HAZARDS IN THE AIR

Relating reported illnesses to air pollutants detected near oil and gas operations in and around Karnes County, Texas

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EARTHWORKS

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Earthworks is dedicated to protecting communities and the environment from the adverse impacts of mineral and energy development while promoting sustainable solutions.

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Executive Summary

Not everyone living within Texas's Eagle Ford shale oil and gas boom has benefited from it. This is becoming apparent in Karnes County, where residents report a decline in their health as shale development increased.

Hazards in the Air, a collaboration between Earthworks and Northeastern University's Social Science Environmental Health Research Institute, explores the known human health hazards of chemicals found in air samples taken close to oil and gas operations in, and upwind of, Karnes County, and compares them to health problems reported by people living in Karnes County.

The study was conducted in two parts:

1) In-depth interviews with 18 Karnes County residents about their health and concerns for air quality impacts by oil and gas operations.
2) Air sampling at eight oil and gas facilities selected based upon community concerns for sensitive populations – e.g., daycare centers – adjacent to oil and gas operations, agency reports of violation, and/or volatile organic compound pollution detected by an optical gas imaging (OGI) camera (FLIR GasFinder 320).

The study's findings

Resident interviews revealed:

- 75% of interviewees with health issues reported neurological problems such as migraines, memory loss, forgetfulness, confusion or lack of focus, dizziness, and numbness in extremities.
- 50% reported respiratory problems including difficulty breathing, asthma, shortness of breath, pulmonary fibrosis, and chronic obstructive pulmonary disease (COPD).
- 89% expressed concern for environmental impacts on their health.

Analysis of air samples taken close to oil and gas facilities found a mixture of compounds that can cause neurological, respiratory and immunological problems at concentrations that are concerning, including:

- **Benzene:** A carcinogen, legally classified as a Hazardous Air Pollutant (HAP) under the Clean Air Act.
- **Hydrogen sulfide (H_2S):** A neurotoxic gas, that can cause chronic health effects in humans. Many industries are required to publicly report H_2S emissions to EPA's Toxics Release Inventory (TRI).[1] However oil and gas production is exempt from TRI reporting.[2]
- **Cyclohexane:** An eye, skin, and respiratory irritant that may affect the nervous system and cause death in high doses. It is regulated by the Texas Commission on Environmental Quality (TCEQ), but not the federal Environmental Protection Agency (EPA).
- **Naphthalene:** Hazardous to the liver, eyes, nervous system, and linked to increased risk of some cancers. It is on the EPA's list of HAPs under the Clean Air Act.
- **n-Hexane:** Classified by the EPA as a HAP, it can irritate the skin, eyes, and throat. In the long term, it can affect the central nervous system.
- **Mixed xylenes:** Eye, nose, and throat irritants that also affect the nervous system. Xylenes are on the EPA's list of HAPs.

Resident interviews and the air sample findings reinforced one another

The mixtures of chemical compounds detected in the air samples could harm exposed persons' immune, respiratory, and neurological systems if they were inhaled regularly over extended periods of time (a year or more). People routinely exposed to the mixtures and concentrations of compounds identified in these samples may also be at an increased risk of cancer.

Together, the two studies' findings reinforce one another: the chemicals detected in the air study can cause health problems that can produce the symptoms similar to those reported in the interview study.

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Recommendations

Our overarching recommendation is that the TCEQ should act to protect the health of Karnes area residents by ensuring that they are not exposed to chemicals, both individually and in mixtures, such as those we detected, and that pollution is not in violation of federal and state guidelines. Furthermore, federal and state regulations that prioritize protecting public health over short term economic gain need to be established.

In order to protect Karnes residents, the TCEQ needs to take concrete steps to prioritize public health ahead of oil and gas operator financial interests.

- **Adequately monitor the air.** In contrast to the current situation, where there is inadequate monitoring, TCEQ needs to increase monitoring of air pollution from oil and gas operations in Karnes and throughout the Eagle Ford Shale region. As a state agency, TCEQ should establish a standard methodology for choosing the type, number, and location of air monitors given the existing and predicted oil and gas development they are intended to monitor. Further, TCEQ should transparently explain its methodology, and hold regional public hearings seeking public input on and providing public explanation for its proposed application of that methodology in that region. We recommend that TCEQ seek input from air quality experts with experience in emerging methods of real-time mobile monitoring.
- **Transparently report air monitoring results.** As with its existing monitors, the new monitors should dynamically report online information so that scientists, regulators, operators, local government, and the public can easily access data in real-time and in aggregate.
- **Encourage Karnes residents to participate in their own protection.** TCEQ staff, even with adequate resources, cannot be everywhere at all times. Karnes residents, however, live in the area and also have a strong incentive to ensure that oil and gas facilities operate in a manner that protects the general public health and their own health, specifically. TCEQ should collaborate with concerned residents by establishing standards and procedures that encourage residents to share their concerns about polluting facilities and make it easy for residents to follow up on their cases.
- **Commission assessment of oil and gas emissions, Karnes County residents exposures, and evaluation of potential health impacts.** Our mutually reinforcing air study and resident interview study strongly suggest that Karnes residents could be suffering from exposure to threatening levels of air pollution from oil and gas development. TCEQ should request the appropriate funding and authorization from the Texas Legislature to conduct a rigorous assessment of emissions, exposures and potential health impacts.

- **Create a credible enforcement system to prevent future and repeated air emissions violations.** Investigations by news and civil society organizations reveal that regulators do not adequately or sufficiently enforce regulations and further, punish[3] those that do. These investigations found that regulators are failing to protect public health by:[4] [5] [6]

    1. Firing employees who have tried to enforce regulations that penalized or prohibited industry operations.
    2. Warning[7] oil and gas operators rather than sanction them.[8]
    3. Creating legislation that weakens regulations and enforcements and opposing new legislation that creates stricter regulations and raises standards for community health.

The TCEQ needs to take concrete steps to prioritize public health ahead of oil and gas operator financial interests.

Introduction

Karnes County, Texas residents report an increase in chronic health problems coincident with the oil and gas boom in the Eagle Ford Shale. To further investigate the connection between health problems and oil and gas extraction, this report combines data from two independent studies conducted in and around Karnes County during the summer of 2015:

- **A small scale air pollution study**, conducted by Earthworks and researchers from Northeastern University and Memphis University, analyzed nine short-term air samples taken at eight oil and gas facilities, in and upwind of, the Karnes County region.
- **An interview study**, conducted by a University of North Texas researcher, analyzed interviews with Karnes County residents about their health problems.

Together, the two studies' findings reinforce one another: the chemicals detected in the air study can cause health problems that can produce the symptoms similar to those reported in the interview study.

This report arose from Earthworks' previous publication, *Reckless Endangerment*, a case study of the health problems experienced by the Cerny family in Karnes County. That case study demonstrated the failure of Texas regulators[9] to investigate community complaints until shamed into doing so. Once they did investigate, the regulators:

- Found violations so serious as to require the regulators to immediately evacuate an oil and gas site;
- Then notified the violating company of their violations, without penalty;
- Never notified the residents forced to live with the pollution – the same residents whose complaints forced state regulators to investigate in the first place.

Prompted in part by the Cernys' experiences and those of other Karnes residents, Earthworks began looking for (and finding) pollution at oil and gas facilities in the area with an optical gas imaging camera[10] specifically tuned to detect methane and volatile organic compounds (VOCs) like benzene. These compounds are normally invisible to the naked eye. Earthworks' inspections frequently uncovered large plumes of emissions traveling across facility fence lines, onto public roads, and into surrounding areas.

Hydrogen sulfide (H_2S), a neurotoxic gas released by many oil and gas facilities, was a particular concern for Karnes area residents. In order to address those concerns, Earthworks began a collaboration with Northeastern University researchers to develop a tool communities could use to study H_2S. While results from that work are forthcoming, the study also included VOC samples taken by researchers and H_2S monitoring with a Jerome Meter, the gold standard tool in workplace H_2S detection. The VOC levels in those samples were concerning enough to warrant reporting because, even though they are from a limited number of short term air samples, they illustrate the need for further investigation. The pollutants detected in the air samples were then compared to self-reported health symptoms from in-depth interviews with Karnes County residents about their health conditions.

The Need to Study Air and Health Hazards in Karnes County and its Surrounding Areas

Oil and gas production boom

Karnes County, 50 miles southeast of San Antonio, is at the center of the Eagle Ford Shale 'play'. This shale is an oil and gas rich band of rock 400 miles long, 50 miles wide, an average of 250 feet thick, and ranges from 4,000-14,000 feet in depth.[11,12] Oil and gas development rapidly increased in the Eagle Ford Shale in 2010 and then surged in 2012 and 2013,[13] making Karnes the top oil producing county in Texas.[14]

The Eagle Ford Shale produced:

- 1.2 million barrels of oil[15] and 6 billion cubic feet of natural gas per day in 2015.[16]
- About 435 million barrels of oil[17] and 2.2 trillion cubic feet of natural gas[18] for all of 2015.

Karnes County produced:

- Approximately 95.3 million barrels of oil and 154.6 million cubic feet of gas in 2015.[19]
- 23 million barrels of condensate[20], associated with natural gas (described further in the Results section of this report).[21]
- Of the 2,352 wells permitted for oil and gas production in Karnes County by the Texas Railroad Commission, about 514 of these wells were regularly producing gas, and 1,552 were regularly producing oil[22] in September 2015, a month after the fieldwork for this report was conducted.[23]

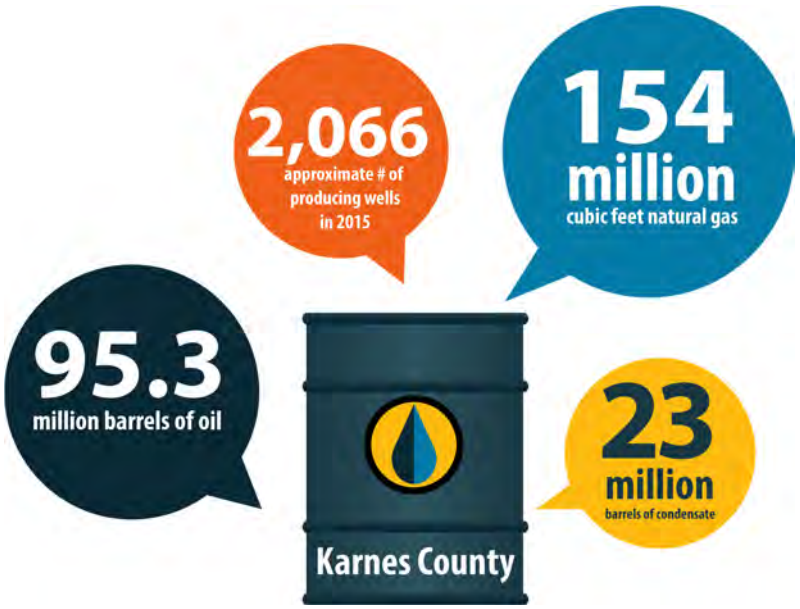


Figure 1. Oil and gas production in Karnes County in 2015.

Air pollution concerns have not been prioritized

Community concerns about air pollution and environmental health were on the rise as oil and gas operations increased in the region.[24] [25] The state agency responsible for regulating air quality is the Texas Commission on Environmental Quality (TCEQ). In order to meet federal air quality standards and monitor air quality conditions, TCEQ currently operates air monitors in prioritized areas of high population density.[26] Although they maintain 52 air monitors[27] in rural areas across Texas, only one air monitor[28] [29] currently operates in the 754 square mile area of Karnes County, despite over 2,300 wells associated with oil and gas production.[30]

This 40 ft. by 40 ft. monitor was added to the grounds of the Karnes City Courthouse in December 2014.[31] It was added following community concerns and extensive reporting about air pollution from the Eagle Ford Shale oil and gas boom by *InsideClimate News*, *The Center for Public Integrity* and *The Weather Channel*.[32] Although this monitor was sited to assess exposures in a location where the population density is high, it may not adequately address exposure for the largely rural population of the county. While roughly 3,457 people live in Karnes City, that is less than a quarter of the County's total population (~15,000 people).[33] Approximately half of the Karnes County population live rurally outside of the three populations centers (Karnes City, Kenedy, and Falls City).[34] This monitor is unlikely to reflect the daily exposures of people living in Kenedy or Falls City or those experienced by Karnes residents who live rurally among oil and gas wells and production facilities like those discussed in this report.

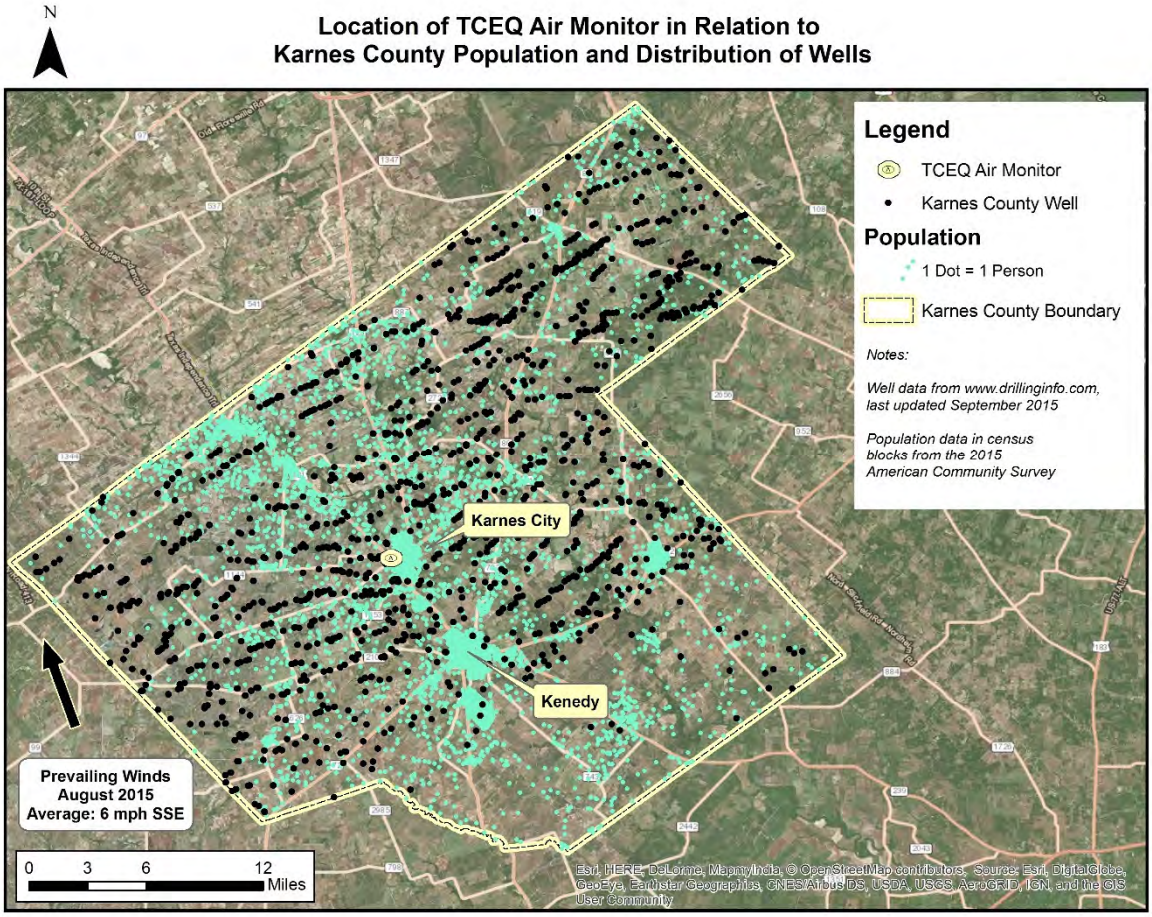


Figure 2. Even though the TCEQ air monitor is at the center of the county in Karnes City where the population is densest, wells and people are widely spread throughout the area.

Chronic air pollution concerns often take a back seat to immediate hazards in the region. Over the past four years, several notable Karnes-area explosions and accidents related to oil and gas development have occurred:

- September 2013: two major incidents occurred – a water pipe burst and injured six workers, then an 18-wheeler truck collided with a pickup truck and killed four oil field workers.[35]
- April 17, 2015: lightning struck an NGL Energy Partners facility three miles north of Karnes City; the facility exploded and authorities were forced to close Highway 181. This accident engulfed twelve oil and saltwater tanks in flames, with a large plume of smoke spreading for miles.[36]
- May 19, 2015: a well owned by Encana Corporation blew out during hydraulic fracturing. Fifteen to twenty families were forced to evacuate their homes. Roads and trees were covered in oil, which left large patches of dead fields and plant life (see photos on the following pages).[37]
- September 2016: an 18-wheeler truck flipped onto its side and spilled oil field waste along the road and into a neighboring field.[38]

Figure 3. This aerial photograph shows the ¼ mile of dead plant life left by the May 19th, 2015 Encana blow out. This brown patch of land is right next to the fracking well and contrasts sharply with the surrounding green fields. Photo credit: Greenpeace, 2015.[39] Reproduced with permission.

Figure 4. Two months after the May 19, 2015 Encana blowout. The photo shows dead foliage from the blowout. On Earthworks' site visit in August 2015, the trees and other vegetation next to the well were still largely dead and a dull brown.

These types of incidents are important to address and receive significant media attention.[40,41,42] When investigating the public and environmental health impacts of oil and gas extraction, it is also important to consider along with these emergency events, the chronic, often invisible, hazards emitted during daily operations.

Background on Unconventional Oil and Gas Development

Shale rock, thousands of feet beneath the earth's surface, often contains oil and natural gas formed over time from decomposing matter. Unconventional oil and gas development (UOGD) from shale is a widely used method of oil and gas extraction in Karnes County and the surrounding region. UOGD typically involves hydraulic fracturing (fracking) and horizontal drilling to access the oil and gas trapped within the shale matrix by injecting high-pressure fluids to break (fracture) the rock. In the Karnes area, oil and gas extracted from wells is transported to central collection facilities, processed, and stored.

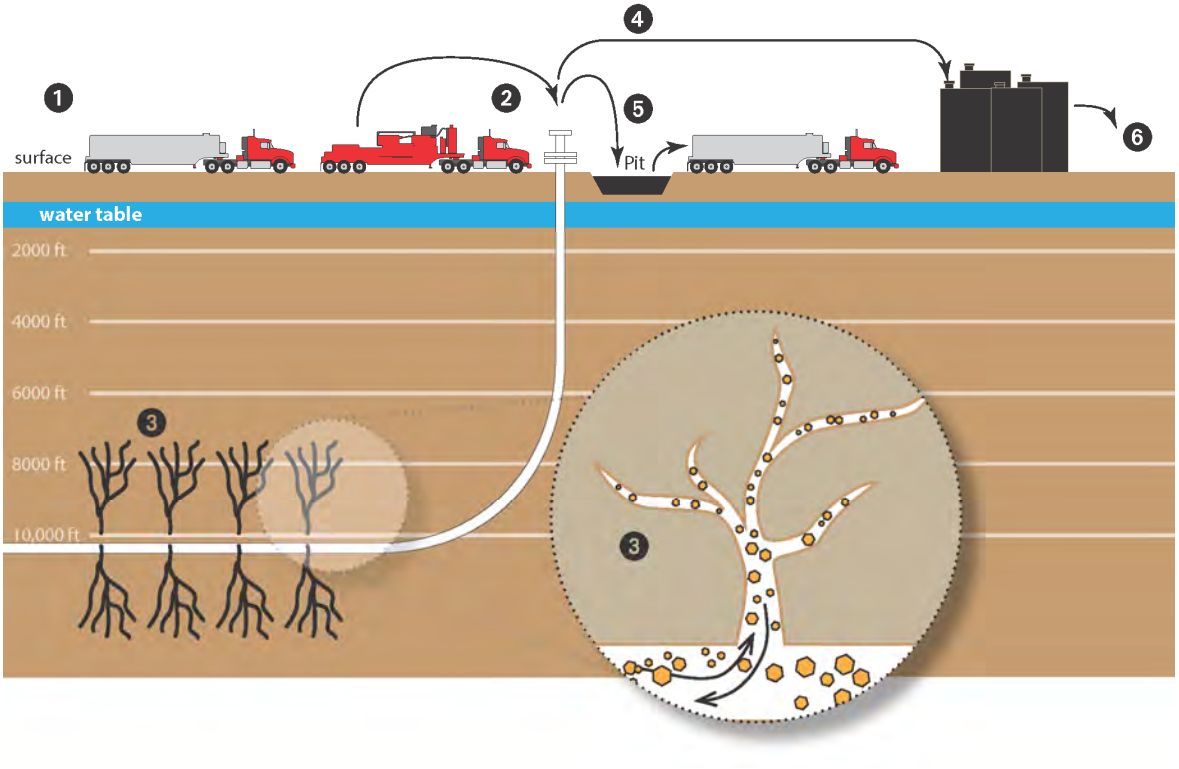


Figure 5. Hydraulic fracturing involves injecting more than 1,000,000 gallons of water, sand and chemicals at high pressure down into the well, as deep as 10,000 feet. The pressurized mixture causes the rock to crack. The cracks, fissures, are propped open by the sand particles so oil or gas can flow from the rock into the well. Oil and/or natural gas flows out of the well, and is piped or trucked for processing and delivery. Also water/oil mixture is stored in open pits and then hauled to treatment. Diagram inspired by Frank Vaculin at Lubbock-Avalanche Journal.[43]

Oil and gas development typically has five stages:

1) Pre-production: preparation of the well pad, drilling, completing and fracking the well.
2) Production: active extraction of oil, gas, and associated waste fluids.[44]
3) Transmission, storage, and distribution of oil and gas.
4) End-use: use of oil and gas by consumers.
5) Well production end-of-life – closing and plugging an exhausted well.[45,46,47]

Stages of UOGD and sources of environmental contamination

Research shows that generally more air pollution is generated during the "pre-production" and finishing phases of a well than during extraction itself.[48] Pre-production includes the entire process of preparing a well for production, including drilling, fracking, and flaring.[49] One source of air pollution, during the pre-production phase, is from diesel trucks transporting water and other materials; each well requires approximately 2,300 truck trips during early development.[50] Since Karnes has thousands of wells concentrated in the area, it is likely that diesel-associated pollution will also occur.[51]

Millions of gallons of fluid are used for each frack to open fissures in shale and other rock formations holding oil and gas. These fractures create routes for the oil and gas to reach the wellbore. Oil and gas wastewater, including fracking fluid, cannot be returned to the water supply.[52] "Flowback" comprised of hydraulic fracturing wastes and saltwater can contain radioactive material from underground and chemicals from fracking.[53,54] This wastewater is stored in tanks or open impoundment pits (sometimes called "ponds"). These pits are where water separates from salt and proppant such as sand grains that were mixed with frack fluid.[55]

Oil and gas wastewater is often disposed of via EPA Class II oil and gas related injection/disposal wells.[56] The underground injection of these fluids can also destabilize the subsurface and cause earthquakes.[57,58,59]

When active production occurs, "surface leaks, spills, releases from holding tanks, poor well construction, leaks and accidents during transportation of fluids, flowback and produced water to and from the well pad, and run-off during blowouts, storms, and flooding events" can all potentially expose workers and the public to contaminants.[60]

In the area of Karnes where we sampled, central collection facilities receive a three phase stream (composed of gas, oil/condensate, wastewater) from production wells via pipeline, which is routed to separators and heater treaters. The wastewater goes into storage tanks and is transported off site by trucks. The oil and condensate is stored in tanks for removal by truck or is transported off site by pipeline. The gas goes through further separation and, what is not used onsite, goes into a pipeline.

In sour gas and oil fields like the Eagle Ford Shale, H_2S is often a waste product that is scrubbed from the oil and gas. Unwanted waste gas and gas that cannot be transported to market is burned off through a pipe in a process called flaring. [61] Flaring and venting of waste gas can release toxic compounds into the air during both pre-production and production.[62]

Facilities like drip stations, central collection facilities, impoundment pits, and injection wells are the primary focus of this report because little is known about their air emissions and they are located throughout the Karnes County region.

Air pollution and health risks associated with UOGD

Hundreds of studies have been conducted to look at potential adverse human health outcomes associated with oil and gas development. Between 2009 and 2015, 685 peer reviewed studies were published on the impacts of UOGD.[63] Out of the 46 studies on air quality, 87% indicated elevated air pollutant emissions and/or atmospheric concentrations.[64] [65]

87% of 46 air quality studies indicate elevated, or higher than normal, air pollutant emissions and/or atmospheric concentrations.

Findings from a 2016 peer-reviewed study assessing the balance of evidence in studies that examined the air quality impacts of UOGD.

Twenty-six our of 31 studies on health impacts associated with UOGD contain findings that indicated public health hazards, elevated risks, or adverse health outcomes.[66] Since public health studies that reveal the presence of health hazards are more easily published, than those that find no problem, these percentages may overstate the balance of evidence.[67] However, it is undeniable that many studies have found elevated pollution and adverse health risks among communities living near UOGD. Additionally this literature search may not have captured every relevant peer-reviewed scientific paper.[68]

84% of 31 studies indicated public health hazards, elevated risks, or adverse health outcome.

Findings from a 2016 peer-reviewed study assessing the balance of evidence in studies that examined the health impacts of UOGD.

Air pollutants are frequently released as a consequence of UOGD.[69]

Oil and gas wastewater in impoundment pits releases volatile organic compounds like benzene, toluene, ethylbenzene, and xylenes (BTEX) that are mixed in with drilling fluids.[70] Benzene is a carcinogen, and human exposure to BTEX is associated with effects on human development and immune, metabolic, respiratory, and reproductive functions.[71]

Pollutants such as formaldehyde, hydrogen sulfide, acrylonitrile, methylene chloride, sulfuric oxide, nitrogen oxides, trimethyl-benzenes, acetone, isobutene, aliphatic hydrocarbons, diesel PM, radon gas, and methane, which is a greenhouse gas, may also be produced during extraction.[72,73,74]

Diesel transport trucks are also sources of particulate matter.[75]

Federal exemptions from reporting requirements of the Clean Air Act for oil and gas production and downstream treatment facilities mean that the public does not know the exact locations, types, and quantities of contaminants that are produced by UOGD.[76]

Communities near oil and gas development can be exposed to highly toxic chemicals that are known to cause:

- **Chronic headaches**
- **Birth defects**
- **Respiratory issues**
- **Asthma**
- **Cancer**

Mash, Minnaar, and Mash 2014, ASTDR 2007, OSHA 2005

UOGD air pollutants we focus on

We focus on hydrogen sulfide (H_2S) and volatile organic compounds (VOCs) in this study because both can cause a wide array of health impacts. Previous studies have shown them to be associated with UOGD, and the Eagle Ford Shale is particularly rich in H_2S with an estimated concentration of 2,452 ppm.[77] There are other air contaminants associated with UOGD such as ozone, formaldehyde, and particulate matter that we did not have the capacity to monitor in this limited study.

- Hydrogen sulfide (H_2S), commonly called sewer gas, stink damp, swamp gas and manure gas, is a colorless, flammable, extremely hazardous gas with a "rotten egg" smell.[78] H_2S can form during decomposition of organic materials into oil and gas.
- Volatile organic compounds (VOCs) are carbon-based molecules that easily vaporize and are commonly associated with oil and gas production. Benzene, toluene, ethylbenzene, and xylenes (BTEX), known health hazards, are VOCs regulated by the EPA and TCEQ. More information on the health effects for these and other VOCs we found are described in the section entitled "Air Test Results".

Human exposure to UOGD air pollution

Factors such as the person's location, the local weather conditions and geographic topology, and the stage of oil and gas production determine how humans are exposed to air pollution from UOGD. The health consequences of such exposures depend on the route of exposure, its duration, dose and the mixture of chemicals, as well as the exposed person's personal vulnerabilities which are shaped by factors such as their age, genetic predispositions, medical history and their history of environmental exposures.[79]

Residents living near oil and gas operations may breathe in hazardous air pollutants and become sick over time with illnesses that affect various parts of the body such as the respiratory, circulatory, neurological, digestive, and integumentary systems.[80] Individuals can be exposed to contaminants through their mouths, noses, ears, eyes, and skin.[81]

Figure 6. Routes of human exposure to pollutants includes: breathing pollutants in through nose or mouth, drinking or bathing in contaminated water, and eating foods that contain contaminants either through polluted irrigation water or soil.

The two studies in this report aim to investigate the linkages between emissions of air pollution from unconventional oil and gas development and the impact on human health. In reporting the results from our two studies, we begin with the interview study in order to understand the human health experiences reported by Karnes residents who live close to oil and gas wells and facilities. To explore the emissions from possible sources of pollution, we analyze the results from air samples taken near oil and gas facilities in or upwind of the Karnes County areas. To explore potential connections between the detected contaminants and reported health impacts, we compare the health effects associated with the chemicals we detected and the symptoms reported by residents.

Neither of these studies address the actual exposures experienced by participants in the interview study. Analyzing actual exposures would look at the concentrations people experience through various routes of exposure to assess the final doses they received. Such work requires continuous long-term personal monitoring and is beyond the scope of these two research projects, which only look at what is found in short term air samples taken on public property close to oil and gas facilities and self-reported health effects.

Interview Study Methods and Findings

Karnes resident interviews

To learn more about Karnes County residents' health issues and perspectives regarding local air quality, a study consisting of 18 one-hour interviews was conducted individually with local residents.[82] Each interview was transcribed and analyzed based on an interview guide and on the three major questions which were the focus of the study.[83] Health issues and similar thoughts, ideas, or perceptions expressed by residents were categorized to build an understanding of how Karnes residents experienced and defined environmental health risks.

The study was conducted from June through September 2015 and approved by the University of North Texas Institutional Review Board (IRB). With two exceptions, all interviews were conducted in residents' homes to better understand their concerns about foul odors, dust, high volumes of traffic, noise, proximity to oil and gas facilities, and visible property damage.

Forty residents approached for interviews chose not to participate.[84] Many community members did not participate due to timing or inconvenience. However, the controversial and personal nature of the interview questions could also have negatively influenced participation. Due to the sensitivity of the study, all 18 interviewees were given pseudonyms to protect their confidentiality.

Limitations

This interview study is based on residents' self-reported experiences of health symptoms. Their experiences represent an important and vital voice that researchers in this study believe is first place to begin environmental health research. The reports of human health complaints in the area drove the researchers to conduct this study. Shared changes in health or shared symptoms of illness provide the first clues that something may have changed in a shared environment and therefore be causing shared health problems.

Like all forms of data, self-reported health information has limitations. Most people for instance, have faulty memories and may not remember even their own health experiences accurately (for example, try to name the exact date you last went to the doctor). Asking residents to recall their health issues, prior to and after the oil and gas boom, relied solely on their ability to recall those experiences. Also, people who are experiencing health problems are potentially more likely to respond to an interview request than those who are not experiencing health problems. Therefore, the reports here could be weighted toward reporting the experiences of residents who feel that their health has been strongly impacted.

Background on interview study participants

All interviewees were Karnes County residents. Most participants were long-time residents or county natives:

- Fourteen participants have been Karnes County residents for about 40 years.
- Four participants have resided in Karnes County for less than 4 years.
- Nine males and nine females participated and although 18 people were interviewed, 13 households participated in the study since five couples were interviewed together. Residents ranged from 84 to 34 years old with an average age of 60. All interviewees were homeowners. Eight of the 13 households reported annual income; the average annual household income was $38,000.[85] Five out of 18 participants were Hispanic and some spoke Spanish, but all of the interviews were conducted in English.

Although none of the interviewees were affiliated with, or employed by, the oil and gas industry, 50% of the participants were receiving some form of compensation from the industry. This includes residents who have leased out their land to the industry and/or are receiving royalties for mineral rights.

Disclosing whether or not residents were being compensated was important in determining if compensation influenced the attitudes and beliefs residents had about industry and their health. Susan, for example, spoke to this issue:

> *And I have mixed emotions because I get a little bit of that pie so I don't mind suffering a little bit but like I said I don't know enough about it; but I do wish they could do something so that the air wouldn't be so bad.* – Susan

For those like, Mr. Adams, who did not lease out his land or receive a "piece of the pie":

> *We're not just pissed off because we're not leased, these issues are real. We're not starving. We're not any worse off than we were before except health wise.* – Mr. Adams

Health issues reported by residents

Sixteen out of 18 residents reported health issues. The top three reported health issues were neurological, respiratory, and sinus congestion or allergies (see graph next page). Twelve residents reported neurological problems such as migraines, memory loss, brain fog, dizziness, and numbness in extremities. Eight interviewees reported issues with respiratory problems including difficulty breathing, asthma, coughing, shortness of breath, pulmonary fibrosis, and chronic obstructive pulmonary disease (COPD). Seven reported persistent issues with sinus congestion and allergies. According to residents, all reported health issues either appeared or worsened in the last five years, aligning with the timeline of the oil boom beginning in 2010.

Residents reported health issues in pairs or clusters of symptoms (see graph next page). For example, seven residents who reported headaches also reported upper respiratory issues. Residents also reported that their headaches or sore throats were persistent and ongoing which concerned them. Additionally, of the 16 residents who reported health issues, the two who reported the most, a total of 12, were not in the older age range.

Of the 18 residents interviewed, 16 expressed concern for environmental impacts by the oil and gas industry. (see graph next page). The two residents who did not report any health issues also had little or no concern about environmental health risks or impacts to their environment by the industry.

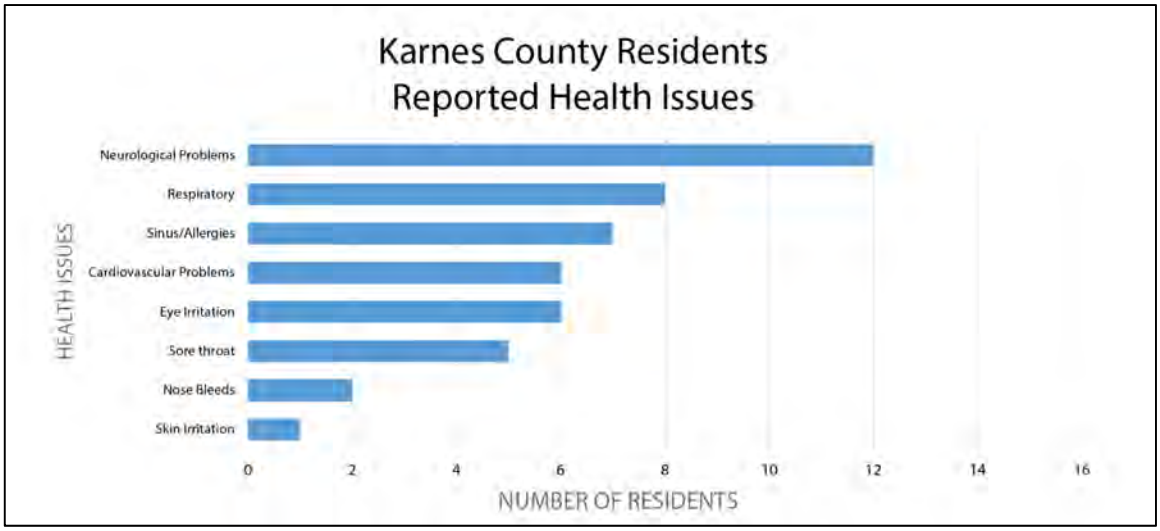


Figure 7. Frequency of health symptoms reported by the 16 of 18 interviewees who reported health problems (*n* = 16). The two people who reported no health symptoms were not included.

Participant	Health Issues Reported by Interviewees
Mr. Adams	Atrial fibrillation (A-Fib: irregular or rapid heartbeat), eye irritation, allergy/sinus issues, dry/sore throat
Mrs. Adams	Eye irritation
Alejandro	Persistent cough, nosebleeds, dizziness, stress/anxiety
Antonio	Headaches
Armando	Persistent headache and sore throat
Mr. Calloway	Atrial fibrillation (A-Fib)
Mrs. Calloway	Atrial fibrillation (A-Fib), heart attack (heart disease), dizziness, allergy/sinus issues, shortness of breath
Francis	Migraines, brain fog, memory loss, numbness in hands and legs (peripheral neuropathy), dizziness, skin irritation and rashes, asthma, allergy and sinus issues, stress/anxiety
Mr. Fischer	Pulmonary Fibrosis (scarring in the lungs), COPD (chronic emphysema or chronic bronchitis), heart disease, allergies/sinus issues, persistent headaches, and lack/loss of energy23
Mrs. Fischer	Persistent headaches, brain fog
Luke	Difficulty breathing, shortness of breath, congestion, allergy/sinus issues, ear canal blockage, scratchy throat
Mrs. Sherman	Tachycardia (fast heartbeat), headaches, eye irritation, dizziness
Mr. Sherman	Atrial fibrillation (A-Fib), sleep apnea, eye irritation, headaches
Susan	Sinus issues, brain fog, persistent cough, persistent sore throat, headaches, eye irritation, congestion
Mrs. Valdez	Persistent headaches, flu-like symptoms
Mr. Valdez	Migraines, sinus problems, congestion, dizziness, shortness of breath, pneumonia, bronchitis, eye irritation, persistent sore throat, weight gain, flu-like symptoms, dizziness, nosebleeds

Figure 8. The health symptoms reported by interviewees.[86]

Residents noticed their symptoms appeared or worsened when they spent long hours outdoors. Six participants reported spending less time outside because of foul odors, high levels of dust, or because they "feel better" when inside:

Residents noticed their symptoms appeared or worsened when they spent long hours outdoors.

> *Well when I'm out working on my property I've felt dizzy spells. It hasn't been prevalent. It's not like every time but I feel woozy, like I'm going to faint or something like that. It's hard to describe but it's an unusual feeling. I want to attribute it to not lack of balance but it feels like I can't control myself, that's the best way I can describe it.* – Alejandro

Mrs. Fischer worried about her husband going outside because she had noticed his symptoms worsen. They had also noticed a difference when they visited north Texas:

> *We went to see our son in north Texas and they have a porch at the house and he [Mr. Fischer] just stayed out there. That's the first time he's been outside and I said yeah, if you could breathe around our house we could have him sit outside and enjoy it but you can't do that if you can't breathe. It makes a difference; you didn't have any problems or feel ugly when you were there.* – Mrs. Fischer

The Shermans, who frequently stay at their lake house, also noticed a difference in their health when they leave Karnes County:

> *I thought about it because my issues originated here with all the stuff that's going on here. I think the weather aggravates it and the air quality aggravates it for him [Mr. Sherman] because I know, when we're at Culver Lake, they're not drilling up there at all.* – Mrs. Sherman

Respiratory issues were reported by eight residents. Asthma, for example, was discussed by a local nurse who noticed a drastic increase in this diagnosis among schoolchildren:

> *When I started, we had, throughout the whole school district, maybe about 5% [of asthmatics] and now I would say we're probably up to about 45%-50%. But I have to say, I don't know if it's a true diagnosis of asthma either. Many of the kids are running, they become short of breath, and they come in to see me; their oxygen levels are all fine but they just can't get their breath.* – Nurse Eleanor

"When I started… we had maybe 5% [with asthma]…I would say we're probably up to about 45%-50%"

- Nurse Eleanor

She was also concerned that students' healthcare providers limited their physical activities to the point that it would lead to a decline in their overall health:

> *It all goes back to the kids doing less, the inactivity of the kids, the video games and social media. They used to go outside and play but now it's not safe.* – Eleanor

Mr. Fischer, struggling to talk through his breathing mask, was frustrated and bewildered at the sudden decline in his health within the last five years:

> *If you could make it to 70 [years old] without any problems and then within a couple of months you can't hardly breathe at all.* – Mr. Fischer

Prior to the oil and gas operations' widespread presence in Karnes, Mr. Fischer reported good health. He blamed his poor health directly on the oil and gas industry's transformation of his environment:

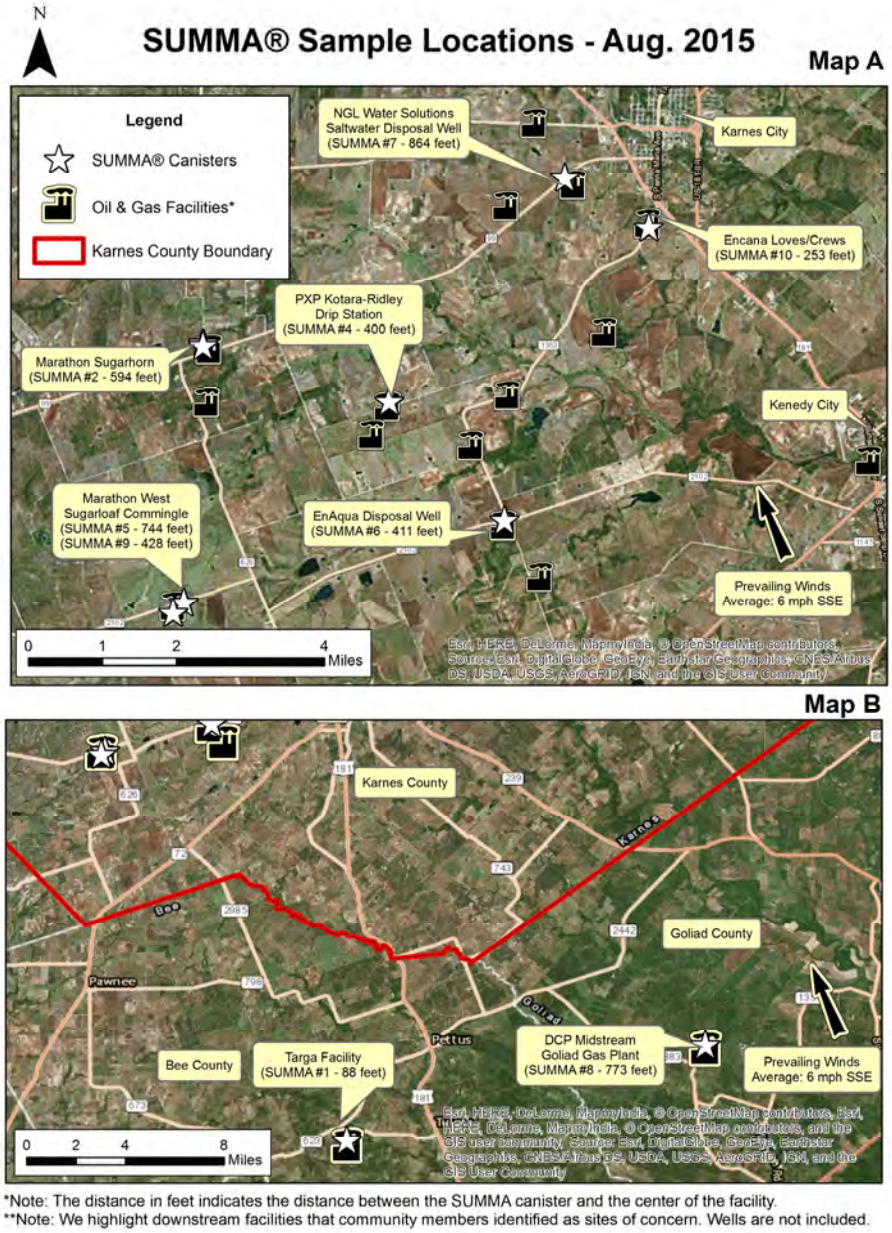
> *At night when they drilled, you could smell gas literally once you stepped out the front door. It seems like that's where it's coming from, because when they flare you just see that big black smoke and you get that suffocating smell that's coming from the air.* – Mr. Fischer

Air Monitoring Study Methods and Findings

Air testing site selection

In August of 2015, Northeastern University, ShaleTest, and Earthworks researchers took nine grab[87] samples of air at eight different oil and gas facilities during normal industrial operating and weather conditions.[88]

The testing locations were selected based on community concerns, agency reports, and pollution detected with the FLIR Optical Gas Imaging (OGI) camera. Grab samples of air were taken on public roads at fence lines of facilities where Earthworks' OGI monitoring had recorded oil and gas air pollution close to vulnerable populations, including a day care center, nursing home, correctional facility, and an immigrant detention facility.[89] We also used a Jerome J605, the industry-standard tool made by Arizona Instruments LLC, to measure H_2S at these locations.



*Note: The distance in feet indicates the distance between the SUMMA canister and the center of the facility.
**Note: We highlight downstream facilities that community members identified as sites of concern. Wells are not included.

Figure 9. SUMMA® Air Sample locations. The map shows only the downstream facilities that community members identified as sites of concern (other UOGD production facility and wells not shown as their location's data are not publicly available). Map by Christine Luong

Our testing focused on the western side of Karnes County, downwind[90] of several large facilities and upwind of community members' homes, including the Cernys who were featured in *Reckless Endangerment*. Additionally, we included the row of Marathon Oil Corporation facilities on Farm to Market Road 2102 in southern Karnes County. Based on community interest, we also tested the Goliad and Targa facilities approximately five miles south of the Karnes County line but upwind of the rest of the sampling area and locations of the participants in the interview study since plumes often travel northwest (the dominant wind direction during the period we took our samples). Therefore, when we discuss our air testing results, we refer to the testing area as the Karnes County region since two of the sampling sites were located in adjacent Beeville and Goliad counties, not Karnes County proper.

We designated locations for air sampling using a Google map we created of the facilities where residents and TCEQ reports had documented complaints about emissions. We chose these sampling locations with the aim of characterizing the emissions from pinpointed sources to see the types and levels of emitted contaminants. Since the facilities are on private property, we sampled as close to the facilities as possible on adjacent public roads.

Limitations

Our air study was preliminary and limited by cost and time. Due to cost and availability of researchers, we could only conduct monitoring during two weeks in August, 2015. A more systematic air quality study would more accurately investigate emissions at different times of the year and different times of day.

Additionally, the primary purpose of this study was not to systematically monitor VOC emissions from oil and gas facilities but to test a low cost method for monitoring Hydrogen Sulfide. We took the short term grab samples reported here to investigate whether any gases present in the air might interfere with our H_2S monitoring, not to provide a full investigation of VOCs.

We decided to report the VOC results because the concentrations detected in our grab samples warrant further investigation. A thorough VOC study to accurately characterize emissions from these facilities would require long-term extensive monitoring designed to systematically gather emissions data across a range of conditions such as time of year, day, and weather conditions. Such a study would be very costly and is outside of the scope of this report. Just the 10 SUMMA® samples used in this study cost over $25,000 (one of our air samples was improperly handled during transport and was unable to be analyzed).

Finally our study was limited to gathering samples on public property, hence we can not definitively say that the detected VOCs came directly, or only, from the facility adjacent to where we sampled. We attempted to identify plumes of VOC emissions with the FLIR OGI camera and take samples of those emissions. However, in the majority of cases, plumes passed several feet above the researchers, making it infeasible to directly sample the plume. Therefore, our sample results likely underestimate the concentrations found within the major emissions plumes, however, they do potentially characterize the types and mixtures of compounds a person might breathe in when standing at the testing locations, which were all on public roads.

Emissions studies would be best conducted directly at the source of an emission. During a variety of environmental conditions, emissions could be tracked and characterized as to how far and in what directions the plumes travel.

Further studies, based on monitoring in their homes and workplaces, are needed to better understand human exposures to these emissions and how frequently people in Karnes are exposed to hazardous air conditions.

Optical gas imaging

We used an Optical Gas Imaging (OGI) instrument[91] to identify leaks at oil and gas facilities, most of which came from storage tanks. A certified thermographer used the industry-standard FLIR GF320 camera to be able to see normally invisible VOC pollution. The GF320 camera is specifically calibrated to detect VOCs, although it doesn't identify individual gases or their quantities. The camera showed hydrocarbon pollution crossing facilities' fencelines into the surrounding community, informing further monitoring via canister sampling that allowed identification of the individual gases and their concentration. The VOCs benzene, hexane, methane, pentane, propane, toluene, and xylene can be detected by an OGI camera and were analyzed in our SUMMA® air samples.

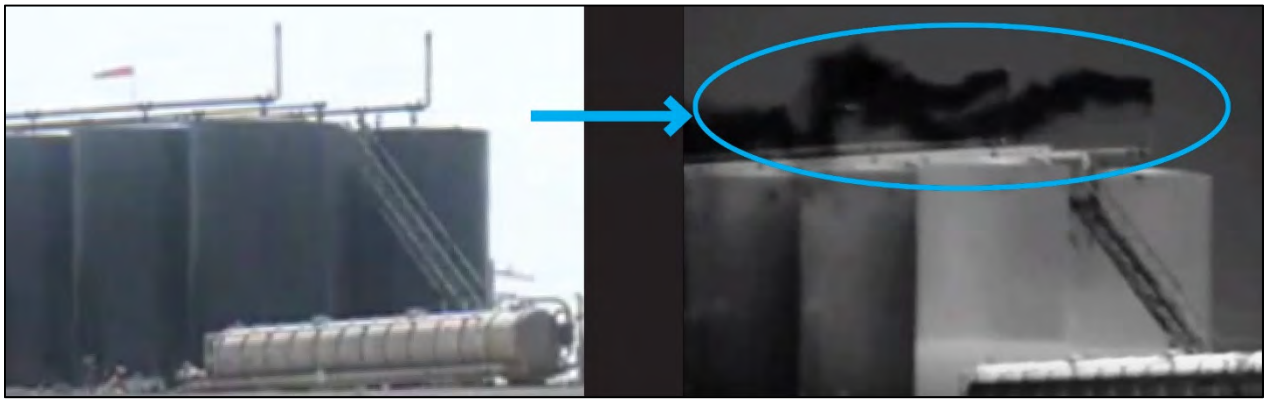


Figure 10, top: The FLIR Optical Gas Imaging camera (OGI) records infrared images of VOC emissions. At left shows the tanks as seen with the naked eye, and at right as seen with the OGI camera.

Marathon Sugarhorn facility in Karnes County images taken by TCEQ and obtained by Earthworks through an open records request.

Figure 11: Earthworks' Sharon Wilson, a certified FLIR operator, uses the FLIR OGI camera. FLIR is the acronym for Forward Looking Infra Red.

With these images and videos, we can document the pollution that may be linked to these health and environmental problems reported by communities to warrant air monitoring, operational changes, new emission control technologies and regulatory action.

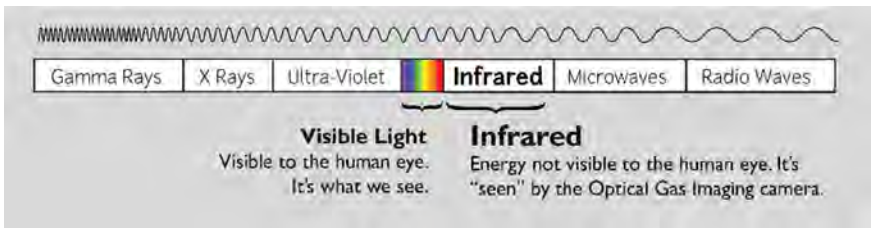


Figure 12: The light spectrum. The infrared camera sees light wavelengths that humans cannot. Graphic by Haley Stiel.

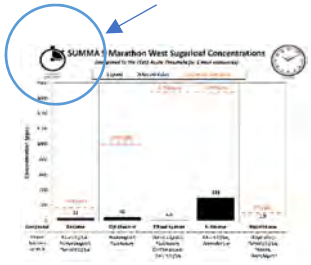
Air testing methods

The air testing team employed SUMMA® air canisters, the same type that the EPA and Occupational Safety and Health Administration (OSHA) commonly use to measure concentrations of VOCs in ambient air. The canisters contain a vacuum that draws in ambient air when the valve is opened.

To take a sample, the testing team:

- Traveled to a site of concern.
- Conducted a visual inspection for running automobiles, passing traffic and surveyed the area with the OGI camera, ensuring that there were no other potential sources of emissions besides the oil and gas facility in question.
- Assessed whether the facilities appeared to be operating normally, i.e. no audible or visible alarms were noted or unusual worker activity.
- Opened the intake valve for 10-14 seconds

Notice this icon on the graphs later in this report indicating a 14-second sample



The team used a Jerome Meter J605, the standard industry tool, to test air for H_2S. The Jerome Meter actively samples the air by drawing air into the device over the course of approximately a minute. The sampled air passes over a sheet of gold foil that senses the amount of sulfur in the sample.[92,93]

Both the canisters and the Jerome meter provide a snapshot of pollutant concentrations at a particular location and time. They do not provide long-term concentration data. The SUMMA® canisters air samples were sent to Middle Tennessee State University,[94] for analysis with a spectrometer for 71 possible compounds.[95] These chemicals were measured in concentrations of µg/m^3 converted to parts per billion (ppb) so that they can be compared to regulatory thresholds which are reported in ppb. This ppb unit allows us to measure very small amounts of chemicals since 1 ppb represents one particle out of 1,000 million particles. One ppb is roughly comparable to one drop of ink in a backyard swimming pool. [96] Despite how small that amount seems, many chemicals impact the body at concentrations of just a few parts per billion (ppb).

Scientists at the University of Memphis[97] calculated the risks which the detected compounds pose to human health, based on their concentrations and mixtures.

Regulatory thresholds and their limitations

State and federal agencies develop thresholds above which exposure to a chemical is considered hazardous, depending upon the length of time a person is exposed.[98,99] Specific thresholds are set by balancing scientific risk assessment and economic feasibility. There is considerable debate over whether these thresholds truly protect public health.[100,101]

Most regulatory thresholds assume that a person is consistently exposed to a single chemical over some set period of time - usually a work day or a lifetime. In reality, exposures often vary over time. People may be exposed to spikes of high concentrations that, over a day, average below a regulatory threshold. However, such a spike could still cause harm. Consider this analogy: if a gunshot is fired next to your ear, the sound of the shot could produce a sudden spike in noise that ruptures an eardrum. When that momentary loud noise from the shot is averaged over a whole day, it would not exceed a regulatory daily noise threshold even though the spike in sound caused harm. Similarly, risks from chemical contaminants are commonly calculated as an average over time periods ranging from an hour to a lifetime and not from one instance of acute exposure.

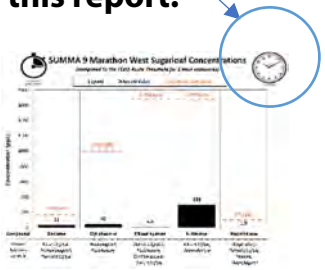
Exposure scenarios

In this report, we use thresholds relevant to three different exposure scenarios. These scenarios are hypothetical, based on the assumption that our short term samples could have been characteristic of emissions from these facilities.

Acute Exposure as Defined by TCEQ

According to Texas Commission on Environmental Quality (TCEQ), an acute exposure is when a person is exposed to hazardous concentrations of a chemical over the course of an hour. In order for a person to have an acute exposure, they would have to continuously breathe air samples, with concentrations of chemicals like the ones we detected, for an hour. This case might apply if someone was working on the roadside beside a facility for an extended period of time such as mending a fence or for livestock grazing for an extended period of time.

The TCEQ defines acute exposure as 1 hour. Notice this icon on the graphs later in this report.

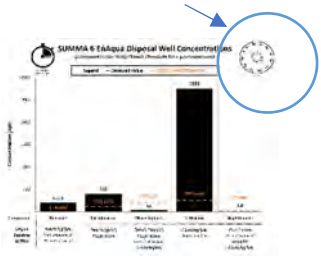


The TCEQ uses "air monitoring comparison value" (AMCV)[102] as an umbrella term to cover both short-term (Acute) and long-term (Chronic) Effect Screening Levels (ESLs). An air pollutant is not considered to pose a health risk if its level does not exceed an ESL Threshold. Exceedance of an ESL "does not necessarily indicate a problem but rather triggers a review in more depth" by the TCEQ.[103] Additionally, a report by *InsideClimate News* and the *Center for Public Integrity* found "that nearly 60 percent of the TCEQ guidelines for outdoor air quality are less protective than similar numbers used by the Environmental Protection Agency and by California, whose guidelines are among the strictest in the nation".[104] Therefore the acute and chronic TCEQ thresholds discussed in this report may not be as protective as those used by the EPA or in other states.

Chronic exposure as defined by TCEQ

A long term chronic exposure in Texas is defined as an exposure to a contaminant that is experienced over one year or more. Generally, the thresholds for chronic exposures are lower than acute exposures based on the idea that your body can tolerate a higher exposure for a short period of time.

The TCEQ defines chronic exposure as 1 year. Note this icon on the graphs later in the report.



To have a chronic exposure to the levels detected in our samples, the air sample we took would have to be characteristic of emissions from that facility and a person would need to spend most of their time near and downwind of that facility. This case might apply if one's home is very close to and downwind from one of the locations we tested or if one lives very close to multiple facilities.

Chronic exposure as defined by the environmental protection agency (EPA)

Federal standards for chronic chemical exposure thresholds are set by the Environmental Protection Agency (EPA) and are called Reference Concentrations (RfCs). The EPA set its thresholds for chronic exposures based on the concentrations of a chemical that it predicts (based on scientific studies) a person could be routinely exposed to over the course of a 70 year life-time without increased risks of health problems.

RfCs are helpful in estimating the health risks to a human population continuously inhaling a given compound over a lifetime but do not take into account the complexities of some pollutants, such as n-Hexane, that might be more harmful at lower doses than higher doses. This type of threshold is relevant to long term residents close to and downwind of the facilities we monitored if the levels we identified were characteristic of their exposures.

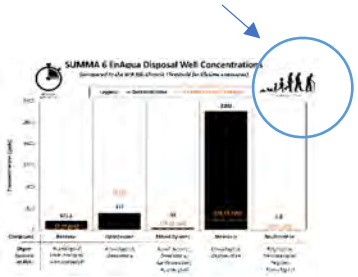
There are no reference thresholds for the short term (14 second) samples taken in this study so these hour-long, year-long and life-long exposure limits are provided to give readers insight into whether the levels we detected would be hazardous if the emissions and exposures were routine. These comparisons also offer us insight into whether further long-term testing is warranted.

Threshold gaps and inconsistencies

We analyzed these air samples according to all applicable state and federal thresholds for the Karnes County region (see Appendix 2). In some cases, compounds are not regulated by the TCEQ but are by the EPA, or vice versa.

Many chronic Texas thresholds are lower than those considered safe by the EPA because TCEQ considers long-term to be one year, while EPA considers life-long exposure of 70 years. Therefore, it is important to consider both federal and state thresholds since they address different periods of time and vary in the amount of protection they provide for a given pollutant.

The EPA defines chronic exposure as a human lifetime (approximately 70 years). Notice this icon on the graphs later in the report.



Air Test Results

Hydrogen sulfide (H_2S)

We detected H_2S close to or above a concentration of 1 ppm at three facilities: Kotara-Ridley Drip Station, EnAqua Disposal Well, and Marathon West Sugarloaf Commingle (see map next page).

The American Conference of Governmental Industrial Hygienists (ACGIH) establishes a threshold of 1 ppm for workplace exposure over an 8 hour work day.[105] Research by the Center for Disease Control (CDC) of H_2S exposure in homes from improperly manufactured drywall found residents experienced health impacts at levels as low as 0.014 ppm.[106]

A person working a full day, close to where we took our air samples, might experience exposures to H_2S over ACGIH recommendations if emissions in these areas continued to be at or above 1 ppm. Additionally, families living down wind and close to these facilities might be chronically exposed to H_2S at concerning levels if the concentrations we found were routinely emitted from these facilities.

Corroboration with resident interviews

Five residents reported rotten egg-like odors. The human nose is very sensitive to H_2S: people can begin smelling H_2S at just 0.01 ppm, at 3 ppm the odor becomes offensive and over 30 ppm the odor is described as "sweet" or "sickeningly sweet".[107] 16 residents reported symptoms consistent with hydrogen sulfide exposure including: severe headaches, eye burning, nasal/sinus and throat irritation and difficulty breathing.[108] Luke reported nausea as a result of the odor (according to OSHA exposure to 2-5 ppm of H_2S for an extended period can cause nausea).[109]

> *Sometimes if you catch a whiff of that stuff, if it's a certain breeze and wind speed we can't stay out on our patio. Just to smell that makes me feel nauseous, my wife and my son, and it affects him faster than it does us. It's just a rotten egg smell. It's not good at all.* – Luke

People can begin smelling H_2S at just 0.01 ppm.

We detected H_2S close to or above a concentration of 1 ppm at three facilities.

Figure 13. A windsock is often used at sites with H_2S for workers to safely stay upwind of emissions.

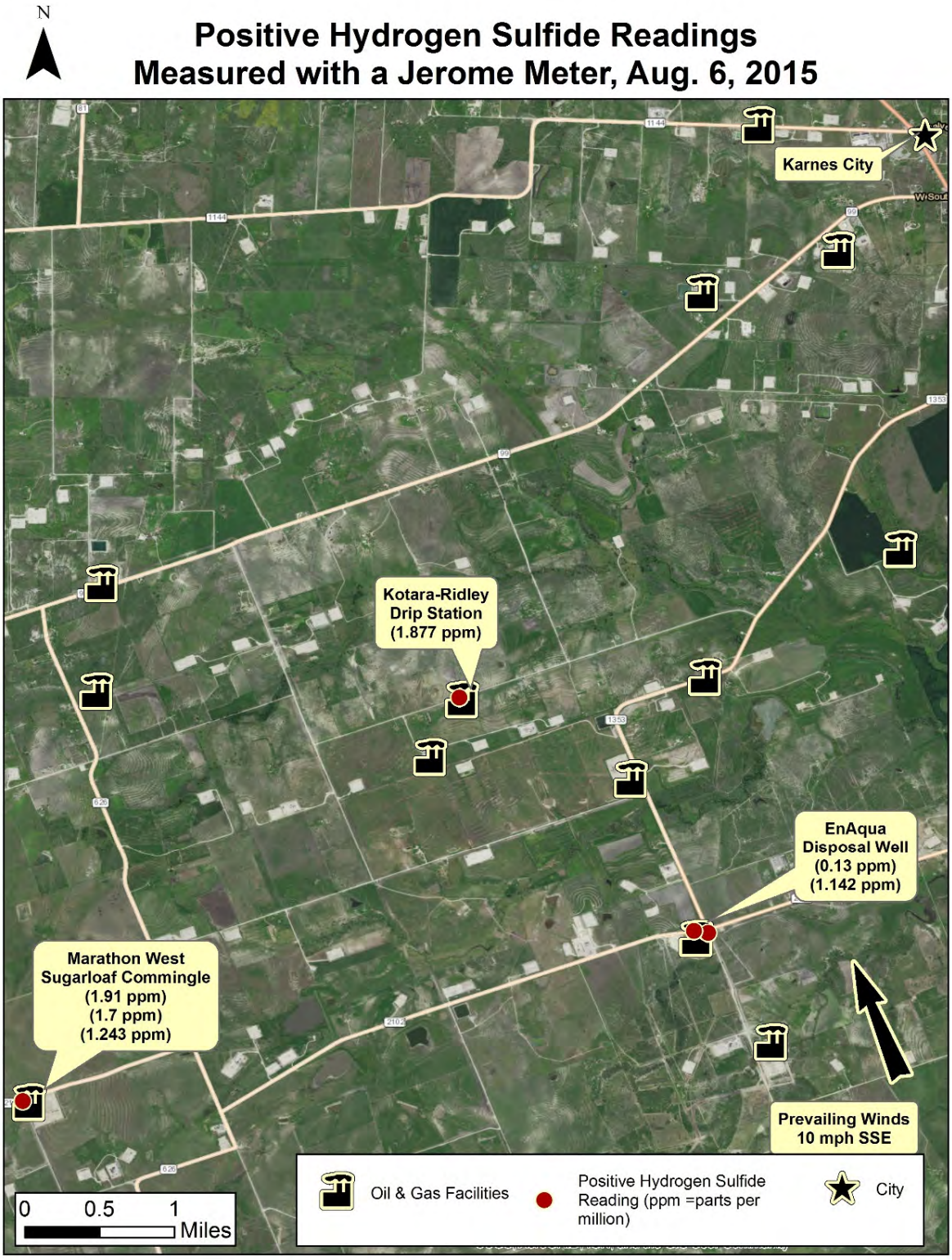


Figure 14. H_2S levels detected with a Jerome Meter. Note: Jerome Readings were not necessarily taken at the same time as the SUMMA® samples.

Volatile Organic Compounds (VOCs)

We analyzed nine SUMMA® canisters for 71 chemicals and identified 38 different compounds in the air samples as seen in Appendix 2.[110]

Five compounds with serious health effects were found at especially concerning levels in multiple locations: benzene, cyclohexane, naphthalene, n-Hexane and mixed xylenes. The health effects and levels detected of these compounds are further described below.

The remaining 33 compounds were detected in some or all samples but did not exceed EPA RfCs or TCEQ thresholds. However, eight of those 33 identified compounds do pose risks to human organ systems.

Five compounds with serious health effects were found at especially concerning levels in multiple locations.

Eight other compounds did not exceed EPA RfCs or TCEQ thresholds, but do pose risks to human organ systems.

1) 1,3- Butadiene – hazardous to part of the immune system called the lymphatic system according to the EPA and neurological system (the brain and nervous system) according to TCEQ.
2) Acetone – hazardous to the hepatic (liver), renal (kidney) (EPA), and neurological (brain and nervous system) systems according to the TCEQ.
3) Carbon disulfide – hazardous to neurological (brain and nervous system), cardiovascular (heart and blood vessels), reproductive, ophthalmologic (eyes), and renal (kidneys) systems (TCEQ).
4) Chloromethane – according to the ATSDR, it is hazardous to neurological (brain and nervous system), cardiovascular (heart and blood vessels), and hepatic (liver) systems but does not have affected organ systems identified by the EPA or TCEQ.
5) Methylene chloride – hazardous to hepatic (liver) (EPA) and neurological (brain and nervous system) systems (TCEQ).
6) Ethyl methyl ketone – hazardous to the neurological system (TCEQ) with no target systems identified by the EPA.
7) Styrene – hazardous to hepatic (liver) and hematopoietic (involved in the production of blood) systems (EPA). The TCEQ links it to neurological effects (brain and nervous system). Styrene is considered to be a reasonably anticipated carcinogen by the ATSDR.
8) Toluene – hazardous to the neurological system (brain and nervous system) (TCEQ and EPA).

Figure 15. Marathon Sugarloaf Comingle Facility.

Benzene

The most concerning compound identified in our samples is Benzene. Benzene is a common pollutant since it is a component of gasoline; it can also be emitted by fires and volcanoes. However, it is a carcinogen, and we found it in all of our samples. If these levels persisted, they would, in the case of one of our samples, exceed acute thresholds and in the others, exceed the more protective chronic thresholds of exposure set by the EPA and TCEQ.

Benzene chemical properties and health effects associated with exposure

Benzene can enter the body through direct contact with skin, breathing (through the nose and mouth), and/or by drinking contaminated water. Benzene can cause childhood leukemia, which is a form of cancer. Extended exposure to benzene for a year or more can harm blood cells (called hematoxicity) and cause bone marrow cancer (leukemia).

Benzene also causes a range of acute but less deadly health issues such as eye and skin irritation and headaches. The research team experienced symptoms of low-level, short-term benzene exposure (eye, skin irritation, dizziness, and headaches) when taking the air samples.

Benzene, a carcinogen, was found in all of our samples.

Benzene can also affect the brain, leading to depression, and cause respiratory problems like asthma. Pregnant women are particularly vulnerable to benzene exposures as developmental exposure to benzene can affect fetal brain development such as increasing neural tube defects.[111,112,113] The likelihood of childhood leukemia can increase if the mother is exposed to benzene during early stages of pregnancy.[114]

Other studies have also found that high levels of benzene can be emitted during oil and gas development. One study estimated that cumulative cancer risks over a lifetime are 10 in a million for residents living within a half mile of an unconventional oil or gas well and 6 in a million for those living over a half mile away but still in relatively close proximity.[115] This is, respectively, 10 and 6 times higher than the EPA's acceptable risk level of 1 in a million additional cancer cases over 70 years.

Though benzene is regulated by the EPA, unfortunately, the facilities we monitored are exempt from federal level reporting requirements.

Benzene exposure scenarios

Benzene is regulated by the EPA as a Hazardous Air Pollutant (HAP). Facilities emitting HAPs are required to report their emissions although their reports, however these reports may be inaccurate if there are tank leaks and equipment malfunctions.[116] Unfortunately, the facilities we monitored are exempt from federal level reporting requirements.[117]

Figure 16 at right. Encana Kotara-Ridley Drip Station.

Acute Exposure Scenario: Benzene was detected in all nine air samples. In one sample, we found levels of Benzene that would exceed Texas's Acute exposure threshold if they continued over an hour. We sampled air close to this location because it is close to homes and half a mile from a daycare facility. Families living close to this sampling location could potentially experience an acute exposure if they were to spend an extended amount of time being directly exposed to levels of pollutants like those we detected. However, it is more likely that they might experience chronic exposure to lower doses, as the levels we detected would be diluted since the wind usually carries emissions from their sources and disperses them.

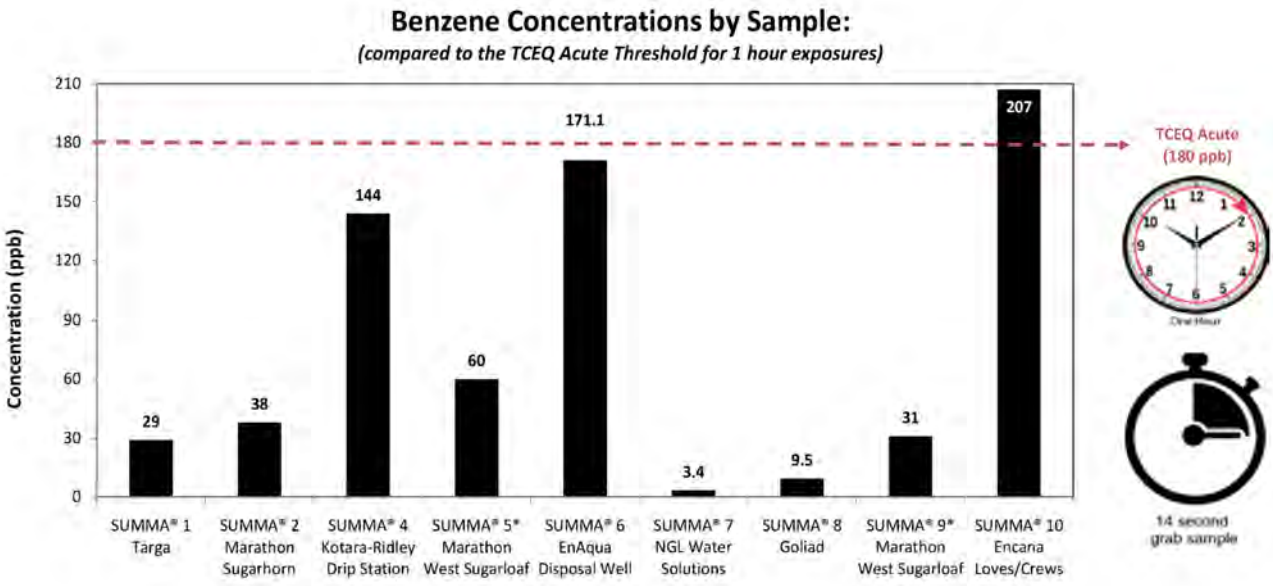


Figure 17. Benzene Acute Exposure Scenarios: SUMMA® air sample concentrations compared to acute TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

Chronic Exposure Scenario: At the concentrations we detected, all nine samples could exceed either TCEQ or EPA thresholds if they persist over a year or lifetime (see graphs next page). The average amount of benzene in the samples would be 8.2 times above the EPA reference concentration and 54.8 times the chronic TCEQ threshold if emissions were to persist over a lifetime and year, respectively. However, given how much our sample concentrations varied and that we gathered air samples very close to sources, it is unlikely that the average of the concentrations we measured accurately represents the general benzene concentrations in this region. To give an idea, within a 48 square mile area in Karnes County, we found a range of 3.4 - 207 ppb of benzene at six different locations.

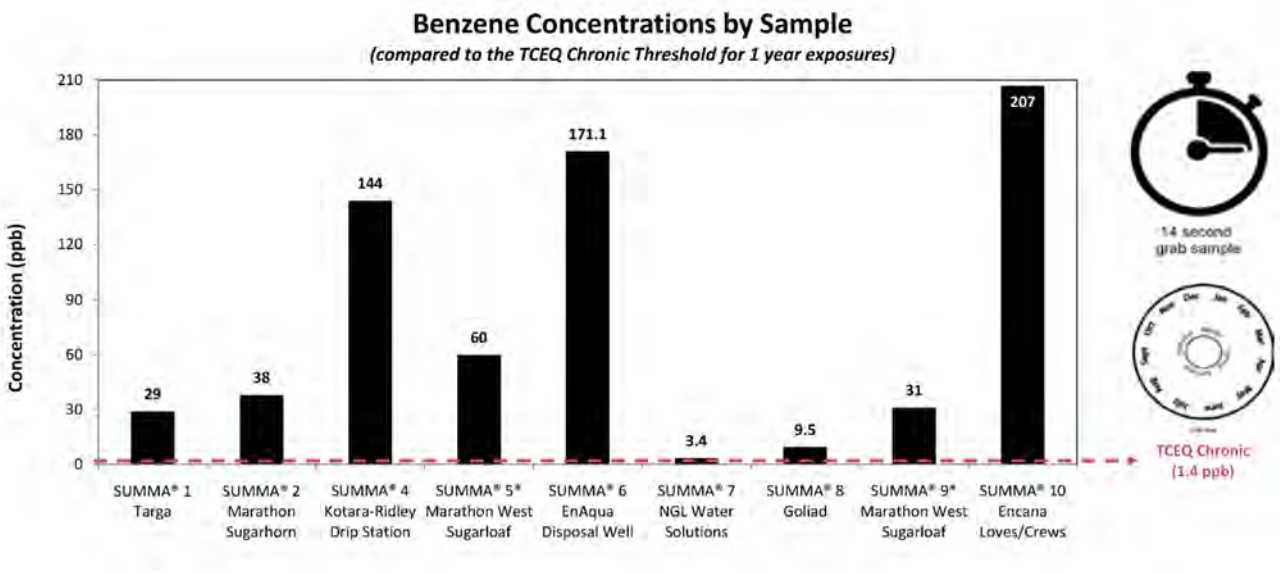


Figure 18. Benzene Chronic Year-long Exposure Scenarios: SUMMA® air sample concentrations compared to chronic TCEQ thresholds (AMCVs). SUMMA® samples # 5 and 9 were taken at the same location but on different days.

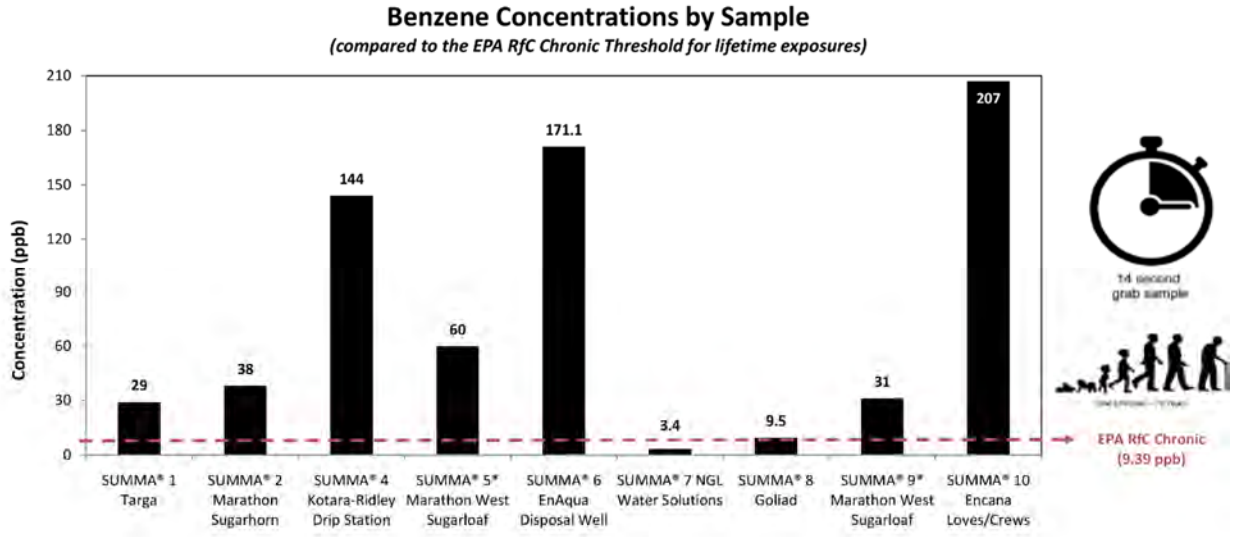


Figure 19. Benzene Chronic Lifetime Exposure Scenarios: SUMMA® air sample concentrations compared to EPA thresholds (RfCs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

The TCEQ monitor located in Karnes City recorded an average benzene concentration of 0.54 µg/m^3 (0.169 ppb) during the period of time when we gathered air samples. Comparatively, the average concentration of benzene of our sample was far higher at 77 µg/m^3 (24.1 ppb). TCEQ's monitor does not show a concerning average benzene concentration suggesting that this monitor is not capturing the emissions from these facilities. It also suggests that the primary populations to be concerned about exposures to benzene are not residents who live and work in the center of Karnes, but those who live and work among oil and gas operations.

Spikes of 207 ppb and 171 ppb were found at two separate facilities 16 days apart, and levels of 60 ppb and 31 ppb were found at the same facility 18 days apart. These results suggest that these two facilities may routinely emit such levels of benzene. We recommend routine sampling to confirm or rule out this possibility. Follow up studies should be done to ensure that community members living close to or working near such are not being chronically exposed to this carcinogen.

Cyclohexane

This compound is an irritant that can cause eye and skin irritation, drowsiness, dizziness, weakness, vomiting, and it may be fatal if swallowed or inhaled directly in very high doses. We detected cyclohexane in all of our samples probably because it is a component of petroleum. None of the concentrations we detected would exceed acute health standards in Texas, if they were continuous. However, in two samples, we found levels that could exceed the chronic long-term exposure threshold if these emissions were continuous over long periods of time.

Cyclohexane chemical properties and health effects associated with exposure

Cyclohexane can have a sweet, pungent, chloroform-like odor. This compound is highly flammable, more dense than air, and degrades by 50% every 2.3 days (half-life). Petroleum usually consists of 0.5%-1.0% cyclohexane, which may be released during petroleum refining, vaporization of gasoline, oil spills, and in gasoline exhaust. It can also be released from volcanic emissions, tobacco smoke, and plant volatiles.[118]

Human exposure to cyclohexane primarily occurs through skin or eye contact and inhalation.[119] Common health effects include eye and skin irritation, drowsiness, dizziness, weakness, vomiting, and it may be fatal if swallowed or inhaled directly. Skin and eyes may become red, and skin can get dry around concentrations of 300 ppm. Respiratory symptoms may include a cough, and high levels can induce unconsciousness. Cyclohexane may be absorbed by water and poses a high threat to aquatic life. [120]

Cyclohexane exposure scenarios

Acute Exposure Scenarios: None of the concentrations of cyclohexane in our 14-second air samples exceeded the TCEQ acute threshold (1000 ppb over an hour). In terms of cyclohexane exposure, breathing air with concentrations we identified for an hour is not predicted to cause human health effects (see chart on next page).

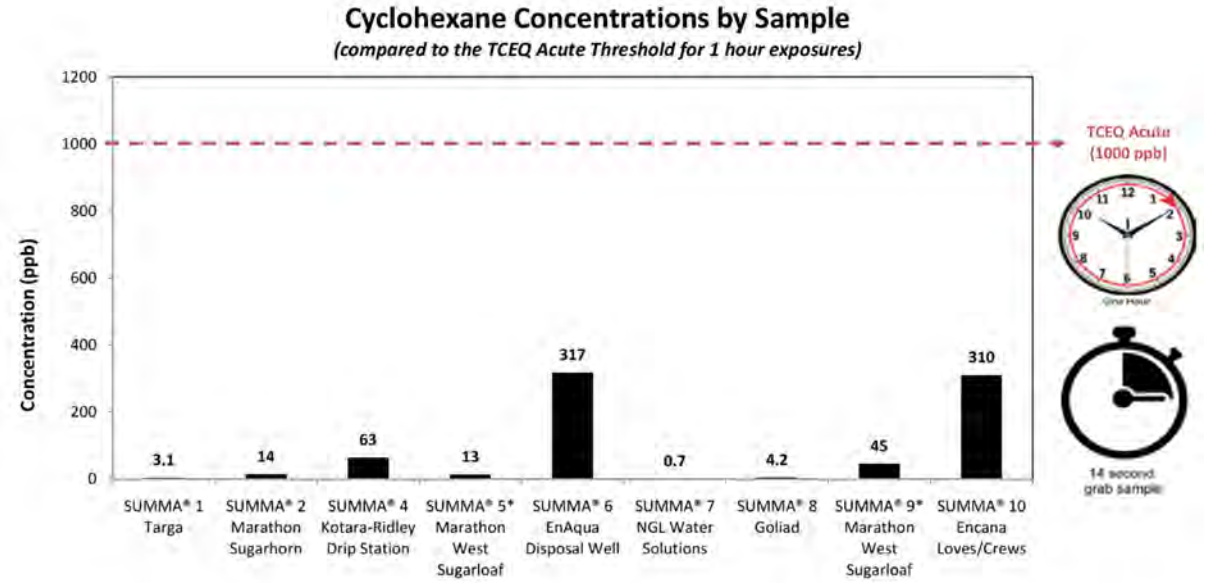


Figure 20. Cyclohexane Acute Exposure Scenarios: SUMMA® air sample concentrations compared to acute TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

Chronic Exposure Scenarios: We detected levels of cyclohexane in two of our samples that, if continuously inhaled over a year, could potentially cause health concerns. The TCEQ threshold for chronic cyclohexane exposure over a year is 100 ppb. The EPA does not have a RfC threshold value for cyclohexane. We found levels of cyclohexane in all of our samples. These measurements ranged from very low (0.70 ppb) to quite high (317.00 ppb). At Encana Loves/Crews Central Processing Facility and EnAqua Disposal well, we found levels of 310.0 ppb and 317.00, respectively. These two levels would exceed TCEQ's thresholds of 100 ppb for chronic exposure threefold if they continued over a year.

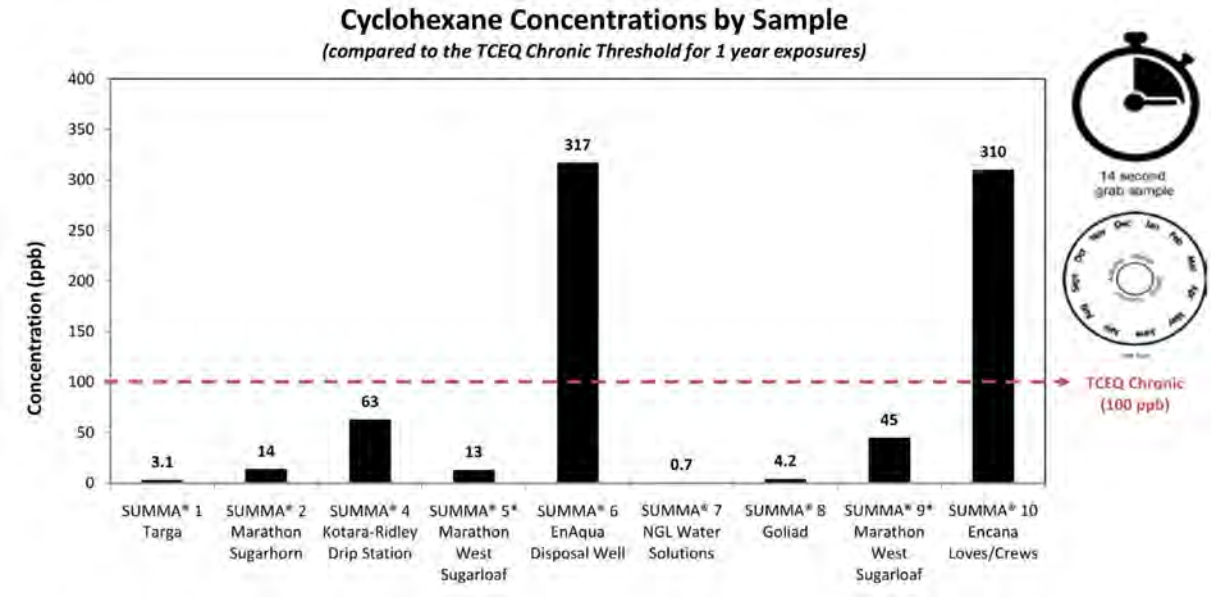


Figure 21. Cyclohexane Chronic Year-long Exposure Scenarios: SUMMA® air sample concentrations compared to chronic TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

Naphthalene

Naphthalene is a byproduct of petroleum distillation. We found naphthalene in three of our samples at concentrations which would exceed chronic thresholds for exposure set by TCEQ and EPA, if such levels remained consistent over a year or lifetime. Naphthalene is hazardous to the liver, eyes and nervous system and is also linked to increased risks of some cancers. Exposure to naphthalene could potentially pose a risk to people living or working close to these facilities.

Naphthalene chemical properties and health effects associated with exposure

Naphthalene is a solid polycyclic hydrocarbon that occurs naturally and comes from petroleum distillation. It readily volatilizes, or turns into gas, from soil and water containing the compound. Trace amounts of naphthalene are present in black walnut, essential oils, and magnolias. Mothballs contain high amounts of naphthalene, which is what gives them their distinct odor and makes them toxic.

Naphthalene can cause liver and neurological damage, among other health effects. Chronic naphthalene exposure among workers has led to cataracts and retinal damage. Moreover, infants suffering from hemolytic anemia, the destruction of red blood cells, have been born to mothers who reported inhaling fumes from mothballs during their pregnancies. Scientists are currently in the process of determining whether it is a human carcinogen since studies have associated it with an increased risk of laryngeal and colorectal cancer.[121] Exposure to naphthalene can occur by means of inhalation, oral ingestion, or absorption through the skin.

Naphthalene exposure scenarios

Acute Exposure Scenarios: None of the concentrations of naphthalene in our 14-second air sample exceeded TCEQ's acute exposure threshold (over 95 ppb for an hour). Therefore, in terms of naphthalene exposure, breathing air containing the concentrations we identified over an hour is not predicted to cause human health effects by TCEQ's standards.

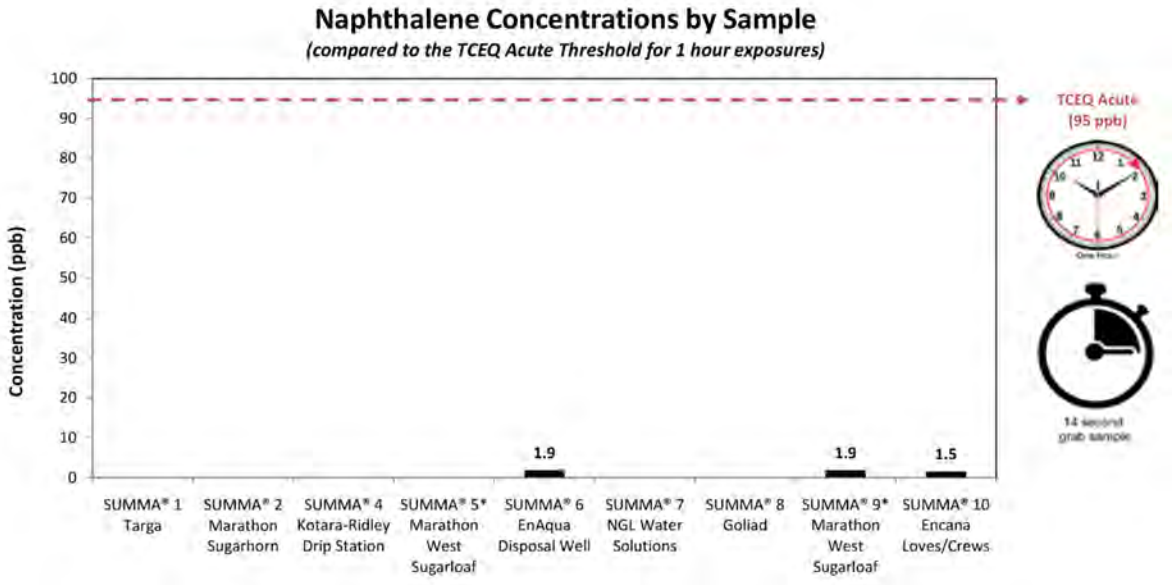


Figure 22. Naphthalene Acute Exposure Scenarios: SUMMA® air sample concentrations compared to acute TCEQ thresholds (AMCVs)[122]. SUMMA® samples #5 and #9 were taken at the same location but on different days.

Chronic Exposure Scenarios: The concentrations of naphthalene detected in our three positive samples would not exceed TCEQ's chronic exposure threshold of 9.5 ppb for naphthalene over the course of a year. Therefore, breathing concentrations of naphthalene at the levels we detected over the course of a year is not predicted to cause harm by the TCEQ.

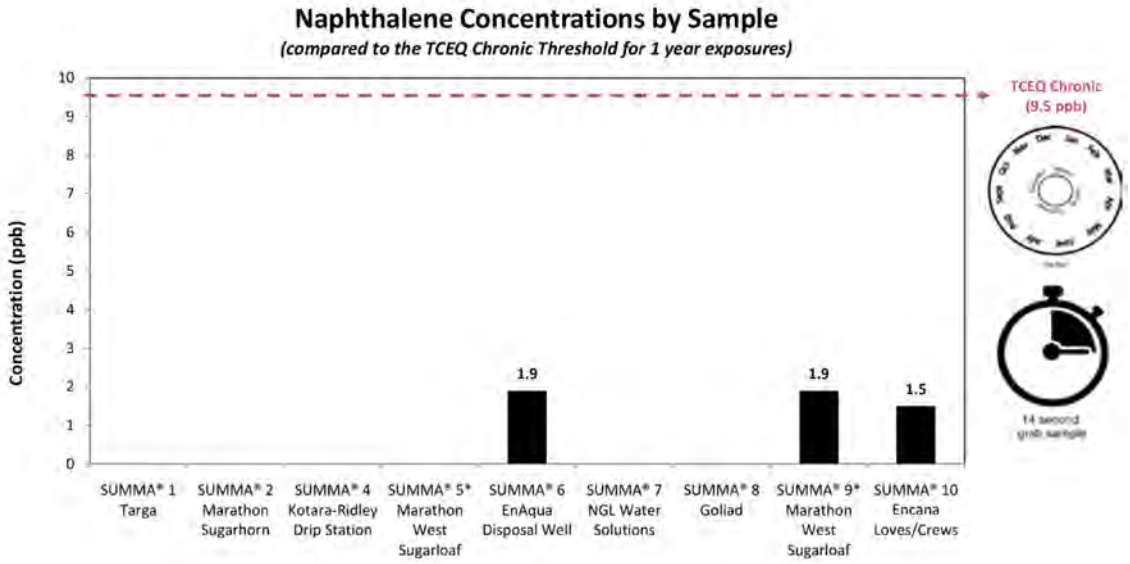


Figure 23. Naphthalene Chronic Year-long Exposure Scenarios: SUMMA® air sample concentrations compared to chronic TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

The EPA RfC is 0.57 ppb over the course of a human lifetime. The levels we detected would exceed EPA RfC if continuous at three locations: on the public road outside EnAqua disposal well (we detected 1.9 ppb), outside Marathon West Sugarloaf (we detected 1.9 ppb) and on the public road beside Encana Loves/Crews (we detected 1.5 ppb). These concentrations could potentially pose a health risk to people living very close to these facilities for the majority of their lives.

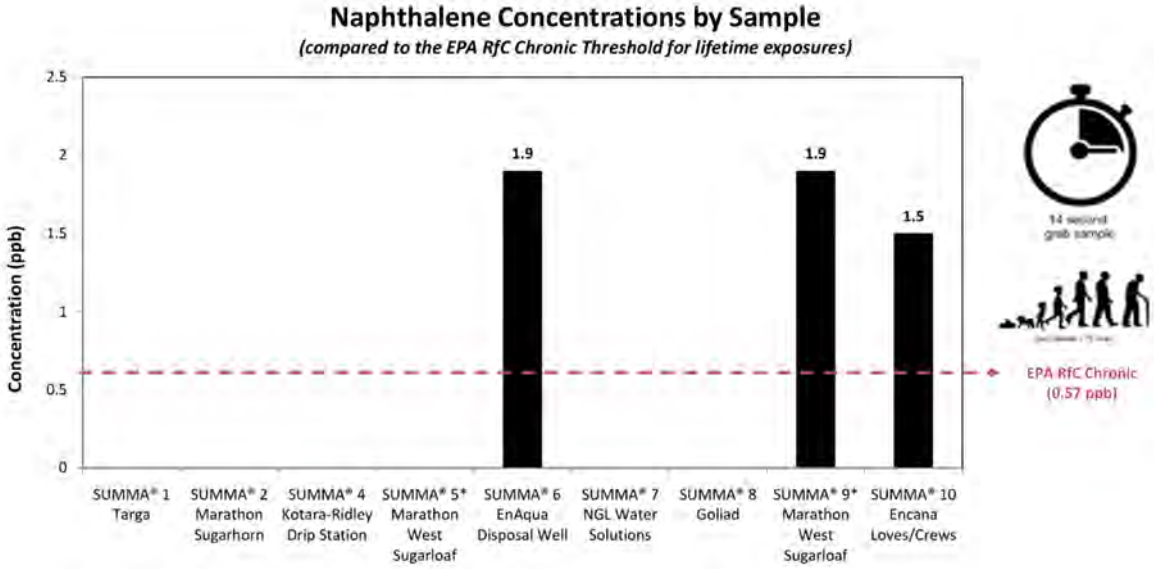


Figure 24. Naphthalene Chronic Lifetime Exposure Scenarios: SUMMA® air sample concentrations compared to EPA thresholds (RfCs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

N-Hexane

N-Hexane was detected in eight of our nine samples. Exposure to n-Hexane can harm the brain and nervous system. The level we detected in one sample would exceed TCEQ's acute threshold for n-Hexane exposure if such levels were breathed over one hour. N-Hexane exposure could potentially pose a health risk to someone working for an hour in the location where we sampled. Additionally, in this sample and three others, the concentrations we detected could exceed TCEQ and EPA chronic thresholds. Accordingly, levels of n-Hexane in these locations could potentially pose chronic risks to people living very close to these facilities for a year or longer.

N-Hexane health effects associated with exposure

Symptoms of short-term inhalation exposure to high levels of n-hexane mainly pertain to the central nervous system. They include headache, mild nausea, giddiness, and dizziness in addition to skin, eye, and throat irritation. Chronic exposure also has nervous system effects such as polyneuropathy, which includes muscle weakness, blurred vision, headache, numbness of extremities, and fatigue. The compound's cancer-causing potential is not yet known.[123]

Acute Exposure Scenarios: At EnAqua Disposal Well we detected 2,202 ppb of n-Hexane in our short term air sample. This would exceed TCEQ's acute exposure threshold of 1,700 ppb. This means that if these levels were consistently present and inhaled over the course of an hour, they could pose an immediate risk to human health.

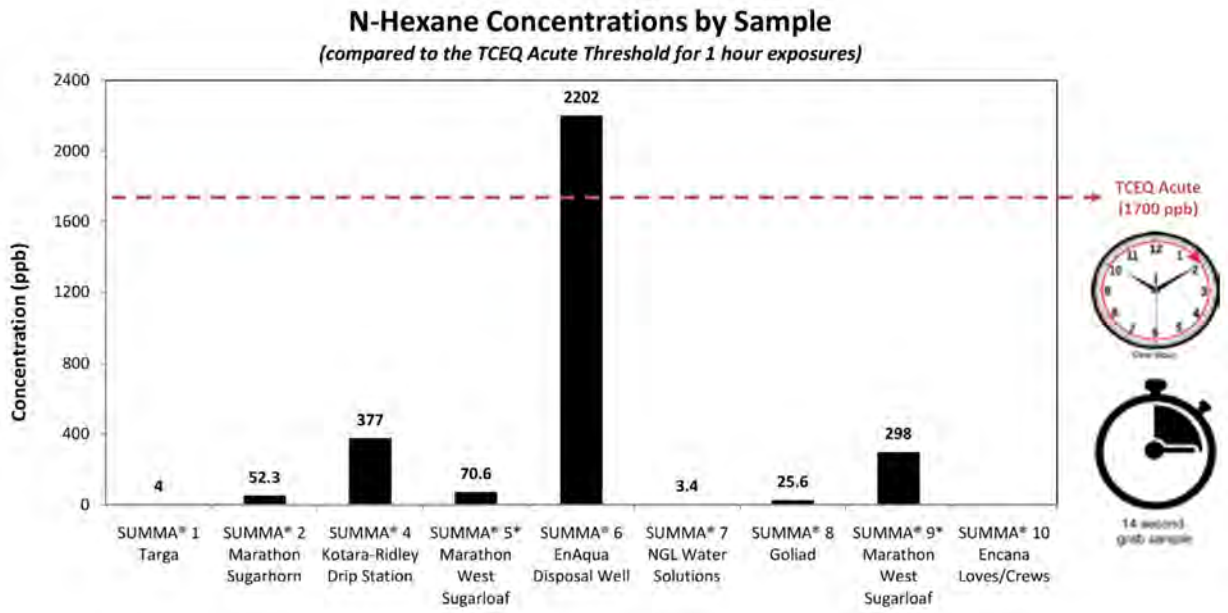


Figure 25. N-Hexane Acute Exposure Scenarios: SUMMA® air sample concentrations compared to acute TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

N-Hexane chronic exposure scenarios

At four locations the concentrations of n-Hexane detected could exceed the TCEQ year-long exposure threshold (190 ppb) and the EPA lifetime exposure threshold (198.62 ppb) if the concentrations we detected were routine. It is important to note n-Hexane may follow a nonlinear dose response curve (where low doses can cause health effects) and its status as a carcinogen is still being studied by scientists.[124,125] The TCEQ provides an acute exposure threshold of 1,700 ppb calculated by more conventional methods and a year-long chronic threshold value of 190 ppb.[126]

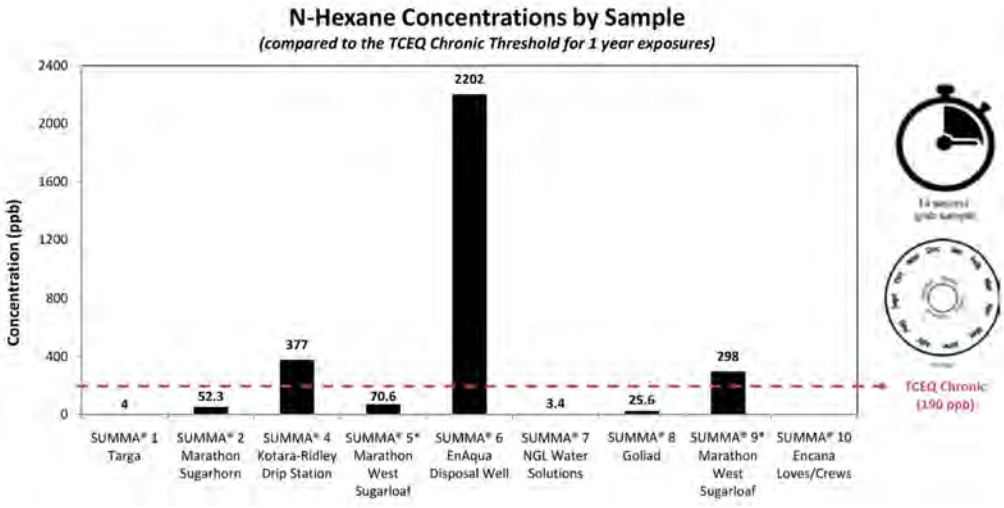


Figure 26. N-Hexane Chronic Year-long Exposure Scenarios: SUMMA® air sample concentrations compared to chronic TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

If the concentrations were to be routinely present in these four locations, over the course of a year or multiple years, such levels could pose a health risk to people living very close to our sampling locations. Follow up studies should be done to ensure that community members are not being chronically exposed to this gas.

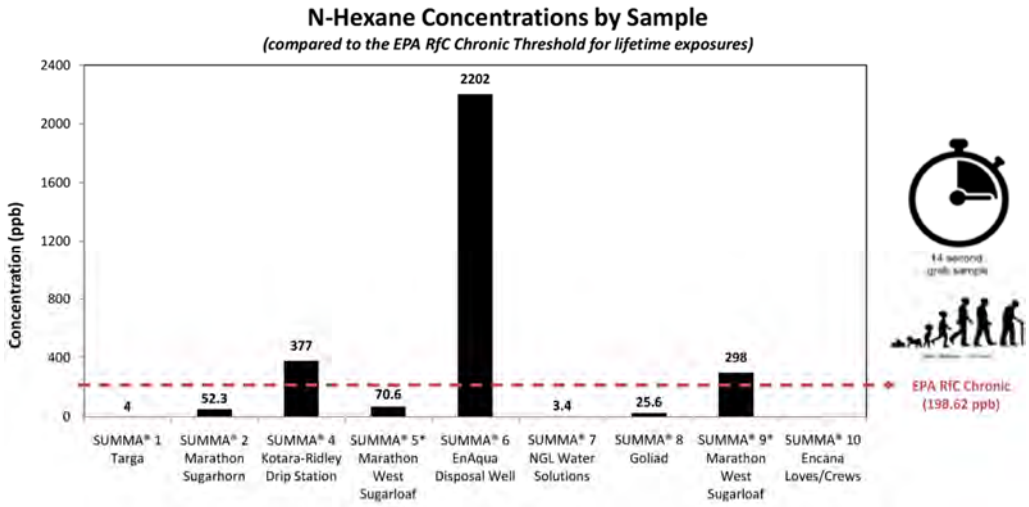


Figure 27. N-Hexane Chronic Lifetime Exposure Scenarios: SUMMA® air sample concentrations compared to EPA thresholds (RfCs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

Mixed xylenes

Exposure to xylenes can cause irritation to the eyes, nose and throat and harm to the nervous system. Xylenes can be released from many industrial sources, as well as automobile exhaust and from solvents. Humans are primarily exposed to xylenes through inhalation. We calculated values for mixed xylenes by adding together volumes of o-xylene and m,p-xylene in our samples. In one of our samples, mixed xylenes could exceed TCEQ's chronic exposure threshold if the emissions persisted over the course of a year. In that sample, and one other, the mixed xylene concentrations could exceed EPA thresholds for life-time exposure if they were routine, potentially posing a risk to people who live close to these sampling locations for extended periods of time.

Xylene health effects associated with exposure

According to the EPA, acute (short-term) inhalation of mixed xylenes in humans can irritate the eyes, nose, and throat. It can also cause gastrointestinal symptoms such as nausea, vomiting, and gastric discomfort. Neurological effects from mixed xylenes include impaired short-term memory and reaction time, and alterations in equilibrium and body balance. Meanwhile, chronic (long-term) inhalation exposure to mixed xylenes can damage the central nervous system, causing headache, dizziness, fatigue, tremors, and incoordination. Additionally, respiratory symptoms such as labored breathing and impaired lung function can occur with chronic exposure, along with cardiovascular effects like severe chest pain and abnormal EKG, and kidney effects.[127]

Xylene exposure scenarios

Acute exposure scenarios: Though we detected xylenes in all of our samples, none of the samples found xylene concentrations above TCEQ's acute thresholds for exposure over an hour. Hence, even if these concentrations were persistently inhaled for an hour, TCEQ would not predict immediate health effects would occur.

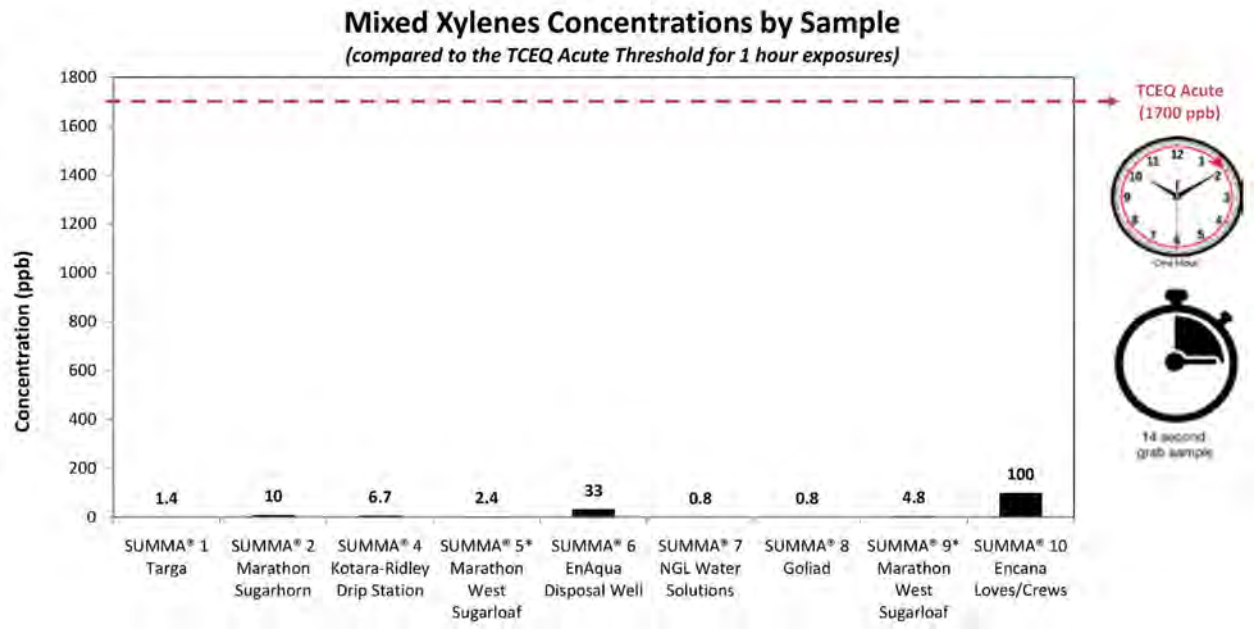


Figure 28. Mixed Xylenes Acute Exposure Scenarios: SUMMA® air sample concentrations compared to acute TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

Chronic Exposure Scenarios: At one of our sampling locations on the public road outside Encana Loves/Crews Central Processing facility, the levels of xylenes could pose a chronic health risk if both emissions and exposure were consistent over the course of a year. The TCEQ chronic threshold is 140 ppb over an hour; we detected 140.56 ppb in our short term air sample. Hence, someone living close to this location for a year or more might be at risk of health impacts from xylenes, if these concentrations or higher were routinely emitted and inhaled.

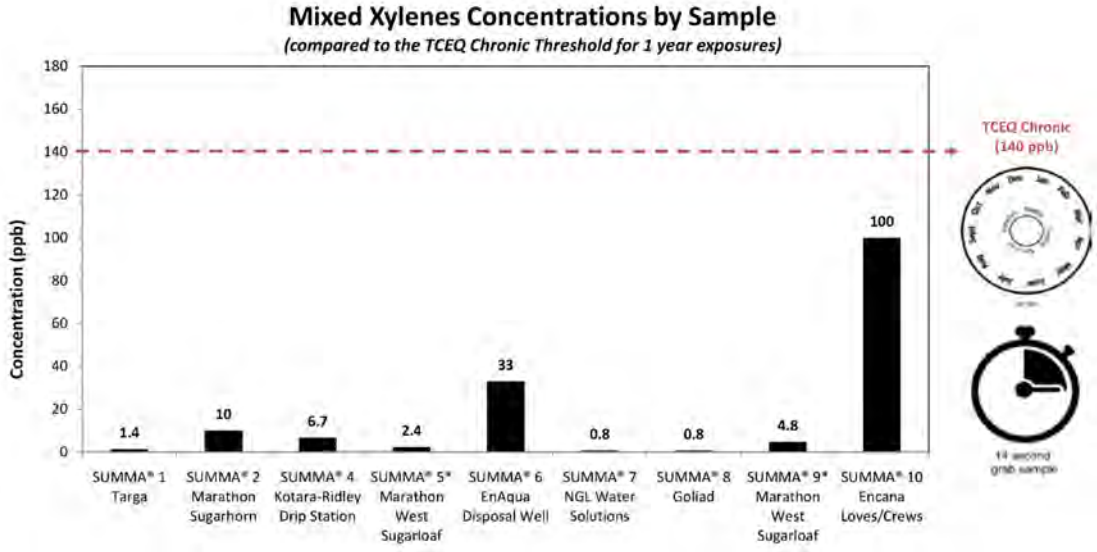


Figure 29. Mixed Xylenes Chronic Year-long Exposure Scenarios: SUMMA® air sample concentrations compared to chronic TCEQ thresholds (AMCVs). SUMMA® samples #5 and #9 were taken at the same location but on different days.

The EPA RfC threshold for mixed xylenes of 23.03 ppb over a lifetime could be exceeded at Encana Love /Crews and one other (EnAqua Disposal Well). This could potentially pose a risk to people who live close to these facilities for a year or more. There were families living close to both facilities (see Appendix 1).

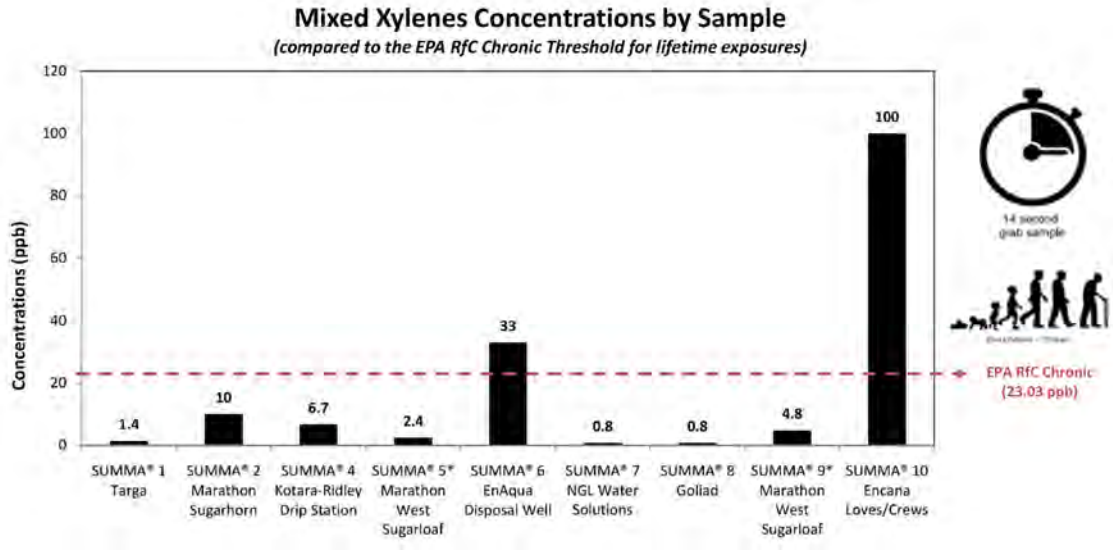


Figure 30. Mixed Xylenes Chronic Lifetime Exposure Scenarios: SUMMA® air sample concentrations compared to EPA thresholds (RfCs).[128] SUMMA® samples #5 and #9 were taken at the same location but on different days.

Complex mixtures and exposure scenarios in a location

While the above chemicals are concerning individually, it is unlikely that anyone would be exposed to them in isolation. It is much more likely that people are exposed to complex mixtures of multiple chemicals at once. Exposure to chemical mixtures can lead to multiple health effects and even "synergistic" effects where the chemicals act together to cause different or more intense health impacts. Additionally, because exposure thresholds are set based on exposure to single chemicals in controlled laboratory settings, they do not take into account simultaneous multiple chemical exposures.

Hence, people may experience health effects from being exposed to a mixture of chemicals when all the chemicals in that mixture are below regulatory thresholds. The complexity of exposures, the unique history, and biological vulnerability of any individual human make it impossible to accurately assess the real risk to any one person from chemical exposures.

If the concentrations and combinations of chemicals we detected were routinely emitted, people living close to and downwind of production facilities may be at increased risk of neurological, respiratory and immunological harm.

The best science can do is look at patterns that occur in large populations; we cannot say whether someone was harmed by a particular exposure, or predict exactly how an individual's exposure could affect them. We can only say that based on population-based studies and lab models, this mixture of chemicals could be expected to pose an increased risk to human health.

Much more research is needed to examine the mixture of chemicals that Karnes residents might actually be exposed to. However, we can look at the pattern of health effects that the chemicals we detected might cause to different organ systems if people were breathing the air similar to the samples we took over extended periods of time.

Acute effects from chemical mixtures

We can examine the potential health effects of chemical mixtures by looking at the different organ systems that the various chemicals we detected can impact. Then, we examine if those chemicals could exceed regulatory thresholds. In this case, we use TCEQ's hour-long acute threshold assuming that the concentrations we detected were to persist for an hour.

For instance, 11 of the chemicals we detected, according to the EPA, can impact the neurological system (hydrogen sulfide, carbon disulfide, toluene, xylenes, styrene, chloromethane, methylene chloride, n-Hexane, acetone, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene). Based on comparisons to TCEQ's acute thresholds, a person's neurological system could be harmed if they spent at least an hour inhaling these chemicals at the concentrations that we measured (See Appendix 2, Figure 81). The driver of the increased risk in this calculation is hydrogen sulfide. This compound was only detected at 3 locations, so this increased risk would likely only pertain to locations where H_2S is emitted. Also, the TCEQ does not have an acute exposure threshold for H_2S. Instead, we used the regulatory threshold established in the Texas Administrative Code (30 TAC Chapter 112) for fence-line emissions on residential, business, or commercial property over 30 minute (~ 77 ppb).[129] This assessment, while necessarily provisional based on our limited samples, suggests that it is important to conduct further assessments of both emissions and exposures to these compounds that can harm the brain and nervous system.

Similarly, we averaged the concentrations of the chemicals we detected that, according to the EPA, could impact the respiratory system (hydrogen sulfide, naphthalene, methyl ethyl ketone, cyclohexane) and compared them to their TCEQ acute thresholds. Given our results (see Appendix 2, Figure 81), an exposed person's respiratory system could be harmed if the levels we detected were inhaled over the course of an hour (See Appendix 2, Figure 81). Again, the driver of this increased risk in this calculation was Hydrogen Sulfide. As we mentioned previously, this compound was only detected at 3 locations therefore it is likely

that this increased risk would pertain only to locations where H_2S is emitted. Also as above, since TCEQ does not have an acute exposure threshold for H_2S, we used the regulatory threshold established for fence-line emissions on residential property over 30 minute (~ 77 ppb). With these caveats in mind, it is important that further monitoring be conducted to assess both emissions of and exposures to the above compounds that can harm the respiratory system.

We also averaged the detected concentrations of chemicals that affect the immunological, hepatic, renal and reproductive systems (according to the EPA) and compared them to the TCEQ acute thresholds. Our results show that increased risk to these organ systems is not likely to occur.

However, averaging these concentrations is misleading because our samples were targeted to detecting emissions not to assess the general ambient air. Therefore, our samples likely had much higher concentrations than that of average air in the region. The averages discussed above are more likely represent conditions very close to and downwind of facilities. Also, averaging the concentrations ignores the potential for increased risk at locations where we detected particularly high chemical concentrations and inflates the risk for locations where we detected lower levels.

At locations where we detected the highest chemical concentrations, acute exposures might also be possible.

Case study for location specific exposures to chemical mixtures: Encana Loves/Crews

Close to and downwind of Encana Loves/Crews, a central production facility located on the border of Karnes City, we detected levels of benzene that if persistent could pose an acute risk.[130]

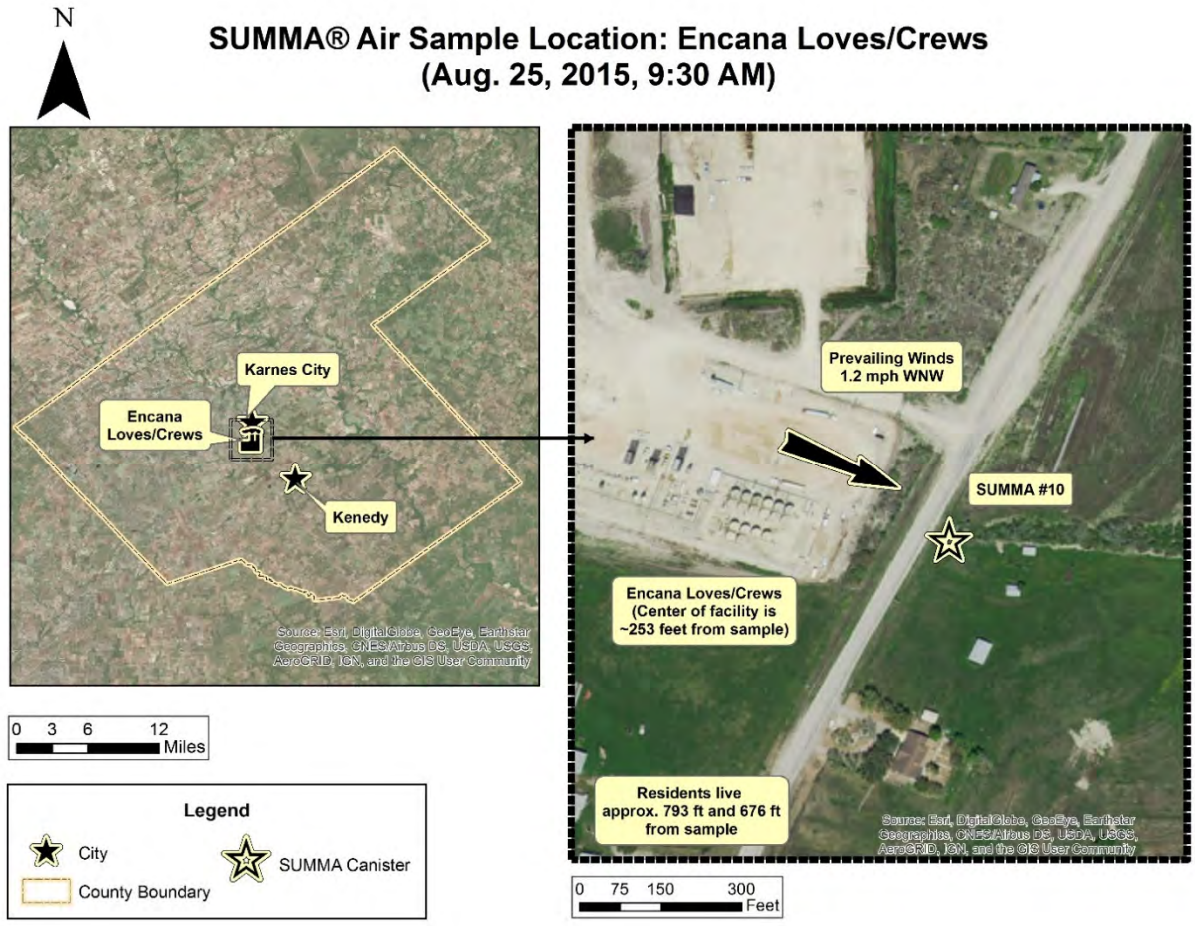


Figure 31. SUMMA® Air Sample Location outside Encana Loves/Crews.

Figure 32. Images taken by an Earthworks certified operator show the Encana Loves/Crews Central Collection Facility in Karnes County as seen with the naked eye and as seen with the Optical Gas Imaging camera.

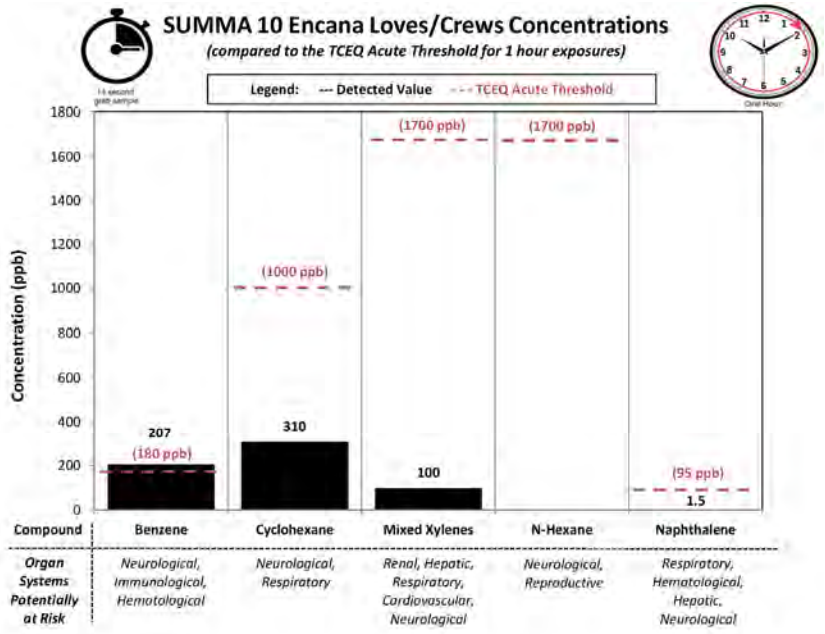


Figure 33. Encana Loves/Crews Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios. SUMMA® samples #5 and #9 were taken at the same location but on different days.

Additionally, in the air sample at this location, we identified cyclohexane, mixed xylenes, and naphthalene. At 140.56 ppb, mixed xylenes would exceed the chronic TCEQ threshold by 0.56 ppb and EPA RfC by over six times. We also found cyclohexane at 310 ppb, which would exceed the chronic TCEQ value of 100 ppb by three times if these concentrations were to persist. Cyclohexane is an irritant to the nose and throat, but the EPA does not currently maintain an established RfC for it. Naphthalene was found at 1.5 ppb, which would exceed the EPA RfC of 0.57 ppb more than twice if this concentration were to persist in the air over a lifetime.

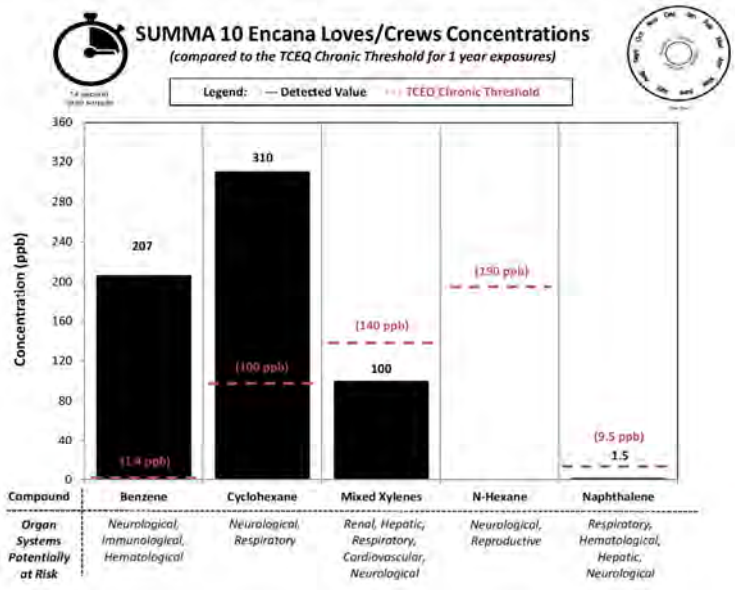


Figure 34. Encana Loves/Crews Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios. SUMMA® samples #5 and #9 were taken at the same location but on different days.

Two of the compounds detected in these samples are carcinogens (naphthalene and benzene). Two can harm the nervous system (n-Hexane and xylene) and two can harm the respiratory system (cyclohexane and naphthalene). People living close to these facilities could potentially be exposed to this mixture of chemicals, chronically, at the concentrations we detected. If such exposures were chronic, they might experience a range of health effects across those organ systems.

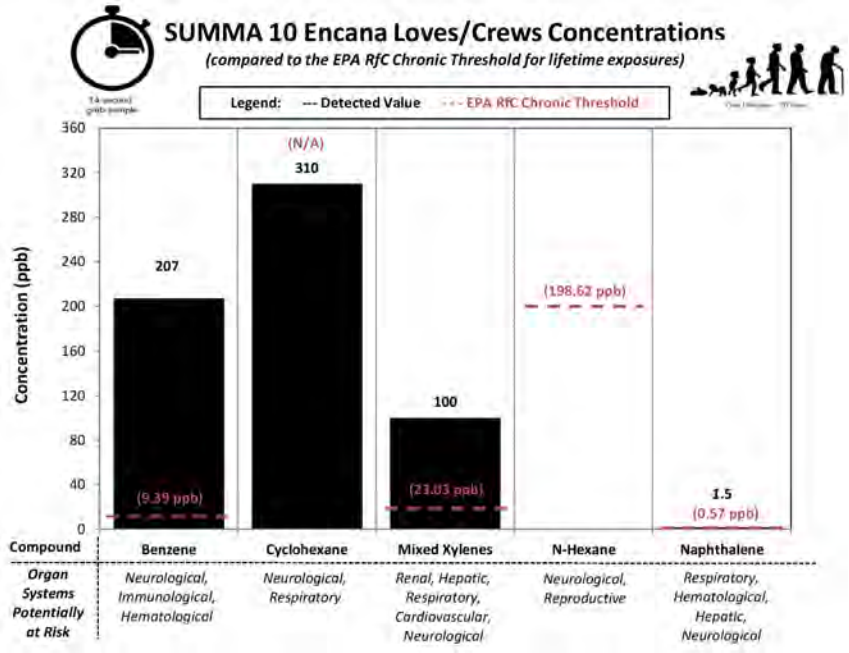


Figure 35. Encana Loves/Crews Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios. SUMMA® samples #5 and #9 were taken at the same location but on different days.

A home with a child is only 471 feet (or 1.5 city blocks) away and a child's daycare center is half a mile away from the facility.[131] Additionally, an immigrant detention facility and county correctional facility are less than a mile and a half away from Encana Loves/Crews. Based on our air sample, and the proximity of residents, we strongly recommend that thorough real-time monitoring is conducted at this facility. For further analysis of our monitoring results for the particular locations monitored please see Appendix 1.

Chronic risks from chemical mixtures

It is important to consider the risk of chronic exposure to people who live close to facilities, or downwind of multiple facilities. Such people might be exposed to mixtures like those we identified. If that were the case, based on EPA's chronic exposure thresholds, three organ systems could be affected by the mixtures of chemicals we identified: the immune system, the neurological system (brain and nervous systems), and the respiratory system.

Benzene was primarily responsible for the risk to immunological systems, while 10 of the chemicals we identified can affect the brain and nervous system (hydrogen sulfide, carbon disulfide, toluene, xylenes, styrene, chloromethane, methylene chloride, n-Hexane, acetone, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene). Similarly a large range of chemicals could affect the respiratory system (hydrogen sulfide, naphthalene, methyl ethyl ketone, cyclohexane). In both cases, the driver of the risk to the respiratory and nervous system was hydrogen sulfide.

We would expect no increased risk to the hepatic, reproductive, and renal systems from the mixtures of chemicals we detected.

Limitations of current TCEQ monitoring to evaluate air pollution risks for those living close to oil and gas facilities

The one TCEQ monitor in the 754 square mile area of Karnes County is located in the center of Karnes City at the courthouse. It was located here to monitor ambient air in this area where the population density is highest. While this monitor may be sufficient for evaluating the safety of air inhaled by people living in Karnes City, the results from our samples suggest it is inadequate for assessing exposures for people who live outside of Karnes City and close to oil and gas facilities.

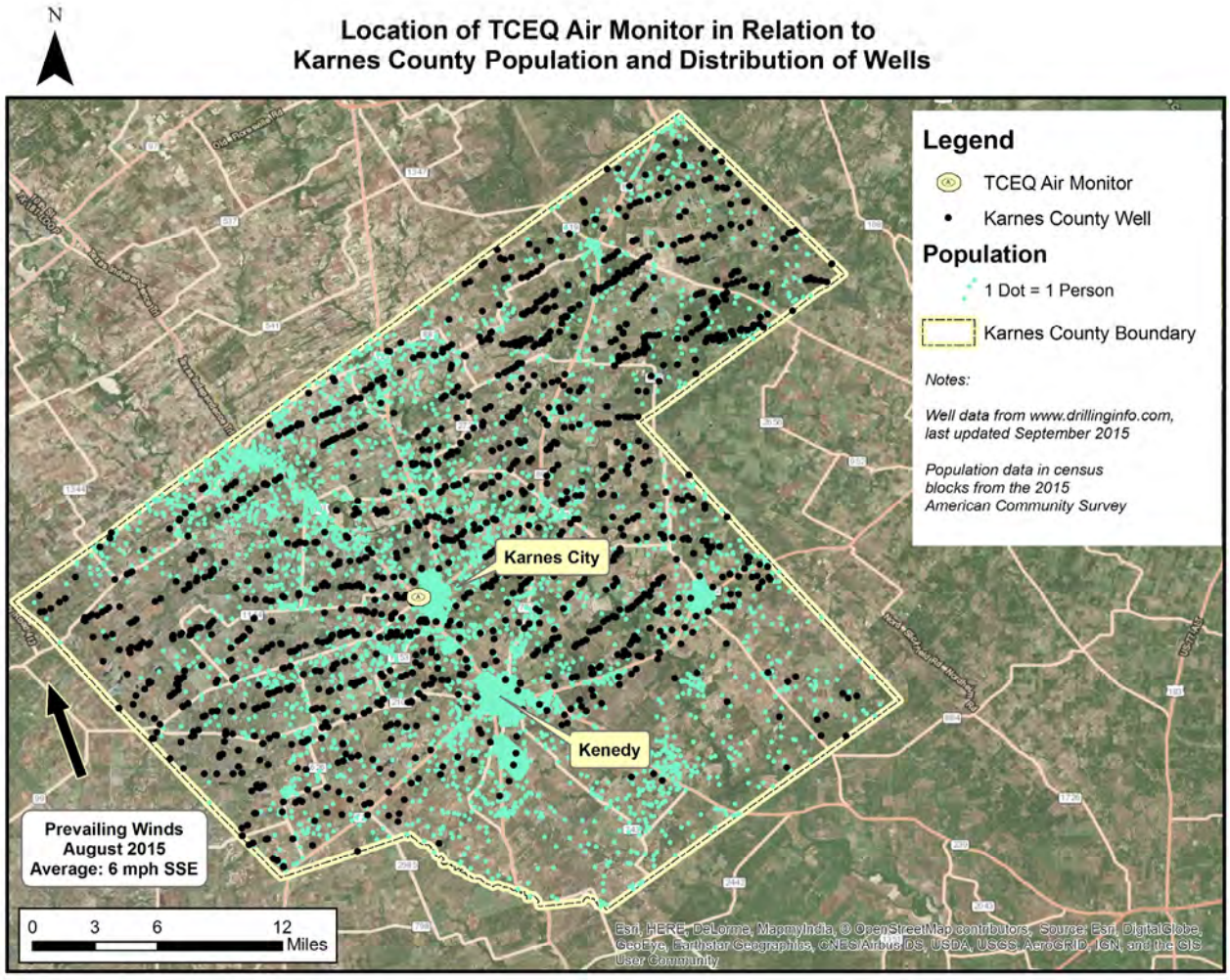


Figure 36. Karnes County Texas TCEQ monitor location and population data.

The table below shows data from the Karnes City TCEQ air monitor during our testing period of August 9th to 25th, 2015.[132] Fifteen compounds were detected in both our air samples and the TCEQ monitor. Detection frequencies for overlapping compounds were similar between the two datasets. This overlap is reassuring in that the mixture of chemicals detected by our canisters and the TCEQ monitor are similar in composition. However, the datasets differ in the relative concentrations of the chemicals detected.

Comparison between Chemicals Measured by the TCEQ Monitor*1 and our SUMMA® Samples*2								
Unit (ppb)	TCEQ				Summa® Samples			
Compound	Number of detects *3	Detection frequency % *4	Average (ppb)	Max (ppb)	Number of detects	Detection frequency %	Average (ppb)	Max (ppb)
1,3-Butadiene	116	34	0.0045202	0.35	1	10	0.2	0.7
n-Hexane	344	100	3.72	86.56	8	80	336	2202
Benzene	341	99	0.54	6.92	9	90	77	207
Cyclohexane	319	93	0.64	13.43	9	90	85.6	317
2,2,4-Trimethylpentane	83	24	0.06	2.38	4	40	0.3	1.1
Heptane	322	94	1.12	32.56	8	80	228.1	1175
Toluene	344	100	1.18	14.11	8	80	61.7	272
Ethyl Benzene	300	87	0.1	1.56	7	70	4.7	27

1* Data Retrieved from TCEQ "AutoGC Data by Day by Site"
https://www.tceq.texas.gov/cgi-bin/compliance/monops/agc_daily_summary.pl?user_site=48_255_1070
2* One limitation of our SUMMA samples is that we did not test for isobutane and ethane variability, which can predict whether or not benzene came from oil and gas sources.[133]
3* Detects are the number of hours in the testing period that measured chemicals over the detection level, excluding measurements that were used for quality assurance and control by the TCEQ.
4* Detection Frequency refers to the percent of total instances (a measurement is taken each hour by the TCEQ monitor) in which the chemical was detected over the minimum detection level.

Figure 37. These chemicals were detected by both our SUMMA® air samples and the Karnes City TCEQ monitor during August 9th-25th, 2015 and their relative concentrations.

In general, higher concentrations were captured with the grab samples compared to the TCEQ monitor. This is to be expected as our grab samples were taken close to potential emissions sources. The grab samples recorded much higher maximum concentrations of benzene, toluene, ethylbenzene and xylenes (BTEXs) , N-hexane, and cyclohexane.[134] Our maximums were between 600 - 950% of the maximum values recorded at the TCEQ monitor. The levels we detected were likely vastly diluted before they reached the TCEQ monitor.

The relatively low maximum levels detected by the TCEQ monitor suggests that people breathing the ambient air in Karnes City during our testing period of August 2015 were not at increased risk of adverse health impacts from these compounds (assuming the monitor is characteristic of Karnes City's ambient air). However, the much higher maximum levels detected in our samples taken close to potential sources suggests that there could be increased risks for people living close to these facilities and thereby chronically exposed to higher levels of these compounds.

Potential chronic health risk compared to resident interviews

The health issues reported in resident interviews aligned with the systems that analysis of the health risks posed by the chemical mixtures identified as being most at risk. Health complaints from 13 Karnes residents were connected to the neurological system including fatigue, dizziness, and headaches.

Neurological effects were the most commonly reported. Some residents found it difficult to explain a mixture of dizziness, fatigue, and short-term memory loss especially when they were outside. Sixty-year-old Francis experiences dizziness, chronic headaches, and short-term memory loss. Her short-term memory loss worried her to the point that she decided to have a consultation with her primary care physician to get tested for Alzheimer's disease.

> *I also have issues with brain fog, I thought I was starting with Alzheimer's and I went to the doctor about that and they said no I do not have Alzheimer's, the brain fog is environmental. I was having to put sticky notes on myself I would go start the washer and not remember that I had water in the washer and I would start another task and not finish it and I was not getting anything done so I just started wearing sticky notes, that way I pulled a sticky note off and oh yeah I have water in the washer.* – Francis

Francis, for example, experiences random bouts of numbness in her extremities and feels dizzy when she is outside gardening:

> *I also have issues where I have numbness sometimes in my hands and numbness in my legs, dizzy spells, sometimes I will just be walking and have to sit down because I'm feeling either nauseated or dizzy. I fell last year with a dizzy spell and I injured my ankle.* – Francis

A total of 12 residents reported neurological symptoms such as headaches or dizziness. Armando explains that his headaches have become more severe and frequent after he and his family moved to Karnes:

> *I just had a really bad headache it just wouldn't go away. I know every time I go out back to the house it's just like automatic. Once I breathe in those fumes it just comes back to me within seconds.* – Armando

When asked if this was something he experienced often, he said, "Occasionally but not every day, maybe 3-4 times a year at the most."

The second highest percentage of resident health complaints was the respiratory system.

> *And I have tried to live really healthy previous to this. I get lots of exercise and try to eat right and lo and behold look what happens. And I still have chronic shortness of breath from exertion...You feel like you can't go outside because you're afraid to breathe the air.* – Mrs. Calloway

Eight out of 18 residents report health effects that could be related to the respiratory system. Mr. Valdez reported a rapid decline in his health over the last five years. The Valdez family lives just 600 feet from a large oil and gas facility. Mrs. Valdez explains her husband's symptoms and the decline in his health, which they notice worsens when he spends long hours outside:

> *He started getting sick with sinuses, headaches, dizziness, shortness of breath, everything. He goes outside, he can be okay for a little bit but there's a certain extent that he's gotta come back in because he gets shortness of breath has severe headaches things like that, he feels suffocated, can't breathe, he just starts to get sinuses congestion.* – Mrs. Valdez

Mr. Valdez reported a total of 12 health issues, some of which he experiences on a daily basis. Health care providers treat his symptoms but he has made trips to the hospital when his sore throat causes breathing trouble.

> *My throat was getting so tight, my mouth, my eyes were red. So he [the doctor] had to give me about three shots and three medications right away to get it under control. He said if it doesn't go away in thirty minutes we'll have to try something else. – Mr. Valdez*

The third highest in resident complaints was the immunological system, which was classified as allergy and sinus complaints. Seven out of 18 residents reported allergy and sinus complaints. Mr. Adams, noted that an increase in allergy issues was the first symptom he experienced shortly after a large facility was built near his home.

Mr. Adams: *I was in the hospital the four days with atrial fibrillation, they call it A-fib, where your heart is racing. Never had that before.*

Priscilla: *When did that happen?*

Mr. Adams: *Dec 5th, 2014. Before that I had a lot of allergy problems, I hardly ever had any of that. This little facility over here, I tried to get them to move it 300 feet west, there is nobody living in that direction for 15 miles or more. Our wind always blows this way, if they would have moved it over there and that wind came up it would have missed us, it wouldn't affect us or our neighbor at all. Sometimes you have some stink coming out of there. It smells to me like propane, but it isn't propane, they put something in that sour gas.*

Resident interviews did not reveal health complaints associated with renal, hepatic, and reproductive systems. However, most of the people we interviewed were over 40 years old and therefore may be unlikely to report reproductive symptoms. Renal and hepatic disorders may take longer to develop than respiratory or neurological symptoms and therefore not be experienced or reported yet. Also interviewees may have felt more hesitant to report symptoms associated with these systems due to social stigma.

However, the overlap of symptoms reported in the independent interview study and the predicted health risks to three organ systems by contaminants identified in air monitoring close to oil and gas facilities is concerning. These findings warrant further measures to prevent acute and chronic exposures for people 22

Cancer risk posed by detected pollutants

Additionally, we can estimate the overall increased cancer risk for the pollutants we detected, assuming residents were chronically exposed to the combination and levels of carcinogens we identified (see Appendix 2). This is a problematic estimate as the concentrations of carcinogens varied widely in our samples and the high peak levels detected mean that the average of the samples were quite high. This average concentration is unlikely to represent average air in Karnes that most people routinely breathe. Rather this estimate is probably relevant only for people living and working very close to facilities if the levels we identified were routinely emitted and inhaled.

If people breathed these concentrations of carcinogens routinely over a lifetime they would be at increased risk of developing cancer.

Overall, ten of the chemicals we identified were carcinogens: benzene, ethylbenzene, naphthalene, methylene chloride, chloroform, 1,2-dichloroethane, carbon tetrachloride, 1,1,2,2-Tetrachloroethane, 1,3-butadiene, and methyl tert-butyl ether. The levels of benzene and naphthalene were the most concerning because their high concentrations were primarily responsible for the increased cancer risk (see Appendix 2). If people were exposed to these concentrations of carcinogens routinely over a lifetime, then the overall risk of cancer to people routinely breathing such concentrations would be 55 times (2,200 in 1 million) the national average (40 people in 1 million).

Conclusion & Recommendations

Our air tests detected multiple hazardous chemicals close to oil and gas facilities, at multiple times in multiple locations, in and around Karnes County. The concentrations detected could exceed chronic regulatory thresholds established by either, or both, the EPA and TCEQ to protect public health – assuming that the detected concentrations represent normal or chronic exposure. We also detected some pollutants that, under the same assumption, could exceed acute (shorter term exposure) thresholds such as: n-Hexane, benzene (a carcinogen), xylene and cyclohexane.

Our results represent a snapshot in time because they are grab samples. For this reason, we cannot definitively say whether the concentrations we detected were representative of the air that community members breathe on a daily basis. The concentration of chemicals at the testing locations at other times could be higher or lower than what we detected. However, our samples were taken, to the best of our knowledge, during normal operating conditions.[135] Additionally, since we could not sample within the center of emission plumes (as they passed over the heads of researchers), it is unlikely that the concentrations we detected represent the highest levels of contaminants in those plumes. Our samples should be thought of as snapshots of what a person could breathe at the testing locations. Taken together, these snapshots suggest that people breathing such air continuously over extended periods of time may be at an increased risk for cancer and harm to their neurological (brain and nervous system), respiratory (throat and lungs), and immunological systems (the body's system for defending against disease).

Interestingly, residents in the independent health study conducted at the same time as the air sampling reported health symptoms associated with those three systems. This overlap raises the question of whether their illnesses might be related to exposure to chemical mixtures similar to those identified in our air samples.

Additionally, resident interviews revealed very similar health issues among participants along a very similar timeline. The most alarming component for residents was the rise in occurrence and severity of their health issues. Headaches for example, reported by 12 residents, were experienced by some residents several times a week. According to the World Health Organization (WHO), headaches occurring 15 or more days a month affect only 1.7-4% of the world's adult population.[136] The corroboration of residents' health complaints with the air test findings is concerning. Further monitoring and potential regulatory actions should be taken to protect residents' health.

> *We are the ones that know, we are the authorities on our lives, you who do not live in our circumstances can never fully understand.* – Luke

The profile of symptoms reported in this community is similar to the profile of symptoms reported in other communities impacted by UOGD.[137] A study conducted in collaboration with Earthworks on health outcomes associated with UOGD in Pennsylvania found communities reporting very similar health effects as those in this study.[138] This further supports the argument that these symptoms may be related to exposure to air emissions from UOGD and suggests that other communities might be exposed to profiles of contaminants similar to those in our samples.

The compounds we identified have been reported in other studies on emitted pollutants by oil and gas facilities. This suggests that our measurements are not unique, but may be characteristic of emissions from oil and gas facilities such as drip stations, central collection facilities, and injection wells.[139] Other studies in Texas identified benzene and xylene as specific concerns from oil and gas point sources with significant spikes of benzene levels in Karnes County.[140] Moreover, scientists found higher levels of BTEX and VOCs in Karnes than in places surrounded by highways.[141]

Further research is required to assess:

1) **Whether the levels and combinations of compounds we identified are characteristic and routinely emitted by the facilities adjacent to our testing locations.**

2) **How frequently people are exposed to such emissions.**

Conducting such studies would take more time and money. For example, these preliminary studies were conducted in 2015, yet it has taken a year and half to analyze and report these findings. During the time it takes to conduct further studies, more people could be exposed to pollutants and become sick. Additionally, future studies designed to answer questions 1 and 2 above would still be unable to prove whether or not people's illnesses were due to exposures.

Science cannot prove direct causation between an individual's illness and an exposure event (unless the effects are immediate and acute); instead, long term epidemiological studies are used to make correlations between the rate and types of illnesses and chemical exposures. Such epidemiological studies statistically compare the illnesses experienced by exposed populations to non-exposed populations. From a community perspective, these studies have many problems:

- They require large numbers of people (this can be hard to achieve in rural areas).
- They work best when they look at only one illness or chemical, but communities frequently experience many different health effects from exposures to complex mixtures and doses of chemicals.
- Most importantly, epidemiological studies cannot prevent health impacts in studied populations as they are limited to studying either the rate of illnesses as they occur or after they have occurred.

Communities living amid oil and gas development are stuck in a vicious cycle. It is very difficult, if not impossible, to prove that individual health outcomes are caused by specific exposure events. Yet, regulatory and legal systems frequently demand such scientific proof in order to take action. We live in a system where the onus to prove harm is on exposed communities, yet we do not have the scientific methods to track individual chemical exposures or predict individual health outcomes.

Because of this inequality and the absence of adequate research studies and methods, studies such as this one are even more important because they compare individuals' reported experiences with the health effects of chemicals identified in their air. Unfortunately, we cannot statistically estimate the probability that the two studies in this report converge in order to assess the probability that two independent studies' results would converge in this manner. However, we can say that when exposed communities report symptoms predicted from the chemicals detected in air samples from potential sources of contamination, reasonable actions should be taken to prevent potential harm to health, in addition to pursuing further research.

Recommendations

Our overarching recommendation is that the TCEQ should act to protect the health of Karnes area residents by ensuring that they are not exposed to chemical mixtures, such as those we detected, and that pollution is not in violation of federal and state guidelines. Furthermore, federal and state regulations that prioritize protecting public health over short term economic gain need to be established.

In order to protect Karnes residents, the TCEQ needs to take concrete steps to demonstrate that it is willing to prioritize public health ahead of oil and gas operator financial interests.

Adequately monitor the air. In contrast to the current situation, where there is inadequate monitoring, TCEQ needs to increase monitoring of air pollution from oil and gas operations in Karnes and throughout the Eagle Ford Shale region. As a state agency, TCEQ should establish a standard methodology for choosing the type, number, and location of air monitors given the existing and predicted oil and gas development they are intended to monitor. Further, TCEQ should transparently explain its methodology, and hold regional public hearings seeking public input on and providing public explanation for its proposed application of that methodology in that region. We recommend that TCEQ seek input from air quality experts with experience in emerging methods of real-time mobile monitoring.

Transparently report air monitoring results. As with its existing monitors, the new monitors should dynamically report online information so that scientists, regulators, operators, local government, and the public can easily access data in real-time and in aggregate.

Encourage Karnes residents to participate in their own protection. TCEQ staff, even with adequate resources, cannot be everywhere at all times. Karnes residents, however, live in the area and also have strong incentives to ensure that oil and gas facilities operate in a manner that protects the general public health and their own health, specifically. TCEQ should collaborate with concerned residents by establishing standards and procedures that encourage residents to share their concerns about polluting facilities and make it easy for residents to follow up on their cases.

Commission an independent health study of Karnes residents. Our mutually reinforcing air study and resident interview study strongly suggest that Karnes residents could be suffering from exposure to threatening levels of air pollution from oil and gas development. TCEQ should conduct a thorough independent and peer-reviewed follow up study to assess oil and gas emissions and exposures.

Create a credible enforcement system to prevent future and repeated air emissions violations. Numerous investigations by news and civil society organizations reveal that Texas regulators only warn oil and gas operators[142] (so as to avoid having to sanction[143] operators), punish regulators[144] when they try to protect the public at the expense of oil and gas operators, and otherwise fail[145] to protect public health.[146,147] The TCEQ must begin to demonstrate that it prioritizes public health ahead of oil and gas operator financial interests in order to uphold its mission of protecting the public.

Appendix 1:
Air Test Results by Company and Location

Our results can be analyzed by the location of the grab sample in relation to the emissions source of interest. We think it is important to report the data in this way because it is a first step toward identifying chemical footprints for the different facilities involved in oil and gas production.[148] Also it is important to consider the emission footprint of oil and gas companies as a whole. For instance, we found hazardous chemicals in grab samples taken downwind of two Encana facilities. Encana is the company whose well blew out in Karnes County in 2015 (see photo in the Introduction).[149] Encana facilities in particular should be reviewed for their emissions.

Encana Corporation

(SUMMAs® #4:L5518 at Kotara-Ridley Drip Station and #1: L5514 at Encana Loves/Crews):

The Encana Corporation owns two of the sites next to the public roads where we took our SUMMA® samples: the Kotara-Ridley Drip Station and Encana Loves/Crews Central Production Facility. At both testing locations we found levels of benzene, a cancer-causing agent, that would exceed regulatory thresholds set by TCEQ and EPA if emissions were to continue over time at the same level we found.

Two families reporting health impacts live within a 1 ½ mile radius of the Encana Corporation sites may be in a position to experience chronic exposures as defined by TCEQ and EPA and have experienced health problems including headaches and difficulty breathing since oil and gas development intensified in the area.

Encana Kotara-Ridley Drip Station

At Kotara-Ridley Drip Station, natural gas is transported from wells through pipelines, cooled, and then deposited into a high-pressure chamber that separates the gas from its condensate (see figure next page).[150]

Condensate contains impurities such as hydrogen sulfide gas and the heavy hydrocarbons propane, butane, pentane, and hexane. In the first high-pressure chamber, water separates from the gas and then the remaining condensate is released into another chamber. The gas in the high-pressure chamber moves to a gas compressor and then into a pipeline to a natural gas processing plant. Since the condensate has not been fully separated, it moves to a low-pressure separator that further separates out gas and water. The condensate is then transported to an oil refinery or harvested for other uses such as motor fuel made by propane or lighter fluid containing butane.

Figure 38 at right: Encana Kotara-Ridley Drip Station.

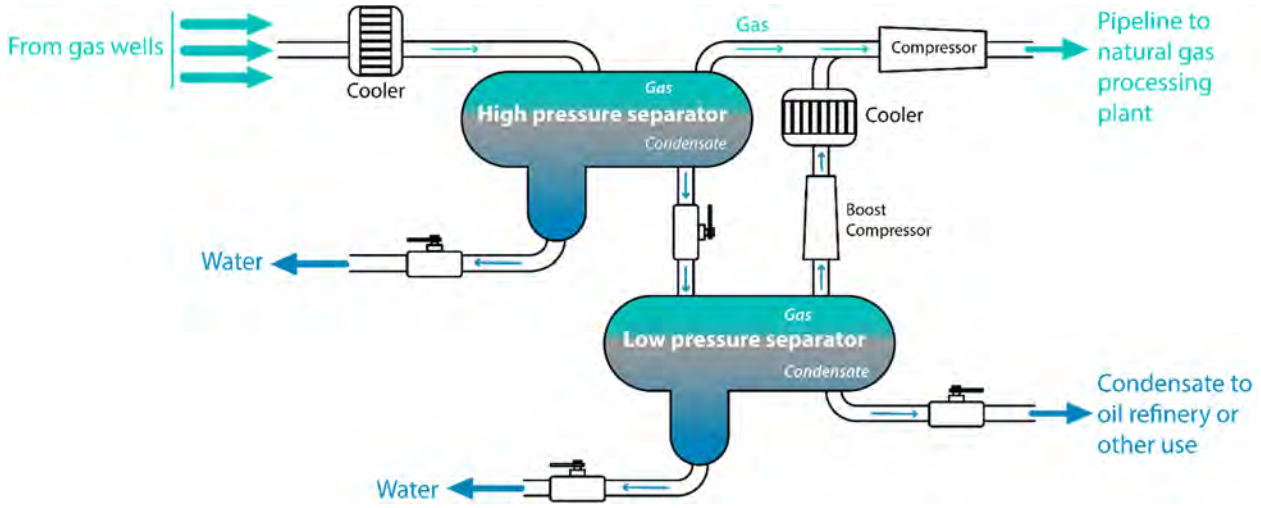


Figure 39. How a drip station works. Diagram inspired by Wikipedia Commons diagram.[151]

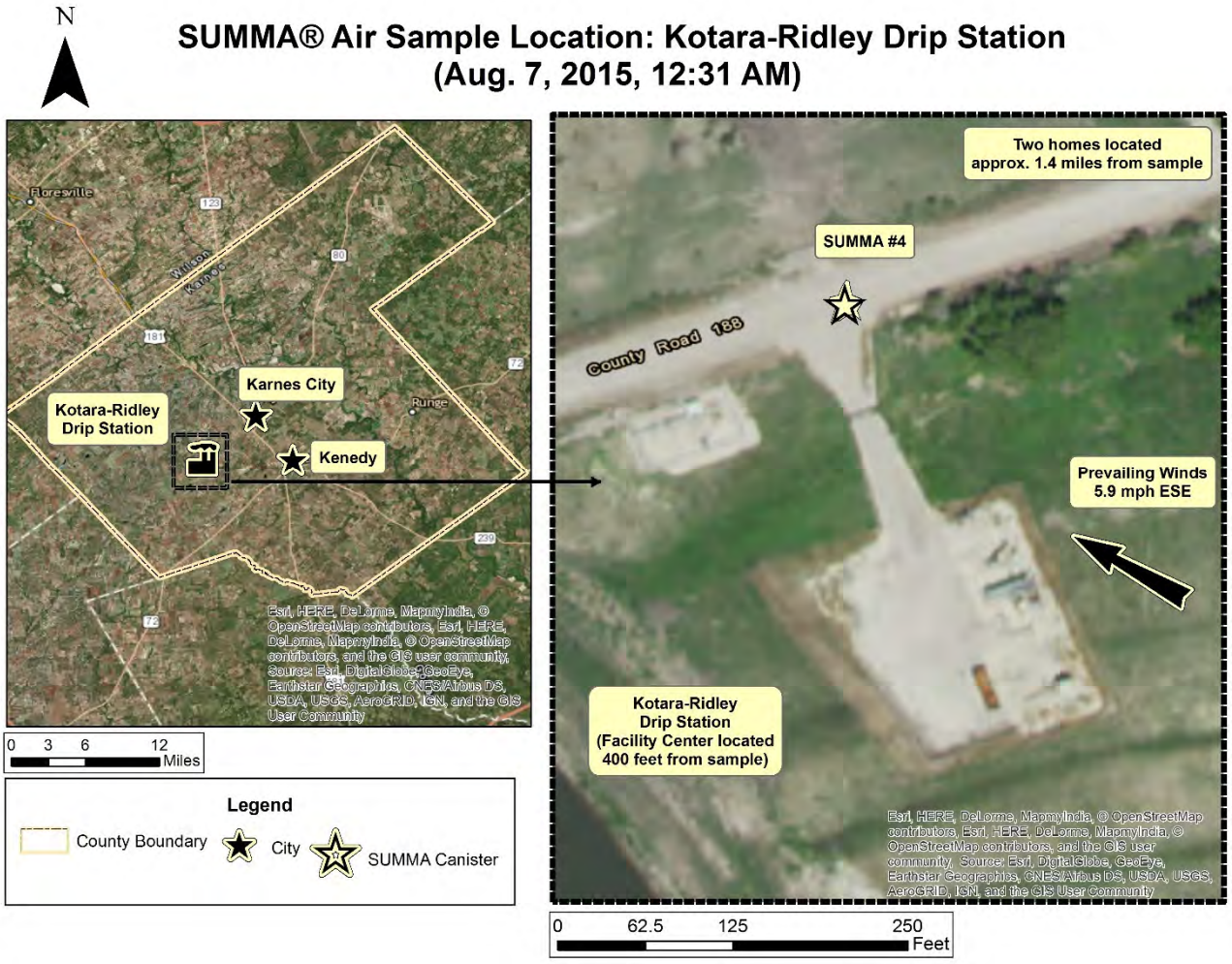


Figure 40. Air sampling location at Kotara-Ridley Drip Station.

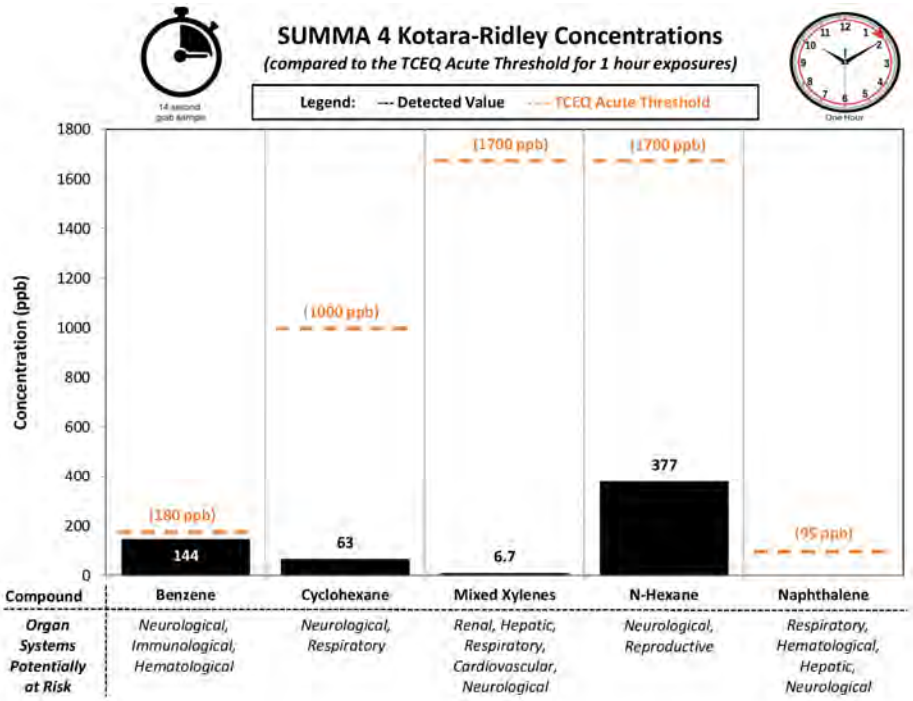


Figure 41. Kotara-Ridley Drip Station Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios.

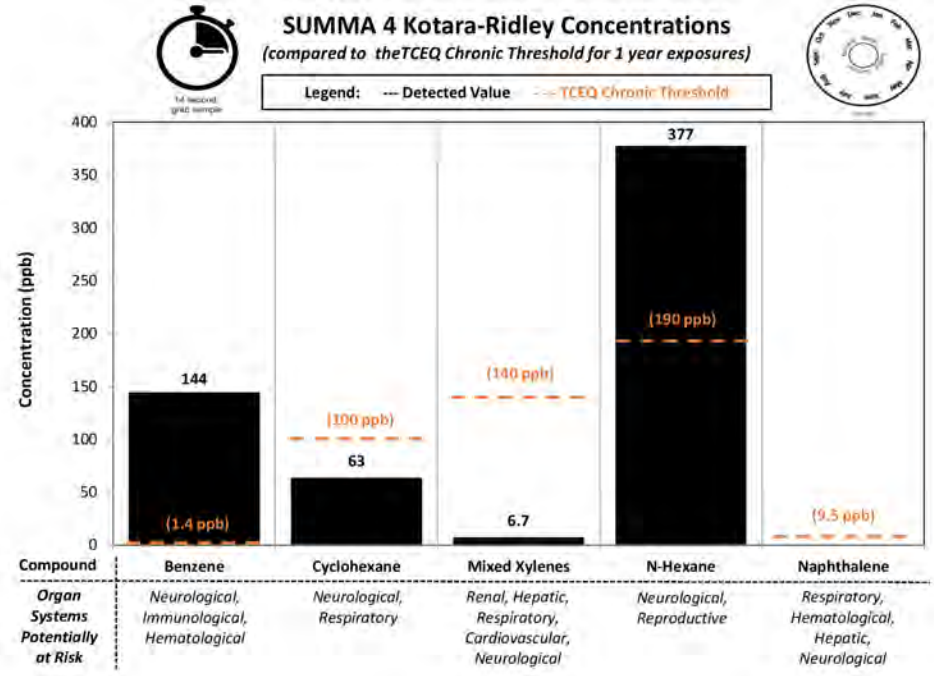


Figure 42. Kotara-Ridley Drip Station Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios.

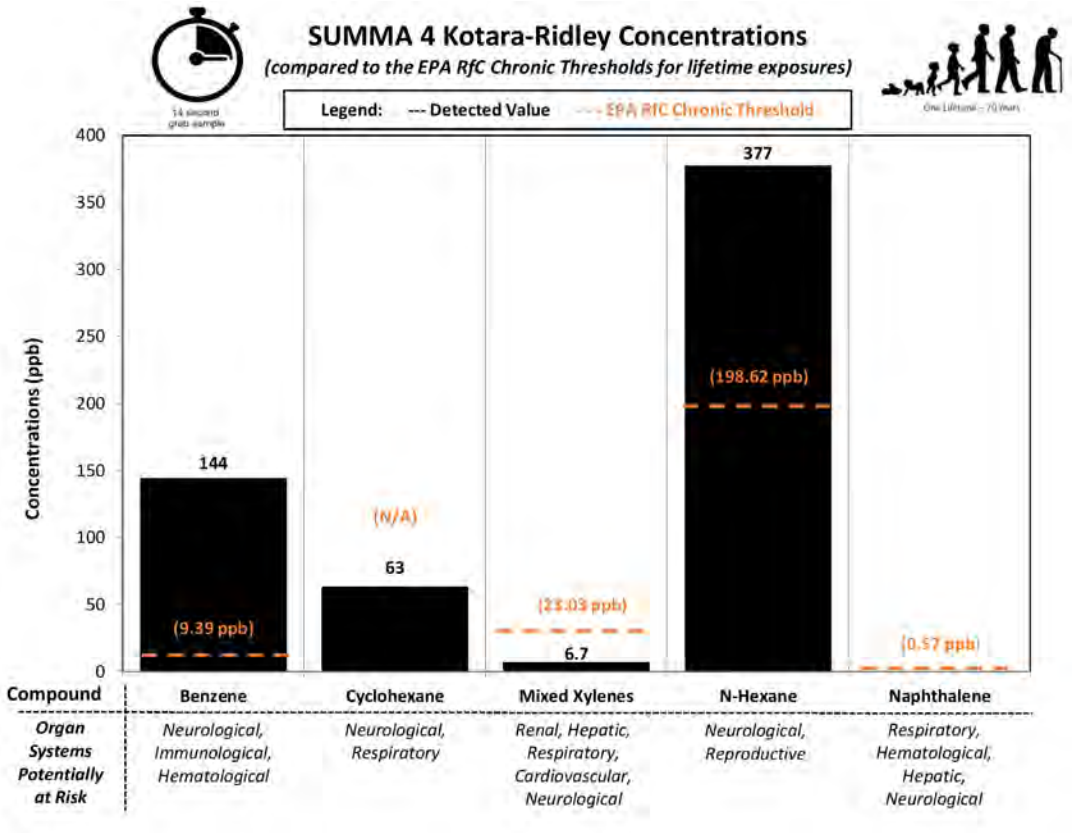


Figure 43. Kotara-Ridley Drip Station Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

Figure 44. Images taken by an Earthworks certified operator show Kotara-Ridley Drip Station facility in Karnes County as seen with the naked eye and as seen with the Optical Gas Imaging camera.

The compounds that we found on a public road 545 feet north northeast and downwind from the center of the site are common impurities in condensate or, like benzene, are naturally occurring components of gas: n-Hexane, benzene, cyclohexane, and mixed xylenes.

The level of benzene at 144 ppb would dangerously exceed the EPA's recommended short-term exposure threshold of 9.39 ppb if emissions continued at the level we found. This level would be 143.6 ppb over the long-term limit set by the TCEQ and close to the acute threshold of 180 ppb if emissions were to continue. When researchers from Earthworks visited this site in 2013, there was 28 ppb of benzene in the SUMMA® sample they took.[152] The average level of these two samples taken two years apart, 86 ppb, would violate the TCEQ chronic threshold of 1.40 ppb a year.

The SUMMA® sample contained 377 ppb of n-Hexane, which would be almost double the reference concentration for chronic exposure of 198.62 ppb set by the EPA if this level persisted. We also found cyclohexane at 63 ppb; however there is no RfC set by the EPA for cyclohexane.[153] Freon 11 was measured at 0.6 ppb and can cause skin and respiratory irritation but does not have reference concentrations set by the EPA.[154] As a type of chlorofluorocarbon that depletes the ozone layer, Freon 11 was banned in 1990 by the Clean Air Act.

Encana Loves/Crews Central Production Facility

The results of our sample taken downwind of Encana Loves/Crews are described within the report in the section titled "Acute Risks from Chemical Mixtures".

Marathon Oil

We took a total of three air samples on public county roads adjacent to two facilities, Marathon West Sugarloaf Commingle and Marathon Sugarhorn Central Collection Commingle, owned by Marathon Oil, and identified potentially concerning levels of pollutants. Marathon Oil has been operating in the Eagle Ford play since 2011 and holds approximately 180,000 net acres as of 2014.[155] Other sites, including Marathon East Longhorn and Marathon East Sugarloaf, were also identified as common sources of emissions by community members.

Marathon West Sugarloaf Commingle

One sample at Marathon West Sugarloaf Commingle was taken during the daytime, 744 feet downwind from the center of the facility (see following page). The other sample, taken outside Marathon West Sugarloaf, was during the nighttime and 428 feet upwind from the site since the field researchers were attempting to capture emissions from the nearby impoundment pit (see on the following pages).

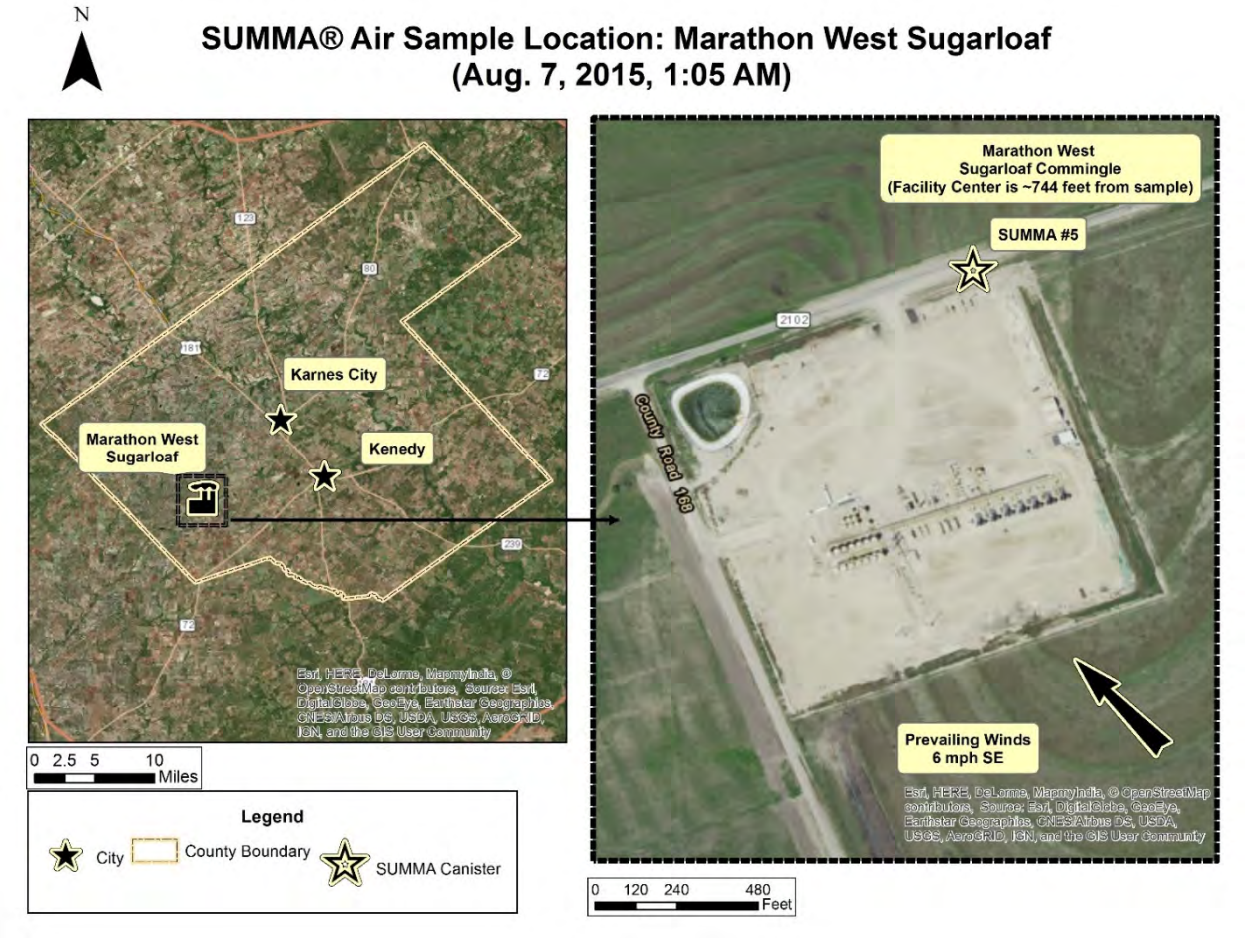


Figure 45. SUMMA® Sample #5 location at Marathon West Sugarloaf.

Figure 46. Marathon West Sugarloaf comingle facility

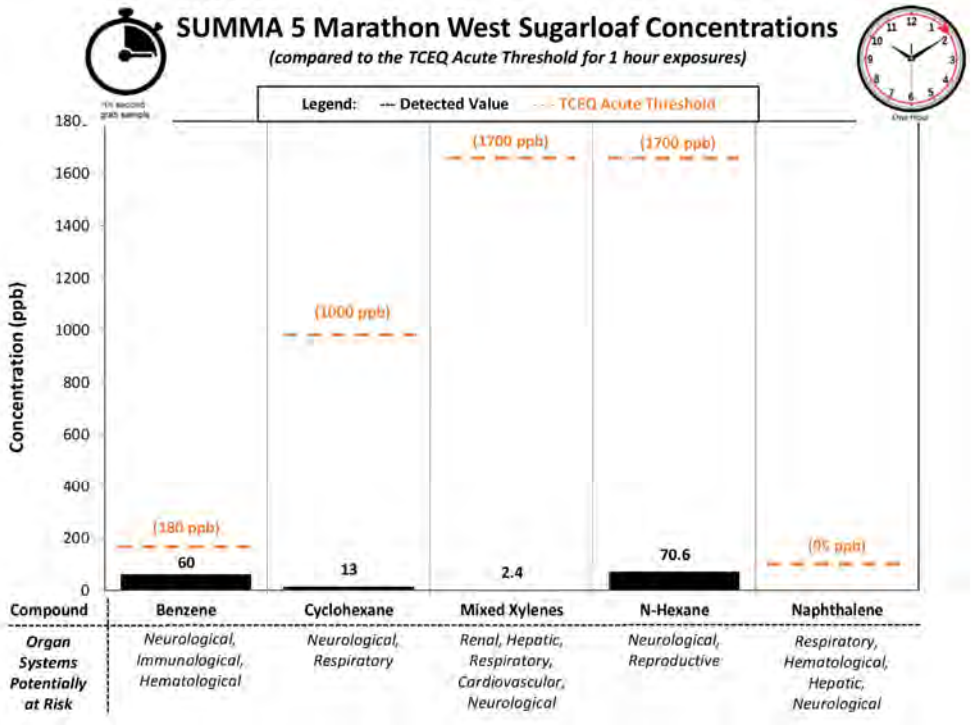


Figure 47. Marathon West Sugarloaf Acute Exposure Scenario: SUMMA® Sample concentrations compared to acute TCEQ exposure scenarios.

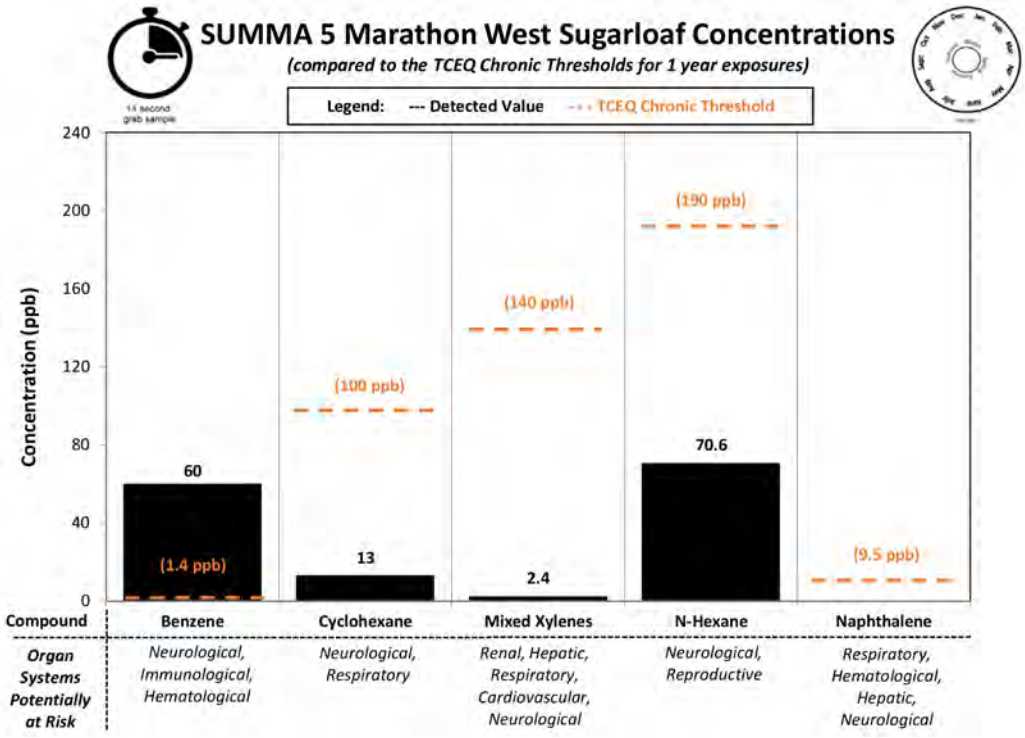


Figure 48. Marathon West Sugarloaf Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios.

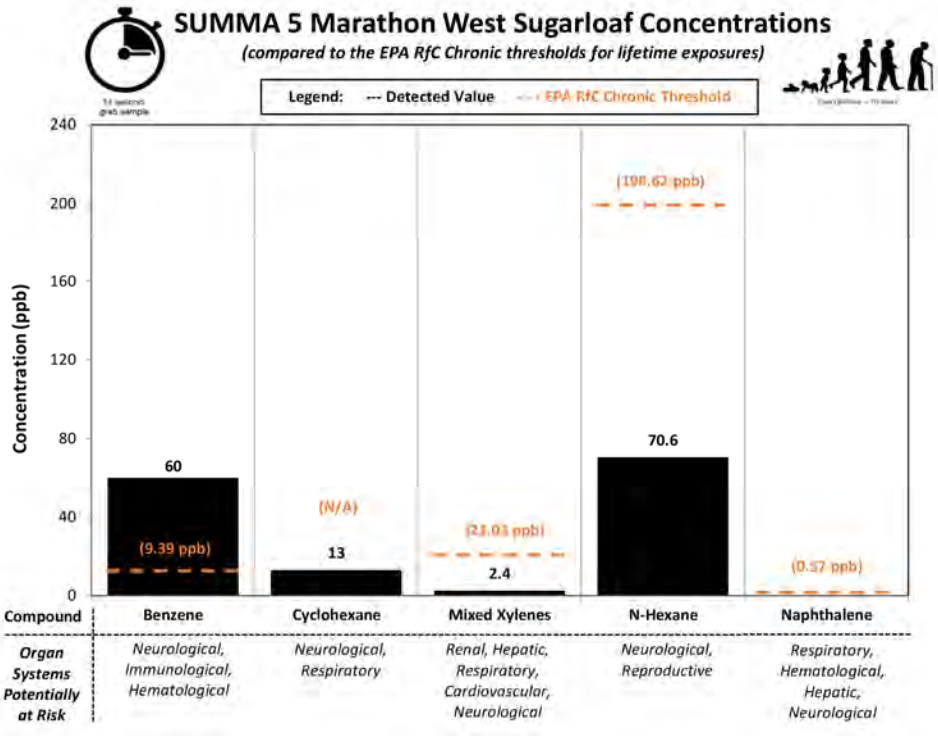


Figure 49. Marathon West Sugarloaf Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

At a commingle facility, fluids such as oil, gas, or condensate are piped in from other production sites and mixed together into their respective storage tanks or holding facilities. Researchers noticed a pipe discharging facility water into a nearby impoundment pit. They noticed a strong smell of gas, stains on the liner of the pond, and a corroded tank and pipe. Hydrogen sulfide, a known corrosive compound, was measured at 1.91ppm with the team's Jerome meter.

The SUMMA® canister sample taken here on August 7th contained 16 compounds, including 60 ppb of carcinogenic benzene, for which many scientists agree that there is no safe level. While this concentration would not exceed TCEQ's acute threshold for an hour long exposure, if this level were to persist over an individual's lifetime, it would be almost six times the EPA RfC of 9.39 ppb. Mixed xylenes were also found at 3.62 ppb and n-Hexane at 70.6 ppb. Chemicals found that do not have established RfCs but have known health effects were: propene (457 ppb), ethanol (121 ppb), Freon 11 (1.3 ppb), ethyl methyl ketone (4.6 ppb), and cyclohexane (13 pbb).

Figure 50. Images taken by an Earthworks certified operator show the Marathon West Sugarloaf Commingle Facility with the waste pit in Karnes County as seen with the naked eye and as seen with the Optical Gas Imaging camera.

Considering the strong gas odors and corrosion present at this site, the team returned two weeks later to collect another SUMMA® sample in the same location, during the night, and under similar weather conditions. There have been noted differences between contaminant levels at nighttime and daytime, which have been documented in studies such as that by Brown et al.[156] Exposure levels can increase during the night because of decreased air column mixing, and residents are more likely to open the window at night while sleeping, not realizing the extent of their exposures.[157] As we took our samples during the summer, we likely did not capture the worst pollution levels that would presumably occur during inversions. Inversions occur more frequently during fall and winter months when warmer air higher in the atmosphere traps the dense, cooler air and the pollutants it contains closer to the earth's surface.[158] More extensive research should systematically look at air quality near oil and gas facilities at different times of year and different times of day.

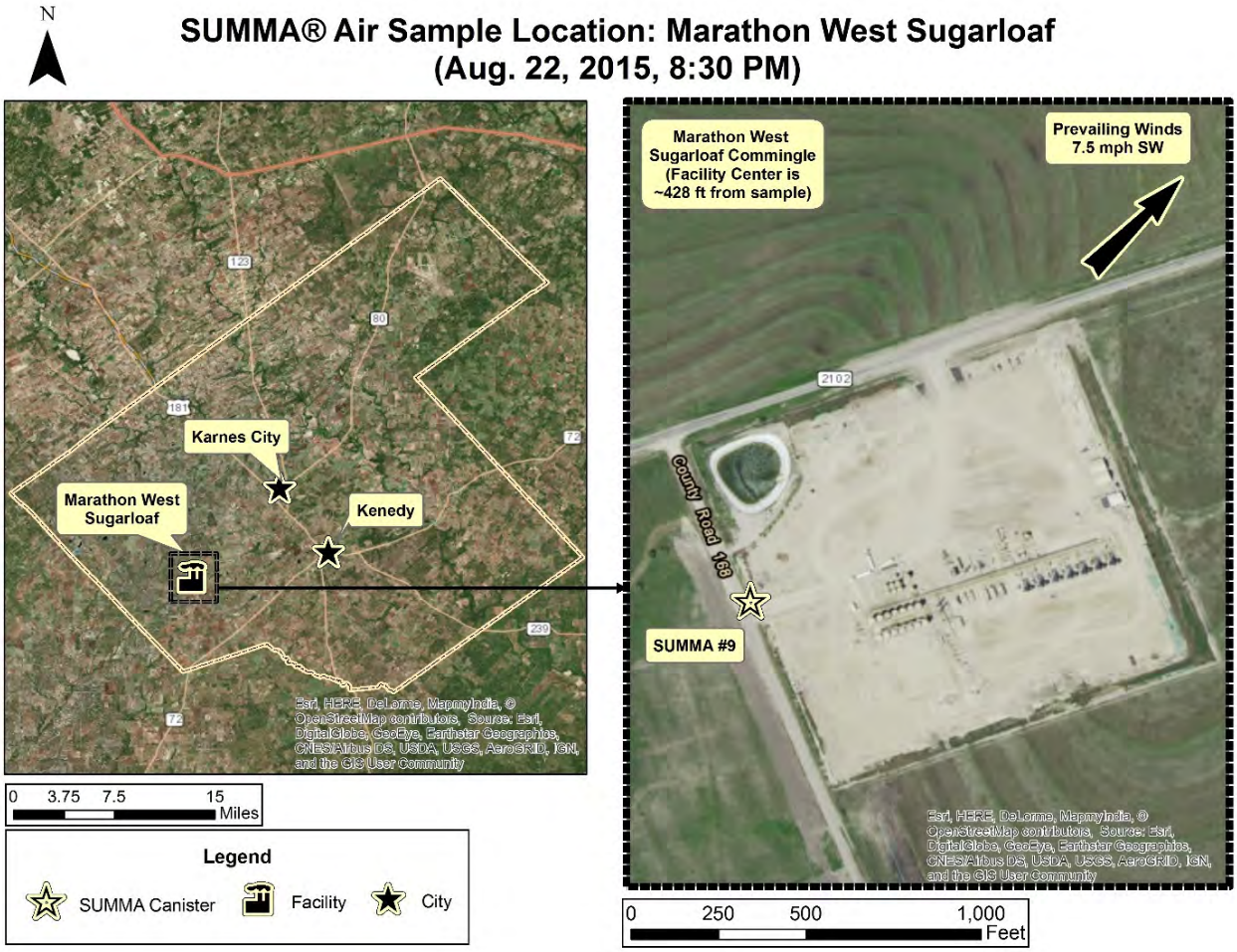


Figure 51. SUMMA® sample #9 location at Marathon West Sugarloaf.

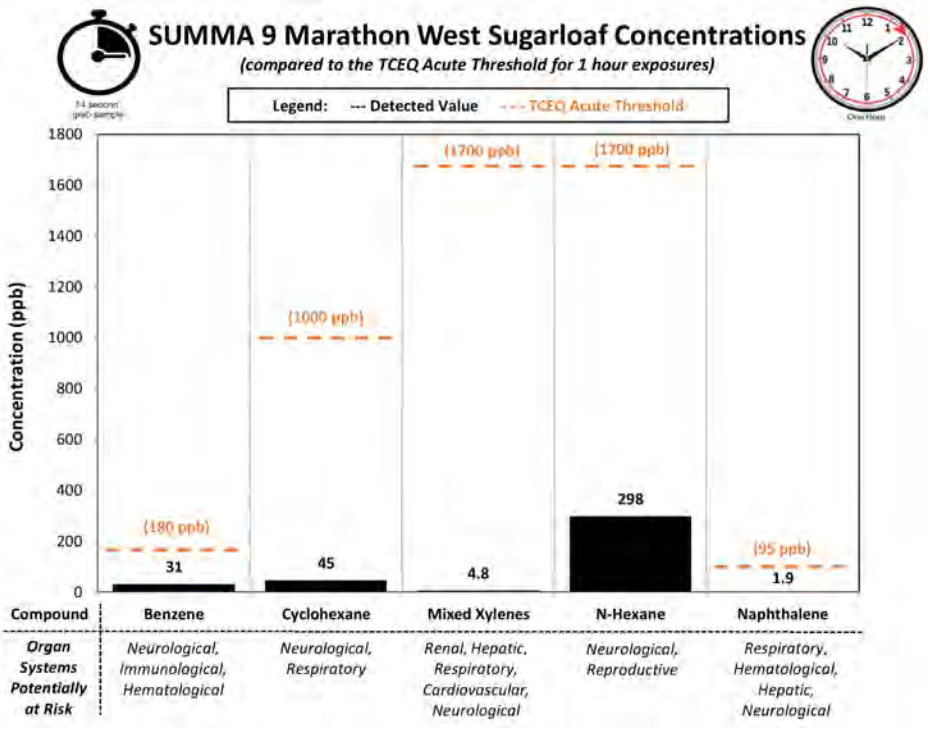


Figure 52. Marathon West Sugarloaf Acute Exposure Scenario: SUMMA® sample #9 concentrations compared to acute TCEQ exposure scenarios.

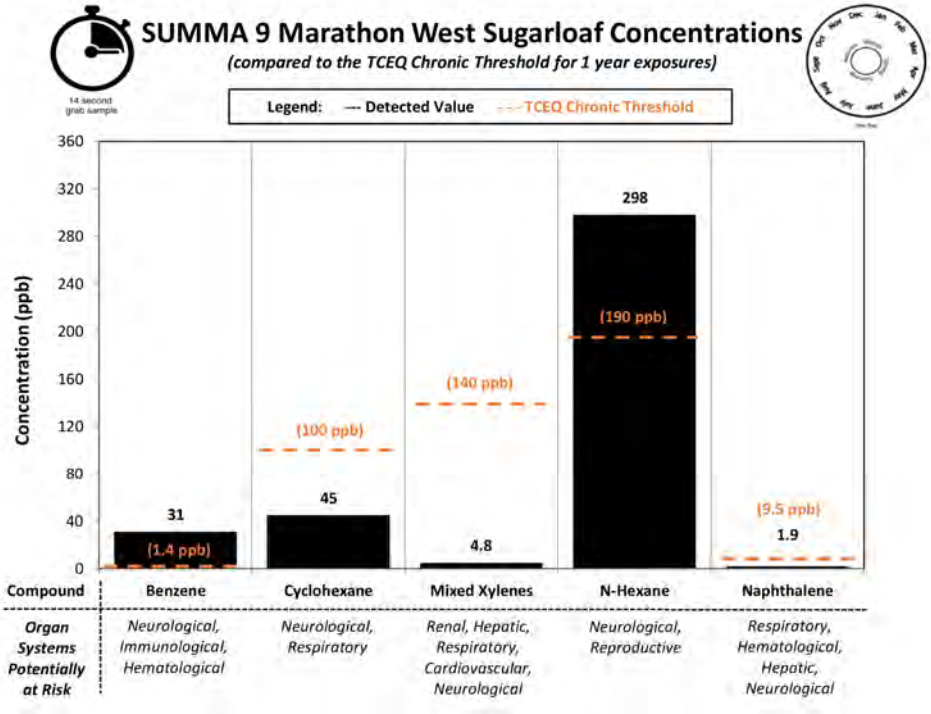


Figure 53. Marathon West Sugarloaf Chronic 1 Year Exposure Scenario: SUMMA® sample #9 concentrations compared to chronic TCEQ exposure scenarios.

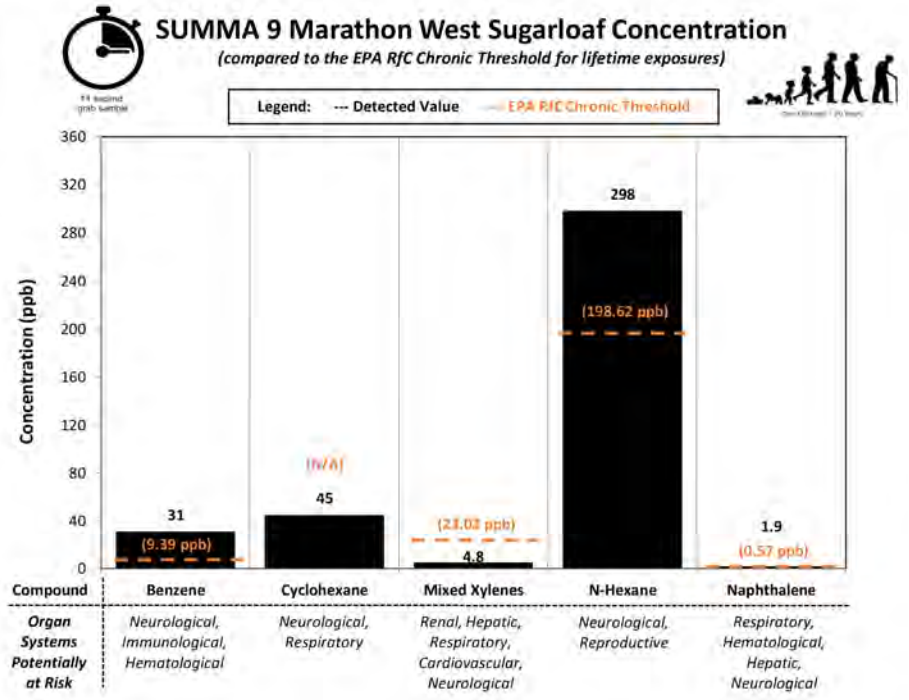


Figure 54. Marathon West Sugarloaf Lifetime Exposure Scenario: SUMMA® sample #9 concentrations compared to chronic EPA exposure scenarios.

Based on our night-time sample, pollutant concentrations at Marathon West Sugarloaf would not exceed TCEQ acute thresholds (though the concentrations may have been lower because this sample was taken upwind). However, 29 compounds were detected in this sample while 16 were detected in the previous sample taken outside Marathon West Sugarloaf during the day. Moreover, multiple flares and vents were observed through FLIR OGI camera technology at the facility both at night and during the day. Researchers found a similar array of compounds at night, as during the day, including benzene at 31 ppb, which if persistently emitted would be orders of magnitude greater than the RfC of 9 ppb. Levels of naphthalene (1.9 ppb) and n-Hexane (298 ppb) would also exceed the EPA RfCs by 3.33 times and 1.5 times, respectively. There was also a higher level of mixed xylenes at 6.86 ppb. As for chemicals without established RfCs, we also found propene (30 ppb), ethanol (490 ppb), Freon 11 (0.8 ppb), and cyclohexane (45 ppb). One other compound we found that was not present elsewhere was isopropyl alcohol at 2.6 ppb which is used as a solvent for oil mud.[159] Another chemical we found was 1,3-butadiene at 0.7 ppb, approaching its RfC of 0.9 ppb.

Even though the SUMMA® samples only measure the contaminant in the air at a given time and location, the fact that we found a similar set of hazardous compounds two weeks later that exceeded reference concentrations in both cases, suggests that residents living close to this facility might be at risk of chronic exposures to these chemicals as it suggests that they might be routinely emitted. For example, 31 ppb of benzene was found on the second visit and 60 ppb of benzene on the first. Both results would fall above regulatory thresholds if these levels are consistent over time. Long-term sampling is necessary to ensure that nearby residents are not continuously exposed to high levels of these hazardous compounds.

Marathon Sugarhorn Central Collection Commingle

Marathon Sugarhorn is 1.31 miles from one home where residents report health effects and 1.82 miles from another home where residents report health impacts, and a ¼ mile from the closest home. High levels of VOCs have been measured at this facility previously, including June 15, 2012 when TCEQ measured 132 ppm of total VOCs with a Toxic Vapor Analyzer and determined the levels were too high to safely test using a SUMMA® canister.[160] In March 2014, atmospheric scientist Gunnar Schade noticed a relatively high spike in air pollutant levels on a TCEQ monitor 22 miles north of the site in Floresville.[161] According to his plume dispersion model that takes distance and wind direction into consideration, he concluded that the high levels of hydrocarbons at the site of emission could have been 100-1,000 times more than what the monitor measured in Floresville. He hypothesizes that the hydrocarbons emitted at Marathon Sugarhorn likely exceeded several TCEQ thresholds for VOCs such as benzene, hexane, ethene, propene, and other compounds such as acetylene and NOx.

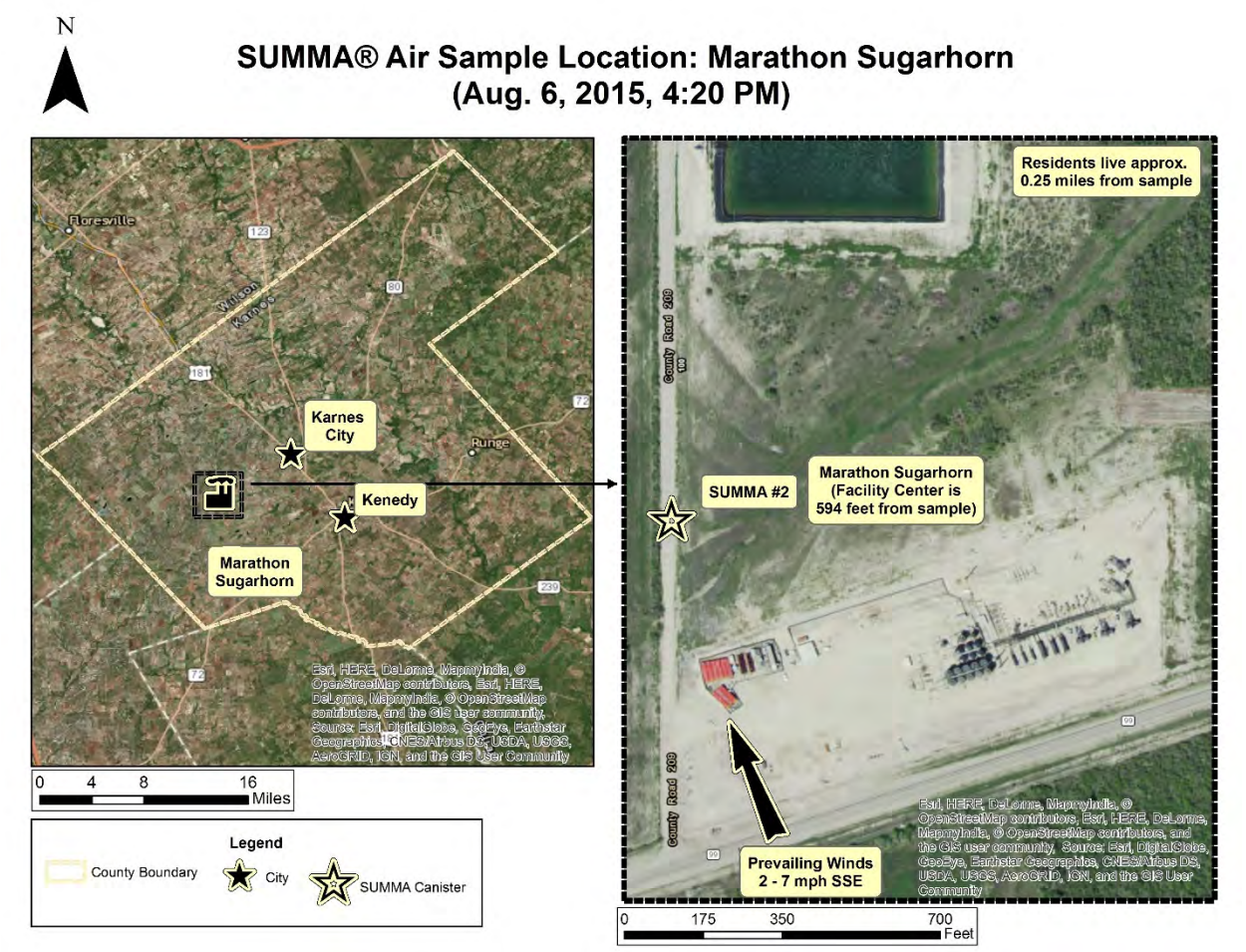


Figure 55. SUMMA® sample location at Marathon Sugarhorn.

Figure 56. Still image of FLIR OGI video taken on March 7, 2014, showing Marathon Sugarhorn emission event that spiked a TCEQ air monitor 23 miles away. This emission event stretched over the course of three days, and during this time FLIR images were taken at Marathon Sugarhorn showing a plume emerging from equipment on site and travelling north towards Floresville.[162]

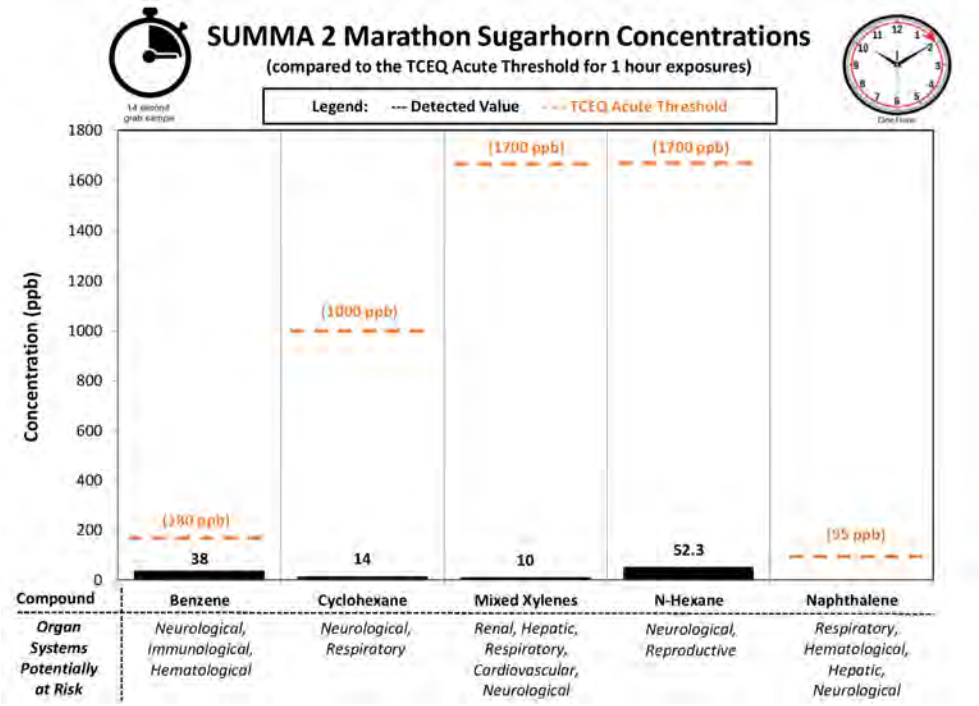


Figure 57. Marathon Sugarhorn Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios.

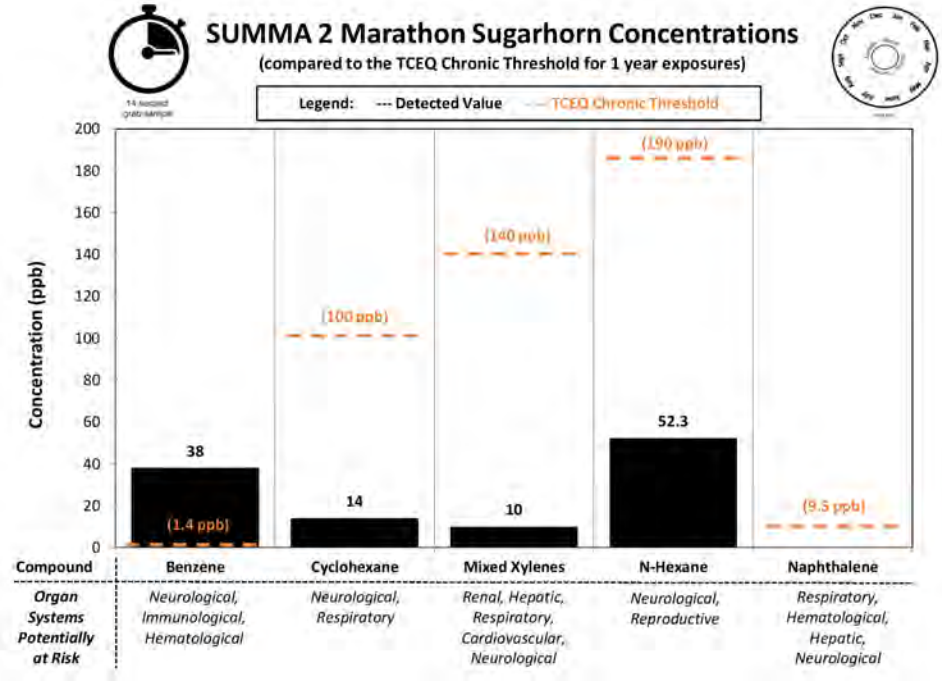


Figure 58. Marathon Sugarhorn Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios.

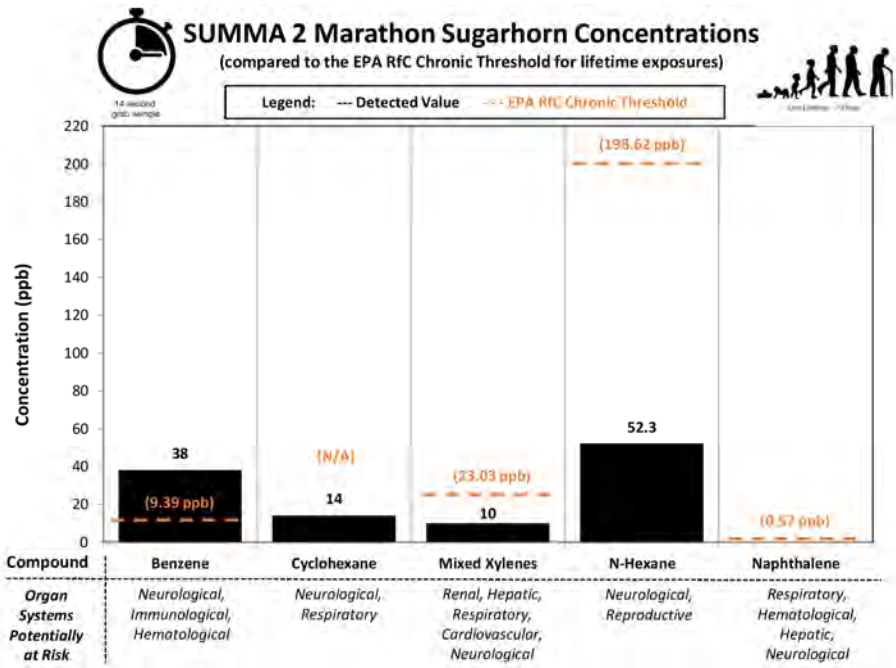


Figure 59. Marathon Sugarhorn Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

Figure 60. Marathon Sugarhorn Central Collection Facility in Karnes County as seen with the naked eye.

The sample taken at Marathon Sugarhorn was approximately 594 feet downwind from the center of the site We found 38 ppb of benzene, which would exceed the reference concentration of 9.4 ppb if these levels were consistently emitted. Fourteen ppb of cyclohexane was present, along with 15.37 ppb of mixed xylenes and 14 ppb of propene, both of which have established health effects but lack reference concentrations from the EPA.

Disposal wells

We detected concerning levels of pollutants in samples taken close to two disposal wells: EnAqua Cat-Kenedy Disposal Well and NGL Water Solutions.

EnAqua Cat-Kenedy Disposal Well

EnAqua Disposal Well receives wastes, primarily saltwater, from oil and gas production for "disposal" underground via reinjection. When the waste arrives by truck it is treated with chemicals that remove H_2S. The waste is then further separated into oil and salt water. The saltwater is reinjected at an injection well 1.5 miles away.[163]

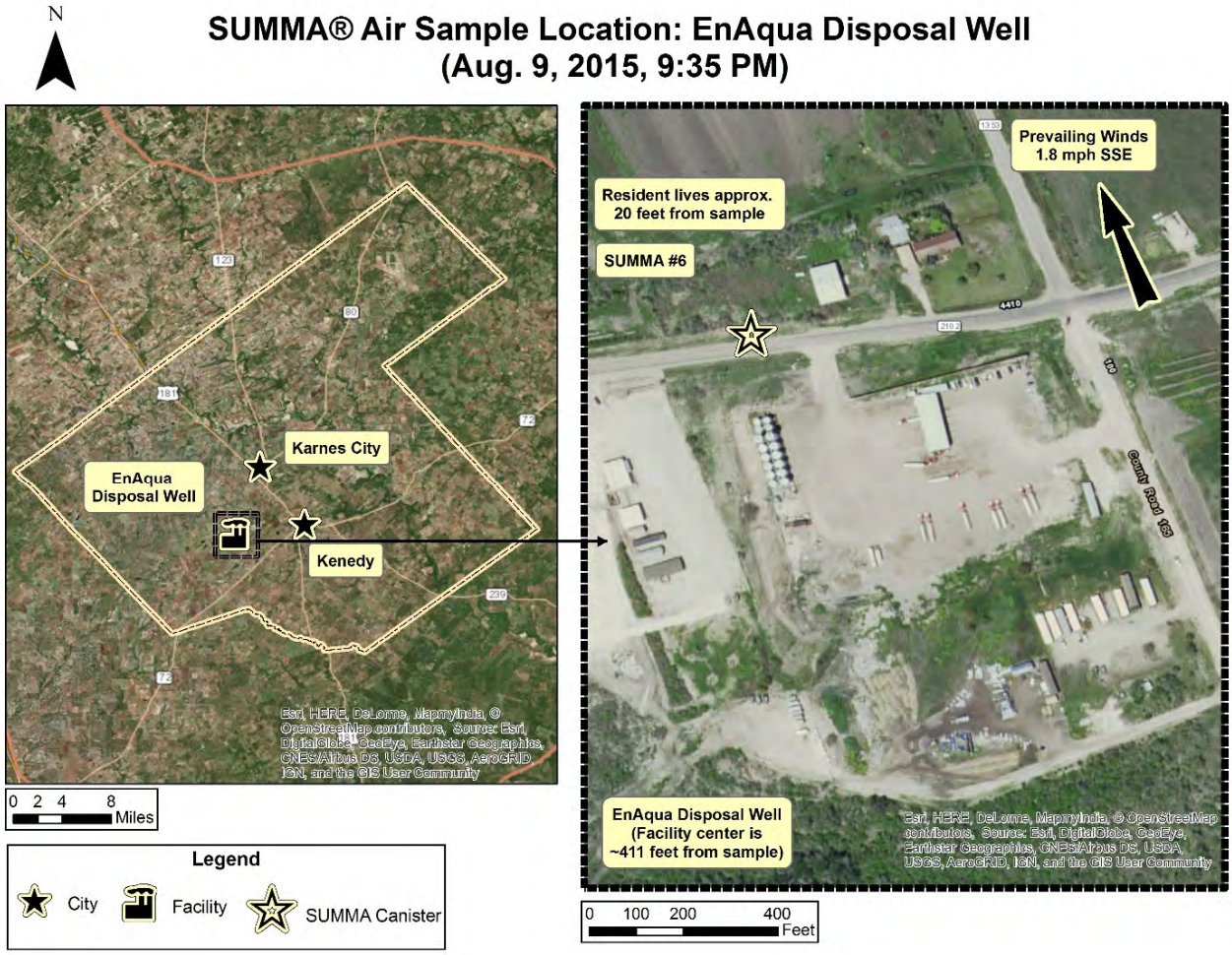


Figure 61. SUMMA® sample #6 location at EnAqua Disposal Well.

Our air sample, taken on public roads 420 feet north northeast from the center of this location, found 30 different chemical compounds. Of these 30 chemicals, we identified concerning levels of benzene and n-Hexane that would either meet, or exceed, TCEQ short and long-term exposure thresholds if emissions persisted. Emissions from this location are clearly visible in FLIR OGI camera videos taken at night.

Figure 62. Images taken by an Earthworks certified operator show EnAqua Saltwater Disposal Facility in Karnes County as seen with the naked eye and as seen with the Optical Gas Imaging camera.

A Karnes area resident lives only 200 feet from the disposal well and endures frequent chemical exposures. A report conducted by the TCEQ shows that an air quality test taken across the street from his house registered 88 ppb of benzene. They also found up to 6,564 ppb of other VOCs.[164] Additionally, Earthworks staff filed a facility complaint to the TCEQ over the course of the air sampling fieldwork for this study. This complaint included FLIR OGI video recorded on August 6, 7, 9, and 23, 2015, using an optical gas imaging camera. The videos on each date show a dense plume of emissions coming from what appears to be a malfunctioning tank thief hatch. The emissions are seen traveling far outside the fenceline of the facility and onto the property across the street. A highly offensive petroleum odor was detected on each day.

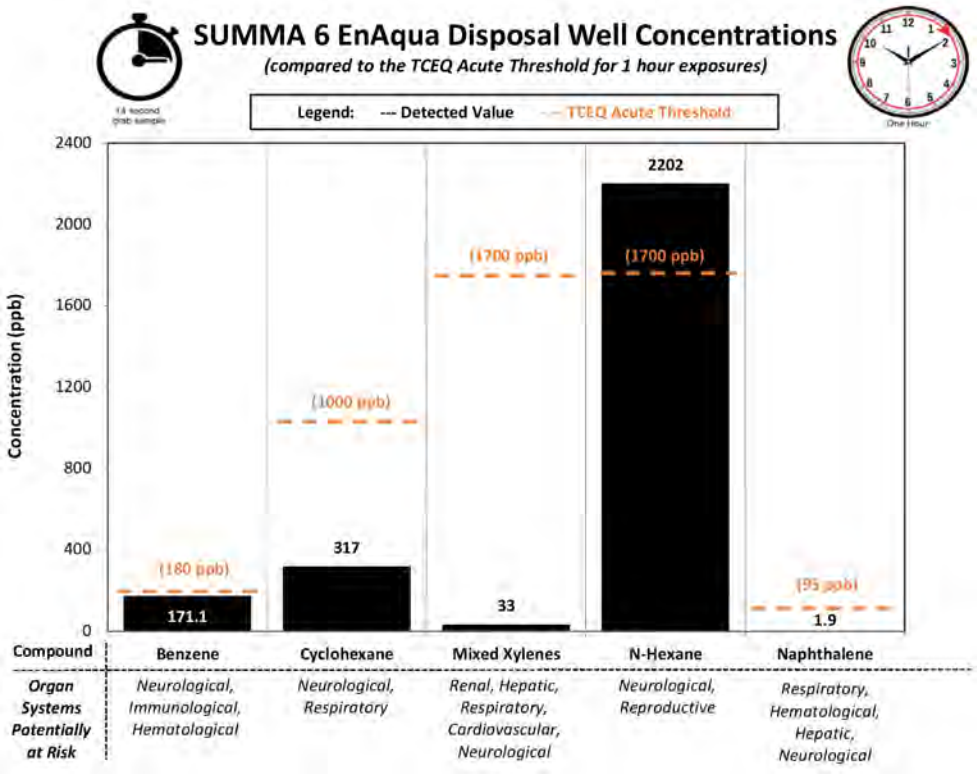


Figure 63. EnAqua Disposal Well Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios.

Our sample outside of EnAqua disposal well also contained a high level of benzene at 171 ppb, which would approach the TCEQ short-term exposure threshold (180 ppb) and would be 122.21 times the TCEQ long-term exposure threshold of 1.4 ppb if these levels were to persist. Similarly, the n-Hexane level (2,202 ppb) in our sample would far exceed the short-term TCEQ value (1,700 ppb) by 500 ppb if it were to persist throughout the day and long-term exposure thresholds (190 ppb for the TCEQ and 198.62 ppb for the EPA) by over 10 times if levels lasted a year. Cyclohexane (317 ppb) would exceed the TCEQ chronic threshold value of 100 ppb and 0.7 ppb, respectively. In addition to the medley of chemicals detected in the SUMMA® canister samples, the neurotoxic gas hydrogen sulfide was also detected at this location using a Jerome meter. The detected 1.14 ppm of hydrogen sulfide exceeds the 1 ppm workplace exposure threshold set by the American Conference of Governmental Industrial Hygienists for an 8-hour work day.[165]

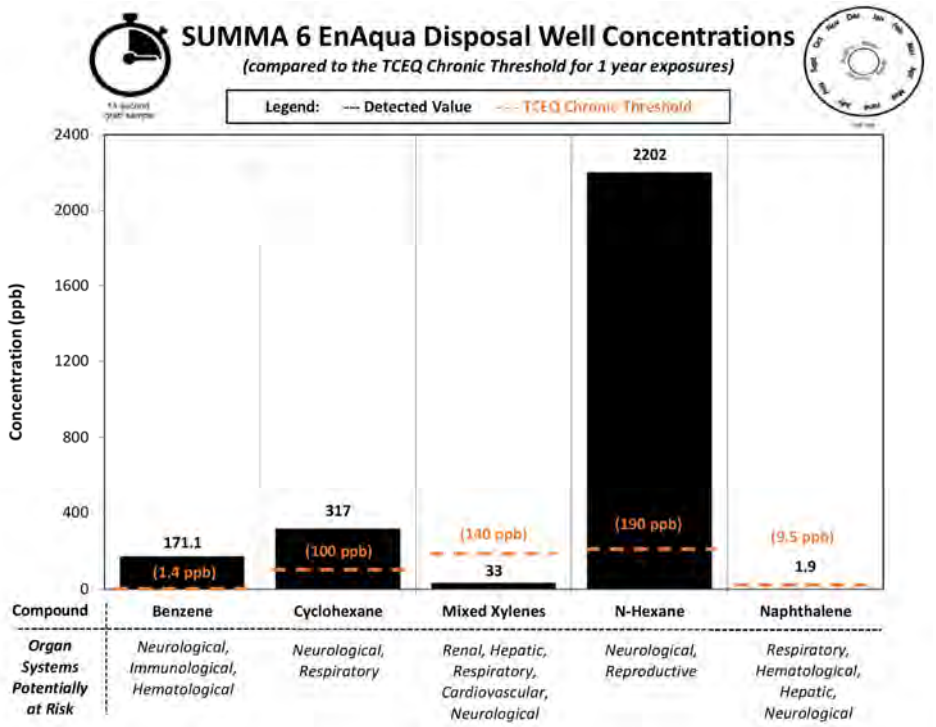


Figure 64. EnAqua Disposal Well Chronic Year-long Exposure Scenario: SUMMA® Sample concentrations compared to chronic TCEQ exposure scenarios.

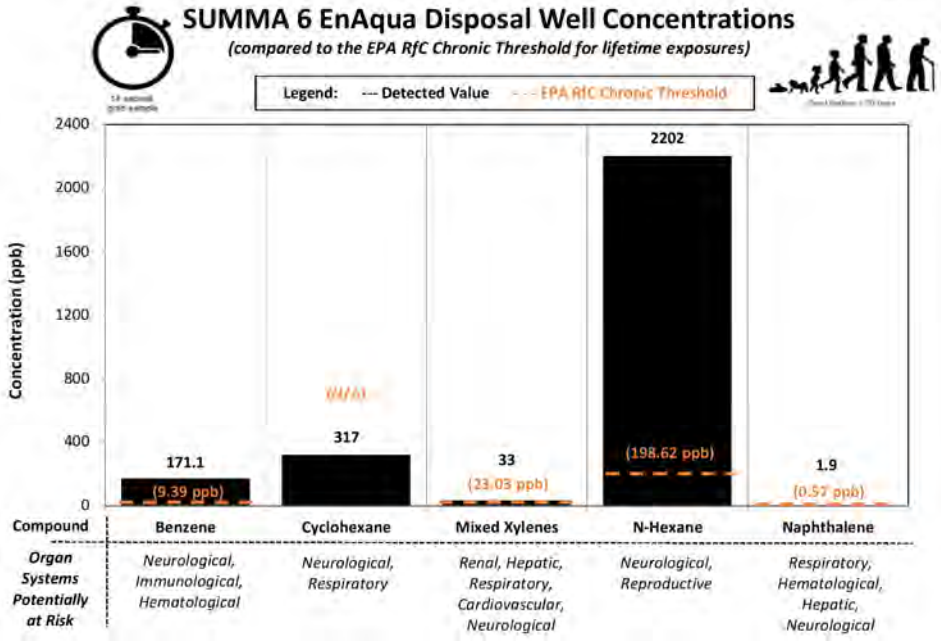


Figure 65. EnAqua Disposal Well Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

NGL Water Solutions Highroller Karnes Salt Water Disposal Well

We found concerning levels of chemicals at another disposal well run by NGL Energy Partners LP. NGL water solutions is a saltwater disposal well located on FM 99 close to Karnes City. Here, during sampling, trucks were being cleaned at the disposal site and a researcher experienced a "choking" odor of produced water, smelling like a cross between hydrocarbons and sewage. The researchers also noted swelling in their eyes, burning in their eyes and nose, and throat irritations.

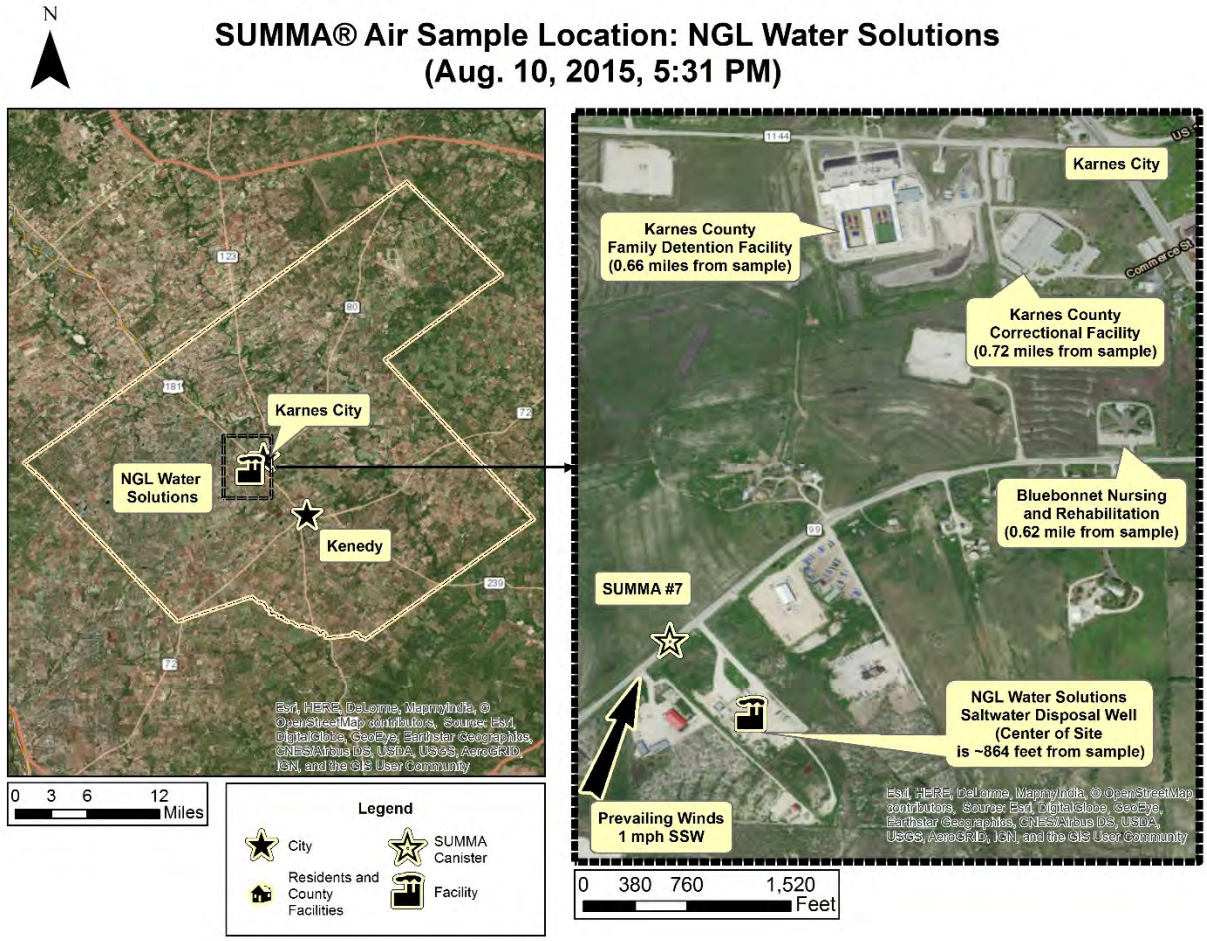


Figure 66. SUMMA® sample #7 location at NGL Water Solutions.

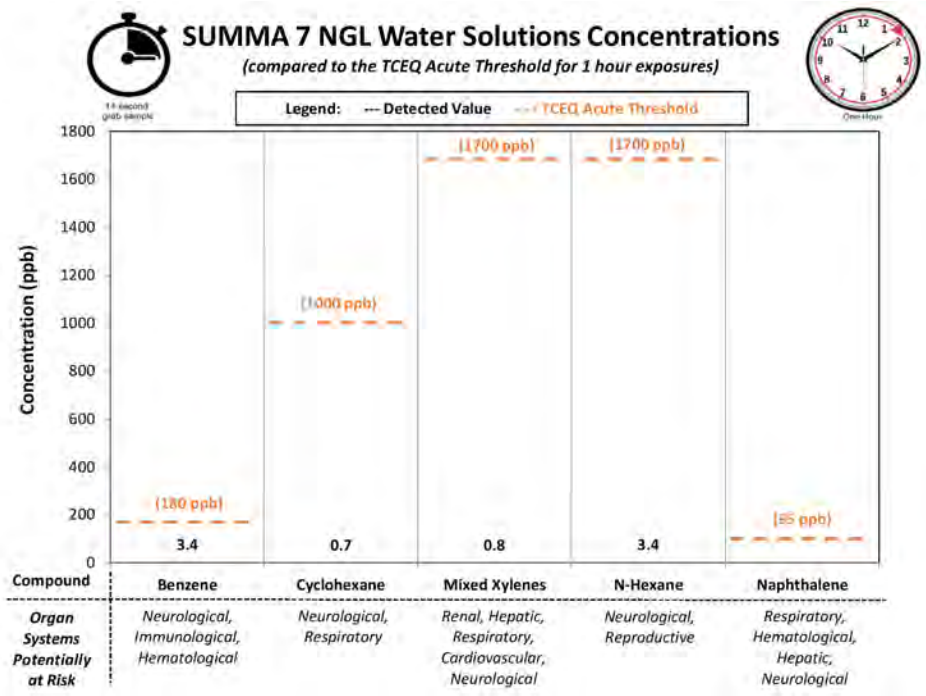


Figure 67. NGL Water Solutions Acute Exposure Scenario: SUMMA® Sample concentrations compared to acute TCEQ exposure scenarios.

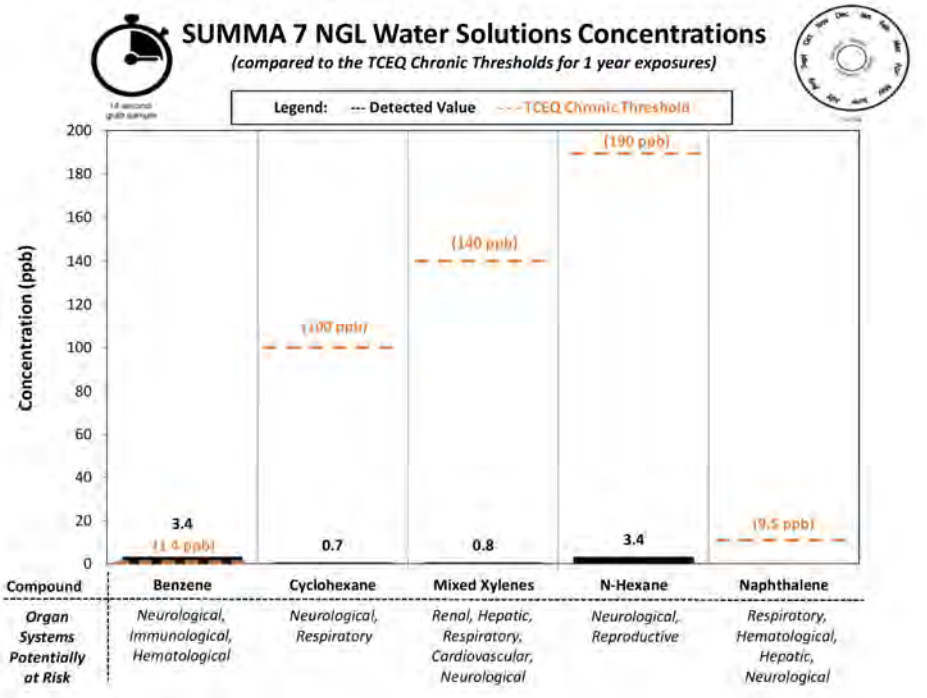


Figure 68. NGL Water Solutions Chronic Year-long Exposure Scenario: SUMMA® Sample concentrations compared to chronic TCEQ exposure scenarios.

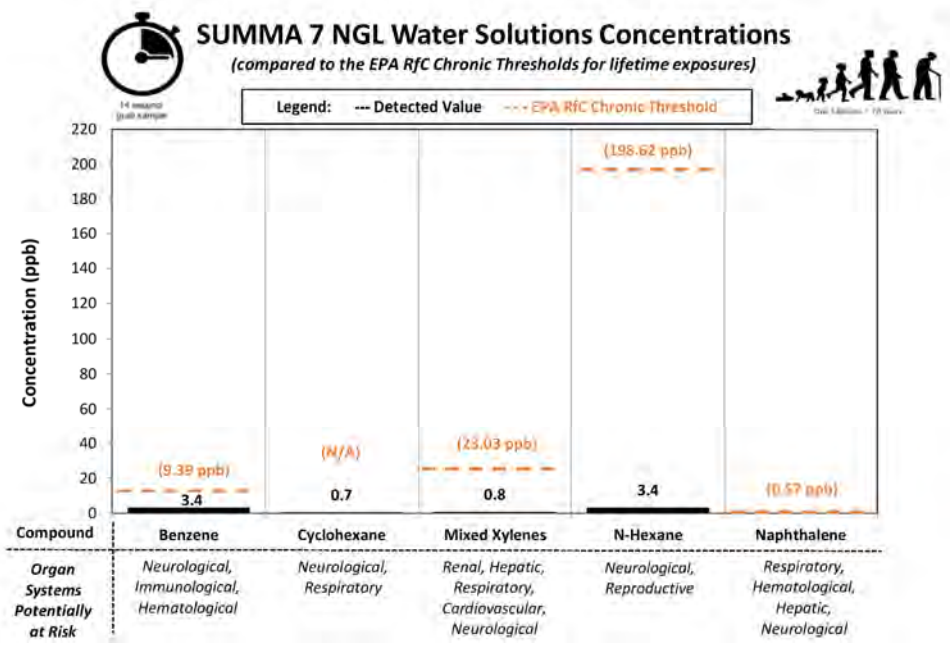


Figure 69. NGL Water Solutions Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

Figure 70. Daylight image of NGL Water Solutions. No FLIR OGI image was taken because there were no visible emissions

Despite these experiences, overall the SUMMA® canister pollutant concentrations were low here compared to other samples. This may have been due to researchers being unable to take a sample directly downwind of the facility because they had to stay on public property. It is possible that the researchers were exposed to compounds that we did not test for in laboratory analysis. However, at the NGL Water Solutions site, the amount of benzene, 3.4 ppb, would have exceeded the chronic TCEQ threshold of 1.40 ppb if such emissions were to persist over the course of a year.

Sampling locations outside and upwind of Karnes County

Targa Facility

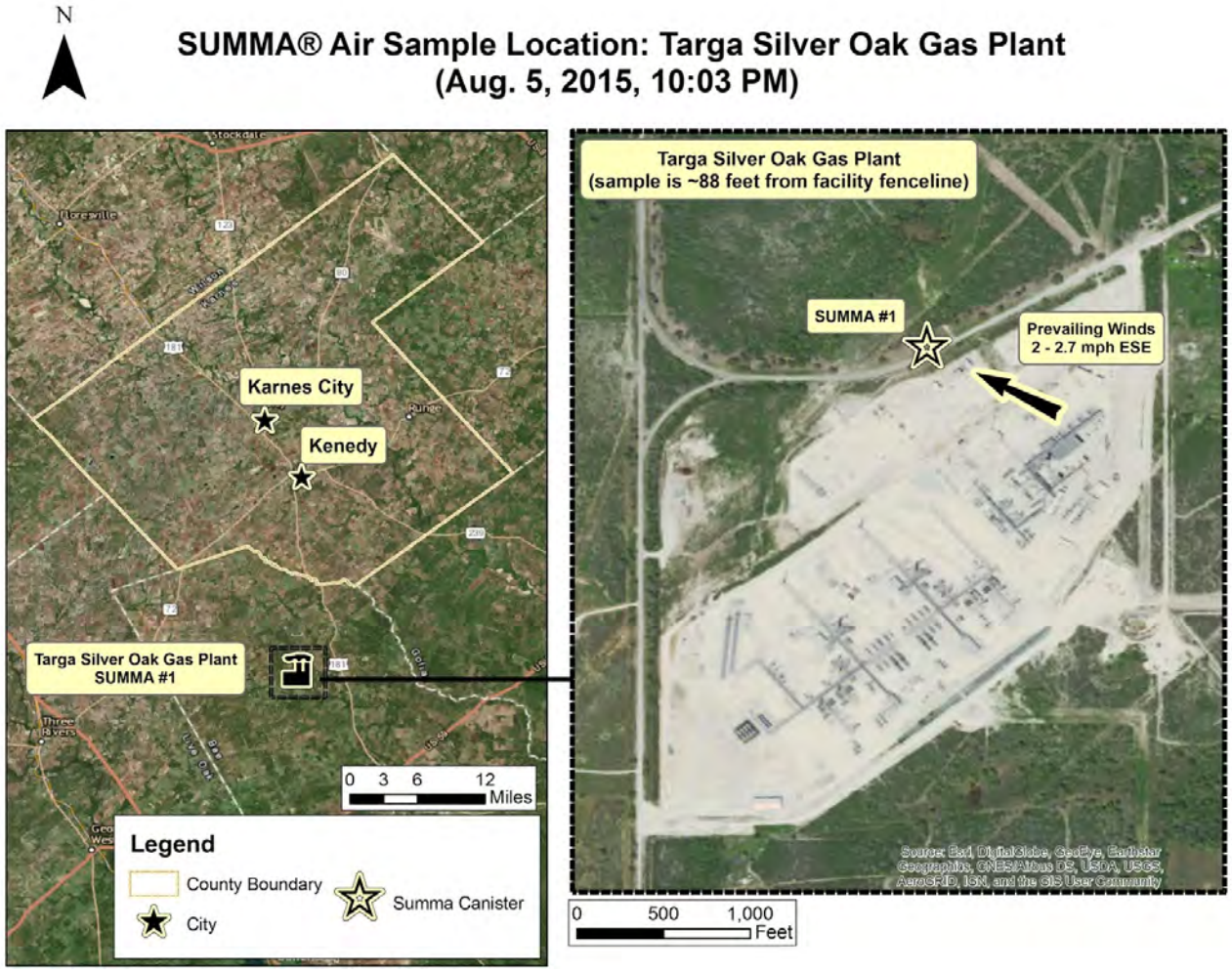


Figure 71. SUMMA® sample location at Targa Silver Oak Gas Plant.

The Targa facility is outside of Karnes County. It is upwind of Karnes County and located at the intersection of Farm to Market Road 1465 and County Road 107. It consists of the combination of the Targa Silver Oak Gas Plant and Lonestar Plant. The total area is about the same size as the nearby town, Tuleta. This facility is a collection of many sites run by many operators. Each site has its own permit, so it is difficult to point to a specific site or source that is releasing emissions.

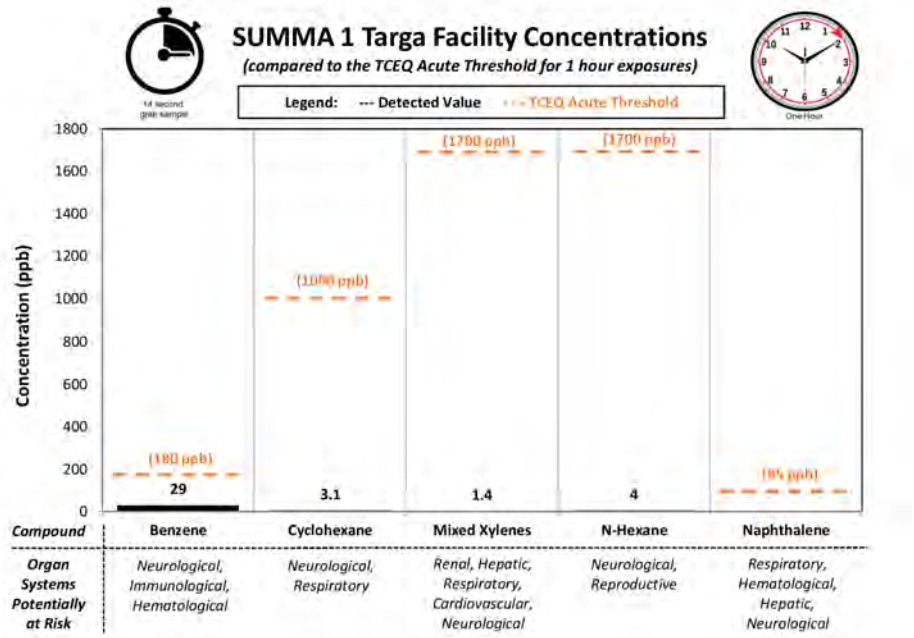


Figure 72. Targa Silver Oak Gas Plant Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios.

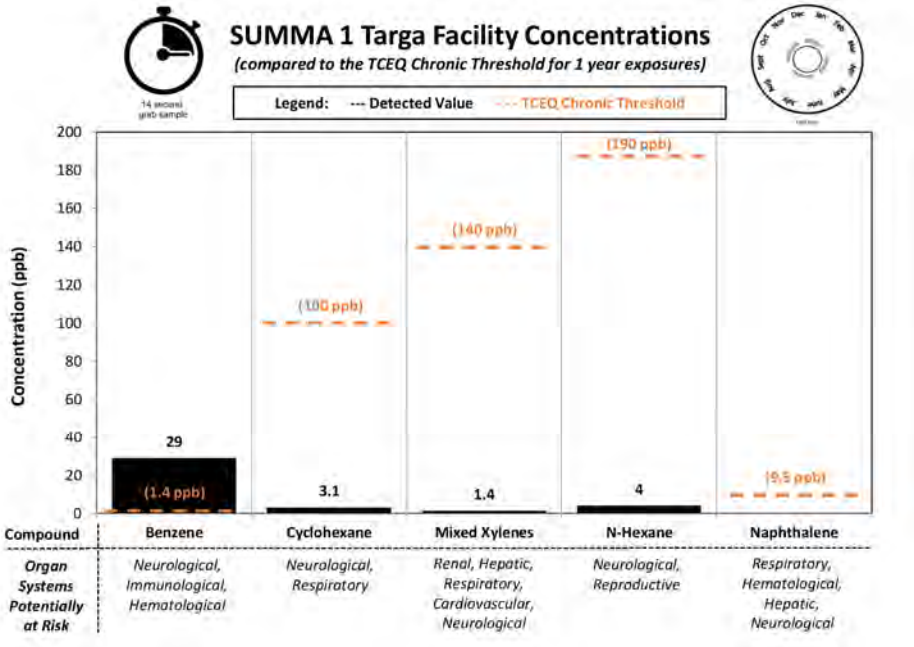


Figure 73. Targa Silver Oak Gas Plant Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios.

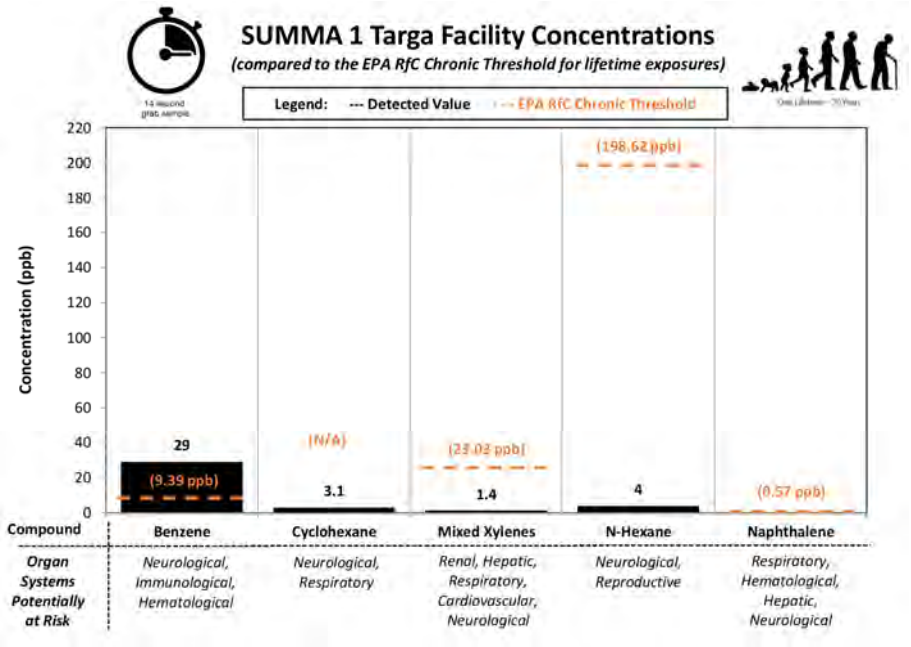


Figure 74. Targa Silver Oak Gas Plant Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

The SUMMA® sample was taken 88 feet from the center of the Targa Facility, which is an average of 18.85 miles away from the other sampling sites. The sample contained 29.0 ppb of benzene, which would not exceed TCEQ's acute hour-long exposure threshold but would be three times the EPA RfC and 20 times the TCEQ chronic threshold if emissions were to persist for a lifetime or year, respectively. We also found levels of n-Hexane (4.0 ppb), mixed xylenes (1.36 ppb), and cyclohexane (3.1 ppb) in the sample.

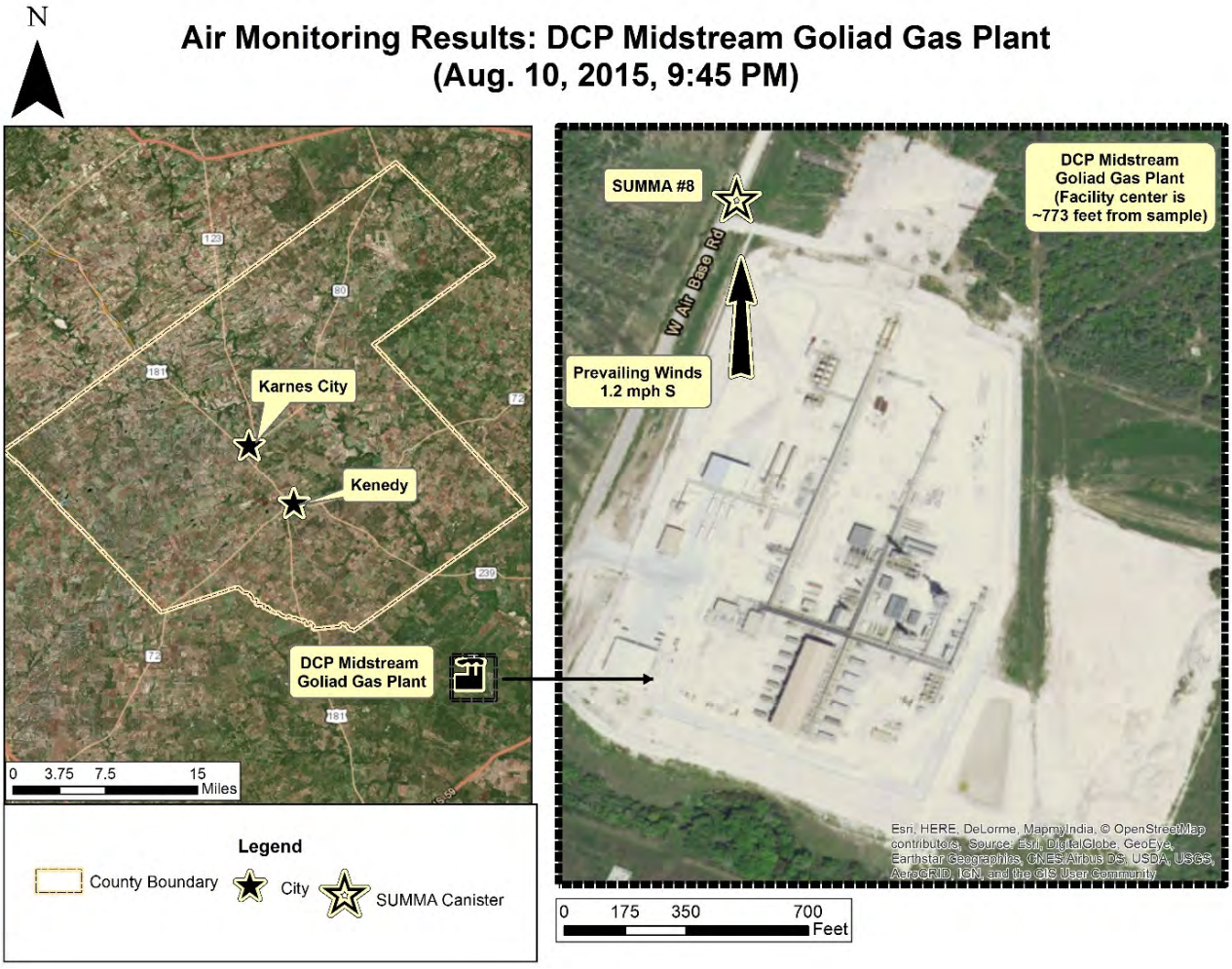


Figure 75. SUMMA® sample location at DCP Midstream Goliad Gas Plant.

The Goliad facility, is also outside but upwind of Karnes County. The site, officially named the Goliad II Gas Plant, is located approximately one mile directly west of the Goliad County Industrial Airpark. It is operated by DCP Midstream Partners and runs under a Clean Air Act Title V permit, which allows different parts of the plant to be permitted by different permits. This allows the plant to report emissions in parts, not as an aggregated total.

The SUMMA® air sample was taken 773 feet from the center of the facility on a public road, which is an average of 23.23 miles away from the other sampling sites. The sample measured 9.5 ppb of benzene, which would not exceed the TCEQ threshold for acute exposures over an hour but it could exceed the EPA RfC and be 6.8 times the TCEQ chronic threshold if emissions were to persist for a lifetime or year, respectively. We also found levels of n-Hexane (25.6 ppb), mixed xylenes (0.8 ppb), and cyclohexane (4.2 ppb) in the sample.

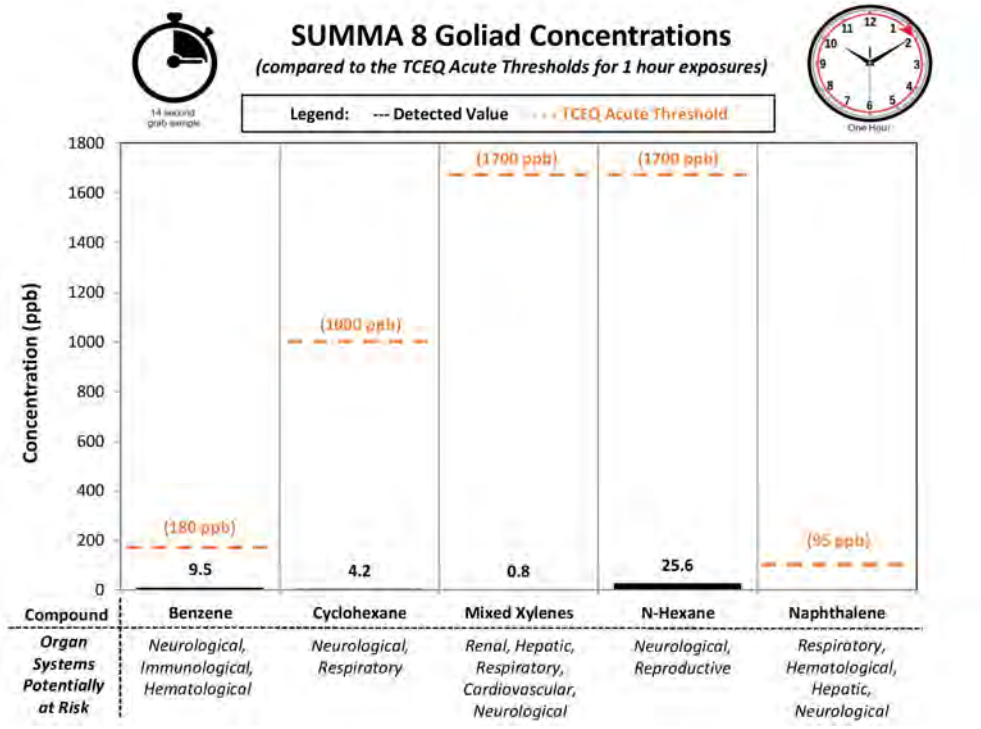


Figure 76. DCP Midstream Goliad Gas Plant Acute Exposure Scenario: SUMMA® sample concentrations compared to acute TCEQ exposure scenarios.

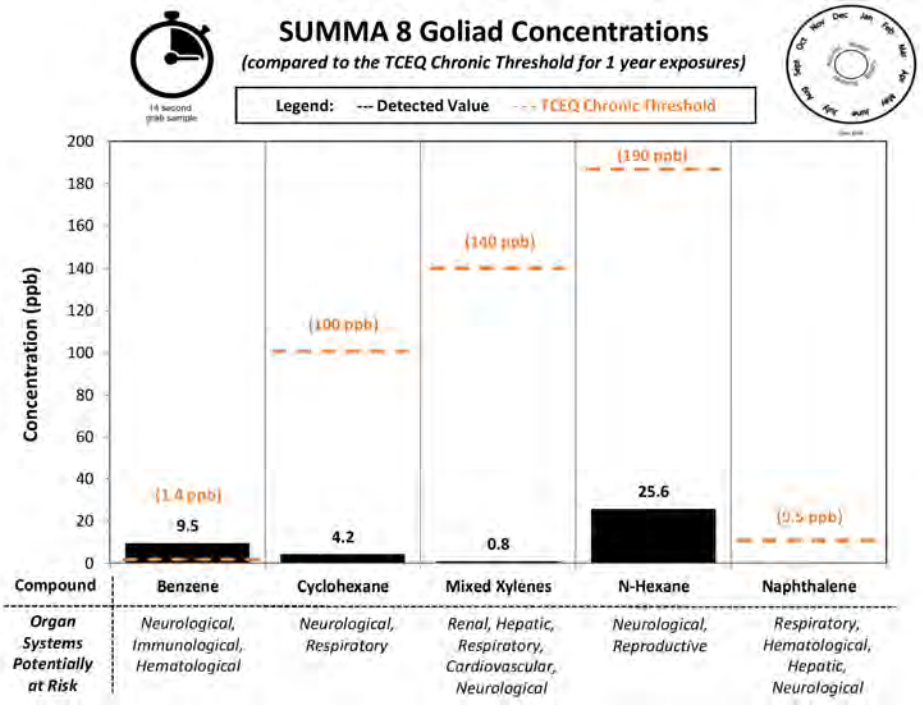


Figure 77. DCP Midstream Goliad Gas Plant Chronic Year-long Exposure Scenario: SUMMA® sample concentrations compared to chronic TCEQ exposure scenarios.

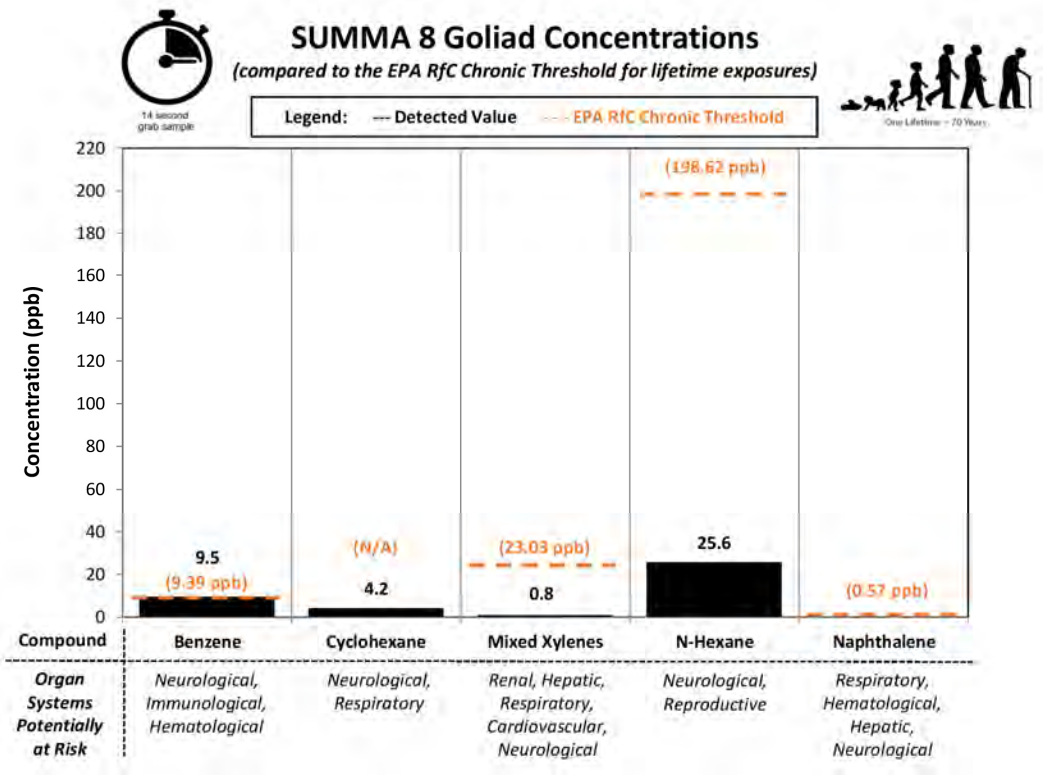


Figure 78. DCP Midstream Goliad Gas Plant Chronic Lifetime Exposure Scenario: SUMMA® sample concentrations compared to chronic EPA exposure scenarios.

Appendix 2: Data

Regulatory thresholds used in this report from TCEQ and EPA.			
Compound	Acute AMCV, ppb	Chronic AMCV, ppb	RfC, ppb
1,1-DICHLORO ETHENE	N/A	N/A	50.44
1,1,2,2-TETRACHLORO ETHANE	10.00	1.00	N/A
1,2-DICHLORO ETHANE	N/A	N/A	592.97
1,2,4-TRIMETHYL BENZENE	3000.00	37.00	N/A
1,3-BUTA DIENE	1700.00	9.00	0.90
1,3,5-TRIMETHYL BENZENE	3000.00	37.00	N/A
2-CHLORO TOLUENE	N/A	N/A	N/A
2,2,4-TRIMETHYL PENTANE	N/A	N/A	N/A
4-ETHYL TOLUENE	N/A	N/A	N/A
ACETONE	11000.00	6700.00	N/A
BENZENE	180.00	1.40	9.39
BROMO DICHLORO METHANE	N/A	N/A	N/A
CARBON DISULFIDE	N/A	N/A	224.78
CARBON TETRACHLORIDE	20.00	2.00	15.89
CHLOROBENZENE	100.00	10.00	217.22
CHLOROFORM	20.00	2.00	20.07
CHLOROMETHANE	500.00	50.00	43.58
CYCLOHEXANE	1000.00	100.00	N/A
ETHANOL	N/A	N/A	N/A
ETHYL ACETATE	4000.00	400.00	N/A
ETHYL BENZENE	20000.00	440.00	230.31
ETHYL METHYL KETONE	N/A	N/A	N/A
FREON 11	N/A	N/A	N/A
HEPTANE	N/A	N/A	N/A
HYDROGEN SULFIDE	80 - 120	N/A	1.43
ISO PROPYL ALCOHOL	N/A	N/A	N/A
ISO PROPYL BENZENE	N/A	N/A	81.37
MIXED XYLENES	1700.00	140.00	23.03
METHYL-tert-BUTYL ETHER	500.00	50.00	832.10
METHYLENE CHLORIDE	3400.00	100.00	172.71
n-BUTYL BENZENE	N/A	N/A	N/A
n-PROPYL BENZENE	510.00	51.00	N/A
n-HEXANE	1700.00	190.00	198.62
NAPHTHALENE	95.00	9.50	0.57
PROPENE	N/A	N/A	N/A
SEC- BUTYL BENZENE	N/A	N/A	N/A
STYRENE	5200.00	110.00	234.78
TETRAHYDROFURAN	N/A	N/A	N/A
TOLUENE	4000.00	1100.00	1326.93

Figure 79. Regulatory thresholds used in this report from TCEQ and EPA.

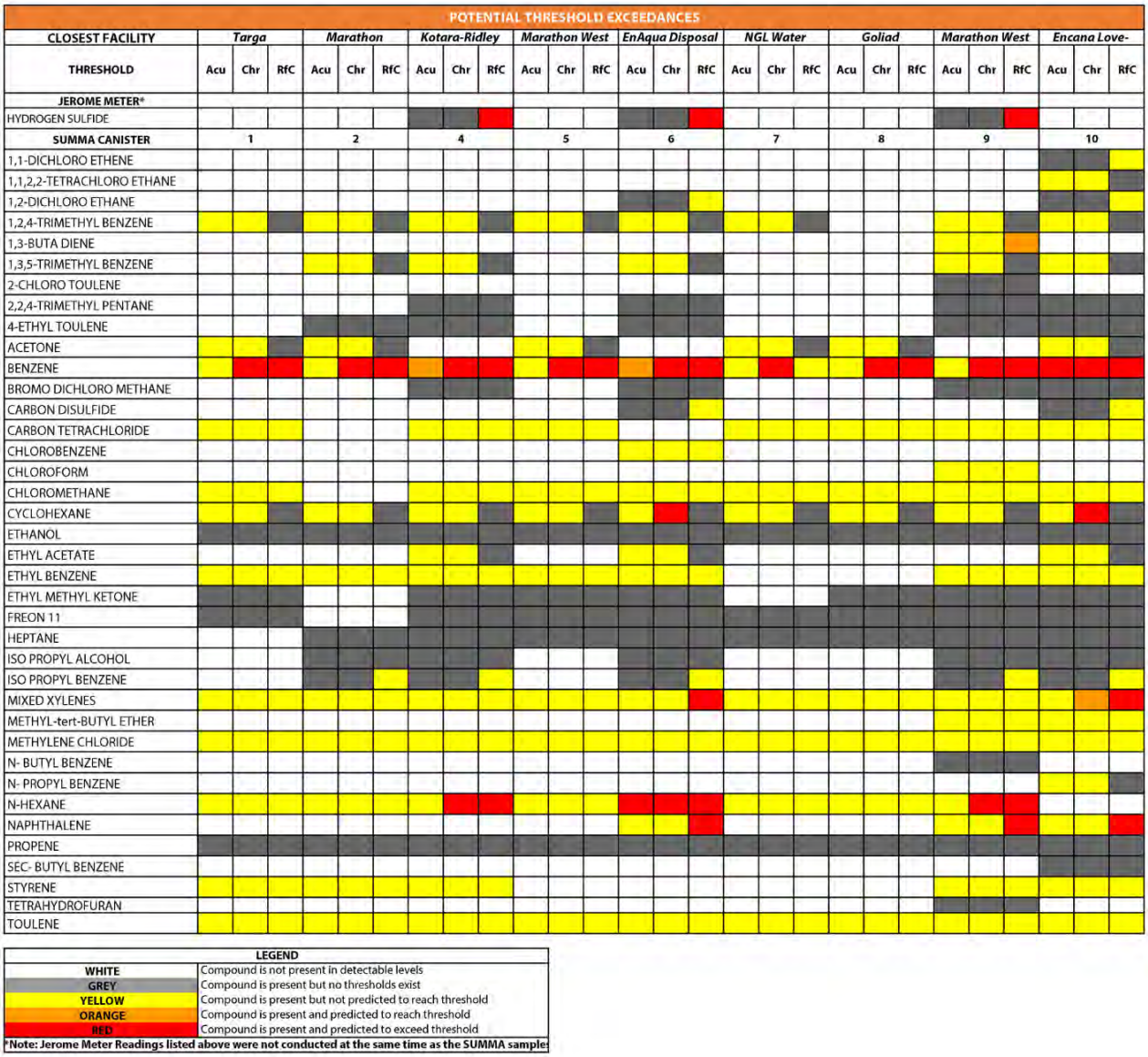


Figure 80. All identified VOCs and their potential exceedances assuming the concentrations were emitted for the applicable length of time for the thresholds listed.

Targeted Organ System Health Index Report 2017 - TOSHI											
Effects	**Compounds**	**Acute**					**Chronic**				
		Ave	SD	Min	Med	Max	Ave	SD	Min	Med	Max
Neurological	Hydrogen sulfide, Carbon disulfide, Toluene, Xylenes, Styrene, Chloromethane, Methylene chloride, n-Hexane, Acetone, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene	4.7	8.3	0.0	0.1	24.5	322.9	531.9	0.2	1.2	1310.6
Respiratory	Hydrogen sulfide, Naphthalene, Methyl Ethyl Ketone, Cyclohexane	4.6	8.2	0.0	0.0	24.3	322.2	531.8	0.7	0.8	1309.4
Immunological	Benzene	0.4	0.4	0.0	0.2	1.2	8.2	8.1	0.4	4.0	22.0
Hepatic	1,1-Dichloroethene, 1,2-Dichloroethane, Carbon tetrachloride, Chlorobenzene, 1,1,2,2-Tetrachloroethane	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.4
Renal	Ethylbenzene, Isopropylbenzene, Chloroform, Methyl tert-butyl ether	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Reproductive	1,3-Butadiene	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.8

Figure 81. This table shows Target Organ System Hazard Indexes (TOSHIs) calculated by Dr. Chunrong Jia based on our air samples. TOSHIs can be used to estimate whether organ systems are at increased risks from mixtures of chemicals where multiple chemicals can cause harm to multiple organ systems. TOSHIs are a method used by the US EPA to calculate the "Hazard Index," or the risk posed by groups of compounds to different organ systems. Any hazard index over 1 is considered an increased risk to that organ system.

1. **The hazard index is calculated by identifying to which organ systems the different compounds detected in a mixture pose risks. One compound, such as benzene, can pose risks to multiple organs and a collection of compounds can similarly affect multiple organ systems.**
2. **The relative concentrations of the compounds in the mixture are then factored in by dividing the amount of each compound detected by its EPA threshold RfC. The resulting ratio is called a "hazard quotient". Any hazard quotient greater than 1 reflects that the RfC for the compound was exceeded in the sample.**
3. **To understand the overall risk that a collection of compounds poses to a target organ system the individual hazards quotients can be added together into the Hazard Index. The benefit of this approach is you can estimate the health risks posed by a collection of chemicals. You can then identify if one or two of the chemicals in that mixture are "driving" the effect, i.e. contributing the highest hazard quotient number and thereby accounting for the majority of the risk.**

In this calculation to assess the potential for Acute effects from exposure to the concentrations and mixtures we detected we used TCEQ's Acute AMCV values which assume an hour long exposure. We used EPA's RfC thresholds which assume a life-time of exposure in order to assess the risks of Chronic effects from exposure to the concentrations and mixtures we detected. We do not report the numbers in our report as they likely overstate the risk to these organ systems given that our samples were taken at fence-lines where the concentrations of emissions are likely to be higher than the ambient concentrations that people further downwind would routinely inhale.

Karnes County Air Toxics Monitoring: Cancer Risk Assessment									
Air Toxics		DF (%)	Ave ppb	SD ppb	Min ppb	Med ppb	Max ppb	Risk (×10-6)	Unit Risk
Aromatics									
	Benzene	90	77.0	76.2	3.4	38.0	207.0	600.6	7.8E-06
	Ethylbenzene	70	4.7	8.6	0.0	1.6	27.0	11.7	2.5E-06
	Naphthalene	30	0.8	0.7	0.4	0.4	1.9	28.6	3.4E-05
Haloginated compounds									
	Methylene chloride	80	5.0	2.5	0.1	5.2	9.9	0.0	1.0E-08
	Chloroform	10	0.1	0.1	0.0	0.0	0.2	0.3	5.3E-06
	1,1-Dichloroethene	10	0.1	0.0	0.1	0.1	0.2	0.0	0.0E+00
	Carbon tetrachloride	70	0.2	0.1	0.0	0.2	0.5	1.3	6.0E-06
	1,1,2,2-Tetrachloroethane	10	0.1	0.1	0.0	0.0	0.4	4.5	5.8E-05
Alkanes and alkenes									
	1,3-Butadiene	10	0.2	0.2	0.1	0.1	0.7	5.2	3.0E-05
Carbonyls and others									
	Methyl tert-butyl ether	20	0.2	0.2	0.0	0.0	0.7	0.0	2.6E-07
TVOC		**45**						**652.3**	

Figure 82. This cancer risk assessment table, calculated by Dr. Chunrong Jia, estimates the increased risk of cancer posed by exposure to the mixtures and concentrations of cancer causing compounds identified in our samples. It does not likely reflect the risk of breathing ambient air in the region but rather estimates the risk of cancer if a person were to inhale the average mixture and concentrations of compounds we detected routinely.

Cancer risks for individual carcinogenic compounds were estimated by multiplying the concentration by the corresponding Inhalation Unit Risk (IUR), available from IRIS (USEPA 2011). The total risk was the sum of all individual risks assuming risks are additive from simultaneous exposure to multiple carcinogens. Exposure to eight individual compounds had cancer risks exceeding 10-6, the benchmark risk level of concern. In particular, the risks from benzene and naphthalene were 19×10-4 and 1.5×10-4, respectively, which exceeded the acceptable risk range by EPA. They contributed to 88% and 7.0% of the total risk, and could be named as "risk drivers" (USEPA 2016). Compounds with cancer risks above 10-6, including 1,3-Butadiene, chloroform, 1,2-dichloro ethane, carbon tetrachloride, ethyl benzene, 1,1,2,2-tetrachloroethene, were "risk contributors"..

Appendix 3: Health Survey Questions

Residence Questions

1) Health
   - What are your current health issues?
   - Have they changed or worsened within the past 5 years?
   - How often do they occur?
   - Have they been diagnosed?
   - Are you taking any medication?
   - How often do you seek medical attention?
   - Are these health issues present in your family's medical history?
   - What have you heard about health concerns associated with fracking?
2) Have you received information on health risks from:
   - the industry
   - medical professionals
   - media outlets
   - public health officials
   - environmental agencies
3) Actions needed/taken
   - What should be done to improve air quality?
   - Who should do it?
   - What other types of pollution do you experience?
   - What types of actions have you taken to report pollution?
     - legal actions
     - protested
     - filed complaints to the TCEQ or RRC
4) Are you familiar with the TCEQ?
   - With the RRC?
5) Demographics
   - Age
   - Sex
   - Ethnicity
   - Marital status
   - Children
   - Annual income
   - Occupation
   - Years in residence
   - Years in county
   - Number of people in residence

- Distance of residence to nearest active gas well
- Number of gas wells within 2 mile radius

Medical Professional Interview Questions

1) Health
   - How long have you worked/practiced in Karnes County?
   - What are the most common health issues addressed in Karnes County?
   - In your time in Karnes, have you noticed an influx of patients?
   - Are your patients also oil and gas workers?
   - If so, what types of health issues are they experiencing?
   - Have you made an association between environmental pollutants and health issues in Karnes?
   - What types of health issues are associated to environmental pollutants in Karnes?
   - What medical advice have you given residents in Karnes?
2) Actions Needed/taken
   - What should be done to improve air quality?
   - Who should do it?
   - What types of actions have you taken to report pollution?
     - legal actions
     - protested
     - filed complaints to the TCEQ or RRC
3) Are you familiar with the TCEQ?
   RRC?
4) Demographics
   - Age
   - Sex
   - Ethnicity
   - Occupation
   - Years in medical field
   - Years in county
   - Drink
   - Smoke
   - Illegal drugs

Government Officials Interview Questions

1) How long have you worked here?
2) What is your role in government?
3) Do you live in Karnes County?
4) What complaints have you heard about pollution in Karnes County?

5) What are the processes you or your agency takes towards residential complaints?

6) How long do these processes usually take?

7) Are you aware of health risks associated to environmental pollutants in Karnes?

8) Have you been involved in any legal actions related to environmental health and/or the oil and gas industry?

9) Demographics
   - Age
   - Sex
   - Ethnicity
   - Occupation
   - Years in field
   - Years in county
   - Years in state

Endnotes

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[82] To try and capture a diverse set of perspectives, residents were recruited through different means:

Snowball sampling: Four residents were introduced to me by other participants and were interested in participating in the research.

Opportunity sampling: Four residents were recruited at a local community workshop. Eight were recruited through an ad in the local newspaper that asked for residents to call in if they lived near oil and gas wells. The other two were recruited by calling targeted environmental and health institutions.

[83] Major Questions:

According to residents, what health issues are they experiencing and of these, which do they believe are related to pollution caused by oil and gas processes in Karnes County?

According to residents, what personal, governmental, and industry actions are needed to improve environmental conditions for Karnes County residents?

What are the next steps needed to empower and engage residents in environmental justice actions?

[84] Initial recruitment efforts in Karnes involved a stratified random sample using Census data.

[85] The poverty threshold in 2015 for a 2 person household was $15, 930. https://aspe.hhs.gov/2015-poverty-guidelines

[86] Pseudonyms were chosen at random to represent participants' language, culture, and gender. Additionally, interviewees interviewed together because they shared a household and were married, were given honorifics such as "Mr." and "Mrs."

[87] A sample that is taken over a short period of time.

[88] Northeastern researchers were led by Dr. Sara Wylie, who is developing a low cost, do-it-yourself photopaper tool to measure and visualize long-term, low level H_2S emissions. Based on the high levels of H_2S in the area shale, the grab samples were also used to see if the VOCs present could interfere with the tool's H_2S sampling ability.

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