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Heart of Texas Council of Governments Ozone Advance Action Plan: 2019 Update

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Heart of Texas Council of Governments Ozone Advance Action Plan: 2019 Update

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LIST OF ACRONYMS AND ABBREVIATIONS

AQAC	HOTCOG Air Quality Advisory Committee
CAMS	Continuous Air Monitoring Station
CAMx	Comprehensive Air Quality Model with Extensions
CC	Combined cycle
CEM	Continuous emissions monitor
CO	Carbon monoxide
CTG	Combustion turbine generator
DFW	Dallas-Fort Worth
DV	Design value
DVs	Design values
EGU	Electric generating unit
EPA	Environmental Protection Agency
HOTCOG	Heart of Texas Council of Governments
Hr	Hour
K	Degrees Kelvin
kW	Kilowatt
MDA8	Daily maximum 8-hour average
MOVES	Motor Vehicle Emissions Simulator
MPO	Metropolitan Planning Organization
MW	Megawatt
NAA	Non-Attainment Area (for the ozone NAAQS)
NAAQS	National Ambient Air Quality Standard
NNA	Near non-attainment area
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen
NSR	New Source Review
O_3	Ozone
OSAT	Ozone Source Apportionment Tool
OSD	Ozone season day
ppb	Parts per billion
SC	Simple cycle
SIP	State Implementation Plan (for the ozone NAAQS)
SO_2	Sulfur dioxide
STARS	State of Texas Air Reporting System
STG	Steam turbine generator
TCEQ	Texas Commission on Environmental Quality
Ton	English short ton (2000 pounds)
tpd	Tons per day
tpy	Tons per year
VOC	Volatile organic compound
WRF	Weather Research and Forecasting Model
yr	Year

EXECUTIVE SUMMARY

The Heart of Texas Council of Governments (HOTCOG) is participating in the U.S. Environmental Protection Agency's (EPA's) Ozone Advance Program[1] on behalf of the region surrounding Waco, Texas. HOTCOG represents the six Texas counties of McLennan, Bosque, Hill, Falls, Limestone and Freestone. The Texas Commission on Environmental Quality (TCEQ) operates a Continuous Air Monitoring Station (CAMS) in McLennan County, and ozone measurements from this site, Waco Mazanec (CAMS 1037), are used to determine attainment of the National Ambient Air Quality Standard (NAAQS) for ozone. As of November 11, 2019, the 8-hour ozone design value for the Waco Mazanec (CAMS 1037) monitor is 65 parts per billion (ppb), which is lower than the 70 ppb 2015 ozone NAAQS.

The HOTCOG area's ozone air quality has seen improvement since ozone monitoring began in Waco in 2007. The Waco monitor's ozone levels have been below the current NAAQS since 2014 and during 2017-2019, only one day had air quality that exceeded the NAAQS and was classified as "unhealthy for sensitive groups". The rest of the days during 2017-2019 had air quality classified as "moderate" or better. This represents an improvement in air quality from previous years.

Ozone forms in the atmosphere from emissions of ozone precursors, mainly nitrogen oxides (NOx) and volatile organic compounds (VOC.) Ozone levels exceeding 70 ppb can occur in the HOTCOG area on days when local temperatures exceed 90°F, wind speeds are low, and wind directions range between northerly clockwise through southwesterly. These wind directions are favorable for transport of polluted air masses of continental origin into the HOTCOG area. High ozone days in the HOTCOG area are generally characterized by high incoming background ozone levels plus a far smaller contribution from local emissions sources. Although the ozone contribution from local sources is relatively small in the HOTCOG area, some ozone reductions are possible via reductions in local ozone precursor emissions.

The HOTCOG area's NOx emission inventory is dominated by emissions from power plants, motor vehicles, agricultural equipment and oil and gas exploration and production equipment. VOC emissions in the HOTCOG area are dominated by natural (biogenic) sources such as trees and vegetation rather than human activities. The abundance of biogenic VOC ensures that there is always enough VOC available to form ozone so that the amount of ozone formed is determined by the amount of anthropogenic NOx emissions. HOTCOG's analyses of the area's ambient data, NOx and VOC emission inventories and photochemical modeling are consistent in showing that ozone formation in the 6-county HOTCOG area is limited by the amount of available NOx. Therefore, local emission control strategies have been focused on reducing NOx.

In 2010, the HOTCOG Air Quality Advisory Committee (AQAC) was formed in response to the Waco area's inclusion in the Texas Rider 7/8 Program for ozone Near Nonattainment Areas. The AQAC includes representatives from local government, industry, the TCEQ, EPA, and private citizens. Ramboll Environ provides the AQAC with technical expertise on ozone air quality and precursor emissions. The AQAC has worked vigorously to study local ozone air quality and to develop voluntary programs that improve air quality while protecting the regional economy.

The AQAC has implemented measures and programs in order to reduce ozone in the HOTCOG area including:

- Retrofit/replacement of municipal fleet heavy-duty diesel engines

[1] http://www3.epa.gov/ozoneadvance/

- Bicycle parking rack installation with monitoring to document utilization
- Public outreach activities including:
  - Public web site with ozone air quality forecasts, information on ozone and specific actions citizens can take to improve air quality as well as contact information for citizens who would like to become more involved in addressing local air quality issues
  - Facebook page on ozone air quality that provides high ozone day alerts and actions citizens can take to reduce ozone
  - Air quality-themed signage for public buses

The City of Waco and the Waco Metropolitan Planning Organization have also implemented programs that will benefit local air quality through reduction of NOx emissions.

City of Waco Emissions Reduction Measures:

- The City of Waco has implemented two free shuttle services in the downtown area, to reduce car trips, traffic congestion and idling in downtown Waco
- The City of Waco is developing a Pilot Shared Mobility System, to offer residents a visitors a convenient and affordable way to bike around the city. The system will include two types of shared mobility devices, to appeal to a wide variety of users in the city.

Waco MPO Emissions Reduction Measures:

- Explored the feasibility of developing a rapid transit corridor and bus service enhancements
- Implemented the Waco Metropolitan Area Active Transportation Plan (ATP) to assist in the development of a comprehensive, regional, multi-modal transportation system in McLennan County.

The HOTCOG area joined the EPA's Ozone Advance Program in 2012. As part of its participation in Ozone Advance, HOTCOG prepared an Ozone Action Plan and submitted it to EPA in July, 2014. In January 2016, HOTCOG submitted an Ozone Action Plan Update. In 2018, the State of Texas discontinued funding for the Rider 7/8 Program under which HOTCOG's air quality planning program was supported. This resulted in a lapse in the area's activity in the Ozone Advance Program. However, the HOTCOG area, recognizing the importance on ongoing air quality planning activities, allocated local funding for ongoing air quality planning work. The HOTCOG area's conceptual model for ozone was revised and this 2019 Update of the HOTCOG Ozone Action Plan was developed to support the Waco area's continued participation in the Ozone Advance Program.

In this document, we update the HOTCOG Ozone Advance Action Plan with new technical analyses and provide information on current and planned emission reductions. The Action Plan summarizes our understanding of ozone formation in the HOTCOG area and outlines measures being taken to reduce local ozone levels. The schedule for implementation of each measure/program is provided as well as the means of verification of emissions reductions, where applicable.

1.0 INTRODUCTION

HOTCOG is participating in the U.S. EPA's Ozone Advance Program on behalf of the region surrounding the Waco, Texas area. HOTCOG represents the 6-county area consisting of McLennan, Bosque, Hill, Falls, Limestone and Freestone Counties and is an organization of local governments working together voluntarily to solve mutual problems and plan for the future of the area. HOTCOG has over 80 member governments made up of counties, cities, school districts, community colleges, and special districts, and was established in 1966. HOTCOG's responsibilities include:

- Planning for area development,
- Implementing regional plans or recommendations,
- Contracting with members to provide certain services,
- Providing review and comment on proposals seeking federal and state financial assistance,
- Implementing grant services from federal and state programs, and
- Administrative and fiscal agent for the Heart of Texas Workforce Development Board.

More information on HOTCOG may be found at http://www.hotcog.org/default.aspx.

The HOTCOG area joined the EPA's Ozone Advance Program in 2012. As part of its participation in the EPA's Ozone Advance Program, HOTCOG prepared an Ozone Action Plan and submitted it to EPA in July, 2014. In January 2016, HOTCOG submitted an Ozone Action Plan Update. In 2018, the State of Texas discontinued funding for the Rider 7 Program under which HOTCOG's air quality planning program was supported. This resulted in a lapse in the area's activity in the Ozone Advance Program. However, the HOTCOG area, recognizing the importance on ongoing air quality planning activities, allocated local funding for ongoing air quality planning work. The HOTCOG area's conceptual model for ozone was revised and this 2019 Update of the HOTCOG Ozone Action Plan was developed to support the Waco area's continued participation in the Ozone Advance Program.

This 2019 Action Plan Update gives an overview of ozone air quality and describes the 6-county HOTCOG region (Section 1), summarizes our understanding of ozone formation in the HOTCOG area (Section 2) and outlines measures being taken to reduce 6-county area ozone levels (Sections 3 and 4). In Section 2, we discuss the HOTCOG area's emission inventory of ozone precursors and summarize analyses of ambient monitoring data and photochemical modeling that informed the selection of emissions control strategies. Stakeholder involvement is discussed in Section 3. Finally, in Section 4, we describe the emissions reductions measures and/or programs that have been and will be implemented in the 6-county area. The schedule for implementation of each measure/program is shown as well as the responsible party and means of verification of emissions reductions, where applicable. Plans described in this Ozone Action Plan are effective through November 2019.

1.1 Ozone Air Quality: Background

Ozone is the main ingredient in photochemical smog. Ozone affects human lung function, increasing the prevalence and severity of asthma and bronchitis, and damages vegetation. The U.S. EPA sets a National Ambient Air Quality Standard (NAAQS) for ozone in order to protect public health and the environment. The NAAQS is based on health impacts for sensitive groups and there are economic penalties for areas that fail to attain it.

Under the Clean Air Act, the EPA is required to review the NAAQS periodically. EPA's most recent review of the ozone standard was finalized on October 1, 2015. On October 1, the EPA lowered the 8-hour ozone NAAQS from the 75 ppb value set in 2008 to a more stringent value of 70 ppb.

The Texas Commission on Environmental Quality (TCEQ) operates a Continuous Air Monitoring Station (CAMS) in McLennan County at the Texas State Technical College (TSTC) Waco Airport. Ozone measurements made at the Waco Mazanec (CAMS 1037) monitoring station determine whether the HOTCOG area complies with the ozone NAAQS. On November 16, 2017, the EPA designated McLennan County as being in attainment of the 2015 NAAQS based on 2014-2016 monitoring data from the Waco Mazanec monitor, which had a design value of 63 ppb for this period[2]. The other five HOTCOG area counties do not have ozone monitors and were also designated as unclassifiable / attainment.

Although the current CAMS 1037 design value of 65 ppb is lower than the NAAQS, it is within 5 ppb of the 70 ppb standard. Because failure to comply with the NAAQS can adversely affect public health and inhibit economic development, ozone air quality planning remains critical for the HOTCOG area.

Ozone is not emitted directly into the atmosphere, but forms from NOx and VOC in the presence of sunlight. NOx and VOC are emitted by both natural processes and human activities. Conditions that favor the formation of ground-level ozone are strong sunlight, high temperatures, and high precursor (NOx and VOC) concentrations. High precursor concentrations in the atmosphere occur when emissions are large and/or weather conditions allow precursors to accumulate. When winds are calm, and the atmosphere is stable, emitted precursors do not disperse and are available for ozone formation. On the other hand, if the atmosphere is unstable, ozone and precursors can be transported aloft away from the ground, and if winds are brisk, emitted pollutants are transported away from the area so that ozone does not build up.

Ozone is removed from the atmosphere by chemical reactions, photolysis (destruction by sunlight), deposition onto surfaces, and uptake by plants. Ozone has a lifetime of several days to weeks at ground level; this lifetime is long enough to allow ozone to be transported thousands of miles. At any given location, therefore, measured ozone is partly due to a contribution from local emissions and partly due to transported ozone, which is often referred to as background ozone. High background ozone exacerbates local ozone problems but is not a necessary condition for an area to have high ozone. Ozone problems solely from transport can occur but are rare. Regional and national emissions control measures such as the Federal vehicle emissions standards aim to reduce the contribution from transported ozone.

In order to reduce ozone in a given area, the ozone problem must be studied to determine the relative importance of local emissions and transported ozone. Photochemical modeling is used to assess the magnitude of the local and transported contributions. If local ozone precursor emissions are shown to contribute to ozone levels, then local emissions control measures can be developed. The Ozone Advance Program was developed to assist areas in developing local emissions control strategies designed to reduce ozone.

1.2 Waco and the Heart of Texas Region

The HOTCOG area lies on the central Texas plain between the major metropolitan areas of Dallas-Fort Worth to the north and Austin to the south. A map of the area is shown in Figure 1-1. The six HOTCOG counties together occupy an area of 5,611 square miles. The region is relatively flat, with the highest terrain reaching a height of approximately 300-400 meters. Two major interstate highways, I-35 and I-45, pass through the area. These highways connect the Dallas-Fort Worth area with Austin and Houston to the south and are major thoroughfares.

The population in the HOTCOG area is concentrated in the City of Waco. There are smaller towns throughout the area (Figure 1-1 and Figure 2-1), but much of the area in all six counties is rural land.

[2] https://www.govinfo.gov/content/pkg/FR-2017-11-16/pdf/2017-24640.pdf

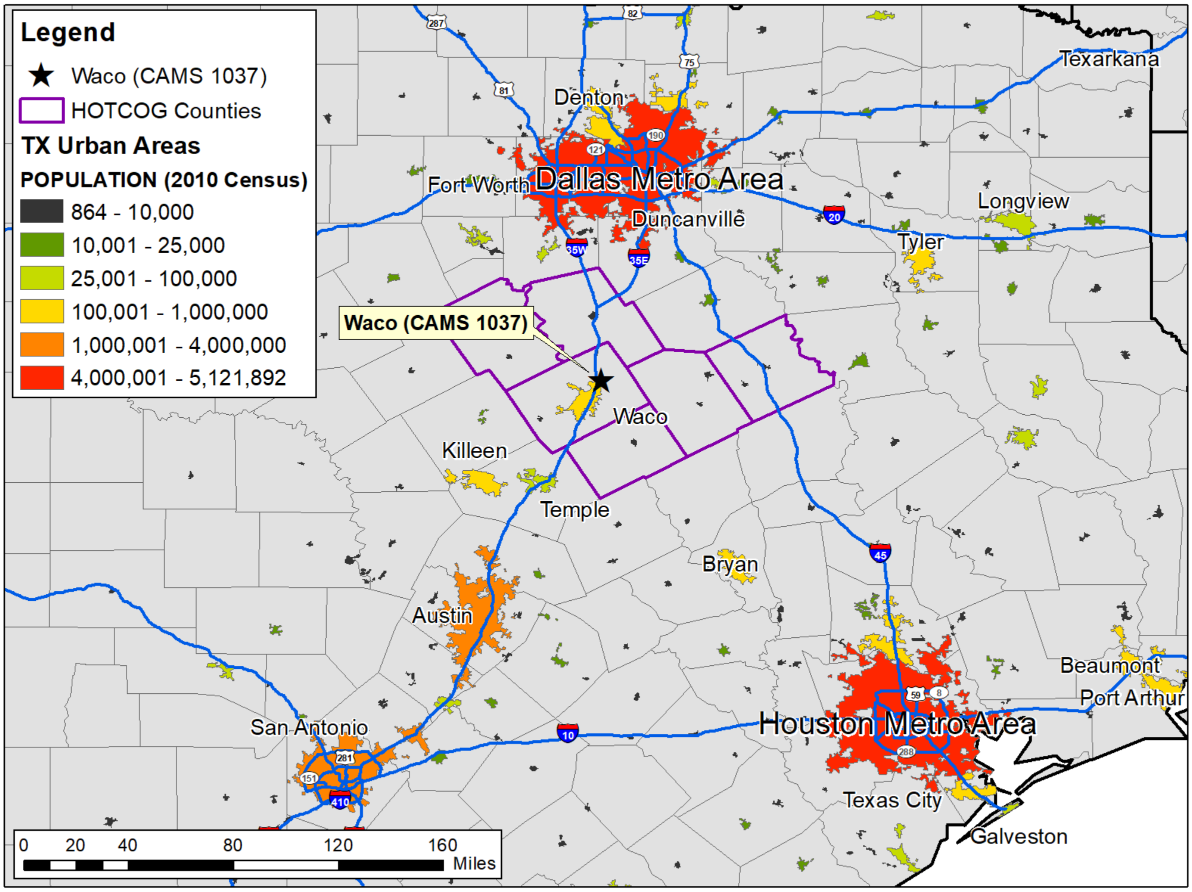


Figure 1-1. Waco Mazanec (CAMS 1037) monitor location (black star). Urban areas are shaded, and their color indicates population as of 2018. The HOTCOG 6-county area is outlined in purple and interstate highways are shown in blue.

Population estimates for 2018[3] (Figure 1-2) indicate that McLennan County had a population of 250,941, which is 67% of the population of the entire HOTCOG 6-county area (375,626). During the 2010-2018 period, HOTCOG counties saw increases in population ranging from 7-10% (Figure 1-2). During the period 2010-2014, all of the HOTCOG counties saw declines in population except for Limestone and McLennan Counties, which had small (<5%) increases in population.

Figure 1-3 shows that urban areas to the north and south of the HOTCOG counties are growing rapidly. The Dallas-Fort Worth, Houston, San Antonio and Austin areas all had growing populations, and these areas are frequently upwind of the HOTCOG area on high ozone days (see Section 2 of this document and McGaughey et al., 2010a; 2012). In summary, the HOTCOG area has had modest population growth in recent years, while surrounding areas have undergone much more rapid growth. Growth in population is typically associated with growth in emissions of ozone precursors due to increases in traffic, need for air conditioning, etc.

The HOTCOG area overlies productive oil and natural gas fields. There are a large number of natural gas wells in Limestone and Freestone County that access conventional natural gas reservoirs, while

[3] https://www.dshs.texas.gov/chs/popdat/st2018.shtm

Hill County marks the southernmost extent of the Barnett Shale natural gas development. There is also oil production in McLennan County, but the number of oil wells is relatively small.

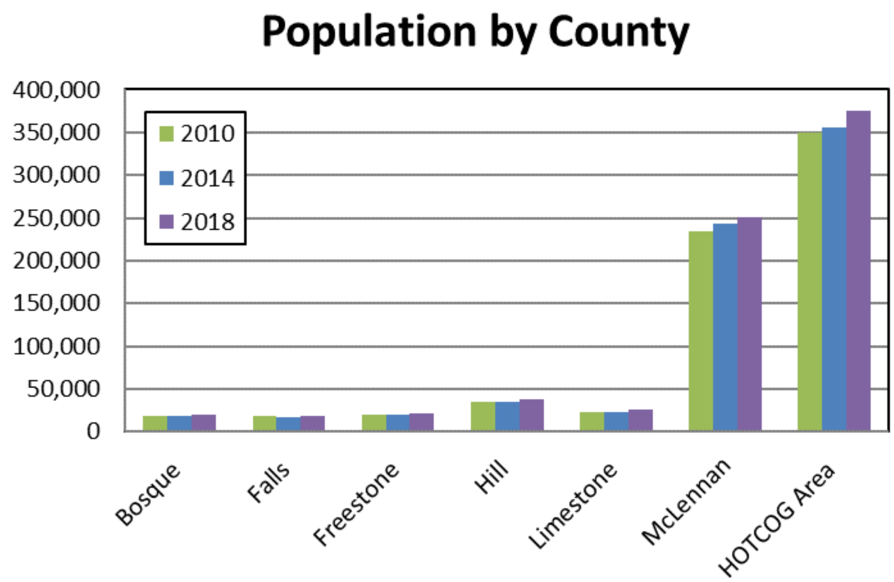
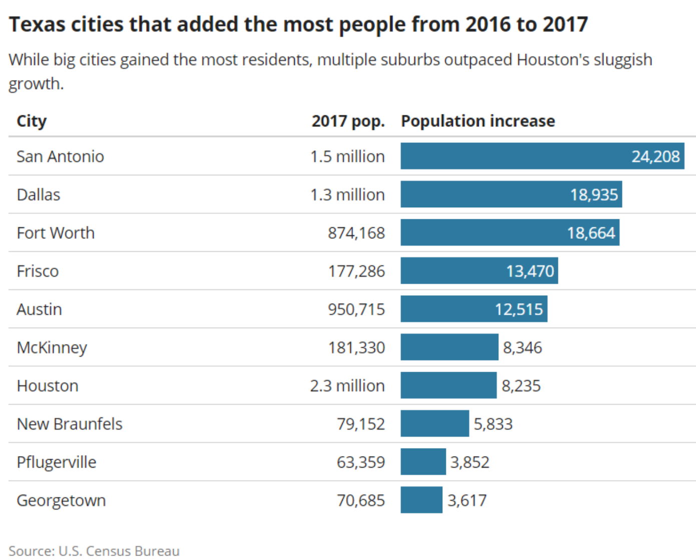


Figure 1-2. Population of HOTCOG Area Counties for 2010 and estimated population for 2014 and 2018 based on U.S. Census data[4] and the Texas Department of Health and Human Services[5].



Texas cities that added the most people from 2016 to 2017

While big cities gained the most residents, multiple suburbs outpaced Houston's sluggish growth.

City	2017 pop.	Population increase
San Antonio	1.5 million	24,208
Dallas	1.3 million	18,935
Fort Worth	874,168	18,664
Frisco	177,286	13,470
Austin	950,715	12,515
McKinney	181,330	8,346
Houston	2.3 million	8,235
New Braunfels	79,152	5,833
Pflugerville	63,359	3,852
Georgetown	70,685	3,617

Source: U.S. Census Bureau

Figure 1-3. Texas population growth from 2010-2014. Figure from Texas Tribune based on U.S. Census data[6].

[4] http://quickfacts.census.gov/qfd/states/48/48309.html
[5] https://www.dshs.texas.gov/chs/popdat/st2018.shtm
[6] https://www.texastribune.org/2018/05/24/texas-census-san-antonio-tops-national-list-population-houston-growth/

2.0 CONCEPTUAL MODEL OF OZONE FORMATION IN THE HOTCOG AREA

The purpose of the conceptual model is to provide a basis of understanding of ozone in the Waco region and to provide a foundation for all ozone air quality planning activities. EPA's *Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$ and Regional Haze*[7] indicates that the first activity to be completed in ozone air quality planning is the formulation of a conceptual model that qualitatively describes ozone formation mechanisms and provides a rationale for selection of episodes for photochemical modeling. EPA's Modeling Guidance specifies that the key components of the conceptual model are analyses of air quality, meteorological and emissions data. Through these analyses, relationships between weather conditions and high ozone events may be established, important emissions sources and trends may be identified, and periods of high ozone suitable for modeling may be selected. Ozone modeling may be used to shed light on the causes of high ozone events as well as the likely effectiveness of proposed control strategies. Section 2 summarizes the conceptual model of ozone formation in the HOTCOG area (McGaughey et al., 2010a; 2012; Parker et al., 2013; Parker et al., 2016; Johnson et al., 2019) and describes results of recent analyses of air quality, emissions and meteorological data and trends.

2.1 Attainment Status and Recent Ozone Trends

The location of the TCEQ's Waco Mazanec ozone monitor (CAMS 1037) is shown in Figure 2-1. The Waco Mazanec monitor is located northeast of the Waco metropolitan area in McLennan County. The Waco Mazanec site began operating in April 2007 and has always monitored attainment of the ozone NAAQS.

At the Waco site, the following measurements are currently made on a routine basis: meteorological data (winds, temperature, solar radiation), ozone, carbon monoxide, sulfur dioxide, and fine particulates ($PM_{2.5}$). NOx was monitored during the period 2010-2017, but NOx measurements ceased in July 2017 and, as of November 2019, NOx measurements for CAMS 1037 are not being reported through the TCEQ's Texas Air Monitoring Information System (TAMIS). All measurements are made available through the TCEQ's TAMIS system on an hourly basis.

During 2017, monitoring proceeded normally from January 1 through 11 pm July 11. Starting at midnight on July 12, 2017 and continuing through February 21, 2018, all ambient measurements made at CAMS 1037 (air quality and meteorology) were assigned the AQI quality flag, indicating that TCEQ validators had rejected the measurements as invalid. On February 22, 2018, measurements resumed for all species except NOx. Because of the extended period of missing data, the 2017 4th high value is marked with an asterix in TCEQ's design value reporting website[8] indicating incomplete data for the year.

[7] https://www3.epa.gov/ttn/scram/guidance/guide/O3-PM-RH-Modeling_Guidance-2018.pdf

[8] https://www.tceq.texas.gov/cgi-bin/compliance/monops/8hr_attainment.pl

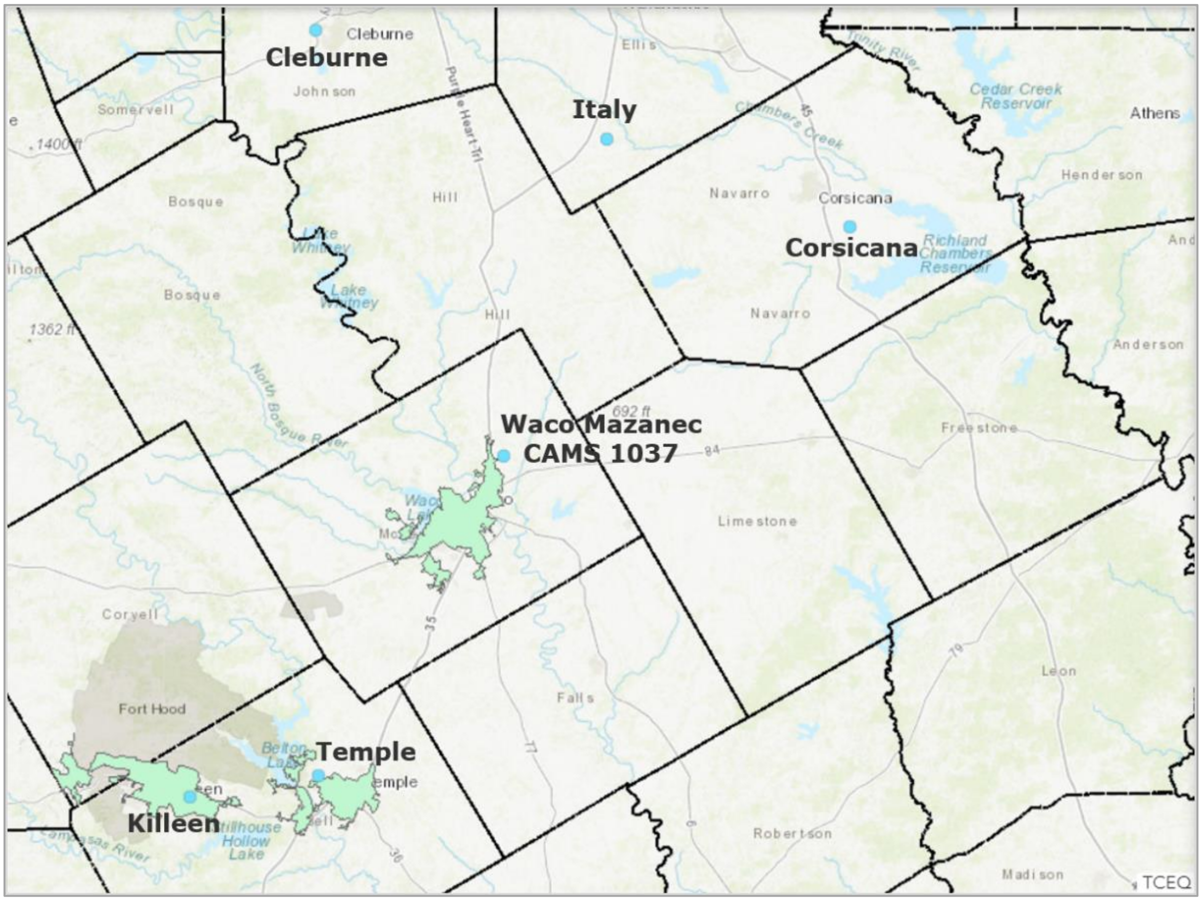


Figure 2-1. Waco Mazanec CAMS monitor location. Adaptation of TCEQ figure from http://gis3.tceq.state.tx.us/geotam/index.html, accessed October 25, 2019. Blue circles indicate the locations of ozone monitors. Green shading indicates urban area.

The upper panel of Figure 2-2 shows recent trends in 4th highest daily maximum 8-hour average ozone values (MDA8) and 8-hour ozone design values at the Waco Mazanec monitor. The 4th high values are more variable than design values due to the averaging procedure used to calculate the design values. Since the Waco monitor began operating in 2007, its 4th high MDA8 value has varied between a low of 60 ppb and a high of 78 ppb. Between 2007 and 2012, the 4th high value alternated between increases and decreases, showing a weakly positive trend (0.3 ppb/yr). The 4th high value in 2016 was the lowest recorded and from 2014-2019 the 4th high value remained below 70 ppb. The overall trend from 2007-2019 is downward (-0.86 ppb/yr). The overall downward trend is likely driven by regional and local emissions reductions with year-to-year variations due to weather.

The Waco Mazanec monitor's design value ranged between 70-72 ppb until the 2011-2013 period, when the design value rose to 74 ppb (lower panel of Figure 2-2). Overall, the design value shows a decreasing trend from 2013-2016 and a small increase from 2016-2019. The overall trend from 2007-2019 is downward (-0.98 ppb/yr). The current design value is 65 ppb, which is 5 ppb below the 70 ppb NAAQS. Because the Waco monitor's current design value is within 5 ppb of the NAAQS, air quality planning remains important for the HOTCOG area.

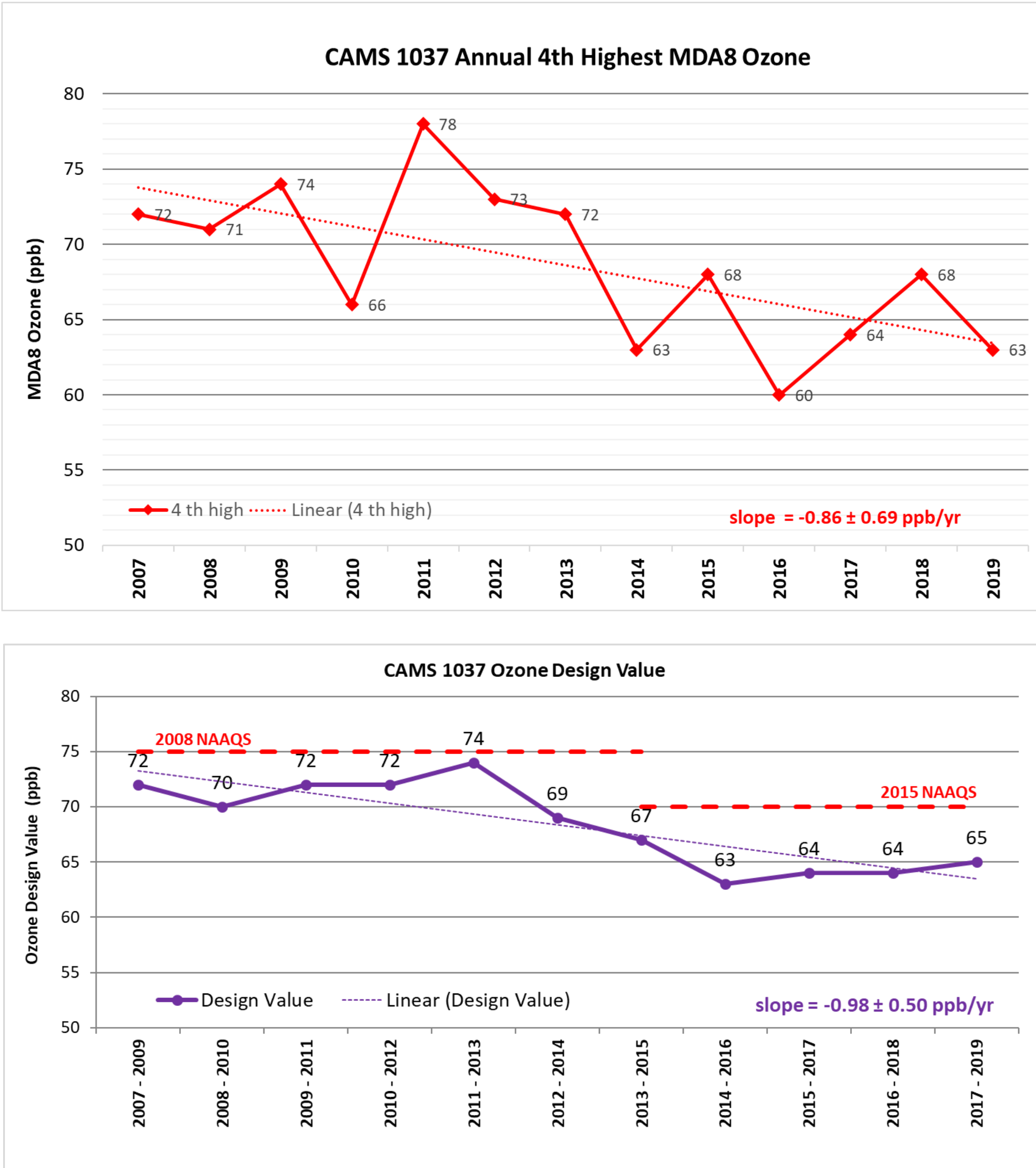


Figure 2-2. Trends in annual 4th highest daily maximum 8-hour ozone values (upper panel) and design values (lower panel) at Waco Mazanec CAMS 1037 in McLennan County. The dashed red line indicates the 2008 75 ppb ozone standard and the 2015 70 ppb ozone standard. All data through 2018 have been validated by the TCEQ.

Figure 2-3 shows the number of days with MDA8>70 ppb at the Waco monitor for each year from 2007-2019. We define a high ozone day to be a day on which the MDA8 exceeded 70 ppb at the Waco Mazanec (CAMS 1037) monitor. 2011 had the largest number of high ozone days as well as the highest value of the 4th high MDA8 (Figure 2-2). The hottest summer ever recorded in Texas occurred in 2011[9] and hot weather is conducive to ozone formation. In 2011, Texas was also affected by numerous wildfires, and wildfire emissions can contribute to high ozone.

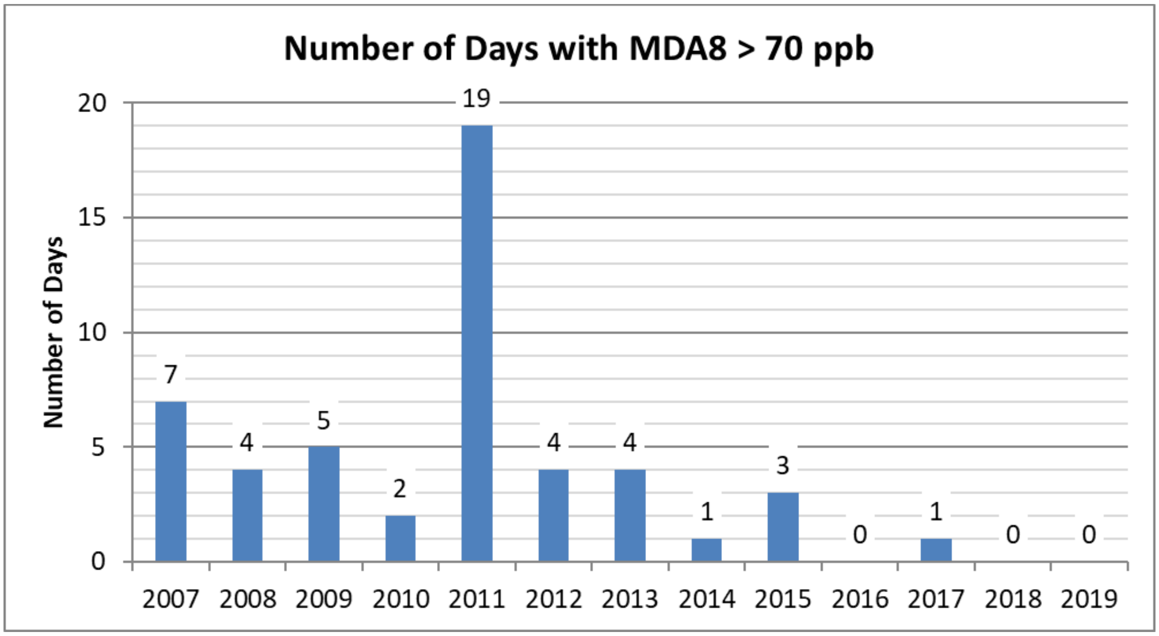


Figure 2-3. Number of days with MDA8>70 ppb at the Waco (CAMS 1037) monitor during 2007-2019.

The seasonal variation of high ozone days at the Waco monitor is shown in Figure 2-4. The Waco monitor had the largest number of high ozone days during the August-September period during the years 2007-2019 with 14 days with MDA8>70 ppb in each month. The monitor had six high ozone days in June and October, and a smaller number in May (six) and July (four). There were no days with MDA8>70 ppb during the months of January-April and November-December at the Waco (CAMS 1037) monitor.

The number of high ozone days by day of week for the Waco Mazanec (CAMS 1037) monitor is shown in Figure 2-5 and Figure 2-6. Figure 2-5 shows the raw count of number of high ozone days for each day of week at the monitor, and Figure 2-6 shows the number of high ozone days by weekend day versus weekday. In Figure 2-6, the number of days in each category is normalized to give equal weight to weekend and weekdays. The total number of weekdays at each monitor is divided by five and the total number of weekend days is divided by two. Figure 2-5 and Figure 2-6 indicate that the Waco monitor has more high ozone days on weekdays than on weekends. This suggests the importance of vehicle emissions in contributing to local ozone, since vehicle activity generally reaches its peak values during weekday commuting hours.

[9] http://www.ncdc.noaa.gov/sotc/national/2011/8

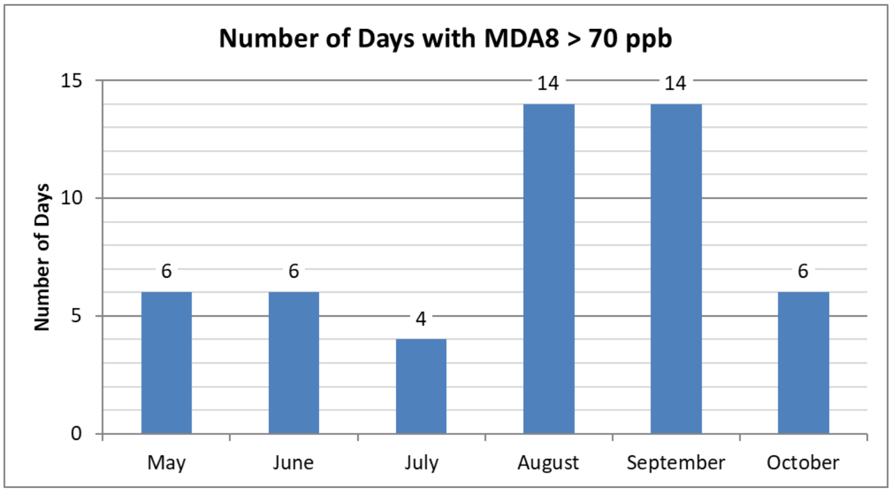


Figure 2-4. Number of days during each month with MDA8>70 ppb at the Waco (CAMS 1037) monitor during the period 2007-2019.

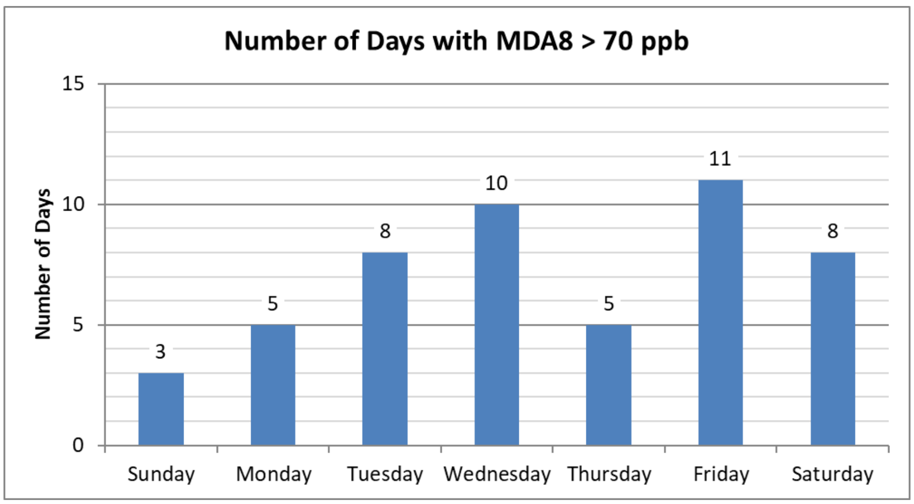


Figure 2-5. Number of days with MDA8>70 ppb by day of week at the Waco (CAMS 1037) monitor during the period 2007-2019.

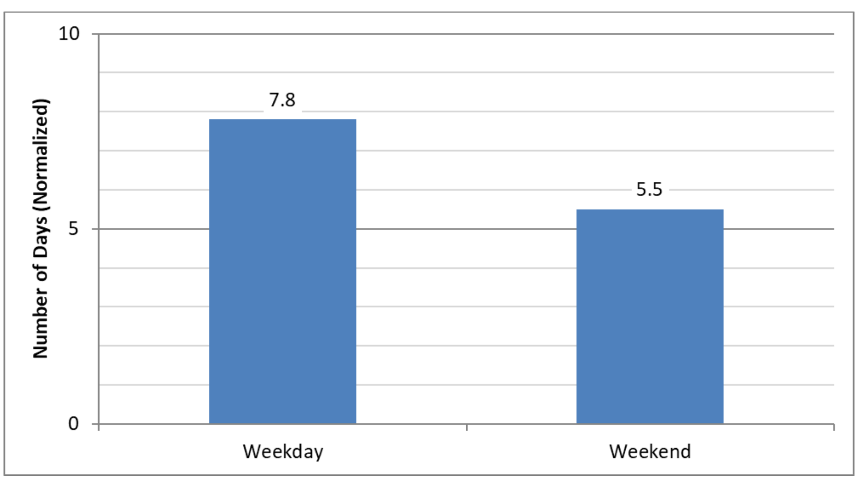


Figure 2-6. Number of high ozone days by day of week at the Waco (CAMS 1037) monitor during the period 2007-2019 normalized by number of days per week in each category.

2.2 Emissions

In this section, we review the emission inventory of ozone precursors for the HOTCOG area. As discussed in Section 1.1, ozone is not emitted directly, but is formed in the atmosphere from precursor emissions, mainly NOx and VOC. In Section 2.2, we provide an overview of the most recent HOTCOG area emission inventory, note recent emissions trends, and discuss the source categories that make the most important contributions to the HOTCOG area's NOx and VOC emission inventories.

At the time of this Conceptual Model Update, the most recent year for which HOTCOG area and Texas-wide emissions inventories were available for power plants was 2018, for other anthropogenic sources was 2017, and for biogenic sources was 2012. The 2018 power plant NOx emission inventory was developed by Ramboll for this analysis based on March 2018 through November 2018 average day emissions by power plant and emission unit available from EPA Air Markets Program Data (AMPD)[10]. The 2017 industrial point source emission inventory is based on the 2017 State of Texas Air Reporting System (STARS) emission inventory[11] which includes annual emissions by industrial facility for facilities subject to 30 Texas Administrative Code 101.10. 2017 nonpoint and mobile anthropogenic and 2012 biogenic emission inventories were developed by the TCEQ for use in photochemical modeling by the Texas Near-Nonattainment Areas and are broken down by county and emissions source category[12]. In addition to the recent year, 2017-2018, emission inventory described above, Ramboll also analyzed emission trends based on 2012-2018 emission inventories.

2.2.1 Emissions Summary

The HOTCOG area recent year emission inventory is summarized below to establish the relative importance of emissions by sector in the HOTCOG area emission inventory. Point sources are large stationary emissions sources that exceed a specified emissions threshold and therefore are tracked individually in the emissions inventory. Area sources are sources that may be spread out geographically and are small individually (such as oil and gas wells), but, taken together, may constitute a sizeable amount of emissions. On-road emissions are from light duty (e.g. passenger cars and light trucks) and heavy duty (medium- and heavy-duty trucks and buses) vehicles licensed or certified for highway use. Off-road mobile source emissions are from mobile and portable internal combustion powered equipment not generally licensed or certified for highway use. Biogenic emissions are emitted by natural sources such as trees, agricultural crops and microbial activity in soils.

Figure 2-7 shows recent year NOx and VOC emissions by source category in the HOTCOG area. NOx emissions are presented as two pie charts to show an emission inventory that includes only 2017 emissions and another that shows 2018 emissions for power plants and 2017 emissions for all other sources. Two NOx charts are included because power plant emissions decreased substantially from 2017 to 2018 as a result of the October 2017 shutdown of the Big Brown coal-fired power plant in Freestone county.

HOTCOG-wide total emission estimates are 105 tpd NOx for the 2017 emission inventory which includes the Big Brown power plant and 86 tpd based on the 2017-2018 inventory which does not include the Big Brown power plant. For the 2017 inventory, the largest three NOx emissions source categories, point sources (54 tpd, 51%), on-road vehicles (16 tpd, 15%) and off-road sources (14 tpd, 13%), account for 82% of HOTCOG-wide NOx emissions. For the 2017-2018 inventory, the same three sectors are the largest sources of emissions, accounting for 77% of HOTCOG-wide NOx emissions. In the 2017-2018 inventory, relative contributions from power plants (36 tpd, 42%)

[10] https://ampd.epa.gov/ampd/

[11] https://www.tceq.texas.gov/assets/public/implementation/air/ie/pseisums/2013thru2017statesum.xlsx

[12] https://www.tceq.texas.gov/airquality/airmod/data/tx2012

decrease, and the relative contributions for on-road vehicles (16 tpd, 19%) and off-road sources (14 tpd, 16%) increase. Figure 4-1 also shows VOC emissions by source category for the HOTCOG area. HOTCOG-wide total VOC emission estimates are 682 tpd. VOC emissions are not available from the EPA AMPD, therefore only 2017 VOC emission estimates are shown. Point sources account for less than 1% of total VOC emissions; therefore, decreases to power plant VOC emissions as a result of the Big Brown power plant shutdown will not have a substantial effect on the emission inventory. Biogenic sources are the largest VOC category, comprising 93% (633 tpd) of HOTCOG-wide total VOC emissions. Anthropogenic sources account for 7% of VOC emissions with contributions from area sources (36 tpd, 5%), off-road sources (6 tpd, <1%), on-road vehicles (5 tpd, <1%) and point sources (2 tpd, <1%).

Biogenic emission estimates for 2012 were developed by the TCEQ using the Model of Emissions of Gases and Aerosols from Nature (MEGAN; Guenther et al., 2012) version 2.10. MEGAN results provide hourly, day-specific emissions that depend on photosynthetically active solar radiation and temperature as well as other inputs such as land cover and plant type. Episode average biogenic emissions were calculated from the TCEQ 2012 biogenic emission inventory[13] for the HOTCOG area for the period June 1-30, 2012. Episode average biogenic emissions totals by county were estimated from the data for each county in the HOTCOG area. Each model grid cell was assigned to a county using Geographic Information System (GIS) tools.

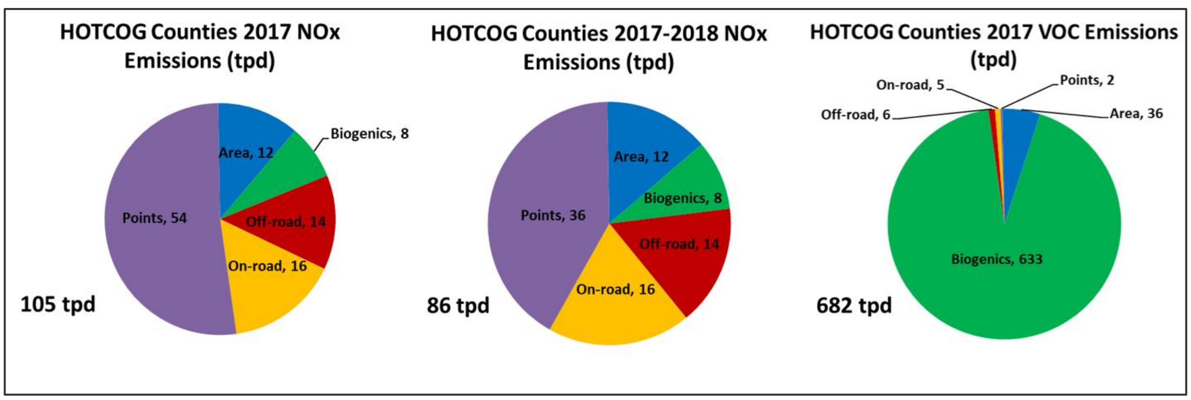


Figure 2-7. 2017 HOTCOG counties emissions by source category for NOx 2017 (left), NOx 2017-2018 (middle), and VOC (right).

2.3 Anthropogenic Source Emissions Overview

The 2017-2018 anthropogenic emission inventory is summarized below to establish the geographical distribution of point source, area source, on-road and off-road emissions in the HOTCOG area. The 2017-2018 inventory was analyzed because it reflects emissions subsequent to the permanent shutdown of the Big Brown power plant and, therefore, is expected to be most applicable to current and future ozone planning. Figure 2-8 shows NOx emissions and VOC emissions for 2017-2018 by county for all anthropogenic source categories.

82% of the 2017-2018 HOTCOG area anthropogenic NOx emissions are from three counties, Limestone (38%), McLennan (25%), and Freestone (19%), with contributions from each of the remaining three counties of 9% or less. Point sources make the largest 2017-2018 contribution to the anthropogenic NOx inventory in Limestone County (82%) and Bosque County (51%). On-road vehicle NOx emissions are the largest contributor to NOx emissions in McLennan County (45%) and Hill

[13] http://www.tceq.texas.gov/airquality/airmod/data/tx2012

County (51%) due to higher population in McLennan County relative to other counties in the HOTCOG area and in both McLennan and Hill County due to the presence of the heavily-trafficked interstate highway I-35. Off-road equipment emissions are the largest contributor to NOx emissions in Falls County (67%). Area sources are the largest contributor to NOx emissions in Freestone County (52%). HOTCOG-wide, 46% of the anthropogenic NOx emissions are from point sources, 21% are from on-road vehicles, 18% are from off-road sources and 15% are from area sources.

A majority of the 2017-2018 HOTCOG area anthropogenic VOC emissions (73%) are from area sources. McLennan County (37%), Freestone County (28%) and Limestone County (15%) together account for 81% of VOC emissions from anthropogenic sources in the HOTCOG area. The remaining 19% of VOC emissions are emitted in Hill County (11%), Bosque County (5%) and Falls County (3%). Area sources are the largest source of anthropogenic VOC emissions for each county (except for Bosque County) in the HOTCOG area, contributing between 56% and 89% of each county's anthropogenic VOC emissions. 46% of VOC emissions in Bosque County are from off-road sources and 41% of Bosque County VOC emissions are from area sources. Off-road sources are the second largest source of VOC emissions in Falls County (15%), Hill County (29%), and Limestone County (12%). While on-road sources are a much smaller contributor to VOC emissions than area sources, on-road vehicles are the second largest emissions source in McLennan County (17%). Point sources are the second largest source of VOC emissions in Freestone County (5%). HOTCOG-wide anthropogenic VOC emissions by source are as follows: area sources (73%), off-road sources (13%), on-road vehicles (11%) and point sources (4%).

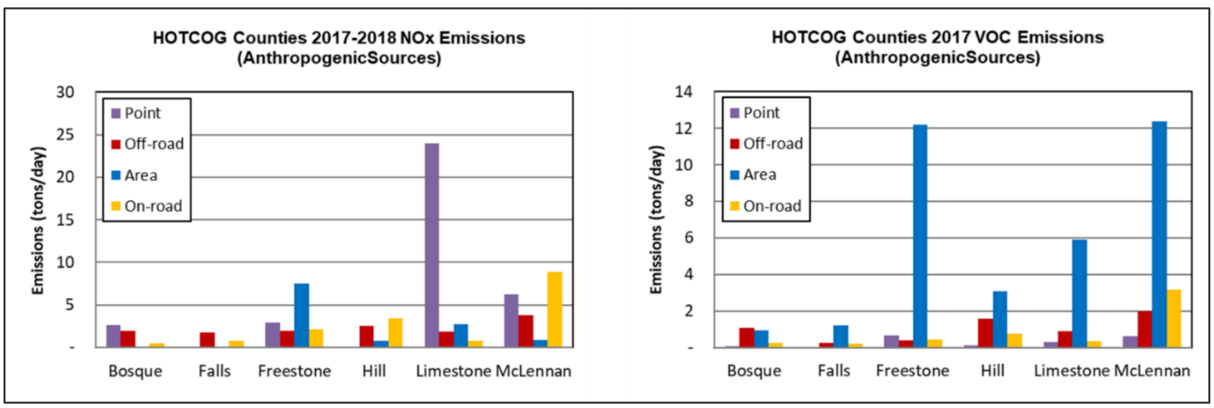


Figure 2-8. 2017-2018 HOTCOG anthropogenic NOx emissions (left) and VOC (right) emissions by county.

2.4 2012 to 2018 Emission Trends

2012 and 2017-2018 emission inventories are compared below to evaluate HOTCOG area emissions trends between 2012 and 2017-2018. Figure 2-9 shows by-source-category anthropogenic NOx and VOC emissions in the HOTCOG area for 2012 and 2018.

HOTCOG anthropogenic (excluding biogenic sources) NOx emissions decreased from 131 tpd in 2012 to 78 tpd in 2018 (-40%): on-road vehicle NOx emissions decreased by 13 tpd (-45%), point source NOx emissions decreased by 27 tpd (-43%), area source NOx emissions decreased by 6 tpd (-35%) and off-road mobile NOx emissions decreased by 6 tpd (-31%).

HOTCOG anthropogenic VOC emissions decreased from 60 tpd in 2012 to 49 tpd in 2018 (-19%): area source VOC emissions decreased by 3 tpd (-8%), on-road vehicle VOC emissions decreased by 3 tpd (-34%), off-road mobile VOC emissions decreased by 2 tpd (-28%) and point source VOC emissions decreased by 3 tpd (64%).

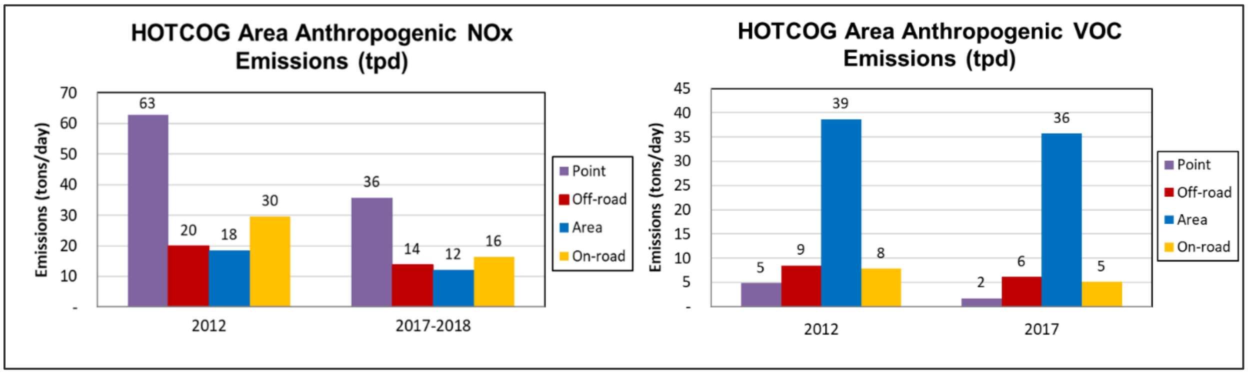


Figure 2-9. 2017-2018 HOTCOG area anthropogenic NOx emissions (left) and VOC emissions (right).

On-road emissions changes from year-to-year are due to changes in vehicle activity (vehicle miles travelled; VMT) and fleet turnover. The effect of fleet turnover is to decrease emissions over time as the fleet changes to newer vehicles adhering to more stringent, cleaner emission standards.

Changes in emissions from off-road sources are the result of both changes in activity (i.e. equipment population and annual use) and fleet turnover to new equipment. Decreases in off-road NOx and VOC emissions from 2012 to 2017 are expected as the result of fleet turnover to newer, cleaner burning equipment between 2012 and 2017 rather than decreases in off-road activity.

Changes in area source emissions from 2012 to 2018 are likely due to a combination of factors: oil and gas activity decreases from 2012 to 2018 and small increases in human population from 2012 to 2018.

Next, we present trends in oil and gas production from 2006-2018 for HOTCOG counties (Figure 2-10). Consistent with emission trends shown above, the focus below is on changes during the 2012 to 2018 period. Over the 2012 to 2018 period, gas production, condensate production, and oil production decreased in the HOTCOG area. Oil production in the HOTCOG region (upper panel of Figure 2-10) is due almost entirely to activity in Limestone and Freestone counties which together account for 98% of HOTCOG oil production in 2018. Oil production in Limestone County decreased by 23% from 2012 to 2018 and oil production in Freestone County has decreased by 54% from 2012 to 2018. Oil production in Falls and McLennan counties together constitute about 2% of HOTCOG oil production. The middle panel of Figure 2-10 shows that only Limestone and Freestone counties have substantial condensate production (>99%). Both counties show a decline in condensate production from 2012 to 2018 (Limestone: -55%; Freestone: -49%). The lower panel of Figure 2-10 presents gas production for the six HOTCOG counties. Limestone and Freestone counties account for 93% of all gas production in the HOTCOG area, with Hill County accounting for the remaining 7% of gas production. Similar to oil production, there is a substantial decrease in gas production from 2012 levels in Freestone County (54%) and Limestone County (54%).

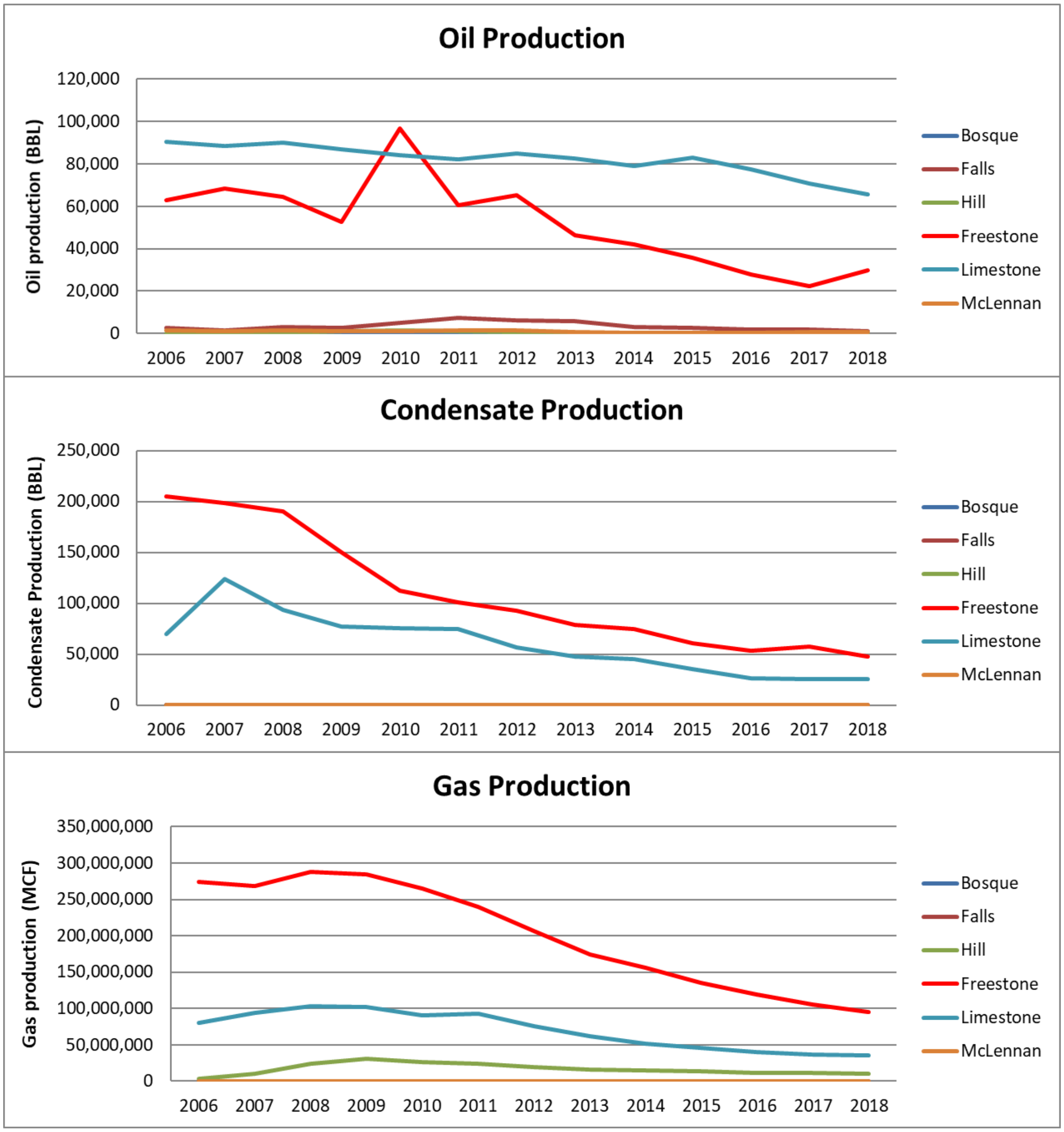


Figure 2-10. 2006-2018 trends in oil (top panel), condensate (middle) and gas (bottom) production in each of the HOTCOG counties.

2006 to 2018 trends in HOTCOG oil and gas well counts by county are shown in Figure 2-11. Consistent with emission trends shown above, the focus below is on changes during the 2012 to 2018 period. Natural gas well counts and oil well counts are stable over the 2012 to 2018 period. The natural gas well count increased in Freestone and Limestone Counties from 2006 to 2012. By 2012, low natural gas prices led to decreases in the drilling of new wells; the number of wells stabilized and then began to decline slowly in 2015. Freestone and Limestone counties had 3% fewer active gas and oil wells in 2018 compared to 2012. Oil well counts in HOTCOG counties are relatively low and only showed small changes from 2012 to 2018.

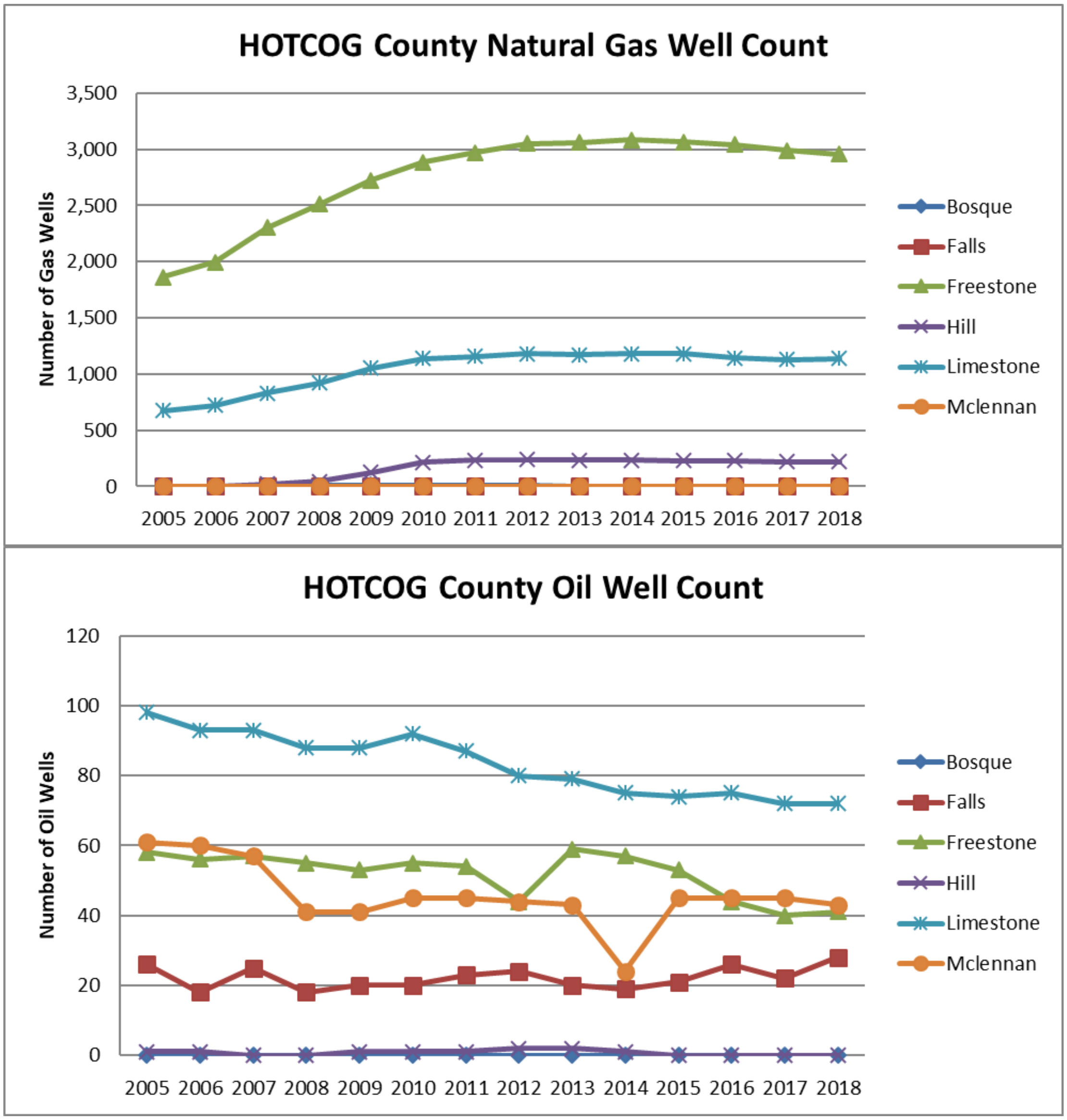


Figure 2-11. Trends in natural gas well (upper panel) and oil well (lower panel) counts for HOTCOG counties.

2.5 Point Sources

Point sources make the largest contribution to the HOTCOG area NOx emission inventory. Figure 2-7 above shows emissions by source category in the HOTCOG area. Point sources account for 46% of total anthropogenic NOx emissions in the HOTCOG area in 2017-2018. Point source emissions account for a relatively small amount of total VOC emissions, representing approximately 4% of the total VOC emissions in the HOTCOG area in 2017-2018.

Point sources are large stationary emissions sources that exceed a specified emissions threshold. Point source emissions are typically released through an exhaust stack. In non-attainment areas, the TCEQ defines a point source to be any industrial, commercial or institutional source that emits actual levels of criteria pollutants at or above the following amounts: ten tons per year (tpy) of VOC; 25 tpy of NOx; or 100 tpy of any of the other criteria pollutants including CO, SO2, PM10, or PM2.5. In attainment areas of the state, such as the HOTCOG area, any facility that emits a minimum of 100 tpy of any criteria pollutant must submit a point source emissions inventory to the TCEQ. The TCEQ began a special inventory of McLennan County in 2012; identified sources that met the ozone nonattainment area thresholds (10 tpy VOC, 25 tpy NOx) were requested to submit a point source emission inventory to TCEQ. Each point source has a well-defined location (latitude and longitude) as well as ancillary information known as stack parameters that indicate the height at which emissions are released, the diameter of the emitting stack and other factors.

2.5.1 2018 Point Source Emission Trends

Trends in point source emissions from EGU and non-EGU industrial sources are shown in Figure 2-13. From 2012-2018, EGUs accounted for a majority (87%-92%) of HOTCOG-wide point source NOx emissions. EGU NOx emissions vary from year-to-year, with the largest change in EGU NOx emissions occurring between 2017 and 2018. From 2017 to 2018, EGU NOx emissions decreased by 18.7 tpd (38%), primarily as a result of the shutdown of Big Brown coal-fired power plant (Figure 2-13 shows emission changes by power plant). From 2012 to 2018, HOTCOG-wide EGU NOx emissions decreased by 23.8 tpd (43%) as a result several factors: 1) the 2017 Big Brown power plant shutdown; 2) decreases in NOx emissions from the Limestone Generating Station power plant; and 3) decreases in NOx emissions from Sandy Creek Energy Station power plant. Table 2-1 shows fuel types and emission controls from EPA AMPD by power plant and generating unit. According to EPA AMPD, emission controls for HOTCOG area EGUs did not change between 2012 and 2018; NOx emission decreases resulted from the Big Brown power plant shutdown and we infer that activity reductions occurred at other power plants. From 2012 to 2018, non-EGU industrial facilities accounted for 8% to 13% of HOTCOG-wide point source NOx emissions. From 2012 to 2017, non-EGU industrial facility NOx emissions decreased by 3.3 tpd (42%) as a result of NOx emission reductions across several facilities, with the largest reductions (2.1 tpd) from the Glass Center in McLennan County.

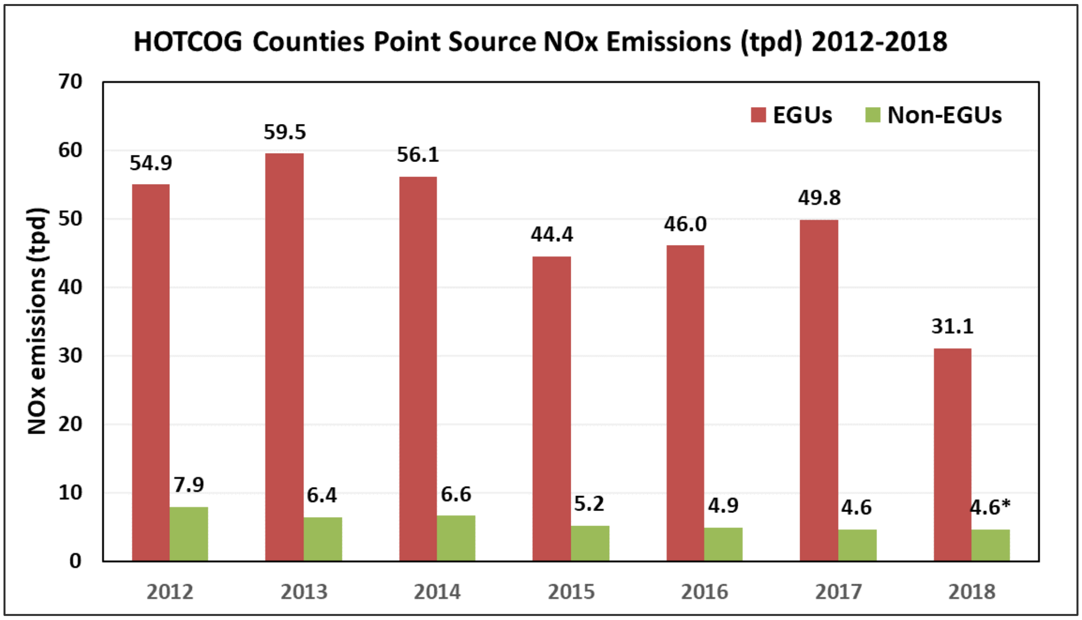


Figure 2-12. HOTCOG-wide 2012-2018 point source OSD NOx emission inventory trends[14].

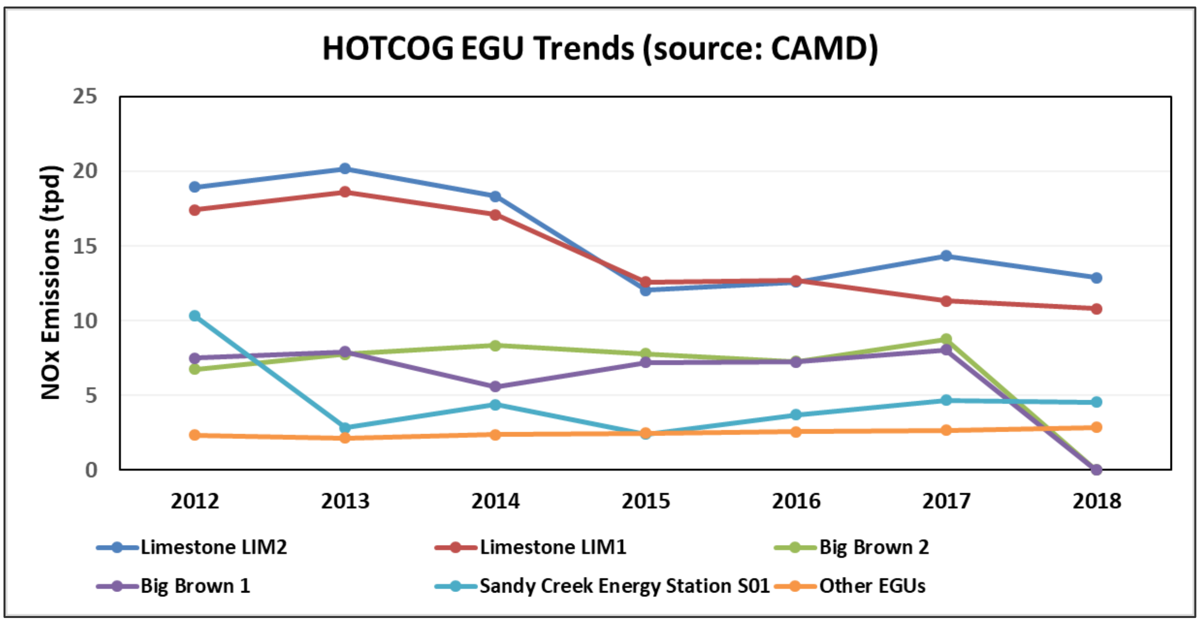


Figure 2-13. 2012-2018 HOTCOG EGU OSD NOx emissions trends.

[14] 2018 non-EGU emissions were not readily available at the time that this report was compiled, therefore, 2018 non-EGU emissions were set equal to 2017 non-EGU emissions.

Table 2-1. HOTCOG EGU emission controls and recent year NOx emissions.

County	Facility Name	Unit ID	Fuel Type	NOx Control(s)	2017 OSD NOx Emissions (tpd)	2018 OSD NOx Emissions (tpd)
Limestone	**Limestone**	LIM2	Coal	Overfire Air	14.4	12.9
		LIM1	Coal	Overfire Air	11.3	10.8
Freestone	**Big Brown**	2	Coal	Low NOx Burner Technology w/ Separated OFA, Selective Non-catalytic Reduction	8.7	0.0
		1	Coal	Low NOx Burner Technology w/ Separated OFA, Selective Non-catalytic Reduction	8.0	0.0
McLennan	**Sandy Creek Energy Station**	S01	Coal	Selective Catalytic Reduction	4.7	4.6
Freestone	**Freestone Power Generation**	GT4	Natural Gas	Dry Low NOx Burners	0.5	0.6
		GT2	Natural Gas	Dry Low NOx Burners	0.5	0.5
		GT1	Natural Gas	Dry Low NOx Burners	0.5	0.5
		GT3	Natural Gas	Dry Low NOx Burners	0.4	0.5
Bosque	**Bosque County Power Plant**	GT-3	Natural Gas	Dry Low NOx Burners	0.5	0.5
		GT-2	Natural Gas	Selective Catalytic Reduction, Dry Low NOx Burners	0.2	0.2
		GT-1	Natural Gas	Selective Catalytic Reduction, Dry Low NOx Burners	0.2	0.2

2.5.2 Regional Point Sources

Ozone at CAMS 1037 may be affected by emissions from sources within and outside the HOTCOG area. Figure 2-14 compares the 2012 and 2017-2018 NOx TCEQ NOx emission inventories for the HOTCOG counties and the surrounding area of East Texas. Figure 2-14 shows point source NOx emissions as circles with radii that indicate the magnitude of the NOx emissions. The underlying gridded data represent low-level (i.e. non-point) sources of NOx emissions; data were taken from CAMx model-ready files for June 29, 2017 at 7 am, which was a randomly selected Friday. Grid cell resolution is 4 km x 4 km. The gridded data shows emissions from urban areas, on-road mobile sources and rural areas with oil and gas production.

The HOTCOG counties are outlined in black. The largest point sources of NOx in the HOTCOG area are the Big Brown (2012 only) and Limestone power plants located to the east and southeast of CAMS 1037. The Oak Grove and Twin Oaks power plants lie just outside the southeastern boundary of the HOTCOG area. There are several prominent non-point NOx emissions sources within the HOTCOG counties. The City of Waco is located southwest of the green star that shows the location of CAMS 1037. Waco has both point and non-point sources of NOx. Highway I-35 passes through the City of

Waco and near CAMS 1037. Highway I-45, which connects the DFW and HGB areas, passes through Freestone County. Freestone and Limestone Counties are rural areas with 2018 populations of 20,438 and 23,983, respectively, but have areas with relatively large emissions of NOx due to natural gas production (Johnson et al., 2019; Grant et al., 2016). Northern Hill County also has a region of relatively high NOx emissions due to natural gas production; Hill County lies within the Barnett Shale region (Johnson et al., 2019; Grant et al., 2016).

The DFW metropolitan area is identifiable as the large region with yellow and orange grid cells north of the HOTCOG counties. Highway I-35 continues further south-southwest of the HOTCOG counties through the Austin and San Antonio urban areas which can be identified as regions with clusters of point sources (black circles) and larger areas of yellow grid cells around the I-35 freeway. The HGB area can be identified northwest of the Galveston Bay along the Gulf of Mexico as a region of yellow, orange and red grid cells. Other smaller urban areas such as cities in Northeast Texas are also identifiable as regions of yellow grid cells and other major freeways are can be seen crisscrossing East Texas. There are several power plants in Northeast Texas with large NOx emissions.

In summary, Figure 2-14 shows that CAMS 1037 has large NOx emissions sources to its north clockwise through southeast. This distribution of regional emissions is consistent with the analysis of winds and transport pathways presented in the 2016 update to the ozone conceptual model (Parker et al., 2017) that showed that winds typically are from the north clockwise through southwest on days with MDA8 > 70 ppb at CAMS 1037. These wind directions will bring air masses influenced by local and regional NOx emissions sources to CAMS 1037.

The spatial distribution of point source and nonpoint source NOx emissions are similar in 2012 and 2017-2018. Several large point sources (>4 tpd NOx) that were not present or had smaller emissions in 2012 are shown in 2017-2018 such as: Sandy Creek Power Plant in the HOTCOG area, Oak Grove Steam Electric Power Plant south of the HOTCOG area, and the Midlothian Cement Plant north of the HOTCOG area. Several point sources with emissions greater than 4 tpd NOx in 2012 either were shut down or emissions decreased to less than 4 tpd NOx in 2017-2018 such as Big Brown Power Plant in the HOTCOG area, Sandow Steam Power Plant south of the HOTCOG area, Calaveras Plant in San Antonio and Monticello Power Plant in Northeast Texas. Low-level NOx emissions generally decreased from 2012 to 2017-2018 on highways (e.g., Interstate-35), in urban areas (e.g., Dallas Metropolitan Area), and in rural areas (e.g., rural area to the west-southwest of the HOTCOG area). One exception to NOx emission decreases is in the area of the Eagle Ford Shale which appears to the east and south of San Antonio in the lower left area of both maps and shows increased NOx in 2017-2018 due to ongoing development of oil and gas resources.

In summary, Figure 2-14 shows that CAMS 1037 has large NOx emissions sources to its north clockwise through southwest. This distribution of regional emissions is consistent with the analysis of winds and transport pathways presented in the 2017 update to the ozone conceptual model (Parker et al., 2017) that showed that winds typically are from the north clockwise through southwest on days with MDA8 > 70 ppb at CAMS 1037. These wind directions will bring air masses influenced by local and regional NOx emissions sources to CAMS 1037. Figure 2-14 also shows significant NOx reductions in both point and area source emission categories that are consistent with the decreasing design values at Waco CAMS 1037.

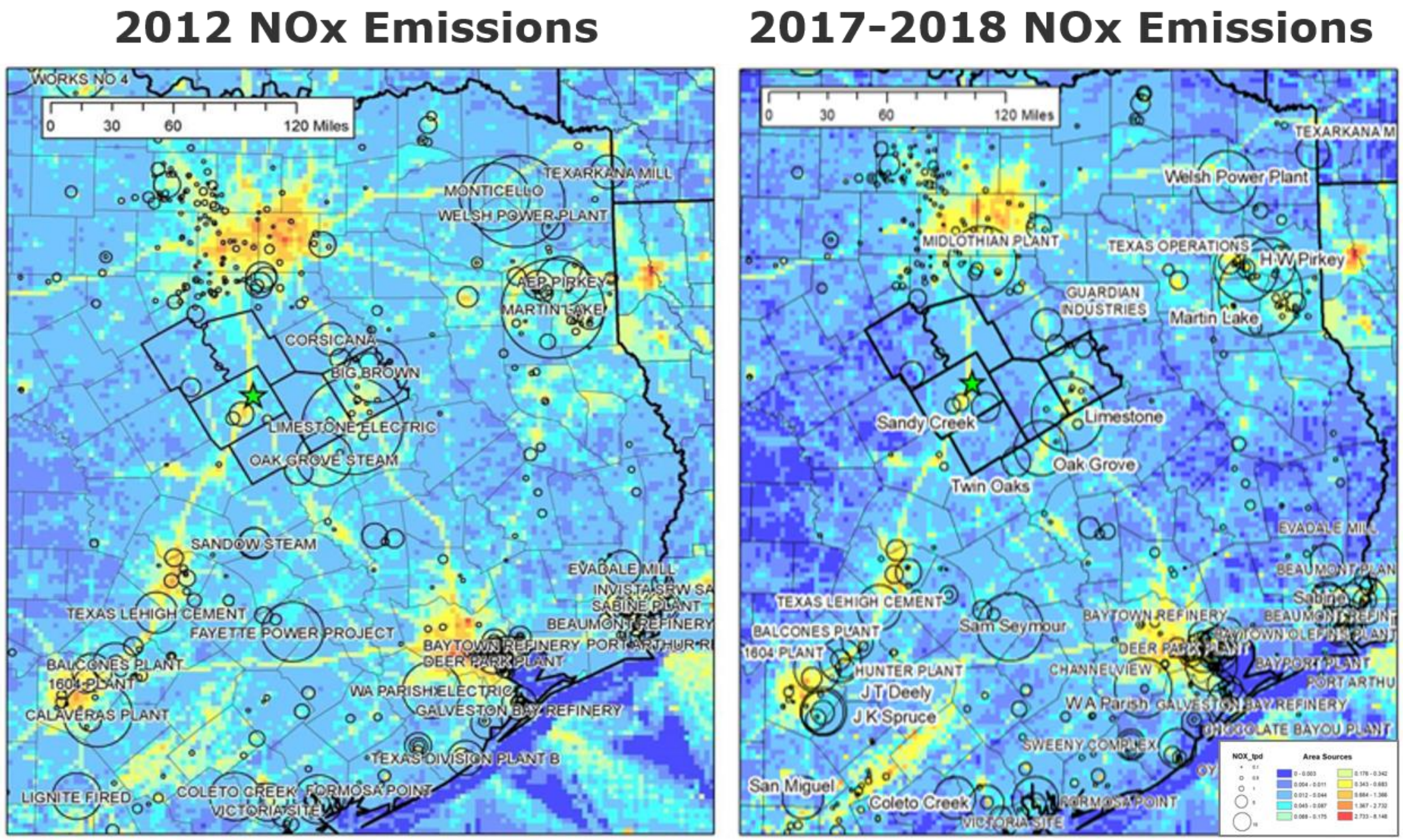


Figure 2-14. Side by side comparison of 2012 and 2017-2018 NOx emission inventories. Left panel: TCEQ June 29, 2012 modeling inventory NOx emissions sources in East Texas. Point sources are represented by circles with radii proportional to NOx emissions superimposed on gridded low level emissions. Right panel: As in left panel for 2017-2018 modeling inventory NOx emissions sources in East Texas.

2.6 Relative Importance of NOx and VOC Emissions in Ozone Formation

In order to develop emission control strategies for the HOTCOG area that will reduce the local contribution to ozone, it is necessary to understand how ozone formation in the area depends on the amount of available NOx and VOC. Ozone formation depends on the amount of NOx and VOC present as well as on the ratio of VOC to NOx, where the ratio is taken in terms of ppbC/ppb. When the VOC/NOx ratio is higher than about 10, ozone formation is limited by the amount of available NOx and reducing NOx tends to decrease peak ozone concentrations. However, if the VOC/NOx ratio is less than about 7, reducing NOx tends to increase ozone levels, and the area is said to be VOC-limited. In this situation, which can occur in urban cores of large cities, ozone is suppressed in the urban area due to titration by large amounts of fresh NO emissions. When NOx emissions are reduced, the suppression of ozone by NO is lessened and ozone increases.

For 2017-2018 emission inventory VOC/NOx ratio for the HOTCOG area is 21.6 ppbC/ppb for 2017 and 26.1 ppbC/ppb for 2017-2018, which is well within the NOx-limited regime. The presence of abundant biogenic VOC emissions ensures that there are generally sufficient VOCs to allow ozone formation and that ozone formation is limited by the amount of available NOx. This means local emissions control strategies should focus on reducing NOx emissions. The VOC/NOx ratios for current and past HOTCOG emission inventories are presented in Table 2-2. For all years, the VOC/NOx ratio is greater than 10, which indicates that ozone formation is limited by the amount of available NOx. This finding is consistent with the results of HOTCOG's ozone modeling, which also indicated that ozone formation in the HOTCOG area is NOx-limited (Section 2.8).

Table 2-2. VOC/NOx (ppbC/ppb) ratios for the HOTCOG 6-County Area for current and past emission inventories.

2006	2012	2017	2017-2018
24.7	16.2	21.6	26.1

2.7 Effects of Weather on Ozone Formation in the HOTCOG Area

High ozone at the Waco monitor typically occurs on days when local temperatures are high (average daily maximum temperature of 97°F), wind speeds are low and wind directions range between north-northeasterly clockwise through south-southeasterly (McGaughey et al., 2010; 2012; Parker et al., 2017; Johnson et al., 2019). Wind rose plots that characterize near-surface wind speed and direction at the Waco Mazanec monitor over the 2009-2012 period are shown in Figure 2-15. In a wind rose diagram, the orientation and length of spokes indicate the frequency with which a given wind direction occurs. The spokes show the direction from which wind blows toward the monitor, and the colored bands indicate the percentage of time the winds fall in a given speed range. Two sets of wind rose diagrams are shown, corresponding to: (1) no MDA8 threshold (all days), and (2) days with MDA8 ≥ 75 ppb. 75 ppb is used as the threshold for a high ozone day because this analysis was performed before the ozone NAAQS was revised in October 2015. Based on analysis of high ozone days at CAMS 1037 (Parker et al., 2017; Johnson et al., 2019), we believe the results to be broadly applicable to high ozone days under the lower 70 ppb NAAQS.

The wind data used to develop the wind roses are divided into morning (6 am – 11 am) hours and afternoon (12 noon – 5 pm) hours in order to investigate whether wind shifts between morning and afternoon are present on high ozone days. For each threshold, the morning and afternoon plots are based on the same set of days, and the MDA8 ≥ 75 ppb threshold plots are based on fewer days than the no threshold plots. The number of input data points is the same for the morning and afternoon wind rose plots for each monitor and threshold (unless some wind data are missing). Because there are fewer days with very high ozone (MDA8≥75 ppb) there are far fewer days of data represented in the MDA8≥ 75 ppb plots than in the no threshold plots.

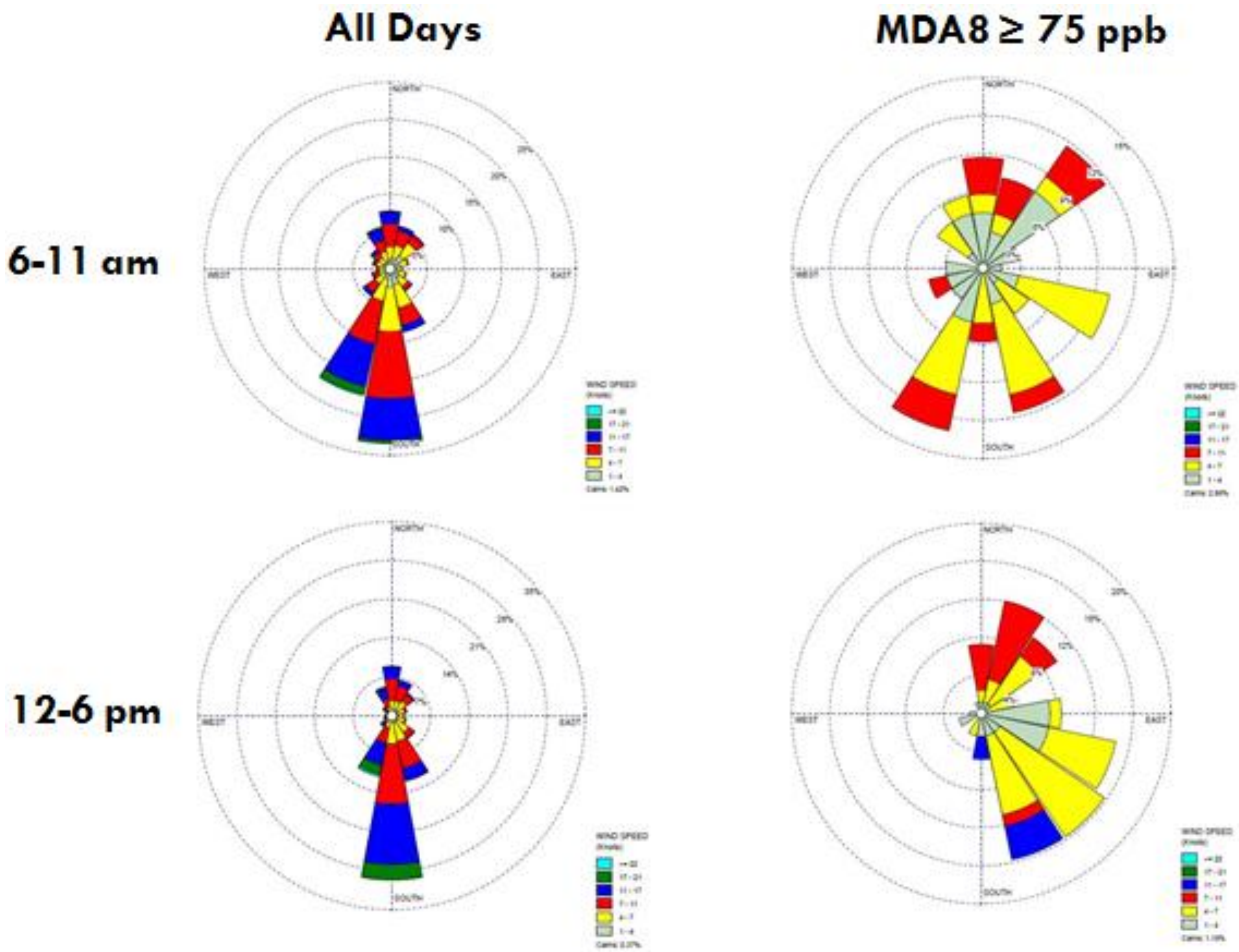


Figure 2-15. Waco wind roses for morning (upper panels) and afternoon (lower panels) on all days (left panels) and days with MDA8≥75 ppb (right panels).

The no threshold plots for morning and afternoon (left panels of Figure 2-15) show that winds at the Waco monitor are most frequently from the south. Less frequently, winds are from the north. Only very rarely are winds from the east or west. Wind speeds are typically faster than 7 knots. Because the all days plots are strongly weighted toward days with MDA8<75 ppb, this indicates that low ozone days at the Waco monitor are characterized by relatively strong southerly winds. The strong southerly winds prevent buildup of ozone and precursors over the area and bring clean Gulf air into central Texas. The afternoon wind pattern for no threshold days is similar to the morning wind pattern. By contrast, on high ozone days (right panels of Figure 2-15), morning winds can be from any direction and winds speeds are typically slower than 7 knots. The afternoon wind for high ozone days is typically from southeast (~54%) or northeast (~30%), with average wind speed from southeast predominantly 4-7 knots and typical wind speeds from northeast at least 7 knots but less than 11 knots. This suggests that multiple emission source regions affect the Waco monitor, consistent with the NOx emission inventory data shown in Figure 2-14.

Conditions conducive to the transport, formation, and accumulation of ozone are primarily dependent on the prevailing large-scale weather patterns. The continental-scale atmospheric circulation features during high ozone episodes at the Waco monitor for 2007-2012 were investigated using a case study approach (McGaughey et al., 2012). More recent analyses by Parker et al. (2017) and Johnson et al. (2019) confirm the following findings. On high ozone days in the HOTCOG area, surface ridge of high pressure often extends south from the Central Plains or southwest from the eastern U.S. into Texas. The ridge is typically associated with clear skies, warm temperatures, and light wind speeds at the surface. High pressure is sometimes over Texas at upper levels as well; however, northerly or zonal (i.e., east/west) flow aloft is more common. Most high ozone episodes have high ozone concentrations at monitoring locations throughout the eastern half of Texas, demonstrating the regional nature of high ozone events.

Many high ozone episodes are initiated by the passage of a cold front through the HOTCOG area. Some cold fronts are accompanied by strong gusty winds and the transport of noticeably cooler air into Texas, while other cold fronts primarily represent a diffuse and ill-defined transition zone between drier continental air to the north and moister, maritime air to the south. For these latter systems, increased solar radiation and drier air are associated with increases in the daytime maximum temperatures compared to pre-frontal conditions.

For some high ozone episodes, the southward movement of the surface ridge of high pressure into Texas was associated with long-range transport of continental air into the HOTCOG area from locations located well north of Texas. Other high ozone episodes were initiated when a surface high pressure ridge over eastern portions of the US expanded southwestward into Texas. For this latter scenario, the high pressure ridge was sometimes associated with a cold front that had moved south into or through the eastern U.S. during previous days and was associated with long-range transport from the northeast. A few high ozone days had inland-moving tropical low pressure systems in the western Gulf of Mexico that may have enhanced northeasterly or easterly winds in the lower atmosphere over eastern Texas.

Overall, these analyses found that the necessary (but not sufficient) criteria for high ozone concentrations at the Waco monitor were local meteorological conditions conducive to the accumulation and formation of ozone near the surface (warm temperatures, light wind speeds) as well as the occurrence of large-scale lower-tropospheric atmospheric circulation features favorable for the long-range transport of air of recent continental (as opposed to maritime) origin into the HOTCOG area.

Long-range back-trajectories initiated within the daytime mixed layer suggest that the inflow of continental air into Texas at one or more layers above the surface is a necessary condition for high ozone concentrations at the Waco monitor (McGaughey et al., 2012; Parker et al., 2017; and Johnson et al., 2019). Figure 2-16 from Johnson et al. (2019) shows inter-state back-trajectory maps based on five-day HYSPLIT model (Draxler and Rolph, 2013) back-trajectories initiated at a height of 1 km above ground level (AGL) for the 4 highest ozone days in each year at CAMS 1037 from 2017-2019. These days were selected because of their role in determining the CAMS 1037 design value for 2017-2019. A 70 ppb threshold was not used to select the days because there was only one day from 2017-2019 that had MDA8 > 70 ppb at CAMS 1037.

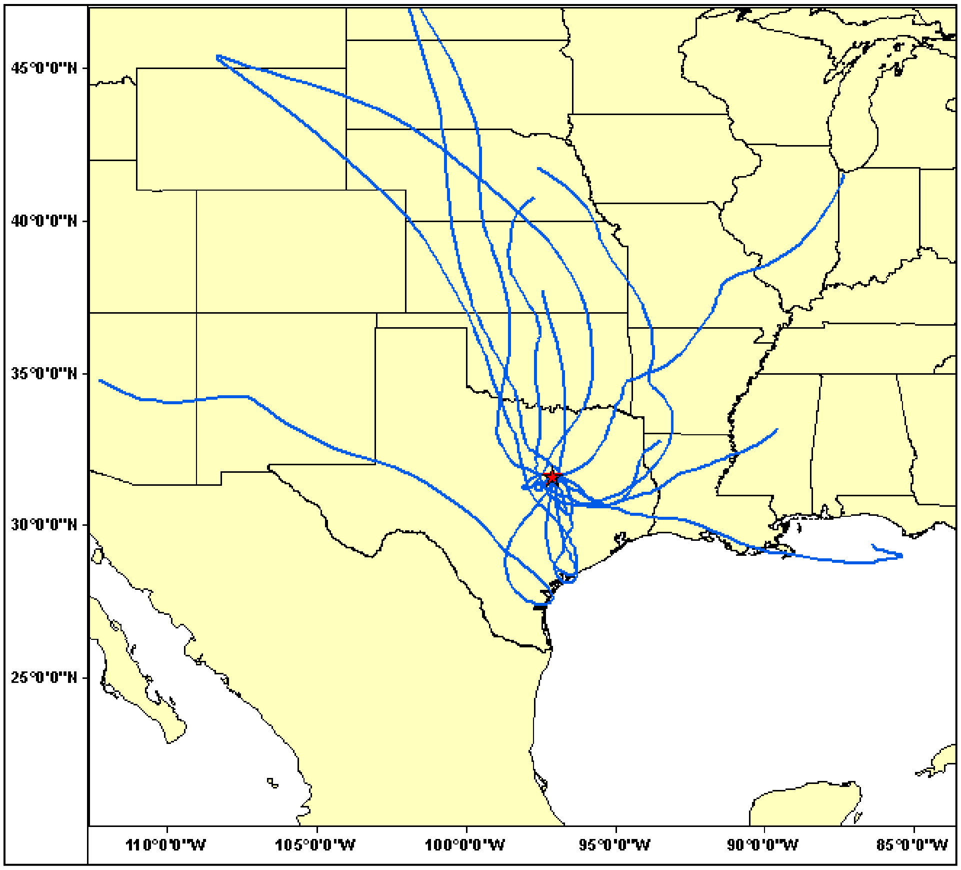


Figure 2-16. Interstate back-trajectories (based on 3-day HYSPLIT back-trajectories initiated at 1 km AGL) during 2017-2019 for the 4 highest ozone days in each year at CAMS 1037. The red star denotes the location of CAMS 1037.

The three-day trajectory duration was selected to capture long-range transport not only within Texas, but also from distant areas, such as the central and southeastern U.S. The back-trajectory initialization height of 1 km AGL was used since this height approximates the middle of the afternoon mixed layer on high ozone days in the HOTCOG area. The majority of back-trajectories indicate flow into Texas from continental regions located to the north and northeast of eastern Texas; three back-trajectories indicate flow over the southeastern U.S. One back trajectory indicates flow over the southwestern U.S. Common upwind areas include wide portions of the Great and Central Plains and the Mississippi Valley. Within Texas, many back-trajectory paths show a looping behavior which indicate shifting winds and recirculation patterns that tend to keep ozone and precursors over Texas, increasing ozone levels.

Figure 2-17 shows the same back trajectories as Figure 2-16, but zoomed in to show more detail within Texas. The back-trajectories indicate that high ozone days have a wide variation of inflow paths ranging from northerly clockwise through southwesterly. Roughly half of the high ozone days are also characterized by a northerly component within Texas. The looping nature of the trajectories is more evident in Figure 2-17, suggesting a recirculation pattern of continental air. The trajectory arriving into Texas from the southwestern U.S. circles over Corpus Christi, then moves over the San Antonio and Austin areas before arriving at CAMS 1037

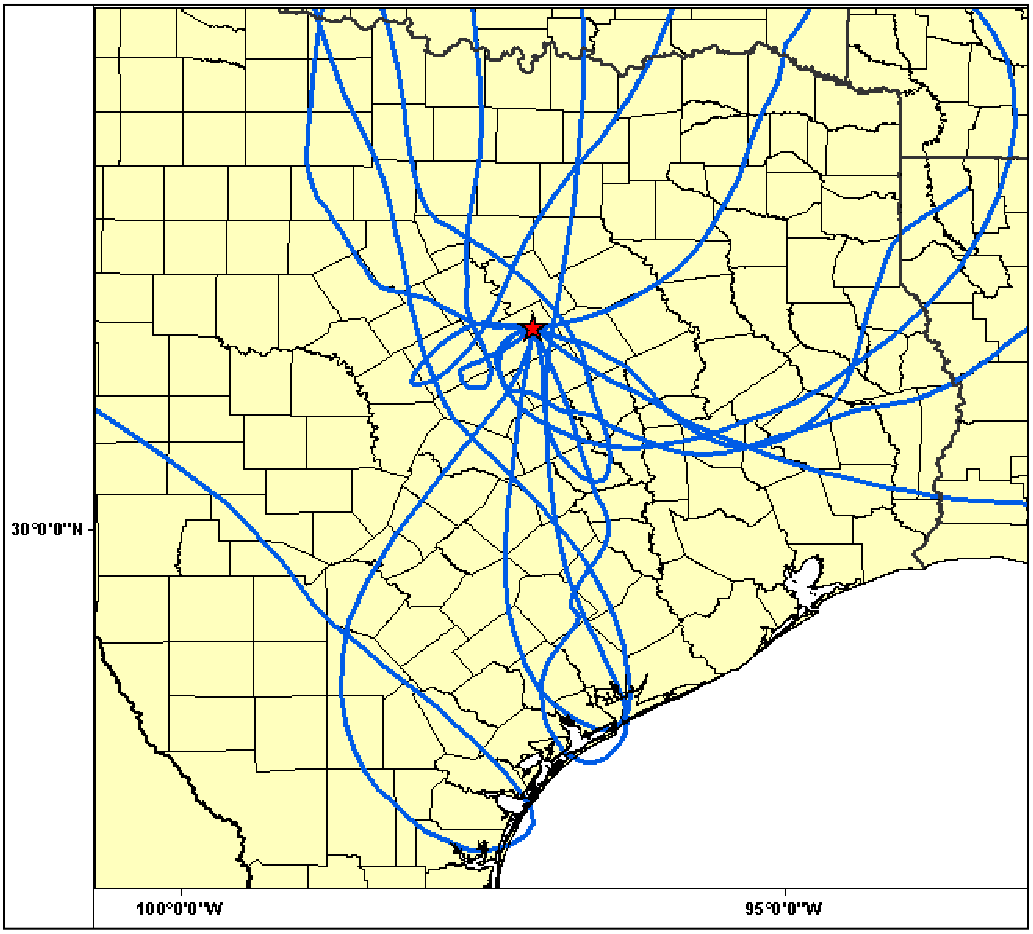


Figure 2-17. Intrastate back-trajectories (based on 3-day HYSPLIT back-trajectories initiated at 1 km AGL) during 2017-2019 for the 4 highest ozone days in each year at CAMS 1037. The red star denotes the location of CAMS 1037.

Of the 12 days that determined the 2017-2019 design values at CAMS 1037, 11 had estimated regional background ozone levels exceeding 50 ppb across large areas of East Texas. On the other day, background ozone levels across most of East Texas were relatively low (~45-50 ppb), but CAMS 1037 was likely influenced by the Houston urban plume. On many of the 12 days, a period of northerly or northeasterly winds brought polluted continental air into Texas and was then followed by a shift in the low-level winds. The shift in the winds from northerly to southerly then brought air northeastward along the I-35 corridor over the Austin, Killeen-Temple and Waco urban areas toward CAMS 1037. This wind pattern brings ozone and precursors from distant and local emission sources to CAMS 1037. As the NAAQS has become more stringent, the role played by transported ozone from outside Texas and from other regions within Texas has become more important as the area is more easily be brought to the brink of an ozone exceedance through the effect of transport alone.

Continental air masses transported into Texas likely contained elevated background concentrations of ozone and its precursor compounds associated with both biogenic and anthropogenic emissions. Many of the days for which back trajectories are shown in Figure 2-16 and Figure 2-17 had wildfire and/or agricultural burning activity and north/northeast of Texas with smoke apparent on satellite imagery (Kemball-Cook et al., 2019). Upwind areas within Texas mostly included eastern portions of Texas east of a north-south line between DFW and Victoria; common upwind non-Texas areas were the

Mississippi River Valley and geographic areas to the west such as Louisiana, Arkansas, eastern Oklahoma, and Missouri and portions of surrounding states.

In summary, HOTCOG's ozone modeling and ambient and emissions data analyses all indicate the importance of regional emissions sources outside the HOTCOG area in determining ozone levels within the HOTCOG area. Ozone formed within the HOTCOG area is often augmented by transport of air with elevated ozone concentrations from outside the area, almost always from the north clockwise through southwest.

2.8 Ozone Modeling

Ozone modeling is used in concert with analysis of ambient data and emissions information to form a conceptual picture of the conditions that lead to high ozone days as well as to test emission control strategies. Use of source apportionment tools within the framework of an ozone model can shed light on the importance of regional transport relative to contributions of local sources.

The CAMx (Ramboll, 2019) photochemical grid model was used to model ozone concentrations in the HOTCOG area. Estimates of the contributions to ozone from different regions within and outside Texas were obtained as well as estimates of the contributions to ozone from different types of emissions source categories. The model configuration for the CAMx modeling and model performance evaluation against observed ground level ozone are detailed in a modeling report (Johnson et al., 2017). This section presents key modeling results that provide insight into the conceptual model of ozone in the HOTCOG area.

We present results of two 2017 CAMx ozone source apportionment simulations. In a source apportionment simulation, the photochemical model estimates the contributions from multiple emissions source regions, emissions source types, and pollutant types to ozone throughout the modeling domain. The first simulation was designed to examine ozone impacts from the major emissions sectors within the HOTCOG region, while the other simulation was designed to estimate the ozone impacts of oil and gas development from the major shale regions in East Texas and Louisiana.

2.8.1 Model Configuration

This analysis is designed to be relevant to current emissions levels, rather than historical emissions, and so uses a 2017 TCEQ emission inventory. The 2012 historical modeling episode was evaluated against observed data and we determined that the model performs well enough in simulating observed ozone to be used as a tool for understanding HOTCOG area air quality. Then, we used the CAMx model with TCEQ's 2017 emissions modeling platform to conduct a source apportionment analysis for the HOTCOG area. This configuration is a 2017 future year emissions simulation using 2012 weather conditions. All CAMx model inputs from the 2012 historical year were held constant for the 2017 future year scenario except for: (1) 2012 anthropogenic emissions inventory was replaced by 2017 anthropogenic emissions and (2) 2012 CAMx model initial conditions and 36 km grid boundary conditions were replaced by 2017 initial and boundary conditions. Both sets of updated inputs were obtained from TCEQ's Houston SIP modeling database.

EPA's Modeled Attainment Test Software (MATS) tool was used to project 2017 future year design values (DV) at monitoring locations. We followed EPA's guidance for performing modeled ozone attainment demonstration as outlined in the EPA's then-current 8-hour ozone and modeling guidance document (EPA, 2014).

2.8.2 Source Apportionment Results

The source apportionment results showed that ozone formation in the HOTCOG area under 2017 conditions was limited by the amount of available NOx. This finding is consistent with the 2017-2018 emission inventory analysis (See Section 2.6), which indicated that the VOC emission inventory for the 6-county area is dominated by biogenic VOC. The abundance of biogenic VOC ensures that there is always enough VOC available to form ozone so that the amount of ozone formed is determined by the amount of NOx emissions. This finding means that emission control strategy development in the HOTCOG area should focus on controlling NOx emission sources rather than VOC sources.

For the Waco Mazanec monitor, the contribution of ozone and ozone precursors transported into the HOTCOG area (60.8 ppb) to the 2017 design value is far larger than the contribution of ozone from local HOTCOG emissions sources (4.2 ppb). The largest contributions to the Waco Mazanec monitor design value from local HOTCOG area emissions are from on-road mobile sources such as cars and trucks (1.1 ppb) and power plants (1.0 ppb).

2.8.3 Local Contributions to Future Year Ozone Design Values

We calculated 2012 and 2017 modeled design values according to EPA guidance procedures for performing 8-hour ozone DV projections (Johnson et al., 2017). We used the CAMx ozone source apportionment model results to estimate relative contributions from each emissions source region and source category to ozone design values at CAMS 1037 to understand factors driving the design value.

We present ozone contribution design value results for CAMS 1037 in Table 2-3. The 2012 observed DV of 71.7 ppb – which slightly exceeds the current ozone NAAQS standard – was projected to be reduced to 65.0 ppb in 2017. The 2015-2017 design value at CAMS 1037 based on ozone measurements was 64 ppb (Figure 2-2). The good agreement between the model and observations for this value suggest that the ozone model is capturing the general downward trend in ozone at the Waco monitor. Because the 2017 ozone model uses an identical configuration as the 2012 model except for model boundary conditions on the 36 km grid and emissions, these two model inputs must be responsible for the ozone decreases represented by the 2017 design value.

Table 2-3. 2012 observed DV, 2017 modeled DV and contributions to 2017 ozone DV from HOTCOG emissions sources at CAMS 1037.

			HOTCOG Local Emissions Contribution to 2017 DV					
Site name	**2012 Observed DV**	**2017 Projected DVF**	**Natural**	**EGU**	**On-road**	**Oil+Gas**	**Other**	**Total**
Waco Mazanec	71.7	65.0	0.8	1.0	1.1	0.3	1.0	4.2

Previous HOTCOG ozone modeling has shown that ozone at CAMS 1037 is influenced more strongly by transport than by local 6-county area emissions sources (Kemball-Cook et al., 2015; Johnson et al., 2017; Parker et al., 2017). This study also supports this finding – HOTCOG emissions account for only 4.2 ppb of the 65 ppb design value. Therefore, we conclude that the amount of transported ozone has been reduced and is likely responsible for much of the decrease in ozone design value at CAMS 1037. We also note that HOTCOG total NOx emissions in 2017 are reduced about 16% from 2012, so the local contribution to ozone is also reduced.

The total contribution from HOTCOG emissions sources to the modeled 2017 ozone DV at CAMS 1037 is 4.2 ppb. Table 2-3 shows that natural, EGU, on-road and the other (non-road/off-road mobile, other area, low level point sources, elevated shipping and other non-EGU) emissions source categories each contribute from 0.8 to 1.1 ppb. O&G emissions from the HOTCOG region contribute only 0.3 ppb to the Waco Mazanec monitor's 2017 design value.

Figure 2-18 shows spatial maps for the modeled 2017 ozone DV (top left) and contributions to the 2017 DV from HOTCOG emissions source categories. HOTCOG EGU contributions are shown in the top right panel, followed by natural sources (middle left), oil and gas (middle right), on-road mobile (bottom left) and other sources (bottom right).

We note that the modeled total ozone 2017 DV map shows that no part of the 6-county region has a design value above the current ozone NAAQS (red grid cells in top left panel of Figure 2-18 shows areas with design values exceeding 70 ppb). The EGU contribution map is shown in the top right panel of Figure 2-18. The map shows the signature of the Limestone Electric Generating Station operated by NRG Energy, a coal-fired power plant near the border of Limestone and Freestone Counties. The EGU impacts on ozone DV are around 5-6 ppb in the immediate vicinity of the power plant. A secondary peak of around 4 ppb is collocated with the Big Brown Steam Electric facility in Freestone County. Note that this facility is no longer operating. Finally, on the border of McLennan and Falls Counties, the Sandy Creek EGU results in about a 2 ppb contribution to 2017 ozone DV in the immediate vicinity of the facility. The EGU contribution from all sources in the HOTCOG region at CAMS 1037 is 1.0 ppb (Table 2-3).

In the middle left panel of Figure 2-18, the HOTCOG natural contribution to 2017 ozone DVs shows areas exceeding 1 ppb to the west of the Waco city center in McLennan County and portions of Falls County, likely associated with biogenic soil NOx emissions. Near the Waco monitor, we see natural contributions slightly less than 1 ppb. The HOTCOG oil and gas contribution (middle right panel of Figure 2-18) shows a 2-3 ppb contribution in Limestone County near the border of Freestone County. The O&G contribution at the Waco monitor is less than 0.5 ppb.

In the bottom left panel of Figure 2-18, the on-road mobile contribution shows a peak (~2.5 ppb) co-located with the Waco city center and a substantial region in McLennan County exceeds 2 ppb. The contribution at CAMS 1037 is around 1 ppb. Finally, the bottom right panel of Figure 2-18 shows the Other emissions category with a maximum (2.6 ppb) that occurs just southwest of Waco city center. Areas exceeding 2 ppb are located mostly in McLennan and Bosque Counties. The Other contribution at CAMS 1037 is around 1 ppb.

Figure 2-19 shows 2017 ozone DV impacts from oil and gas contributions from the three major shale regions in Texas/Louisiana (Eagle Ford, Haynesville and Barnett). We note that all of these shale regions lie outside the HOTCOG area. Oil and gas production from the Haynesville Shale (0.4 ppb; ENE of Waco) and Eagle Ford Shale (0.6 ppb; SW of Waco) result in about a 1.0 ppb contribution at CAMS 1037. Most of the HOTCOG region shows contributions from oil and gas emissions above 1 ppb and small parts of Limestone and Falls Counties are above 2 ppb. An area of 3 ppb impacts is seen in Robertson County, near the Limestone County border. This region lies near the northernmost extent of the Eagle Ford Shale. Figure 2-19 indicates that the HOTCOG area is outside the area of largest ozone impacts from shale gas development in East Texas.

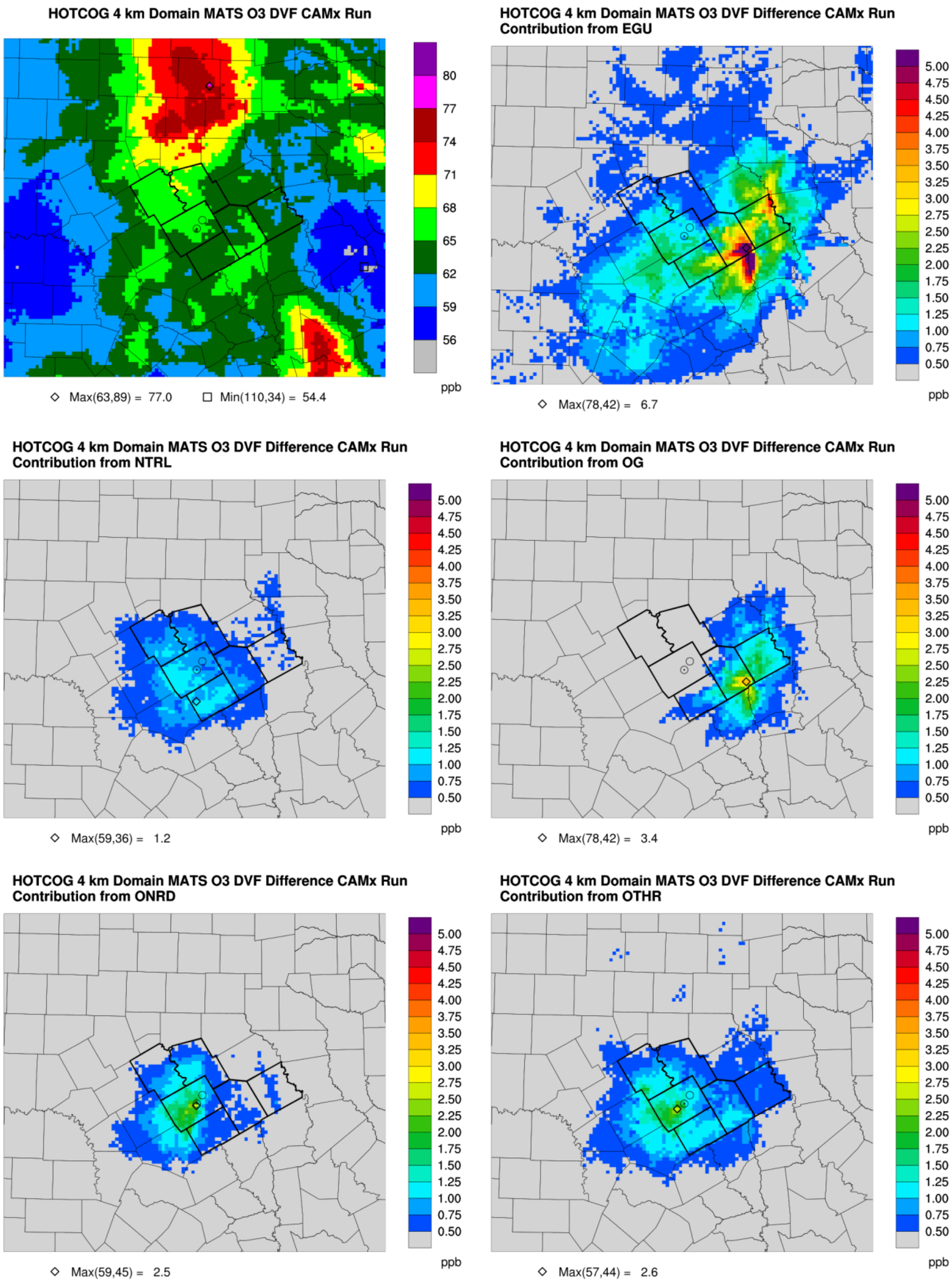


Figure 2-18. 2017 ozone DVF (top left) and HOTCOG contributions to 2017 ozone DVF from EGUs (top right), natural sources (middle left), oil and gas emissions (middle right), on-road mobile (bottom left) and other emissions (bottom right).

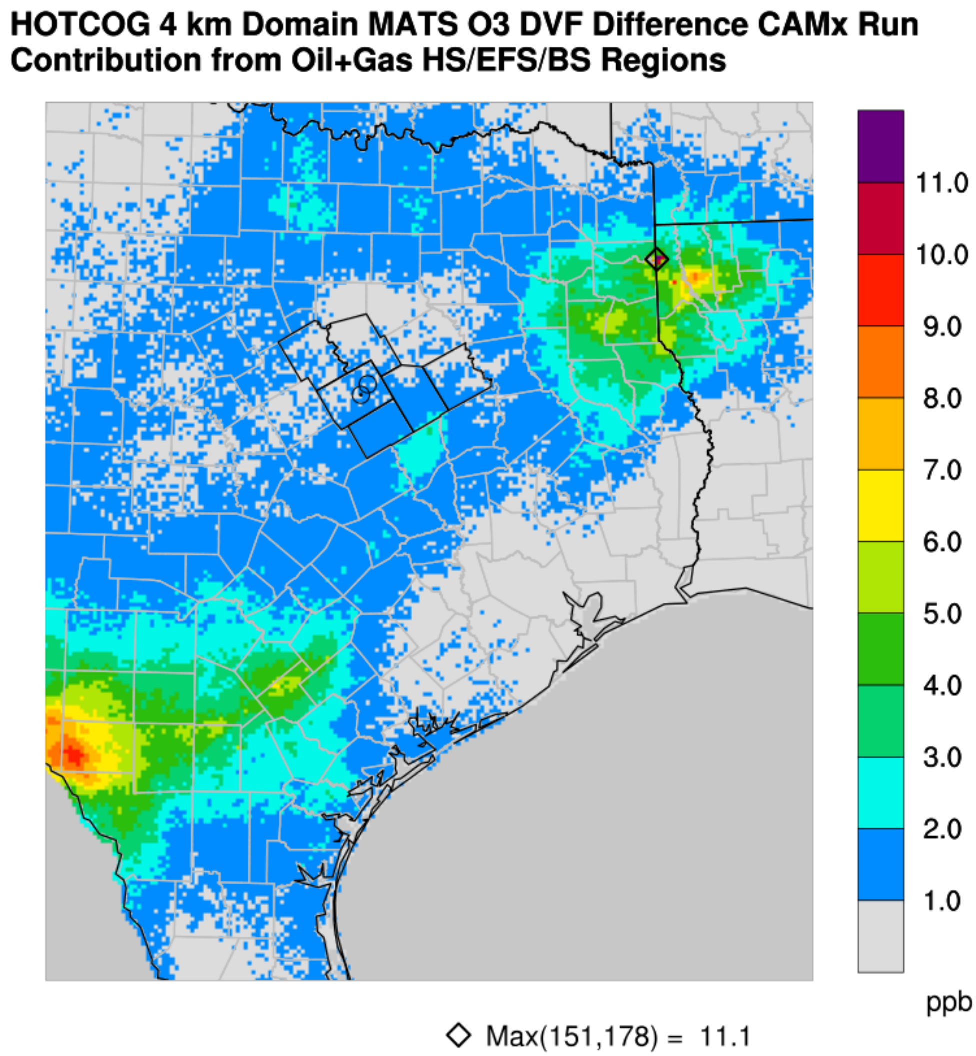


Figure 2-19. Oil and gas contributions from the three major shale regions.

2.8.4 Source Apportionment Results for CAMS 1037

In order to develop emission control strategies for the HOTCOG area that will reduce the local contribution to ozone, it is necessary to understand how ozone formation in the area depends on the amount of available NOx and VOC. Previous studies have shown that because of an abundance of biogenic VOC emissions in the area, ozone forms under NOx-limited conditions almost exclusively (Parker et al., 2017; Kemball-Cook et al., 2015). Figure 2-20 shows NOx-limited (blue) and VOC-limited (red) contributions to episode average (top) and maximum (bottom) MDA8 ozone at CAMS 1037 for the May-September 2017 modeling period. Consistent with previous HOTCOG modeling efforts (Parker et al., 2017; Kemball-Cook et al., 2015) and with the emission inventory analysis reported in Section 2.3 of this document, we note that the vast majority of contributions to ozone occur under NOx-limited conditions. Therefore, we expect that NOx emission controls on local sources will be far more effective than VOC emissions controls at reducing local production of ozone at CAMS 1037.

Figure 2-20 also gives a sense of the relative contributions of each source category. The episode average contributions to MDA8 ozone (top panel of Figure 2-20) for Natural, EGU, On-road mobile and Other categories are all between 0.8 and 1.0 ppb. The contribution from oil and gas emissions is much smaller (0.2 ppb). The episode maximum contributions to MDA8 ozone (bottom panel of Figure 2-20) show a similar relationship – contributions from the four categories other than oil and gas are similar (3.5 to 4.4 ppb), though the contribution from oil and gas is relatively larger (2.2 ppb).

We note that the location of CAMS 1037 was not frequently downwind of EGU sources in Limestone and Freestone counties on high ozone days during the May-September 2012 ozone season (weather data from 2012 was used in this modeling). Our analysis showed four monitors outside of the HOTCOG region (Kaufman, Corsicana Airport, Killeen Skylark and Tyler Airport) with higher episode maximum contributions (from 4.3 to 5.2 ppb) from HOTCOG EGU emissions than found at CAMS 1037 (3.7 ppb). However, analysis of ambient data on the four highest days ozone days at CAMS 1037 in each year from 2017-2019 showed no evidence of impacts from coal-fired power plants (i.e. SO_2 generally less than 1 ppb and no SO_2 peaks coincident with ozone peaks) on these days (Kemball-Cook et al., 2019). This finding is consistent with the CAMx results.

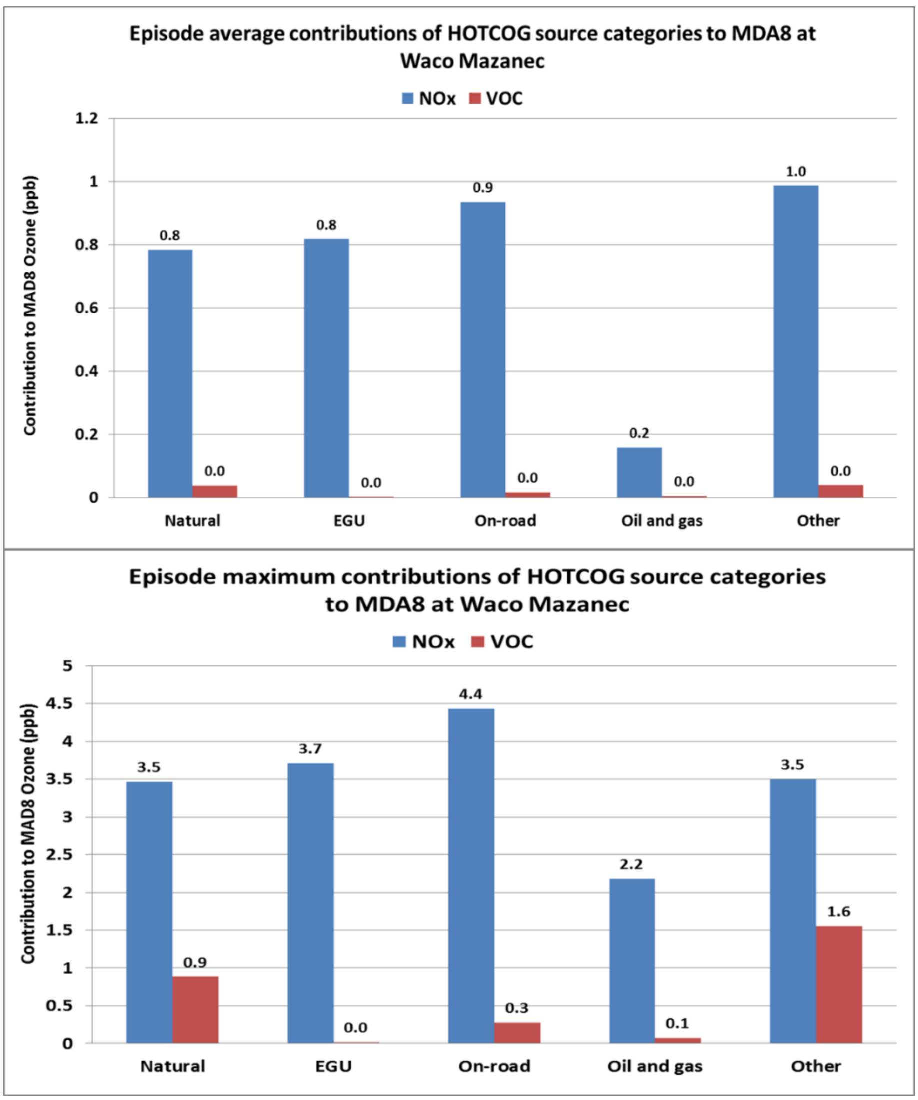


Figure 2-20. Comparison of the NOx vs. VOC-limited contributions to episode average (top) and maximum (bottom) MDA8 ozone at CAMS 1037 during the May-September 2017 period.

The main results of the CAMx modeling of 2017 were:

- HOTCOG area emissions of ozone precursors (NOx and VOC) decreased between 2012 and 2017.
- HOTCOG area ozone design values were projected to decrease between 2012 and 2017.
- For CAMS 1037, the contribution of ozone transported into the HOTCOG area (61 ppb) to the 2017 design value is far larger than the contribution of ozone from local HOTCOG emissions sources (4 ppb).
- The largest contributions to CAMS 1037 design value from local HOTCOG area emissions are from on-road mobile sources such as cars and trucks (1.1 ppb) and power plants (1.0 ppb).
- The contribution from HOTCOG area O&G sources to the 2017 CAMS 1037 ozone design value is 0.3 ppb.
- The combined contribution from Eagle Ford, Haynesville and Barnett Shale O&G sources to the 2017 Waco Mazanec monitor ozone design value is 1.0 ppb
- The 2017 modeling showed ozone formation in the HOTCOG area is limited by the amount of available NOx. This finding is consistent with previous HOTCOG studies.
- HOTCOG area emission reduction efforts should continue to focus on NOx reductions rather than VOC reductions.

3.0 STAKEHOLDER INVOLVEMENT

3.1 HOTCOG Air Quality Advisory Committee

In January 2010, the HOTCOG Air Quality Advisory Committee (AQAC) was formed in response to the Waco area's inclusion in the Texas Rider 8 Program for Near Nonattainment Areas and the potential for EPA to promulgate a new, more stringent ozone NAAQS which could have led to the HOTCOG area's designation as a nonattainment area. Although a more stringent NAAQS was not adopted at that time, and the area has continued to attain the NAAQS, the AQAC has worked vigorously to study local ozone air quality and to develop voluntary programs that improve air quality while protecting the vitality of the regional economy. The AQAC meets monthly and has carried out a variety of activities which are described in Section 4. The AQAC includes representatives from local government, industry, the TCEQ, and private citizens. Organizational support is provided by HOTCOG. The members of the AQAC are listed in Table 3-1.

Table 3-1. HOTCOG AQAC membership.

Falen Bohannon – Heart of Texas Council of Governments Environmental Planner
Jeremy Halland - Luminant
Chris Evilia - Waco Metropolitan Planning Organization (MPO)
Ted Guth – Bosque County
Jay Elliott – County Judge, Falls County
Dick Van Dyke – Heart of Texas Economic Development District
Frank Patterson - Waco/McLennan County Emergency Management Coordinator
David Litke – Freestone County
Daryl Sparks – Limestone County
David Duncan - Luminant
Kris Collins - Waco Chamber Economic Development
John Hendrickson - Waco Transit System
Matt Groveton – Limestone County
Rebecca Sheesley, Baylor University
Allen Hunter – McLennan County
Randy Riggs - Private Citizen
Ed Kabobel - TxDOT – Waco District
Henry Witt – McLennan County
Kris Collins – McLennan County
Trey Buzbee - Brazos River Authority
Wiley Stem - Waco City Manager

4.0 DESCRIPTION OF MEASURES AND PROGRAMS

In this section, we describe programs and measures aimed at improving ozone air quality in the 6-county HOTCOG area. These programs and measures were implemented by the HOTCOG AQAC and are either currently in place or are planned for the near future (i.e. 2020-2021).

4.1 Participation in TCEQ Near Nonattainment Area Air Quality Planning Programs

From 2010-2017, the HOTCOG area has participated in the TCEQ's Rider 7/8 Air Quality Planning Program. The program is named after the Texas Legislature Rider under which funding was allocated. The name of the program was changed to from Rider 8 to Rider 7 in 2015 following the 2015 session of the Texas Legislature and renewal of the air quality program under a different Rider. The Rider 7/8 Program was designed to help Texas Near Nonattainment Areas (NNAs) maintain compliance with the ozone NAAQS. This program allowed the NNAs to receive funding for their air quality planning efforts and to leverage the TCEQ's ongoing emission inventory development and meteorological and photochemical modeling.

The TCEQ established the following goals for the Texas NNAs under the Rider 7/8 Program[15]:

- Develop a conceptual understanding of local ozone formation processes;
- Evaluate local emissions inventories developed by the TCEQ (identifying possible areas of improvement);
- Analyze local ambient air quality monitoring
- Identify local emissions controls for future in-depth study
- Assess potential local monitoring networks and recommend enhancements or special studies;
- emissions inventory improvements;
- Implement local emission control strategies;
- Use a photochemical modeling episode developed by the TCEQ to analyze ozone sources and conduct sensitivity tests
- Improve public understanding of the ozone problem and motivate the public to voluntarily reduce its contribution to ozone pollution; and
- Involve local stakeholders in local air quality planning so that these efforts have broad support within local communities.

Rider 7/8 Program activities aligned well with HOTCOG's participation in Ozone Advance.

In 2018, the State of Texas discontinued funding for the Rider 7/8 Program under which HOTCOG's air quality planning program was supported. This resulted in a lapse in the area's activity in the Ozone Advance Program. However, the HOTCOG area, recognizing the importance on ongoing air quality planning activities, allocated local funding for ongoing air quality planning work. The HOTCOG area's conceptual model for ozone was revised and this 2019 Update of the HOTCOG Ozone Action Plan was developed to support the Waco area's continued participation in the Ozone Advance Program.

In 2019, the State of Texas approved funding for NNA air quality planning during the 2020-2021 biennium and the HOTCOG area intends to participate in this program.

4.2 Emissions Reduction Measure: Rapid Transport Corridor Feasibility Study

The Waco Transit Systems (WTS) and the Waco Metropolitan Planning Organization (MPO) conducted a study to determine the feasibility of developing rapid transit corridor and bus service enhancements, to support the proposed Bus Rapid Transit (BRT) service in the City of Waco (Figure 4-1). By offering

[15] http://www.tceq.texas.gov/airquality/airmod/rider8/rider8-background

residents improved trip times, efficiency and access to transit, the proposed Rapid Transit Corridor (RTC) hopes to improve ridership and shift more trips from automobiles to buses, thereby reducing vehicle miles travelled and on-road NOx emissions.

The RTC feasibility study was evaluated by determining the main transit corridors used, developing potential solutions, and determining the alternative that best suits the local community. Proposed alternatives were evaluated based on metrics including infrastructure, technology, and service needs; effects on riders, stakeholders, and transportation provides; and capital and operating costs. Alternatives that were considered were defined to meet requirements for the Federal Transit Administration (FTA) Capital Improvement Grant (CIG) Program.

Three potential alignment alternatives were identified with rigorous involvement from the public. The FTA Simplified Trips-on-Project Software (STOPS) was used to evaluate the alignment options and potential ridership, and the recommended alternative was identified. FTA STOPS showed approximately a 65% increase in total system ridership by 2023 under the recommended alternative. If local buses were re-routed into a more efficient system by incorporating the RTC, total system ridership is expected to approximately double by 2023.

Figure 4-1. A Bus Rapid Transit system will be implemented in the City of Waco.

Schedule for Implementation: Design and engineering for the project will occur during 2020 and a route alignment study will occur later in 2020 and 2021 to modify bus routes for the optimized system.

Responsible Party: The BRT has been accepted into the FTA CIG program. Waco Transit will design and engineer for the project and will perform the route alignment study in collaboration with the MPO.

4.3 Emissions Reduction Measure: Active Transportation Plan

The Waco MPO implemented the Waco Metropolitan Area Active Transportation Plan (ATP) to assist in the development of a comprehensive, regional, multi-modal transportation system in McLennan

County. Active transportation refers to human-powered modes of transportation such as walking and biking. The plan aims to improve and expand the active transportation network, prioritize active transportation in regional transportation planning, increase the safety and convenience of active transportation, improve active transportation connections to public transit, and increase the quality of life in McLennan County by reducing emissions and encouraging physical activity.

The Waco MPO conducted public outreach to understand community needs with regards to active transportation, and summarized existing active transportation infrastructure, transit services and crash data for bicycle- and pedestrian-involved accidents. 200 recommended bicycle and pedestrian projects were proposed throughout McLennan County. Proposed bicycle pathways include separated bikeways (off- or on-street), buffered bikeways and shared bikeways, as shown in Figure 4-2. In addition to these infrastructure improvements, the Waco MPO recommended education and outreach programs focused on National Bike Month and National Pedestrian Events, as well as recommended policies and best management practices for an active transportation network.

Progress towards the objectives of the ATP will be evaluated by the Waco MPO. This will include tracking the construction of active transportation infrastructure and measuring indicators including bicycle and pedestrian counts, sidewalk and bikeway inventory, crash data for bicycle- and pedestrian-involved accidents, non-motorized access to destinations, and percent completion of regional- and local-priority projects.

Regional implementation efforts of the ATP have begun. The Waco MPO has assisted several cities in applications to the Texas Department of Transportation's (TxDOT) Safe Routes to Schools and Transportation Alternatives Programs. Successful applications to these grant opportunities will be announced in late 2019.

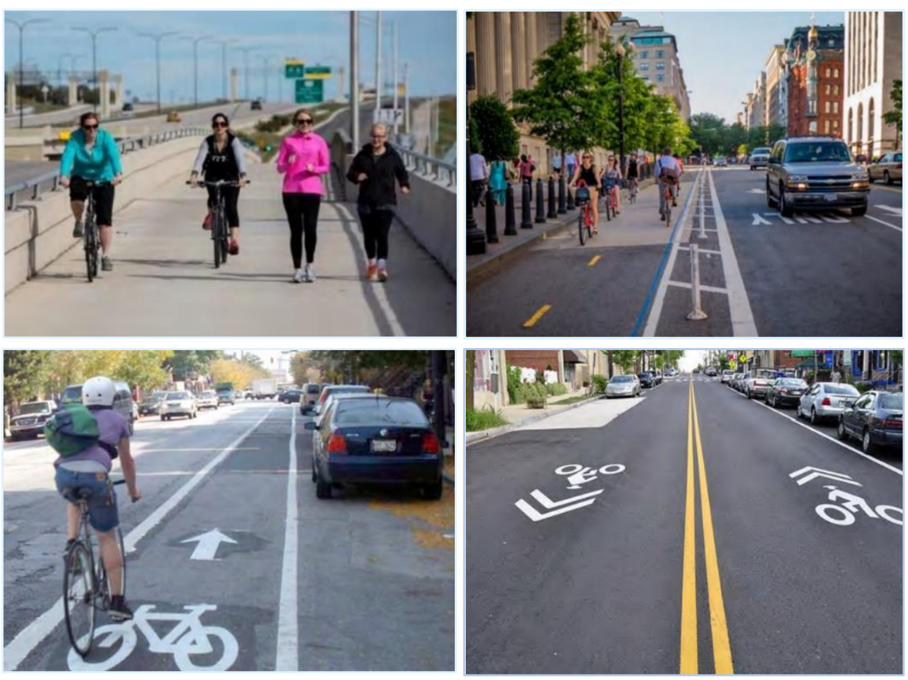


Figure 4-2. Proposed bikeways include off-street separated bikeways, on-street separated bikeways, buffered bikeways and shared bikeways.

Schedule for Implementation: The ATP was adopted in July 2019, and development will occur over the next 25 years.

Responsible Party: The Waco MPO coordinates transportation planning in the region, but the owners/operators of various transportation networks are responsible for the design, construction and implementation of transportation projects (e.g. TxDOT, McLennan County, Waco Transit or local municipalities). The Waco MPO will evaluate progress towards the ATP objectives.

4.4 Emissions Reduction Measure: Free Downtown Shuttle Services

The City of Waco has implemented two free shuttle services in the downtown area, to reduce car trips, traffic congestion and idling in downtown Waco, thereby reducing on-road mobile source emissions. The Silo District Trolley runs a 10-minute loop around downtown Waco, designed to make it easy to access the most popular areas for shopping, dining and other attractions. The LaSalle-Circle shuttle covers downtown Waco and extends to La Salle Avenue, allowing residents and tourists easy access to antique and décor shops, and restaurants on the circle. Both services run a FLAG-STOP route, meaning you can catch and alight from the bus at any safe location along the route by flagging the driver.

Schedule for Implementation: The Silo District Trolley began running in July 2016, and the LaSalle-Circle shuttle began running in March 2018.

Responsible Party: The shuttle services are run by the Waco Transit System.

4.5 Emissions Reduction Measure: City of Waco Shared Mobility System

The City of Waco issued a Request for Proposal (RFP) for a Pilot Shared Mobility System, to offer residents a visitors a convenient and affordable way to bike around the city. The system will include two types of shared mobility devices, to appeal to a wide variety of users in the city. At least one of these devices will be bikes (pedal bikes or e-bikes), and the second could be e-scooters, adaptive/accessible bikes, or some other mobility device. The aim of this program is to increase bicycle travel within the city, to improve bicycle culture and to make Waco a more attractive city for residents and visitors.

The system will run for 12 months with the potential to renew for an additional year. The RFP outlines requirements for vendors regarding the shared mobility fleet design (e.g. safety requirements for bikes and scooters), cost and affordability of the system, customer support for users, education and marketing, and data sharing and reporting. In May, the City of Waco approved Gotcha Bikes LLC for a one-year pilot program, to provide 50 e-bikes and 50 e-scooters to the downtown Waco area.

Schedule for Implementation: Pilot program anticipated to launch in late 2019.

Responsible Party: The City of Waco issued an RFP for a Pilot Shared Mobility System and signed a contract with Gotcha Bikes LLC to provide this service.

4.6 Emissions Reduction Measure: Waco Cycling Map

Waco City staff, MPO board and Waco Bicycle Club (WBC) Bicycle Advocacy Committee worked together to develop a cycling map of the City downtown and surrounding area. The cycling map promotes bicycling trips by identifying preferred routes around Waco. The map also identifies important destinations such as schools, libraries, parks, grocery stores and lodging. The map was developed to allow commuters to travel around Waco more safely by bike, and to encourage bikes as an alternative to automobiles.

Schedule for Implementation: The map was developed and published in April of 2019.

Responsible Party: The map was published by the Waco Bicycle Club.

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