Benzene from Petroleum Refineries is an Underreported Threat to Public Health

Executive Summary

Air pollution from oil refineries is a widespread and longstanding problem that causes disproportionate impacts on low-income communities and communities of color in the United States. One pollutant in particular – benzene – receives attention because it is known to cause leukemia and a variety of noncancer illnesses at relatively low concentrations. Although the U.S. Environmental Protection Agency (U.S. EPA) estimates benzene exposure using various modeling tools, the U.S. EPA tools routinely underestimate actual exposure. This is one problem that we explore below. Given the weaknesses in U.S. EPA's modeling tools, the exercise described here was designed to better approximate benzene exposure near refineries by using monitoring data from refinery fencelines.

The Environmental Integrity Project's Center for Applied Environmental Science worked with Dr. Andrew Gray and Dr. Ranajit Sahu, two experts in the area of air pollution modeling and controls, to analyze benzene emissions from three oil refineries in Texas and New Mexico. As part of this exercise, we also looked at benzene concentrations measured in a series of monitors around each facility's fenceline. We then asked two questions. First, do the benzene emissions reported by each facility line up with what is being measured at the fenceline? Second, how much benzene are people being exposed to in their homes, schools, and parks?

To answer the first question, Dr. Gray and Dr. Sahu modeled the emissions and dispersion of benzene from flares, storage tanks, and other sources at each facility to estimate annual average benzene levels at each facility fenceline. If the emissions inventories are accurate, then <u>estimated</u> fenceline concentrations should roughly correspond to <u>measured</u> fenceline concentrations. One complicating factor is the presence of other sources of benzene in the area – there will be some amount of "background" benzene at the fenceline even in the absence of the refinery. We corrected for that background to get closer to a direct comparison of modeled and measured benzene concentrations at facility fencelines.

Dr. Gray and Dr. Sahu also attempted to estimate annual benzene concentrations at locations within nearby communities, based only on benzene releases reported to the emissions inventory from each refinery. Based on their review of benzene fenceline concentrations, the study concluded that annual benzene levels at these downwind locations would likely be much higher than suggested based on the emission inventory reports from all three refineries. We also looked at shorter-term "spikes" in fenceline benzene levels, which were attributed to specific onsite sources of benzene. Dr. Gray was able to estimate the rate of emissions from these discrete sources, and then model the short-term exposures in neighboring communities.

Our analysis reveals that:

- The three refineries appear to be underestimating and/or underreporting their benzene emissions by roughly seven-fold (Houston Refining), 28-fold (Pasadena Refinery), and 27-fold (Navajo Refinery). This is based on an analysis that accounts for background benzene levels.
- U.S. EPA models like the Air Toxics Screening Assessment (AirToxScreen) and Risk Screening Environmental Indicators (RSEI) underestimate local exposure and risk, in part because they rely on benzene emissions as reported by industry to state and federal agencies.
- Based on reported emissions, estimated chronic benzene exposures in neighboring communities are likely to exceed the levels that are thought to cause unacceptable leukemia risks. However, because these emissions are underreported, the actual exposures may be much higher. After adjusting for underreported emissions, it is likely that some locations in the neighborhoods near the refineries experience chronic exposures that exceed health guidelines designed to protect against both cancer and non-cancer health effects.
- Perhaps most troubling are the short-term exposures that frequently exceed one-hour health guidelines. A roughly two-month release from the Navajo Refinery in New Mexico was comparable in magnitude to a 2010 release from a refinery in Texas that caused a range of toxic effects in local children including unsteady gait, memory loss, headaches, altered blood cell counts, and signs of liver toxicity.[1] In line with that historical example, Dr. Gray's modeling suggests that exposures in the community during the Artesia release would have repeatedly exceeded California's one-hour health guideline by an order of magnitude or more.

In sum, benzene monitoring data from refinery fencelines demonstrate that (a) benzene emissions are being underreported, (b) benzene releases are likely to be causing unsafe exposure, both chronic and acute, in neighboring communities, and (c) U.S. EPA's modeling tools – which rely on emissions data provided by refinery owners – underestimate actual exposure and risk by a significant margin. In order to adequately protect public health, U.S. EPA should require improvements in emissions reporting and/or assume a margin of safety in modeling tools that rely on (underreported) industry emission estimates.

[1] M.A. D'Andrea and G.K. Reddy, Health effects of benzene exposure among children following a flaring incident at the British Petroleum Refinery in Texas City, 31 Pediatr. Hematol. Oncol. 1 (Feb. 2014), cited by California Office of Environmental Health Hazard Assessment, Technical Supporting Document for Noncancer RELs at Appendix D, 155 (Updated July 2014), available at https://oehha.ca.gov/media/downloads/crnr/appendixd1final.pdf.

Contents

List of Tables

List of Figures

Benzene from Petroleum Refineries is an Underreported Threat to Public Health

A. Introduction and Background

Petroleum refineries can release significant amounts of benzene and other hydrocarbons when turning crude oil into gasoline and other fuels or chemicals. These pollutants can be released from flares and other combustion devices, or as vapor from leaking production units, storage tanks, or wastewater treatment units. Emissions from these different sources can be unpredictable and difficult to measure. To better monitor this pollution and protect local residents from emissions, the Environmental Integrity Project (EIP) and Earthjustice filed a lawsuit in 2012 on behalf of seven community and environmental groups against the U.S. Environmental Protection Agency (U.S. EPA) to set limits on hazardous air pollution from petroleum refineries. Responding to these concerns, in 2015 the Agency developed a rule requiring refineries to monitor benzene levels along the perimeters of their facilities, and to investigate and take corrective action when fenceline concentrations are high.[2]

Benzene is a well-known carcinogen that can cause leukemia and other noncancer health effects. In addition, benzene serves as an indicator, with high concentrations indicating the presence of other air pollutants dangerous to human health. Although benzene is the focus of U.S. EPA's fenceline regulation, the monitoring network is intended to use benzene as a surrogate pollutant to track and limit overall fugitive emissions of hazardous air pollutants.

To evaluate and communicate risks associated with exposure to benzene and other toxics, state and federal agencies assess exposure and risk using local monitors as well as computer models that estimate the dispersion of air pollutants and the resulting concentrations in the areas around the emissions source. Computer models are a useful tool because they can provide estimates of potential exposure in areas where no monitoring data are available. However, their accuracy is limited by available data and the assumptions used to describe physical conditions in the real world.

Most importantly, U.S. EPA models are critically limited by the accuracy of industry-reported emissions. The analyses described in this report provide insights into the accuracy of emissions reported by the refineries and into the actual impacts of these refineries on benzene concentrations in the surrounding communities. The analysis models dispersion of reported benzene emissions from three refineries – LyondellBasell's Houston Refining in Houston, Texas; Chevron's nearby Pasadena Refinery located in Houston and the adjacent city of Pasadena; and HollyFrontier's Navajo Refinery in Artesia, New Mexico – and compares the results to existing measurements and estimates of benzene concentrations.

[2] 40 CFR §63.658.

1. Benzene toxicity

Benzene is known to cause leukemia after prolonged exposure, and it also causes a range of non-cancer health effects after shorter exposures, including bone marrow damage, depressed immune function, and neurotoxicity. Studies in mice show that exposure *in utero* can result in long-term reductions in blood cell production after birth.

The effects of short-term benzene releases are not simply theoretical. In 2010, a flaring event at a refinery in Texas City released roughly 8.5 tons of benzene (along with large quantities of other chemicals) over a period of 40 days. This release was associated with a range of toxic effects in local children including unsteady gait, memory loss, headaches, altered blood cell counts, and signs of liver toxicity.[3]

To protect against non-cancer health effects, the California Environmental Protection Agency recommends that exposures to benzene stay below Reference Exposure Levels, or RELs, which are defined as "the concentration level at or below which no adverse non-cancer health effects are anticipated for the specified exposure duration."[4] For short-term, hourly exposures, benzene concentrations should be below 27 micrograms per cubic meter (µg/m^3). For long-term exposure (nine years or more), benzene concentrations should stay below 3 µg/m^3. With respect to cancer, the U.S. EPA estimated in 2000 that exposure to 0.13 to 0.45 µg/m^3 over a lifetime would result in one excess cancer per million people. More recently, in 2011 California derived its own cancer potency estimates. According to the California EPA, exposure to 0.03 µg/m^3 can cause a risk of one in one million. These and other related health guidelines are presented in **Table 1** below.

[3] M.A. D'Andrea and G.K. Reddy, Health effects of benzene exposure among children following a flaring incident at the British Petroleum Refinery in Texas City, 31 Pediatr. Hematol. Oncol. 1 (Feb. 2014), cited by California Office of Environmental Health Hazard Assessment, Technical Supporting Document for Noncancer RELs at Appendix D, 155 (Updated July 2014), available at https://oehha.ca.gov/media/downloads/crnr/appendixd1final.pdf.

[4] California Office of Environmental Health Hazard Assessment, Air Toxics Hot Spots Program, Risk Assessment Guidelines, Guidance Manual for Preparation of Health Risk Assessments at 1-6 (Feb. 2015).

Table 1: Health-based Thresholds for Benzene Exposure

Agency	Threshold type	Time period	Last Updated	Target organ/effects	Critical effect	Threshold (µg/m³)
			Noncancer			
ATSDR	Acute MRL[5]	1-14 days	2007		Depressed peripheral lymphocytes	29[6]
California EPA	Acute REL	1 hour[7]	2014	Developmental; Immune System; Hematologic	Decreased early nucleated red cell counts	27
ATSDR	Intermediate MRL	14-364 days	2007		Immunodepression	20[8]
U.S EPA	Reference Concentration[9]	Lifetime	2003	Immune	Decreased lymphocyte count	30
ATSDR	Chronic MRL	1 year or more	2007		Decreased lymphocyte count	10[10]
California EPA	Chronic REL[11]	9 years or more[12]	2014	Hematologic	Decreased peripheral blood cell counts	3
			Cancer			
U.S. EPA	1 in 1,000,000 cancer risk	Lifetime	2000		Leukemia	0.13 – 0.45
California EPA	1 in 1,000,000 cancer risk	Lifetime	2011		Leukemia	0.03

[5] See generally, ATSDR, Minimal Risk Levels for Hazardous Substances, available at https://www.atsdr.cdc.gov/mrls/index.html.
[6] 9 ppb x 3.26 = 29.3 µg/m³. ATSDR, Toxicological Profile for Benzene at 241 and A-3.
[7] Strictly speaking, California's acute RELs are designed "to protect against a 1-hour exposure duration occurring infrequently (e.g., no more than once every two weeks)." California EPA, Technical Support Document for the Derivation of Noncancer Reference Exposure Levels at 2 (June 2008).
[8] 6 ppb x 3.26 = 19.6 µg/m³. ATSDR, Toxicological Profile for Benzene at 241 and A-5.
[9] U.S. EPA, Integrated Risk Information System – Benzene, available at https://iris.epa.gov/ChemicalLanding/&substance_nmbr=276.
[10] 3 ppb x 3.26 = 9.8 µg/m³. ATSDR, Toxicological Profile for Benzene at 241 and A-8.
[11] The California EPA also has an 8-hour REL, which is designed to protect against repeated 8-hour exposures over several years (i.e., workplace exposures). In the case of benzene, the 8-hour REL was simply set to the same level, and on the same basis, as the chronic REL. California EPA, Benzene Reference Exposure Levels, Technical Support Document for the Derivation of Noncancer Reference Exposure Levels, Appendix D1, at 48 (June 2014).
[12] California EPA, Technical Support Document for the Derivation of Noncancer Reference Exposure Levels at 2 (June 2008).

The California EPA's acute REL was derived from studies of developmental exposures. Specifically, California looked at a study of pregnant mice exposed to benzene for 10 days, which found that the offspring (who had been exposed in the womb) had reduced blood cell counts for at least seven weeks after birth, which for mice means into adulthood.[13] Although the mice were exposed for longer than one hour, the California EPA support document notes that:

> developmental toxicity may occur in response to just one exposure during a specific window of susceptibility. A literature search found 133 single-day exposure developmental toxicity studies involving 58 chemicals (Davis et al., 2009). The same endpoints observed in repeat dose studies are often observed with single exposures, an acute effect. The acute REL derived above is a level not to be exceeded in any one-hour period.[14]

California's acute REL is therefore designed to protect against early childhood health risks after very short (one hour) exposures of pregnant women to benzene.

2. Data used to evaluate model results

This report evaluates benzene concentrations using dispersion models in the communities surrounding three refineries. One model, which includes the area around Houston Refining and the Pasadena Refinery, evaluates benzene concentration in communities along the Houston Ship Channel and near those refineries. The other evaluates benzene concentrations in Artesia, New Mexico, where Navajo Refinery is located. Additional data, as available, were used to evaluate the model results. These include measured benzene concentrations, both at the refinery fencelines and at local monitors in the communities. The modeled concentrations are also compared to separate models developed by the U.S. EPA to characterize risks associated with air pollutants.

a. Measured benzene data sources for comparison

The dispersion of an air pollutant such as benzene can be highly variable and dependent on complex wind and weather patterns and local topography. Measurements of benzene concentrations at specific points can help to characterize the likely concentrations in nearby areas.

Fenceline measurements are one reference point for evaluating simulations of benzene dispersion. These monitors, close to the emissions sources, are likely to measure concentrations that are primarily the result of emissions at the refinery rather than other sources that are further away.

[13] California Office of Environmental Health Hazard Assessment, TSD for Noncancer RELs, Appendix D1, pages 139-216 (rev. July 2014); K.A. Keller and C.A. Snyder, Mice exposed in utero to 20 ppm benzene exhibit altered numbers of recognizable hematopoietic cells up to seven weeks after exposure. Fundam Appl Toxicol 10(2): 224-32 (1988).

[14] California Office of Environmental Health Hazard Assessment, TSD for Noncancer RELs, Appendix D1, pages 182-183 (rev. July 2014)

In highly industrialized, urban areas such as Houston, there are sometimes air monitors at sites in local communities that track ambient concentrations of various pollutants, including benzene. Local monitors are less common in rural areas where pollutant levels are expected to be lower. These monitors provide an additional reference point for assessing the validity of modeled concentrations. However, the concentrations measured by these monitors are the result of many sources of benzene and it is difficult to attribute these concentrations to a single source, particularly in areas where there are multiple industrial facilities emitting large quantities of pollutants.

b. Existing models

The U.S. EPA estimates exposure to air pollution, including refinery pollution, using models such as the Air Toxics Screening Assessment (AirToxScreen) and the Risk Screening Environmental Indicators model (RSEI). These models, particularly AirToxScreen, are useful in providing a rough estimate of the cumulative cancer risk associated with air pollution, which includes exposure to benzene and many other air pollutants not only from refineries, but also from other point and mobile sources.

The accuracy of the model results is limited by their inputs and modeling assumptions. Some significant limitations that affect the estimates of benzene concentrations and the associated hazards are:

- Emissions from point sources that are one input to the model are as reported by the facility owners. If emissions are underestimated, then exposure and risk are also underestimated.
- The model assumes that the total annual emissions from a facility are uniformly emitted throughout the year. While all reported emissions are included in the model, short-term variability – including short-term spikes in exposure that might cause short-term health impacts – are not captured.

1. AirToxScreen

AirToxScreen is the most recent iteration of a national assessment produced using emissions data from U.S. EPA's National Emissions Inventory (NEI), which includes point, non-point, mobile, and other sources. For point sources such as refineries, the inventory relies on emissions data reported by the facilities. If owners underreport their emissions, then EPA will end up underestimating exposure and risk.

Each iteration includes an update to the methods based on currently available tools and data sources. The AirToxScreen assessment evaluated below is for emissions in 2017. Six prior EPA models were known as National Air Toxics Assessments (NATA).

AirToxScreen and the prior NATA studies report results that include estimated ambient concentrations, "exposure concentrations" that account for the likely activities of the local population according to age groups, and cancer and non-cancer risk estimates for each pollutant. Results are reported at the census tract level, aggregating estimates of point concentrations at the centroids of census blocks.

AirToxScreen uses a modeling tool known as AERMOD, which stands for the American Meteorological Society/Environmental Protection Agency Regulatory Model. AERMOD is a dispersion model for estimating local-scale impacts from industrial sources of pollution. This is the same modeling tool that Dr. Gray used to model emissions and exposure at the three refineries described here. AirToxScreen also uses the Community Multiscale Air Quality (CMAQ) modeling tool, which simulates the secondary formation of hazardous air pollutants in the atmosphere. Benzene is included in the CMAQ model and the reported benzene concentrations in AirToxScreen are a hybrid of the results generated from the two modeling platforms.[15]

Other data used in the assessment include physical data to characterize emission sources, meteorological data describing weather patterns, and toxicity data used to ascribe health risks to pollutant concentrations. The health risk estimates rely primarily on assessments from U.S. EPA's Integrated Risk Information System (IRIS), with assessments from other sources such as the Agency for Toxic Substances and Disease Registry (ATSDR) where there are gaps.

2. RSEI

The Risk Screening Environmental Indicators (RSEI) model estimates impacts from point source emissions that are reported to U.S. EPA's Toxics Release Inventory (TRI). Like AirToxScreen, RSEI uses AERMOD to model the dispersion of pollution. Emissions from each facility are modeled independently, and the modeled ambient concentrations are mapped to a grid of cells approximately one-half mile in size. As with AirToxScreen, RSEI relies on emissions data as reported by the facilities. If the emissions are underreported, then the modeled concentrations and the associated hazards will be underreported. Several simplifying assumptions are used in the RSEI model such as flat terrain and placement of each facility within a single grid cell, but site-specific parameters such as stack heights are used where available. Unlike AirToxScreen, RSEI is produced annually.

3. U.S. EPA Analysis to Support 2015 Fenceline Rule

As part of the technical analysis to support the development of the 2015 rule, U.S. EPA modeled expected benzene concentrations around each of the 148 refineries operating in the U.S. at the time. These models estimated that the maximum annual average offsite concentrations found near a single facility would be 9 $\mu g/m^3$ and that only four facilities would cause concentrations of 4 $\mu g/m^3$ or greater. These offsite concentrations were typically "at or just adjacent to the facilities fenceline[s]."[16] Maximum offsite concentrations across all facilities averaged 0.8 $\mu g/m^3$ [17] These estimates were developed using reported emissions from each of the refineries and did not account for any other sources of benzene.

---

[15] U.S. EPA, Technical Support Document: EPA's Air Toxics Screening Assessment (2017 AirToxScreen TSD), March 2022

[16] U.S. EPA, Memorandum to Brenda Shine regarding "Fenceline Ambient Benzene Concentrations surrounding Petroleum Refineries" at 2 (Jan. 7, 2014). Docket ID Number EPA–HQ–OAR–2010–0682.

[17] *Id*.

However, as documented by EIP, the actual concentrations measured by the fenceline monitors are much higher than the concentrations estimated by EPA.[18] Where EPA's estimate that only one facility would cause a maximum offsite concentration as high as 9 $\mu g/m^3$, actual fenceline monitoring data showed ten refineries with net annual average concentrations greater than 9 $\mu g/m^3$ in 2019, and thirteen refineries exceeding this threshold in 2020.

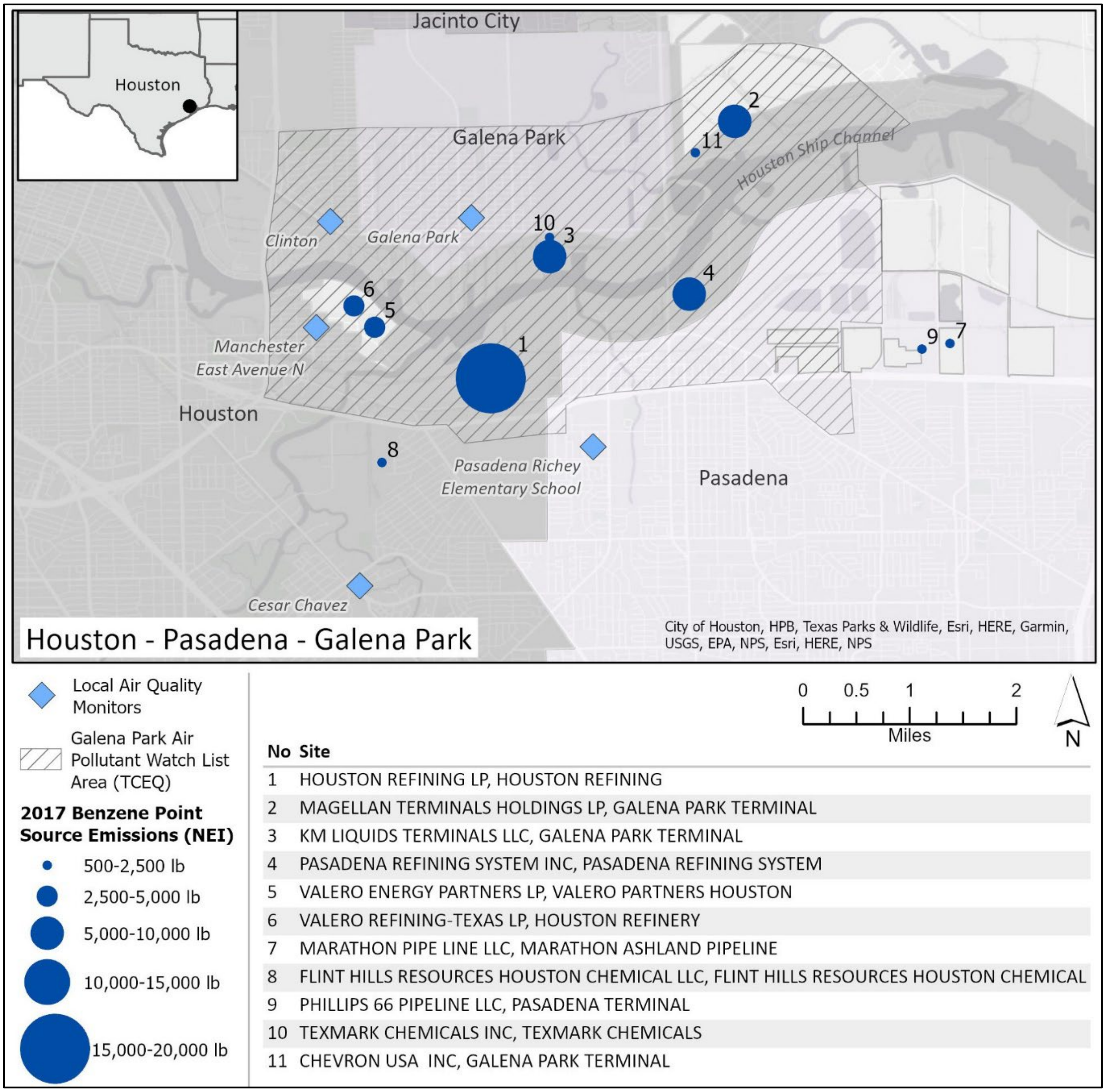
B. The refineries analyzed in this report

1. Houston Refining and Pasadena Refinery

The two Houston-area refineries in this report are along the Houston Ship Channel in the eastern part of Houston. Houston and its surrounding communities are densely populated with two million residents in Houston and nearly seven million people living in the metropolitan area. The refineries are part of this dense urban area and are surrounded by residential communities in Houston and the adjacent cities of Galena Park and Pasadena. Over 1,500 people live within one mile of each facility. These communities are also disproportionately low-income and Latino: 25% and 54% of the households within one mile of Houston Refining and the Pasadena Refinery have annual incomes less than $25,000 (compared to 17% for the Houston-Woodlands-Sugarlands Metropolitan Statistical Area), and the residents living within one mile of Houston Refining and the Pasadena Refinery are 95% and 88% Latino, respectively (compared to 37% for Houston-Woodlands-Sugarlands Metropolitan Statistical Area).[19]

The refineries are also within an area previously designated by the Texas Commission on Environmental Quality (TCEQ) as an Air Pollutant Watch List (APWL) site for benzene emissions. TCEQ's Air Pollutant Watch List is a program to address areas with persistent, elevated concentrations of pollutants.[20] There are five air quality monitors within three miles of the two refineries that regularly record benzene concentrations (see **Figure 1**). The APWL area includes several other industrial facilities that report benzene emissions. In the 2017 NEI, Houston Refining reported 18,600 lbs of benzene emissions and the Pasadena Refinery reported 6,600 lbs of benzene emissions, 34% and 12%, respectively, of all NEI point source emissions within one mile of the APWL area in 2017.

[18] See https://environmentalintegrity.org/reports/monitoring-for-benzene-at-refinery-fencelines/ and https://environmentalintegrity.org/news/13-oil-refineries-in-u-s-released-cancer-causing-benzene-above-epa-action-levels-in-2020/
[19] American Community Survey 2015-2019 5-year estimates, accessed through EJScreen mapping tool (https://ejscreen.epa.gov/mapper/), July 22, 2022; American Community Survey 2015-2019 5-year estimates
[20] https://www.tceq.texas.gov/toxicology/apwl



No	Site
1	HOUSTON REFINING LP, HOUSTON REFINING
2	MAGELLAN TERMINALS HOLDINGS LP, GALENA PARK TERMINAL
3	KM LIQUIDS TERMINALS LLC, GALENA PARK TERMINAL
4	PASADENA REFINING SYSTEM INC, PASADENA REFINING SYSTEM
5	VALERO ENERGY PARTNERS LP, VALERO PARTNERS HOUSTON
6	VALERO REFINING-TEXAS LP, HOUSTON REFINERY
7	MARATHON PIPE LINE LLC, MARATHON ASHLAND PIPELINE
8	FLINT HILLS RESOURCES HOUSTON CHEMICAL LLC, FLINT HILLS RESOURCES HOUSTON CHEMICAL
9	PHILLIPS 66 PIPELINE LLC, PASADENA TERMINAL
10	TEXMARK CHEMICALS INC, TEXMARK CHEMICALS
11	CHEVRON USA INC, GALENA PARK TERMINAL

Figure 1: Houston study area

Wind speed and direction greatly influence the dispersion of air pollutants. A wind rose plot of local winds recorded at Houston Hobby Airport in 2019 is shown in **Figure 2**. The plot shows that winds primarily originated out of the south-southeast, as well as the southeast (particularly for lower-speed winds which tend to result in higher concentrations). As a result, residents to the north-northwest of the facilities would be more likely to experience impacts from air emissions, although, as shown in the plot, winds did occasionally originate from all directions, so all neighboring residents are potentially affected some of the time.

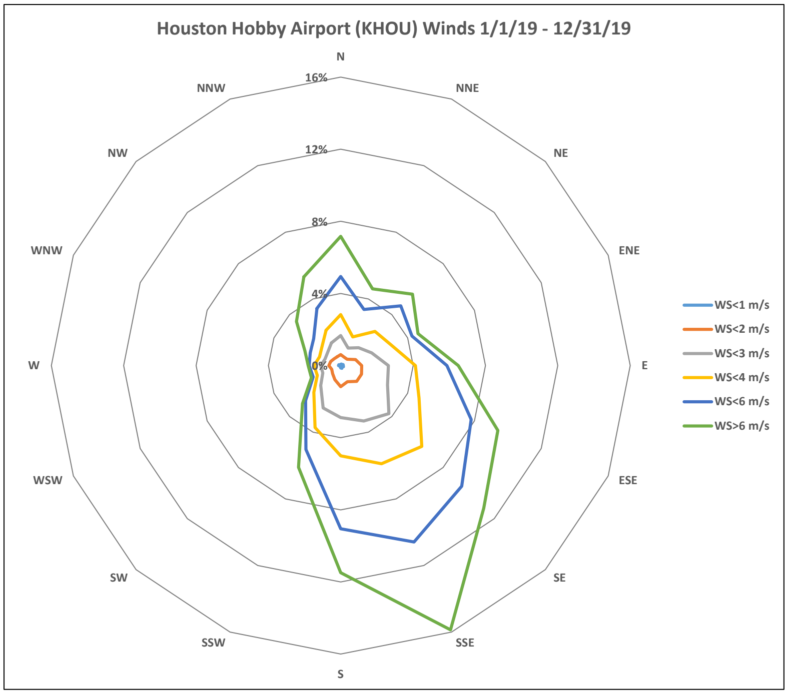


Figure 2: Houston wind rose (2019)

The figure shows the magnitude and direction of winds at Houston Hobby Airport in 2019. The directions in the plot indicate the direction the wind is coming from.

a. Local air monitor network

In the neighborhoods surrounding Houston Refining and the Pasadena Refinery, there are several air quality monitors maintained by TCEQ. The five monitors within three miles of the refineries, shown in **Figure 1** above, regularly sample and report benzene concentrations on a 1-hour basis or on a 24-hour basis, with both 1-hour and 24-hour sampling at one location (Galena Park). Annual average concentrations from 2017 to 2020 at each of these sites are shown in **Table 2**.

Table 2: Annual Average Benzene Concentrations at Air Quality monitors within three miles of Houston Refining and Pasadena Refinery[21]

Site	Sampler Type[22]	Distance to Refinery (mi)		Annual Average Benzene Concentration (µg/m3)			
		Houston Refining	Pasadena Refinery	2017	2018	2019	2020
Galena Park (482010057)	24hr/1hr	0.8	1.7	2.9/2.7	3.5/ 2.4	4.1/ 3.1	3.3/ 2.7
Manchester East Avenue N (482010307)	24hr	0.7	2.9	1.1	1.2	1	1.1
Pasadena Richey Elementary School (482011049)	24hr	0.4	1.3	0.8	2	1.2	1.4
Clinton (482011035)	1hr	1.6	2.8	0.9	0.9	1.1	1
Cesar Chavez (482016000)	1hr	1.6	3.5	0.8	0.7	0.9	0.7

As shown in **Table 2**, measured benzene concentrations tend to be higher at the Galena Park monitor located to the north of the refineries (and close to other nearby point sources of benzene), and the lowest measured concentrations were at the two monitors located over a mile from either refinery: Clinton (located northwest of the refineries, but close to other significant benzene emission sources) and Cesar Chavez (located to the southwest). The measured concentrations at the Galena Park monitor routinely approach or exceed the California EPA long-term REL of 3 µg/m^3, which means that the exposures in this area may be associated with risks of non-cancer health effects like reduced blood counts, and all of the monitors measured annual concentrations that would result a cancer risk in excess of one in one million.

b. Fenceline measurements

Another source of benzene concentration data is the fenceline monitor network at each refinery. The measurements are two-week averages measured over the course of the year (summarized as annual averages in **Tables 6 and 7** in Section D.2 below). The locations of the fenceline monitors around each refinery are shown in **Figure 3**. As shown in the tables and figure, there is wide variation in the annual average at each monitor, and higher concentrations tended to be along the northern edges of the facilities, corresponding with the prevailing wind direction. At one Pasadena Refinery monitor, VOC1, the annual average benzene concentration is significantly higher. There were elevated benzene

[21] Annual average concentrations are as reported by TCEQ via the Texas Air Monitoring Information System (TAMIS) website (https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=report.main)
[22] TCEQ uses two sampler types at its air monitoring stations, 24 hour samples collected with a Summa canister every six days and samples continuously by AutoGC at 1 hour intervals. As demonstrated in the annual average concentrations measured by the collocated samplers of each type at Galena Park, there is uncertainty in both measurement methods, due both the collection and analysis methods and gaps in measurement periods.

concentrations at this monitor over several weeks, resulting in an annual average benzene concentration that exceeded the U.S. EPA action level of 9 µg/m^3. The refinery conducted an incident report which identified a leak at a marine loading incinerator near the monitor as the likely source of the elevated benzene concentration.

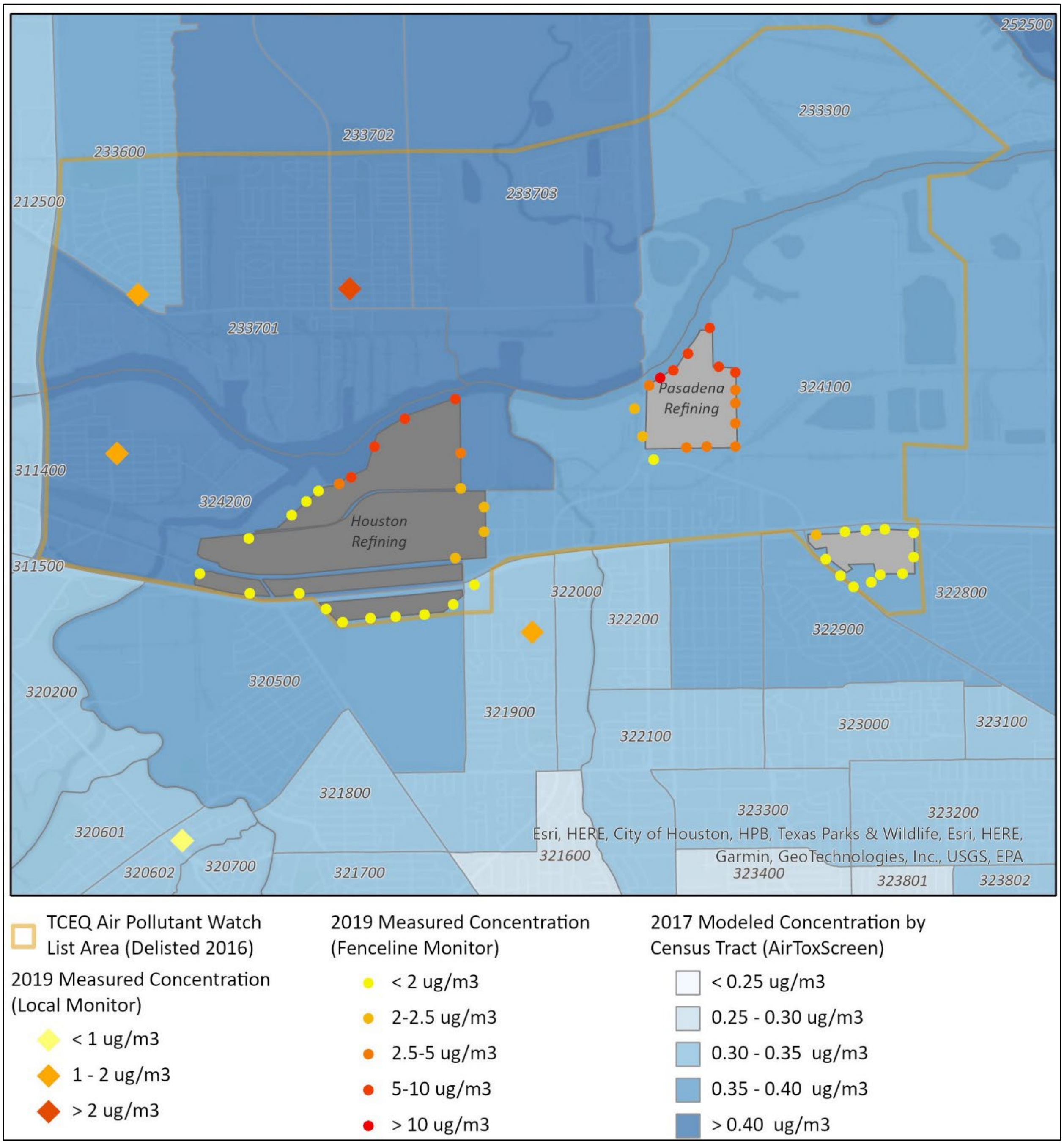


Figure 3: Measurements and estimates of benzene concentrations in communities around Houston Refining and Pasadena Refinery

c. EPA models

Ambient benzene concentrations estimated by the 2017 AirToxScreen for census tracts where local air monitors and the Houston and Pasadena refineries are located are summarized in **Table 3**. **Figure 4** shows the range of modeled concentrations in the census tracts within and adjacent to the APWL area previously identified by TCEQ as an area of concern for ambient benzene concentrations.

As shown in **Table 3**, the estimated ambient benzene concentrations are much higher in the census tracts near the refineries than in Harris County overall and the estimated concentrations from all point sources comprise a significant portion of the overall estimated benzene concentration, much higher than in the countywide estimates. And while there is some variation in the estimates generated in each assessment model, these trends generally hold true between the 2011, 2014, and 2017 iterations (data not shown).

Table 3: Ambient Benzene Concentrations estimated by USEPA Air Toxics Models (Houston)

Census Tract	Site in Census Tract	Modeled 2017 Annual Average (AirToxScreen)				
		Total Conc (μg/m³)	Point Sources (% of Total Concentration)	Mobile Sources	Non-Point Sources	Fire
000000	***Harris County***	*0.15*	*3%*	*37%*	*50%*	*10%*
233702	**Galena Park (482010057)**	0.43	54%	34%	8%	4%
324200	**Manchester East Avenue N (482010307)**	0.47	56%	32%	8%	4%
233600	**Clinton (482011035)**	0.35	41%	43%	10%	5%
320602	**Cesar Chavez (482016000)**	0.31	28%	52%	15%	5%
321900	**Pasadena Richey Elementary School (482011049)**	0.34	39%	44%	12%	5%
324200	**Houston Refining**	0.47	56%	32%	8%	4%
324100	**Pasadena Refinery (North)**	0.39	49%	38%	10%	4%
322800	**Pasadena Refinery (South)**	0.38	46%	40%	10%	4%

Although AirToxScreen is a screening tool, and EPA cautions against relying too heavily on census-tract level risk estimates, it is worth noting that the AirToxScreen estimates of ambient benzene concentrations are routinely much lower than the community monitoring data. As discussed in more detail in the discussion of the site-specific models, one likely explanation for the discrepancy is an underestimate of point source emissions in U.S. EPA's National Emissions Inventory (NEI).

AirToxScreen also includes a model-to-monitor comparison for certain community monitors to evaluate the accuracy of the model. This statistical comparison uses data from comparable monitors (monitors using the same measurement methods) across the country in the evaluation. While U.S. EPA does not make any adjustments to the model based on the comparison, the comparison provides information about how well the model predicts actual ambient concentrations: a model-to-monitor ratio of one would indicate good agreement between modeled and measured values; a ratio less than one indicates that the model underpredicted concentrations; and a ratio greater than one would show that the model overpredicted concentrations.[23]

For benzene, the comparison showed that the model tended to underpredict benzene concentrations. **Table 4**, below, shows measured and modeled 2017 benzene concentrations for three monitors located near Houston Refining and Pasadena Refinery, as well as two monitors – Channelview and Channelview Drive Water Tower – located to the east of the study area. Although these latter two monitors are unlikely to be influenced by the refineries in our study, we include them here to show how consistently AirToxScreen underestimates ambient benzene concentrations. In short, U.S. EPA's model-to-monitor comparison confirms what we see in **Tables 2 and 3** above – EPA's models are underestimating exposures in the community.

Table 4: AirToxScreen Modeled and Measured Benzene Concentrations

Site	Sampler Type	2017 Average Annual Benzene Concentration ($\mu g/m^3$)		Model-to-Monitor Ratio
		AirToxScreen Modeled[24]	Measured[25]	
Galena Park (482010057)	1 hr/ 24 hr	0.52	2.68/ 2.90	0.2
Clinton (482011035)	1 hr	0.41	0.92	0.4
Manchester East Avenue N (482010307)	24 hr	0.42	1.06	0.4
Channelview (482010026)	1 hr	0.48	1.24	0.4
Channelview Drive Water Tower (482010036)	24 hr	0.48	3.09	0.2

The U.S. EPA uses AirToxScreen to, among other things, "help target risk reduction activities" and "better understand risks from air toxics."[26] Those purposes are undermined if the NEI underestimates emissions and AirToxScreen underestimates exposure and risk. The Agency states that another purpose of AirToxScreen is to "improve data in emissions inventories." The data in this report demonstrate that the U.S. EPA does indeed have to improve the data in its emissions inventories, because they do not currently line up with observed ambient benzene concentrations. The U.S. EPA should use all of the data at its disposal – community monitors, fenceline monitors, fenceline monitoring root cause analyses, and models – to understand where the NEI is failing and then make improvements to the NEI.

In addition to the AirToxScreen estimates of ambient concentrations from all sources, U.S. EPA's RSEI model and the technical analysis to support the 2015 fenceline rule estimate concentrations around the facilities that result from the facility's emissions alone. In the RSEI model, with results mapped to a one-

[23] U.S. EPA, Technical Support Document EPA's Air Toxics Screening Assessment: 2017 AirToxScreen TSD (Section 3.7 and Appendix E, 2022

[24] U.S. EPA, Appendix E to 2017 AirToxScreen TSD: supporting data, 2022 (https://www.epa.gov/AirToxScreen/2017-airtoxscreen-technical-support-document)

[25] Annual average concentrations are as reported by TCEQ via the Texas Air Monitoring Information System (TAMIS) website (https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=report.main)

[26] U.S. EPA, AirToxScreen Overview (https://www.epa.gov/AirToxScreen/airtoxscreen-overview)

half mile grid, the highest estimated concentrations outside of the grid cells representing facility emissions were 1.0 μg/m^3 and 0.1 μg/m^3 for Houston Refining and the Pasadena Refinery, respectively. For the analysis to support the fenceline rule, the highest estimated concentrations were 0.1 μg/m^3 and 0.3 μg/m^3 at each of the facilities. As shown in **Figure 3** above and **Tables 6 and 7** below, these values are much lower than actual measured concentrations at the fencelines, even when adjusting to account for background benzene concentrations.

2. Navajo Refinery

In New Mexico, the HollyFrontier Navajo Refinery is the only local point source that reported benzene emissions to the Toxic Release Inventory in 2019. The refinery is in the city of Artesia, which has a population of approximately 12,000 and is located in the southeastern part of the state, approximately 40 miles from Carlsbad. More than 2,500 people live within one mile of the refinery. These residents are also disproportionately low-income and Latino: 50% of the households have an annual income less than $25,000 (compared to 28% overall in the city of Artesia) and 61% are Latino (compared to 53% overall in the city of Artesia).[27]

The refinery is located at the eastern edge of the city (see **Figure 4**) with residential areas including homes, schools, and parks within one mile to the west. In the unincorporated area to the east of the facility there are rural farm and ranchlands. There are no local air quality monitors in this community.

As noted above, wind speed and direction greatly influence the dispersion of air pollutants. A wind rose plot of local winds recorded at the Artesia Airport from 2016 to 2020 is shown in **Figure 5**. The plot shows that predominant winds, particularly lower speed winds which tend to result in higher concentrations, were out of north and northwest, with a significant portion of winds originating from the south. As a result, residents to the south and north would be more likely to experience impacts from air emissions, although, as shown in the plot, winds did occasionally originate from all directions, so all neighboring residents are potentially affected some of the time.

[27] American Community Survey 2015-2019 5-year estimates, accessed through EJScreen mapping tool (https://ejscreen.epa.gov/mapper/), July 22, 2022; American Community Survey 2015-2019 5-year estimates

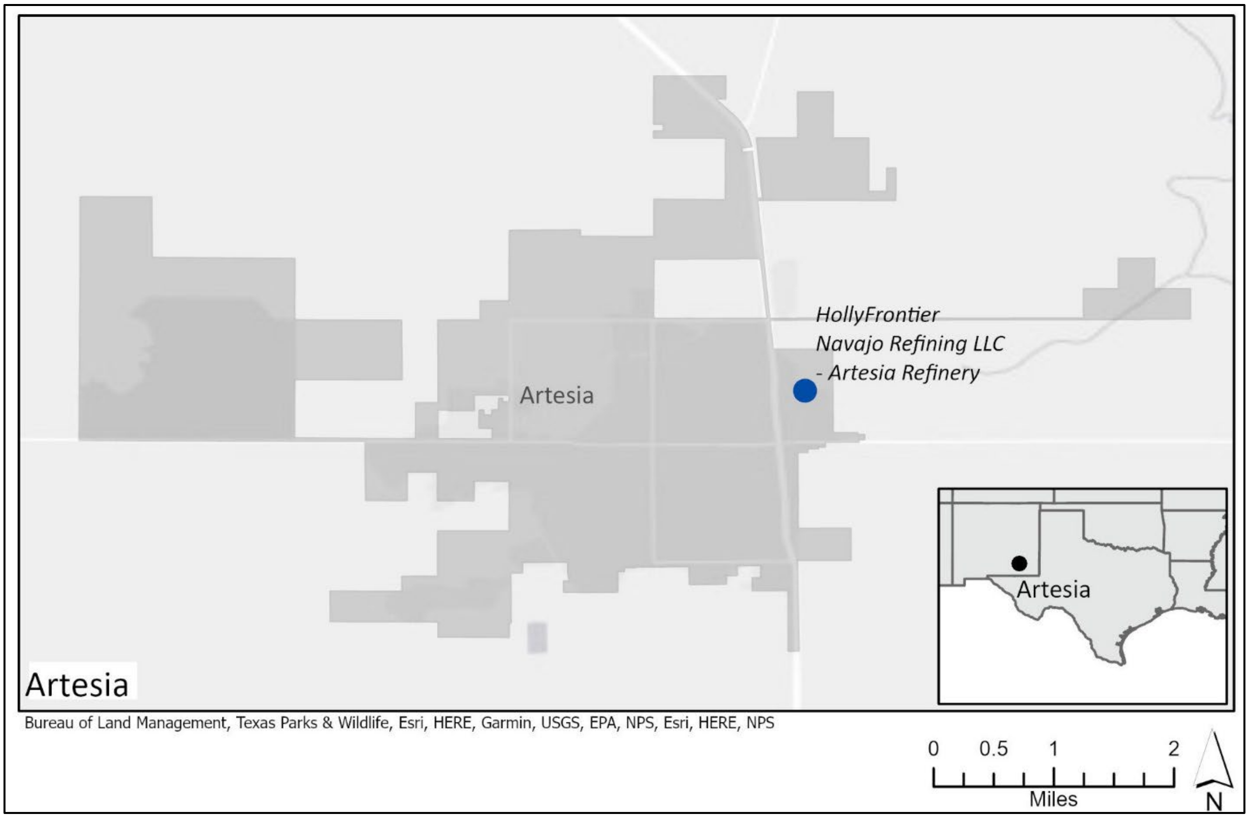


Figure 4: Navajo Refinery in Artesia, New Mexico

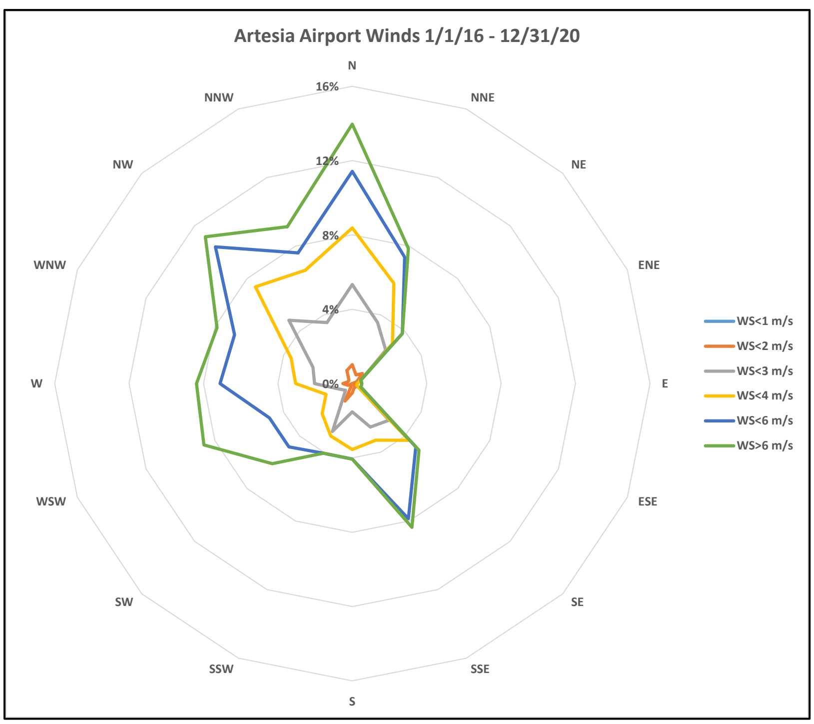


Figure 5: Artesia Wind Rose (2016-2020)

a. Fenceline measurements

The Navajo Refinery fenceline measurements are the only source of measured benzene concentrations in the area. The measurements are two-week averages measured over the course of the year, summarized as annual averages in **Table 10** below. The locations of the monitors around the refinery are shown in **Figure 6**. The concentrations shown in **Figure 6** are not adjusted to account for sources of benzene outside the refineries (though we did make these adjustments in our analysis, as described below). **Table 10** and **Figure 6** show wide variation in the annual average at each monitor. Monitors along the southeastern edge of the facility show relatively high benzene concentrations, corresponding with the prevailing wind direction. There are also particularly high concentrations at monitors 14 and 15, on the western side of the facility. As discussed in more detail below, the annual average at these monitors exceeded the U.S. EPA action level during a period from the end of March through late May. An investigation by the refinery identified a nearby tank as the likely emission source.

b. EPA models

Ambient benzene concentrations estimated by the 2017 AirToxScreen for the census tract where the Navajo Refinery is located are summarized in **Table 4**. **Figure 8** shows the range of modeled concentrations in the census tracts in and around Artesia.

As shown in **Table 5**, the estimated ambient benzene concentrations are much higher in the census tract containing the Navajo Refinery than in Eddy County overall. And, although more than half of the estimated benzene concentration in both Eddy County and in the tract containing the refinery is estimated to come from non-point and mobile sources, the calculated concentration from all point sources in the tract containing the Navajo Refinery comprise a significant portion of the overall estimated benzene concentration (18%), much higher than in the countywide estimates (1%).

Although fenceline concentrations are likely to be higher than average census tract exposures, it is worth noting that AirToxScreen estimates for this census tract (0.25 µg/m^3) are much lower than benzene concentrations measured around the Navajo Refinery fenceline (>5 µg/m^3 at several monitors).

As with the Houston Refining and the Pasadena Refinery, U.S. EPA's RSEI model and the technical analysis to support the 2015 fenceline rule estimate concentrations around the facility that are much lower than the measured fenceline concentrations. In the RSEI model, with results mapped to a one-half mile grid, the highest estimated concentrations outside of the grid cell representing facility emissions was 0.2 µg/m^3. For the analysis to support the fenceline rule, the highest estimated concentration was 2.0 µg/m^3. As shown in **Figure 6** and **Table 10** below, these values are much lower than actual measured concentrations at the fencelines, even when adjusting to account for background benzene concentrations.

Table 5: Ambient Benzene Concentrations estimated by USEPA Air Toxics Models (Artesia)

Census Tract	Site in Census Tract	Modeled 2017 Annual Average (AirToxScreen)				
		Total Conc	Point Sources	Mobile Sources	Non-Point Sources	Fire
		(µg/m³)	(% of Total Concentration)			
000000	***Eddy County***	*0.20*	*1%*	*4%*	*91%*	*4%*
001000	**HollyFrontier Navajo Refinery**	0.25	18%	14%	65%	3%

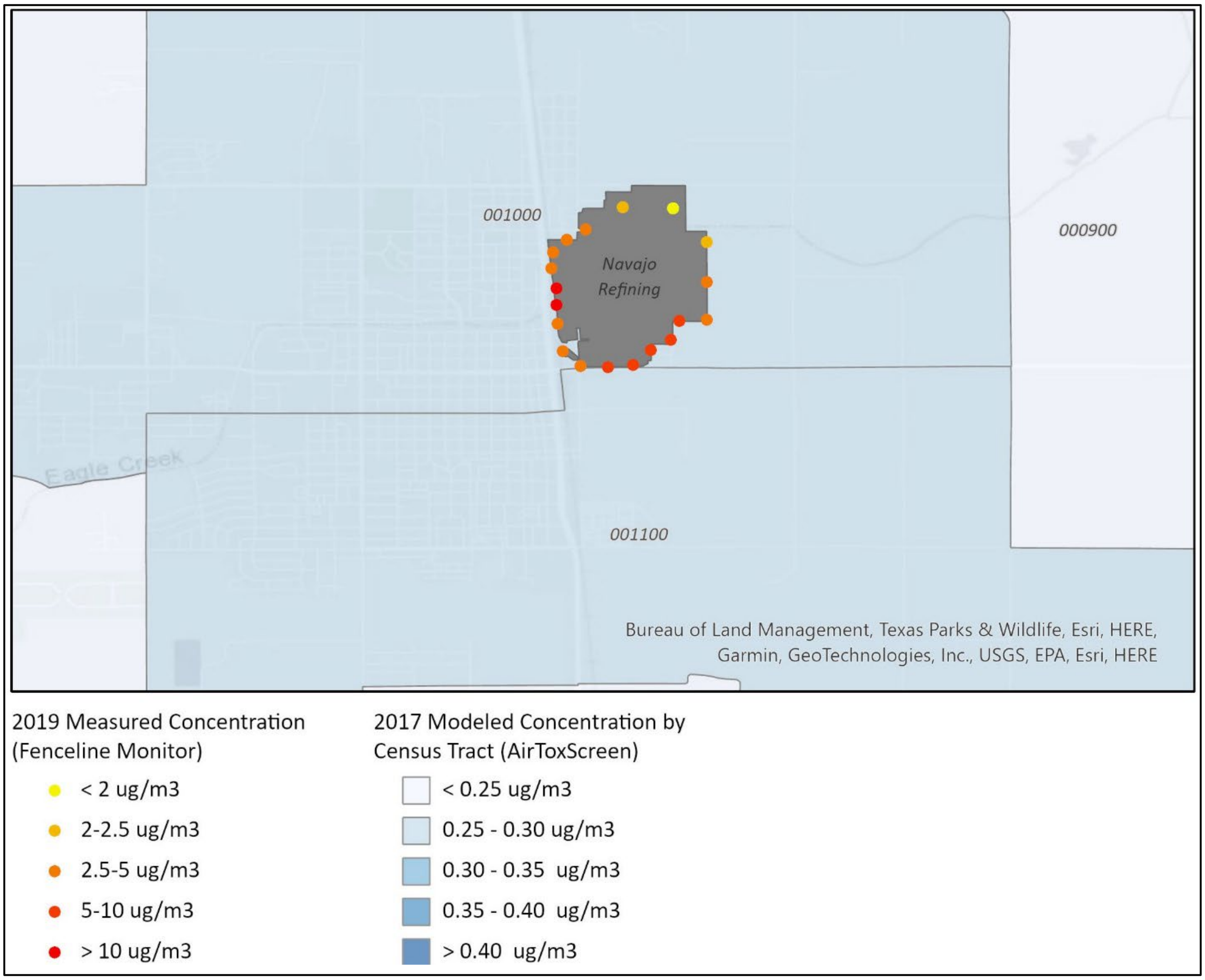


Figure 6: Measurements and estimates of benzene concentrations in communities around the Navajo Refinery

C. Site-specific model development methods

EIP worked with Dr. Gray and Dr. Sahu to simulate ambient benzene concentrations resulting from emissions from each refinery in 2019. Their methods and detailed results (including results for other pollutants) are attached to this report as **Appendices A and B**. We chose to focus on 2019 because it allowed us to obtain a variety of documents that may not be available for more recent years (such as emission inventories or root cause investigations into high fenceline concentrations), and because we knew that these refineries reported unusually high fenceline values in 2019, which provided us with an opportunity to model spikes in benzene emissions.

Emissions data came from the facility owners in reports to state agencies, as did important characteristics of each source (such as stack height, exit velocity, and exit temperature). The transport of benzene emissions was modeled for each facility using AERMOD. As described above, AERMOD is U.S. EPA's preferred dispersion model for estimating local-scale impacts from industrial sources, and U.S. EPA uses it in both AirToxScreen and RSEI. To simulate the dispersion of reported emissions from the refineries, the models use topographic and meteorological data along with site specific data on emission source locations and quantities.

1. Houston Refining and the Pasadena Refinery

The two Houston-area refineries were incorporated into a single model capable of estimating concentrations resulting from the dispersion of emissions from each refinery individually or the two sites together. Model outputs are generated across a series of points called receptors. For this model, a 20 km x 20 km square (about 77 mi^2) centered on the refineries was created. Receptors were spaced regularly across the grid with increased density in the central area closer to the refineries. In addition to these regularly spaced receptors, several schools, parks, and homes located near the refineries were added to each model as a set of community receptors where impacts from elevated benzene emissions would be of particular concern. See Appendix A (Figures 3 and 4). Outputs were generated as 1-hour averages.

Emissions data, including the quantity, location, source type, and source details such as height, temperature, and dimensions used information published by TCEQ for each refinery through the State of Texas Air Reporting System (STARS) system. Location data provided for fugitive sources was inconsistent with the site information and boundaries, so these sources were totaled and distributed uniformly across the facility. Terrain data came from U.S. Geological Survey (USGS) 1x1 degree digital elevation model tiles and the meteorological inputs used wind data collected at Houston Hobby Airport and upper air soundings collected at Lake Charles, Louisiana.

2. Navajo Refinery

The model for the Navajo Refinery in Artesia used similar methods. Results were mapped to a 20 km x 20 km square (about 77 mi^2) centered on the refinery. Receptors were spaced regularly across the grid with increased density in the central area closer to the refineries. In addition to these regularly spaced receptors, several schools, parks, and homes located near the refineries were added to each model as a set of community receptors.

Emissions data, including the quantity and source type, were provided by the New Mexico Environment Department's (NMED) Air Quality Bureau. Locations and stack data were not provided for the 21 benzene sources as part of the emissions data or in permit documentation. The largest portion of the emissions (65%) were attributed to the cooling tower, so the location of this source was identified and it was added as a point source in the model, but for all other sources where locations were not available, the emissions were totaled and distributed uniformly across the facility. Terrain data came from USGS 1x1 degree digital elevation model tiles and the meteorological inputs used wind data collected at Artesia Municipal Airport and upper air soundings collected at Midland, Texas.

D. Annual Emissions

1. Methods

a. Emissions estimates

The emissions data were reported by the facilities as annual totals (tons per year), so the models had to assume a uniform rate of release over the course of the year, masking short-term variability in emissions and underestimating the impacts of large, discrete emission events. With the detailed wind and atmospheric data, however, the models incorporate meteorological variability and estimate the impacts of changes in wind speed and direction. This is similar to the method used in AirToxScreen for calculating annual average concentrations.

b. Accounting for background in comparisons to measured data

The estimated fenceline monitor estimates generated by Dr. Gray are derived from reported refinery emissions and do not account for other, offsite sources of benzene. In order to compare modeled and measured benzene concentrations, we subtracted our best estimate of background benzene levels from the fenceline monitoring results to estimate net benzene concentrations attributable to each refinery.

The EPA fenceline monitoring rule generally operates on the principle that the lowest measured benzene concentration in any two-week period reflects background.[28] A similar approach to adjusting the data for all monitors would be to calculate the "net" benzene (in excess of background) for each monitor in a two-week period by subtracting the lowest benzene concentration found in that period from each monitor's result.

[28] See 40 CFR §63.658(f).

In some cases, the rule allows owners to make more nuanced adjustments that account for wind direction and upwind sources of benzene in Site-Specific Monitoring Plans (SSMPs).[29] Houston Refining and the Pasadena Refinery have SSMPs that identify certain monitors that are sometimes downwind of potentially significant offsite benzene sources. To account for upwind sources, the facilities installed supplemental monitors that measure benzene concentrations as well as wind speed and direction. Each SSMP provides for the use of the supplemental data to calculate corrected concentrations in certain circumstances (when the wind speed and direction are within a range that suggests that upwind sources may be the primary source of benzene concentrations at the monitor). Although the Pasadena Refinery did not provide any corrected measurements in 2019, Houston Refining frequently used measurements adjusted according to their SSMP for four monitors on the northern edge of the site.

For this analysis, we calculated the net benzene concentration for each monitor and for each two-week period by adapting the method prescribed by U.S. EPA to account for background concentrations in the fenceline monitoring rule. We adjusted for background by either (a) using the adjusted concentrations reported by the refinery owner pursuant to its SSMP, or (b) subtracting the lowest fenceline value for each period from each monitor's recorded concentration. For each monitor, an annual average net concentration was calculated by averaging the net concentrations for the 26 two-week periods in 2019.[30]

2. Results

a. Houston Refining and Pasadena Refinery

1. Comparing measured and modeled concentrations at the fenceline

Tables 6 and 7 show that benzene levels measured at the fenceline were much higher than the site-specific emissions model suggests that they should have been, even after adjusting for background. At Houston Refining, adjusted fenceline measurements were about 7 times higher than the model estimates (**Table 6**). At the Pasadena Refinery, adjusted fenceline values were 20 to 30 times higher than model estimates (**Table 7**).

These results strongly suggest that the refinery's emissions inventories were incomplete or otherwise underestimating benzene emissions. If the refineries were really emitting the amounts of benzene that they reported, then the measured fenceline values would have been seven times lower at Houston Refining and 28 times lower at the Pasadena Refinery.

[29] Id. at §63.658(c)(2).
[30] To be more precise, we calculated the annual average as the average of 365 daily concentrations. This was because the monitoring periods did not line up perfectly with the calendar year, and some monitoring periods began in 2018 or ended in 2020, meaning that some periods were only overlapping with a few days in 2019. We therefore calculated the average of 365 daily concentrations, with each daily average equal to the average of the two-week period within which it was located.

Table 6: Houston Refining Measured and Modeled Fenceline Concentrations

Sampler Name	Annual Average Benzene Concentration (µg/m³)			Ratio of adjusted measurement to model estimate
	Measured	Adjusted for background	Modeled	
1	6.05	2.10	0.18	11.6
2	8.66	3.69	0.56	6.6
3	7.56	3.35	0.25	13.4
4	2.72	1.66	0.07	23.8
5	2.35	1.33	0.08	16.4
6	2.34	1.31	0.05	25.7
7	2.17	1.15	0.05	23.0
8	2.06	1.06	0.08	13.1
9	1.45	0.47	0.24	2.0
10	1.38	0.40	0.23	1.7
11	1.22	0.26	0.24	1.1
12	1.29	0.32	0.25	1.3
13	1.37	0.40	0.23	1.8
14	1.12	0.16	0.18	0.9
15	1.28	0.32	0.20	1.6
16	1.33	0.36	0.20	1.8
17	1.21	0.25	0.13	1.8
18	1.27	0.29	0.11	2.6
19	1.29	0.32	0.19	1.7
20	1.68	0.70	0.41	1.7
21	1.55	0.57	0.50	1.1
22	1.74	0.76	0.65	1.2
23	2.82	1.79	0.24	7.5
24	6.42	3.33	0.27	12.2
Average of all monitors	2.60	1.10	0.23	**7.4**

Table 7: Pasadena Refinery Measured and Modeled Fenceline Concentrations

Sampler Name	Annual Average Benzene Concentration (µg/m^3)			Ratio of adjusted measurement to model estimate
	Measured	Adjusted for background	Modeled	
North Unit				
R2	3.68	2.35	0.16	14.71
R3	6.15	4.82	0.31	15.56
R4	5.94	4.66	0.12	38.81
R5	5.03	3.70	0.08	46.29
R6	4.68	3.36	0.06	55.92
R7	3.76	2.43	0.05	48.67
R8	2.51	1.18	0.04	29.57
R9	3.14	1.81	0.04	45.25
R10	2.77	1.45	0.04	36.15
R11	1.83	0.50	0.03	16.64
WP1	2.37	1.04	0.07	14.89
WP12	2.09	0.76	0.04	18.95
VOC1	28.96	27.63	1.66	16.65
VOC2	6.16	4.83	0.47	10.27
VOC3	6.51	5.18	0.16	32.37
VOC4	4.77	3.44	0.07	49.14
Average of North Unit Monitors	5.65	4.32	0.21	**30.6**
South Unit				
RB14	2.26	0.95	0.02	47.49
RB15	1.59	0.28	0.02	13.86
RB16	1.71	0.40	0.02	20.04
RB17	1.85	0.52	0.02	26.15
RB18	1.71	0.39	0.01	38.66
RB19	1.55	0.22	0.01	22.33
RB20	1.52	0.20	0.01	19.78
RB21	1.45	0.12	0.01	12.27
RB22	1.41	0.09	0.01	8.54
RB23	1.55	0.22	0.01	21.83
RB24	1.56	0.23	0.01	22.86
RB25	1.62	0.30	0.01	29.53
Average of South Unit Monitors	1.65	0.33	0.01	**23.6**
Average of all monitors	3.99	2.67	0.13	**27.6**

2. Benzene exposure in the community

The emissions inventory produced by each refinery provides total annual benzene emissions, from which it is possible to model annual average benzene exposure resulting from the reported emissions in the communities adjacent to each refinery. To estimate benzene exposure in neighboring communities, Dr. Gray ran a model simulation that included emissions from both refineries, generating benzene concentration estimates that would result from the combined emissions of the refineries at the network of community receptors that include residences, parks, and schools. See Appendix A, Figures 3 and 4. In general, the estimated annual exposures were less than 0.2 µg/m^3 at the community sites. See Appendix A at Table 18. While this is less than California's reference exposure level (REL) for noncancer health effects (3 µg/m^3), it overlaps with the range of concentrations that U.S. EPA associates with a cancer risk of one in one million (0.13-0.45 µg/m^3).

However, if emissions were underreported, then Dr. Gray's estimates of community exposures are also underestimates. The fenceline monitor analysis described above provides a rough sense of how much the community exposures might be underestimated. Looking at the two fenceline monitor networks (Houston Refining and the Pasadena Refinery) as a group, estimates based on reported emissions tended to underpredict fenceline values by about 18-fold. If community exposures were underestimated by a similar margin, then many community receptor locations may be experiencing a cancer risk in excess of one in one million, and some locations may exceed the California REL for noncancer health effects. For example, the emissions estimate model predicts that two locations in the Houston area would experience annual average concentrations of 0.21 µg/m^3 (Appendix A, Table 18). Increasing this by 18 times yields a concentration of 3.7 µg/m^3, exceeding California's chronic REL of 3 µg/m^3. Although this is only a rough back-of-the-envelope calculation and the actual margin between estimated and actual exposure may be different at different locations in the community, it shows that actual emissions may be contributing to significant exposures and risks.

It is also important to remember that the site-specific models only account for emissions from two of several point sources, and do not account for non-point or mobile sources of benzene in the area. Thus, the actual benzene concentrations and associated health risks experienced by people in the community would be much greater than the exposure and risk attributable to the two refineries.

3. Comparing sources

Each of the measurements and model estimates described in this report are associated with some degree of uncertainty. The monitors fully account for all sources of benzene at the point of collection, but may have gaps in data collection, as with the community air monitors, or provide average concentrations over an extended period that mask shorter periods with high concentrations, as with the two-week measurements at the refinery fencelines. The models reflect numerous sources of uncertainty including representations of physical conditions, emissions source characteristics, emissions estimates, and meteorology.

With that uncertainty in mind, it is worth noting that there is some consistency among model estimates (including those produced here and those derived by AirToxScreen or RSEI), and that these model estimates are much lower than observed benzene concentrations. **Table 8** summarizes the various estimates.

Table 8: Modeled and measured benzene concentrations near two Houston refineries.

Source		Benzene Concentration (µg/m3)		Year(s)
		Mean	Range	
Model estimates	Site-specific models (this paper – see Tables 6 & 7) *(Refinery fenceline)*	0.2	0.01 – 1.7	2019
	AirToxScreen (see Table 3) *(Census tracts containing refineries and community sites)*	0.4	0.3 – 0.5	2017
	RSEI *(Adjacent to refinery)*	0.2	0.01 – 1.0	2019
Measure-ments	Community monitors (see Table 2) *(Community sites)*	1.5	0.7 – 4.1	2017-2020
	Fenceline monitors (raw – see Tables 6 & 7) *(Refinery fenceline)*	3.3	1.1 – 29.0	2019
	Fenceline monitors (adjusted – see Tables 6 & 7) *(Refinery fenceline)*	1.9	(0.1 – 27.6)	2019

Notably, the results of the AirToxScreen are closer to the results from the site-specific models developed for this study than to concentrations measured at monitors. Although the AirToxScreen results are aggregated over the entire census tract rather than just the refinery site, the model also includes several other point sources such as those listed in **Table 2** and shown in **Figure 1**.

The 2019 RSEI model predicts fenceline concentrations that are similar in magnitude to those estimated by the site-specific models discussed in this paper, and significantly lower than measured fenceline values. For example, in a grid cell that contains Houston Refining monitors 2, 3, and 4, RSEI predicts a benzene concentration of 0.4 µg/m^3. Dr. Gray predicted average fenceline concentrations of 0.3 µg/m^3 for these monitors. The actual measurements at these three monitors, adjusted for background, averaged 2.9 µg/m^3.

Emissions from each refinery varied between 2017 and 2019. **Table 9** shows the emissions reported to TCEQ in 2019 (and used in the site-specific models described here), the 2017 emissions listed in the National Emissions Inventory (NEI) and used in the AirToxScreen model, and the releases reported to the Toxic Release Inventory (TRI) across several years and used in the RSEI model. As shown in the table, there is some variation in emissions, particularly at the Pasadena Refinery where emissions reported for 2017 were more than double the emissions reported in 2019.

Table 9: Reported Emissions at Houston Refining and Pasadena Refinery

Facility	Reported Emissions (tons)					
	2017 NEI	2019 TCEQ Reported Emissions	Toxic Release Inventory			
			2017	2018	2019	2020
Houston Refining	9.3	10.2	9.3	9.9	10.2	8.7
Pasadena Refinery	3.3	1.3	3.7	6.7	1.1	1.8

b. Navajo Refinery

1. Comparing measured and modeled concentrations

The Artesia model was run with the emissions as reported by the Navajo Refinery. **Table 10** shows that benzene levels measured at the fenceline were much higher than the site-specific emissions model suggests that they should have been, even after adjusting for background. Specifically, the adjusted (net) benzene concentrations at the Navajo Refinery were, on average, more than 25 times higher than the modeled concentrations.

Table 10: Navajo Refining Measured and Modeled Fenceline Concentrations

Sampler Name	Annual Average Benzene Concentration (µg/m^3)			Ratio of adjusted measurement to model estimate
	Measured	Adjusted for background	Modeled	
1	2.46	0.78	0.18	4.31
2	1.83	0.14	0.12	1.20
3	2.03	0.34	0.14	2.44
4	2.91	1.22	0.17	7.20
5	2.81	1.12	0.15	7.45
6	6.07	4.38	0.26	16.85
7	8.23	6.54	0.30	21.80
8	6.96	5.28	0.04	131.90
9	5.13	3.45	0.33	10.44
10	7.37	5.68	0.28	20.29
11	3.72	2.03	0.18	11.28
12	3.72	2.03	0.17	11.95
13	4.61	2.92	0.02	146.16
14	22.96	21.27	0.30	70.91
15	10.17	8.48	0.31	27.36
16	4.71	3.02	0.28	10.79
17	3.47	1.78	0.28	6.36
18	3.77	2.08	0.34	6.13
19	3.54	1.85	0.38	4.88
Average	5.60	3.92	0.22	27.35

2. *Benzene exposure in the community*

As with the Houston-area refineries, long-term exposure estimates based on reported emissions were less than 0.2 µg/m^3 at the community receptors. See Appendix B at Table 7. This is less than California's REL for noncancer health effects (3 µg/m^3) but overlaps with the range of concentrations that U.S. EPA associates with a cancer risk of one in one million (0.13-0.45 µg/m^3). Specifically, there were four locations in Artesia that exceeded the lower end of U.S. EPA's cancer risk range. The modeled concentrations exceeded the concentration that California associates with a cancer risk of one in one million (0.03 µg/m^3) at many more locations.

However, as with the benzene concentrations near the Houston refineries, it is important to remember that these are almost certainly underestimates of the actual benzene concentrations at these locations. First, the underlying emissions data for the site-specific models were underestimated. The model underpredicted adjusted fenceline measurements by roughly 27-fold. Exposures in the community may also be significantly higher than the emissions inventory model predicts. If Dr. Gray's community exposure estimates were, like the fenceline estimates, 27 times too low, then four locations may have experienced long-term average concentrations in excess of the California chronic REL of 3 µg/m^3.[31] Again, this is only a rough back-of-the-envelope calculation, and the actual margin between estimated and actual exposure may be different at different locations in the community, but it shows that actual emissions may be contributing to significant exposures and risks.

In addition, the site-specific model only accounts for emissions from the refinery and does not account for non-point or mobile sources of benzene in the area. Thus, the actual, cumulative benzene concentrations and associated health risks would be greater than the concentrations calculated by the model.

3. *Comparing sources*

As with the Houston Refineries, a comparison of available data shows differences in measured and modeled concentrations. **Table 11** compares the estimates of ambient benzene concentrations around the Navajo Refinery. As shown in the table, the measured fenceline concentrations are higher than the modeled concentrations for both the site-specific model and AirToxScreen. Note that the AirToxScreen estimate is aggregated over the entire census tract, not just at the refinery fenceline, which would lower the estimated concentration given that the refinery is the only large point source of benzene in the tract.

Table 12 shows the emissions reported to NMED in 2019 and used in the site-specific models, the 2017 emissions listed in the National Emissions Inventory (NEI) and used in the AirToxScreen model, and the releases reported to the Toxic Release Inventory (TRI) across several years and used in the RSEI model. As shown in the table, there is some variation in emissions, particularly in 2019 where the tons reported to TRI are approximately 30% less than the tons reported to NMED.

[31] See Appendix B, Table 7, showing four locations with 5-year average concentrations greater than 0.11 µg/m^3,

The 2019 RSEI model of the refinery emissions estimates concentrations at the refinery fenceline that are similar in magnitude to those estimated by the site-specific model discussed in this paper. The average of concentrations in the grid cells containing the facility footprint is 0.4 µg/m^3.

Table 11: Modeled and measured benzene concentrations near Navajo Refinery.

Source		Benzene Concentration (µg/m3)		Year(s)
		Mean	Range	
Model estimates	Site-specific models (this paper – see Table 10) *(Refinery fenceline)*	0.2	0.02 – 0.4	2019
	AirToxScreen (see Table 5) *(Census tract containing refinery)*	0.3	0.3	2017
	RSEI *(Adjacent to refinery)*	0.4	0.1 – 1.6	2019
Measure-ments	Fenceline monitors (raw – see Table 10) *(Refinery fenceline)*	5.6	1.8 – 23.0	2019
	Fenceline monitors (adjusted – see Table 10) *(Refinery fenceline)*	3.9	0.1 – 21.3	2019

Table 12: Reported Emissions at Navajo Refinery

Facility	Reported Emissions (tons)					
	2019 NMED Reported Emissions	2017 NEI	Toxics Release Inventory			
			2017	2018	2019	2020
Navajo Refinery	2.4	1.9	2.0	2.0	1.7	1.3

E. Short-term emissions

Through our review we became aware of two large, discrete benzene releases in 2019 – one at the Navajo Refinery and one at the Pasadena Refinery. Neither one of these releases were captured in the baseline emissions inventories used for the site-wide modeling described above. In each case, the problem was initially evident in high benzene concentrations at one or two fenceline monitors, and the source of each release was subsequently established in investigative reports generated by the refinery owners. This report describes the results of a short-term modeling exercise designed to estimate community exposures to benzene during the emissions event at the Navajo Refinery.

1. Methods

Between March 26 and May 21, 2019, benzene concentrations at Monitors 14 and 15 at the Navajo Refinery were quite high. The two-week average concentrations at Monitor 14 ranged from 56 to 200 µg/m^3, while the two-week average concentrations at Monitor 15 ranged from 17 to 56 µg/m^3. Concentrations dropped significantly in June but remained elevated until October. In response to these high fenceline readings, HollyFrontier conducted an investigation that showed potential emissions from tanks 57, 106 and 737. Tank 57, in particular, was noteworthy for having been removed from service in 2018 due to prior leaks but restored to service on April 4, 2019. Although Tank 57 was "isolated from service" on May 24, it was not emptied of benzene until September 4, 2019. As shown in Figure 7, benzene concentrations at Monitors 14 and 15 correspond closely with when Tank 57 was in use (very high concentrations), or out of service but still containing benzene (elevated concentrations). Tank 57 is located very close to Monitor 14 (approximately 80 yards away) and slightly farther away from Monitor 15.[32]

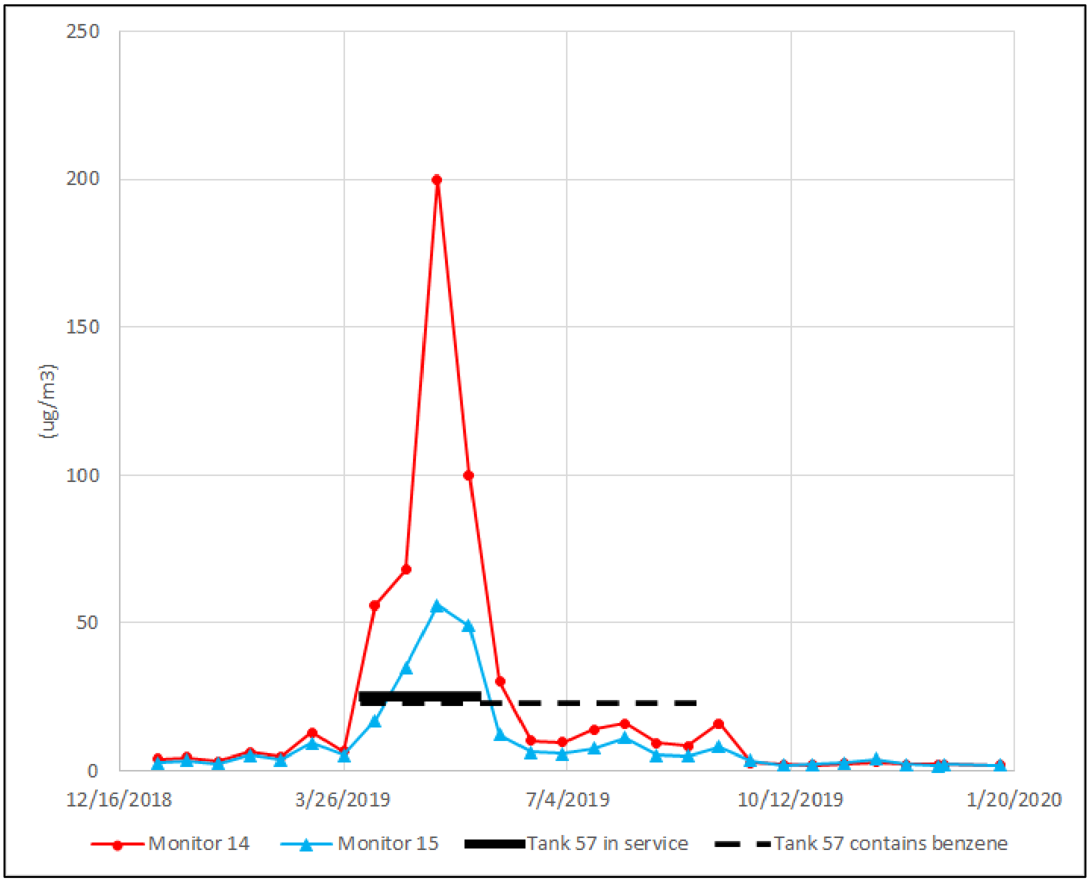


Figure 7: Benzene concentrations at the Navajo Refinery fenceline monitors 14 and 15 (two-week average concentrations)

In order to estimate exposures in the surrounding community during the 8-week release event at Artesia, Dr. Gray used his Navajo Refinery model to estimate the amount of benzene that would have to have been released from Tank 57 to cause the high two-week average fenceline values at Monitors 14 and 15. Given the close temporal correlation between Tank 57 operation and high benzene readings at Monitors 14 and 15 and the physical proximity, we made the simplifying assumption that all of the emissions causing the elevated readings were coming from Tank 57 when modeling this short-term emissions event. The assumed emissions and resulting modeled concentrations are shown in **Table 13**.

[32] HollyFrontier, Amendment to the May 15, 2019 Fenceline Benzene Monitoring Corrective Action plan for the Artesia Refinery, Figure 1 (July 3, 2019).

Table 13: Two-week average concentrations at monitors 14 and 15

Time period (2019)	Emissions from Tank 57 (assumed in calibrated model) (lb/d)	Monitor 14		Monitor 15	
		Measured ($\mu g/m^3$)	Modeled ($\mu g/m^3$)	Measured ($\mu g/m^3$)	Modeled ($\mu g/m^3$)
Mar. 26 – Apr. 9	118.9	56	52.2	17	17.3
Apr. 9 – Apr. 23	347.4	68	75.1	35	31.9
Apr. 23 – May 7	436.1	200	198.9	56	57.8
May 7 – May 21	279.5	100	143.0	49	36.3

Table 13 shows that it was possible to closely reproduce benzene concentrations at two monitors (Monitors 14 and 15) by assuming emissions from a single source (Tank 57). The calibrated model assumes that a total of nearly 16,550 pounds, or 8.3 tons, of benzene were emitted over the eight-week period. This should be cause for concern, even before looking at community exposure estimates, because it is strikingly similar to a release that was associated with significant, documented health effects in children. Specifically, a flaring event at the Texas City refinery in 2010 released roughly the same amount of benzene (8.5 tons) over a similar duration (40 days).[33] Emissions from the event caused a range of toxic effects in local children including unsteady gait, memory loss, headaches, altered blood cell counts, and signs of liver toxicity. Although the predominant wind direction (north to south) influenced the benzene dispersion, the plume from the event dispersed into adjacent communities all around the refinery.[34]

The estimated quantity of emissions from this isolated event (8.3 tons) exceeds the total 2019 emissions reported to NMED and the TRI for that year (see **Table 12**) by more than three times.

2. Results

a. Acute and intermediate exposure and risk

To put a finer point on the risks associated with short-term releases, Dr. Gray used the calibrated Tank 57 emissions model to estimate exposures in the community. **Table 14** provides two-week maximum, one-hour maximum, and ten-hour maximum exposure estimates at each community receptor for this eight-week period, relevant exposure guidelines for each exposure interval, and the estimated number of hours for which the one-hour exposure limit was exceeded. **Figures 8 through 11** show estimated benzene "plumes" during each two-week period.

[33] M.A. D'Andrea and G.K. Reddy, Health effects of benzene exposure among children following a flaring incident at the British Petroleum Refinery in Texas City, 31 Pediatr. Hematol. Oncol. 1 (Feb. 2014), cited by California Office of Environmental Health Hazard Assessment, Technical Supporting Document for Noncancer RELs at Appendix D, 155 (Updated July 2014), available at https://oehha.ca.gov/media/downloads/crnr/appendixd1final.pdf.

[34] *Id.*

Based on the model results, the most troubling exposures from the Tank 57 release would have been very short-term (hourly or daily) exposures. While the estimated concentrations at most locations did not exceed the ATSDR intermediate MRL, nearly all locations may have experienced one-hour maximum concentrations much greater than California's acute REL of 27 µg/m^3. Several locations experienced one or more one-hour periods where the benzene levels were at least ten times higher than the acute REL.

These exposures would have also occurred over multiple one-hour periods. Specifically, there were eight locations with at least 12 one-hour periods where the benzene concentration exceeded the acute REL of 27 µg/m^3, and four locations with at least 36 one-hour exceedances (See **Table 14** below). **Figures 8 through 11** show two-week average concentrations, indicating the size and extent of the plume and areas where there were sustained periods of concentrations above health thresholds. The Tank 57 release was therefore associated with a substantial acute risk of noncancer health effects.

It is also worth noting that there was at least one location where the 10-hour average concentration exceeded an occupational standard. In other words, this location would not have been safe for a healthy adult to work in, much less for children or other sensitive individuals to live in.

Table 14: Estimated exposures in Artesia associated with Tank 57 release in 2019

Location	2-week max	10-hour max	1-hour max	Number of Hours > California Acute REL
	20 µg/m^3 (ATSDR intermediate MRL)	326 µg/m^3 [35] (10-hour occupational limit)	27 µg/m^3 (California acute REL)	
	Modeled Concentration			
Roselawn Elementary School	10.3	164.0	**643.6**	37
Artesia High School	1.1	33.0	**73.0**	6
Abo Elementary School	0.4	5.4	**31.9**	1
Zia Intermediate School	1.0	23.1	**171.3**	6
Hermosa Elementary School	0.6	8.9	**61.9**	2
Central Elementary School	1.9	37.1	**256.0**	9
Yucca Elementary School	0.5	4.8	**34.2**	1
Park Junior High school	0.8	15.5	**84.1**	3
MLK Park	1.9	38.5	**229.9**	6
Guadalupe Park	8.2	116.2	**567.5**	33
Jamaica Park	0.7	9.8	**53.4**	4
Jaycee Park	0.2	3.1	18.5	0
Eagle Draw Park	19.4	291.4	**970.9**	63
Residential 1	5.1	**437.2**	**437.2**	31
Residential 2	9.1	107.2	**363.2**	57
Residential 3	16.2	165.9	**786.7**	78
Residential 4	8.1	116.5	**642.7**	26
Residential 5	2.5	37.5	**230.2**	16

[35] This value (converted from 0.1 ppm) is an occupational "recommended exposure limit" published by the National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/npg/npgd0049.html.

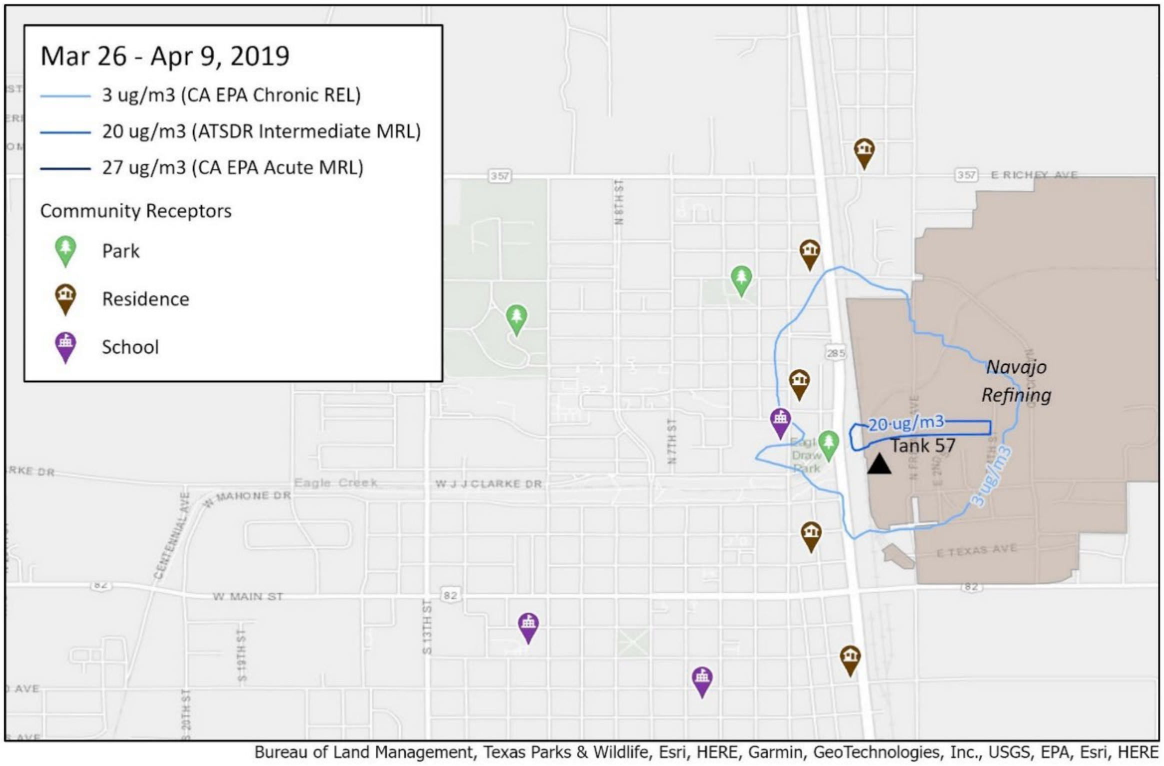


Figure 8: Two-week average benzene exposure from Tank 57 release, March 26 – April 9, 2019

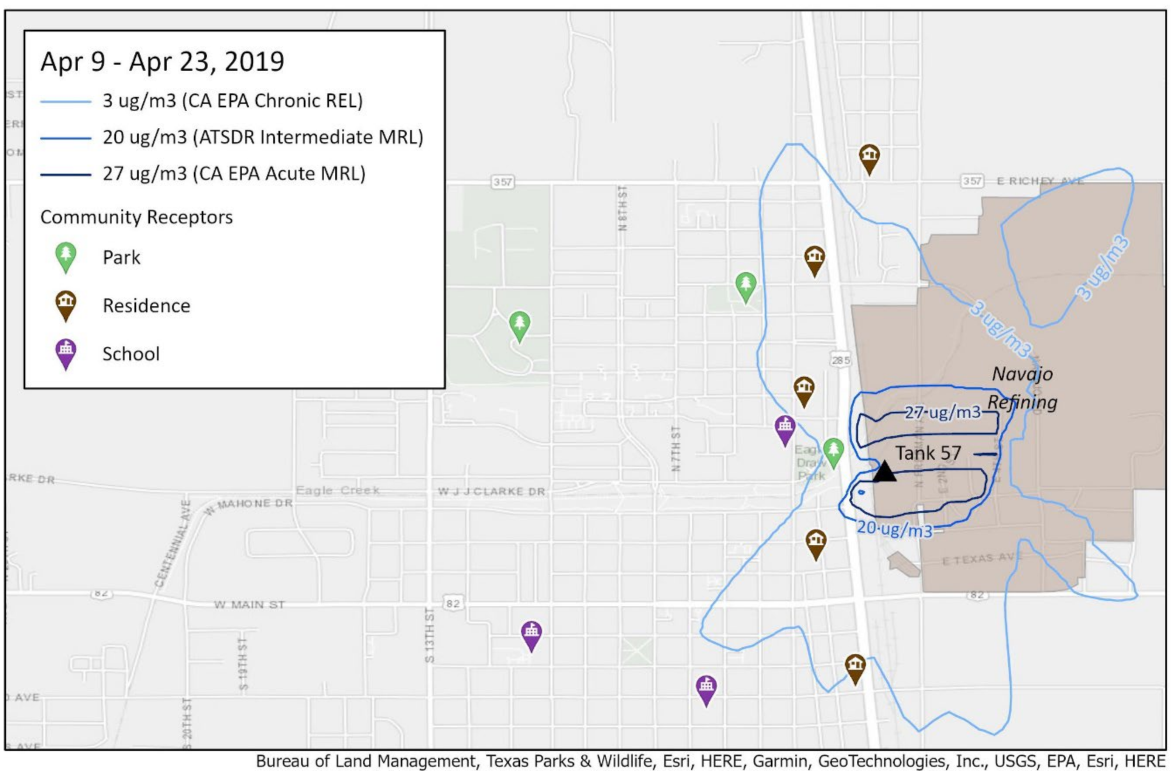


Figure 9: Two-week average Benzene exposure from Tank 57 release, April 9 – April 23, 2019

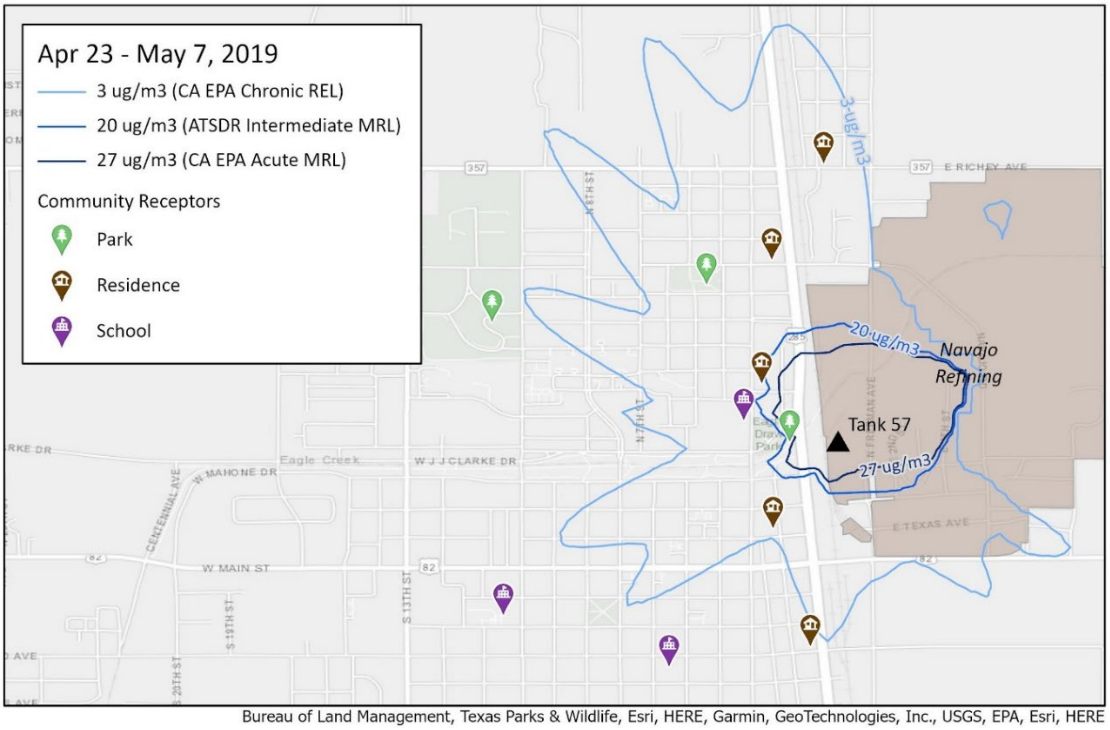


Figure 10: Two-week average Benzene exposure from Tank 57 release, April 23 – May 7, 2019

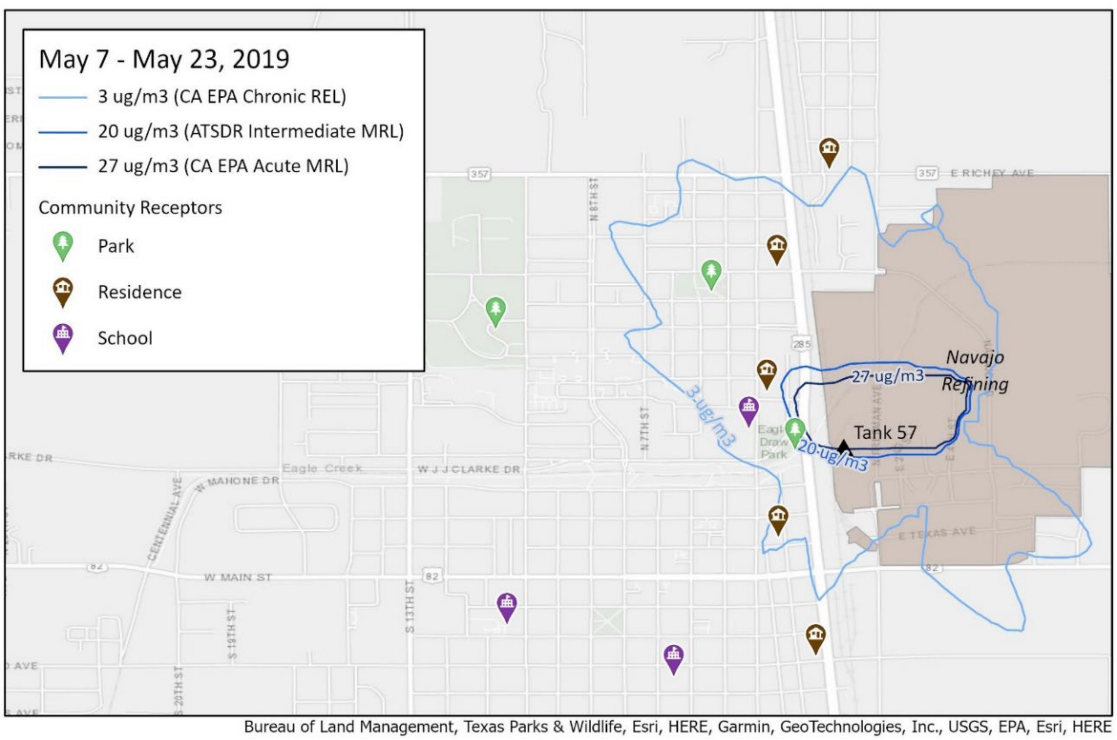


Figure 11: Two-week average Benzene exposure from Tank 57 release, May 7 – May 21, 2019

F. Conclusions and Recommendations

This report shows that refinery owners are underestimating and/or underreporting benzene emissions. Dr. Gray's and Dr. Sahu's modeling suggests that net benzene concentrations at the refinery fencelines are 7 to 28 times higher than one would expect to see based on reported emissions. In other words, reported emissions are 7 to 28 times too low.

Dr. Sahu provides several examples of problems with refinery owner's emissions estimates at Houston Refining and the Pasadena Refinery (see **Appendix A**). Among other issues, Dr. Sahu notes that the reported emissions do not appear to use site-specific emissions estimation methods as recommended by U.S. EPA, no underlying data are provided to document the estimates, and the estimate of VOC destruction efficiency at flares (99%) is unrealistic and unverifiably high for the open stack flares present at the refineries. These issues, along with incomplete reporting of accidental and fugitive releases, are likely to be contributing to the problem.

If emissions are underreported, then U.S. EPA modeling that uses emissions reports as an input will underestimate exposure and risk. U.S. EPA models like AirToxScreen and RSEI may be underestimating benzene exposure and risk by orders of magnitude.

When fenceline monitors spike, the community should be concerned. When Tank 57 at the Navajo Refinery was leaking benzene, exposures in the neighboring community were frequently 10, 20, and even 30 times higher than acute health guidelines. The air was simply not safe to breathe. This demonstrates that fenceline monitoring data are not only a way to demonstrate compliance with a regulation or to detect leaks – they can also be used to protect public health.

Benzene from these three refineries is only one small part of the air pollution burden facing the communities in the study areas. Residents are simultaneously being exposed to benzene from the refineries, to benzene from other sources, to other pollutants from the refineries, and to other pollutants from other sources. It is critically important to keep this cumulative risk in mind as we evaluate the significance of refinery benzene exposure. Even if benzene exposures from any one point source are below health guidelines, they may be contributing to a significant cumulative threat.

In light of these conclusions, we make the following recommendations:

- U.S. EPA should not assume that emissions reports are accurate. Actual emissions may be much higher than reported emissions. Until U.S. EPA can build confidence in its emissions inventories, the agency should assume a margin of safety in modeling large industrial point source emissions.
- At the same time, U.S. EPA should use fenceline monitoring data to validate emissions reports. If, as in this report, fenceline monitors indicate that emissions were underreported, U.S. EPA should require facility owners to update their emissions inventories.

- When fenceline monitors exceed the U.S. EPA action level, there may be an immediate risk to the community, and refinery owners should find and rectify the problem as soon as possible – not within weeks or months, but within hours.
- Fenceline monitor exceedances are based on two-week average concentrations. Emissions are not evenly distributed over time, and within any two-week period there will be short-term spikes in emissions and exposure. When fenceline monitors exceed the U.S. EPA action level, owners should immediately begin hourly monitoring at the fenceline location in question to ensure that the refinery is not contributing to acute health risks.
- Air quality monitors should be installed, where they do not already exist, in communities downwind of refineries. These are an important tool for understanding and communicating risks in communities that are burdened by exposures to not only benzene, but other air pollutants as well.

Appendix A:
Emissions, Dispersion Modeling, and Potential Emissions Controls of the Houston and Pasadena Refineries

Emissions, Dispersion Modeling, and Potential Emissions Controls of the Houston and Pasadena Refineries

Dr. H. Andrew Gray, Gray Sky Solutions, San Rafael, CA
Dr. Ranajit (Ron) Sahu, Alhambra, CA
May 2022

A. Introduction

Dr. H. Andrew Gray of Gray Sky Solutions and Dr. Ron Sahu were retained by Air Alliance Houston and the Environmental Integrity Project to address air emissions of selected pollutants, perform air dispersion modeling to determine the current air quality impacts in the surrounding communities due to emissions from LyondellBasell's Houston and Chevron's Pasadena refineries located in Houston, Texas, and to opine on potential additional emission reduction strategies that may be applicable. Activities at the two refineries cause emissions of nitrogen oxides (NO_X), sulfur dioxide (SO_2), particulate matter with aerodynamic diameters less than or equal to 10 microns (PM_{10}), and benzene among numerous other pollutants. The current analysis focuses on these pollutants. Using emissions reported by the respective refineries, dispersion modeling was conducted to evaluate the resulting concentration impacts.

B. Emissions

While emissions reported by each refinery was used in the modeling analysis since there was no direct ability to interact with each refinery and to make more accurate assessments of the reported emissions, it is apparent that there are several potentially problematic issues with the emissions as reported by each refinery.

First, the basis for the emissions reported to the TCEQ which we have used in this analysis in the absence of any better alternatives and their accuracy is not clear in most instances. For example, it does not appear that each refinery used the more accurate (and site specific) methods to estimate emissions as recommended by the US EPA in its Emissions Estimation Protocol for Petroleum Refineries, Version 3, April 2015.[1] This document provides a hierarchical set of emissions calculation methods, from most to least accurate, to estimate emissions from various refinery processes. There are no indications that the protocol was relied upon.

[1] https://www.epa.gov/sites/default/files/2020-11/documents/protocol_report_2015.pdf

Second, as an example for a specific deficiency, we discuss the emissions from flares. In the reported emissions for the Pasadena refining, the following are provided for flare emissions:

EPN NAME	CONTMAINANT	METHOD	ANNUAL TPY	SMSS TPY	EE TPY
MARINE LOAD INCENERATOR	NITROGEN OXIDES	A	3.0212	0	0
EMERGENCY FLARE - WEST	BENZENE	B	0.4278	0	0
MARINE LOAD INCENERATOR	PART-U	A	0.2199	0	0
MARINE LOAD INCENERATOR	PM10 PART-U	A	0.2199	0	0
EMERGENCY FLARE - WEST	NITROGEN OXIDES	A	0.1823	0	0
EMERGENCY FLARE - EAST	BENZENE	B	0.1046	0	0.016
MARINE LOAD INCENERATOR	BENZENE	A	0.097	0	0
EMERGENCY FLARE - EAST	NITROGEN OXIDES	A	0.0486	0	0
MARINE LOAD INCENERATOR	SULFUR DIOXIDE	A	0.0298	0	0
EMERGENCY FLARE - WEST	SULFUR DIOXIDE	A	0.0016	0	0
EMERGENCY FLARE - EAST	SULFUR DIOXIDE	A	0.0004	0	0

Several deficiencies are noteworthy: (i) there are no emissions for Scheduled Maintenance, Startup, and Shutdown (SMSS) from any flare, which is not credible; (ii) the total annual emissions of SO_2, highlighted in yellow, are collectively 0.0318 tons in 2019 from the entire refinery. This too is not credible given our experience with SO_2 emissions from refinery flaring; and (iii) the method of estimation designation is either A or B. A stands for AP-42 or other unspecified EPA- or TCEQ-approved factors and B stands for material balance. Regarding the A-factors, it is not clear whether AP-42 of some other "approved" emission factor was used – and, to what extent any of the factors used is representative of each flare. It is easy to prove that the quality of the AP-42 flare emission factors is very poor. As for material balance used to estimate SO_2 and benzene emissions, none of the underlying data are available in the record. And, as noted the emissions of SO_2 in particular are not credible as reported.

The table below shows the similar report from the flares at Houston refining.

EPN NAME	CONTMAINANT	METHOD	ANNUAL TPY	SMSS TPY	EE TPY
NO. 1 PLANT FLARE	TOTAL PM2.5 PARTICULATE	D	0.0458	0	0
NO. 1 PLANT FLARE	BENZENE	D	0.1383	0	0.0007
NO. 1 PLANT FLARE	NITROGEN OXIDES	D	7.3566	0	0.0163
NO. 1 PLANT FLARE	SULFUR DIOXIDE	D	150.6609	0	0.4111
NO. 2 PLANT FLARE	TOTAL PM2.5 PARTICULATE	D	0.0444	0	0
NO. 2 PLANT FLARE	BENZENE	D	0.0263	0	0
NO. 2 PLANT FLARE	NITROGEN OXIDES	D	4.3792	0	0.2404
NO. 2 PLANT FLARE	SULFUR DIOXIDE	D	38.708	0	173.397
HOUSTON STREET FLARE	TOTAL PM2.5 PARTICULATE	D	0.0051	0	0
HOUSTON STREET FLARE	BENZENE	D	0.0122	0	0
HOUSTON STREET FLARE	NITROGEN OXIDES	D	0.0669	0	0
HOUSTON STREET FLARE	SULFUR DIOXIDE	D	17.7868	0	0
NO. 3 PLANT FLARE	TOTAL PM2.5 PARTICULATE	D	0.0245	0	0
NO. 3 PLANT FLARE	BENZENE	D	0.0949	0	0.0004
NO. 3 PLANT FLARE	NITROGEN OXIDES	D	13.7024	0	0.289
NO. 3 PLANT FLARE	SULFUR DIOXIDE	D	118.2875	0	21.3367
NO. 4 PLANT FLARE	TOTAL PM2.5 PARTICULATE	D	0.0147	0	0
NO. 4 PLANT FLARE	BENZENE	D	0.0689	0	0
NO. 4 PLANT FLARE	NITROGEN OXIDES	D	9.9215	0	0.0125
NO. 4 PLANT FLARE	SULFUR DIOXIDE	D	44.3284	0	0.0051
736 COKER FLARE	TOTAL PM2.5 PARTICULATE	D	0.0245	0	0
736 COKER FLARE	BENZENE	D	0.0907	0	0
736 COKER FLARE	NITROGEN OXIDES	D	13.6113	0	0
736 COKER FLARE	SULFUR DIOXIDE	D	12.6499	0	3.5682

While the SO_2 emissions reported for this refinery appear to be more realistic (i.e., over 100 tons per year each for No. 1 and No. 3 flares and 44.3 tons for No. 4 flare, etc.), there are still no reported SMSS emissions. And, curiously the basis designated for all of the emissions is D, which stands for continuous emission monitoring. Since emissions from these open stack flares cannot be directly monitored like, for example, at a stack using continuous emission monitors, the reference to such a method for all of the pollutants is not only puzzling but also unsupportable.

Third, for VOCs from flares, the calculations assume a destruction efficiency of 99% with no supporting basis even though this likely represents an unverifiably high level of destruction of VOC compounds in the open, stack flares present at each refinery, which are subject to significant flame distortion and variability just from weather-related variables such as cross-winds and rainfall alone. Previous measurements that we are aware of conducted using remote monitoring methods have confirmed that destruction efficiencies in such flares can be substantially lower than 99%. We note that even small reductions in this destruction efficiency (say, from 99% to 98%) can result in large increases in emissions (in this case, a doubling as a result of the efficiency dropping from 99% to 98%)

Fourth, as the results of the modeling of benzene emissions (and comparisons to fenceline benzene monitoring), as discussed below make clear, emissions of VOCs (including benzene) are likely significantly underestimated from a multitude of refinery sources, including from storage tanks, loading operations, and fugitive emissions.

The underestimation of emissions has two broad impacts – one that the estimated impacts using modeling are correspondingly also underestimated; and second, cost-effectiveness calculations typically conducted as part of air pollution control assessments (and expressed as dollars per ton of emissions reduced) under various regulatory programs such as determinations of RACT and BACT are adversely distorted by making such cost-effectiveness determinations higher than they should be – and thus avoiding more stringent controls.

It is recommended that any future analysis, if attempted, use more complete and accurate emissions data – including discussions with the refineries, if at all possible.

C. Modeling

The American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) modeling system (version 19191) was used to simulate the transport of pollutant emissions from the refineries to the surrounding community. AERMOD[2,3,4] is a steady-state plume model that simulates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. AERMOD has been adopted by the U.S. Environmental Protection Agency (US EPA) in Appendix W to its Guideline on Air Quality Models[5] as the preferred dispersion model for estimating local-scale impacts from industrial pollutant emissions sources.

There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using USGS Digital Elevation Data. In addition, the AERMINUTE meteorological pre-preprocessor was used to incorporate 1-minute ASOS wind data to generate hourly average winds for input to AERMET, and the AERSURFACE program was used to develop surface characteristics for input to AERMET. No background concentrations were added to the modeled impacts, therefore the modeled concentrations represent the incremental impact to the surrounding community from the refineries.

This report describes the modeling exercises that were conducted using the AERMOD model to evaluate the impact of airborne pollutant emissions from the refineries on ambient concentrations in the area surrounding the two refinery facilities. The

---

[2] U.S. Environmental Protection Agency. *AERMOD: Description of Model Formulation*. EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. September 2004.
[3] U.S. Environmental Protection Agency. *User's Guide for the AMS/EPA Regulatory Model (AERMOD)*. EPA-454/B-19-027. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. August 2019.
[4] U.S. Environmental Protection Agency. *Addendum: User's Guide for the AMS/EPA Regulatory Model – AERMOD*. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, March 2011.
[5] U.S. Environmental Protection Agency. *Guideline on Air Quality Models, 40 CFR Part 51, Appendix W*. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.

necessary input data including emissions rates and other source data, receptor, terrain, and meteorological data, and modeling options are described below, followed by a summary of the model results.

C.1 Source Data

Spreadsheet files for the Houston and Pasadena refineries were obtained from Air Alliance Houston.[6] These files included source data for the refineries that were obtained from the State of Texas Air Reporting System (STARS), including a list of emissions points and associated emission point numbers (EPN), EPN names, EPN locations (latitude and longitude), source type (stack, fugitive, or flare) stack and flare parameters (including stack height, exit temperature, stack diameter, and exit velocity), fugitive source parameters (release height, length and width, and orientation), and annual emission rates (tons per year) for 2018 and 2019 for each pollutant. From these spreadsheet files, emissions data for NO_X, SO_2, PM_{10} and benzene for 2019 were extracted.

For modeling purposes, the effective temperatures and exit velocities for all flare sources were set to 1273K (1340F) and 20 m/s (65.6 ft/s), respectively, to account for the appropriate plume characteristics, as typically used by regulators, recognizing that actual parameters can vary substantially. A number of significant inconsistencies were discovered within the source data, including the locations of a few of the point sources and almost all of the fugitive sources.[7] Since the fugitive sources accounted for a very small percentage of total emissions for NO_X, SO_2, and PM_{10}, these sources were omitted from the modeling.[8] For benzene, the fugitive source emission rates for each facility were summed and spread across each facility uniformly.[9]

For the Pasadena refinery, there were a number of few stack sources (17 NO_X and SO_2 sources, and 16 PM_{10} sources) for which the location and stack parameter data were not provided (location, stack height, exit temperature, and diameter). These sources

---

[6] Files named HoustonRefining_EPN.xlsx and HoustonRefining_EPN.xlsx were obtained via email from Corey Williams on June 4, 2021.

[7] Inspection of the locations of a few stack (point) sources did not appear to be correct, however it was assumed that the actual source locations were close enough so that the spreadsheet locations were used for modeling. The location of all the fugitive sources (corner locations, length and width of the source rectangles, and orientation) appeared to be incorrect (including a number of fugitive sources in which the source rectangles extended far beyond the facility property, and many others that did not correspond to a footprint of any refinery activity). The north/south or east/west orientation of the length and width were not identified.

[8] The omitted fugitive sources accounted for: Pasadena NO_X: 0.43 tpy (2 sources) out of 490.65 tpy (total, 45 sources); Pasadena SO_2: 0.49 (2) out of 470.89 (43); Pasadena PM_{10}: 0.51 (2) out of 79.52 (42); Houston NO_X: 0.023 (5) out of 802.78 (66); Houston SO_2: 0.096 (5) out of 758.75 (63); Houston PM_{10}: 0.85 (6) out of 182.37 (81).

[9] For Pasadena, the benzene fugitives accounted for 0.13 tpy (7 sources) out of a total of 1.76 tpy (51 sources). For Houston, the benzene fugitives accounted for 7.14 tpy (35 sources) out of a total of 10.21 tpy (157 sources).

consisted of a few diesel engines, Tank 400 water pump (1 and 2), a temporary boiler (NO_X and SO_2 only), and several emergency diesel engines. These sources are not significant and accounted for a very small percentage of total reported emissions, therefore these source were also not modeled.[10]

The modeled 2019 annual emission rates and source parameters for all four modeled pollutants at each refinery are shown in Tables 1 through 8, below (ordered by emissions rate).[11] The combined benzene fugitive emissions at each refinery were modeled as VOLUME sources within AERMOD, centered at the locations with lateral dimensions (length) shown in Tables 4 and 8.

[10] The omitted Pasadena sources accounted for: NO_X: 7.24 tpy (1.5% of total emissions), SO_2: 2.84 tpy (0.6%), and PM_{10}: 0.23 tpy (0.3%).
[11] Stack exit temperatures were not provided for Pasadena sources VTLSG001 (LSG Regenerator Vent), VTFCC003 (FCC Seal Pot Stack), and TKFTK827 (Tank 827). Stack diameters were not provided for Pasadena sources VTLSG001 and TKFTK827. Stack exit velocities were not provided for Pasadena sources VTLSG001, VTFCC003, TKFTK827, and TKFTK210 (Tank 210). For these sources, the missing modeled temperatures were assumed to be (for modeling) 68F, missing diameters were assumed to be 0.03 ft/s, and missing exit velocities were assumed to be 0.03 ft/s.

Table 1. Pasadena NO_X Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
HTBLR010	STEAM BOILER # 10	236.5681	STACK	29.721733	-95.211078	140	550	10	26.63
HTREF2631	REFORMER #3 HEATERS	132.8553	STACK	29.721619	-95.207944	244	400	12	28.7
HTCRU001-S	CRUDE SCR SYSTEM	30.3217	STACK	29.720897	-95.210925	95	769	10	43
HTBLR004	STEAM BOILER # 4	16.5284	STACK	29.720061	-95.206364	100	350	6	53
INSRU001	SULFUR RECOVERY UNIT	9.4198	STACK	29.722261	-95.209394	120	1000	2	28.9
HTCRU001-S	CRUDE SCR SYSTEM	8.1804	STACK	29.720897	-95.210925	95	769	10	43
HTFCC002	FCC CHARGE HEATER	8.1185	STACK	29.721853	-95.210892	121	975	5	22.14
HTREF201	REFORMATE SPLITTER HEAT.	5.6134	STACK	29.720122	-95.208422	75	655	3.08	12
HTALK002	#2 ALKY HEATER	4.7460	STACK	29.720808	-95.208603	128	720	5	18.84
HTBLR006	BOILER 6	4.5186	STACK	29.720478	-95.206672	60	500	2	25
HTCRU004	CRUDE TOWER HEATER	4.4393	STACK	29.720889	-95.210108	33	430	3	19.73
HTLSG001	HEATER H-3701	3.7621	STACK	29.721256	-95.211014	131	500	2	25
HTALK001	#1 ALKY HEATER	3.4197	STACK	29.720278	-95.209061	128	790	5	19.78
INDOK001	MARINE LOAD INCENERATOR	3.0212	STACK	29.726178	-95.210253	30	900	6.9	0.01
FLRFNWEST	EMERGENCY FLARE - WEST	2.8765	FLARE	29.722825	-95.209128	195	1832	2	65.6
FLRFNEAST	EMERGENCY FLARE - EAST	2.8073	FLARE	29.722497	-95.207042	195	1832	3	65.6
HTREF002	REFORMER #2 HYDROTREATER	1.9679	STACK	29.721628	-95.210942	33	710	3	39.56
HTREF001	REFORMER #2 HYDROTREATER	1.2975	STACK	29.721536	-95.210950	36	700	3	47.99
FLRFNMSS	MSS FROM EAST AND WEST FLARES	0.9401	FLARE	29.723889	-95.208889	195	1832	3	65.6
FLRFNMSS	MSS FROM EAST AND WEST FLARES	0.7189	FLARE	29.723889	-95.208889	195	1832	3	65.6
HTCRU001	ATM.TOWER HEATER	0.4330	STACK	29.720897	-95.210925	95	890	10	31.35
FLRFNWEST	EMERGENCY FLARE - WEST	0.1823	FLARE	29.722825	-95.209128	195	1832	2	65.6
HTCRU002	VACUUM TOWER HEATER	0.1168	STACK	29.721086	-95.210931	78	820	7	26.48
VTLSG001	LSG REGENERATOR VENT	0.0578	STACK	29.721306	-95.210944	126	68	0.03	0.03
FLRFNEAST	EMERGENCY FLARE - EAST	0.0486	FLARE	29.722497	-95.207042	195	1340	3	65.6
VTREF001	REFORMER #3 CAT REGEN VNT	0.0163	STACK	29.721650	-95.207861	120	833	0.5	52.6
Not Modeled: Fugitive Sources									
FUMTB001	MTBE, UDEX, MISC UNIT FUGITIVES	0.4141	FUGITIVE						
FUMSS	FUGITIVE/PORTABLE MSS EMISSIONS TO ATMOSPHERE IN R	0.0119	FUGITIVE						
Not Modeled: no source information									
NEMENG003	ALKY GENERATOR DIESEL ENGINE	4.9644							
NEMENG002	CRUDE WEST GENERATOR DIESEL ENGINE	1.1406							
NEMENG001	CRUDE EAST GENERATOR DIESEL ENGINE	0.4141							
EMENG001	EMERGENCY GENERATOR DIESEL ENGINE 1	0.2259							
EMENG002	EMERGENCY GENERATOR DIESEL ENGINE 2	0.1396							
EMENWW001	EMERGENCY WASTEWATER PUMP DIESEL ENGINE 1	0.1111							
EMENW001	EMERGENCY FIREWATER PUMP DIESEL ENGINE 1	0.0718							
EMENW002	EMERGENCY FIREWATER PUMP DIESEL ENGINE 2	0.0558							
EMENW003	EMERGENCY FIREWATER PUMP DIESEL ENGINE 3	0.0320							
NEMENW002	TANK 400 WATER PUMP NO.2	0.0264							
TEMPBOILER	TEMPORARY BOILER FOR 807 CLEANING	0.0184							
EMENG006	EMERGENCY GENERATOR DIESEL ENGINE 6	0.0171							
EMENG007	EMERGENCY GENERATOR DIESEL ENGINE 7	0.0096							
EMENW005	EMERGENCY FIREWATER PUMP DIESEL ENGINE 5	0.0044							
EMENW004	EMERGENCY FIREWATER PUMP DIESEL ENGINE 4	0.0043							
NEMENW001	TANK 400 WATER PUMP NO.1	0.0038							
EMENW006	EMERGENCY FIREWATER PUMP DIESEL ENGINE 6	0.0043							

Table 2. Pasadena SO_2 Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
HTBLR010	STEAM BOILER # 10	436.7858	STACK	29.721733	-95.211078	140	550	10	26.63
INSRU001	SULFUR RECOVERY UNIT	12.7107	STACK	29.722261	-95.209394	120	1000	2	28.9
VTLSG001	LSG REGENERATOR VENT	7.1416	STACK	29.721306	-95.210944	126	68	0.03	0.03
FLRFNMSS	MSS FROM EAST AND WEST FLARES	2.7157	FLARE	29.723889	-95.208889	195	1832	3	65.6
FLRFNWEST	EMERGENCY FLARE - WEST	2.4192	FLARE	29.722825	-95.209128	195	1832	2	65.6
HTREF2631	REFORMER #3 HEATERS	1.7899	STACK	29.721619	-95.207944	244	400	12	28.7
FLRFNEAST	EMERGENCY FLARE - EAST	1.3435	FLARE	29.722497	-95.207042	195	1832	3	65.6
HTBLR006	BOILER 6	0.6808	STACK	29.720478	-95.206672	60	500	2	25
HTBLR004	STEAM BOILER # 4	0.5090	STACK	29.720061	-95.206364	100	350	6	53
FLRFNMSS	MSS FROM EAST AND WEST FLARES	0.4786	FLARE	29.723889	-95.208889	195	1832	3	65.6
HTALK002	#2 ALKY HEATER	0.1642	STACK	29.720808	-95.208603	128	720	5	18.84
HTALK001	#1 ALKY HEATER	0.1340	STACK	29.720278	-95.209061	128	790	5	19.78
HTCRU001-S	CRUDE SCR SYSTEM	0.1293	STACK	29.720897	-95.210925	95	769	10	43
HTFCC002	FCC CHARGE HEATER	0.1239	STACK	29.721853	-95.210892	121	975	5	22.14
HTLSG001	HEATER H-3701	0.1196	STACK	29.721256	-95.211014	131	500	2	25
HTCRU004	CRUDE TOWER HEATER	0.0962	STACK	29.720889	-95.210108	33	430	3	19.73
HTREF201	REFORMATE SPLITTER HEAT.	0.0658	STACK	29.720122	-95.208422	75	655	3.08	12
HTREF002	REFORMER #2 HYDROTREATER	0.0497	STACK	29.721628	-95.210942	33	710	3	39.56
HTCRU001-S	CRUDE SCR SYSTEM	0.0349	STACK	29.720897	-95.210925	95	769	10	43
HTREF001	REFORMER #2 HYDROTREATER	0.0321	STACK	29.721536	-95.210950	36	700	3	47.99
INDOK001	MARINE LOAD INCENERATOR	0.0298	STACK	29.726178	-95.210253	30	900	6.9	0.01
HTCRU001	ATM.TOWER HEATER	0.0106	STACK	29.720897	-95.210925	95	890	10	31.35
FLRFNWEST	EMERGENCY FLARE - WEST	0.0016	FLARE	29.722825	-95.209128	195	1832	2	65.6
FLRFNEAST	EMERGENCY FLARE - EAST	0.0004	FLARE	29.722497	-95.207042	195	1832	3	65.6
Not Modeled: Fugitive Sources									
FUMTB001	MTBE, UDEX, MISC UNIT FUGITIVES	0.4763	FUGITIVE						
FUSRU001	SRU FUGITIVES	0.0096	FUGITIVE						
Not Modeled: no source information									
NEMENG003	ALKY GENERATOR DIESEL ENGINE	1.8846							
NEMENG001	CRUDE EAST GENERATOR DIESEL ENGINE	0.4763							
NEMENG002	CRUDE WEST GENERATOR DIESEL ENGINE	0.3597							
EMENWW001	EMERGENCY WASTEWATER PUMP DIESEL ENGINE 1	0.0407							
NEMENW002	TANK 400 WATER PUMP NO.2	0.0174							
EMENG001	EMERGENCY GENERATOR DIESEL ENGINE 1	0.0149							
TEMPBOILER	TEMPORARY BOILER FOR 807 CLEANING	0.0140							
EMENG006	EMERGENCY GENERATOR DIESEL ENGINE 6	0.0058							
EMENG002	EMERGENCY GENERATOR DIESEL ENGINE 2	0.0054							
EMENW001	EMERGENCY FIREWATER PUMP DIESEL ENGINE 1	0.0048							
EMENW002	EMERGENCY FIREWATER PUMP DIESEL ENGINE 2	0.0037							
EMENG007	EMERGENCY GENERATOR DIESEL ENGINE 7	0.0034							
NEMENW001	TANK 400 WATER PUMP NO.1	0.0025							
EMENW003	EMERGENCY FIREWATER PUMP DIESEL ENGINE 3	0.0021							
EMENW004	EMERGENCY FIREWATER PUMP DIESEL ENGINE 4	0.0014							
EMENW005	EMERGENCY FIREWATER PUMP DIESEL ENGINE 5	0.0014							
EMENW006	EMERGENCY FIREWATER PUMP DIESEL ENGINE 6	0.0014							

Table 3. Pasadena PM_{10} Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
HTBLR010	STEAM BOILER # 10	25.3828	STACK	29.721733	-95.211078	140	550	10	26.63
HTREF2631	REFORMER #3 HEATERS	22.3563	STACK	29.721619	-95.207944	244	400	12	28.7
HTCRU001-S	CRUDE SCR SYSTEM	8.7821	STACK	29.720897	-95.210925	95	769	10	43
HTBLR006	BOILER 6	4.6247	STACK	29.720478	-95.206672	60	500	2	25
HTBLR004	STEAM BOILER # 4	3.4574	STACK	29.720061	-95.206364	100	350	6	53
VTLSG001	LSG REGENERATOR VENT	2.7251	STACK	29.721306	-95.210944	126	68	0.03	0.03
HTCRU001-S	CRUDE SCR SYSTEM	2.3693	STACK	29.720897	-95.210925	95	769	10	43
VTFCC003	FCC SEAL POT STACK (STARTUP/SHUTDOWN)	1.5485	STACK	29.721997	-95.210700	160	68	6.5	0.03
HTALK002	#2 ALKY HEATER	1.1155	STACK	29.720808	-95.208603	128	720	5	18.84
FUCTWCPX	COMPLEX COOLING TOWER	1.0079	STACK	29.722375	-95.210322	30	80	12	30
HTALK001	#1 ALKY HEATER	0.9100	STACK	29.720278	-95.209061	128	790	5	19.78
HTFCC002	FCC CHARGE HEATER	0.8413	STACK	29.721853	-95.210892	121	975	5	22.14
HTREF201	REFORMATE SPLITTER HEAT.	0.8365	STACK	29.720122	-95.208422	75	655	3.08	12
HTLSG001	HEATER H-3701	0.8125	STACK	29.721256	-95.211014	131	500	2	25
HTCRU004	CRUDE TOWER HEATER	0.6537	STACK	29.720889	-95.210108	33	430	3	19.73
HTREF002	REFORMER #2 HYDROTREATER	0.3378	STACK	29.721628	-95.210942	33	710	3	39.56
INDOK001	MARINE LOAD INCENERATOR	0.2199	STACK	29.726178	-95.210253	30	900	6.9	0.01
HTREF001	REFORMER #2 HYDROTREATER	0.2177	STACK	29.721536	-95.210950	36	700	3	47.99
FUCTWALK	ALKY COOLING TOWER	0.1816	STACK	29.720547	-95.208819	30	80	12	30
VTREF001	REFORMER #3 CAT REGEN VNT	0.1752	STACK	29.721650	-95.207861	120	833	0.5	52.6
INSRU001	SULFUR RECOVERY UNIT	0.1001	STACK	29.722261	-95.209394	120	1000	2	28.9
HTCRU001	ATM.TOWER HEATER	0.0720	STACK	29.720897	-95.210925	95	890	10	31.35
FUCTWMTB	MTBE COOLING TOWER	0.0471	STACK	29.720083	-95.206022	30	80	12	30
HTCRU002	VACUUM TOWER HEATER	0.0003	STACK	29.721086	-95.210931	78	820	7	26.48
Not Modeled: Fugitive Sources									
FURFNROAD	FUGITIVE ROAD DUST	0.4636	FUGITIVE						
FUMTB001	MTBE, UDEX, MISC UNIT FUGITIVES	0.0465	FUGITIVE						
Not Modeled: no source information									
NEMENG003	ALKY GENERATOR DIESEL ENGINE	0.0919							
NEMENG001	CRUDE EAST GENERATOR DIESEL ENGINE	0.0465							
NEMENG002	CRUDE WEST GENERATOR DIESEL ENGINE	0.0351							
NEMENW002	TANK 400 WATER PUMP NO.2	0.0187							
EMENG001	EMERGENCY GENERATOR DIESEL ENGINE 1	0.0160							
EMENW001	EMERGENCY FIREWATER PUMP DIESEL ENGINE 1	0.0051							
EMENG002	EMERGENCY GENERATOR DIESEL ENGINE 2	0.0044							
EMENW002	EMERGENCY FIREWATER PUMP DIESEL ENGINE 2	0.0040							
EMENWW001	EMERGENCY WASTEWATER PUMP DIESEL ENGINE 1	0.0039							
NEMENW001	TANK 400 WATER PUMP NO.1	0.0027							
EMENW003	EMERGENCY FIREWATER PUMP DIESEL ENGINE 3	0.0023							
EMENG006	EMERGENCY GENERATOR DIESEL ENGINE 6	0.0008							
EMENG007	EMERGENCY GENERATOR DIESEL ENGINE 7	0.0005							
EMENW004	EMERGENCY FIREWATER PUMP DIESEL ENGINE 4	0.0001							
EMENW005	EMERGENCY FIREWATER PUMP DIESEL ENGINE 5	0.0001							
EMENW006	EMERGENCY FIREWATER PUMP DIESEL ENGINE 6	0.0001							

Table 4. Pasadena Benzene Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
FLRFNWEST	EMERGENCY FLARE - WEST	0.4278	FLARE	29.722825	-95.209128	195	1832	2	65.6
TKTKF353	TANK 353	0.1727	STACK	29.727442	-95.207919	40	70	3	0.01
TKTKF341	TANK 341	0.1561	STACK	29.726864	-95.206819	40	70	3	0.01
TKTKF340	TANK 340	0.1523	STACK	29.726858	-95.207128	40	70	3	0.01
FLRFNEAST	EMERGENCY FLARE - EAST	0.1046	FLARE	29.722497	-95.207042	195	1832	3	65.6
INDOK001	MARINE LOAD INCENERATOR	0.0970	STACK	29.726178	-95.210253	30	900	6.9	0.01
FLRFNMSS	MSS FROM EAST AND WEST FLARES	0.0850	FLARE	29.723889	-95.208889	195	1832	3	65.6
TKTKF825	TANK 825	0.0829	STACK	29.724886	-95.205886	50	70	3	0.01
TKTKF818	TANK 818	0.0482	STACK	29.728156	-95.206717	50	70	3	0.01
TKTKF810	TANK 810	0.0460	STACK	29.726728	-95.206103	48	70	3	0.01
TKTKF826	TANK 826	0.0379	STACK	29.724850	-95.204800	50	70	3	0.01
TKTKF812	TANK 812	0.0373	STACK	29.726011	-95.206097	48	70	3	0.01
TKTKF811	Q	0.0346	STACK	29.727572	-95.206042	48	70	3	0.01
TKTKF827	TANK 827	0.0207	STACK	29.725072	-95.204186	55	68	0.03	0.03
TKTKF831	TANK 831	0.0165	STACK	29.710017	-95.188453	50	70	3	0.01
TKTKF830	TANK 830	0.0148	STACK	29.709989	-95.190183	50	70	3	0.01
TKTKF210	TANK 210	0.0135	STACK	29.723083	-95.208025	62	79	3	0.03
TKTKF815	TANK 815	0.0113	STACK	29.711439	-95.190753	50	70	3	0.01
TKTKF822	TANK 822	0.0103	STACK	29.711336	-95.195158	50	70	3	0.01
TKTKF051	TANK 51	0.0090	STACK	29.724864	-95.208039	40	70	3	0.01
TKTKF813	TANK 813	0.0077	STACK	29.711761	-95.189631	48	70	3	0.01
TKTKF824	TANK 824	0.0075	STACK	29.724878	-95.206906	50	70	3	0.01
TKTKF342	TANK 342	0.0059	STACK	29.725992	-95.207108	40	70	3	0.01
HTBLR010	STEAM BOILER # 10	0.0057	STACK	29.721733	-95.211078	140	550	10	26.63
TKTKF343	TANK 343	0.0046	STACK	29.726464	-95.206800	40	70	3	0.01
TKTKF807	TANK 807	0.0046	STACK	29.711781	-95.188197	50	70	3	0.01
TKTKF816	TANK 816	0.0044	STACK	29.711406	-95.191922	50	70	3	0.01
HTCRU001-S	CRUDE SCR SYSTEM	0.0024	STACK	29.720897	-95.210925	95	769	10	43
TKTKF332	TANK 332	0.0024	STACK	29.726244	-95.204300	48	70	3	0.01
HTREF2631	REFORMER #3 HEATERS	0.0017	STACK	29.721619	-95.207944	244	400	12	28.7
TKTKF349	TANK 349	0.0016	STACK	29.727500	-95.206944	40	70	3	0.01
TKTKF350	TANK 350	0.0014	STACK	29.727525	-95.206814	40	70	3.28	0.01
HTBLR006	BOILER 6	0.0013	STACK	29.720478	-95.206672	60	500	2	25
TKTKF814	TANK 814	0.0013	STACK	29.726439	-95.208864	50	70	3	0.01
HTBLR004	STEAM BOILER # 4	0.0010	STACK	29.720061	-95.206364	100	350	6	53
HTCRU001-S	CRUDE SCR SYSTEM	0.0007	STACK	29.720897	-95.210925	95	769	10	43
HTALK001	#1 ALKY HEATER	0.0003	STACK	29.720278	-95.209061	128	790	5	19.78
HTALK002	#2 ALKY HEATER	0.0003	STACK	29.720808	-95.208603	128	720	5	18.84
HTCRU004	CRUDE TOWER HEATER	0.0002	STACK	29.720889	-95.210108	33	430	3	19.73
HTFCC002	FCC CHARGE HEATER	0.0002	STACK	29.721853	-95.210892	121	975	5	22.14
HTLSG001	HEATER H-3701	0.0002	STACK	29.721256	-95.211014	131	500	2	25
HTREF201	REFORMATE SPLITTER HEAT.	0.0002	STACK	29.720122	-95.208422	75	655	3.08	12
HTREF001	REFORMER #2 HYDROTREATER	0.0001	STACK	29.721536	-95.210950	36	700	3	47.99
HTREF002	REFORMER #2 HYDROTREATER	0.0001	STACK	29.721628	-95.210942	33	710	3	39.56
						length ft			
Fugitive Sources (combined into a single VOLUME source)									
FEWWS	WASTEWATER SYSTEM REFINERY	0.0903	FUGITIVE	29.724151	-95.207361	3,117			
FUTKFBLD	BLENDER TANK FARM FUGITIVE EMISSIONS	0.0109	FUGITIVE						
FUBZSTR	BENZENE STRIPPER FUGITIVE EMISSIONS	0.0077	FUGITIVE						
FUCRU001	CRUDE UNIT FUGITIVES	0.0150	FUGITIVE						
FUSRU001	SRU FUGITIVES	0.0046	FUGITIVE						
FEWWS	WASTEWATER SYSTEM REFINERY	0.0011	FUGITIVE						
FUTKFP02	NO. 2 PUMPER TANK FARM FUGITIVES	0.0005	FUGITIVE						

Table 5. Houston NO_X Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
732B0002	FCCU CO BOILER WET GAS SCRUBBER	266.5055	STACK	29.710219	-95.231825	224	142	11	50.5
634F0001	634 REACTOR FEED HEATER	41.1256	STACK	29.714942	-95.231661	120	600	6.5	18
536F0002	VACUUM TOWER HEATER	35.6058	STACK	29.715603	-95.233597	180	360	10.75	9.7
537F0001	CRUDE HEATER NO. 1	35.1838	STACK	29.715642	-95.234031	190	400	9.5	27
737SP0080	HEATER F001-2	29.4774	STACK	29.713872	-95.240958	55	500	2	20
536F0001A	ATMOSPHERIC TOWER HEATER	28.5176	STACK	29.715678	-95.232967	190	326	9.5	11
736F0101A	736 COKER EAST HEATER H-101A	27.4904	STACK	29.712947	-95.242911	197	475	11.3	13.4
737SP0080	HEATER F001-2	27.3333	STACK	29.713872	-95.240958	55	500	2	20
736F0101B	736 COKER WEST HEATER H-101B	26.1974	STACK	29.712953	-95.243119	197	475	11.3	13.4
536F0001B	ATMOSPHERIC TOWER HEATER	25.5569	STACK	29.715669	-95.233350	190	294	9.5	10.5
537F0002	VACUUM HEATER NO. 1	23.3131	STACK	29.715642	-95.233981	190	400	7	38.5
440SP2010	THERMAL OXIDIZER CEMS	18.8608	STACK	29.717525	-95.232544	300	600	6	66.9
435SP1403	SRU THERMAL OXIDIZER	18.2291	STACK	29.719308	-95.233256	300	600	6	66.9
734F0101	BTU-DEPENT HEATER	15.6504	STACK	29.711108	-95.231564	161	700	6.5	17.4
533F0001	533 ATMOSPHERIC TOWER HEATER	13.7949	STACK	29.719136	-95.231214	120	699	4.5	22.7
338K0007	NO. 3 PLANT FLARE	13.7024	FLARE	29.713736	-95.237381	450	1832	5	65.6
736K0101A	736 COKER FLARE	13.6113	FLARE	29.714228	-95.242464	175	1832	3	65.6
733F0005	HEATER B5 - 733 LEF REBOILER	11.3136	STACK	29.712475	-95.233528	160	695	8	22.7
633F0001	633 FRACTIONATOR REBOILER	10.7243	STACK	29.713294	-95.231417	121	691	5	22.4
338K0008	NO. 4 PLANT FLARE	9.9215	FLARE	29.715222	-95.236947	300	1832	5	65.6
637F0001	637 REACTOR FEED HEATER	8.9923	STACK	29.713439	-95.233550	100	300	3	83.7
735SP0006	UNIFINER STRIP. REBOILER	7.3831	STACK	29.712914	-95.232092	110	700	5	19.7
735SP0006	UNIFINER STRIP. REBOILER	7.3831	STACK	29.712914	-95.232092	110	700	5	19.7
338K0001	NO. 1 PLANT FLARE	7.3566	FLARE	29.722208	-95.230281	260	1832	4	65.6
735SP0003	735 UNIFINER HEATER	7.0933	STACK	29.713039	-95.230492	121	950	5	14.3
735SP0003	735 UNIFINER HEATER	7.0933	STACK	29.713039	-95.230492	121	950	5	14.3
635F0001	635 REACTOR FEED HEATER	6.2471	STACK	29.714581	-95.231619	110	600	5	31.9
632F0002	632 LEF REBOILER	6.1272	STACK	29.711169	-95.233881	99	348	2.5	27.1
633F0002	633 REACTOR FEED HEATER	5.9722	STACK	29.713258	-95.231417	122	615	6	12.4
732F0001A	732 WEST HEATER	5.5679	STACK	29.710003	-95.231850	130	825	8.5	15.6
636F0001	636 REACTOR FEED HEATER	5.1331	STACK	29.713550	-95.231236	122	400	6.5	17.9
636F0002	636 FRACTIONATOR FEED HEATER	4.4516	STACK	29.714506	-95.231228	122	400	7.5	17.9
338K0002	NO. 2 PLANT FLARE	4.3792	FLARE	29.720953	-95.230356	325	1832	4	65.6
630F0001	SR HEATER	4.0476	STACK	29.710950	-95.233483	81	860	2	72.7
139SP1700A	MARINE VAPOR COMBUSTOR	4.0353	STACK	29.718664	-95.234058	71	1600	11.5	56.3
732F0001	732 EAST HEATER	3.6189	STACK	29.710000	-95.231994	130	825	8.5	15.6
534F0005	DEPENTANIZER TOWER HEATER	3.5116	STACK	29.712786	-95.233161	111	470	5.5	21.1
631F0002	LCO FEED HEATER	3.4169	STACK	29.711031	-95.233486	115	865	3.25	29.5
313TO0001	SSPU THERMAL OXIDZER	2.3573	STACK	29.716858	-95.235661	8	1400	4	4
533F0002	533 VACUUM TOWER HEATER	1.8130	STACK	29.719136	-95.231111	120	300	5	3
831F0201	831 REACTOR FEED HEATER	1.3164	STACK	29.718703	-95.231186	120	482	4.42	4.8
336COMP-1	TEMP COMPRESSORS	0.4707	STACK	29.716733	-95.233456	8	881	0.54	188
035P1905	035P1905	0.3772	STACK	29.722492	-95.233864	20	830	0.67	135
035P1902	035P1902	0.3730	STACK	29.718686	-95.237014	20	576	0.67	20
035P1901	035P1901	0.3709	STACK	29.718739	-95.236994	20	576	0.67	20
833F0001	833 1ST STAGE HEATER	0.2599	STACK	29.719319	-95.230900	100	200	5	2.1
336C0001	336C0001	0.2204	STACK	29.716792	-95.233261	8	925	0.42	333
833F0002	833 2ND STAGE HEATER	0.1696	STACK	29.719367	-95.230869	118	300	5	2.4
336C0002	336C0002	0.1497	STACK	29.716789	-95.233322	8	925	0.42	333
115-ENG1	ABRASIVE BLAST YARD ENGINE 1	0.1459	STACK	29.718606	-95.229983	5	840	0.25	265
632F0001	632 REACTOR FEED HEATER	0.1353	STACK	29.711025	-95.234383	100	347	2.5	12.1
035P0100	FIREWATER PUMP NO. 4 ENGINE	0.0951	STACK	29.716822	-95.236767	13	870	0.5	68
035P1904	035P1904	0.0948	STACK	29.723125	-95.232192	18	576	0.67	20
336C0003	336C0003	0.0873	STACK	29.716786	-95.233489	8	925	0.42	333
115-ENG2	ABRASIVE BLAST YARD ENGINE 2	0.0767	STACK	29.718697	-95.229811	5	840	0.25	265
338K0005	HOUSTON STREET FLARE	0.0669	FLARE	29.714383	-95.236981	50	1832	2	65.6
336C0004	336C0004	0.0651	STACK	29.716786	-95.233550	8	925	0.42	333
221G0001	221G0001	0.0530	STACK	29.708300	-95.238147	15	576	0.5	20
732G0001	732G0001	0.0231	STACK	29.709806	-95.232828	7	576	0.25	20
364G0003	364G0003	0.0152	STACK	29.709625	-95.235511	7	576	0.42	20
364G0001	364G0001	0.0050	STACK	29.709892	-95.236383	10	576	0.33	20
Not Modeled: Fugitive Sources									
365-MAINT	MAINTENANCE ACTIVITIES	0.0956	FUGITIVE						
338-UNIT	PIPERACK FUGITIVES	0.0140	FUGITIVE						
630-UNIT	FUGITIVE EMISSIONS 630	0.0070	FUGITIVE						
732-UNIT	FUG. FCCU	0.0001	FUGITIVE						
736-UNIT	736-UNIT	0.0007	FUGITIVE						

Table 6. Houston SO_2 Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
338K0001	NO. 1 PLANT FLARE	150.6609	FLARE	29.722208	-95.230281	260	1832	4	65.6
435SP1403	SRU THERMAL OXIDIZER	143.8928	STACK	29.719308	-95.233256	300	600	6	66.9
338K0007	NO. 3 PLANT FLARE	118.2875	FLARE	29.713736	-95.237381	450	1832	5	65.6
440SP2010	THERMAL OXIDIZER CEMS	98.2159	STACK	29.717525	-95.232544	300	600	6	66.9
732B0002	FCCU CO BOILER WET GAS SCRUBBER	71.0365	STACK	29.710219	-95.231825	224	142	11	50.5
338K0008	NO. 4 PLANT FLARE	44.3284	FLARE	29.715222	-95.236947	300	1832	5	65.6
338K0002	NO. 2 PLANT FLARE	38.7080	FLARE	29.720953	-95.230356	325	1832	4	65.6
338K0005	HOUSTON STREET FLARE	17.7868	FLARE	29.714383	-95.236981	50	1832	2	65.6
736K0101A	736 COKER FLARE	12.6499	FLARE	29.714228	-95.242464	175	1832	3	65.6
537F0001	CRUDE HEATER NO. 1	6.3617	STACK	29.715642	-95.234031	190	400	9.5	27
536F0002	VACUUM TOWER HEATER	5.8254	STACK	29.715603	-95.233597	180	360	10.75	9.7
537F0002	VACUUM HEATER NO. 1	5.7013	STACK	29.715642	-95.233981	190	400	7	38.5
313TO0001	SSPU THERMAL OXIDZER	4.8992	STACK	29.716858	-95.235661	8	1400	4	4
536F0001B	ATMOSPHERIC TOWER HEATER	4.8817	STACK	29.715669	-95.233350	190	294	9.5	10.5
536F0001A	ATMOSPHERIC TOWER HEATER	4.7484	STACK	29.715678	-95.232967	190	326	9.5	11
737SP0080	HEATER F001-2	3.7401	STACK	29.713872	-95.240958	55	500	2	20
733F0005	HEATER B5 - 733 LEF REBOILER	3.5251	STACK	29.712475	-95.233528	160	695	8	22.7
737SP0080	HEATER F001-2	3.3888	STACK	29.713872	-95.240958	55	500	2	20
736F0101A	736 COKER EAST HEATER H-101A	3.2148	STACK	29.712947	-95.242911	197	475	11.3	13.4
736F0101B	736 COKER WEST HEATER H-101B	3.2106	STACK	29.712953	-95.243119	197	475	11.3	13.4
637F0001	637 REACTOR FEED HEATER	1.7587	STACK	29.713439	-95.233550	100	300	3	83.7
634F0001	634 REACTOR FEED HEATER	1.3814	STACK	29.714942	-95.231661	120	600	6.5	18
636F0002	636 FRACTIONATOR FEED HEATER	1.2332	STACK	29.714506	-95.231228	122	400	7.5	17.9
633F0001	633 FRACTIONATOR REBOILER	1.2260	STACK	29.713294	-95.231417	121	691	5	22.4
633F0002	633 REACTOR FEED HEATER	1.0243	STACK	29.713258	-95.231417	122	615	6	12.4
636F0001	636 REACTOR FEED HEATER	0.9412	STACK	29.713550	-95.231236	122	400	6.5	17.9
533F0001	533 ATMOSPHERIC TOWER HEATER	0.8629	STACK	29.719136	-95.231214	120	699	4.5	22.7
734F0101	BTU-DEPENT HEATER	0.8177	STACK	29.711108	-95.231564	161	700	6.5	17.4
635F0001	635 REACTOR FEED HEATER	0.5699	STACK	29.714581	-95.231619	110	600	5	31.9
732F0001A	732 WEST HEATER	0.4994	STACK	29.710003	-95.231850	130	825	8.5	15.6
735SP0006	UNIFINER STRIP. REBOILER	0.4561	STACK	29.712914	-95.232092	110	700	5	19.7
735SP0006	UNIFINER STRIP. REBOILER	0.4553	STACK	29.712914	-95.232092	110	700	5	19.7
732F0001	732 EAST HEATER	0.3647	STACK	29.710000	-95.231994	130	825	8.5	15.6
632F0002	632 LEF REBOILER	0.3641	STACK	29.711169	-95.233881	99	348	2.5	27.1
631F0002	LCO FEED HEATER	0.3234	STACK	29.711031	-95.233486	115	865	3.25	29.5
534F0005	DEPENTANIZER TOWER HEATER	0.2765	STACK	29.712786	-95.233161	111	470	5.5	21.1
735SP0003	735 UNIFINER HEATER	0.2602	STACK	29.713039	-95.230492	121	950	5	14.3
735SP0003	735 UNIFINER HEATER	0.2579	STACK	29.713039	-95.230492	121	950	5	14.3
630F0001	SR HEATER	0.2531	STACK	29.710950	-95.233483	81	860	2	72.7
533F0002	533 VACUUM TOWER HEATER	0.1504	STACK	29.719136	-95.231111	120	300	5	3
139SP1700A	MARINE VAPOR COMBUSTOR	0.0242	STACK	29.718664	-95.234058	71	1600	11.5	56.3
336COMP-1	TEMP COMPRESSORS	0.0167	STACK	29.716733	-95.233456	8	881	0.54	188
632F0001	632 REACTOR FEED HEATER	0.0091	STACK	29.711025	-95.234383	100	347	2.5	12.1
831F0201	831 REACTOR FEED HEATER	0.0036	STACK	29.718703	-95.231186	120	482	4.42	4.8
833F0001	833 1ST STAGE HEATER	0.0023	STACK	29.719319	-95.230900	100	200	5	2.1
833F0002	833 2ND STAGE HEATER	0.0015	STACK	29.719367	-95.230869	118	300	5	2.4
115-ENG1	ABRASIVE BLAST YARD ENGINE 1	0.0007	STACK	29.718606	-95.229983	5	840	0.25	265
336C0001	336C0001	0.0004	STACK	29.716792	-95.233261	8	925	0.42	333
336C0002	336C0002	0.0003	STACK	29.716789	-95.233322	8	925	0.42	333
035P0100	FIREWATER PUMP NO. 4 ENGINE	0.0002	STACK	29.716822	-95.236767	13	870	0.5	68
035P1905	035P1905	0.0002	STACK	29.722492	-95.233864	20	830	0.67	135
115-ENG2	ABRASIVE BLAST YARD ENGINE 2	0.0002	STACK	29.718697	-95.229811	5	840	0.25	265
336C0003	336C0003	0.0002	STACK	29.716786	-95.233489	8	925	0.42	333
035P1901	035P1901	0.0001	STACK	29.718739	-95.236994	20	576	0.67	20
035P1902	035P1902	0.0001	STACK	29.718686	-95.237014	20	576	0.67	20
035P1904	035P1904	0.0001	STACK	29.723125	-95.232192	18	576	0.67	20
336C0004	336C0004	0.0001	STACK	29.716786	-95.233550	8	925	0.42	333
430TK0871	FIXED-ROOF TANK NO. 430TK0871	0.0567	STACK	29.720558	-95.233531	40	80	3	0.01
Not Modeled: Fugitive Sources									
365-MAINT	MAINTENANCE ACTIVITIES	0.0098	FUGITIVE						
430-UNIT	FUGITIVES	0.0037	FUGITIVE						
630-UNIT	FUGITIVE EMISSIONS 630	0.0025	FUGITIVE						
732-UNIT	FUG. FCCU	0.0607	FUGITIVE						
736-UNIT	736-UNIT	0.0194	FUGITIVE						

Table 7. Houston PM_{10} Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
732B0002	FCCU CO BOILER WET GAS SCRUBBER	98.1690	STACK	29.710219	-95.231825	224	142	11	50.5
537F0001	CRUDE HEATER NO. 1	7.5585	STACK	29.715642	-95.234031	190	400	9.5	27
536F0002	VACUUM TOWER HEATER	7.0300	STACK	29.715603	-95.233597	180	360	10.75	9.7
537F0002	VACUUM HEATER NO. 1	6.7394	STACK	29.715642	-95.233981	190	400	7	38.5
536F0001B	ATMOSPHERIC TOWER HEATER	5.9402	STACK	29.715669	-95.233350	190	294	9.5	10.5
536F0001A	ATMOSPHERIC TOWER HEATER	5.7634	STACK	29.715678	-95.232967	190	326	9.5	11
737SP0080	HEATER F001-2	4.6046	STACK	29.713872	-95.240958	55	500	2	20
737SP0080	HEATER F001-2	4.2979	STACK	29.713872	-95.240958	55	500	2	20
733F0005	HEATER B5 - 733 LEF REBOILER	4.2884	STACK	29.712475	-95.233528	160	695	8	22.7
736F0101B	736 COKER WEST HEATER H-101B	3.9580	STACK	29.712953	-95.243119	197	475	11.3	13.4
736F0101A	736 COKER EAST HEATER H-101A	3.9109	STACK	29.712947	-95.242911	197	475	11.3	13.4
440SP2010	THERMAL OXIDIZER CEMS	2.8726	STACK	29.717525	-95.232544	300	600	6	66.9
435SP1403	SRU THERMAL OXIDIZER	2.7764	STACK	29.719308	-95.233256	300	600	6	66.9
637F0001	637 REACTOR FEED HEATER	2.1132	STACK	29.713439	-95.233550	100	300	3	83.7
635CT3701	635 COOLING TOWER	1.7828	STACK	29.715756	-95.230469	20	80	10	15
634F0001	634 REACTOR FEED HEATER	1.7152	STACK	29.714942	-95.231661	120	600	6.5	18
636F0002	636 FRACTIONATOR FEED HEATER	1.5096	STACK	29.714506	-95.231228	122	400	7.5	17.9
633F0001	633 FRACTIONATOR REBOILER	1.4688	STACK	29.713294	-95.231417	121	691	5	22.4
633F0002	633 REACTOR FEED HEATER	1.3025	STACK	29.713258	-95.231417	122	615	6	12.4
636F0001	636 REACTOR FEED HEATER	1.1463	STACK	29.713550	-95.231236	122	400	6.5	17.9
734F0101	BTU-DEPENT HEATER	1.0373	STACK	29.711108	-95.231564	161	700	6.5	17.4
533F0001	533 ATMOSPHERIC TOWER HEATER	0.9123	STACK	29.719136	-95.231214	120	699	4.5	22.7
732CT3701	732 COOLING TOWER	0.9041	STACK	29.711936	-95.230178	20	80	10	15
536CT3701	536 COOLING TOWER	0.7412	STACK	29.715758	-95.230892	20	80	10	15
635F0001	635 REACTOR FEED HEATER	0.7141	STACK	29.714581	-95.231619	110	600	5	31.9
637CT3701	637 COOLING TOWER	0.6094	STACK	29.713475	-95.232486	20	80	10	15
732F0001A	732 WEST HEATER	0.5886	STACK	29.710003	-95.231850	130	825	8.5	15.6
537CT3701	537 COOLING TOWER	0.5480	STACK	29.717519	-95.232906	20	80	10	15
735SP0006	UNIFINER STRIP. REBOILER	0.5478	STACK	29.712914	-95.232092	110	700	5	19.7
735SP0006	UNIFINER STRIP. REBOILER	0.5477	STACK	29.712914	-95.232092	110	700	5	19.7
737D0001DP	737 COKER DRUM DEPRESSURIZATION	0.4570	STACK	29.713578	-95.240878	196	212	1.5	115
632F0002	632 LEF REBOILER	0.4411	STACK	29.711169	-95.233881	99	348	2.5	27.1
736D0101DP	736 COKER DRUM DEPRESSURIZATION	0.4072	STACK	29.712764	-95.243547	1	212	0.67	115
732F0001	732 EAST HEATER	0.3802	STACK	29.710000	-95.231994	130	825	8.5	15.6
631F0002	LCO FEED HEATER	0.3663	STACK	29.711031	-95.233486	115	865	3.25	29.5
534F0005	DEPENTANIZER TOWER HEATER	0.3200	STACK	29.712786	-95.233161	111	470	5.5	21.1
735SP0003	735 UNIFINER HEATER	0.3092	STACK	29.713039	-95.230492	121	950	5	14.3
735SP0003	735 UNIFINER HEATER	0.3091	STACK	29.713039	-95.230492	121	950	5	14.3
139SP1700A	MARINE VAPOR COMBUSTOR	0.3072	STACK	29.718664	-95.234058	71	1600	11.5	56.3
630F0001	SR HEATER	0.2935	STACK	29.710950	-95.233483	81	860	2	72.7
430CT3701	SRU COOLING TOWER (439 TGU)	0.2856	STACK	29.722353	-95.233053	20	80	10	15
430CT3791	SRU COOLING TOWER (439 CLAUS)	0.2183	STACK	29.722433	-95.233067	20	80	10	15
313TO0001	SSPU THERMAL OXIDZER	0.1792	STACK	29.716858	-95.235661	8	1400	4	4
533F0002	533 VACUUM TOWER HEATER	0.1586	STACK	29.719136	-95.231111	120	300	5	3
533CT3701	533 COOLING TOWER	0.1535	STACK	29.718714	-95.232083	20	80	10	15
737CT3701	COKER COOLING TOWER (737)	0.1381	STACK	29.715061	-95.239600	20	80	10	15
115-ENG1	ABRASIVE BLAST YARD ENGINE 1	0.1337	STACK	29.718606	-95.229983	5	840	0.25	265
831F0201	831 REACTOR FEED HEATER	0.1194	STACK	29.718703	-95.231186	120	482	4.42	4.8
338K0001	NO. 1 PLANT FLARE	0.0458	FLARE	29.722208	-95.230281	260	1832	4	65.6
338K0002	NO. 2 PLANT FLARE	0.0444	FLARE	29.720953	-95.230356	325	1832	4	65.6
736CT3701	COKER COOLING TOWER (736)	0.0442	STACK	29.713603	-95.242036	20	80	10	15
115-ENG2	ABRASIVE BLAST YARD ENGINE 2	0.0428	STACK	29.718697	-95.229811	5	840	0.25	265
035P1902	035P1902	0.0265	STACK	29.718686	-95.237014	20	576	0.67	20
035P1901	035P1901	0.0263	STACK	29.718739	-95.236994	20	576	0.67	20
338K0007	NO. 3 PLANT FLARE	0.0245	FLARE	29.713736	-95.237381	450	1832	5	65.6
736K0101A	736 COKER FLARE	0.0245	FLARE	29.714228	-95.242464	175	1832	3	65.6
737D0001DO	737 COKER DRUM OPENING	0.0229	STACK	29.713519	-95.240878	167	212	3	0.01
833F0001	833 1ST STAGE HEATER	0.0212	STACK	29.719319	-95.230900	100	200	5	2.1
736D0101DO	736 COKER DRUM OPENING	0.0204	STACK	29.712675	-95.242997	120	212	3	0.01
336COMP-1	TEMP COMPRESSORS	0.0147	STACK	29.716733	-95.233456	8	881	0.54	188
338K0008	NO. 4 PLANT FLARE	0.0147	FLARE	29.715222	-95.236947	300	1832	5	65.6
833F0002	833 2ND STAGE HEATER	0.0131	STACK	29.719367	-95.230869	118	300	5	2.4
632F0001	632 REACTOR FEED HEATER	0.0081	STACK	29.711025	-95.234383	100	347	2.5	12.1
035P1905	035P1905	0.0077	STACK	29.722492	-95.233864	20	830	0.67	135
336C0001	336C0001	0.0077	STACK	29.716792	-95.233261	8	925	0.42	333
336C0002	336C0002	0.0052	STACK	29.716789	-95.233322	8	925	0.42	333
338K0005	HOUSTON STREET FLARE	0.0051	FLARE	29.714383	-95.236981	50	1832	2	65.6

Table 7. Houston PM_{10} Emissions and Source Parameters (continued)

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
035P0100	FIREWATER PUMP NO. 4 ENGINE	0.0038	STACK	29.716822	-95.236767	13	870	0.5	68
221G0001	221G0001	0.0038	STACK	29.708300	-95.238147	15	576	0.5	20
336C0003	336C0003	0.0031	STACK	29.716786	-95.233489	8	925	0.42	333
336C0004	336C0004	0.0023	STACK	29.716786	-95.233550	8	925	0.42	333
035P1904	035P1904	0.0022	STACK	29.723125	-95.232192	18	576	0.67	20
732G0001	732G0001	0.0016	STACK	29.709806	-95.232828	7	576	0.25	20
364G0001	364G0001	0.0014	STACK	29.709892	-95.236383	10	576	0.33	20
364G0003	364G0003	0.0011	STACK	29.709625	-95.235511	7	576	0.42	20
Not Modeled: Fugitive Sources									
115-PAINT	PAINT BOOTH	0.5298	FUGITIVE						
737-LD-COK	737 RAILCAR COKE LOADING	0.1217	FUGITIVE						
365-MAINT	MAINTENANCE ACTIVITIES	0.0918	FUGITIVE						
134-UNIT	TANK 601	0.0585	FUGITIVE						
736-LD-COK	736 RAILCAR COKE LOADING	0.0333	FUGITIVE						
115-BLAST	SAND BLASTING ACTIVITIES	0.0179	FUGITIVE						

Table 8. Houston Benzene Emissions and Source Parameters

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
637CT3701	637 COOLING TOWER	0.4569	STACK	29.713475	-95.232486	20	80	10	15
137TK0687	IFR TANK NO. 137TK0687	0.2115	STACK	29.713019	-95.235936	48	80	3	0.01
137TK0865	IFR TANK NO. 137TK0865	0.1987	STACK	29.715642	-95.235147	48	80	3	0.01
635CT3701	635 COOLING TOWER	0.1878	STACK	29.715756	-95.230469	20	80	10	15
940TK0670	IFR TANK NO. 940TK0670	0.1459	STACK	29.713661	-95.235311	30	78	3	0.01
338K0001	NO. 1 PLANT FLARE	0.1383	FLARE	29.722208	-95.230281	260	1832	4	65.6
940TK0669	IFR TANK NO. 940TK0669	0.1360	STACK	29.713661	-95.235403	30	78	3	0.01
939TK0693	IFR TANK NO. 939TK0693	0.1350	STACK	29.713667	-95.235011	30	80	3	0.01
137TK0667	IFR TANK NO. 137TK0667	0.1243	STACK	29.714097	-95.235764	48	78	3	0.01
137TK0668	IFR TANK NO. 137TK0668	0.1133	STACK	29.714092	-95.236014	48	78	3	0.01
338K0007	NO. 3 PLANT FLARE	0.0949	FLARE	29.713736	-95.237381	450	1832	5	65.6
736K0101A	736 COKER FLARE	0.0907	FLARE	29.714228	-95.242464	175	1832	3	65.6
737D0001DP	737 COKER DRUM DEPRESSURIZATION	0.0729	STACK	29.713578	-95.240878	196	212	1.5	115
338K0008	NO. 4 PLANT FLARE	0.0689	FLARE	29.715222	-95.236947	300	1832	5	65.6
737-UNIT	737 COKER HEATER	0.0670	STACK	29.713983	-95.233953	6	70	1	0.01
736D0101DP	736 COKER DRUM DEPRESSURIZATION	0.0650	STACK	29.712764	-95.243547	1	212	0.67	115
134TK0609	FIXED-ROOF TANK NO. 134TK0609	0.0455	STACK	29.709331	-95.235400	42	80	3	0.01
536CT3701	536 COOLING TOWER	0.0435	STACK	29.715758	-95.230892	20	80	10	15
732CT3701	732 COOLING TOWER	0.0422	STACK	29.711936	-95.230178	20	80	10	15
134TK0619	EFR TANK NO. 134TK0619	0.0342	STACK	29.709289	-95.243222	48	64	3	0.01
537CT3701	537 COOLING TOWER	0.0319	STACK	29.717519	-95.232906	20	80	10	15
135TK0807	EFR TANK NO. 135TK0807	0.0271	STACK	29.707567	-95.238256	40	68	3	0.01
338K0002	NO. 2 PLANT FLARE	0.0263	FLARE	29.720953	-95.230356	325	1832	4	65.6
430CT3791	SRU COOLING TOWER (439 CLAUS)	0.0209	STACK	29.722433	-95.233067	20	80	10	15
313TO0001	SSPU THERMAL OXIDZER	0.0186	STACK	29.716858	-95.235661	8	1400	4	4
135TK0560	EFR TANK NO. 135TK0560	0.0183	STACK	29.708750	-95.229114	46	68	3	0.01
135TK0572	FIXED-ROOF TANK NO. 135TK0572	0.0182	STACK	29.707239	-95.241658	41	68	3	0.01
136TK0674	EFR TANK NO. 136TK0674	0.0177	STACK	29.710781	-95.230142	48	78	3	0.01
135TK0578	EFR TANK NO. 135TK0578	0.0172	STACK	29.707564	-95.250139	40	68	3	0.01
135TK0571	FIXED-ROOF TANK NO. 135TK0571	0.0166	STACK	29.707372	-95.240203	41	68	3	0.01
430CT3701	SRU COOLING TOWER (439 TGU)	0.0158	STACK	29.722353	-95.233053	20	80	10	15
737CT3701	COKER COOLING TOWER (737)	0.0158	STACK	29.715061	-95.239600	20	80	10	15
135TK0806	EFR TANK NO. 135TK0806	0.0137	STACK	29.707675	-95.237244	40	68	3	0.01
135TK0808	EFR TANK NO. 135TK0808	0.0132	STACK	29.707883	-95.235081	40	68	3	0.01
134TK0017	EFR TANK NO. 134TK0017	0.0126	STACK	29.711669	-95.237314	40	80	3	0.01
135TK0565	EFR TANK NO. 135TK0565	0.0123	STACK	29.707981	-95.234069	46	68	3	0.01
338K0005	HOUSTON STREET FLARE	0.0122	FLARE	29.714383	-95.236981	50	1832	2	65.6
139SP1700A	MARINE VAPOR COMBUSTOR	0.0119	STACK	29.718664	-95.234058	71	1600	11.5	56.3
133TK0884	IFR TANK NO. 133TK0884	0.0118	STACK	29.706006	-95.233611	48	84	3	0.01
133TK0878	IFR TANK NO. 133TK0878	0.0117	STACK	29.705511	-95.238767	48	108	3	0.01
135TK0809	EFR TANK NO. 135TK0809	0.0117	STACK	29.707714	-95.236067	40	68	3	0.01
134TK0613	IFR TANK NO. 134TK0613	0.0114	STACK	29.709122	-95.247672	48	67	3	0.01

Table 8. Houston Benzene Emissions and Source Parameters (continued)

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
134TK0802	EFR TANK NO. 134TK0802	0.0109	STACK	29.712422	-95.236078	40	85	3	0.01
133TK0879	IFR TANK NO. 133TK0879	0.0108	STACK	29.704836	-95.237586	48	60	3	0.01
135TK0576	EFR TANK NO. 135TK0576	0.0104	STACK	29.707050	-95.247017	48	68	3	0.01
134TK0777	EFR TANK NO. 134TK0777	0.0101	STACK	29.712628	-95.238347	40	78	3	0.01
135TK0562	EFR TANK NO. 135TK0562	0.0092	STACK	29.708300	-95.230728	46	68	3	0.01
135TK0564	EFR TANK NO. 135TK0564	0.0091	STACK	29.708083	-95.232903	46	130	3	0.01
533CT3701	533 COOLING TOWER	0.0091	STACK	29.718714	-95.232083	20	80	10	15
135TK0563	EFR TANK NO. 135TK0563	0.0090	STACK	29.708200	-95.231883	46	68	3	0.01
134TK0776	EFR TANK NO. 134TK0776	0.0085	STACK	29.712472	-95.237331	40	78	3	0.01
135TK0561	EFR TANK NO. 135TK0561	0.0083	STACK	29.708414	-95.229872	46	68	3	0.01
134TK0774	EFR TANK NO. 134TK0774	0.0079	STACK	29.711603	-95.236050	40	78	3	0.01
135TK0577	EFR TANK NO. 135TK0577	0.0071	STACK	29.707142	-95.247958	48	68	3	0.01
138TK0892	EFR TANK NO. 138TK0892	0.0067	STACK	29.718781	-95.229275	48	85	3	0.01
139SP1700A	MARINE VAPOR COMBUSTOR	0.0066	STACK	29.718664	-95.234058	71	1600	11.5	56.3
133TK0886	EFR TANK NO. 133TK0886	0.0059	STACK	29.706028	-95.232206	48	82	3	0.01
138TK0893	EFR TANK NO. 138TK0893	0.0058	STACK	29.718575	-95.229064	48	85	3	0.01
133TK0890	EFR TANK NO. 133TK0890	0.0052	STACK	29.706408	-95.229394	48	86	3	0.01
134TK0618	EFR TANK NO. 134TK0618	0.0050	STACK	29.710369	-95.243267	48	66	3	0.01
432TK0855	IFR TANK NO. 432TK0855	0.0048	STACK	29.716983	-95.237431	48	70	3	0.01
133TK0880	IFR TANK NO. 133TK0880	0.0046	STACK	29.705694	-95.236972	48	77	3	0.01
432TK0835	EFR TANK NO. 432TK0835	0.0045	STACK	29.720319	-95.229506	48	100	3	0.01
432TK0854	IFR TANK NO. 432TK0854	0.0044	STACK	29.716289	-95.237414	48	70	3	0.01
133TK0885	EFR TANK NO. 133TK0885	0.0043	STACK	29.705350	-95.232781	48	69	3	0.01
137TK0815	IFR TANK NO. 137TK0815	0.0042	STACK	29.713506	-95.236031	48	68	3	0.01
136TK0558	EFR TANK NO. 136TK0558	0.0037	STACK	29.715522	-95.227653	48	70	3	0.01
737D0001DO	737 COKER DRUM OPENING	0.0036	STACK	29.713519	-95.240878	167	212	3	0.01
736D0101DO	736 COKER DRUM OPENING	0.0032	STACK	29.712675	-95.242997	120	212	3	0.01
736CT3701	COKER COOLING TOWER (736)	0.0031	STACK	29.713603	-95.242036	20	80	10	15
133TK0881	133TK0881	0.0028	STACK	29.704961	-95.236047	48	77	3	0.01
138TK0272	FIXED-ROOF TANK NO. 138TK0272	0.0022	STACK	29.717319	-95.230803	32	200	3	0.01
537F0001	CRUDE HEATER NO. 1	0.0021	STACK	29.715642	-95.234031	190	400	9.5	27
134TK0850	EFR TANK NO. 134TK0850	0.0020	STACK	29.709319	-95.240889	40	76	3	0.01
536F0002	VACUUM TOWER HEATER	0.0020	STACK	29.715603	-95.233597	180	360	10.75	9.7
136TK0030A	TANK 30A	0.0019	STACK	29.711886	-95.228822	48	80	3	.01
537F0002	VACUUM HEATER NO. 1	0.0019	STACK	29.715642	-95.233981	190	400	7	38.5
536F0001B	ATMOSPHERIC TOWER HEATER	0.0017	STACK	29.715669	-95.233350	190	294	9.5	10.5
536F0001A	ATMOSPHERIC TOWER HEATER	0.0016	STACK	29.715678	-95.232967	190	326	9.5	11
138TK0006	EFR TANK NO. 138TK0006	0.0015	STACK	29.713400	-95.228981	40	80	3	0.01
737SP0080	HEATER F001-2	0.0013	STACK	29.713872	-95.240958	55	500	2	20
432TK0838	EFR TANK NO. 432TK0838	0.0012	STACK	29.719247	-95.228881	47	100	3	0.01
733F0005	HEATER B5 - 733 LEF REBOILER	0.0012	STACK	29.712475	-95.233528	160	695	8	22.7
737SP0080	HEATER F001-2	0.0012	STACK	29.713872	-95.240958	55	500	2	20
736F0101A	736 COKER EAST HEATER H-101A	0.0011	STACK	29.712947	-95.242911	197	475	11.3	13.4
736F0101B	736 COKER WEST HEATER H-101B	0.0011	STACK	29.712953	-95.243119	197	475	11.3	13.4
313CA0001	SSPU H-1 HOPPER CARBON ADSORBER	0.0010	STACK	29.716583	-95.234953	7	114	0.33	1
313CA0002	SSPU BACK - UP VENT CARBON ADSORBER	0.0010	STACK	29.716772	-95.235472	7	114	0.33	1
313-LOAD	SSPU TRANSFER OPERATIONS	0.0010	STACK	29.716864	-95.235414	5	114	3	0.5
736TK0923	FIXED ROOF TANK 736TK0923	0.0010	STACK	29.713031	-95.244361	22	80	3	0.01
136TK0100	IFR TANK NO. 136TK0100	0.0008	STACK	29.709350	-95.228953	40	70	3	0.01
138TK0271	FIXED-ROOF TANK NO. 138TK0271	0.0008	STACK	29.717328	-95.230381	32	200	3	0.01
138TK0273	FIXED-ROOF TANK NO. 138TK0273	0.0008	STACK	29.717317	-95.231050	32	185	3	0.01
134TK0012	FIXED-ROOF TANK NO. 134TK0012	0.0007	STACK	29.711728	-95.238150	40	80	3	0.01
137TK0873	IFR TANK NO. 137TK0873	0.0007	STACK	29.715217	-95.235739	48	85	3	0.01
135TK0573	EFR TANK NO. 135TK0573	0.0006	STACK	29.707131	-95.242750	48	68	3	0.01
634F0001	634 REACTOR FEED HEATER	0.0005	STACK	29.714942	-95.231661	120	600	6.5	18
637F0001	637 REACTOR FEED HEATER	0.0005	STACK	29.713439	-95.233550	100	300	3	83.7
133TK0883	IFR TANK NO. 133TK0883	0.0004	STACK	29.705117	-95.234356	48	78	3	0.01
139SP1700A	MARINE VAPOR COMBUSTOR	0.0004	STACK	29.718664	-95.234058	71	1600	11.5	56.3
533F0001	533 ATMOSPHERIC TOWER HEATER	0.0004	STACK	29.719136	-95.231214	120	699	4.5	22.7
633F0001	633 FRACTIONATOR REBOILER	0.0004	STACK	29.713294	-95.231417	121	691	5	22.4
633F0002	633 REACTOR FEED HEATER	0.0004	STACK	29.713258	-95.231417	122	615	6	12.4
636F0001	636 REACTOR FEED HEATER	0.0004	STACK	29.713550	-95.231236	122	400	6.5	17.9
636F0002	636 FRACTIONATOR FEED HEATER	0.0004	STACK	29.714506	-95.231228	122	400	7.5	17.9
139SP1700A	MARINE VAPOR COMBUSTOR	0.0003	STACK	29.718664	-95.234058	71	1600	11.5	56.3
734F0101	BTU-DEPENT HEATER	0.0003	STACK	29.711108	-95.231564	161	700	6.5	17.4
137TK0804	EFR TANK NO. 137TK0804	0.0002	STACK	29.717458	-95.236025	40	75	3	0.01
430TK4001	IFR TANK NO. 430TK4001	0.0002	STACK	29.720328	-95.229000	51	100	1	0.01

Table 8. Houston Benzene Emissions and Source Parameters (continued)

EPN	EPN Name	Emissions tons/yr	Source Type	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/sec
432TK0818	EFR TANK NO. 432TK0818	0.0002	STACK	29.719833	-95.230467	40	60	3	0.01
635F0001	635 REACTOR FEED HEATER	0.0002	STACK	29.714581	-95.231619	110	600	5	31.9
735SP0006	UNIFINER STRIP. REBOILER	0.0002	STACK	29.712914	-95.232092	110	700	5	19.7
735SP0006	UNIFINER STRIP. REBOILER	0.0002	STACK	29.712914	-95.232092	110	700	5	19.7
137TK0420	EFR TANK NO. 137TK0420	0.0001	STACK	29.716858	-95.235692	40	80	3	0.01
137TK0920	IFR TANK NO. 137TK0920	0.0001	STACK	29.715642	-95.235147	48	77	1	0.01
139SP1700A	MARINE VAPOR COMBUSTOR	0.0001	STACK	29.718664	-95.234058	71	1600	11.5	56.3
139SP1700A	MARINE VAPOR COMBUSTOR	0.0001	STACK	29.718664	-95.234058	71	1600	11.5	56.3
430TK4002	IFR TANK NO. 430TK4002	0.0001	STACK	29.719994	-95.228992	10	75	3	1
432TK0810	EFR TANK NO. 432TK0810	0.0001	STACK	29.719794	-95.229058	48	70	3	0.01
432TK0819	EFR TANK NO. 432TK0819	0.0001	STACK	29.719831	-95.230672	24	70	3	0.01
732F0001	732 EAST HEATER	0.0001	STACK	29.710000	-95.231994	130	825	8.5	15.6
732F0001A	732 WEST HEATER	0.0001	STACK	29.710003	-95.231850	130	825	8.5	15.6
Fugitive Sources (combined into a single VOLUME source)						length ft			
940-UNIT	FUGITIVES, ARU BT UNIT	1.4265	FUGITIVE	29.714499	-95.233002	4,987			
737-UNITCF	737 DECOKING OPERATIONS	0.8924	FUGITIVE						
736-UNITCF	736 DECOKING OPERATION	0.8920	FUGITIVE						
137-UNIT	CENTRAL TK FM FUG	0.7767	FUGITIVE						
432-SEWER	WASTEWATER UNIT FUGITIVES	0.6355	FUGITIVE						
365-MAINT	MAINTENANCE ACTIVITIES	0.5309	FUGITIVE						
734-UNIT	BTU FUGITIVES	0.4021	FUGITIVE						
338-UNIT	PIPERACK FUGITIVES	0.3194	FUGITIVE						
736-UNIT	736-UNIT	0.2852	FUGITIVE						
139-UNIT	FUGITIVE EMISS, DOCKS	0.1503	FUGITIVE						
439-UNIT	439 SRC NEW SECT FUG	0.1321	FUGITIVE						
536-UNIT	536 FUGITIVES	0.1049	FUGITIVE						
432TK0005	API SEPARATOR	0.0847	FUGITIVE						
430-UNIT	FUGITIVES	0.0749	FUGITIVE						
537-UNIT	FUGITIVES	0.0732	FUGITIVE						
632-UNIT	632HDS	0.0655	FUGITIVE						
230-UNIT	230 GAS PLANT FUG	0.0506	FUGITIVE						
735-UNIT	735 FUGITIVES	0.0487	FUGITIVE						
135-UNIT	FUGITIVE EMIS, SO TK FARM	0.0433	FUGITIVE						
134-UNIT	TANK 601	0.0366	FUGITIVE						
635-UNIT	635HDS	0.0259	FUGITIVE						
631-UNIT	631HDS	0.0212	FUGITIVE						
534-UNIT	534 FUG	0.0167	FUGITIVE						
733-UNIT	733	0.0128	FUGITIVE						
533-UNIT	533 FUG	0.0095	FUGITIVE						
235-UNIT	MEROX TREATER FUG	0.0093	FUGITIVE						
136-UNIT	EAST TK FM FUGITIVES	0.0053	FUGITIVE						
234-UNIT	BLACK LAKE UNIT FUG	0.0038	FUGITIVE						
233-UNIT	BRU FUGITIVES	0.0031	FUGITIVE						
432-UNIT	FUGITIVES-EMISSIONS	0.0023	FUGITIVE						
133-UNIT	225 TANK FM FUG	0.0021	FUGITIVE						
633-UNIT	633 FUGITIVES	0.0013	FUGITIVE						
634-UNIT	634HDS	0.0005	FUGITIVE						
432TK0008	GCWDA LIFT STATION	0.0004	FUGITIVE						
732-UNIT	FUG. FCCU	0.0003	FUGITIVE						

The locations of the Pasadena and Houston refineries are shown in Figure 1, below.

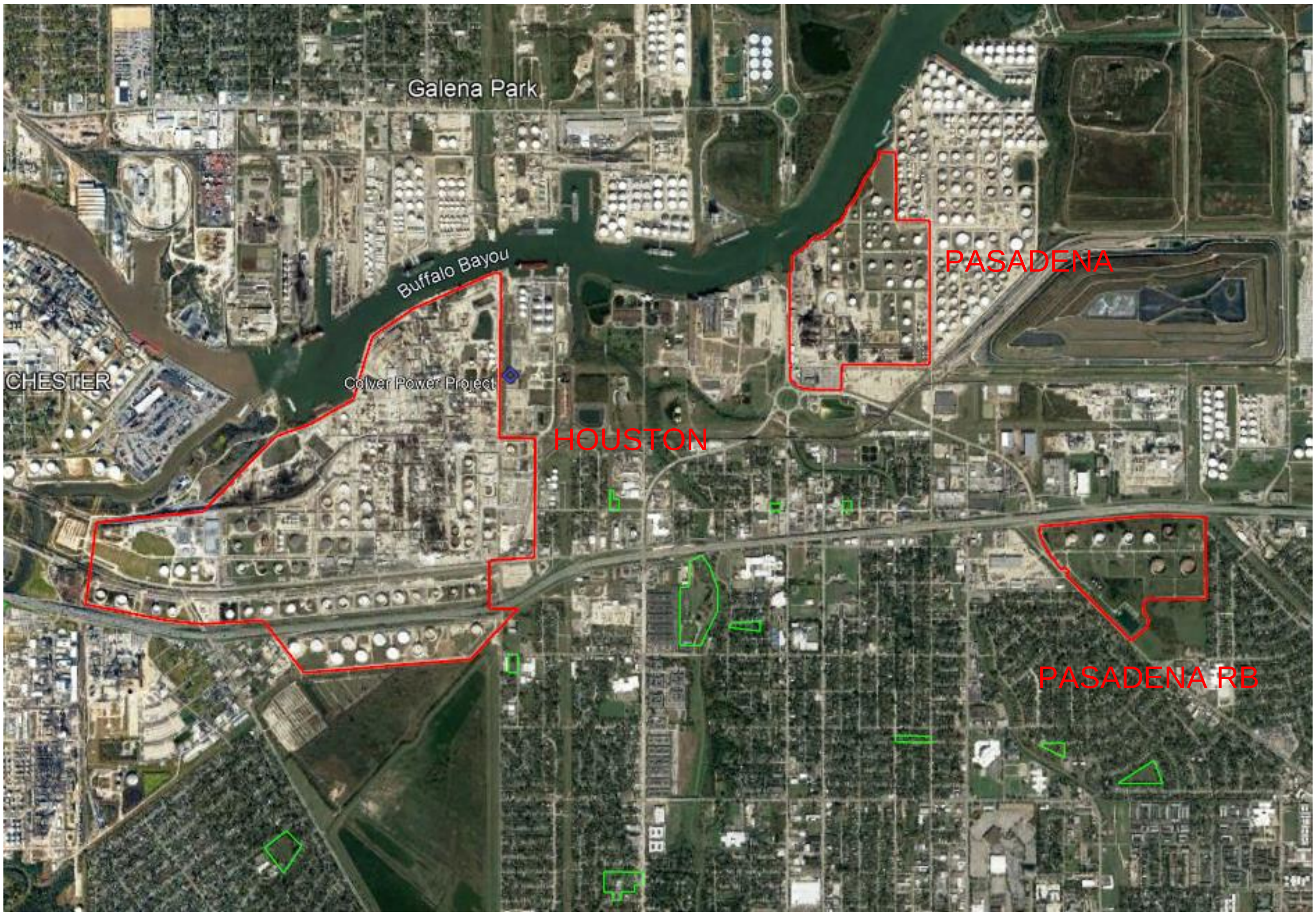


Figure 1. Houston and Pasadena refineries

C.2 Modeling Domain and Receptor Locations

The AERMOD modeling domain is a 20 km x 20 km square area, with the refineries located in the center of the domain. The AERMOD model is designed to estimate pollutant concentrations at a specified set of locations within the modeling domain, which are referred to as the modeled “receptors”. A nested grid of receptors covering the entire modeling domain was developed, with spacing of 100 m extending out to 5 km from the center, and 500 m spacing out to 10 km from the center. Receptors within the two refinery property boundaries were removed from the inner 100 m spaced grid, resulting in a total of 11,022 total receptors. The modeling domain (outer red box) and nested receptor grid (orange dots) are shown in Figure 2, below.

Figure 2. Modeling domain and nested receptor grid

In addition to the gridded receptors, a discrete set of sensitive neighborhood receptor locations were also developed at a number of residences, parks and schools surrounding the two refineries. The locations of these sensitive receptors are shown in Table 9 and Figures 3 and 4.

Table 9. Sensitive Receptor Locations

Receptor Site	Elevation	Location	
	m	LAT	LON
Galena Park Residence 1	2.71	29.733739	-95.229793
Galena Park Residence 2	4.15	29.732689	-95.230545
Galena Park Residence 3	9.69	29.733149	-95.246515
Galena Park Residence 4	8.92	29.733174	-95.254599
Galena Park Elementary School	8.46	29.735184	-95.239293
Galena Park Middle School	7.91	29.734833	-95.236608
Galena Park High School	7.09	29.739224	-95.236737
Galena Park City Park	7.35	29.742912	-95.23685
Galena Manor Park	8.17	29.743488	-95.249144
Greens Bayou Residence 1	6.81	29.751784	-95.217321
Greens Bayou Residence 2	7.74	29.758885	-95.198887
Manchester Residence	5.94	29.716157	-95.254756
Allendale Residence 1	8.51	29.704914	-95.242145
Allendale Residence 2	8.24	29.700867	-95.241952
Sunset Terrace Residence	7.41	29.707713	-95.225983
Blackwell Residence 1	7.08	29.712126	-95.225873
Blackwell Residence 2	6.77	29.715325	-95.223381
Magnolia Court Residence	6.72	29.715552	-95.21364
Memorial Park	6.03	29.708486	-95.217536
San Jacinto Terrace Residence	7.17	29.716125	-95.204723
Crane Park	6.78	29.713026	-95.208231
Pasadena Gardens Residence	7.62	29.708379	-95.194736
Gardens Park	7.97	29.70091	-95.195783
Red Bluff Terrace Residence	7.71	29.711842	-95.187174
Red Bluff Park	8.76	29.706455	-95.177932
Deepwater Residence	8.98	29.71086	-95.171217

Figure 3. Sensitive receptors (North)

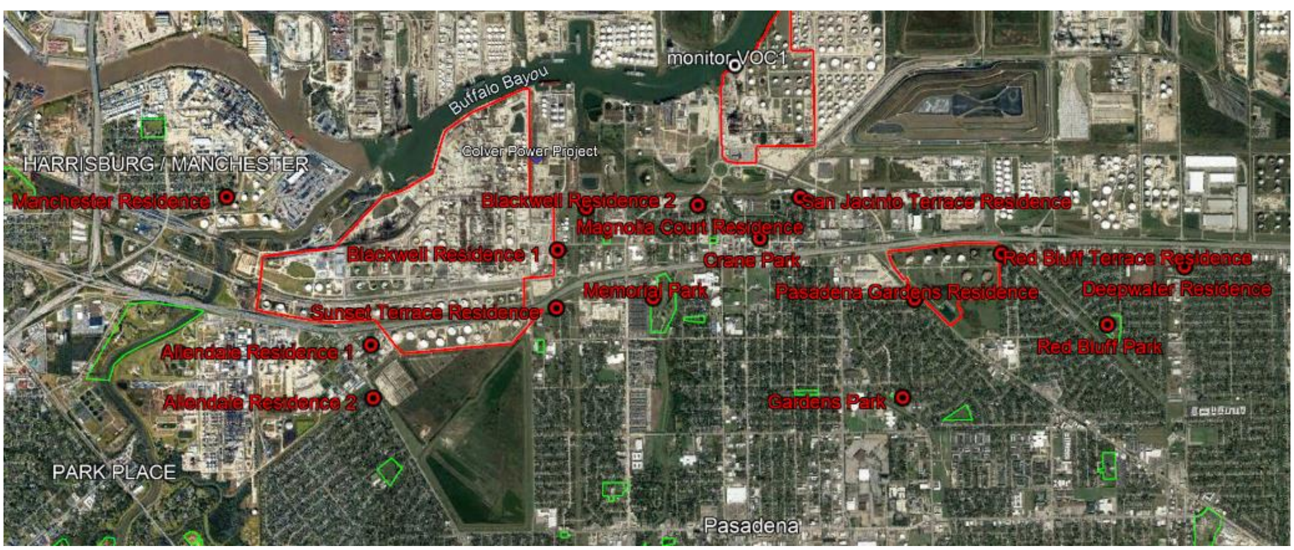


Figure 4. Sensitive receptors (South)

C.3 Terrain data

The elevations of all receptors within the nested receptor grid, the sensitive receptors, and all modeled point sources were obtained from the USGS 1x1-degree tiles for N34 W119 and N35 W119 which contain 1 arc-second resolved digital elevation model (DEM) data.[12] The DEM elevation data were processed using the AERMAP program (version 18081).

C.4 Meteorological Data

A set of meteorological data was developed for the current modeling application representing meteorological conditions during the calendar year 2019. The meteorological data were developed using the AERMET pre-processor program (version 16216)[13] which prepares the meteorological data necessary for input to AERMOD. The meteorological data incorporated hourly surface data and one-minute ASOS wind data collected at the Houston Hobby Airport (KHOU) meteorological monitoring station,[14] located about 8 km SW of the Houston refinery. The one-minute ASOS data were processed using the AERMINUTE program (version 15272)[15] which removes the overwhelming majority of the calm wind hours (which cannot be processed by AERMOD). The upper air data consisted of twice-daily radiosonde measurements (soundings) recorded each day at 0000 GMT and 1200 GMT at Lake Charles, LA.[16]

Surface characteristics in the vicinity of the meteorological tower were developed using 2016 land cover/land use data, percent impervious data, and percent tree canopy data from the National Land Cover Database (NLCD) obtained from the Multi-Resolution Land Characteristics (MRLC) Consortium[17]. These data were processed using AERSURFACE (version 20060)[18] to compute the surface roughness, albedo, and Bowen ratio for each month of the year, which were input to AERMET.

The AERMET meteorological preprocessor was used to merge the hourly surface and upper air data, and to estimate a number of required boundary layer parameters using the meteorological data and surface characteristics.

---

[12] Available from the USGS National Map at https://apps.nationalmap.gov/downloader/#/ or at https://gaftp.epa.gov/Air/aqmg/3dep/1_arcsecond/.

[13] U.S. Environmental Protection Agency. *User's Guide for the AERMOD Meteorological Preprocessor (AERMET)*. EPA-454/B-16-010. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. December 2016.

[14] Hourly surface data for station 722440-12918 (Houston Hobby Airport) are available at ftp://ftp.ncdc.noaa.gov/pub/data/noaa/. One minute ASOS wind data for the Houston Hobby Airport (station KHOU) are available at ftp://ftp.ncdc.noaa.gov/pub/data/asos-onemin/.

[15] U.S. Environmental Protection Agency. *AERMINUTE User's Guide*. EPA-454/B-15-006. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. October 2015.

[16] https://ruc.noaa.gov/raobs/

[17] https://www.mrlc.gov/viewer/. Also available at https://gaftp.epa.gov/Air/aqmg/nlcd/2016/.

[18] U.S. Environmental Protection Agency. *User's Guide for AERSURFACE Tool*. EPA-454/B-20-008. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. February 2020.

A wind rose plot showing the distribution of wind speeds and directions used in the current modeling application is shown in Figure 5, below (the wind directions indicate the direction that the wind is coming from). Although winds in 2019 occasionally originated from all directions, the predominant wind direction was from the SSE (however the direction for lower wind speeds which tend to result in higher concentration impacts is slightly oriented towards the southeast).

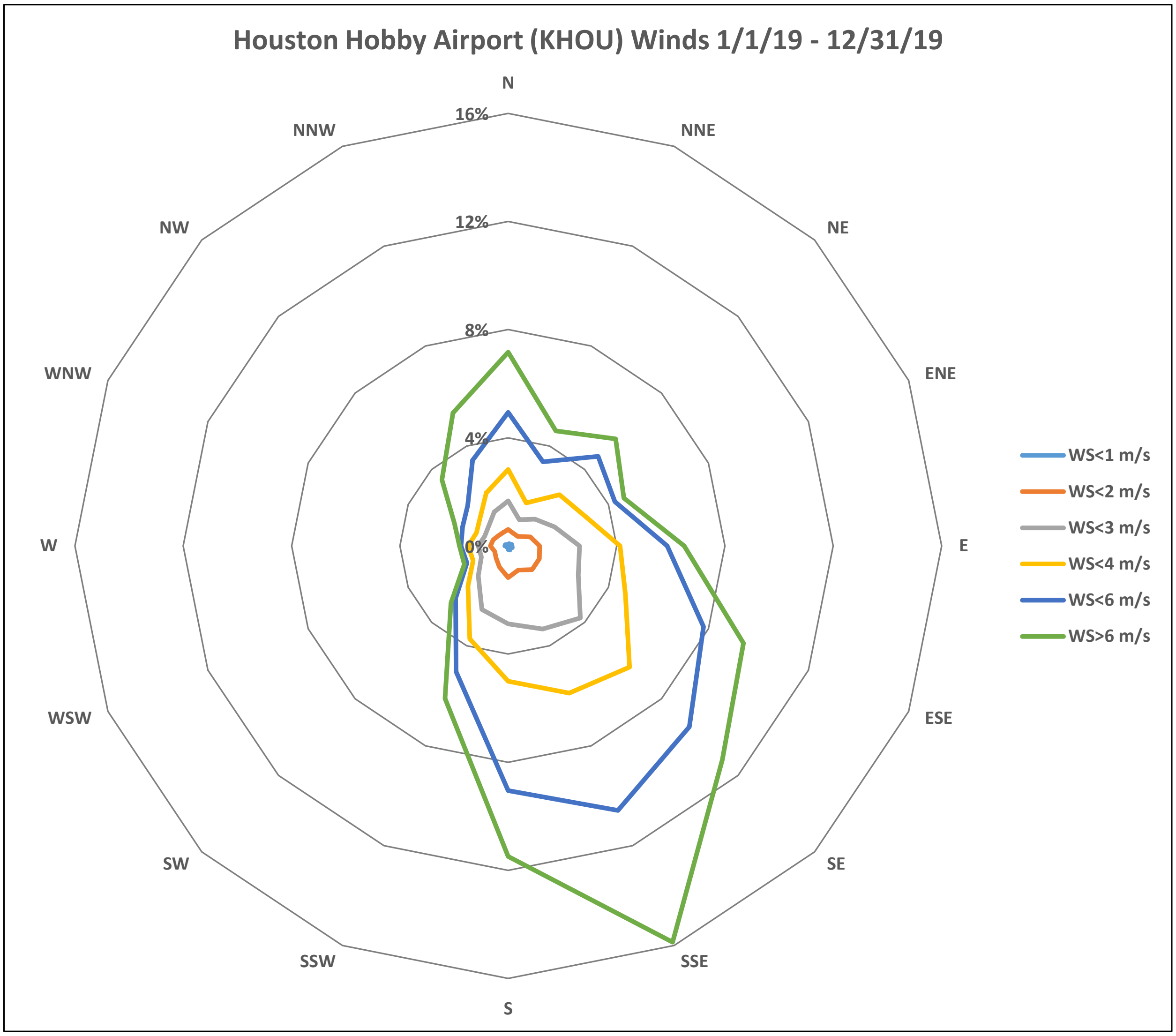


Figure 5. Houston wind rose for 2019

C.5 Modeling Options

A number of control options must be specified in order to execute the AERMOD model. For this application, regulatory default options were followed, which include the use of stack-tip downwash (for point releases), elevated (non-flat) terrain effects, and the calms and missing data processing as set forth in US EPA's modeling guidelines.[19] The model's averaging time was set to one hour and default flagpole receptor heights (for computation of ambient pollutant concentrations) were assumed to be 1.5 m. Since the two refineries are located in Houston, Texas, an urban area (estimated population: 2,310,000), therefore the "URBAN" modeling option was selected within AERMOD.[20]

C.6 Fenceline Benzene Monitoring

During 2019, monitors were used to measure two-week average benzene concentrations at a number of fenceline locations around each refinery. The fenceline monitoring locations are shown in Figures 6 through 8.

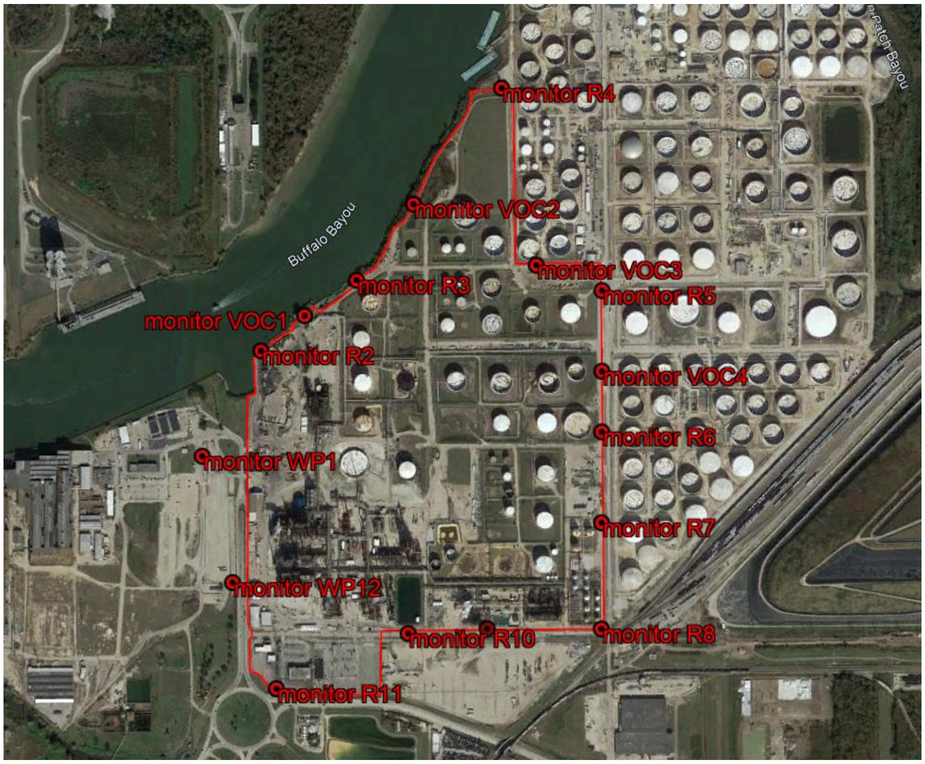


Figure 6. Pasadena Refinery fenceline benzene monitors

[19] U.S. Environmental Protection Agency. *Guideline on Air Quality Models, 40 CFR Part 51, Appendix W*. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.
[20] The "URBAN" modeling option incorporates the effects of increased surface heating from an urban area on pollutant dispersion under stable nighttime atmospheric conditions.

Figure 7. Pasadena refinery RB fenceline benzene monitors

Figure 8. Houston Refinery fenceline benzene monitors

C.7 Model Results

The AERMOD dispersion model was used to estimate the ambient pollutant concentrations on an hourly basis during 2019 based on hourly meteorological data and reported annual emission rates (converted to hourly average emission rates) for the various reported sources at the two refineries.

First, the modeled annual average benzene concentrations at each of the Pasadena and Houston refinery fenceline monitor locations are compared to the measured fenceline monitor benzene concentrations, as shown In Tables 10 and 11, below. As can be seen, the modeled annual average benzene concentrations <u>are much lower than the observed (measured) values</u>, which is a strong indication that the benzene emissions reported are likely significantly under-estimated. The ratio between measured and modeled annual average fenceline concentrations ranged from 13 to 167 for the Pasadena monitors and ranged from 3 to 43 for the Houston fenceline monitors. The modeled average of all the Pasadena fenceline monitors is only 3% of the average observed values and it is just 9% of the average observed values at the Houston fenceline monitoring locations.

The ratio of the average measured annual benzene concentrations divided by the average modeled annual benzene concentrations at all 28 Pasadena fenceline monitors is 30.9. The ratio of the average measured annual benzene concentrations divided by the average modeled annual benzene concentrations at the 12 RB Pasadena fenceline monitors is 116.6.

Table 10. Comparison Between Measured and Modeled 2019 Annual Average Benzene Concentrations at the Pasadena Refinery Fenceline Monitors

	Pasadena Refinery			Annual Average Benzene Concentration		Max 1-hr
				Measured	Modeled	Modeled
monitor	type	LAT	LON	µg/m³	µg/m³	µg/m³
R2	Regular Monitor	29.7255	-95.2114	3.657	0.162	2.892
R3	Regular Monitor	29.7269	-95.2092	6.182	0.312	3.405
R4	Regular Monitor	29.7307	-95.2059	6.056	0.117	2.158
R5	Regular Monitor	29.7267	-95.2036	5.013	0.080	2.726
R6	Regular Monitor	29.7239	-95.2036	4.677	0.059	2.456
R7	Regular Monitor	29.7221	-95.2036	3.751	0.047	1.857
R8	Regular Monitor	29.7200	-95.2036	2.512	0.042	1.365
R9	Regular Monitor	29.7200	-95.2062	3.041	0.044	1.265
R10	Regular Monitor	29.7199	-95.2080	2.811	0.040	1.129
R11	Regular Monitor	29.7188	-95.2110	1.829	0.032	0.931
WP1	Regular Monitor	29.7234	-95.2127	2.355	0.068	1.345
WP12	Regular Monitor	29.7209	-95.2120	2.077	0.044	1.072
VOC1	Regular Monitor	29.7262	-95.2104	29.236	1.660	12.674
VOC2	Regular Monitor	29.7284	-95.2079	6.176	0.468	4.132
VOC3	Regular Monitor	29.7272	-95.2051	6.510	0.158	4.054
VOC4	Regular Monitor	29.7251	-95.2036	4.736	0.069	2.480
RB14	Regular Monitor	29.7120	-95.1963	2.241	0.016	0.481
RB15	Regular Monitor	29.7123	-95.1937	1.573	0.017	0.450
RB16	Regular Monitor	29.7124	-95.1918	1.699	0.022	0.452
RB17	Regular Monitor	29.7125	-95.1901	1.859	0.023	0.399
RB18	Regular Monitor	29.7122	-95.1875	1.713	0.011	0.391
RB19	Regular Monitor	29.7100	-95.1875	1.551	0.011	0.401
RB20	Regular Monitor	29.7085	-95.1885	1.520	0.012	0.465
RB21	Regular Monitor	29.7084	-95.1905	1.397	0.013	0.363
RB22	Regular Monitor	29.7077	-95.1913	1.408	0.010	0.380
RB23	Regular Monitor	29.7073	-95.1929	1.535	0.009	0.388
RB24	Regular Monitor	29.7083	-95.1941	1.547	0.011	0.400
RB25	Regular Monitor	29.7098	-95.1954	1.622	0.013	0.434
	Average of all 28 Fenceline Monitors			3.939	0.128	
	Average of 12 RB Fenceline Monitors			1.639	0.014	

Table 11. Comparison Between Measured and Modeled 2019 Annual Average Benzene Concentrations at the Houston Refinery Fenceline Monitors

	Houston Refinery			Annual Average Benzene Concentration		Max 1-hr
				Measured	Modeled	Modeled
monitor	type	LAT	LON	µg/m³	µg/m³	µg/m³
1	Regular Monitor	29.7200	-95.2362	6.023	0.181	2.052
2	Regular Monitor	29.7225	-95.2335	8.265	0.559	4.244
3	Regular Monitor	29.7243	-95.2289	6.877	0.249	3.514
4	Regular Monitor	29.7194	-95.2284	2.549	0.070	1.703
5	Regular Monitor	29.7162	-95.2284	2.235	0.081	3.491
6	Regular Monitor	29.7145	-95.2263	2.210	0.051	2.153
7	Duplicate	29.7123	-95.2263	2.061	0.050	2.234
8	Regular Monitor	29.7099	-95.2289	1.971	0.081	2.226
9	Regular Monitor	29.7075	-95.2272	1.382	0.236	4.611
10	Regular Monitor	29.7057	-95.2291	1.318	0.233	4.325
11	Regular Monitor	29.7048	-95.2317	1.181	0.244	4.135
12	Regular Monitor	29.7046	-95.2343	1.247	0.248	4.206
13	Regular Monitor	29.7045	-95.2366	1.331	0.225	4.112
14	Regular Monitor	29.7041	-95.2391	1.091	0.181	4.035
15	Regular Monitor	29.7053	-95.2406	1.250	0.196	4.048
16	Regular Monitor	29.7067	-95.2430	1.292	0.200	4.055
17	Regular Monitor	29.7067	-95.2475	1.165	0.134	3.413
18	Regular Monitor	29.7085	-95.2520	1.202	0.111	2.846
19	Regular Monitor	29.7117	-95.2476	1.225	0.190	3.823
20	Regular Monitor	29.7138	-95.2437	1.614	0.406	4.790
21	Duplicate	29.7150	-95.2424	1.477	0.503	5.240
22	Regular Monitor	29.7160	-95.2413	1.672	0.650	5.632
23	Regular Monitor	29.7166	-95.2394	2.675	0.238	2.782
24	Regular Monitor	29.7172	-95.2383	5.979	0.274	2.413
	Average of all 24 Fenceline Monitors			2.471	0.233	

In particular, as shown in Table 10, the modeled annual average benzene concentration at Pasadena's VOC1 monitor was 1.66 µg/m³ (with a maximum hourly value of 12.67 µg/m³), which is significantly higher than any other monitoring location, although still much lower than the observed annual average of 29.24 µg/m³. The modeled concentration is almost entirely due to emissions from the marine loading incinerator source (EPN: INDOK001; annual emissions: 0.097 tpy, or 0.53 lb/day, which presumably does not include emissions during an "upset" event(s) that caused the 567 µg/m³ two-week average measured concentration during late October 2019), which is located about 15 meters from the VOC1 monitor. The high observed annual average at VOC1 was greatly impacted by the 43.5 µg/m³ and 567 µg/m³ two-week measurements that were recorded during Aug. 7 - 21, 2019 and Oct. 16 – 29, 2010, respectively (although there were 19 measured two-week average benzene concentrations at the VOC1 monitor out of 26 total that exceeded 4 µg/m³).

Figure 9. Pasadena's VOC1 fenceline monitor

Modeled pollutant concentrations for NO_X, SO_2, PM_{10}, and benzene for 2019 due to each refinery's emissions (using the provided spreadsheet emission inventory rates) are shown below in Tables 12 and 13. The tables show the modeled maximum annual average for each pollutant outside the property boundaries, which generally occurred near each facility. For NO_X, SO_2, and benzene, the tables show the modeled maximum 1-hour average concentration, and for PM_{10}, the tables show the modeled maximum 24-hour concentration. The rightmost column shows the modeled design value concentrations corresponding to the current US Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS)[21] for NO_X, SO_2, and PM_{10}.[22]

[21] https://www.epa.gov/criteria-air-pollutants/naaqs-table

[22] The one-hour NAAQS for NO_2 requires that the 98th percentile (8th high) of 1-hour daily maximum concentration (averaged over 3 years) must be below 100 ppb (188 µg/m^3). The one-hour NAAQS for SO_2 requires that the 99th percentile (4th high) of 1-hour daily maximum concentration (averaged over 3 years) must be below 75 ppb (196.2 µg/m^3). The 24-hour NAAQS for PM_{10} requires that the concentration must not exceed 150 µg/m^3 more than once per year (on average over 3 years).

Table 12. Modeled Concentrations Due to Pasadena Refinery Emissions

Pollutant		$\mu g/m^3$		$\mu g/m^3$		$\mu g/m^3$
NO_X	Max annual average:	13.21	Max 1-hr:	121.64	8th high daily max 1-hr:	107.23
SO_2	Max annual average:	2.10	Max 1-hr:	44.16	4th high daily max 1-hr:	40.28
PM_{10}	Max annual average:	1.29	Max 24 hr:	4.41	2nd high 24-hr average:	4.17
Benzene	Max annual average:	0.51	Max 1-hr:	4.23		

Table 13. Modeled Concentrations Due to Houston Refinery Emissions

Pollutant		$\mu g/m^3$		$\mu g/m^3$		$\mu g/m^3$
NO_X	Max annual average:	5.51	Max 1-hr:	59.69	8th high daily max 1-hr:	51.19
SO_2	Max annual average:	1.75	Max 1-hr:	13.89	4th high daily max 1-hr:	13.32
PM_{10}	Max annual average:	1.15	Max 24 hr:	5.69	2nd high 24-hr average:	5.52
Benzene	Max annual average:	0.76	Max 1-hr:	5.57		

The modeled benzene concentrations at Pasadena's Fenceline Monitor VOC1 due to the nearby marine loading incinerator source (EPN: INDOK001) were compared to the measured benzene concentrations at VOC1 for the seven two-week periods during 2019 in which the measured two-week average benzene concentration exceeded 9.0 $\mu g/m^3$. The ratio of the measured two-week average benzene concentration divided by the modeled two-week average benzene concentration for each period was used to scale, or "calibrate", the emission rate of the marine loading incinerator source so that the modeled two-week averages would match the measured fenceline values for each 2-week period. The marine loading incinerator source was then modeled with the calibrated, higher, emission rate for each two-week period to determine the concentration impacts at each of the 26 sensitive receptor locations. Table 14 shows the calibrated emission rate for the marine loading incinerator source for each period (and the emission inventory value) that was used for this modeling exercise. Tables 15 and 16 show the modeled two-week average benzene concentration due to the marine loading incinerator source and the modeled maximum 1-hour average benzene concentration due to the marine loading incinerator source at each receptor location.

As shown in Table 16, the maximum hourly benzene concentration due to the marine load incinerator source exceeded 11 $\mu g/m^3$ during the late October 2019 2-week period at the Magnolia Court Residence, located 1.2 km SSW of the source.

Table 14. Two-week Average Measured Benzene Concentrations at VOC1 and Calibrated Emission Rates for the Marine Load Incinerator (INDOK001)

Period	Two-week Average Benzene at VOC1 (µg/m3)	Calibrated Benzene Emissions (lb/day)
A: Jan 9 - Jan 27, 2019	9.5	2.55
B: Apr 17 - May 1, 2019	9.1	4.57
C: May 30 - Jun 12, 2019	12.3	2.95
D: Jul 10 - Jul 24, 2019	11	8.19
E: Aug 7 - Aug 21, 2019	43.5	19.05
F: Aug 21 - Sep 4, 2019	10.1	2.19
G: Oct 16 - Oct 30, 2019	567	115.26
Emissions Inventory		0.53

Table 15. Modeled 2-week Average Benzene Concentrations (µg/m^3) Due to Calibrated Marine Load Incinerator (Pasadena) Emissions[23]

Location	UTMx	UTMy	elev (m)	dist (km)	A 2-wk avg	B 2-wk avg	C 2-wk avg	D 2-wk avg	E 2-wk avg	F 2-wk avg	G 2-wk avg
Galena Park Residence 1	284342	3291364	2.7	2.1	0.0074	0.0064	0.0062	0.0046	0.0221	0.0047	0.2908
Galena Park Residence 2	284267	3291249	4.2	2.1	0.0067	0.0052	0.0055	0.0042	0.0239	0.0045	0.3297
Galena Park Residence 3	282723	3291330	9.7	3.6	0.0020	0.0016	0.0022	0.0009	0.0128	0.0018	0.1829
Galena Park Residence 4	281941	3291348	8.9	4.4	0.0012	0.0011	0.0019	0.0007	0.0071	0.0013	0.1263
Galena Park Elementary School	283426	3291542	8.5	3.0	0.0040	0.0021	0.0027	0.0013	0.0153	0.0020	0.2096
Galena Park Middle School	283685	3291498	7.9	2.7	0.0048	0.0027	0.0034	0.0015	0.0162	0.0024	0.2259
Galena Park High School	283682	3291985	7.1	2.9	0.0047	0.0047	0.0041	0.0023	0.0075	0.0024	0.1275
Galena Park City Park	283679	3292394	7.4	3.2	0.0047	0.0070	0.0032	0.0034	0.0079	0.0033	0.0918
Galena Manor Park	282491	3292481	8.2	4.2	0.0026	0.0021	0.0023	0.0010	0.0044	0.0013	0.0685
Greens Bayou Residence 1	285587	3293341	6.8	2.9	0.0022	0.0058	0.0040	0.0290	0.0682	0.0061	0.1048
Greens Bayou Residence 2	287385	3294094	7.7	3.8	0.0008	0.0024	0.0015	0.0064	0.0519	0.0010	0.0576
Manchester Residence	281889	3289462	5.9	4.4	0.0022	0.0008	0.0019	0.0013	0.0024	0.0009	0.1706
Allendale Residence 1	283085	3288192	8.5	3.9	0.0018	0.0005	0.0014	0.0030	0.0025	0.0011	0.0834
Allendale Residence 2	283095	3287743	8.2	4.2	0.0015	0.0004	0.0009	0.0029	0.0022	0.0007	0.0565
Sunset Terrace Residence	284655	3288472	7.4	2.6	0.0023	0.0010	0.0019	0.0040	0.0052	0.0018	0.1007
Blackwell Residence 1	284675	3288961	7.1	2.2	0.0034	0.0013	0.0026	0.0078	0.0069	0.0022	0.1603
Blackwell Residence 2	284923	3289311	6.8	1.7	0.0056	0.0019	0.0041	0.0114	0.0101	0.0034	0.2471
Magnolia Court Residence	285866	3289318	6.7	1.2	0.0152	0.0041	0.0126	0.0178	0.0257	0.0123	0.3949
Memorial Park	285474	3288542	6.0	2.1	0.0062	0.0017	0.0046	0.0055	0.0107	0.0056	0.1502
San Jacinto Terrace Residence	286730	3289365	7.2	1.2	0.0095	0.0169	0.0104	0.0146	0.0272	0.0107	0.2169
Crane Park	286384	3289028	6.8	1.5	0.0118	0.0067	0.0084	0.0179	0.0198	0.0086	0.2320
Pasadena Gardens Residence	287680	3288488	7.6	2.5	0.0031	0.0049	0.0018	0.0037	0.0067	0.0016	0.0660
Gardens Park	287563	3287662	8.0	3.1	0.0020	0.0036	0.0021	0.0029	0.0058	0.0024	0.0450
Red Bluff Terrace Residence	288419	3288858	7.7	2.7	0.0011	0.0043	0.0024	0.0043	0.0134	0.0016	0.0574
Red Bluff Park	289302	3288244	8.8	3.8	0.0006	0.0025	0.0014	0.0024	0.0078	0.0009	0.0323
Deepwater Residence	289961	3288720	9.0	4.1	0.0004	0.0018	0.0010	0.0018	0.0024	0.0008	0.0331

[23] dist = distance (km) between the marine load incinerator source (INDOK001) and the receptor location.

Table 16. Modeled Maximum 1-hour Average Benzene Concentrations (µg/m^3) Due to Calibrated Marine Load Incinerator (Pasadena) Emissions

					A	B	C	D	E	F	G
Location	UTMx	UTMy	elev (m)	dist (km)	max 1-hr	max 1-hr	max 1-hr	max 1-hr	max 1-hr	max 1-hr	max 1-hr
Galena Park Residence 1	284342	3291364	2.7	2.1	0.17	0.30	0.13	0.15	0.61	0.12	5.21
Galena Park Residence 2	284267	3291249	4.2	2.1	0.15	0.22	0.13	0.06	0.71	0.09	6.41
Galena Park Residence 3	282723	3291330	9.7	3.6	0.12	0.19	0.12	0.01	1.06	0.11	6.70
Galena Park Residence 4	281941	3291348	8.9	4.4	0.06	0.10	0.11	0.01	0.59	0.06	4.44
Galena Park Elementary School	283426	3291542	8.5	3.0	0.14	0.13	0.12	0.01	1.14	0.08	6.52
Galena Park Middle School	283685	3291498	7.9	2.7	0.14	0.21	0.14	0.02	1.10	0.09	6.02
Galena Park High School	283682	3291985	7.1	2.9	0.12	0.17	0.17	0.27	0.24	0.10	6.42
Galena Park City Park	283679	3292394	7.4	3.2	0.16	0.16	0.12	0.34	0.43	0.12	5.44
Galena Manor Park	282491	3292481	8.2	4.2	0.10	0.17	0.13	0.07	0.19	0.09	2.22
Greens Bayou Residence 1	285587	3293341	6.8	2.9	0.14	0.18	0.17	0.50	1.22	0.11	7.31
Greens Bayou Residence 2	287385	3294094	7.7	3.8	0.03	0.13	0.06	0.19	0.90	0.05	3.42
Manchester Residence	281889	3289462	5.9	4.4	0.09	0.05	0.08	0.11	0.02	0.04	3.63
Allendale Residence 1	283085	3288192	8.5	3.9	0.12	0.01	0.05	0.14	0.02	0.10	3.44
Allendale Residence 2	283095	3287743	8.2	4.2	0.09	0.01	0.06	0.10	0.01	0.02	1.78
Sunset Terrace Residence	284655	3288472	7.4	2.6	0.08	0.03	0.07	0.12	0.03	0.09	4.34
Blackwell Residence 1	284675	3288961	7.1	2.2	0.12	0.02	0.14	0.25	0.04	0.09	6.10
Blackwell Residence 2	284923	3289311	6.8	1.7	0.28	0.03	0.20	0.32	0.07	0.10	6.45
Magnolia Court Residence	285866	3289318	6.7	1.2	0.58	0.07	0.62	0.44	2.28	0.46	11.07
Memorial Park	285474	3288542	6.0	2.1	0.24	0.05	0.21	0.15	0.90	0.18	6.52
San Jacinto Terrace Residence	286730	3289365	7.2	1.2	0.36	0.81	0.56	0.63	2.06	0.48	5.35
Crane Park	286384	3289028	6.8	1.5	0.40	0.61	0.39	0.63	1.24	0.30	7.56
Pasadena Gardens Residence	287680	3288488	7.6	2.5	0.11	0.39	0.10	0.20	0.39	0.16	1.29
Gardens Park	287563	3287662	8.0	3.1	0.09	0.16	0.13	0.17	0.59	0.13	1.47
Red Bluff Terrace Residence	288419	3288858	7.7	2.7	0.06	0.27	0.13	0.29	1.31	0.12	1.19
Red Bluff Park	289302	3288244	8.8	3.8	0.03	0.17	0.08	0.19	0.91	0.07	0.77
Deepwater Residence	289961	3288720	9.0	4.1	0.00	0.08	0.05	0.16	0.04	0.07	4.56

The modeled benzene concentrations (due to all sources of benzene at the Pasadena refinery) at the 26 sensitive receptor locations were determined using increased emission rates, with emission rates from the spreadsheet emissions inventory scaled to account for the higher fenceline monitor measurements. The emission rates were scaled using (1) the ratio of the average measured annual benzene concentrations divided by the average modeled annual benzene concentrations at all 28 Pasadena fenceline monitors (30.9), and (2) the ratio of the average measured annual benzene concentrations divided by the average modeled annual benzene concentrations at the 12 RB Pasadena fenceline monitors (116.6), as described above (see Table 10). All Pasadena refinery sources were scaled by the same ratio. The resulting modeled benzene concentrations due to the scaled Pasadena emissions are shown in Table 17. The last five locations in the table surround the RB fenceline monitors, so the model results using the 116.6 scaling factor can be considered appropriate for these locations.

Table 17. Modeled Benzene Concentrations Due to Scaled Pasadena Emissions (entire facility), µg/m^3

Location	UTMx	UTMy	elev (m)	max 1-hr emissions x 30.9	max 1-hr emissions x 116.6	max 24-hr emissions x 30.9	max 24-hr emissions x 116.6	annual average emissions x 30.9	annual average emissions x 116.6
North									
Galena Park Residence 1	284342	3291364	2.7	10.46	39.48	2.24	8.45	0.35	1.33
Galena Park Residence 2	284267	3291249	4.2	10.69	40.34	1.99	7.50	0.33	1.26
Galena Park Residence 3	282723	3291330	9.7	7.25	27.36	1.11	4.20	0.14	0.55
Galena Park Residence 4	281941	3291348	8.9	5.80	21.87	0.83	3.14	0.11	0.40
Galena Park Elementary School	283426	3291542	8.5	8.79	33.19	1.34	5.04	0.21	0.78
Galena Park Middle School	283685	3291498	7.9	9.43	35.60	1.56	5.88	0.24	0.89
Galena Park High School	283682	3291985	7.1	8.10	30.55	1.72	6.50	0.23	0.86
Galena Park City Park	283679	3292394	7.4	7.73	29.15	1.43	5.40	0.22	0.85
Galena Manor Park	282491	3292481	8.2	5.76	21.73	1.08	4.08	0.13	0.50
Greens Bayou Residence 1	285587	3293341	6.8	8.49	32.02	1.78	6.73	0.33	1.24
Greens Bayou Residence 2	287385	3294094	7.7	6.85	25.86	1.04	3.91	0.15	0.55
South									
Manchester Residence	281889	3289462	5.9	4.60	17.37	0.74	2.78	0.09	0.32
Allendale Residence 1	283085	3288192	8.5	6.23	23.51	0.83	3.13	0.09	0.33
Allendale Residence 2	283095	3287743	8.2	5.80	21.89	0.86	3.26	0.08	0.30
Sunset Terrace Residence	284655	3288472	7.4	9.38	35.39	1.27	4.79	0.16	0.62
Blackwell Residence 1	284675	3288961	7.1	11.06	41.74	2.10	7.91	0.21	0.80
Blackwell Residence 2	284923	3289311	6.8	13.17	49.68	2.92	11.04	0.29	1.09
Magnolia Court Residence	285866	3289318	6.7	18.90	71.33	2.87	10.83	0.50	1.88
Memorial Park	285474	3288542	6.0	11.03	41.64	1.34	5.06	0.22	0.83
San Jacinto Terrace Residence	286730	3289365	7.2	25.55	96.42	5.96	22.48	0.82	3.11
Crane Park	286384	3289028	6.8	18.12	68.38	3.79	14.30	0.54	2.03
Pasadena Gardens Residence	287680	3288488	7.6	11.72	44.24	2.37	8.95	0.33	1.26
Gardens Park	287563	3287662	8.0	8.87	33.47	1.77	6.68	0.18	0.68
Red Bluff Terrace Residence	288419	3288858	7.7	11.53	43.52	2.54	9.58	0.32	1.20
Red Bluff Park	289302	3288244	8.8	7.92	29.90	1.49	5.63	0.09	0.33
Deepwater Residence	289961	3288720	9.0	6.89	26.00	0.93	3.50	0.07	0.26

D. Potential Emissions Controls

It is clear from the results discussed above that the reported benzene emissions for the two refineries are significantly under-estimated and that, if properly adjusted, can result in significant offsite impacts.

Further, as previously discussed, the emissions reported for the other pollutants are also poorly estimated and do not appear to use site-specific data to accurately estimate emissions under all conditions, especially startup and shutdown, which can result in significant emissions, especially from the flares.

Although refinery-specific process data were not available to conduct a thorough assessment of potential emissions reduction technologies, strategies, or approaches that can and should be considered to reduce the likely higher actual emissions of various pollutants (i.e., higher than what are reported), the following is a general discussion of potential emissions control options that could be used to minimize emissions. While application of RACT and BACT emissions limits are established via specific regulatory triggers, this discussion focuses on the technical aspects of such options without regard to such programmatic regulatory drivers.

First, as a singularly large fraction of emissions of SO_2, VOCs (including HAPs), NO_X, and PM_{10} (from smoking conditions), minimizing flaring emissions can reduce refinery emissions significantly. While so-called flare management plans are now required by regulation (such as MACT Subpart CC, etc.), actual emission reductions are rarely achieved via implementation of such plans. In terms of emissions reductions, the best option is to minimize flaring to the greatest extent feasible by diverting as much of the flare gases for use as fuel gas (after they are cleaned via reduction of sulfur species). This requires additional recovery compressor capacity. This is a commonly used strategy as can be confirmed in numerous flare gas management plans in place at most refineries in the US. So-called flare gas management systems were widely required as a result of EPA's refinery sector enforcement cases since 2000.[24]

As part of flare gas minimization, additional storage of diverted gases should also be considered. Any flaring should be limited to emergency conditions only and as part of meeting safety requirements. Next, to the extent that some flaring is still allowed, any non-emergency destruction and disposal should only be conducted via thermal/catalytic oxidizers or vapor combustors as opposed to open-flame stack flares. The latter are simply not designed to have sufficient residence time in order to ensure proper destruction of VOCs – i.e., they are not air pollution control devices by design and are simply used as such, with no assurance of steady combustion conditions, a pre-requisite for any combustion device that is used to achieve a consistent level of perfrmance. In contrast, vapor combustors and oxidizers are explicitly designed to achieve a requisite level of destruction efficiency, by design. And their NO_X emissions

[24] See, for example, various consent decrees at https://www.epa.gov/enforcement/petroleum-refinery-national-case-results

can also be substantially reduced by using low-NO_X burners and catalytic oxidation where feasible. Implementation of these strategies will reduce flaring emissions of SO_2, PM_{10}, NO_X and VOCs from each refinery.

Second, with regard to additional reductions of SO_2 emissions, the next highest sources are the sulfur plant and the FCCUs. While no additional controls are needed, operational details of the sulfur plant and FCCU often dictate SO_2 emissions from these units. These include operating conditions of the Claus/SCOT units and the details of any SO_2-reducing catalysts used in the FCCU, for example. Unfortunately, reporting of critical process variables is scant for these two refineries. Thus, opportunities for further reduction of SO_2 emissions via optimization, cannot be assessed. Once sulfur compounds are removed from the waste gases throughout the refinery and converted to elemental sulfur in the Claus/SCOT units, the sulfur content of refinery fuel gas is typically low enough that combustion of RFG in the various combustion devices in the refineries should not result in appreciable SO_2 emissions at these devices.

Third, with regard to NO_X emissions, while most of the combustion devices likely already have low-NO_X or similar burners, this cannot be confirmed in each instance, based on a review of the underlying permits. We note that the emissions estimates presume zero efficiency for NOx reduction from the various combustion devices. Any NO_X reduction strategy must ensure that low-NOx burners and combustion optimization strategies such as minimization of air leakage and use of parametric neural networks are used to the maximum extent feasible. Next, as discussed above, flaring (and related NO_X) emissions should be minimized. After these options, the use of add-on NO_X controls such as SCR or SNCR should be considered. While these add-on controls are generally technically feasible, cost considerations (and cost-effectiveness) often preclude their installation. Subject to cost considerations, SCR, for example, can provide dramatic NO_X reductions of over 75-90% depending on inlet NO_X levels.

Fourth, with regard to VOC emissions, minimizing such emissions (and associated VOC HAP emissions) requires addressing emissions from storage tanks, the wastewater system (including collection and distribution systems as well as the final wastewater treatment plant), loading racks, and finally, refinery-wide fugitive emissions from components. There are no one-size-fits-all strategies, unfortunately.

To the extent feasible all volatile liquids (including intermediates and slop tanks) with vapor pressures greater than 5 mm Hg or so should be stored in internal floating roof tanks, with vapor controls since these types of tanks along with vapor control provide the maximum level of emissions control from storage, which would result from the higher vapor pressure materials. Thus, the widespread use of fixed roof tanks or even external floating roof tanks for storing such substances should be avoided. Fugitive emissions from myriad locations in an external floating roof tank, i.e., from various fittings, roof penetrations, and rim seals are particularly problematic.[25]

[25] See, for example, the 2015 refinery protocol previously cited.

Wastewater collection and piping systems should be closed to the maximum extent possible avoiding fugitive emissions as a result. At the wastewater treatment plant, collection and control systems (such as vapor combustors) will reduce VOC emissions substantially. Flaring should be avoided.

As to fugitive emissions from refinery-wide components, it is highly recommended that: (i) leakless components such as sealless pumps or magnetic-drive pumps, be used in all high-VOC containing streams; and (ii) LDAR programs be replaced (or, at the very least, supplemented) by the use of optical gas imaging or continuous monitoring (using technologies similar to fenceline monitoring, for example).[26] Current Method 21-based LDAR programs are resource intensive and not very effective especially as typically implemented relying on large teams of often poorly trained personnel using hand-held sniffers that may or may not be properly used in the field. In contrast, continuous monitoring methods can provide quicker indications of the locations and magnitudes of leaks which can then be repaired more quickly. Periodic scans using optical gas imaging can also provide far quicker indications of large leaks, which often cause the most emissions, if not repaired promptly.

E. Summary and Conclusions

This report summarizes the results of air dispersion modeling conducted using AERMOD, the standard EPA-approved model used for such analyses. Using reported emissions by each refinery, appropriate meteorological data, and the necessary source information, the model was used to estimate pollutant concentrations for benzene, NO_X, SO_2, and PM_{10} from the Pasadena and Houston refineries for year 2019. The source and meteorological data were input to the AERMOD dispersion model which was used to estimate the pollutant concentration impacts at the fenceline and in the surrounding community.

The model results indicate that emissions from the refineries had a significant effect on pollutant concentrations, especially for benzene. Comparisons of modeled concentrations with measured concentrations at the both the Pasadena and Houston fenceline monitors demonstrated that the emissions inventory data for benzene were significantly under-reported for both refineries. The wind rose plots showing the distribution of wind directions confirm that the observed benzene concentrations at the northern fenceline monitors (including Pasadena's Monitor VOC1) were principally caused by emissions from the refinery's emissions sources. Benzene emissions from the marine loading incinerator source at the Pasadena refinery were calibrated to match the observed 2-week average fenceline measurements for periods with high fenceline measurements, resulting in significant modeled benzene concentration impacts in the surrounding community. The modeled maximum hourly benzene concentration exceeded 11 µg/m^3 at the Magnolia Court Residence, located 1.2 km to the SSW of the

[26] We are aware that TCEQ itself has included such technologies in some instances in permits.

marine loading incinerator source. Further, modeling of all of the Pasadena refinery's benzene sources, scaled using the ratio of annual average modeled fenceline benzene concentrations divided by annual average measured benzene concentrations showed very high benzene concentration impacts in the surrounding residential communities, with maximum modeled hourly benzene concentrations ranging from about 7 μg/m^3 to 26 μg/m^3 (or even higher, up to 44 μg/m^3, near Pasadena's southeastern tank facility which is surrounded by the RB fenceline monitors). The modeled annual average benzene concentrations using the scaled Pasadena emissions rates were as high as 0.8 μg/m^3 at the San Jacinto Terrace Residence, located about 0.5 km south of the refinery.

While it was not feasible to scale the emissions of the other pollutants similar to benzene (for which the two-week average fenceline data were available), it is likely that the emissions for the other pollutants are also underestimated for the reasons stated in the report.

The findings noted in this report are based on the available data. Should additional data become available, we reserve the right to reassess and appropriately update the results and conclusions, as warranted.

Appendix B:
Dispersion Modeling of Selected Pollutant Emissions from the Artesia Refinery

Dispersion Modeling of Selected Pollutant Emissions from the Artesia Refinery

Dr. H. Andrew Gray
Gray Sky Solutions
San Rafael, CA

August 2022

Introduction

Dr. H. Andrew Gray of Gray Sky Solutions was retained by the Environmental Integrity Project to perform air dispersion modeling to determine the air quality impacts in the surrounding community due to airborne emissions from the HollyFrontier Navajo Artesia Refinery located in Artesia, New Mexico. Activities at the refinery cause emissions of sulfur dioxide (SO_2), fine particulate matter with aerodynamic diameters less than or equal to 2.5 microns ($PM_{2.5}$), and benzene. Dispersion modeling was conducted to evaluate the resulting concentration impacts due to emissions of each of these pollutants.

The American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) modeling system (version 19191) was used to simulate the transport of pollutant emissions from the refinery to the surrounding community. AERMOD[1,2,3] is a steady-state plume model that simulates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. AERMOD has been adopted by the U.S. Environmental Protection Agency (US EPA) in Appendix W to its Guideline on Air Quality Models[4] as the preferred dispersion model for estimating local-scale impacts from industrial pollutant emissions sources.

There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using USGS Digital Elevation Data. In addition, the AERSURFACE program was used

---

[1] U.S. Environmental Protection Agency. *AERMOD: Description of Model Formulation*. EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. September 2004.
[2] U.S. Environmental Protection Agency. *User's Guide for the AMS/EPA Regulatory Model (AERMOD)*. EPA-454/B-19-027. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. August 2019.
[3] U.S. Environmental Protection Agency. *Addendum: User's Guide for the AMS/EPA Regulatory Model – AERMOD*. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, March 2011.
[4] U.S. Environmental Protection Agency. *Guideline on Air Quality Models, 40 CFR Part 51, Appendix W*. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.

to develop surface characteristics for input to AERMET. No background concentrations were added to the modeled impacts, therefore the modeled concentrations represent the incremental impact to the surrounding community from the refinery.

This report describes the modeling exercises that I conducted using the AERMOD model to evaluate the impact of airborne pollutant emissions from the Artesia Refinery on ambient concentrations in the area surrounding the refinery. The necessary input data including emission rates and other source data, receptor, terrain, and meteorological data, and modeling options are described below, followed by a summary of the model results.

Source Data

A spreadsheet file containing facility emissions data for 2016-2020 for the Artesia Refinery, developed by the New Mexico Environment Department -- Air Quality Bureau, was obtained from the Environmental Integrity Project.[5] A permit application,[6] which included information characterizing the source units at the refinery (including stack parameters and a plot layout showing unit locations) and a subsequent permit revision for flare emissions[7] were also obtained from Environmental Integrity Project.[8] From these documents, a list of all source units emitting SO_2, $PM_{2.5}$, and benzene were compiled, including annual 2019 emission rates, source unit locations, and stack parameters (stack height, exit temperature, stack diameter, and exit velocity).

The modeled 2019 annual emission rates and source parameters for SO_2 and $PM_{2.5}$ are shown in Tables 1 and 2, below.[9] Benzene was emitted from a cooling tower (Unit Number Y-0012), numerous tanks (internal and external floating roof tanks, and fixed roof tanks), and a number of fugitive sources, for which locations could not be determined from the plot layout diagrams within the permit application. The location of the cooling tower (Unit ID: Y-0012, 3.084 tpy) was determined, however stack

---

[5] File named *Emissions Inventory 2016 to 2020.xls* was obtained via email from Abel Russ on October 15, 2021.

[6] *Updated Application for Permit Renewal, Title V Operating Permit No. P051-R3*, submitted to New Mexico Environment Department by the HollyFrontier Artesia Refinery; initially submitted May2019, updated August 2020.

[7] *Application for ISOM Flare Emissions, Technical Permit Revision, NSR Permit No. O195-M39R2*, submitted to New Mexico Environment Department by the HollyFrontier Artesia Refinery, February 2021.

[8] File named *AQBP-App-P051R3-Rev-1_2020 Artesia refinery application.pdf* was obtained via email from Abel Russ on September 22, 2021.

[9] The location of a single point source, Unit 54 HDS Reactor Heater (Unit Number H-5401), could not be determined, so this source was not included in the modeling for SO_2 and $PM_{2.5}$. Emissions for 2019 from H-5401 were: SO_2: 0.20 tons/year and $PM_{2.5}$: 0.20 tons/year (total SO_2 from all sources: 76.1 tons/year, total $PM_{2.5}$ from all sources: 86.8 tpy). Upset and malfunction SO_2 emissions (28.9 tons/year) were distributed (proportionally) to the FCC Regenerator Scrubber (Unit FCC Regen), SRU1 & SRU2 Tail Gas Incinerators (Unit H-0473), and SRU3 Tail Gas Incinerator (Unit SRU3 TGI) sources. Flare SO_2 emissions (Venting SSM to FL-400, FL-401, FL-402, FL-403, and FL-404; 9.1 tons/year) were distributed evenly to Flares FL-400 – FL404.

parameter data were not provided in the permit application.[10] The 2019 benzene emission rates for each unit in the emissions inventory are shown in Table 3. The annual 2019 benzene emissions for all units at the refinery other than the Hydrogen Plants Cooling Tower (Unit ID: Y-0012) were modeled as a VOLUME source within AERMOD, spread uniformly across the facility (1.677 tons/yr, centered at lat/lon: 32.846213, -104.392788, with a lateral radius of 400 m).

While I have used the emissions provided to me and which were reported by the refinery, it is my understanding that the reliability of the emissions is questionable. Attachment A to my report contains a brief critique of some of the emissions by Dr. Ron Sahu.

Table 1. Artesia SO_2 Emissions and Source Parameters

Unit ID	Description	Emissions tons/yr	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/s
H-0019	South Crude Charge Heater	2.2	32.842817	-104.394947	156	450	4.4	21.4
H-0011	Unit 21 Vacuum Flasher Heater	0.7	32.842726	-104.392842	80	850	4.0	26
FCC Regen	FCC Regenerator Scrubber	4.1	32.848939	-104.394371	153	125	6.0	28.3
H-0312	Unit 10 FCC Feed Heater	0.6	32.848841	-104.394500	96	675	4.0	20.4
H-0040	Unit 13 Charge Heater	0.6	32.849189	-104.395641	101	590	4.0	22.8
H-0352/0353/0354	CCR Reformer Heaters (aka: 70-H1, 70-H2, 70-H3)	2.3	32.849171	-104.393760	211	300	8.8	16.5
H-0355	Unit 70 Stabilizer Reboiler Heater (previously 70H-4)	0.4	32.848945	-104.393762	135	442	2.5	28.7
H-0600	Depropanizer Reboiler Heater (previously 3F-1)	1.3	32.849059	-104.393098	177	500	4.6	33
H-0421	Unit 44 Charge Heater (previously H-21)	0.6	32.848394	-104.393520	82	650	3.3	23.7
H-0028	Unit 21 Heater H-28 (previously H-10)	0.2	32.842734	-104.392757	50	850	2.7	18.8
H-0473	SRU1 & SRU2 Tail Gas Incinerators	1.7	32.847820	-104.396046	150	1150	4.0	44.2
B-0007	Boiler B-7	1.7	32.848344	-104.394482	75	275	5.3	47.9
B-0008	Boiler B-8	1.7	32.848182	-104.394462	65	250	4.5	62.8
H-0030	Unit 06 Charge Heater	0.3	32.849144	-104.395630	67	575	4.0	22.5
H-0601	Unit 33 Charge Heater	1.2	32.847842	-104.393160	131	300	6.5	11.6
H-0362/0363/0364	Unit 70 CCR Heater	2.0	32.849172	-104.393931	206	338	7.0	16.9
H-2421	Unit 45 Charge Heater	0.1	32.848394	-104.393520	82	650	3.3	23.7
H-0464	Hot Oil Heater	0.1	32.847558	-104.395962	80	450	2.8	9.6
H-0020	South Crude Charge Heater	1.1	32.842807	-104.394744	175	330	6.5	12.2
H-8801/8802	Unit 63 Hydrogen Plant Reformer Furnace	0.1	32.847863	-104.391931	130	600	3.8	75.4
H-0009	Unit 13 Naphtha Splitter Reboiler	0.4	32.848530	-104.395656	78	530	4.5	17.9
H0018	Naphtha HDS Reboiler	0.5	32.849090	-104.395663	75	700	4.0	19.5
H-2501	ROSE2 Hot Oil Heater (previously ROSE2-HOH)	1.2	32.847103	-104.391445	168	710	7.8	19
H-9851	Unit 64 Hydrogen Plant Reformer	0.3	32.848152	-104.391940	176	350	10.0	23.8
H-3101	SRU3 Hot Oil Heater (Previously SRU3-HOH)	0.1	32.847035	-104.396094	80	450	2.8	9.6
SRU3 TGI	SRU3 Tail Gas Incinerator	9.7	32.847087	-104.395698	150	1200	4.0	49.9
H-3403	Hydrocracker (Unit 34) Reactor Charge Heater	1.0	32.847248	-104.391604	86	705	4.0	19.4
FL-400	Venting SSM to FL-400	1.8	32.849870	-104.394632	162	1832	5.3	65.6
FL-401	Venting SSM to FL-401	1.8	32.844605	-104.393385	200	1832	2.4	65.6
FL-402	Venting SSM to FL-402	1.8	32.849868	-104.394268	167	1832	3.3	65.6
FL-403	Venting SSM to FL-403	1.8	32.850481	-104.394211	220	1832	3.2	65.6
FL-404	Venting SSM to FL-404	1.8	32.850434	-104.391956	200	1832	11.5	65.6
B-0009	Boiler B-9	1.7	32.848419	-104.394909	60	300	5.0	47.7
H-5401	Unit 54 HDS Reactor Heater	0.2			83	643	3.0	8.8
	Upset and Malfunction Emissions (FCC Regen)	7.6	32.848939	-104.394371	153	125	6.0	28.3
	Upset and Malfunction Emissions (H-0473)	3.2	32.847820	-104.396046	150	1150	4.0	44.2
	Upset and Malfunction Emissions (SRU-TGI)	18.1	32.847087	-104.395698	150	1200	4.0	49.9

[10] The stack parameters for the Hydrogen Plants Cooling Tower (Unit ID: Y-0012; lat/lon location: 32.848621, -104.391958) were assumed to be: stack height: 20 m, exit temperature: 300 K, exit velocity: 1 m/s, diameter: 8.5 m.

Table 2. Artesia $PM_{2.5}$ Emissions and Source Parameters

Unit ID	Description	Emissions tons/yr	Latitude	Longitude	Height ft	Temp deg F	Diameter ft	Velocity ft/s
B-0007	Boiler B-7	1.9	32.848344	-104.394482	75	275	5.3	47.9
B-0008	Boiler B-8	1.9	32.848182	-104.394462	65	250	4.5	62.8
B-0009	Boiler B-9	2.2	32.848419	-104.394909	60	300	5.0	47.7
H-0352/0353/0354	CCR Reformer Heaters (aka: 70-H1, 70-H2, 70-H3)	3.3	32.849171	-104.393760	211	300	8.8	16.5
H-0600	Depropanizer Reboiler Heater (previously 3F-1)	1.6	32.849059	-104.393098	177	500	4.6	33
FCC Regen	FCC Regenerator Scrubber	50.0	32.848939	-104.394371	153	125	6.0	28.3
H-0464	SRU Hot Oil Heater	0.1	32.847558	-104.395962	80	450	2.8	9.6
H-3403	Hydrocracker (Unit 34) Reactor Charge Heater	1.0	32.847248	-104.391604	86	705	4.0	19.4
H-3402	Hydrocraker Fractionator Reboiler 1 (previously HCKR-BOIL1)	0.4	32.847193	-104.391465	67	575	4.0	27.9
H-0018	Naphtha HDS Reboiler	0.6	32.849090	-104.395663	75	700	4.0	19.5
H-2501	ROSE2 Hot Oil Heater (previously ROSE2-HOH)	1.3	32.847103	-104.391445	168	710	7.8	19
H-0019	South Crude Charge Heater	2.2	32.842817	-104.394947	156	450	4.4	21.4
H-0020	South Crude Charge Heater	1.0	32.842807	-104.394744	175	330	6.5	12.2
H-0473	SRU1 & SRU2 Tail Gas Incinerators	0.3	32.847820	-104.396046	150	1150	4.0	44.2
H-3101	SRU3 Hot Oil Heater (Previously SRU3-HOH)	0.1	32.847035	-104.396094	80	450	2.8	9.6
SRU3-TGI	SRU3 Tail Gas Incinerator	1.6	32.847087	-104.395698	150	1200	4.0	49.9
H-0030	Unit 06 Charge Heater	0.8	32.849144	-104.395630	67	575	4.0	22.5
H-0312	Unit 10 FCC Feed Heater	0.7	32.848841	-104.394500	96	675	4.0	20.4
H-0040	Unit 13 Charge Heater	0.7	32.849189	-104.395641	101	590	4.0	22.8
H-0009	Unit 13 Naphtha Splitter Reboiler	0.5	32.848530	-104.395656	78	530	4.5	17.9
H-0028	Unit 21 Heater H-28 (previously H-10)	0.2	32.842734	-104.392757	50	850	2.7	18.8
H-0011	Unit 21 Vacuum Flasher Heater	0.6	32.842726	-104.392842	80	850	4.0	26
H-0601	Unit 33 Charge Heater	1.6	32.847842	-104.393160	131	300	6.5	11.6
H-0421	Unit 44 Charge Heater (previously H-21)	0.7	32.848394	-104.393520	82	650	3.3	23.7
H-2421	Unit 45 Charge Heater	0.1	32.847798	-104.393353	87	890	3.5	24.8
H-5401	Unit 54 HDS Reactor Heater	0.2			83	643	3.0	8.8
H-8801/8802	Unit 63 Hydrogen Plant Reformer Furnace	1.4	32.847863	-104.391931	130	600	3.8	75.4
H-9851	Unit 64 Hydrogen Plant Reformer	6.3	32.848152	-104.391940	176	350	10.0	23.8
H-0362/0363/0364	Unit 70 CCR Heater	2.9	32.849172	-104.393931	206	338	7.0	16.9
H-0355	Unit 70 Stabilizer Reboiler Heater (previously 70H-4)	0.6	32.848945	-104.393762	135	442	2.5	28.7

Table 3. Artesia Benzene Emissions

Unit ID	Description	Emissions tons/yr
Y-0012	Hydrogen Plants Cooling Tower (10,000 gpm)	3.084
Many (internal and external)	Floating-Roof	0.354
FUG-70-CCR	CCR Reformer (w/in battery limits)	0.236
Many	Fixed Roof	0.221
FUG-29-BLENDER/TK FARM	Light Oil Tankage	0.166
FUG-54-PRIMEG	Prime G Unit	0.141
FUG-10-FCC	FCC w/CVS	0.104
FUG-06-NHDU	Naphtha HDS Unit 06	0.086
FUG-35-SAT GAS	Saturates Gas Plant	0.083
FUG-13-NHDU	Naphtha HDS Unit 13	0.066
T-0836	Enhanced Biodegradation Tank T-0836	0.059
FUG-08-TRUCK RK	Loading Rack	0.038
FUG-18-LSR MEROX TRT	Merox/Merichem Treating Units	0.034
FUG-02-SPCRUDE	South Division Crude Unit	0.034
FUG-80-WWTP CVS	Oil Water Separator	0.027
FUG-20-ISOM	BenFree Unit	0.016
TL-4	Fuels Truck Loading Rack	0.008
FUG-RRTOTRUCK	Crude oil unloading system, closed loop between railcars & trucks	0.001
T-0829	Equalization Tank T-0829	0.001
FUG-45-DISTHDU	Gas Oil Hydrotreater (incl. CVS)	0.001
FUG-33-DIST HDU	Relocated Diesel HDS Unit w/CVS	0.001
Total, All Units		4.761

The locations of the modeled Artesia source units are shown in Figure 1, below.

Figure 1. Modeled Artesia Source Units

Modeling Domain and Receptor Locations

The AERMOD modeling domain is a 20 km x 20 km square area, with the refinery located in the center of the domain. The AERMOD model is designed to estimate pollutant concentrations at a specified set of locations within the modeling domain, which are referred to as the modeled "receptors". A nested grid of receptors covering the entire modeling domain was developed, with spacing of 50 m extending out to 3 km from the center, 100 m grid spacing between 3 km and 5 km, and then 500 m spacing out to 10 km from the center. Receptors within the refinery property boundary were excluded from the inner 50 m spaced grid, resulting in a total of 21,834 total receptors.

The modeling domain (outer red box) and nested receptor grid (orange dots) are shown in Figure 2, below.

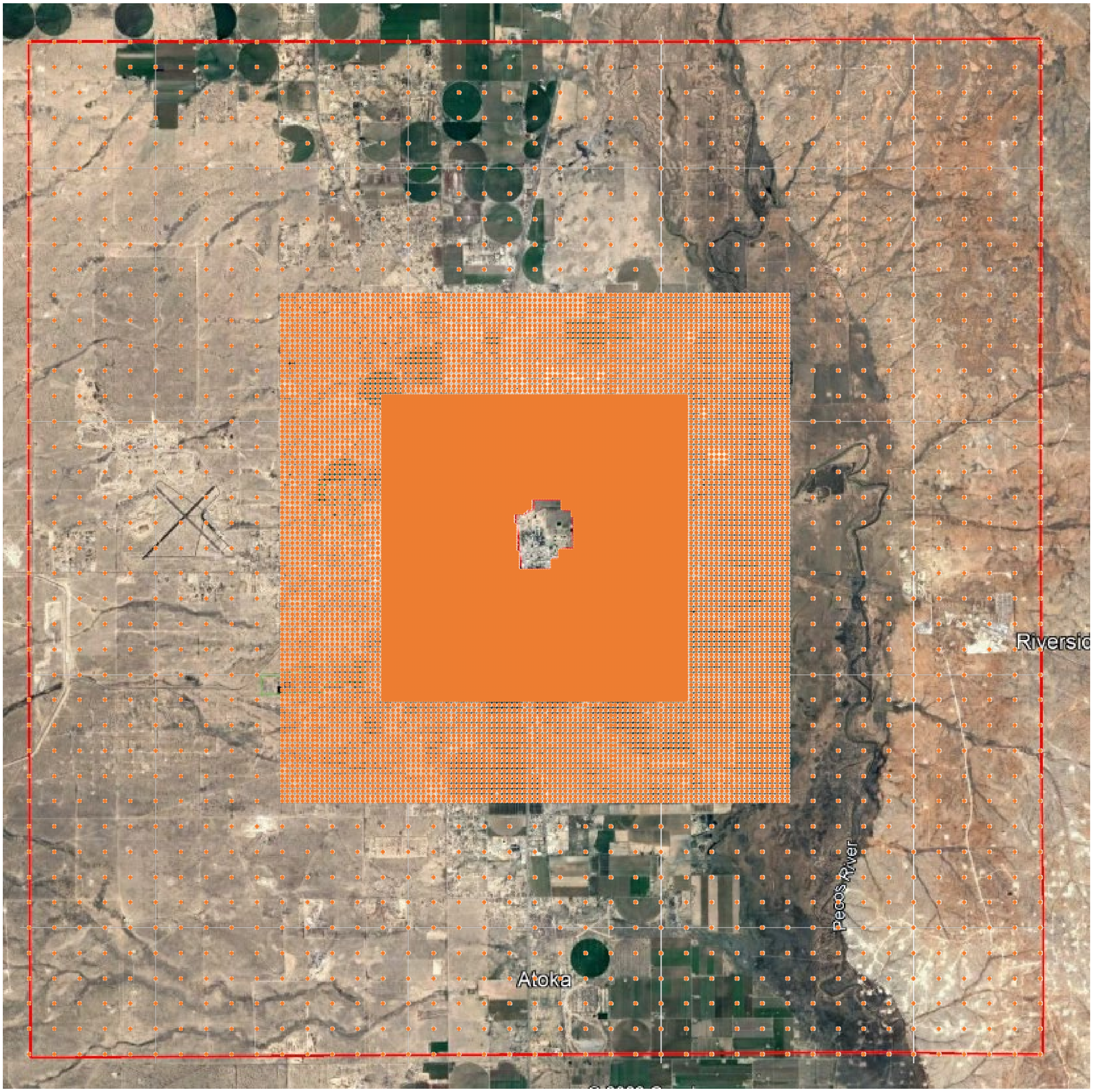


Figure 2. Modeling domain and nested receptor grid

In addition to the gridded receptors, a discrete set of sensitive neighborhood receptor locations were also developed at a number of residences, parks, and schools near the Artesia Refinery. The locations of these sensitive receptors are shown in Table 4 and Figure 3.

Table 4. Sensitive Receptor Locations

Receptor Site	Elevation	Location	
	m	LAT	LON
Roselawn Elementary School	1027.11	32.847722	-104.400160
Artesia High School	1034.30	32.840440	-104.409132
Abo Elementary School	1041.23	32.832377	-104.418951
Zia Intermediate School	1036.51	32.834390	-104.411512
Hermosa Elementary School	1033.75	32.827604	-104.403298
Central Elementary School	1031.88	32.838517	-104.402947
Yucca Elementary School	1036.76	32.850971	-104.413721
Park Junior High School	1039.00	32.853072	-104.415492
MLK Park	1034.15	32.851402	-104.409551
Guadapule Park	1028.35	32.852789	-104.401548
Jamaica Park	1032.63	32.834204	-104.402837
Jaycee Park	1049.99	32.824476	-104.430936
Eagle Draw Park	1026.24	32.846920	-104.398445
Residential 1	1027.67	32.857324	-104.397178
Residential 2	1027.53	32.853725	-104.399115
Residential 3	1026.86	32.849099	-104.399489
Residential 4	1027.79	32.843685	-104.399066
Residential 5	1029.29	32.839276	-104.397674

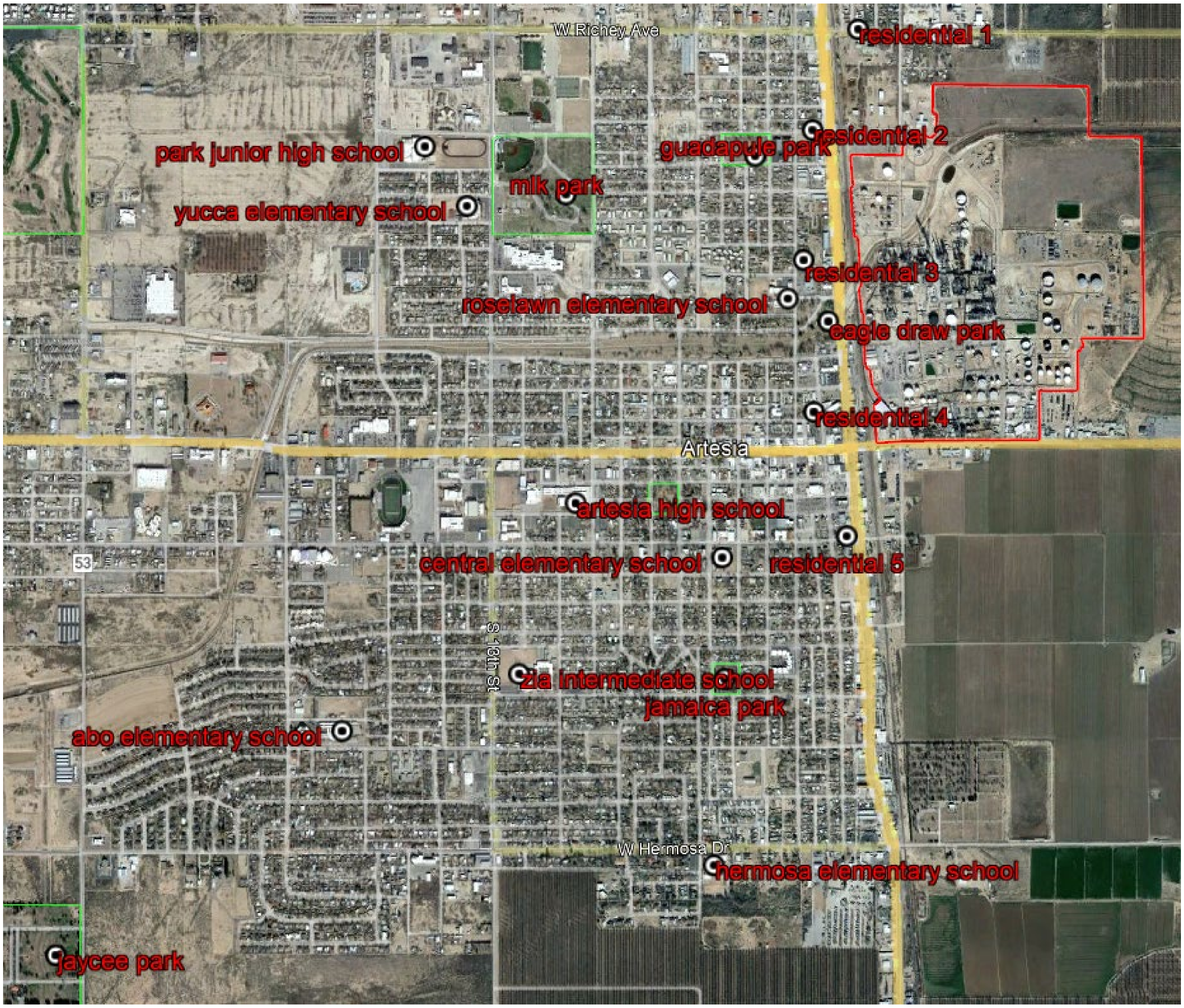


Figure 3. Sensitive receptor locations

Terrain data

The elevations of all receptors within the nested receptor grid and the sensitive receptor locations were obtained from the USGS 1x1-degree tile for N33 W105 which contains 1 arc-second resolved digital elevation model (DEM) data.[11] The DEM elevation data were processed using the AERMAP program (version 18081).

[11] Available from the USGS National Map at https://apps.nationalmap.gov/downloader/#/ or at https://gaftp.epa.gov/Air/aqmg/3dep/1_arcsecond/.

Meteorological Data

A set of meteorological data was developed for the current modeling application representing meteorological conditions during the calendar years 2016-2020. The meteorological data were developed using the AERMET pre-processor program (version 16216)[12] which prepares the meteorological data necessary for input to AERMOD. The meteorological data incorporated hourly surface data collected at the Artesia Municipal Airport (KATS) meteorological monitoring station,[13] located about 6 km west of the Artesia Refinery. Upper air data consisted of twice-daily radiosonde measurements (soundings) recorded each day at 0000 GMT and 1200 GMT at Midland Texas.[14]

Surface characteristics in the vicinity of the meteorological tower were developed using 2016 land cover/land use data, percent impervious data, and percent tree canopy data from the National Land Cover Database (NLCD) obtained from the Multi-Resolution Land Characteristics (MRLC) Consortium[15]. These data were processed using AERSURFACE (version 20060)[16] to compute the surface roughness, albedo, and Bowen ratio for each month of the year, which were input to AERMET. The AERMET meteorological preprocessor was used to merge the hourly surface and upper air data, and to estimate a number of required boundary layer parameters using the meteorological data and surface characteristics.

A wind rose plot showing the distribution of wind speeds and directions used in the current modeling application is shown in Figure 5, below (the wind directions indicate the direction that the wind is coming from). Although winds during 2016-2020 occasionally originated from all directions, the predominant wind direction was from the N to SW (however the direction for lower wind speeds which tend to result in higher concentration impacts is more oriented from the north and northwest, and occasionally from the south).

---

[12] U.S. Environmental Protection Agency. *User's Guide for the AERMOD Meteorological Preprocessor (AERMET)*. EPA-454/B-16-010. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. December 2016.

[13] Hourly surface data for station 722676-03035 (Artesia Municipal Airport) are available at ftp://ftp.ncdc.noaa.gov/pub/data/noaa/. One minute ASOS wind data for the Roswell International Air Center (KROW), located 52 km N/NNW of the Artesia Refinery, were obtained from ftp://ftp.ncdc.noaa.gov/pub/data/asos-onemin/. Comparing wind roses showing the frequency distribution of hourly wind speeds and directions developed using the one-minute KROW data with wind roses of hourly wind data at KATS confirmed that the wind profile at KROW was markedly different than the wind profile at KATS (and the KATS data was more complete and had relatively few calm hourly winds), so therefore the one-minute ASOS data for KROW was not used for this application. Model testing using meteorological data with and without the KROW one-minute ASOS data showed only minor differences between modeled concentration impacts.

[14] https://ruc.noaa.gov/raobs/

[15] https://www.mrlc.gov/viewer/. Also available at https://gaftp.epa.gov/Air/aqmg/nlcd/2016/.

[16] U.S. Environmental Protection Agency. *User's Guide for AERSURFACE Tool*. EPA-454/B-20-008. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. February 2020.

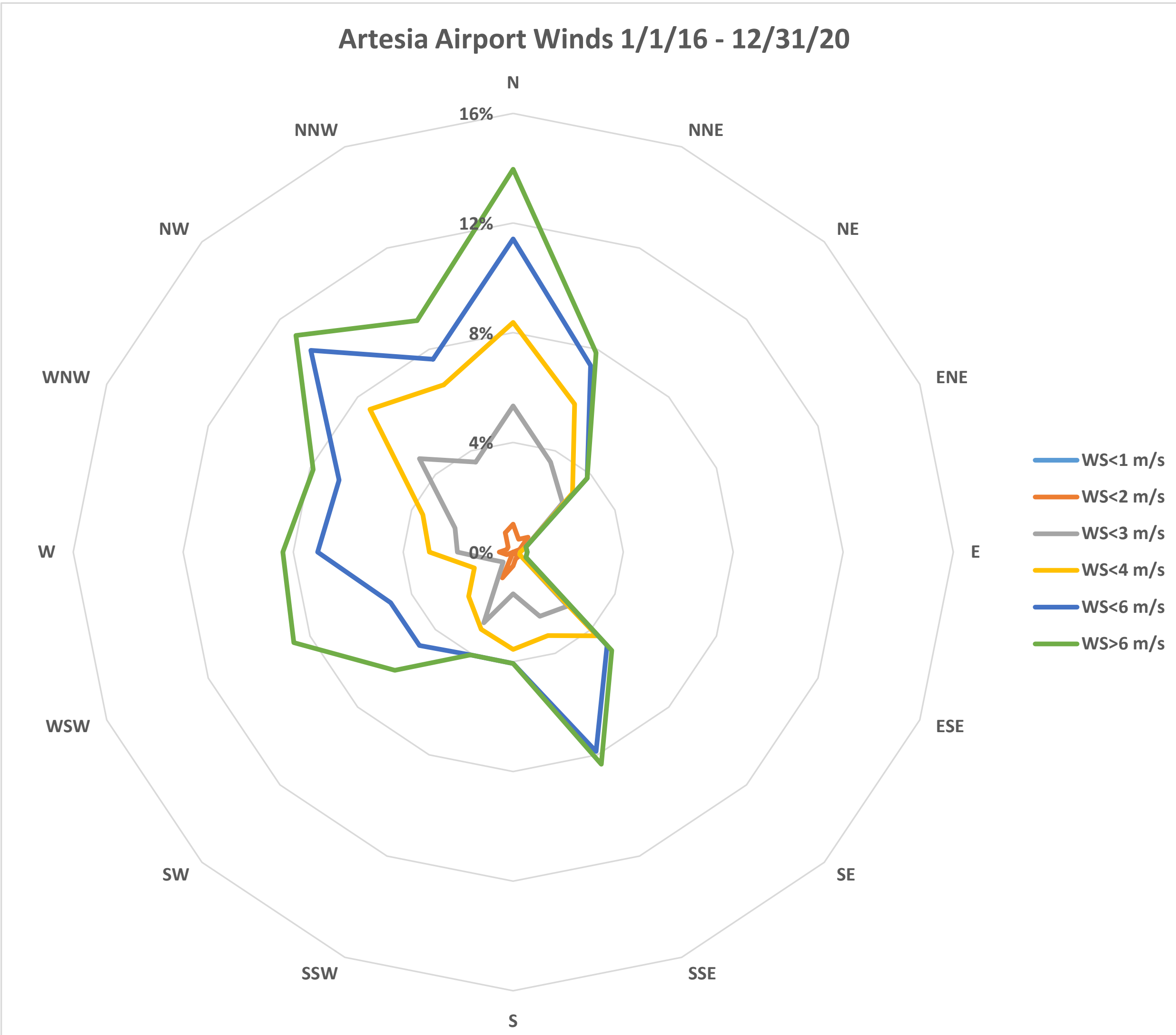


Figure 4. Artesia wind rose for 2016-2020

Modeling Options

A number of control options must be specified in order to execute the AERMOD model. For this application, regulatory default options were followed, which include the use of stack-tip downwash (for point releases), elevated (non-flat) terrain effects, and the calms and missing data processing as set forth in US EPA's modeling guidelines.[17] The model's averaging time was set to one hour and default flagpole receptor heights (for computation of ambient pollutant concentrations) were assumed to be 1.5 m. The Artesia Refinery is located in Artesia, NM, a non-urban area, and therefore the "URBAN" modeling option was not selected within AERMOD.[18]

Fenceline Benzene Monitoring

During 2019, monitors were used to measure two-week average benzene concentrations at a number of fenceline locations around the refinery. The fenceline monitoring locations are shown in Figure 5.

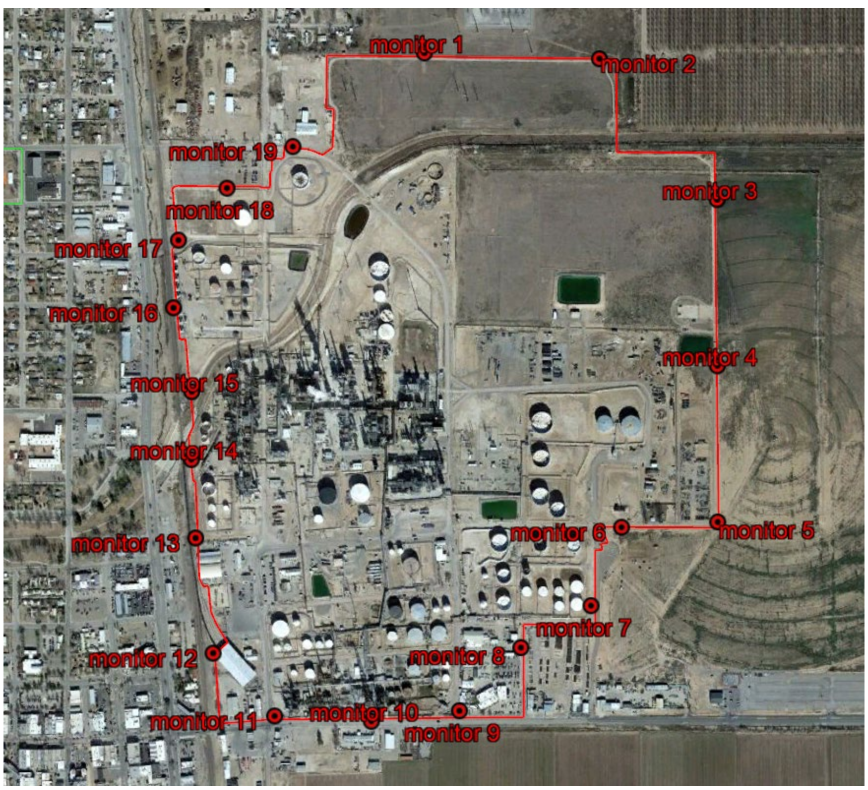


Figure 5. Artesia Refinery fenceline benzene monitors

---

[17] U.S. Environmental Protection Agency. *Guideline on Air Quality Models, 40 CFR Part 51, Appendix W*. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.

[18] The "URBAN" modeling option incorporates the effects of increased surface heating from an urban area on pollutant dispersion under stable nighttime atmospheric conditions.

Model Results

The AERMOD dispersion model was used to estimate the hourly ambient pollutant concentrations during the 5-year period 2016-2020 based on hourly meteorological data and 2019 annual emission rates for the various operations occurring at the refinery.

Modeled pollutant concentrations for the period 2016-2020 due to the refinery emissions (using the provided 2019 emission inventory rates) are shown In Table 5. The table shows the modeled maximum annual average (averaged over 5 years) for each pollutant outside the property boundary, which occurred close to the facility for all three pollutants. For SO_2 and benzene, the table shows the modeled maximum 1-hour average concentration (averaged over 5 years), and for $PM_{2.5}$, the table shows the modeled maximum 24-hour concentration (averaged over 5 years). The rightmost column shows the modeled design value concentrations (averaged over 5 years) corresponding to the current US Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS)[19] for SO_2 and PM_{10}.[20] Tables 6 and 7 show the same modeled concentrations for 2016-2020 (5-year average, maximum 1-hour, and 4th high daily peak 1-hour for SO_2; 5-year average, maximum 1-hour, and 8th high 24-hour for $PM_{2.5}$; and 5-year average, maximum 1-hour, and maximum 10-hour for benzene) at the 18 sensitive receptor locations.

Table 5. Modeled Concentrations (2016-2020) Due to Artesia Refinery Emissions

Pollutant		μg/m³		μg/m³		μg/m³
SO_2	Max annual average:	0.51	Max 1-hr:	6.01	4th high daily max 1-hr:	5.65
$PM_{2.5}$	Max annual average:	0.85	Max 24 hr:	3.64	8th high 24-hr average:	2.88
Benzene	Max annual average:	0.39	Max 1-hr:	31.03		

Figures 6 and 7, below, show contour plots of the modeled 5-year (2016-2020) average benzene concentration and the maximum 1-hr benzene concentration, respectively, due to the 2019 benzene emissions at the refinery.

[19] https://www.epa.gov/criteria-air-pollutants/naaqs-table

[20] The one-hour NAAQS for SO_2 requires that the 99th percentile (4th high) of 1-hour daily maximum concentration (averaged over 3 years) must be below 75 ppb (196.2 μg/m³). The 24-hour NAAQS for $PM_{2.5}$ requires that the 98th percentile (8th high) 24-hr average concentration (averaged over 3 years) must not exceed 35 μg/m³. There is also an annual NAAQS for $PM_{2.5}$ which requires that the annual mean concentration (averaged over 3 years) must be below 12 μg/m³.

Table 6. Modeled SO_2 and $PM_{2.5}$ Concentrations (2016-2020) Due to Artesia Refinery Emissions at the Sensitive Receptor Locations

				SO_2			$PM_{2.5}$		
				5-year Average	Maximum 1-hr	4th High Max Daily 1-hr	5-year Average	Maximum 1-hr	8th High 24-hr
Location	UTMx	UTMy	elev (m)	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
Roselawn Elementary School	556131	3634565	1027.11	0.133	4.43	4.22	0.156	1.16	0.74
Artesia High School	555296	3633753	1034.30	0.030	3.15	2.49	0.040	0.55	0.27
Abo Elementary School	554382	3632854	1041.23	0.017	3.16	1.93	0.024	0.41	0.20
Zia Intermediate School	555077	3633081	1036.51	0.027	3.79	2.24	0.037	0.58	0.29
Hermosa Elementary School	555850	3632333	1033.75	0.041	2.78	2.28	0.054	0.84	0.37
Central Elementary School	555876	3633543	1031.88	0.062	3.70	2.96	0.080	1.14	0.50
Yucca Elementary School	554860	3634918	1036.76	0.029	3.06	2.13	0.035	0.45	0.22
Park Junior High School	554693	3635150	1039.00	0.031	2.61	2.13	0.037	0.64	0.25
MLK Park	555250	3634968	1034.15	0.049	2.88	2.41	0.056	0.68	0.31
Guadapule Park	555998	3635126	1028.35	0.275	3.28	3.11	0.312	2.14	1.29
Jamaica Park	555889	3633065	1032.63	0.055	2.88	2.72	0.070	1.09	0.46
Jaycee Park	553265	3631972	1049.99	0.012	2.67	1.63	0.016	0.32	0.14
Eagle Draw Park	556292	3634477	1026.24	0.144	5.16	4.74	0.213	1.63	1.04
Residential 1	556404	3635631	1027.67	0.234	3.84	3.38	0.403	2.22	1.53
Residential 2	556225	3635231	1027.53	0.431	3.73	3.46	0.629	2.91	2.19
Residential 3	556193	3634718	1026.86	0.218	4.28	4.16	0.218	1.64	1.01
Residential 4	556236	3634118	1027.79	0.133	4.90	4.64	0.175	1.81	0.98
Residential 5	556369	3633630	1029.29	0.123	3.65	3.40	0.152	1.79	0.96

Table 7. Modeled Benzene Concentrations (2016-2020) Due to Artesia Refinery Emissions at the Sensitive Receptor Locations

				Benzene		
				5-year Average	Maximum 1-hr	Maximum 10-hr
Location	UTMx	UTMy	elev (m)	µg/m³	µg/m³	µg/m³
Roselawn Elementary School	556131	3634565	1027.11	0.091	6.36	4.55
Artesia High School	555296	3633753	1034.30	0.014	4.00	1.50
Abo Elementary School	554382	3632854	1041.23	0.007	2.63	1.78
Zia Intermediate School	555077	3633081	1036.51	0.011	3.27	1.48
Hermosa Elementary School	555850	3632333	1033.75	0.016	4.07	1.99
Central Elementary School	555876	3633543	1031.88	0.028	11.80	3.97
Yucca Elementary School	554860	3634918	1036.76	0.015	5.14	1.19
Park Junior High School	554693	3635150	1039.00	0.014	3.93	1.41
MLK Park	555250	3634968	1034.15	0.023	4.73	2.60
Guadapule Park	555998	3635126	1028.35	0.107	6.53	4.19
Jamaica Park	555889	3633065	1032.63	0.023	6.95	2.21
Jaycee Park	553265	3631972	1049.99	0.004	2.02	1.05
Eagle Draw Park	556292	3634477	1026.24	0.148	7.84	4.47
Residential 1	556404	3635631	1027.67	0.184	10.87	3.86
Residential 2	556225	3635231	1027.53	0.182	7.18	4.82
Residential 3	556193	3634718	1026.86	0.137	16.65	6.10
Residential 4	556236	3634118	1027.79	0.072	10.31	4.00
Residential 5	556369	3633630	1029.29	0.061	8.54	3.22

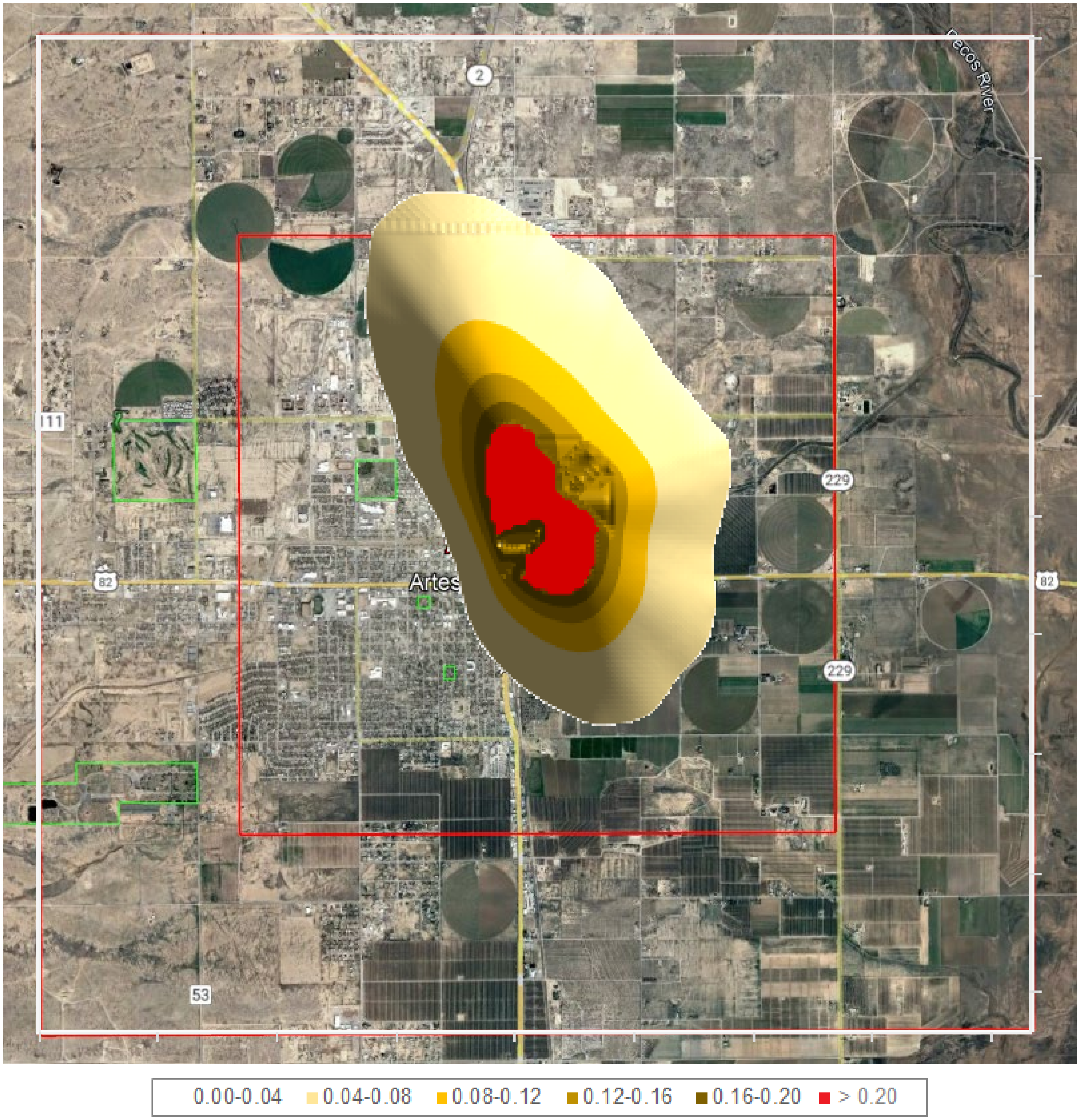


Figure 6. Modeled Benzene Concentration: 2016 – 2020 Average (µg/m^3)

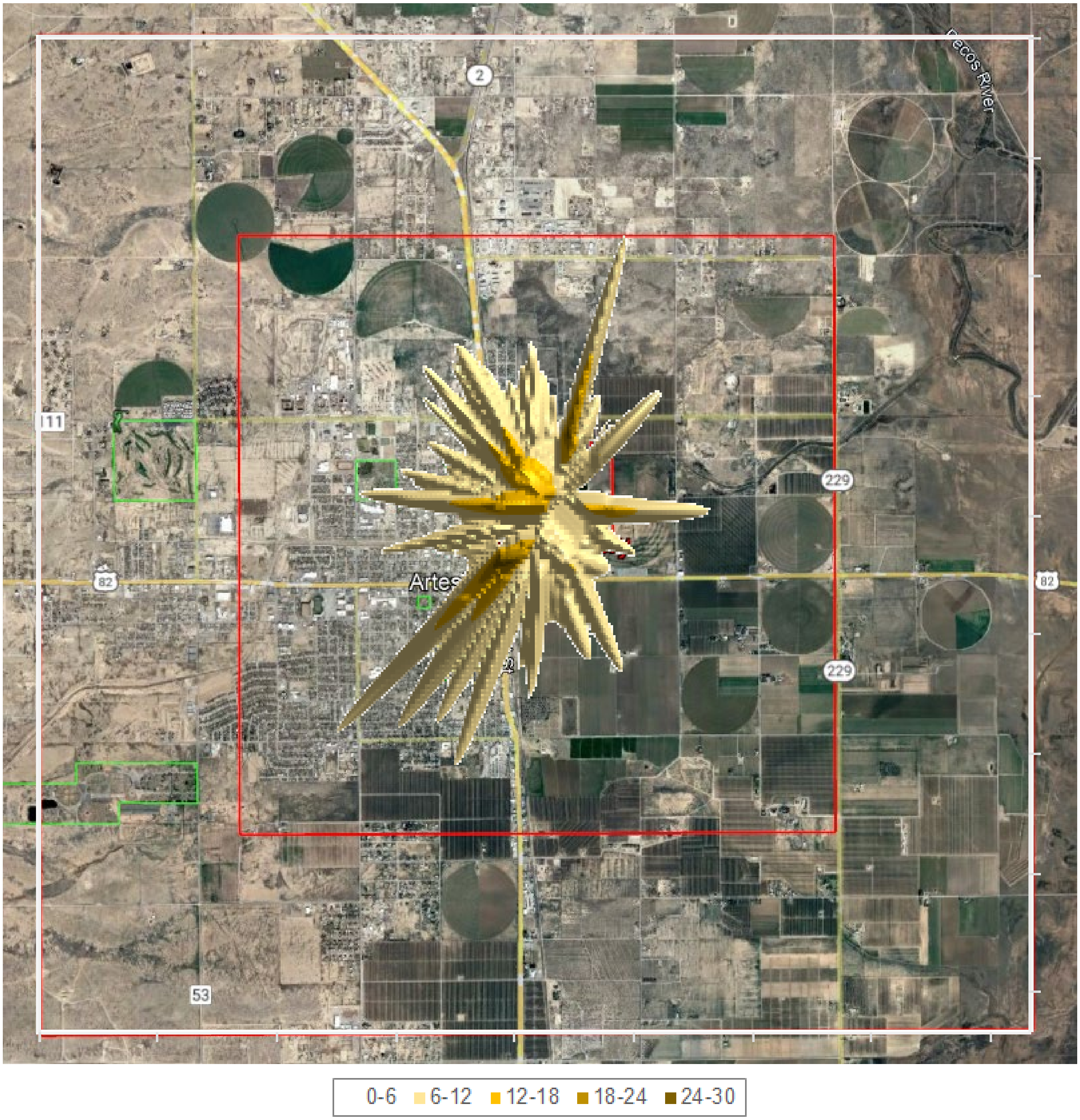


Figure 7. Modeled Benzene Concentration: 2016 – 2020 1-hr Maximum (μg/m^3)

Table 8, below, shows the modeled benzene concentrations for 2016-2020 (5-year average, maximum 1-hour, and maximum 10-hour) at the 19 fenceline monitoring locations (using the provided 2019 emission inventory rates).

Table 8. Modeled Benzene Concentrations (2016-2020) Due to Artesia Refinery Emissions at the Fenceline Monitoring Locations

	Artesia Refinery			Benzene		
				5-year Average	Maximum 1-hr	Maximum 10-hr
monitor	type	LAT	LON	μg/m^3	μg/m^3	μg/m^3
1	Regular Monitor	32.8554	-104.3918	0.184	6.94	3.54
2	Regular Monitor	32.8553	-104.3878	0.121	8.57	3.76
3	Regular Monitor	32.8526	-104.3851	0.133	4.59	2.40
4	Regular Monitor	32.8494	-104.3851	0.165	8.84	4.10
5	Regular Monitor	32.8464	-104.3851	0.155	6.88	5.17
6	Regular Monitor	32.8463	-104.3873	0.265	7.05	6.03
7	Regular Monitor	32.8448	-104.3880	0.302	7.33	4.73
8	Regular Monitor	32.8440	-104.3896	0.043	9.12	2.17
9	Regular Monitor	32.8428	-104.3910	0.343	7.55	4.99
10	Regular Monitor	32.8426	-104.3930	0.291	9.54	4.84
11	Regular Monitor	32.8427	-104.3952	0.190	8.75	4.17
12	Regular Monitor	32.8439	-104.3966	0.169	21.36	8.21
13	Regular Monitor	32.8461	-104.3970	0.018	3.51	1.07
14	Regular Monitor	32.8476	-104.3971	0.292	8.95	6.12
15	Regular Monitor	32.8489	-104.3971	0.306	24.82	5.56
16	Regular Monitor	32.8505	-104.3975	0.274	12.07	4.73
17	Regular Monitor	32.8518	-104.3974	0.275	7.98	5.76
18	Regular Monitor	32.8528	-104.3963	0.333	16.31	5.55
19	Regular Monitor	32.8536	-104.3948	0.358	18.95	4.48

The modeled annual average benzene concentrations for 2019 at the 19 fenceline monitoring locations are compared to the measured fenceline monitor benzene concentrations, as shown In Table 9, below. As can be seen, the modeled annual average benzene concentrations are much lower than the observed (measured) values, which is a strong indication that the reported 2019 benzene emissions are likely significantly under-estimated. The ratio between measured and modeled annual average fenceline concentrations ranged from 10 to 250. The modeled average of all 19 fenceline monitors is only 3.9% of the average observed values.

Table 9. Comparison Between Measured and Modeled 2019 Annual Average Benzene Concentrations at the Artesia Refinery Fenceline Monitoring Locations

	Artesia Refinery			Annual Average Benzene Concentration		Max 1-hr
				Measured	Modeled	Modeled
monitor	type	LAT	LON	μg/m³	μg/m³	μg/m³
1	Regular Monitor	32.8554	-104.3918	2.46	0.18	6.94
2	Regular Monitor	32.8553	-104.3878	1.83	0.12	6.60
3	Regular Monitor	32.8526	-104.3851	2.03	0.14	4.59
4	Regular Monitor	32.8494	-104.3851	2.92	0.17	8.84
5	Regular Monitor	32.8464	-104.3851	2.79	0.15	5.38
6	Regular Monitor	32.8463	-104.3873	6.06	0.26	6.65
7	Regular Monitor	32.8448	-104.3880	8.20	0.30	7.33
8	Regular Monitor	32.8440	-104.3896	6.90	0.04	9.12
9	Regular Monitor	32.8428	-104.3910	5.13	0.33	7.18
10	Regular Monitor	32.8426	-104.3930	7.28	0.28	7.05
11	Regular Monitor	32.8427	-104.3952	3.75	0.18	6.79
12	Regular Monitor	32.8439	-104.3966	3.78	0.17	16.21
13	Regular Monitor	32.8461	-104.3970	4.69	0.02	2.97
14	Regular Monitor	32.8476	-104.3971	23.53	0.30	8.95
15	Regular Monitor	32.8489	-104.3971	10.52	0.31	9.72
16	Regular Monitor	32.8505	-104.3975	4.80	0.28	7.13
17	Regular Monitor	32.8518	-104.3974	3.55	0.28	6.27
18	Regular Monitor	32.8528	-104.3963	3.83	0.34	6.19
19	Regular Monitor	32.8536	-104.3948	3.59	0.38	18.95
	Average of all 19 Fenceline Monitors			5.67	0.22	

The two-week average benzene concentration measured at the fenceline exceeded 9 μg/m³ during 12 of the 26 two-week periods in 2019 at fenceline Monitor 14, and during 9 of the 26 two-week periods at fenceline Monitor 15. This included an 8-week period between March 26, 2019 and May 21, 2019, in which the measured concentration at Monitor 14 exceeded 55 μg/m³. In a number of letters submitted to the New Mexico Environmental Department from the Environmental Manager of the HollyFrontier Navajo

Artesia Refinery[21], issues regarding high fenceline benzene measurements and causes of excess benzene emissions from Tank 57 (Unit T-0057, located on the west side of the refinery close to fenceline Monitors 14 and 15; see Figures 1 and 5) were identified. Unfortunately, no measured or computed estimates of benzene emissions from Tank 57 were provided for these periods. The impacts of Tank 57 benzene emissions on the surrounding community were investigated by modeling emissions from Tank 57 with a unit emission rate during the four two-week periods between March 26 and May 21, 2019 and then determining the emission rate that, if modeled, would closely reproduce the two-week benzene measurements at fenceline Monitors 14 and 15.[22] The model was then used to determine the impacts on the surrounding community using the calibrated (scaled) benzene emission rate for each 2-week period. Table 10 shows the observed two-week average benzene concentrations measured at Monitor 14 and Monitor 15, the calibrated benzene emission rate for Tank 57 that would closely reproduce the measured fenceline concentrations, and the modeled two-week benzene concentrations at Monitor 14 and Monitor 15 due to the calibrated benzene emission rate.

Table 10. Two-week Average Measured Benzene Concentrations at Fenceline Monitors 14 and 15, Calibrated Benzene Emission Rates for Tank 57, and Modeled Two-week Average Measured Benzene Concentrations due to Calibrated Tank 57 Emissions at Fenceline Monitors 14 and 15

	Measured			Modeled	
Period	Two-week Average Benzene at Monitor 14 (µg/m3)	Two-week Average Benzene at Monitor 15 (µg/m3)	Tank 57 Calibrated Benzene Emissions (lb/day)	Two-week Average Benzene at Monitor 14 (µg/m3)	Two-week Average Benzene at Monitor 15 (µg/m3)
A: Mar 26 - April 9, 2019	56	17	118.92	52.2	17.3
B: Apr 9 - Apr 23, 2019	68	35	347.40	75.1	31.9
C: Apr 23 - May 7, 2019	200	56	436.08	198.9	57.8
D: May 7 - May 21, 2019	100	49	279.48	143.0	36.3

[21] For example, see letters dated May 15, 2019, July 3, 2019, September 3, 2019, and October 11, 2019 from Scott M. Denton describing annual average benzene concentrations that exceeded 9 µg/m^3, root cause analyses, and corrective action plans (*EPA-R6-2022-000829 ECDW DOCs Item 1 simplified.pdf*), and the Notice of Violation letter sent to Scott Denton from US EPA Region 6 (*HollyFrontier Artesia Refinery_2019 Inspection Report.pdf*).

[22] The calibration “scaling” factors were very similar for the two monitors during each modeled two-week period which indicates that the model approximately reproduced the observed concentrations and the correct ratio between the benzene measurements at the two monitors.

Tables 11 through 13 show the modeled two-week average benzene concentration, the modeled maximum 1-hour average benzene concentration, and the modeled maximum 10-hour average benzene concentration due to the calibrated Tank 57 benzene emissions at each sensitive receptor location[23]. Figures 8 through 11 show contour plots of the modeled two-week average benzene concentrations in the community surrounding the refinery due to the calibrated Tank 57 benzene emissions. Figures 12 through 15 show the areas in which the modeled two-week average benzene concentrations exceeded 3.0 µg/m^3 due to the calibrated Tank 57 benzene emissions.

Table 11. Modeled 2-week Average Benzene Concentrations (µg/m^3) Due to Calibrated Tank 57 Emissions

			distance	A	B	C	D
Location	**UTMx**	**UTMy**	**km**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**
Roselawn Elementary School	556131	3634565	0.33	2.22	1.19	10.27	4.72
Artesia High School	555296	3633753	1.37	0.29	0.18	1.12	0.11
Abo Elementary School	554382	3632854	2.64	0.02	0.09	0.39	0.03
Zia Intermediate School	555077	3633081	1.97	0.03	0.94	1.03	0.07
Hermosa Elementary School	555850	3632333	2.24	0.16	0.59	0.26	0.09
Central Elementary School	555876	3633543	1.11	0.14	1.89	0.56	1.12
Yucca Elementary School	554860	3634918	1.65	0.04	0.04	0.50	0.21
Park Junior High School	554693	3635150	1.88	0.05	0.03	0.82	0.32
MLK Park	555250	3634968	1.29	0.11	0.07	1.85	0.67
Guadapule Park	555998	3635126	0.78	1.88	2.22	8.16	6.08
Jamaica Park	555889	3633065	1.53	0.24	0.70	0.31	0.19
Jaycee Park	553265	3631972	4.06	0.01	0.04	0.19	0.01
Eagle Draw Park	556292	3634477	0.16	5.94	5.14	19.44	9.90
Residential 1	556404	3635631	1.14	1.45	2.27	5.06	2.54
Residential 2	556225	3635231	0.78	2.65	6.22	9.09	5.80
Residential 3	556193	3634718	0.35	4.31	5.46	16.23	13.06
Residential 4	556236	3634118	0.43	1.04	8.05	3.63	3.83
Residential 5	556369	3633630	0.86	0.49	2.33	2.51	1.97

A: Mar 26 - Apr 9, 2019
B: Apr 9 - Apr 23, 2019
C: Apr 23- May 7, 2019
D: May 7 - May 21, 2019

[23] The distance shown in Tables 9 through 11 is the distance (km) between Tank 57 and the sensitive receptor location. The modeled periods (A, B, C, and D) are shown below Table 9.

Table 12. Modeled Maximum 1-hour Benzene Concentrations (μg/m³) Due to Calibrated Tank 57 Emissions

Location	UTMx	UTMy	distance km	A max 1-hr	B max 1-hr	C max 1-hr	D max 1-hr
Roselawn Elementary School	556131	3634565	0.33	205.56	38.37	643.56	343.58
Artesia High School	555296	3633753	1.37	72.96	17.60	66.83	3.52
Abo Elementary School	554382	3632854	2.64	2.71	9.25	31.89	1.56
Zia Intermediate School	555077	3633081	1.97	2.08	140.84	171.28	9.37
Hermosa Elementary School	555850	3632333	2.24	21.09	61.91	34.82	4.99
Central Elementary School	555876	3633543	1.11	17.30	211.38	37.46	255.97
Yucca Elementary School	554860	3634918	1.65	3.10	1.63	34.22	18.45
Park Junior High School	554693	3635150	1.88	6.18	0.63	84.13	42.56
MLK Park	555250	3634968	1.29	11.62	1.34	229.90	66.33
Guadapule Park	555998	3635126	0.78	113.64	241.92	567.49	371.17
Jamaica Park	555889	3633065	1.53	45.16	53.40	19.69	26.61
Jaycee Park	553265	3631972	4.06	0.50	5.27	18.53	0.55
Eagle Draw Park	556292	3634477	0.16	397.59	164.35	970.93	643.66
Residential 1	556404	3635631	1.14	96.20	226.87	437.15	114.60
Residential 2	556225	3635231	0.78	100.02	363.20	347.57	217.63
Residential 3	556193	3634718	0.35	226.95	703.13	786.73	621.44
Residential 4	556236	3634118	0.43	133.96	570.98	167.14	642.73
Residential 5	556369	3633630	0.86	33.92	198.70	230.22	219.18

Table 13. Modeled Maximum 10-hour Average Benzene Concentrations (μg/m³) Due to Calibrated Tank 57 Emissions

Location	UTMx	UTMy	distance km	A max 10-hr	B max 10-hr	C max 10-hr	D max 10-hr
Roselawn Elementary School	556131	3634565	0.33	29.69	6.05	163.95	65.31
Artesia High School	555296	3633753	1.37	12.24	1.95	33.01	1.49
Abo Elementary School	554382	3632854	2.64	0.47	1.16	5.38	0.42
Zia Intermediate School	555077	3633081	1.97	0.25	15.67	23.12	1.41
Hermosa Elementary School	555850	3632333	2.24	3.02	8.87	5.26	1.07
Central Elementary School	555876	3633543	1.11	2.21	37.07	7.82	36.96
Yucca Elementary School	554860	3634918	1.65	0.46	0.23	4.75	4.68
Park Junior High School	554693	3635150	1.88	0.83	0.13	15.51	7.71
MLK Park	555250	3634968	1.29	1.66	0.29	38.45	12.83
Guadapule Park	555998	3635126	0.78	25.38	63.80	116.24	49.96
Jamaica Park	555889	3633065	1.53	5.67	9.76	2.62	3.41
Jaycee Park	553265	3631972	4.06	0.11	0.57	3.11	0.20
Eagle Draw Park	556292	3634477	0.16	68.78	35.61	291.43	133.48
Residential 1	556404	3635631	1.14	16.26	32.94	437.15	21.52
Residential 2	556225	3635231	0.78	23.83	107.19	102.01	47.51
Residential 3	556193	3634718	0.35	32.75	165.91	143.62	177.56
Residential 4	556236	3634118	0.43	17.01	116.51	35.92	94.90
Residential 5	556369	3633630	0.86	3.88	28.86	37.47	36.27

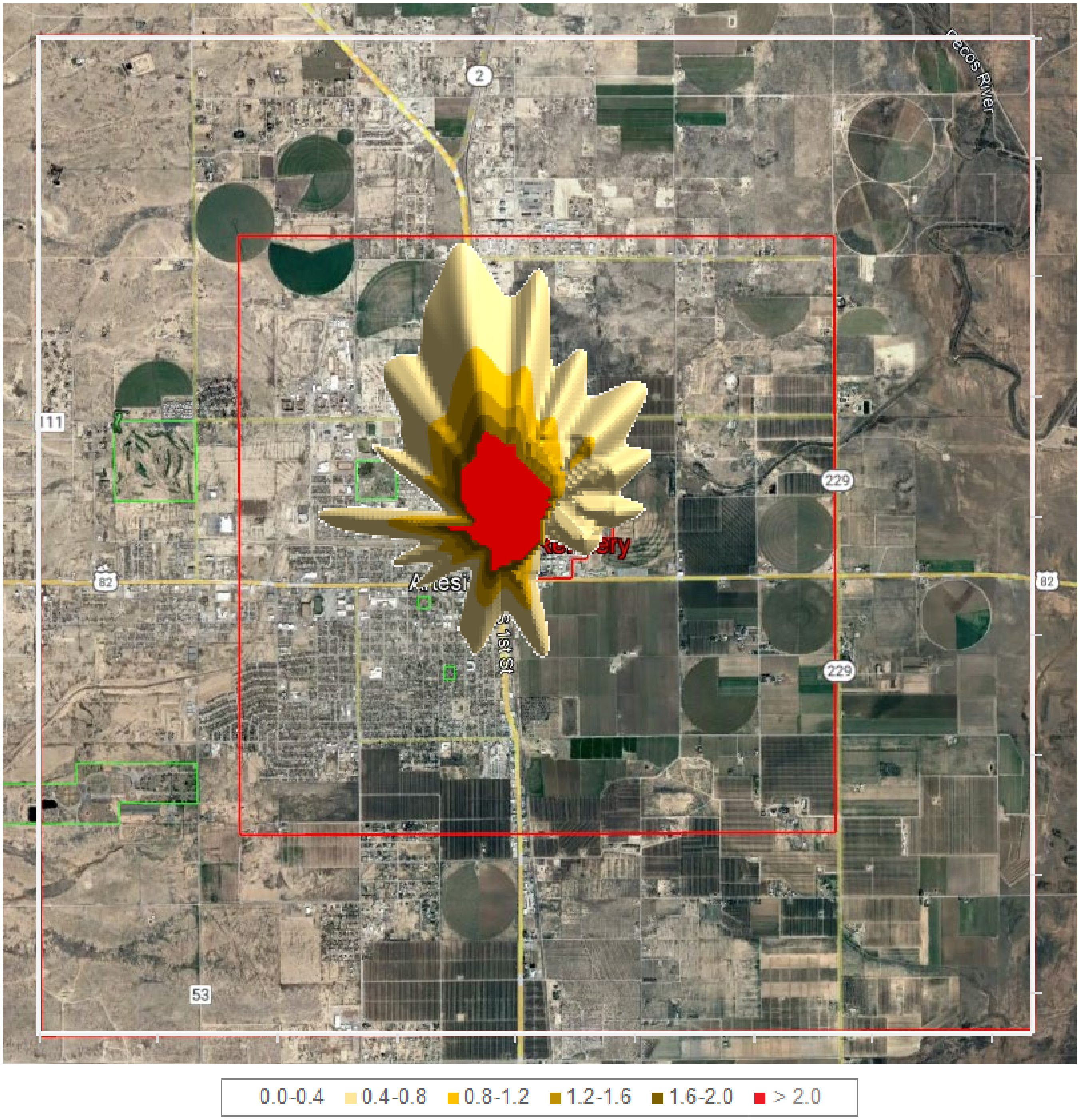


Figure 8. Modeled Two-week Average Benzene Concentration: Mar 26 – Apr 9, 2019 (µg/m^3) Due to Calibrated Tank 57 Emissions

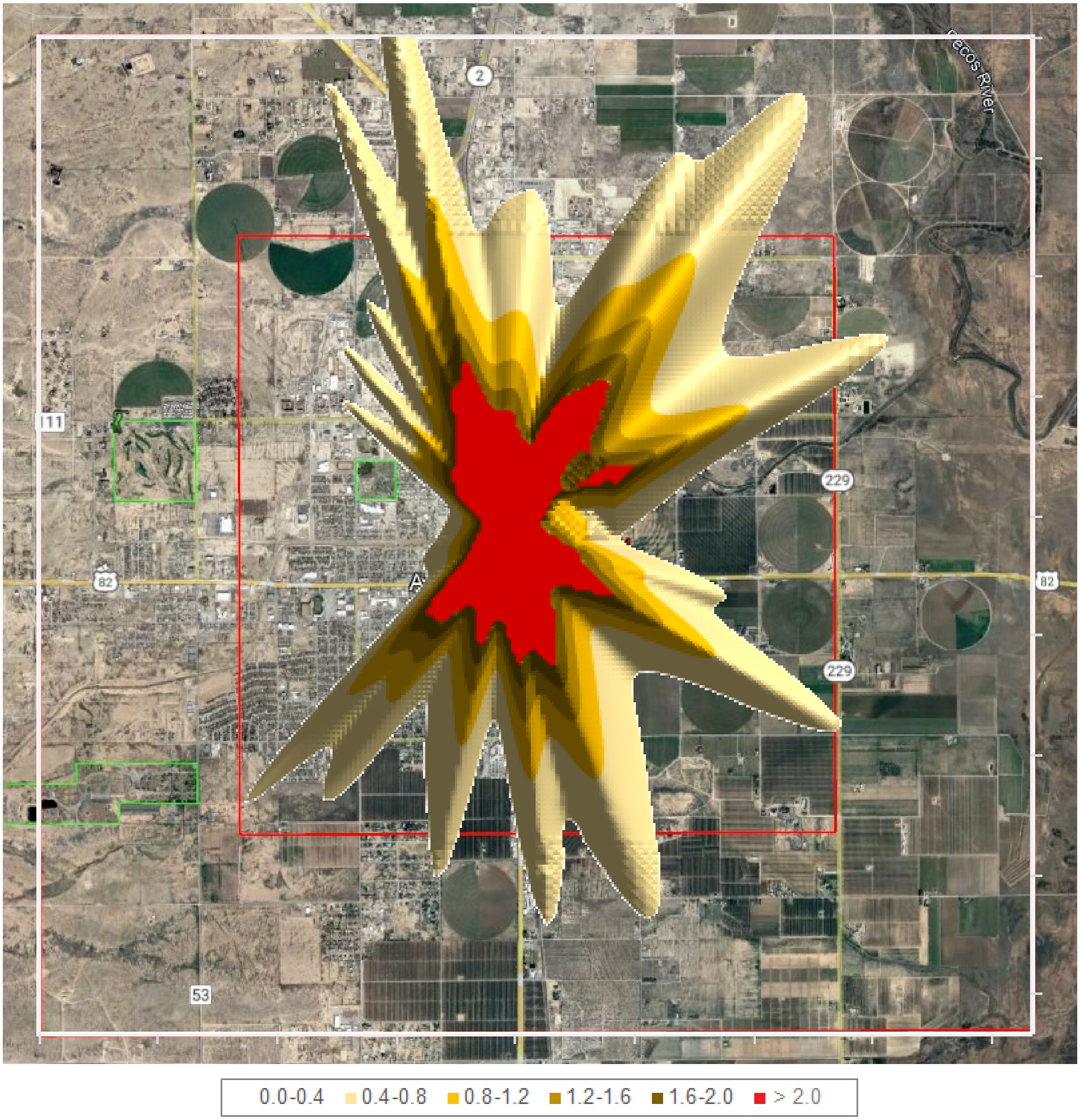


Figure 9. Modeled Two-week Average Benzene Concentration: Apr 9 – Apr 23, 2019 (µg/m³) Due to Calibrated Tank 57 Emissions

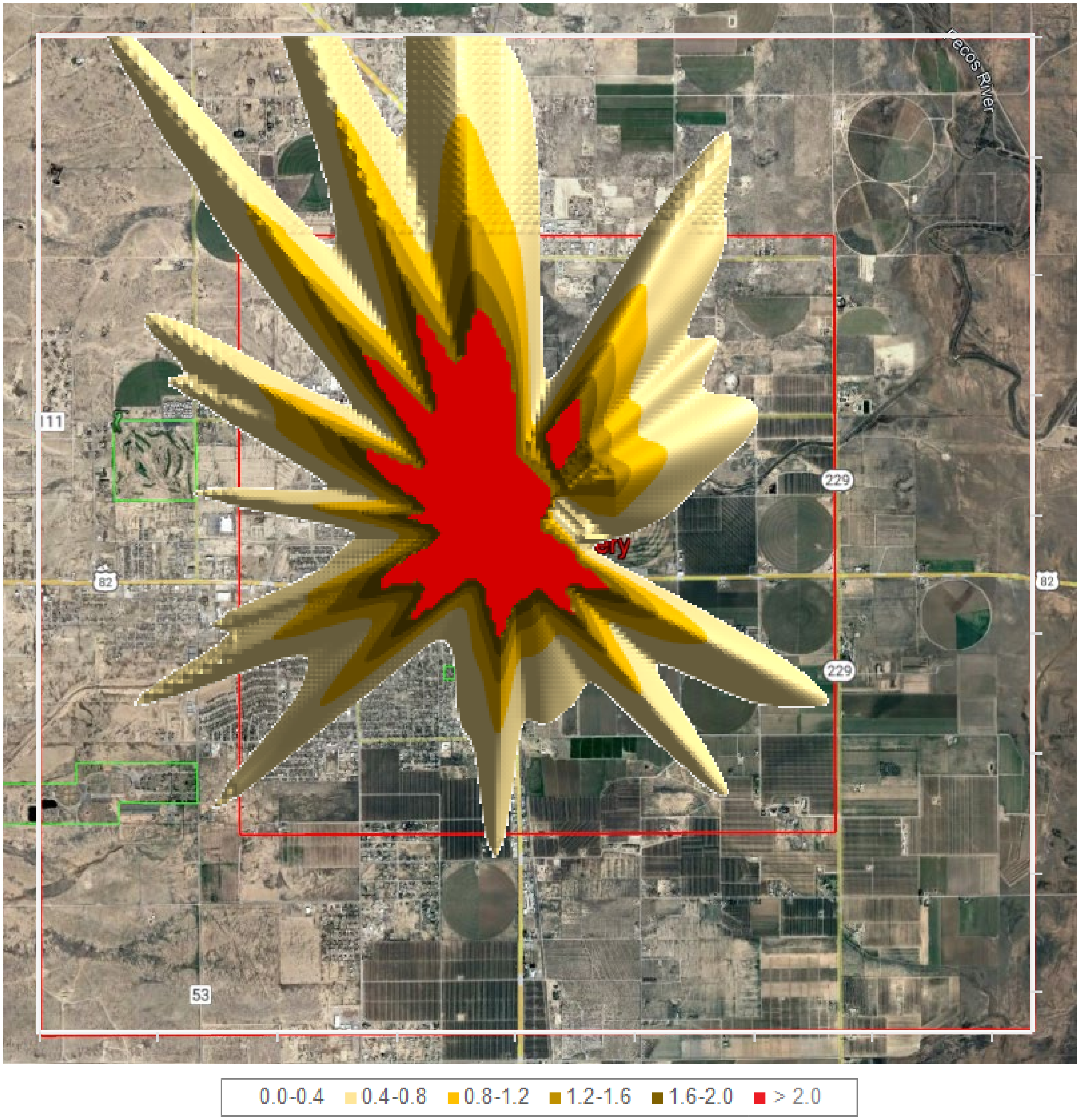


Figure 10. Modeled Two-week Average Benzene Concentration: Apr 23 – May 7, 2019 (μg/m^3) Due to Calibrated Tank 57 Emissions

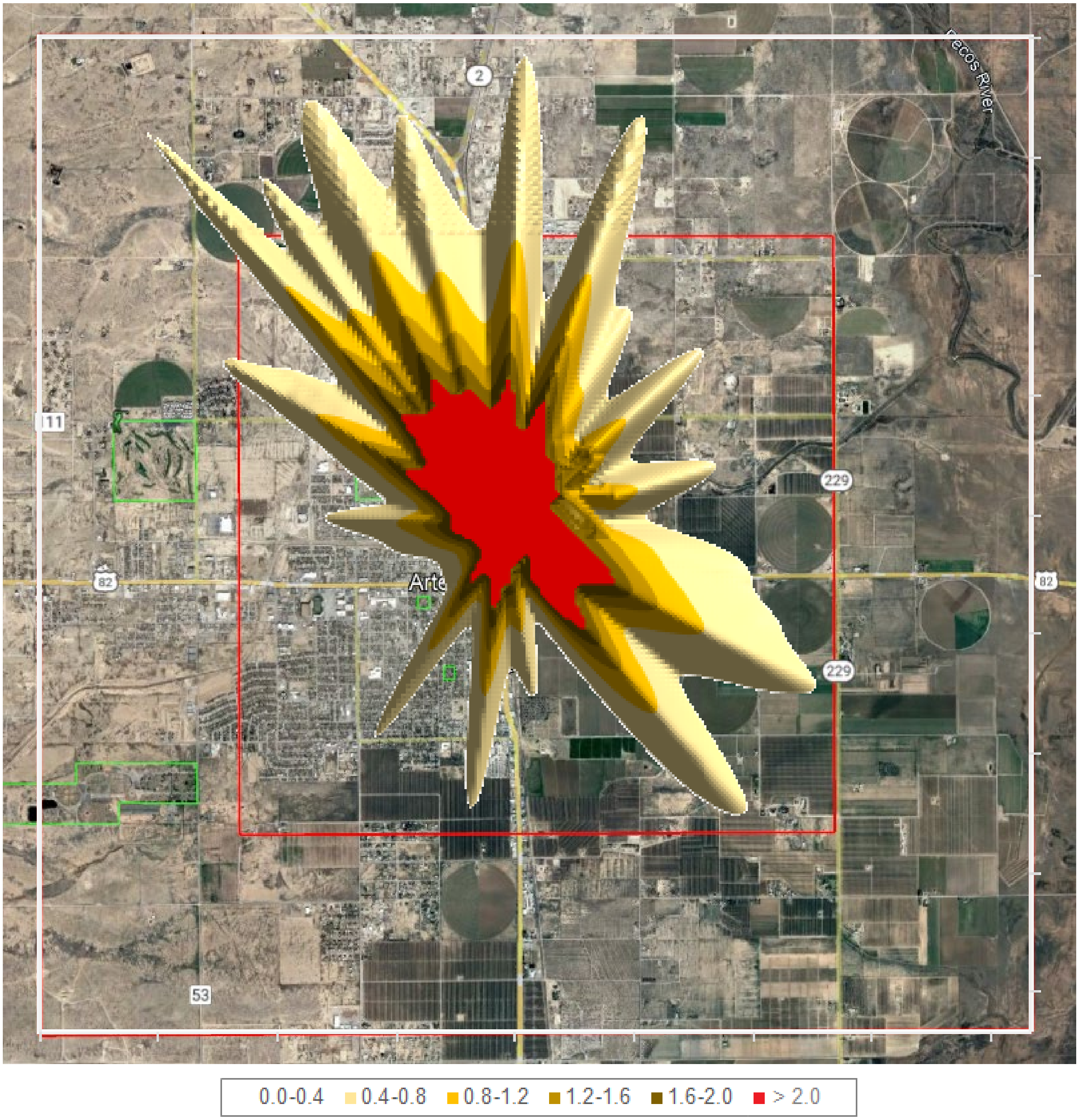


Figure 11. Modeled Two-week Average Benzene Concentration: May 7 – May 21, 2019 (μg/m^3) Due to Calibrated Tank 57 Emissions

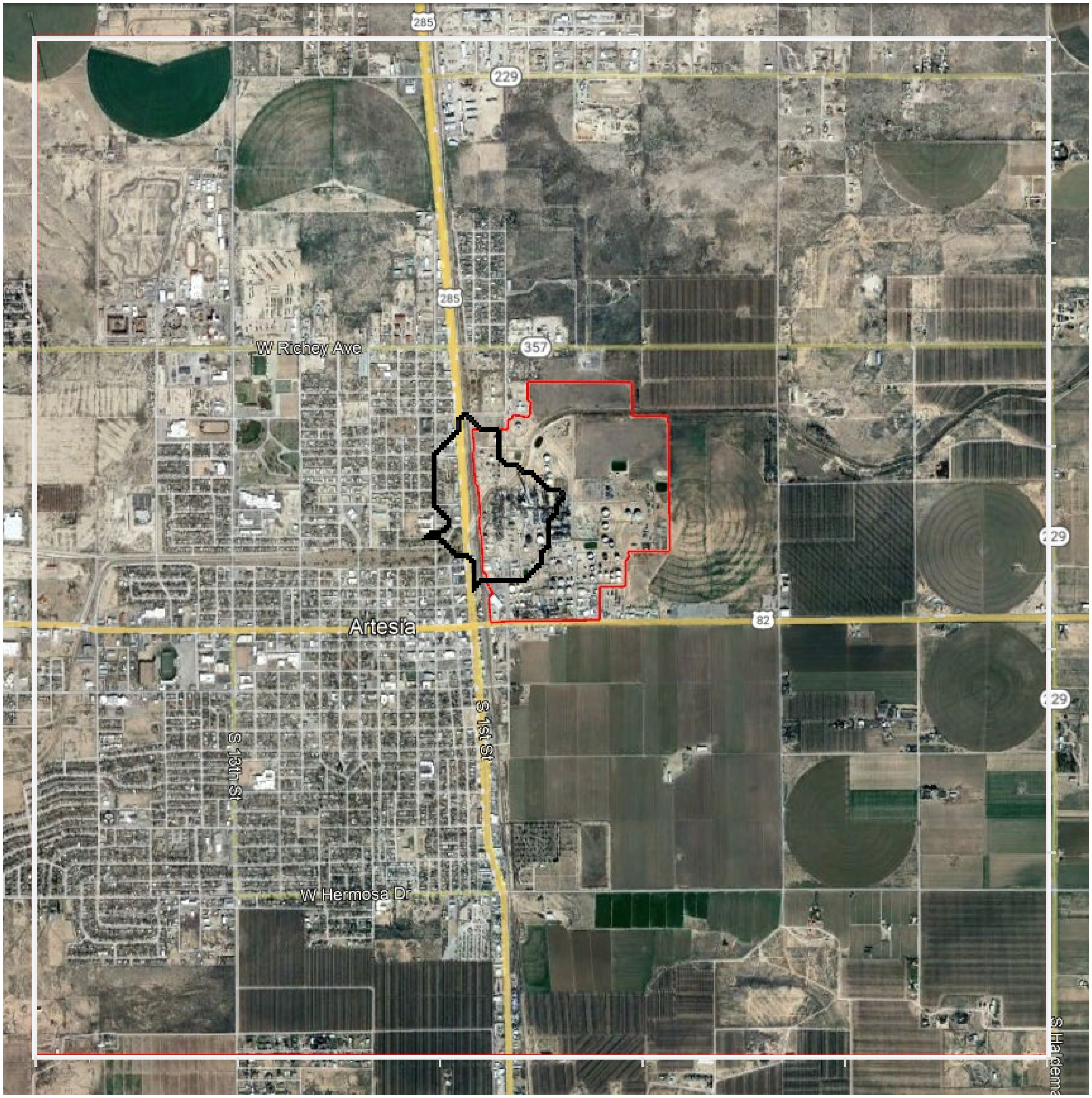


Figure 12. Area in which the Modeled Two-week Average Benzene Concentration Exceeded 3.0 µg/m^3 Due to Calibrated Tank 57 Emissions: Mar 26 – Apr 9, 2019

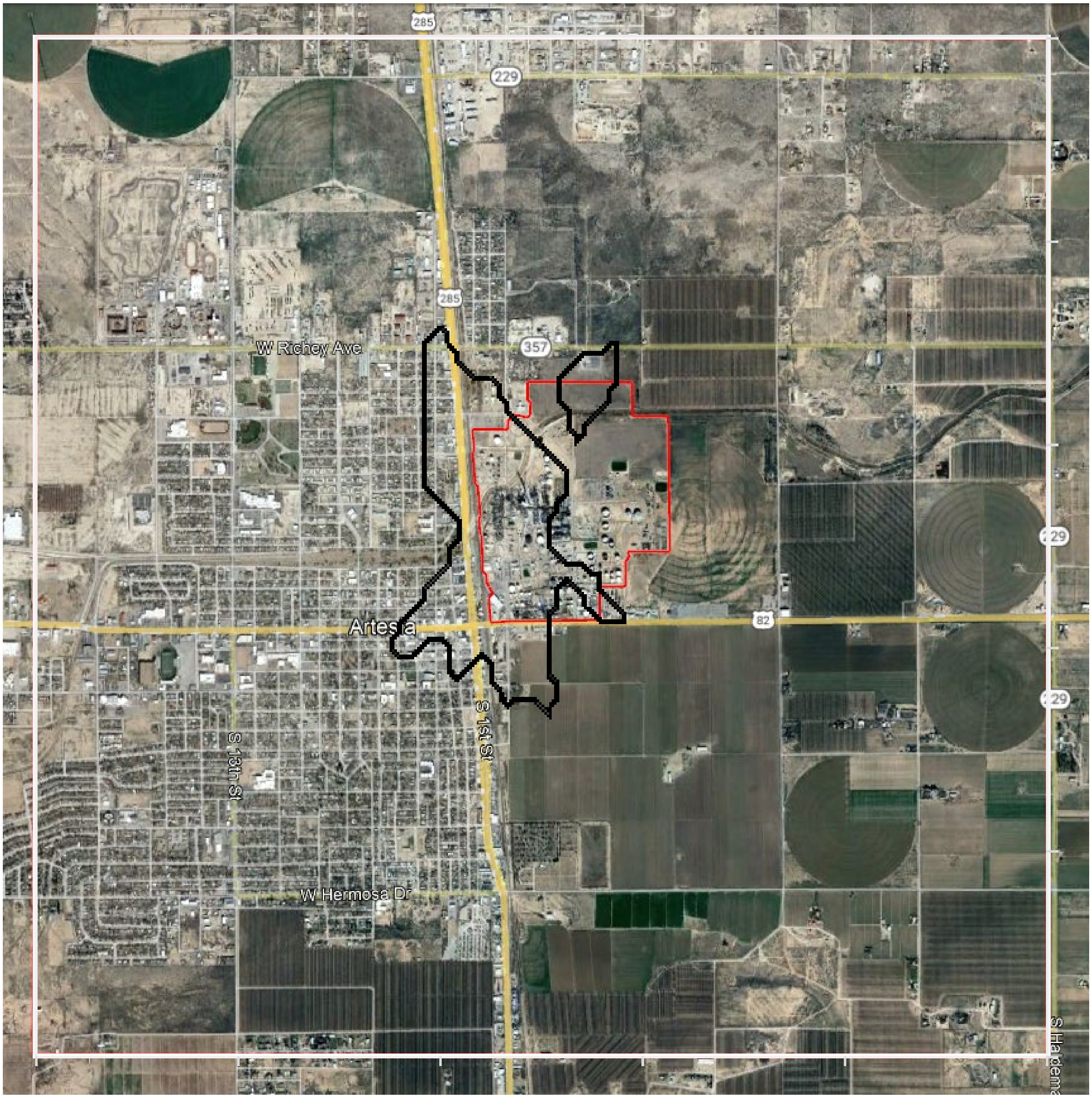


Figure 13. Area in which the Modeled Two-week Average Benzene Concentration Exceeded 3.0 µg/m³ Due to Calibrated Tank 57 Emissions: Apr 9 – Apr 23, 2019

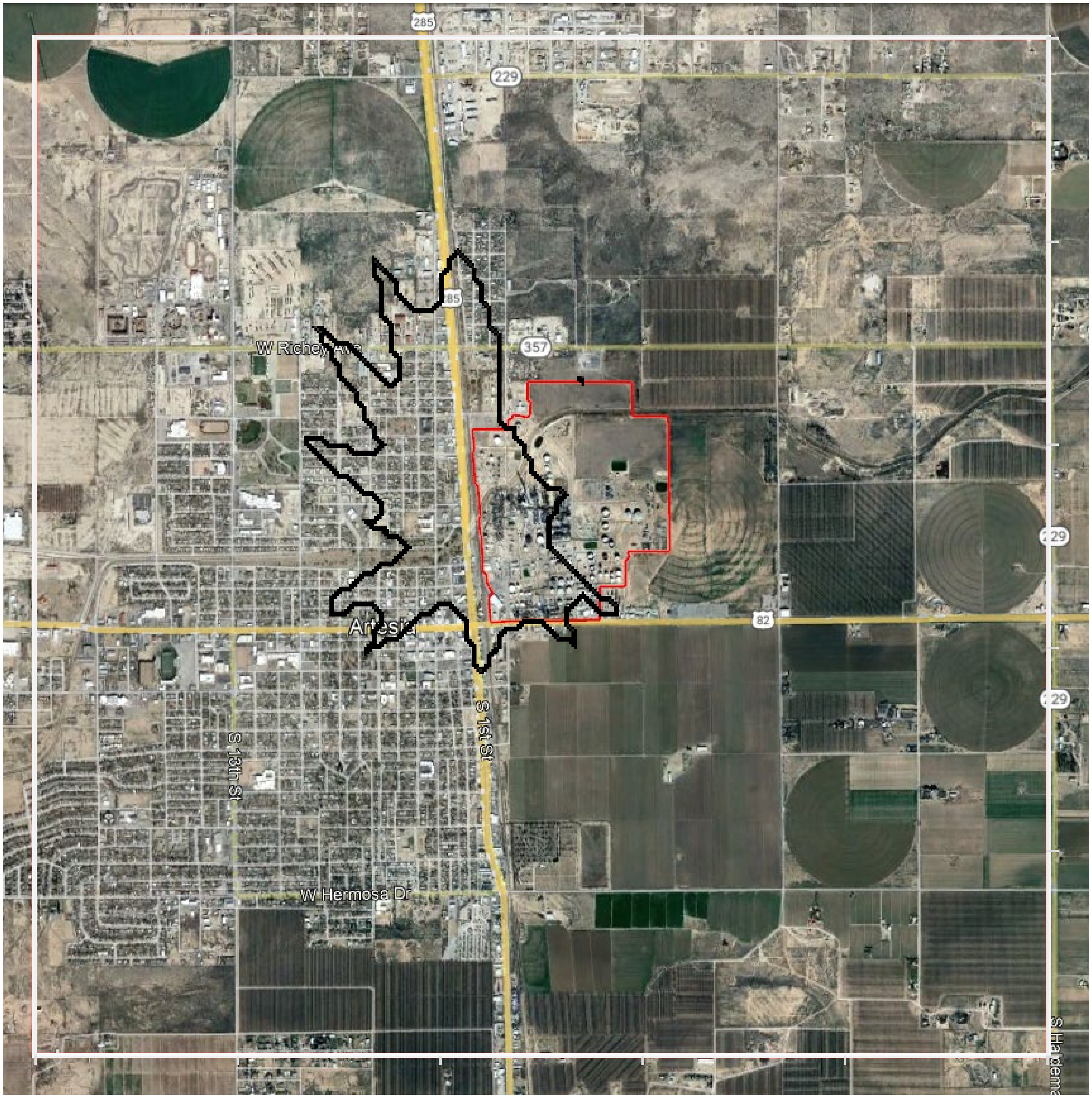


Figure 14. Area in which the Modeled Two-week Average Benzene Concentration Exceeded 3.0 µg/m^3 Due to Calibrated Tank 57 Emissions: Apr 23 – May 7, 2019

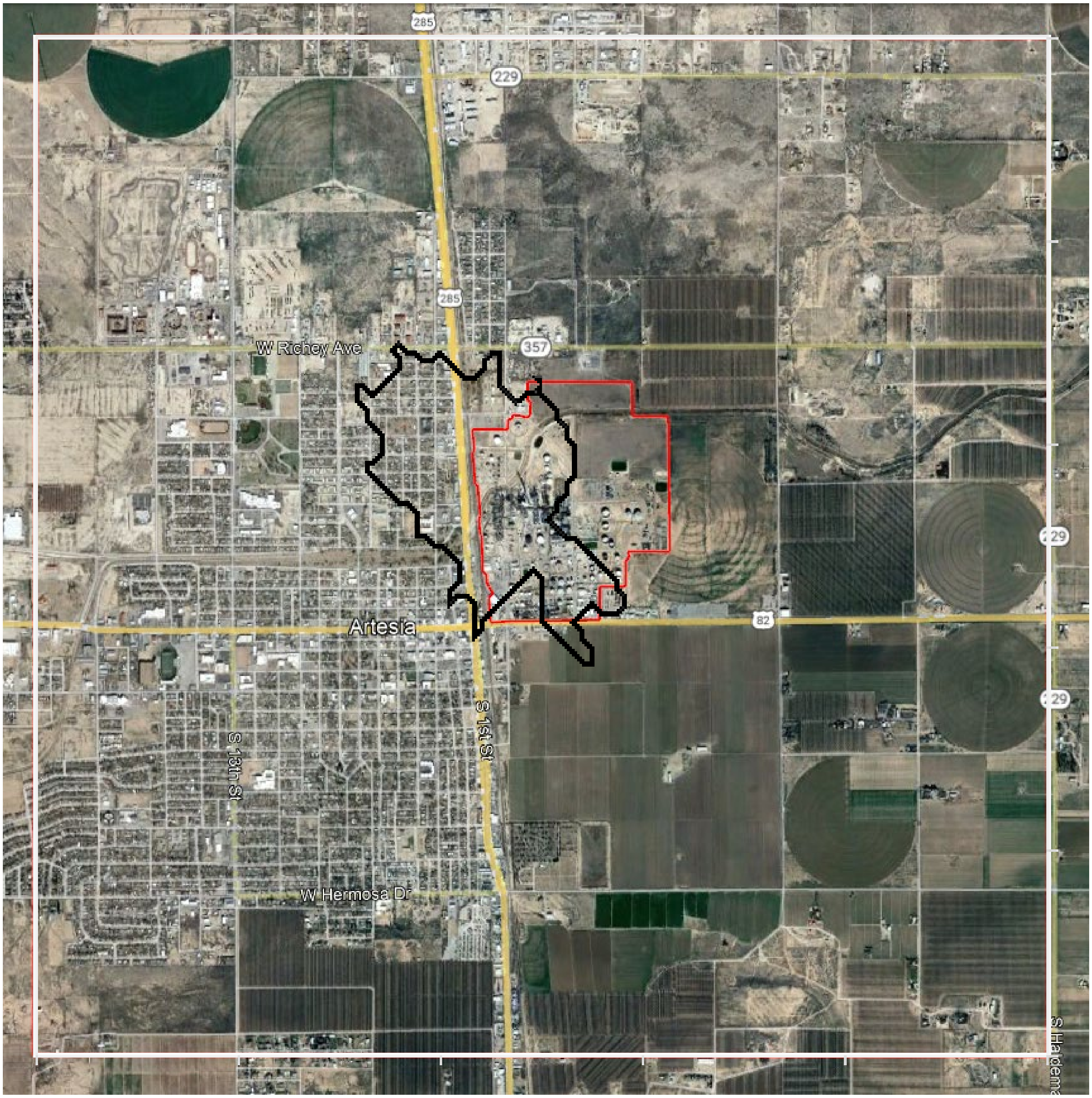


Figure 15. Area in which the Modeled Two-week Average Benzene Concentration Exceeded 3.0 μg/m^3 Due to Calibrated Tank 57 Emissions: May 7 – May 21, 2019

As shown in Table 11, the modeled two-week average benzene concentration due to the calibrated Tank 57 emissions exceeded 10 µg/m^3 at the Roselawn Elementary School, Eagle Draw Park, and the Residential 3 location during April 23 – May 7, 2019 (period C). Table 12 shows that the modeled maximum 1-hour benzene concentration exceeded 100 µg/m^3 at between 6 and 10 of the 18 sensitive receptor locations during the four two-week periods, with a maximum of 971 µg/m^3 at Eagle Draw Park during April 23 – May 7, 2019. Table 13 shows that the modeled maximum 10-hour average benzene concentration exceeded 20 µg/m^3 at between 5 and 11 of the 18 sensitive receptor locations during the four two-week periods and exceeded 100 µg/m^3 at 6 locations during April 23 – May 7, 2019 (period C). Figures 12 through 15 show that the modeled two-week average benzene concentration due to Tank 57 emissions exceeded 3 µg/m^3 over a large area during each modeled period (period A: 0.57 km^2, period B: 1.72 km^2, period C: 2.29 km^2, period D: 1.64 km^2).

Table 14 shows the modeled maximum 1-hour and maximum 10-hour average benzene concentrations due to the calibrated Tank 57 benzene emissions during each two-week period at each of the fenceline monitoring locations.

Table 14. Modeled Maximum 1-hour and 10-hour Average Benzene Concentrations (µg/m^3) Due to Calibrated Tank 57 Emissions

	Max 1-hr (µg/m^3)				Max 10-hr Average (µg/m^3)			
Receptor	period A 3/26-4/9/19	period B 4/9-4/23/19	period C 4/23-5/7/19	period D 5/7-5/21/19	period A 3/26-4/9/19	period B 4/9-4/23/19	period C 4/23-5/7/19	period D 5/7-5/21/19
Monitor 1	79.6	246.1	291.1	190.2	13.3	34.0	146.9	19.1
Monitor 2	82.6	82.5	198.2	113.7	13.8	23.8	26.9	16.5
Monitor 3	57.8	185.4	35.8	28.4	9.7	31.3	14.2	4.4
Monitor 4	33.0	43.5	33.9	103.1	5.1	43.5	13.3	13.5
Monitor 5	9.5	20.9	23.1	111.0	2.7	4.3	6.7	11.4
Monitor 6	13.4	26.4	26.3	185.2	3.9	5.2	8.1	19.0
Monitor 7	17.1	245.9	81.5	218.8	4.4	33.3	11.9	38.6
Monitor 8	23.5	460.9	556.2	370.3	2.8	67.5	112.1	62.9
Monitor 9	43.2	150.3	171.7	180.8	6.3	75.4	40.2	56.7
Monitor 10	18.7	206.6	624.4	472.8	3.9	75.0	90.0	78.1
Monitor 11	134.7	483.9	170.0	221.3	22.2	156.9	38.0	29.1
Monitor 12	78.4	652.8	843.2	268.0	16.3	140.1	121.7	64.9
Monitor 13	423.4	1,453.9	1,674.1	787.1	69.1	358.9	429.4	241.8
Monitor 14	549.7	1,548.2	1,827.9	1,295.1	270.5	502.8	778.9	505.3
Monitor 15	419.4	1,210.8	1,448.9	797.0	130.2	423.0	1,356.2	169.7
Monitor 16	294.0	887.9	974.0	561.4	70.6	270.3	765.2	86.3
Monitor 17	264.6	548.7	887.0	407.7	50.7	158.8	887.0	54.1
Monitor 18	109.3	432.7	684.5	439.4	19.4	144.6	389.4	63.7
Monitor 19	147.2	202.0	79.6	252.5	24.9	30.6	26.0	53.8

A: Mar 26 - Apr 9, 2019
B: Apr 9 - Apr 23, 2019
C: Apr 23- May 7, 2019
D: May 7 - May 21, 2019

Summary and Conclusions

This report summarizes the results of air dispersion modeling conducted using AERMOD, the standard EPA-approved model used for such analyses. Using reported 2019 emissions by the Navajo Artesia Refinery, appropriate meteorological data, and the necessary source information, the model was used to estimate pollutant concentrations for SO_2, $PM_{2.5}$, and benzene from the Artesia Refinery for the five-year period 2016-2020. The source and meteorological data were input to the AERMOD dispersion model which was used to estimate the pollutant concentration impacts at the fenceline and in the surrounding community.

The model results indicate that emissions from the refinery had a significant effect on pollutant concentrations, especially for benzene. Comparisons of modeled concentrations with measured concentrations at the fenceline monitors demonstrated that the emissions inventory data for benzene were significantly under-reported. For a brief critique of the lack of reliability of the emissions that are reported by the refinery please see Attachment A.

Benzene emissions from the Tank 57 source were calibrated to match the observed 2-week average fenceline measurements for four periods with high fenceline benzene measurements, resulting in significant modeled benzene concentration impacts in the surrounding community. The modeled maximum hourly and 10-hour average benzene concentration due to the calibrated Tank 57 emissions exceeded 100 μg/m^3 at numerous sensitive receptor locations.

The findings noted in this report are based on the available data. Should additional data become available, I reserve the right to reassess and appropriately update the results and conclusions, as warranted.

Attachment A

A Brief Critique of the Emissions Reported by the Artesia Refinery

by

Dr. Ranajit (Ron) Sahu, Consultant

I was asked by the Environmental Integrity Project (EIP) to review the emissions reported by the Artesia refinery in its various public submissions to relevant regulatory agencies. I have conducted a targeted review of the refinery's emissions and have identified numerous shortcomings that, collectively, make the reported emissions unreliable.

In order to conduct my review I relied upon the emissions reported by the refinery in a recent renewal application for its Title V major source operating permit.[24] Information provided in such applications is subject to legally enforceable certification by responsible officials of the refinery that the emissions estimates being provided are accurate.

In most instances, based on my prior three+ decades of emissions inventory experience it is my opinion that the emissions are under-reported. In other instances, the emissions reported are simply not properly supported from a technical standpoint. I stress that my review was not intended to provide a comprehensive review of all aspects of the refinery's emissions of all air pollutants under all operations (for example normal operations, operations involving startup and shutdown events, and operations during periods of upset or malfunction events). So, the discussion and findings below are illustrative as opposed to being comprehensive.

A1. Benzene Emissions from Tanks

I show below excerpts from two tables contained in the refinery's permit application noted above. Both are supposedly estimating the Potential to Emit (PTE) or maximum emissions of benzene (and other air toxic pollutants) from materials stored in various tanks at the refinery. Table 1A shows the annual PTE while Table 1B shows the hourly PTE. In each instance I have highlighted the columns showing the benzene emissions. I have also highlighted in redboxes, the vapor weight percent of benzene in the tank's overall VOC emissions. It is always the case that for a parameter like the vapor weight percent, the maximum value on a short-term basis (i.e., hourly) should be higher than the maximum value on a longer term basis (i.e., annual). That is simply because there is always more short-term variability due to many factors including process variations, composition variations, and the like.

Yet, a simple inspection of the benzene vapor weight fraction in the Tables 1A and 1B below shows that the maximum weight fraction (which is to be used for calculating the

[24] Tacosa Alliance Company, Updated Application for Permit Renewal HollyFrontier Artesia Refinery Title V Operating Permit No. P051-R3, submitted to the New Mexico Environment Department, August 2020.

respective PTE values) on an annual basis is higher (and in many cases much higher) than the corresponding value on a hourly basis. This is exactly the opposite of what it should be. Consider, for example, the values for the distillate tanks towards the bottom of each table. The maximum annual value ranges from 20.31% to 50.43% in Table 1A. Yet the hourly maximum values for the same tanks in Table 1A are only 1.61% to 3.22%. The same observation applies to the first entry, Tank 0057 discussed in Dr. Gray's analysis. Again, the annual maximum benzene content reported for the naphtha product is higher than the hourly maximum value. This, of course, does not make any sense whatsoever. Thus, the benzene emissions estimated from the tanks are incorrect.

Table 1A – Excerpt of PTE Calculations of Annual Benzene Emissions from Tanks

STORAGE TANK POTENTIAL TO EMIT HAP

Tank Number	Material	Average Material Vapor Pressure	Tank Type (EFR/IFR)	VOC Emissions		Average Tank	Benzene			Ethylbenzene		
				Lr+Lf+Ld	Lw	Temp[a]	Liquid[b]	Vapor	Emission	Liquid[b]	Vapor	Emission
		psia		ton/yr	ton/yr	°F	wt%	wt%	ton/yr	wt%	wt%	ton/yr
T-0057	Naphtha	3.00	EFR	2.02	0.50	62	3.79%	1.56%	0.050	4.36%	0.17%	0.025
T-0079	Gasolines	5.38	EFR	3.70	0.18	62	0.34%	0.08%	0.003	0%	0.00%	0.000
T-0117	Gasolines	5.38	EFR	4.00	0.11	62	0.34%	0.08%	0.003	0%	0.00%	0.000
T-0401	Gasolines	5.38	EFR	3.01	0.22	62	0.34%	0.08%	0.003	0%	0.00%	0.000
T-0402	Gasolines	5.38	EFR	3.01	0.44	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0411	Gasolines	5.38	EFR	5.04	0.13	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0412	Gasolines	5.38	EFR	5.04	0.05	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0435	Sour Water	6.06	EFR	1.84	2.07	62	3.79%	0.77%	0.093	4.36%	0.08%	0.092
T-0437	Crude Oil	6.06	EFR	4.47	6.29	62	3.79%	0.77%	0.273	4.36%	0.08%	0.278
T-0450	Naphtha	3.00	EFR	3.53	0.37	62	3.79%	1.56%	0.069	4.36%	0.17%	0.022
T-0830	Slop	1.50	EFR	2.66	0.02	62	3.79%	3.12%	0.084	4.36%	0.34%	0.010
T-1225	Crude Oil	6.06	EFR	6.04	1.26	62	3.79%	0.77%	0.094	4.36%	0.08%	0.060
T-0821	Gasolines	5.38	EFR	3.68	0.24	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0011	Gasolines	5.38	IFR	3.38	0.27	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0012	Gasolines	5.38	IFR	3.34	0.28	62	0.34%	0.08%	0.004	0%	0.00%	0.000
T-0020	Gasolines	5.38	IFR	0.96	0.13	62	0.34%	0.08%	0.001	0%	0.00%	0.000
T-0021	Gasolines	5.38	IFR	0.96	0.13	62	0.34%	0.08%	0.001	0%	0.00%	0.000
T-0022	Gasolines	5.38	IFR	0.96	0.13	62	0.34%	0.08%	0.001	0%	0.00%	0.000
T-0023	Gasolines	5.38	IFR	0.96	0.13	62	0.34%	0.08%	0.001	0%	0.00%	0.000
T-0056	Naphtha	3.00	IFR	1.18	0.95	62	3.79%	1.56%	0.054	4.36%	0.17%	0.043
T-0107	Gasolines	5.38	IFR	3.64	0.19	62	0.34%	0.08%	0.003	0%	0.00%	0.000
T-0108	Gasolines	5.38	IFR	2.16	0.21	62	0.34%	0.08%	0.002	0%	0.00%	0.000
T-0109	Gasolines	5.38	IFR	3.04	0.21	62	0.34%	0.08%	0.003	0%	0.00%	0.000
T-0111	Gasolines	5.38	IFR	1.77	0.12	62	0.34%	0.08%	0.002	0%	0.00%	0.000
T-0112	Gasolines	5.38	IFR	1.73	0.00	62	0.34%	0.08%	0.001	0%	0.00%	0.000
T-0124	Gasolines	5.38	IFR	2.16	0.14	62	0.34%	0.08%	0.002	0%	0.00%	0.000
T-0413	Distillates	0.02	IFR	0.02	0.37	62	0.10%	5.61%	0.002	0.10%	0.53%	0.000
T-0415	Gasolines	5.38	IFR	1.82	0.28	62	0.34%	0.08%	0.002	0%	0.00%	0.000
T-0417	Gasolines	5.38	IFR	2.73	0.11	62	0.34%	0.08%	0.002	0%	0.00%	0.000
T-0439	Naphtha	3.00	IFR	2.56	2.67	62	3.79%	1.56%	0.141	4.36%	0.17%	0.121
RW-6	Ground Water	4.90	FX	2.19	-	77	3.79%	2.50%	0.055	4.36%	0.34%	0.008
T-0049	Slop	1.50	FX	44.71	-	64	0.10%	0.21%	0.096	0.10%	0.03%	0.012
T-0055	Distillates	0.01	FX	0.50	-	64	0.10%	50.43%	0.251	0.10%	6.05%	0.030
T-0059	Distillates	0.02	FX	0.16	-	90	0.10%	20.31%	0.032	0.10%	2.44%	0.004
T-0061	Distillates	0.02	FX	1.27	-	90	0.10%	20.31%	0.258	0.10%	2.44%	0.031
T-0418	Distillates	0.02	FX	5.32	-	90	0.10%	20.31%	1.080	0.10%	2.44%	0.130
T-0419	Distillates	0.02	FX	26.99	-	90	0.10%	20.31%	5.482	0.10%	2.44%	0.658
T-0434	Distillates	0.02	FX	16.94	-	90	0.10%	20.31%	3.442	0.10%	2.44%	0.413
T-0815	Distillates	0.02	FX	27.74	-	90	0.10%	20.31%	5.634	0.10%	2.44%	0.676
T-0838	Distillates	0.02	FX	27.18	-	90	0.10%	20.31%	5.521	0.10%	2.44%	0.662
T-0914	Slop	0.74	FX	8.66	-	90	0.10%	0.44%	0.038	0.10%	0.05%	0.005

Table 1B – Excerpt of PTE Calculations of Hourly Benzene Emissions from Tanks

STORAGE TANK POTENTIAL TO EMIT HAP

Tank Number	Material	Maximum Material Vapor Pressure	Tank Type (EFR/IFR)	VOC Emissions		Maximum Tank Temp.	Benzene			Ethylbenzene		
				Lr+Lf+Ld	Lw		Liquid[b]	Vapor	Emission	Liquid[b]	Vapor	Emission
		psia		lb/hr	lb/hr	°F	wt%	wt%	lb/hr	wt%	wt%	lb/hr
T-0057	Naphtha	11.00	EFR	3.11	0.25	100	3.79%	1.11%	0.044	4.36%	0.15%	0.016
T-0079	Gasolines	11.00	EFR	2.80	0.33	100	0.34%	0.10%	0.004	0%	0.00%	0.000
T-0117	Gasolines	11.00	EFR	3.03	0.40	100	0.34%	0.10%	0.004	0%	0.00%	0.000
T-0401	Gasolines	11.0	EFR	2.28	0.05	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0402	Gasolines	11.0	EFR	2.28	0.05	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0411	Gasolines	11.0	EFR	3.82	0.19	100	0.34%	0.10%	0.004	0%	0.00%	0.000
T-0412	Gasolines	11.0	EFR	3.82	0.20	100	0.34%	0.10%	0.004	0%	0.00%	0.000
T-0435	Sour Water	11.0	EFR	1.19	0.47	100	3.79%	1.11%	0.031	4.36%	0.15%	0.022
T-0437	Crude Oil	11.0	EFR	2.89	1.39	100	3.79%	1.11%	0.085	4.36%	0.15%	0.065
T-0450	Naphtha	11.0	EFR	5.43	0.39	100	3.79%	1.11%	0.075	4.36%	0.15%	0.025
T-0830	Slop	11.0	EFR	8.75	0.07	100	3.79%	1.11%	0.100	4.36%	0.15%	0.016
T-1225	Crude Oil	11.0	EFR	3.90	0.11	100	3.79%	1.11%	0.048	4.36%	0.15%	0.011
T-0821	Gasolines	11.0	EFR	2.79	0.06	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0011	Gasolines	11.0	IFR	2.56	0.06	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0012	Gasolines	11.0	IFR	2.53	0.06	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0020	Gasolines	11.0	IFR	0.73	0.06	100	0.34%	0.10%	0.001	0%	0.00%	0.000
T-0021	Gasolines	11.0	IFR	0.73	0.06	100	0.34%	0.10%	0.001	0%	0.00%	0.000
T-0022	Gasolines	11.0	IFR	0.73	0.06	100	0.34%	0.10%	0.001	0%	0.00%	0.000
T-0022	Gasolines	11.0	IFR	0.73	0.06	100	0.34%	0.10%	0.001	0%	0.00%	0.000
T-0056	Naphtha	11.0	IFR	1.82	0.12	100	3.79%	1.11%	0.025	4.36%	0.15%	0.008
T-0107	Gasolines	11.0	IFR	2.76	0.14	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0108	Gasolines	11.0	IFR	1.64	0.04	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0109	Gasolines	11.0	IFR	2.30	0.14	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0111	Gasolines	11.0	IFR	1.34	0.10	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0112	Gasolines	11.0	IFR	1.31	0.10	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0124	Gasolines	11.0	IFR	1.64	0.14	100	0.34%	0.10%	0.002	0%	0.00%	0.000
T-0413	Distillates	11.0	IFR	5.18	0.38	100	0.10%	0.03%	0.002	0.10%	0.00%	0.001
T-0415	Gasolines	11.0	IFR	1.38	0.35	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0417	Gasolines	11.0	IFR	2.07	0.19	100	0.34%	0.10%	0.003	0%	0.00%	0.000
T-0439	Naphtha	11.0	IFR	3.95	1.24	100	3.79%	1.11%	0.091	4.36%	0.15%	0.060
RW-6	Ground Water	11.0	FX	145.2	-	100	3.79%	1.11%	1.612	4.36%	0.15%	0.223
T-0049	Slop	1.5	FX	58.5	-	100	0.10%	0.21%	0.126	0.10%	0.03%	0.015
T-0055	Distillates	0.1	FX	5.46	-	100	0.10%	3.22%	0.176	0.10%	0.39%	0.021
T-0059	Distillates	0.2	FX	3.12	-	130	0.10%	1.61%	0.050	0.10%	0.19%	0.006
T-0061	Distillates	0.1	FX	2.34	-	130	0.10%	3.22%	0.075	0.10%	0.39%	0.009
T-0418	Distillates	0.1	FX	3.12	-	130	0.10%	3.22%	0.100	0.10%	0.39%	0.012
T-0419	Distillates	0.1	FX	3.12	-	130	0.10%	3.22%	0.100	0.10%	0.39%	0.012
T-0434	Distillates	0.1	FX	31.2	-	130	0.10%	3.22%	1.005	0.10%	0.39%	0.121
T-0815	Distillates	0.1	FX	46.8	-	130	0.10%	3.22%	1.507	0.10%	0.39%	0.181
T-0838	Distillates	0.1	FX	8.58	-	130	0.10%	3.22%	0.276	0.10%	0.39%	0.033
T-0914	Slop	0.74	FX	29.6	-	130	0.10%	0.44%	0.129	0.10%	0.05%	0.015

A2. Fugitive VOC (Including Benzene) Emissions

Table 2 below shows the calculations of VOC emissions from the typically thousands of components such as valves, flanges, connectors, pump seals, and similar devices that are present in the refinery. The refinery-wide fugitive VOC emissions from the collection of all of these components rely on: an accurate count of such components that are present in different process areas of the refinery; emission factors that then represent the "uncontrolled" emissions of VOCs from each component; and finally the "control efficiency" that can be reasonably applied to these uncontrolled emissions based on inspections (called Leak Detection and Repair, or LDAR). Once such VOC emissions are estimated, speciated toxic emissions, such as benzene are then estimated by apply a speciation factor (or weight fraction) to the estimated VOC emissions.

Table 2 – Artesia Refinery Estimate of Fugitive VOC Emissions from Components

FUGITIVE PIPING COMPONENT POTENTIAL TO EMIT

		Valves					Flanges		Pump Seals				Relief Valves	
		Gas		Light Liquid		Heavy Liquid	All		Light Liquid			Heavy Liquid	All	
		Non-Monitored	MACT Control	Non-Monitored	MACT Control	Non-Monitored	Non-Monitored	AVO Control	Non-Monitored	Dual Seals	MACT Control	Non-Monitored	Non-Monitored	MACT Control
	Emission Factor: [1]	0.059	96%	0.024	95%	0.00051	0.00055	30%	0.251	100%	88%	0.046	0.35	70%
UNIT ID	**PROCESS UNIT**	**COMPONENT COUNTS**												
FUG-02-SP CRUDE	South Division Crude Unit		314		1054	331	2923				17	10	7	1
FUG-05-KERO	Kerosene HDS Unit	30		27		180	352		2			5	4	
FUG-06-NHDU	Naphtha HDS Unit 06	59	264	5	683	0	2284	0	0	0	13	0	0	0
FUG-07-N AMINE	Amine Unit-Treating/Regen. [2]		273	4	1078	0	643	3			13	0	8	2
FUG-07-SWS1	Sour Water Stripper		124		50		221	13			2		3	
FUG-08-TRUCK RK	Loading Racks		19	6	83	37	54	40	2		1	21	1	
FUG-09-N ALKY	North Alkylation Unit (New-Inside battery limits)		328	4	1663	0	841	92		19	7	0	22	
FUG-10-FCC	FCC w/CVS		181		570	665	1862				16	23	8	4
FUG-13-NHDU	Naphtha HDS Unit 13	0	361		805	0	1211		0	0	24	0	18	0
FUG-18-LSR MEROX TRT	Merox/Merichem Treating Units		6		78	0	116	5			1	0	2	
FUG-20-ISOM	BenFree Unit		32		442		704				4	0	13	
FUG-20-ISOM - New Compone	**BenFree Unit - New Components**				**21**		**53**							
FUG-21-SP VACUUM	Flasher/Vacuum Unit	6	1	22	4	349	900					23	0.00	
FUG-25-ROSE-2	ROSE Unit		343		300	526	1593	40			8	12	0	
FUG-26-RDU	Renewable Diesel Unit				62	535	1493					7		
FUG-29-BLENDER/TK FARM	Light Oil Tankage	0	8	12	1471	15	1167	90	0	0	42	1	7	0
FUG-29-BLENDER/TK FARM - New Components	Light Oil Tankage - New Components				204			570			8			
FUG-31-SRU3/TGTU3/TGI3	SRU3 Unit		50		130	60	300				2	4	0	
FUG-33-DIST HDU	Diesel HDS Unit w/CVS		747		236	1044	1440	46			6	19	21	
FUG-34-HYDROCRACKER	WX Hydrocracker		416		422	912	4520				12	26	0	
FUG-35-SAT GAS	Saturates Gas Plant	174	39	75	305	0	601		5		8	0	9	
FUG-35-SAT GAS - New Compo	**Saturates Gas Plant - New Components**		**1**		**29**		**75**				**4**			
FUG-41-PBC	PBC Unit			64		0	131		4			0	2	
FUG-43-S ALKY	South Alky Unit (W-76)		46		163	0	243				4	0	2	
FUG-44-DIST-HDU	Gas Oil Hydrotreater (incl. CVS)		62	8	42	1172	315	4	1			16	2	
FUG-45-DIST-HDU	Gas Oil Hydrotreater (incl. CVS)		40		50	290	370					11	0	
FUG-54-PRIMEG	Prime G Unit		361		795		2890				6			
FUG-63-H2 PLANT-1	Hydrogen Plant		150		150	0	1260				2	0	0	
FUG-64-H2 PLANT-2	Hydrogen Plant		150		150	0	1260				2	0	0	
FUG-70-CCR	CCR Reformer (w/in battery limits)		1236	5	661	8	1564	52			17	3	29	
FUG-73-SP UTIL	Utilities	109		148		0	422		2			0	8	
FUG-80-WWTP CVS	Oil/Water Separator				36	0	180			6	2	0	0	4
FUG-ASPHALT STG	Asphalt/Heavy Oil Storage					304	656					10	7	
FUG-FUEL GAS	Fuel Gas Distribution System	349		3		0	477					0	6	
FUG-LPG	LPG Storage System	82		208		0	564		6			0	20	
FUG-RLO-ASPHALT	Asphalt/Pitch Loading Rack					222	432					7	0	
FUG-RRTOTRUCK	Crude oil unloading system			2			12							
FUG-SRU1/SRU2/TGTU	SRU1/SRU2/SWS w/CVS		141	3	155	30	120	8			4	4	4	

1. Emission factors (lb/hr/source) are from "Protocol for Equipment Leak Estimates," EPA-453/R-95-017, Table 2-2, Nov. 1995, previously approved submittals to NMED, or equivalent factors from guidance.
2. Monitored under MACT as a voluntary permit condition. Does not contain HAP.
3. Maximum VOC% applies to all stream unless otherwise specified.

Each of these four data inputs should be based on refinery-specific data in order for the VOC (or benzene) emissions to be accurate. For PTE estimates, upper-end or maximum values of these inputs should be used. However, as the excerpted Table 2 above shows, there are shortcomings in each of the inputs for the VOC estimation. First, as to component counts, while the table above lists various numbers of components in different refinery areas, there is no documentation to verify or support these numbers. For example, the numbers of pump seals and relief valves appears to be quite low. Next, the emission factors that are used, citing to a 1995 EPA compilation is significantly dated and is based on a very small number of components tested in the early 1990s, with little statistical power. Finally, the control efficiencies, also based on the 1990s observations, are little more than guesswork. For example as the excerpt in Table 2 above shows, the refinery assumed at control efficiency of 30% for flanges using the "AVO" monitoring method – which stands for Audio, Visual, Olfactory. For most VOCs there would not be audio (unless it was a massive leak) or visual leak. And, olfactory determination in a refinery for specific flanges is next to impossible given the sheer numbers of such potential leak points. In fact, the excerpt above confirms the very large number of flanges that are simply not monitored at all.

While I am not showing the benzene speciation assumption in addition to the VOC assumptions above, I have determined that the speciation of benzene used to estimate emissions of that toxic pollutant were not based on any supporting process data.

Collectively, fugitive emissions of VOC are not only unsupported, they are underestimated based on my experience.

A3. Sulfur Recovery Unit (SRU) SO2 and NOx Emissions

Next, I briefly discuss SO2 emissions from the sulfur recovery units at the refinery, as shown in the excerpted Table 3 below.

Table 3 – SO2 PTE from SRUs

SRU POTENTIAL TO EMIT

TGI Stack Exhaust Flow Rate: 9,600 dscfm

Pollutant	MW	H-0473 (SRU1/SRU2 TGI)				SRU3-TGI			
		Maximum Concentrations	Average Concentrations	Emission Rates		Maximum Concentrations	Average Concentrations	Emission Rates	
		ppmvd		lb/hr	ton/yr	ppmvd		lb/hr	ton/yr
NOx	46	93.0	93.0	6.50	28.47	93.0	93.0	6.50	28.47
CO	28	650.0	650.0	27.66	121.15	352.5	352.5	15.00	65.70
VOC	44	2.0	2.0	0.13	0.59	2.0	2.0	0.13	0.59
SO2	64	308.4	191.9	30.00	81.75	308.4	191.9	30.00	81.75
H2S	34	5.8	5.8	0.30	1.31	5.8	5.8	0.30	1.31

FUG-SRU1/SRU2/TGTU	0	0				0.606	0.069	0.304	1.400	0.000	0.000		100%	2.4	10.4
												TOTAL:	TOTAL:	236.95	1037.83

As the table above makes clear, the maximum and average concentrations in the exhaust gases for each of the Tail Gas Incinerators (TGIs) that are part of the SRUs is assumed to be the same for SRU1/SRU2 and also for SRU3. None are supported by process information. While conceptually the maximum concentration may be assumed to be the same, there is no chance that the average concentration would be the same for these different SRUs. For NOx, for each SRU, the calculations not only assume the same maximum concentrations but also the same (and identical to the maximum) average concentrations as well.

Collectively, these types of implausible assumptions raise significant doubt as to the care with which these emissions were estimated. I have no reason to believe that they are reliable.

A4. SO2 and NOx (and no PM) Emissions from Flares

Finally, I discuss emissions of SO2, NOx, and PM from the many flares at the refinery. Table 4A below, taken from the Title V renewal permit application shows that there are five flares at the refinery FL-400 through FL-404, four of which control VOCs and hydrogen sulfide (H2S) and the fifth which controls only VOCs. The first observation is that all of the control efficiencies for all pollutants for all flares are noted simply as 98%. There is no engineering support for this assumption.

Table 4A – Flares at the Artesia Refinery

Control Equipment Unit No.	Control Equipment Description	Date Installed	Controlled Pollutant(s)	Controlling Emissions for Unit Number(s)[1]	Efficiency (% Control by Weight)	Method used to Estimate Efficiency
D-0829/0830	Main API Carbon Canisters	Unknown	VOC	MAIN API	95%	
FCC Scrubber	FCC Regenerator Tertiary Cyclones and Wet Gas Scrubber	Unknown	PM10 and SO2	FCC Regenerator vent	PM-85% & SO2-99%	
Chlorsorb	CCR Regenerator Vent Control		HAP and PM10	CCR Regenerator Vent	99%	
FL-0400	North Plant Flare		VOC and H2S	Refinery Process Units	98%	
FL-0401	South Plant Flare		VOC and H2S	Refinery Process Units	98%	
FL-0402	FCC Flare		VOC and H2S	Refinery Process Units	98%	
FL-0403	Alky Flare		VOC	Refinery Process Units	98%	
FL-0404	GOHT Flare		VOC and H2S	Refinery Process Units	98%	
H-0473	SRU1 and 2 Tail Gas Incinerator		H2S	SRU1 and SRU2	98%	
SRU3-TGI	SRU3 Tail Gas Incinerator		H2S	SRU3	98%	
SCR	Selective Catalytic Reduction		NOx	H-9851	64%	
FL-HEP-PORT	Portable Flare for Holly Energy Partners (HEP) Pipeline Pigging		VOC	Pipeline Pigging Operations	98%	
TL-4 VRU	Fuels Truck Loading Rack Vapor Recovery Unit		VOC	TL-4	90%	
TL-4 VCU	Fuels Truck Loading Rack Vapor Combustion Unit		VOC	TL-4	98%	

Table 4B below confirms that these are tall, stack flares based on their heights above ground which are in the range of 162 feet to 220 feet. These are therefore open flame, stack flares, subject to weather and wind, in addition to considerable variations in the process gases that they flare – both in quantity and composition. Based on their design and operation, these types of flares do not have stable flames and therefore very variable control efficiencies. Certainly there is no justification to use 98% control efficiency as is done in the calculations for VOCs and H2S. Further, as Table 4B below shows, there is no support for and therefore no reason that the exit temperature and velocity of each flare are assumed to be the same.

Table 4B – Height, Temperature, and Exit Velocities for the Flares

Stack Number	Serving Unit Number(s) from Table 2-A	Orientation (H-Horizontal V=Vertical)	Rain Caps (Yes or No)	Height Above Ground (ft)	Temp. (F)	Flow Rate (acfs)	Flow Rate (dscfs)	Moisture by Volume (%)	Velocity (ft/sec)	Inside Diameter (ft)
H-3101	H-3101	V	No	80	450	57	26	19	9.6	2.8
H-3402	H-3402	V	No	67	575	351	143	19	27.9	4.0
H-3403	H-3403	V	No	86	705	244	88	19	19.4	4.0
H-8801/8802	H-8801/8802	V	No	130	600	870	346	19	75.4	3.8
H-9851	H-9851	V	No	176	350	1869	972	19	23.8	10.0
H-0473	H-0473 (SRU1/SRU2 TGI)	V	No	150	1150	555	145	19	44.2	4.0
SRU3-TGI	SRU3-TGI	V	No	150	1200	627	159	19	49.9	4.0
FCCREGEN	FCC Regenerator	V	No	153	125	800	711.26	0	28.3	6.0
FL-0400	FL-0400	V	No	162	1832	N/A	N/A	N/A	65.6	5.3
FL-0401	FL-0401	V	No	200	1832	N/A	N/A	N/A	65.6	2.4
FL-0402	FL-0402	V	No	167	1832	N/A	N/A	N/A	65.6	3.3
FL-0403	FL-0403	V	No	220	1832	N/A	N/A	N/A	65.6	3.2
FL-0404	FL-0404	V	No	200	1832	N/A	N/A	N/A	65.6	11.5

Next, the excerpted Table 4C below shows the "total" emissions of the various pollutants expected from the five flares. First note the complete absence of any particulate matter or PM emissions of any size (i.e., PM10 or PM2.5). This is a crucial and material omission. All of these types of stack flares "smoke" indicating inefficient combustion and formation/emissions of soot and other particulate matter. There is simply no way to avoid combustion inefficiency for such open-flame, tall stack flares. Yet, the refinery, by assuming, with no support, that these flares will never smoke, omits any PM emissions from these flares. This significantly underestimates PM emissions from these flares and the refinery.

Table 4C – "Total" Emissions from the Flares, with No PM Emissions

TOTAL FLARE EMISSIONS

		Emissions							
		NO_x		CO		VOC		SO_2	
Unit ID	Description	(lb/hr)	(tons/yr)	(lb/hr)	(tons/yr)	(lb/hr)	(tons/yr)	(lb/hr)	(tons/yr)
FL-400	North Plant Flare	2.86	5.36	13.02	24.44	19.25	21.68	5.70	3.49
FL-401	South Plant Falre	0.59	0.97	2.68	4.40	5.61	1.42	9.03	6.98
FL-402	FCC Flare	1.10	1.46	5.01	6.65	9.42	8.59	0.56	0.33
FL-403	Alky Flare	1.12	0.89	5.11	4.07	10.88	8.66	1.26	1.00
FL-404	GOHT Flare	12.58	19.06	57.35	86.90	51.84	58.91	84.79	10.47
	SUM:	**18.24**	**27.74**	**83.17**	**126.46**	**97.00**	**99.27**	**101.34**	**22.28**

Tables 4D and 4E below shows the basis of the emissions that are calculated for the flares. I note that the emission factors for NOx, CO and VOC in each table are taken from AP-42. I have reviewed AP-42's flare emission factors and can attest that they are very poorly supported and, in fact, have no support for these types of tall, stack flares, combusting a wide range of refinery waste gases.

In addition, SSM calculations in Table 4D also shows that the refinery has simply assumed that the H2S content of the flare gases is 2% during SSM conditions. Not only is there no support for this, it appears that the refinery is wrongly assuming that H2S will be the only sulfur compound present in the flare gases. That is simply false. Flare waste gases during SSM, especially from the Coker or even other process units, contains significant quantities of non-H2S sulfur compounds such as mercaptans and thiophenes, which, when combusted, produce SO2. That is not accounted for in the flare SSM emissions estimated by the refinery. It is also worth noting that in addition to the wrong emission factors, the flare SSM calculations also assume that the flare waste gases (heating value and molecular weight) are the same as natural gas. That is also completely incorrect.

Table 4D – Incorrect and Unsupported Assumptions for Flare SSM Emissions

SSM FL-HEP-PORT POTENTIAL TO EMIT

Constants:			
Data	Unit	Description	Data Source
64	lb/lb-mol	MW of SO2	
8.44E-05	T/scf	Consent Decree Conversion Factor	Paragraph 20.D of consent decree
379	scf/lb-mol	Volumetric conversion factor	
0.068	lb/MM Btu	NOx Flare emission factor for high-Btu, steam assisted flare (lb/MM Btu)	AP-42, Chapter 13.5, Industrial Flares, Table 13.5-1, 01/1995.
0.37	lb/MM Btu	CO emission factor.	AP-42, Chapter 13.5, Industrial Flares, Table 13.5-1, 01/1995.
0.063	lb/MM Btu	VOC emission factor.	AP-42, Chapter 13.5, Industrial Flares, Table 13.5-1, 01/1995.
2.0	%	Uncombusted H2S to flare.	Percentage of uncombusted H2S based 98% destruction efficiency basis.

Inputs:			
Data	Unit	Description	Data Source
2,500,000	SCF	Total flow to flare (estimated)	Estimated maximum volume allowed for flaring under 0.5 ton/yr limit required by 20.2.72.202.B(5) NMAC.
	SCF		
0.000004	scf H2S/scf gas	H2S content of gas flared	Pipeline quality natural gas standard of 0.25 gr/100 dscf.
1020	Btu/scf (LHV)	Lower Heating Value (LHV) of gas to flare	Emission factors for Criteria Pollutants and Greenhouse Gases from Natural Combustion, AP-42 Section 1-4, Table 1.4-2, 01/1995, reference a.
17.1	lb/lb-mole	Molecular Weight	Calculated according to composition of natural gas from 2010 NM Gas Company Monthly Analyses Artesia, Purchased Natural Gas LHV Estimate.xls calculation sheet.

Table 4E – Incorrect Assumptions for Flare Non-SSM Calculations

FLARE POTENTIAL TO EMIT

Molar Volume:	**385.4 scf/lbmol (STP 68°F and 14.7 psia)**	
NOx Factor:	**0.068 lb/MMBtu**	per EPA AP-42, Table 13.5-1, dated 12/2016
CO Factor:	**0.31 lb/MMBtu**	per EPA AP-42, Table 13.5-2, dated 12/2016
VOC Factor:	**0.66 lb/MMBtu**	per EPA AP-42, Table 13.5-2, dated 12/2016
Flare VOC Eff:	**98.0%**	

Emission Calculations for Proposed Permit 0195-M39 Emission Limits [a]

	FLOW	LHV	VOC	VOC MW	S	NOx	CO	VOC[b]	SO2
Flare ID	**Mscfh**	**Btu/scf**	**mol%**	**lb/lbmol**	**ppmv**	**lb/hr**			
FL-400	70	600	10%	53	490	2.86	13.02	19.25	5.70
FL-401	16	540	13%	52	3,400	0.59	2.68	5.61	9.03
FL-402	21	770	16%	54	162	1.10	5.01	9.42	0.56
FL-403[c]	22	749	-	-	20.0 gr/100 scf	1.12	5.11	10.88	1.26
FL-404	370	500	5%	54	1380	12.58	57.35	51.84	84.79
					SUM OF PROPOSED EMISSION LIMITS:	**18.24**	**83.17**	**97.00**	**101.34**
						TPY			
FL-400	30	600	6%	53	160	5.36	24.44	21.68	3.49
FL-401	6	540	2%	52	1600	0.97	4.40	1.42	6.98
FL-402	10	490	7%	54	45	1.46	6.65	8.59	0.33
FL-403[c]	4	749	-	-	20.0 gr/100 scf	0.89	4.07	8.66	1.00
FL-404	160	400	3%	54	90	19.06	86.90	58.91	10.47
					SUM OF PROPOSED EMISSION LIMITS:	**27.74**	**126.46**	**99.27**	**22.28**

a. Emission limits are based on flare monitoring data. Inputs used in calculations above (e.g., flow, lower heating value, VOC molecular weight, sulfur content, etc) are for representation purposes only. They are not proposed limits.

b. For flares other than FL-403, a 98% control efficiency is used; however, 99% control is expected on compounds with 3 carbon atoms or less.

c. Hourly and annual SO_2 emission limits are calculated based on permit limit of 20.0 grains or less of total sulfur per 100 standard cubic feet for "natural gas". VOC emissions ae calculated based on repesentative heat content and EPA AP-42 emission factor.