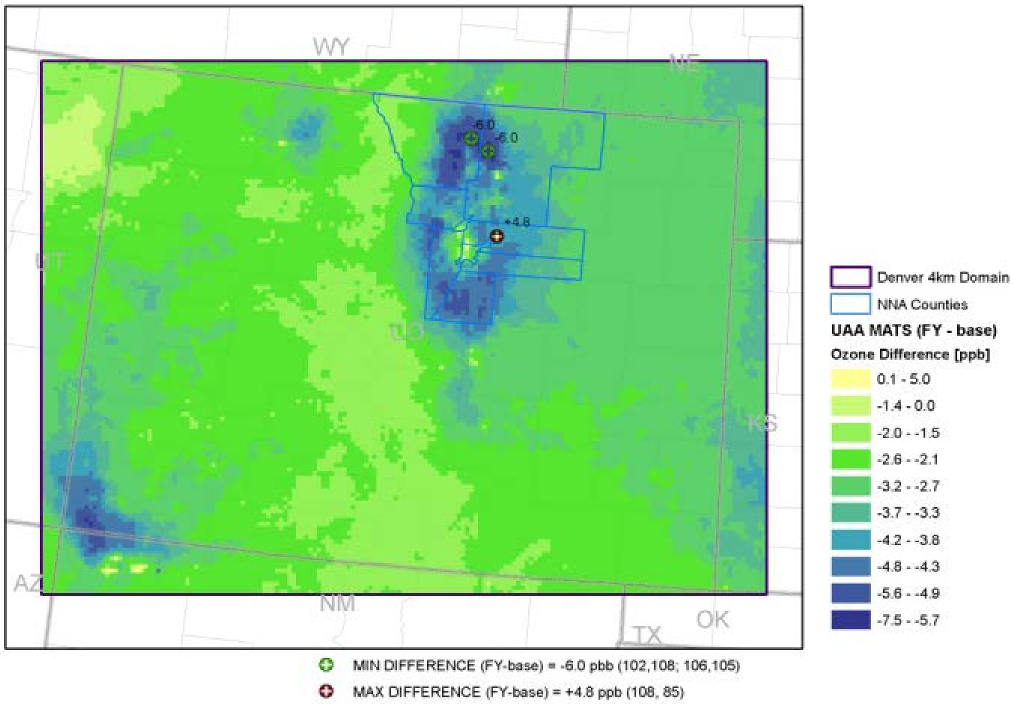

Figure 3-3. Differences in ozone Design Values (ppb) between the 2011 Base Case and the 2017 Future Year emissions scenarios using the MATS tool (2017 DVF – 2011 DVB).

4.0 MODELED WEIGHT OF EVIDENCE ANALYSIS

Although the 2017 Future Base modeling simulates that the Denver Metro/NFR ozone non-attainment area will be in compliance with the 75 ppb ozone standard by 2017, additional Weight of Evidence (WOE) analyses were conducted to assess impact of the modeled attainment demonstration to different ways of calculating the future year DVFs.

The WOE analyses focused on the monitors estimated to have the highest future year Design Values in the 2017 modeling, namely the Chatfield (CHAT), Rocky Flats North (RFNO), National Renewable Energy Lab (NREL) and Fort Collins West (FTCW).

4.1 OZONE PROJECTION SENSITIVITY TO REMOVING SUSPECT OBSERVATIONS

During the 2009 through 2013 period used to determine the base year monitored ozone Design Value (DVB), several ozone observations were flagged by CDPHE monitoring staff as potentially being influenced by exceptional events, which make the observation data of questionable appropriateness for use in air quality planning. The CDPHE did not develop formal exceptional event exclusion documentation for these days because their exclusion would not affect attainment designation for the area, although they would affect the DVBs. The days flagged as exceptional events are listed in Table 4-1. In 2010 and 2011, days were flagged at some monitoring sites due to being impacted by stratospheric ozone intrusion events. And in 2012 and 2013, days were flagged at some monitoring sites due to being impacted by wildfire smoke events. When these days are excluded from the calculation of the fourth highest daily maximum ozone observation, the base (DVB) and future (DVF) ozone design values are reduced. Table 4-1 summarizes the projected future year design values for the four highest sites when flagged days are excluded from the calculations. Future year design values are 1–2 ppb lower and the modeling demonstrates attainment at all monitors when the influences of exceptional events are removed from the analysis.

Table 4-1: Flagged exceptional event ozone days in 2009 through 2013 that influence the Design Values at CHAT, RFNO, NREL and FTCW.

Date	Reason for Exceptional Event Flag
April 13, 2010	Stratospheric Ozone Intrusion Event
April 14, 2010	Stratospheric Ozone Intrusion Event
June 7, 2011	Stratospheric Ozone Intrusion Event
May 15, 2012	Wildfire Smoke Ozone Event
June 17, 2012	Wildfire Smoke Ozone Event
June 22, 2012	Wildfire Smoke Ozone Event
July 4, 2012	Wildfire Smoke Ozone Event
July 5, 2012	Wildfire Smoke Ozone Event
August 9, 2012	Wildfire Smoke Ozone Event
August 21, 2012	Wildfire Smoke Ozone Event
August 25, 2012	Wildfire Smoke Ozone Event
August 31, 2012	Wildfire Smoke Ozone Event
August 17, 2013	Wildfire Smoke Ozone Event

Table 4-2. Base year (DVB) and 2017 future year (DVF) ozone Design Values (ppb) at key ozone monitors with flagged exceptional event days removed from the 2009-2013 DVB.

Monitor	County	Base Year (2011) DVB (ppb)	Exceptional Events Omitted 3x3 Grid Array (4 km)			Exceptional Events Omitted 7x7 Grid Array (4 km)		
			RRF	2017 DVF (ppb)	Final 2017 DVF (ppb)	RRF	2017 DVF (ppb)	Final 2017 DVF (ppb)
Chatfield	Douglas	78.7	0.9453	74.4	74	0.9391	73.9	73
Rocky Flats North	Jefferson	78.7	0.9493	74.7	74	0.9441	74.3	74
NREL	Jefferson	77.7	0.9591	74.5	74	0.9442	73.4	73
Fort Collins West	Larimer	76.3	0.9179	70.0	70	0.9098	69.4	69

4.2 OZONE PROJECTION SENSITIVITY TO NUMBER OF GRID CELLS NEAR THE MONITOR

One of the changes between EPA's previous final (EPA, 2007) and current draft (EPA, 2014d) ozone modeling guidance is how to define the grid cells near the monitor for defining the RRFS used to scale the current year observed ozone DVB to obtain the projected future year DVF. The previous final guidance used a relation where the size of the area around the monitoring site used in constructing the RRFs was defined based on the model grid size. The EPA (2007) guidance recommended that for a 4 km grid resolution a 7 x 7 array of grid cells centered on the monitor be used, while for a 12 km grid resolution a 3 x 3 array is used. The current draft EPA (2014d) guidance recommends that a 3 x 3 array of grid cells be used regardless of grid cell resolution. For the attainment demonstration presented in Section 3 of this report, the 7 x 7 grid cell array was used based on the improved performance of the modeled ozone using a 7 x 7 array vs. 3 x 3 array when evaluated against observations. Table 4-3 presents the projected 2017 ozone DVF results at the key monitors using both the 3 x 3 and 7 x 7 arrays. When a 3 x 3 grid cell definition is used, the future year Design Values are increased by approximately 0.5 ppb, with values of 76.2 ppb at both Chatfield (CHAT) and Rocky Flats North (RFNO).

Table 4-3: Future year Design Values using 3 x 3 and 7 x 7 Grid Cells Surrounding Monitors at Key Ozone Monitors.

AIRS ID	Station	County	3x3 Grid Cell		7x7 Grid Cell	
			RRF	DVF (ppb)	RRF	DVF (ppb)
Denver Metro/NFR Non-Attainment Area						
80350004	CHAT	Douglas	0.9453	76.2	0.9391	75.7
80590006	RFNO	Jefferson	0.9493	76.2	0.9441	75.8
80590011	NREL	Jefferson	0.9591	75.4	0.9442	74.3
80690011	FTCW	Larimer	0.9179	71.5	0.9098	70.9

4.2.1 OZONE PROJECTION SENSITIVITY TO MODEL PERFORMANCE

As was shown in the 2011 Base Case Modeling and Performance Evaluation Report (Ramboll Environ and Alpine Geophysics, 2016), the performance of the CAMx model varies day-to-day at each monitor. Overall, the ozone performance of the 2011 base case was deemed sufficient to use the model for assessing future ozone planning, but the model performed better at certain monitors on some days than at other monitors and days.

To assess the impact of the model performance on the model's estimation of future ozone DVFs, a WOE analysis was conducted where the model results were only used on days when the model performance achieved a certain level of model performance. That is, instead of selecting the top 10 modeled days near the monitoring from the 2011 base case regardless of model performance, we selected the top 10 modeled days near the monitor only on those days in which the predicted and observed daily maximum 8-hour (MDA8) ozone concentration at the monitoring site agreed with each other to within a certain threshold of model performance. The ozone projection model performance analysis examined three thresholds of model performance that required the predicted and observed MDA8 ozone for a day to be within thresholds of 10%, 15% and 20% in order for the modeling results for that day to be used in the RRFs.

Table 4-4 summarizes the 2017 ozone projection analyses related to model performance filters. The composite RRF is provided for the top 10 days for the four key monitors for each of the scenarios based on the 3x3 grid cell array. The analysis was not performed for the 7x7 grid cell array but the 2017 projected ozone DVF results will be slightly lower.

As shown in Table 4-4, excluding poorer performing days (i.e. days with a bias greater than ±20%, ±15%, and ±10%) from the RRF calculation has minimal impact on the final future year design values for the top four monitors. At the ±20% threshold cut-off level, the modeled 2017 ozone DVFs are reduced by 0.1 ppb (0.1%) at the Chatfield and Rocky Flats North monitors. At the NREL monitor the modeled ozone DVF is increased by 0.2 ppb, while at the Fort Collins West the modeled ozone DVF is increased by 1.0 ppb, but is still well below the standard.

Applying the more stringent within ±15% model performance evaluation filter tends to increase the projected 2017 ozone DVF by 0 to 0.2 ppb compared to using the ±20% performance filter. This is because the RRFs calculated using the ±15% performance filter is replacing higher modeled ozone days that are closer to the current year ozone DVB when no or the ±20% filter is used with lower modeled ozone days. The ozone concentrations on these lower modeled ozone days are less responsive to emission controls since more of the ozone is due to background and less ozone is due to emissions that are being reduced. Similarly, use of the ±10% results in increases in the 2017 DVFs of 0 to 0.5 ppb over using the ±15% filter.

Table 4-4. Future year ozone DVFs using different model performance evaluation (MPE) threshold criteria at key ozone monitors.

Monitor	County	Base Year (2011) DVB (ppb)	RRF	Future Year (2017) DVF (ppb)	Final 2017 DVF (ppb)
No Model Performance Filter					
Chatfield	Douglas	80.7	0.9453	76.2	76
Rocky Flats North	Jefferson	80.3	0.9493	76.2	76
NREL	Jefferson	78.7	0.9591	75.4	75
Fort Collins West	Larimer	78.0	0.9179	71.5	71
20% Model Performance Filter					
Chatfield	Douglas	80.7	0.9432	76.1	76
Rocky Flats North	Jefferson	80.3	0.9473	76.1	76
NREL	Jefferson	78.7	0.9608	75.6	75
Fort Collins West	Larimer	78.0	0.9289	72.5	72
15% Model Performance Filter					
Chatfield	Douglas	80.7	0.9428	76.1	76
Rocky Flats North	Jefferson	80.3	0.9496	76.3	76
NREL	Jefferson	78.7	0.9630	75.8	75
Fort Collins West	Larimer	78.0	0.9304	72.6	72
10% Model Performance Filter					
Chatfield	Douglas	80.7	0.9488	76.6	76
Rocky Flats North	Jefferson	80.3	0.9508	76.3	76
NREL	Jefferson	78.7	0.9647	75.9	75
Fort Collins West	Larimer	78.0	0.9364	73.0	73

5.0 CONCLUSIONS

While there is a degree of uncertainty inherent in any modeling analysis due to a number of uncontrollable factors, the 2017 ozone projections and weight of evidence analyses suggest that the control measures contained in the 2017 Denver ozone SIP will likely result in attainment of the 2008 8–hour NAAQS in 2017. This determination is based on the body of evidence presented in this document, consisting of the following:

- A modeling analysis with a justifiable 7x7 grid cell array demonstrates attainment at all monitors in the nonattainment area.
- A modeling analysis with EPA's default recommendation of a 3x3 grid cell array demonstrates attainment at 13 of 15 monitors in the nonattainment area, with only two monitors slightly (less than 0.4%) above the standard threshold.
- A supplemental modeling analysis removing flagged exceptional events during the period from 2009–2013 demonstrates attainment at the four highest monitors in the nonattainment area.
- A supplemental modeling analysis removing poor performing days (days with bias greater than ±20%) shows attainment at all monitors using a 7x7 grid cell array and reduces the projected design value at the two problem monitors in the 3x3 array analysis to less than 0.25% above the standard threshold.
- An unmonitored area analysis that indicates all areas in the region will be below the standard in 2017 and that existing monitoring locations are appropriately capturing high ozone levels in the nonattainment area.

Ozone concentrations in the western U.S., and the Denver Metro/NFR NAA area in particular, are highly dependent on meteorological conditions. This can produce large year-to-year variability in observed ozone concentrations, which are largely independent on emission changes of the magnitude proposed in the SIP. This modeled attainment demonstration has shown that given the meteorological conditions that occurred in 2011, the area would attain the 2008 8-hour NAAQS in 2017. The actual attainment of the ozone NAAQS in 2017 will depend on future meteorological conditions that are impossible to accurately forecast.

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