Health Consultation

Evaluation of Exposure to Landfill Gases in Ambient Air

BRIDGETON SANITARY LANDFILL

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

Prepared by the
Missouri Department of Health and Senior Services
Division of Community and Public Health
Bureau of Environmental Epidemiology

August 11, 2022

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Office of Capacity Development and Applied Prevention Science
Atlanta, Georgia, 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

You may contact ATSDR toll free at
1-800-CDC-INFO
or
visit our home page at: https://www.atsdr.cdc.gov

The Missouri Department of Health and Senior Services (MDHSS) prepared this Health Consultation for the Bridgeton Sanitary Landfill Site, located in Bridgeton, St. Louis County, Missouri. This publication was made possible by a cooperative agreement (program #TS20-2001) with the federal Agency for Toxic Substances and Disease Registry (ATSDR). MDHSS evaluated data of known quality using approved methods, policies, and procedures existing at the date of publication. ATSDR reviewed this document and concurs with its findings based on the information presented by the MDHSS. If you have questions about this report, we encourage you to contact MDHHS directly at (573) 751-6102 or (866) 628-9891.

HEALTH CONSULTATION

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SUMMARY

Introduction

The Missouri Department of Health and Senior Services (MDHSS) developed this health consultation in cooperation with the Agency for Toxic Substances and Disease Registry (ATSDR) to evaluate the potential public health impacts of fugitive emissions of landfill gases from Bridgeton Sanitary Landfill (hereafter referred to as "the landfill") into ambient air. This evaluation was conducted as a result of MDHSS's involvement in the investigation of the Bridgeton Landfill site and at the request of community members and the St. Louis County Department of Public Health following the onset of a subsurface smoldering event (SSE) at the landfill. Bridgeton Landfill first reported evidence of an SSE in the south quarry of the landfill in December 2010. By Spring 2012, there were indications of increased landfill gas and odor emissions into the air.

Bridgeton Landfill is a part of West Lake Landfill, a National Priorities List (NPL or "Superfund") site located in Bridgeton, Missouri, in the Greater St. Louis area. From February 2013 to July 2018, the Missouri Department of Natural Resources (MDNR) monitored chemical concentrations and odor levels in ambient air near the boundary of the south quarry of the landfill, where the smoldering is currently contained. During that time, MDNR and the United States Environmental Protection Agency (EPA) also monitored air quality in the Bridgeton area. In this health consultation, MDHSS/ATSDR evaluate both sets of air data to assess the potential public health implications of breathing fugitive gas emissions and their associated odors from the landfill. MDHSS/ATSDR did not evaluate the health risks of exposure to radiological contaminants associated with West Lake Landfill. A separate public health consultation on radiation in groundwater and air at the site was written by ATSDR in 2015.

The September 2018 public comment version of this document was available for public review and comment from September 21, 2018, to January 18, 2019. Public comments and responses to those comments are in Appendix G of this final health consultation.

Conclusions

MDHSS/ATSDR reached the following conclusions regarding the public health implications of breathing landfill gas emissions and their associated odors in ambient air:

Conclusion 1

Before completion of corrective actions at the landfill in 2014, breathing sulfur-based compounds [i.e., reduced sulfur compounds (RSCs) and sulfur dioxide (SO_2)] at concentrations detected in ambient air near the landfill may have harmed the health of people living or working near the landfill by aggravating chronic respiratory disease (e.g., asthma),

aggravating chronic cardiopulmonary disease, or causing adverse respiratory effects such as chest tightness or difficulty breathing especially in sensitive individuals (e.g., children, elderly adults). Breathing the odors of sulfur-based compounds may have also caused headache, nausea, or fatigue. Sulfur-based compounds were most frequently detected in ambient air near the landfill in 2013, prior to completion of corrective actions at the landfill in 2014.

Basis for Decision

From February 2013 to July 2018, MDNR continuously monitored combined RSCs and SO_2 in ambient air at three fixed AreaRAE® monitoring locations up to ½ mile from the landfill.[1] Occasionally, concentrations of combined RSCs and SO_2 were detected at or above 100 parts per billion (ppb; the lower detection limit of AreaRAE® monitors), exceeding conservative health guidelines for respiratory and neurological effects and sometimes exceeding concentrations shown in human clinical studies to cause adverse respiratory effects.[2,3] Maximum concentrations of combined RSCs detected by AreaRAE® monitors near the landfill were as high as 3,700 ppb. Maximum concentrations of SO_2 detected by AreaRAE® monitors near the landfill were as high as 1,600 ppb.

Depending on the toxicities of the individual RSCs in ambient air, breathing combined RSCs at concentrations detected in ambient air near the landfill for sufficient time periods may have caused acute respiratory effects such as chest tightness, wheezing, or breathing discomfort, especially in sensitive individuals. Breathing SO_2 at concentrations detected in ambient air near the landfill for sufficient time periods may have also caused acute respiratory effects such as chest tightness, wheezing, or breathing discomfort, especially in sensitive individuals. People with asthma and other pre-existing chronic respiratory or cardiopulmonary conditions, as well as children and elderly adults, may be especially sensitive to RSCs and SO_2 in the ambient air.

Respiratory and neurological symptoms including shortness of breath, wheezing, headache, and/or nausea have been reported by residents living up to two miles from the landfill and in numerous studies of

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[1] MDNR's AreaRAE® monitors were equipped with sensors for detection of concentrations of hydrogen sulfide (H_2S) and SO_2 in air. Because the AreaRAE® H_2S sensor may detect not only H_2S but other RSCs in the air [RAE Systems 2015], in this health consultation MDHSS refers to the AreaRAE® H_2S sensor measurements as "combined RSC" concentrations.

[2] Health guidelines include ATSDR's minimum risk levels (MRLs) for acute (0-14 days) exposure to H_2S (70 ppb) and SO_2 (10 ppb) and California EPA's reference exposure level (REL) for acute (1-hour) exposure to H_2S (30 ppb).

[3] Breathing SO_2 at concentrations of 100 ppb or more for 10 minutes was shown in a human clinical study to have adverse respiratory effects in people with asthma [ATSDR 1998]. Breathing H_2S at concentrations of 2,000 ppb or more for 30 minutes was shown in a human clinical study to have adverse respiratory effects in people with asthma [ATSDR 2014a]. Additional details of our evaluation of the AreaRAE® data are provided in the main body of this document.

exposures to malodorous sulfur compound emissions in other communities.

AreaRAE® detections of sulfur-based compounds in ambient air near the landfill occurred most frequently in 2013, when combined RSCs were detected at least once in 28.1% of total monitoring hours and SO_2 was detected at least once in 17.5% of total monitoring hours. Sulfur-based compounds were detected less frequently in subsequent years, following implementation of corrective measures in 2013-2014 to control landfill gas and odor emissions associated with the SSE (e.g., re-engineering of the gas and leachate extraction system, capping of the south quarry with an impermeable liner, and active extraction and onsite pretreatment of leachate from the landfill). From 2013 to 2018, the frequency of detection of sulfur-based compounds decreased significantly by 74.6% (combined RSCs) and 92.3% (SO_2).

Conclusion 2

Before completion of corrective actions at the landfill in 2014, long-term or repeated exposure to sulfur-based compounds and their odors in air near the landfill may have harmed the health or affected the quality of life of people living or working near the landfill by increasing stress, impairing mood, or increasing the risk of respiratory infection.

Basis for Decision

Landfill gases can have objectionable odors at low concentrations. Offensive odors alone, not just the toxicity of the chemicals causing the odors, may induce health effects. With repeated exposures, offensive odors may aggravate chronic respiratory disease, such as asthma. Long-lasting feelings of helplessness and frustration regarding the intensity and frequency of offensive odors, the unpredictability of the onset of offensive odors, and uncertainty regarding the toxicity of the chemicals causing those odors may increase levels of stress and potentially lead to stress-related illness.

In Spring 2012, when the SSE began to intensify, Bridgeton area residents began submitting complaints about noxious odors emanating from the landfill. MDNR staff conducted routine surveillance of odors from April 2013 to July 2018 and most frequently reported offensive odors in the area in 2013, prior to implementation of corrective measures to control gas and odor emissions.

A variety of chemicals produced by the decomposition of organic matter in the landfill likely contributed to those odors. Sulfur-based compounds have relatively low odor thresholds and could have been responsible for much of the odor. In numerous studies in other communities, long-term or repeated exposures to malodorous sulfur emissions have been associated with changes in mood, including increased anxiety, tension, anger, confusion, and depression. Long-term exposures to malodorous sulfur-based compounds have also been associated with increased risk of acute respiratory infection (common cold, bronchitis).

Conclusion 3

Fugitive gas emissions from the landfill decreased significantly as a result of corrective actions at the landfill in 2013 and 2014 and breathing sulfur-based compounds in ambient air near the landfill is currently unlikely to harm people's health. However, the odors of low concentrations of sulfur-based compounds may be occasionally bothersome and affect the quality of life of people living or working near the landfill.

Basis for Decision

From 2013 to 2018, the frequency of detection of combined RSCs in ambient air near the landfill significantly decreased. In 2018, maximum concentrations of combined RSCs detected by MDNR's AreaRAE® monitors (200 ppb) were well below a hydrogen sulfide (H_2S) concentration shown in a human clinical study to cause adverse respiratory effects in people with asthma (2,000 ppb).

From 2013 to 2018, the frequency of detection of SO_2 in ambient air near the landfill also significantly decreased. In 2018, maximum SO_2 concentrations detected by MDNR's AreaRAE® monitors occasionally reached a concentration shown in a human clinical study to cause adverse respiratory effects in people with asthma (100 ppb). However, the majority of detections occurred at the monitoring location in a commercial area only a few hundred feet from the landfill.

In 2016, MDNR installed a pulsed fluorescence SO_2 monitor at their Rider Trail air quality monitoring station located ¾ of a mile south of the landfill. The monitor is a part of a state-wide network of sensitive SO_2 monitors that provides ambient air quality data to EPA's Air Quality System. The 99th percentiles of daily maximum 1-hour average SO_2 concentrations at that location have been similar to values from other monitoring stations in St. Louis County, which have been well below EPA's primary National Ambient Air Quality Standard (NAAQS) for SO_2 (75 ppb).[4] Twenty-four hour average SO_2 concentrations at that location (≤5.7 ppb) have also been below the World Health Organization's 24-hour Air Quality Guideline (7.6 ppb).

From 2013 to 2018, the frequency with which MDNR detected offensive odors in the vicinity of the landfill decreased significantly by more than 98%. Still, sulfur-based compound odors may occasionally be objectionable, especially during periods of construction or other invasive work at the landfill or in instances of landfill equipment malfunction.

[4]Ambient air quality is evaluated by calculating the 3-year average 99th percentile of daily maximum 1-hour concentrations and comparing that average to the NAAQS [EPA 2010].

Children and individuals with chronic respiratory diseases, such as asthma, are particularly sensitive to odors.

Conclusion 4 Breathing other (i.e., non-sulfur based) chemicals detected in ambient air is not expected to have harmed people's health.

Basis for Decision In 2013-2015, MDNR oversaw landfill gas and air sampling at five comprehensive sampling events to characterize the landfill source gas and emissions. In those events, samples were collected for determination of concentrations of a broad range of chemicals in gas, onsite air, and ambient air [e.g., aldehydes, amines, carboxylic acids, dioxins/furans, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs), in addition to sulfur-based compounds]. In ambient air, some aldehydes and VOCs were occasionally detected at concentrations exceeding health-based screening levels and guidelines and were, therefore, targeted for routine ambient air monitoring/sampling. Like sulfur-based compounds, carbon monoxide is a common landfill gas that can be toxic at low concentrations and was, therefore, targeted for routine ambient air monitoring/sampling.

From February 2013 to July 2018, MDNR continuously monitored carbon monoxide (as well as sulfur-based compound) emissions from the landfill. MDNR also conducted routine ambient air sampling upwind and downwind of the landfill to monitor aldehyde and VOC (as well as sulfur-based compound) emissions from the landfill. In three air samples collected a few hundred feet downwind of the landfill in 2013-2014, concentrations of benzene (a VOC) exceeded conservative health guidelines for immunological effects.[5] In those air samples, benzene concentrations were as high as 32.5 ppb. However, they were well below levels shown in animal studies to cause those effects.[6] Concentrations of carbon monoxide measured by AreaRAE® monitors near the landfill did not exceed health guidelines.

In this health consultation, the potential health impacts of single and multiple chemical exposures are evaluated. Experimental studies have shown that exposure to low concentrations of multiple chemicals can sometimes have combined adverse health effects if they target the same tissue or organ. Many chemicals, including sulfur and non-sulfur based compounds, that may jointly target the respiratory or neurological systems were detected in ambient air near Bridgeton Landfill. However,

[5] Health guidelines include ATSDR's minimum risk levels (MRLs) for acute (0-14 days) and intermediate (15-364 days) exposure to benzene (9 ppb and 6 ppb, respectively).
[6] ATSDR based its acute MRL on a human equivalent lowest observed adverse effect level (LOAEL) of 2,550 ppb for 24-hour exposure to benzene and its intermediate MRL on a human equivalent LOAEL of 1,800 ppb for seven-day exposure to benzene [ATSDR 2007]. Additional details of our evaluation of benzene exposure downwind of the landfill are provided in the main body of this document.

concentrations of other (non-sulfur based) chemicals were below levels that might jointly affect those systems and, were therefore, unlikely to cause combined adverse effects.

Conclusion 5

Estimated cancer risks from living and breathing VOCs near Bridgeton Landfill are similar to cancer risks from living in other urban/suburban environments in the United States.

Basis for Decision

Concentrations of acetaldehyde (an aldehyde), formaldehyde (an aldehyde), and several VOCs including benzene occasionally exceeded ATSDR's Cancer Risk Evaluation Guide (CREG) values. CREG values are screening values that represent concentrations expected to result in no more than 1 extra cancer case in a population of 1 million exposed for a lifetime.

Chemicals in urban/suburban air sometimes exceed CREG values. Of those chemicals that exceeded CREG values in air near the landfill, only benzene was frequently detected downwind of the landfill and at long-term average concentrations exceeding ambient air concentrations typical in other urban/suburban areas in the United States. Before and during reconstruction of the gas and leachate extraction system at the landfill, the long-term average concentration of benzene downwind of the landfill was significantly higher than the average concentration in St. Louis City. However, after completion of those corrective actions, long-term average concentrations were similar to the average concentration in St. Louis City.

Based on the assumption of lifetime exposure to benzene from living in the Bridgeton area, MDHSS/ATSDR estimated an increased cancer risk of 7.3×10^{-6}, or slightly more than 7 extra cancer cases in a population of 1 million. Lifetime exposure to typical benzene concentrations in ambient air in urban/suburban areas in the United States poses a similar increased risk of approximately 7 extra cancer cases in a population of 1 million.

Next Steps

After completion of corrective actions at the landfill, fugitive sulfur-based compound gas emissions from Bridgeton Landfill decreased significantly. In addition, over the past several years, subsurface smoldering has shown signs of diminishing. Currently, fugitive gas emissions are unlikely to harm people's health, and data do not indicate an ongoing need for continuous ambient air monitoring in response to the SSE. However, occasional isolated activities or events, including invasive work on the landfill or instances of equipment failure, may warrant short-term air monitoring/sampling. Future air data should allow

MDHSS or other responsible agencies to evaluate the potential public health impacts of breathing chemicals in ambient air in nearby residential and commercial areas. Future data should be provided to MDHSS or other responsible agencies in a timely manner so that the potential public health impacts of acute exposures can be adequately evaluated and addressed.

The Public Health Action Plan (PHAP) for the Bridgeton Landfill site includes a description of actions to be taken by MDHSS:

1. MDHSS will review any additional monitoring/sampling data collected by MDNR or other agencies as they become available or as appropriate.

2. MDHSS will coordinate with MDNR and other agencies to address community health concerns and questions as they arise by providing health professional and community education as requested.

Recommendations for individuals living or working near the landfill are discussed in the *Recommendations* section of this document.

Uncertainties and Limitations of this Evaluation

While multiple agencies collaborated to conduct a comprehensive investigation and effective mitigation of emissions of gases and associated odors from the landfill, it is unlikely that the myriad of chemicals that might be produced by a smoldering landfill were captured by ambient air monitoring and sampling efforts. Multiple monitoring and sampling approaches were used to target a wide range of chemicals. Still, some chemicals may not be included in standard analytical methods or may be present in ambient air at concentrations below lower detection or laboratory reporting limits.

MDHSS/ATSDR used conservative health-based screening levels and guidelines to evaluate the public health impacts of emissions of gases from the landfill. While most detection or laboratory reporting limits are below those screening levels and guidelines, the detection limits of the AreaRAE® H_2S and SO_2 monitors exceeded screening levels and guidelines for H_2S and SO_2. This precludes a detailed assessment of the public health impacts of breathing low concentrations of sulfur-based compounds in ambient air near the landfill, especially among sensitive individuals.

Combined RSC concentrations detected by the AreaRAE® monitors in ambient air near the landfill were similar to or exceeded RSC concentrations associated with adverse respiratory and neurological effects in studies in other communities. Whether RSC emissions from the landfill pose health risks similar to those observed at other sites remains uncertain, however, as the composition and distribution of RSCs in source emissions differs at each site, and the relative toxicities of individual RSCs are not well understood.

Health-based screening levels and guidelines are available for many but not all chemicals detected in ambient air, including many RSCs. Scientific studies of the health effects of multiple chemical exposures are also limited.

Additional uncertainties are discussed in the *Uncertainties and Limitations* section of this document.

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1 PURPOSE

The Missouri Department of Health and Senior Services (MDHSS) developed this health consultation in cooperation with the Agency for Toxic Substances and Disease Registry (ATSDR) and at the request of community members and the St. Louis County Department of Public Health to assess the potential public health impacts of landfill gas and odor emissions from Bridgeton Sanitary Landfill (hereafter referred to as "the landfill") in Bridgeton, Missouri. ATSDR is a federal agency within the United States Department of Health and Human Services.

In December 2010, Bridgeton Landfill, LLC, and its parent company Republic Services, Inc., (hereafter referred to as Republic Services) reported evidence of a subsurface smoldering event (SSE), including elevated temperatures and changes in landfill gas composition, in the southern portion (i.e., the south quarry) of the landfill [MDNR 2014]. As the SSE intensified and the production of leachate significantly increased, odor emissions from the landfill also increased. In the spring of 2012, community members first complained of offensive odors emanating from the landfill to the Missouri Department of Natural Resources (MDNR) [MDNR 2014]. In the months that followed, MDNR initiated site investigations to characterize the landfill source gas (i.e., gas produced within the landfill), determine the nature and extent of landfill gas and odor emissions, and assess the need for corrective action.

From February 2013 to July 2018, MDNR conducted routine ambient air monitoring and sampling near the landfill for evaluation of gas and odor emissions from the landfill. MDNR and the United States Environmental Protection Agency (EPA) also conducted air monitoring and sampling to characterize air quality in the Bridgeton area. In this health consultation, MDHSS/ATSDR evaluate MDNR's and EPA's air data to assess the potential public health implications of breathing gas and odor emissions in ambient air. We draw conclusions on the potential past and current public health impacts and, based on those conclusions, provide recommendations for the protection of public health.

2 SITE DESCRIPTION AND BACKGROUND

Bridgeton Sanitary Landfill is a solid waste landfill located within the boundaries of West Lake Landfill in the Greater St. Louis metropolitan area. From November 1985 to December 2004, municipal wastes were accepted under permit at Bridgeton Landfill, a 52-acre site that was originally a limestone quarry [MDNR 2014]. Prior to the onset of the SSE, the total depth of waste at the landfill was estimated to be 320 feet: 240 feet below and 80 feet above the ground surface [MDNR 2014]. Bridgeton Landfill is located at 13570 St. Charles Rock Road, Bridgeton, MO, 63044.

Other areas of West Lake Landfill contain municipal, construction, and demolition wastes. In 1973, soil containing low-level radioactive waste generated by the Mallinckrodt Chemical Company during the World War II and Cold War eras was used in landfill operations in two of those areas. In 1990, West Lake Landfill was declared a National Priorities List (NPL) site by EPA due to the presence of radioactive waste in the landfill [EPA 2015]. In their 2015 public health consultation on West Lake Landfill, ATSDR found that radiological contamination does not pose a current threat to people living or working near the landfill but may pose a health threat to West Lake Landfill workers if the contaminated soil is disturbed [ATSDR 2015].

The location of West Lake Landfill in the metropolitan St. Louis area is shown in Figures 1 and 2. Waste areas within West Lake Landfill are shown in Figure 3. The portions of West Lake Landfill found to contain radioactive materials have been designated as Operable Unit 1 (OU-1) of the site by EPA and include Area 1, Area 2, the Buffer Zone, and Lot 2A2 of the Crossroads Property. Area 1 of OU1 is adjacent to the north quarry of Bridgeton Landfill and is located several hundred feet north of the south quarry of Bridgeton Landfill. Area 2 of OU1 is located approximately ½ mile northwest of Bridgeton Landfill's north quarry. The Buffer Zone and Lot 2A2 are located near the northwest corner of West Lake Landfill.

The portions of West Lake Landfill not reported to have received radioactive waste are designated as Operable Unit 2 (OU-2). OU-2 includes Bridgeton Landfill, which is the focus of this evaluation.

In December 2010, Republic Services notified MDNR that internal temperatures in the south quarry of Bridgeton Landfill had increased to approximately 200°F, indicative of an SSE (or underground "landfill fire") [MDNR 2014]. Other indicators of the occurrence of an SSE included changes in the landfill source gas composition, including decreased methane and increased carbon monoxide concentrations.[7] As waste deep within the landfill continued to smolder, subsurface voids created by the smoldering waste and production of millions of gallons of leachate caused substantial settlement of the landfill [MDNR 2014].

In 2013-2014, MDNR oversaw efforts by Republic Services to control the SSE and minimize its effects on local air quality. Corrective actions to mitigate landfill gas and odor emissions included reconstruction of the gas and leachate extraction system in the south quarry of the landfill, capping of the south quarry of the landfill with an impermeable liner, and construction of an onsite leachate storage and pretreatment system [MDNR 2014].[8] In 2014, an odor neutralizing system was also installed at the perimeter of the landfill.

The magnitude of the SSE periodically complicated efforts to collect leachate and landfill gas and mitigate the release of odors from the landfill. At times, rapid settlement of the landfill caused both leachate and gas collection equipment malfunctions and tears in the liner, resulting in increased odors. Extreme weather also caused temporary failures in the landfill gas and

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[7] Municipal solid waste landfills typically produce 45% to 60% methane and 40% to 60% carbon dioxide by volume, with trace amounts of other compounds including hydrogen sulfide [ATSDR 2001]. During an SSE, landfill gas composition typically changes. During the SSE at Bridgeton Landfill, landfill source gas was found to contain approximately 7%-12% methane. Other compounds produced by the SSE at Bridgeton Landfill included other VOCs (primarily benzene, 2-butanone, acetone, and tetrahydrofuran) and reduced sulfur compounds (primarily dimethyl sulfide, methyl mercaptan, and dimethyl disulfide, with relatively small amounts of hydrogen sulfide).
[8] In 2013, due to the volume and composition of leachate being produced, the direct discharge of leachate to the Metropolitan Sewer District had to be stopped until a leachate pre-treatment plant was constructed and made operational. This resulted in accumulation of leachate in the landfill that required nearly two years of pumping for removal. With increased moisture in the waste mass, steam pressure developed when temperatures exceeded 212° F. Increased pressure drove gas migration to the surface of the landfill. The engineered cap is an ethylene vinyl alcohol (EVOH) liner used to help capture landfill gas that would otherwise migrate through the landfill soil cover.

leachate collection systems due to freeze-up of condensing moisture in the landfill gas piping as well as freeze-up of leachate piping.

Offensive odors were most frequently detected by MDNR prior to and during Republic Services' implementation of corrective measures to control landfill gas and odor emissions associated with the SSE. Since completion of those actions, odors from the landfill have been only occasionally offensive, particularly during instances of equipment failure.

From February 2013 to July 2018, MDHSS regularly evaluated data collected by MDNR at the site to assess the potential public health risks of acute (short-term) exposure to gas and odor emissions from the landfill and disseminated public health messages online (www.health.mo.gov/bridgeton). In July 2018, Republic Services under MDNR's oversight assumed responsibility for conducting ambient air monitoring near the landfill.[9]

MDNR continues to regulate the Bridgeton Landfill site and monitor general ambient air quality in the Bridgeton area to the present day. Since 2018, subsurface smoldering at Bridgeton Landfill has shown signs of diminishing. Internal temperatures and settlement rates at the landfill have both decreased. If future isolated activities or events such as invasive work or instances of equipment failure warrant additional data collection at the site, MDHSS will evaluate those data for potential public health impacts as appropriate and necessary.

2.1 Demographics

Bridgeton Landfill is surrounded mostly by commercial and light industrial areas. A residential area (Spanish Village) is located approximately ½ mile south-southwest of the landfill, immediately north of Interstate-70. Another residential area (Terrisan) is located approximately 500 feet from the southeast corner of the landfill property line and approximately ½ mile southeast of the landfill waste area. A single residence is located south-southeast of the landfill near the landfill property line.

MDNR received numerous odor complaints from community members living near the landfill and residents living several miles from the landfill. Bridgeton Landfill has been a major source of offensive odors in north St. Louis County, but it is not the only source. Additional sources of chemical and odor emissions include Champ Landfill and a nearby asphalt plant, which are located between 1 and 2 miles from Bridgeton Landfill in Maryland Heights.

Figure 1 shows demographic information for distances ½ mile, 1 mile, and 3 miles from the landfill. According to the 2010 U.S. census, 947 people live within a 1-mile radius of West Lake/Bridgeton Landfill. In this 1-mile radius, approximately 84% of the population is white, 11% is African American, and 2% is composed of other races [U.S. Census 2010]. Approximately 57% of that population are potentially sensitive populations (i.e., children under age 6, adults over age 65, and women of child-bearing age). That estimate does not include individuals with chronic respiratory or cardiopulmonary disease who may be especially sensitive to contaminants in air. Several hundred more people work in commercial and industrial zones

[9] The State of Missouri reached a settlement agreement with Republic Services on June 29, 2018.

around the perimeter of the landfill. Figure 2 shows community gathering, health, and emergency facilities near the landfill.

Figure 1. Map of West Lake/Bridgeton Landfill with Demographic Statistics

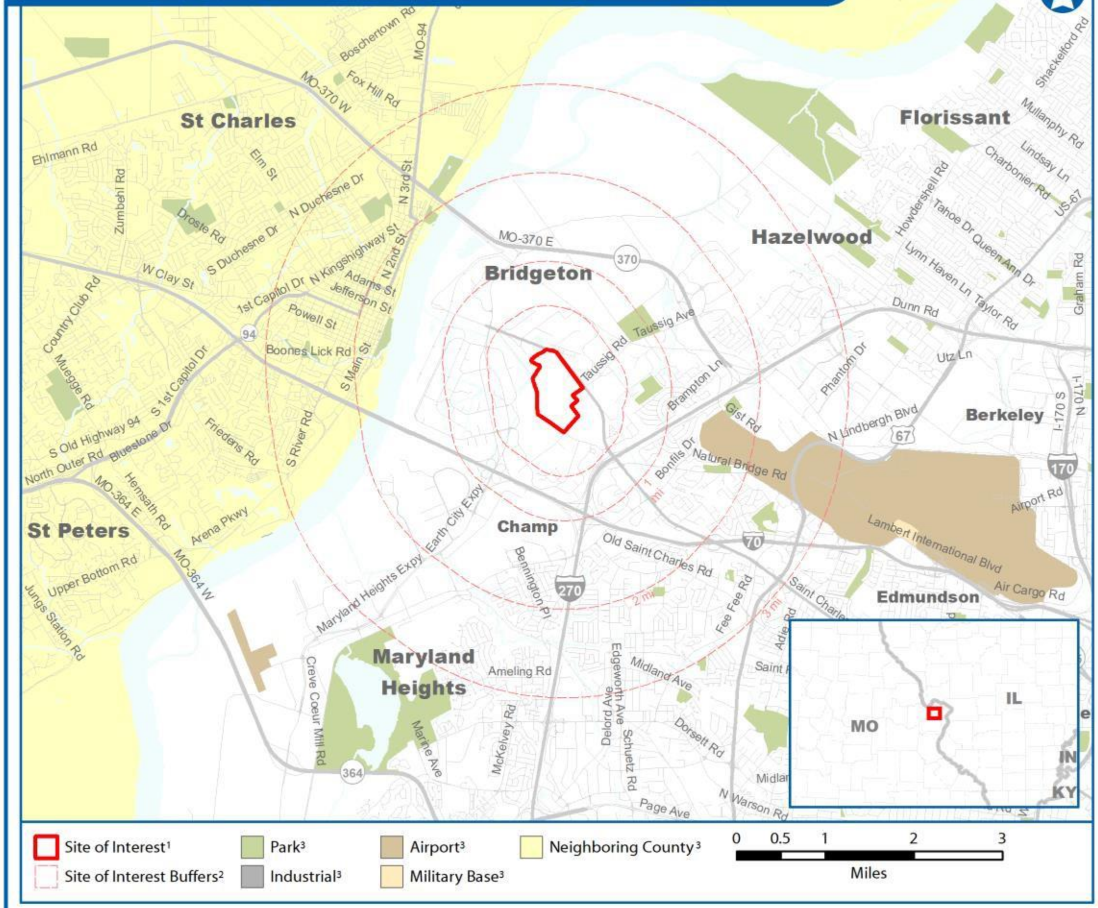
EPA FACILITY ID MOD079900932

INTRODUCTORY MAP SERIES

Westlake Landfill

Bridgeton, St. Louis County, MO

SITE AND DEMOGRAPHIC SNAPSHOT



Demographic Statistics[4,5]
Within 0.5, 1 and 3 Mile buffers of site boundary

Measure	1/2 mile	1 mile	3 mile	Measure	1/2 mile	1 mile	3 mile
Total Population	302	947	43,335	Two or More Races	10	23	871
White Alone	261	798	35,777	Hispanic or Latino[6]	2	14	2025
Black Alone	23	107	4,721	Children Aged 6 and Younger	12	30	3,400
Am. Indian & AK Native Alone	0	1	129	Adults Aged 65 and Older	68	418	7,137
Asian Alone	6	17	891	Females Aged 15 to 44	33	96	8,469
Native Hawaiian & Other Pacific Islander Alone	0	0	13	Housing Units	183	542	19,342
Some Other Race Alone	0	2	930	Housing Units Pre 1950	3	24	3,218

Data Sources: [1]ATSDR GRASP Hazardous Waste Site Boundary Database. [2]ATSDR GRASP. [3]TomTom International BV (2012). [4]US Census 2010.
Notes: [5]Calculated using area-proportion spatial analysis method. [6]Individuals identifying origin as Hispanic or Latino may be of any race.
Projection: NAD 1983 StatePlane Missouri East FIPS 2401 Feet.

PRJ 06263 PSX8 4/11/22

GRASP

Agency for Toxic Substances and Disease Registry

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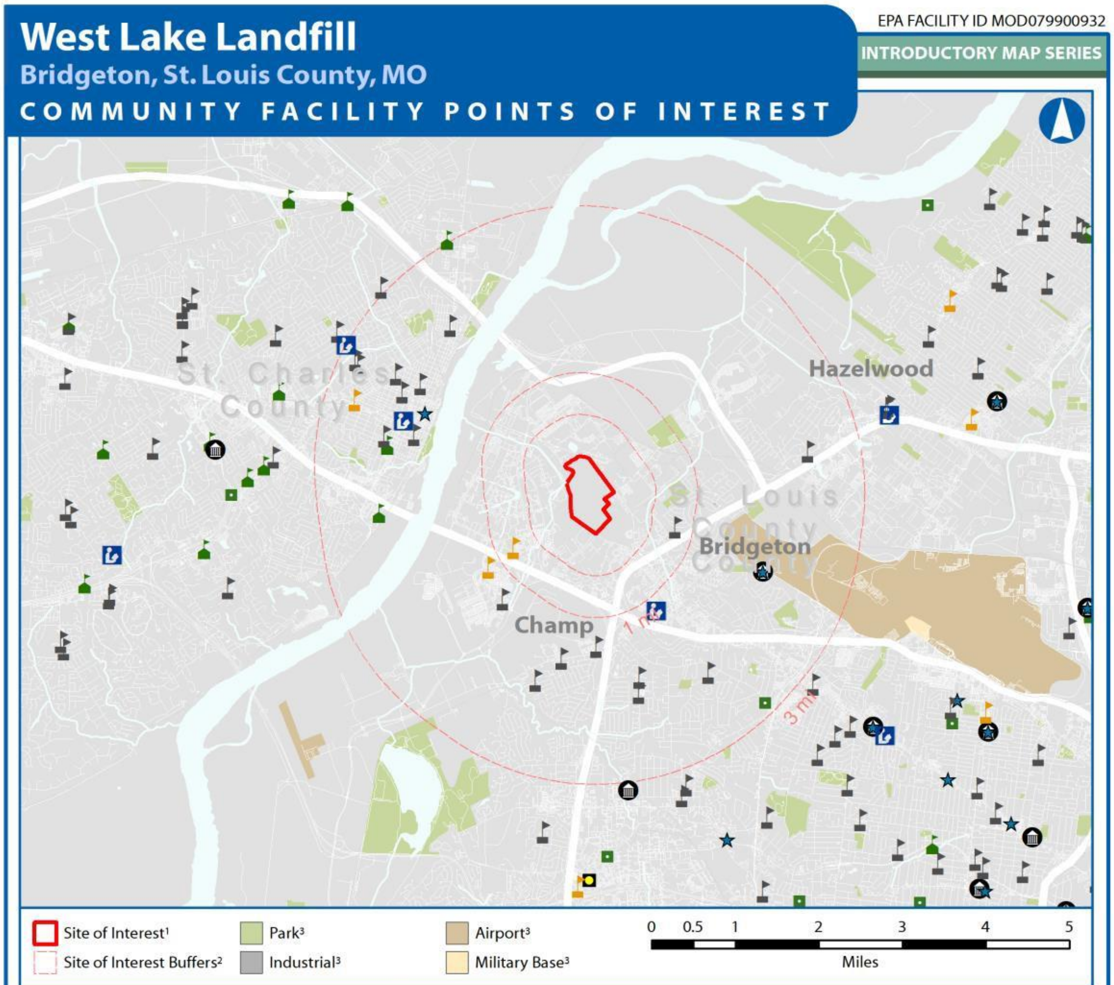
FINAL - FOR PUBLIC RELEASE

Figure 2. Map of Community Facilities near West Lake/Bridgeton Landfill



The **Community Facility Points of Interest Map** depicts the site of interest and community gathering centers in the local area. Information on number, type, and distribution of these facilities is important to efforts to communicate findings to the local population.

Within a **3-mile buffer** of this site are located **43** community gathering centers of which **2.3%** are designated as places of worship.

Community Facility Points of Interest

Within specified distance of site boundary. Not all buffers may be shown on map

Facility	0.5 mile	1 mile	3 miles
Libraries[4]	0	0	3
Schools[4]	0	1	17
Colleges/Universities[4]	0	1	3
City Halls[4]	0	0	2
Civic Centers[4]	0	0	0
Court Houses[4]	0	0	1
Places of Worship[5]	0	0	1
Day Care Centers[6]	0	0	2
Parks[3]	1	3	14

Data Sources: [1]ATSDR GRASP Hazardous Waste Site Boundary Database (2012). [2]ATSDR GRASP. [3]TomTom International BV (2012). [4]NAVTEQ (2010). [5]ESRI. [6]Homeland Security Infrastructure Program 2011.
Projection: NAD 1983 StatePlane Missouri East FIPS 2401 Feet.

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GRASP

Agency for Toxic Substances and Disease Registry

Office of Innovation and Analytics

ATSDR

FINAL - FOR PUBLIC RELEASE

3 INVESTIGATIONS OF GAS AND ODOR EMISSIONS IN AMBIENT AIR

3.1 Chemicals Targeted for Routine Air Monitoring/Sampling

From 2013 to 2015, five comprehensive sampling events were conducted by Republic Services, under MDNR's oversight, for characterization of the landfill source gas and landfill gas emissions into the air. In those events, source gas samples were collected from under the landfill liner, air samples were collected onsite, and ambient (outdoor, offsite) air samples were collected upwind and downwind of the landfill for determination of concentrations of a wide range of chemicals in the landfill gas and air. Targeted chemicals included aldehydes, amines, ammonia, carboxylic acids, carbon monoxide, dioxins/furans, polycyclic aromatic hydrocarbons (PAHs), sulfur-based compounds [i.e., reduced sulfur compounds (RSCs) and sulfur dioxide (SO_2)], and volatile organic compounds (VOCs). The results of comprehensive sampling at upwind and downwind locations are summarized in Appendix A, Table A-1.

MDNR used the comprehensive sampling data to help inform their routine ambient air monitoring/sampling efforts. In comprehensive sampling events, as shown in Appendix A:

- Some aldehyde and VOC concentrations in ambient air occasionally exceeded conservative health-based screening levels and guidelines. Both of those chemical groups (aldehydes and VOCs) were targeted by MDNR for routine ambient air monitoring/sampling.

- Neither sulfur-based compounds nor carbon monoxide were detected in upwind or downwind ambient air samples. However, because they are common landfill gases that can be toxic at low concentrations, sulfur-based compounds and carbon monoxide were targeted by MDNR for routine ambient air monitoring/sampling.

- Other chemicals targeted in the comprehensive sampling events, including amines, dioxins/furans, and PAHs, were either not detected or were detected at concentrations below available screening levels and guidelines. Those chemicals were not selected by MDNR for routine ambient air monitoring/sampling.

Table 1 summarizes MDNR's routine air monitoring/sampling approach. The findings of this health consultation are based on the results of MDNR's routine ambient air monitoring and sampling efforts, in addition to MDNR's and EPA's ambient air quality data collected in the Bridgeton area. Sections 3.2 to 3.4 describe MDNR's routine monitoring and sampling approach in greater detail. Sections 3.5 and 3.6 describe MDNR's and EPA's monitoring and sampling approaches for characterizing air quality in the Bridgeton area.

Table 1. Summary of MDNR's Ambient Air Monitoring/Sampling Approach Bridgeton Landfill, 2013-2018

Monitoring/ Sampling Method	Chemical/ Chemical Class	Monitoring Sampling Locations	Approximate Number of Samples	Sample Duration	Monitoring/ Sampling Frequency	Monitoring/ Sampling Period
AreaRAE® Ambient Air Monitoring	Combined Reduced Sulfur Compounds[a]	3 fixed locations near the landfill	Continuous (>3 million)	Instantaneous	1-3 minutes, 24 hrs/day, 7 days/week	February 2013- July 2018
	Sulfur Dioxide[a]					
	Carbon Monoxide[a]					
Pulsed Fluorescence Ambient Air Quality Monitoring	Sulfur Dioxide[b]	Rider Trail at I-70	Continuous	Instantaneous	24 hrs/day, 7 days/week	May 2016- July 2018[c]
SUMMA® Canister Ambient Air Sampling	VOCs[d]	1-2 upwind, 1-2 downwind of landfill	900	4-hour	Weekly	April 2013- July 2018
Ambient Air Sampling using Sorbent Tubes	Aldehydes[e]	2 upwind, 2 downwind of landfill	80	4-hour	Weekly	April 2013- August 2013
SUMMA® Canister Ambient Air Sampling	Sulfur-Based Compounds[f]	2 upwind, 2 downwind of landfill	156	4-hour	Weekly	April 2013- August 2013
		1 upwind, 1 downwind of landfill		45-50 minute	Monthly	April 2015- July 2018
Surveillance with Hand-held Meters	Benzene[g]	multiple locations in surveillance loop around the landfill	50,800	Instantaneous	Twice daily	April 2013- July 2018
	Hydrogen sulfide[g]					

[a] Combined RSCs, SO_2, and carbon monoxide were measured by AreaRAE® monitors at concentrations at or above 100 ppb, the detection limit of the AreaRAE® sensors. Combined RSCs are hydrogen sulfide (H_2S) and other RSCs detected by the AreaRAE® H_2S sensor.

[b] SO_2 was measured by pulsed fluorescence at concentrations ranging from 0 ppb - 50 ppb or 0 ppb -1000 ppb.

[c] Data continue to be collected to monitor air quality in the Bridgeton area.

[d] Volatile organic compounds (VOCs) were analyzed using EPA method TO-15. Seventy-seven VOCs were targeted in 264 sampling events. Through 2016, two upwind and two downwind samples were typically collected in each sampling event. In 2017-2018, single upwind and downwind samples were collected. Laboratory detection limits varied but were typically <1 ppb.

[e] Aldehydes were analyzed using EPA method TO-11A. Twelve aldehydes were targeted in 20 sampling events. Typically, 2 upwind and 2 downwind samples were collected in each sampling event. Laboratory detection limits varied but were typically <0.5 ppb.

[f] Sulfur-based compounds were analyzed using ASTM method D-5504. Twenty-three sulfur-based compounds were targeted in 58 sampling events. Typically, samples were collected from one (2015-2018) or two (2013) upwind and downwind locations in each sampling event. Laboratory detection limits varied but were typically <20 ppb.

[g] Benzene and H_2S concentrations were measured using hand-held meters during routine surveillance. The detection limit of the UltraRAE® (benzene) meter was 50 ppb. The detection limit of the Jerome® (H_2S) meter was 3 ppb.

3.2 MDNR Continuous Ambient Air Monitoring

From February 2013 to July 2018, MDNR conducted continuous ambient air monitoring at three fixed locations near the landfill (see AreaRAE® Ambient Air Monitoring, Table 1). AreaRAE® monitors were located in residential and commercial areas close to the landfill (i.e., from a few hundred feet to ½ mile from the landfill) to target fugitive gas emissions from the landfill. Continuous operation of the AreaRAE® monitors (24-hours per day, 7 days per week) allowed rapid air quality assessment and response. The monitors were equipped with sensors for measurement of concentrations of hydrogen sulfide (H_2S), SO_2, and carbon monoxide at 100 parts per billion (ppb) or more, in 100 ppb increments, every 1 to 3 minutes.[10,11]

The AreaRAE® sensors are subject to chemical interference [RAE Systems 2015]. They may not only detect a target gas (e.g., H_2S, SO_2) but other, similar chemicals in the air as well. Because the AreaRAE® H_2S sensor is sensitive to methyl mercaptan and potentially sensitive to other RSCs that were detected in the landfill source gas, MDHSS/ATSDR assume that the AreaRAE® H_2S sensors were reading a combination of RSCs in the air and refer to the AreaRAE® H_2S measurements as “combined RSC concentrations” in this health consultation.

As shown in Table 2, multiple AreaRAE® monitors were located at each monitoring station so that at least one AreaRAE® monitor at each of the three fixed monitoring locations was equipped with a sensor for measurement of H_2S (i.e., combined RSCs), SO_2, or carbon monoxide.

Table 2. AreaRAE® Unit Sensors at Monitoring Locations near the Landfill Bridgeton Landfill 2013-2018

Direction from Landfill	AreaRAE® Monitor	Sensor
Southwest	Unit 1	H_2S (combined RSCs), carbon monoxide
	Units 5, 7[a]	SO_2
South, Southeast	Unit 8	SO_2
	Unit 10	H_2S (combined RSCs)
	Unit 12	carbon monoxide
East, Northeast	Unit 2	H_2S (combined RSCs), carbon monoxide
	Unit 13	SO_2

[a] Unit 7 was replaced by unit 5 in October 2014, when unit 7 stopped functioning.

Location of the AreaRAE® monitors was based on multiple factors, including proximity to the landfill, seasonal wind direction, the location of residential areas, and logistical concerns. The air monitors were occasionally relocated in an attempt to measure the highest emissions of gases

[10] AreaRAE® H_2S, SO_2, and carbon monoxide sensor specifications: detection ranges: 0-100 ppm (H_2S), 0-20 parts per million (ppm; SO_2), 0-100 ppm (carbon monoxide); resolution: 0.1 ppm; temperature range: -4°F – 122°F; humidity range: 15% -90% relative humidity [RAE Systems 2015]. The lower detection limit of the sensors was 0.1 ppm (100 ppb).

[11] In this health consultation, MDHSS/ATSDR do not evaluate AreaRAE® measurements of oxygen, total combustible gases, total VOCs, and gamma radiation, which were monitored by MDNR for emergency response purposes.

from the landfill. Figure 3 shows the usual locations of the AreaRAE® monitors and a weather station MDNR installed to monitor meteorological conditions near the landfill.[12] Weather data collected included temperature, relative humidity, wind direction, and wind speed. Wind rose plots showing average seasonal wind speeds and wind directions for the St. Louis area are included in Appendix B.

From April 2013 to July 2018, MDNR staff were stationed near the landfill to monitor the AreaRAE® sensors.[13] MDNR reported hourly maximum and 1-hour averages of the AreaRAE® monitor readings on data sheets posted online at https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill.

3.3 MDNR Ambient Air Sampling for Laboratory Analysis

From February 2013 to July 2018, MDNR regularly collected ambient air samples upwind and downwind of the landfill for laboratory analysis (see SUMMA® Canister Ambient Air Sampling and Ambient Air Sampling using Sorbent Tubes, Table 1). Samples were collected for determination of individual VOC concentrations and periodically for individual aldehyde and sulfur-based compound concentrations. After August 2013, MDNR discontinued sample collection for aldehydes as none had been detected at concentrations of concern downwind of the landfill.

In each sampling event, samples were collected concurrently at locations directly upwind and downwind of the landfill within ½ mile of the West Lake Landfill boundary. Sampling was generally performed on a weekly basis on staggered days of the week. Samples were collected more frequently in May and June 2013 during invasive work on the landfill. From April 2015 to July 2018, samples for sulfur-based compounds were collected on a monthly basis. Selection of sampling times and locations was based on the occurrence of offensive odors, as much as possible, in an attempt to capture peak concentrations of chemicals in ambient air.

Laboratory reporting limits were typically at or below 1 ppb for VOCs, 0.5 ppb for aldehydes, and 20 ppb for sulfur-based compounds. Sampling reports were posted online at https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill.

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[12] The AreaRAE® monitors were initially located east-northeast (units 2 and 13), south-southeast (units 8, 10, 12), and southwest (units 1 and 7) of the landfill. During invasive work in 2013 on the landfill, some of the monitors were temporarily relocated to the north-northeast of the landfill when the winds were predominantly from the south-southwest (not shown). In December 2013, monitors 8, 10, and 12 were relocated to a residential area further to the southeast to better capture landfill gases carried by winds that tend to be from the west/northwest during the colder months. At that time, monitors 2 and 13 were relocated further to the north in anticipation of construction of an isolation barrier between Bridgeton Landfill and Area 1 of OU1 of West Lake Landfill. In October 2014, monitors 8, 10, and 12 were relocated from southeast to east of the landfill.

[13] MDNR omitted from their data reports any AreaRAE® data that were considered invalid due to sensor drift (requiring recalibration of the sensors or sensor replacement), weather extremes, or other interferences. MDHSS did not review the omitted data. Although some of the earlier AreaRAE® measurements from February and March 2013 (prior to set-up of the MDNR station) were likely biased high, MDHSS treated all reported data as valid data.

3.4 MDNR Routine Surveillance

From April 2013 to July 2018, MDNR was stationed near the landfill to regularly check the fixed AreaRAE® monitor readings and conduct twice-daily surveillance of instantaneous H_2S concentrations (using a Jerome® meter) and benzene concentrations (using an UltraRAE® meter) in ambient air near the landfill (see Surveillance with Hand-held Meters, Table 1).[14] MDNR also monitored odor levels using a Nasal Ranger® olfactometer for measurement of odor intensity.[15] Figure 4 shows MDNR's routine surveillance path around the perimeter of West Lake Landfill and in residential and commercial areas up to 2 miles south of the landfill. Shaded in green are residential areas, including the Terrisan and Spanish Village communities located approximately ½ mile southeast and south-southwest of the site.

The lower detection limits of the Jerome® and UltraRAE® meters were 3 ppb and 50 ppb, respectively. Surveillance reports were posted online at https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill.

3.5 MDNR Regional Ambient Air Quality Monitoring

MDNR operates several continuous ambient air monitors throughout Missouri for EPA's Air Quality System. MDNR's regional ambient air quality monitors are equipped with sensors that can measure low concentrations of criteria pollutants, including SO_2, in ambient air.

In May 2016, MDNR installed a special-purpose SO_2 air monitor at the Rider Trail monitoring location, approximately ¾ of a mile south of the landfill at I-70 (see Pulsed Fluorescence Ambient Air Quality Monitoring, Table 1; Figure 4).[16] The Rider Trail monitoring station is one of several air monitoring stations currently located in St. Louis City or County.

The purpose of the SO_2 monitor at the Rider Trail monitoring station is to characterize general ambient air trends in this area, not to characterize Bridgeton Landfill emissions. Data from the station help to put the SO_2 concentrations measured around the landfill into perspective, providing urban/suburban "background" concentrations typical of the area. SO_2 concentrations detected at Rider Trail may have been attributable to landfill emissions but also to other sources in the area, including freeway traffic. Monitoring data submitted to EPA's Air Quality System are available online at https://www.epa.gov/outdoor-air-quality-data [EPA 2021].

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[14] Jerome® J605 meter specifications: detection range: 0.003 ppm-10 ppm H_2S, with accuracies ranging from ±0.03 ppm at low concentrations to ±0.3 ppm at high concentrations; temperature range: 0°C – 40°C [Arizona Instrument LLC 2013]. UltraRAE® 3000 Photoionization Detector specifications: detection range: 0.05 ppm -200 ppm benzene; resolution: 0.05 ppm [RAE Systems 2010].

[15] The Nasal Ranger® olfactometer is used to measure dilution-to-threshold ratios of 1:2 (weaker odors) to 1:60 (stronger odors). Odor intensity is detected by the human nose and is, therefore, a subjective measurement.

[16] Pulsed Fluorescence SO_2 Analyzer, Thermo Environmental Instruments, Inc., Model 43*i*, operated on measurement ranges between 0 ppb - 50 ppb or 0 ppb -1000 ppb with time average setting from 10 to 300 seconds.

Figure 3. Map of MDNR AreaRAE® Monitoring Locations

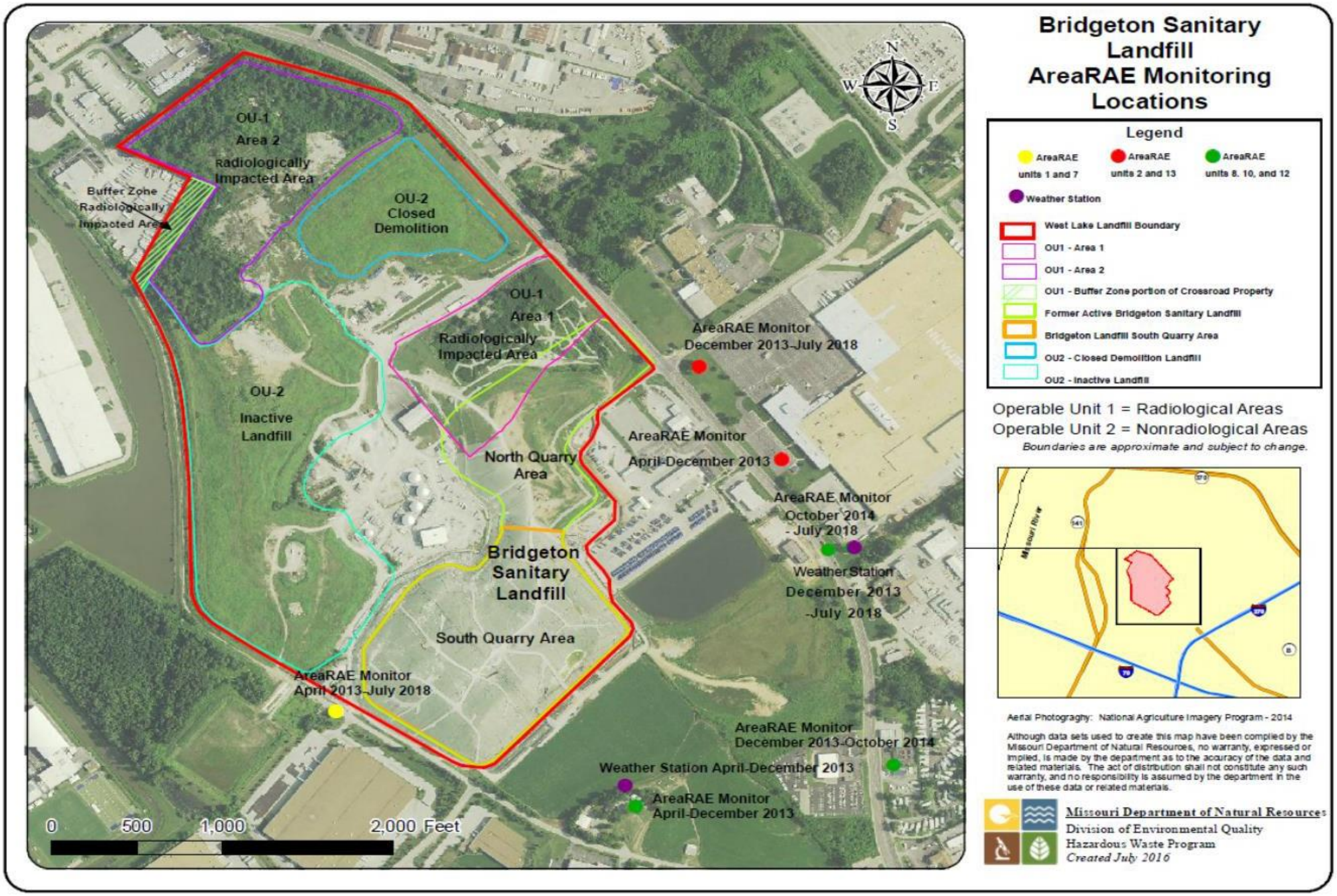
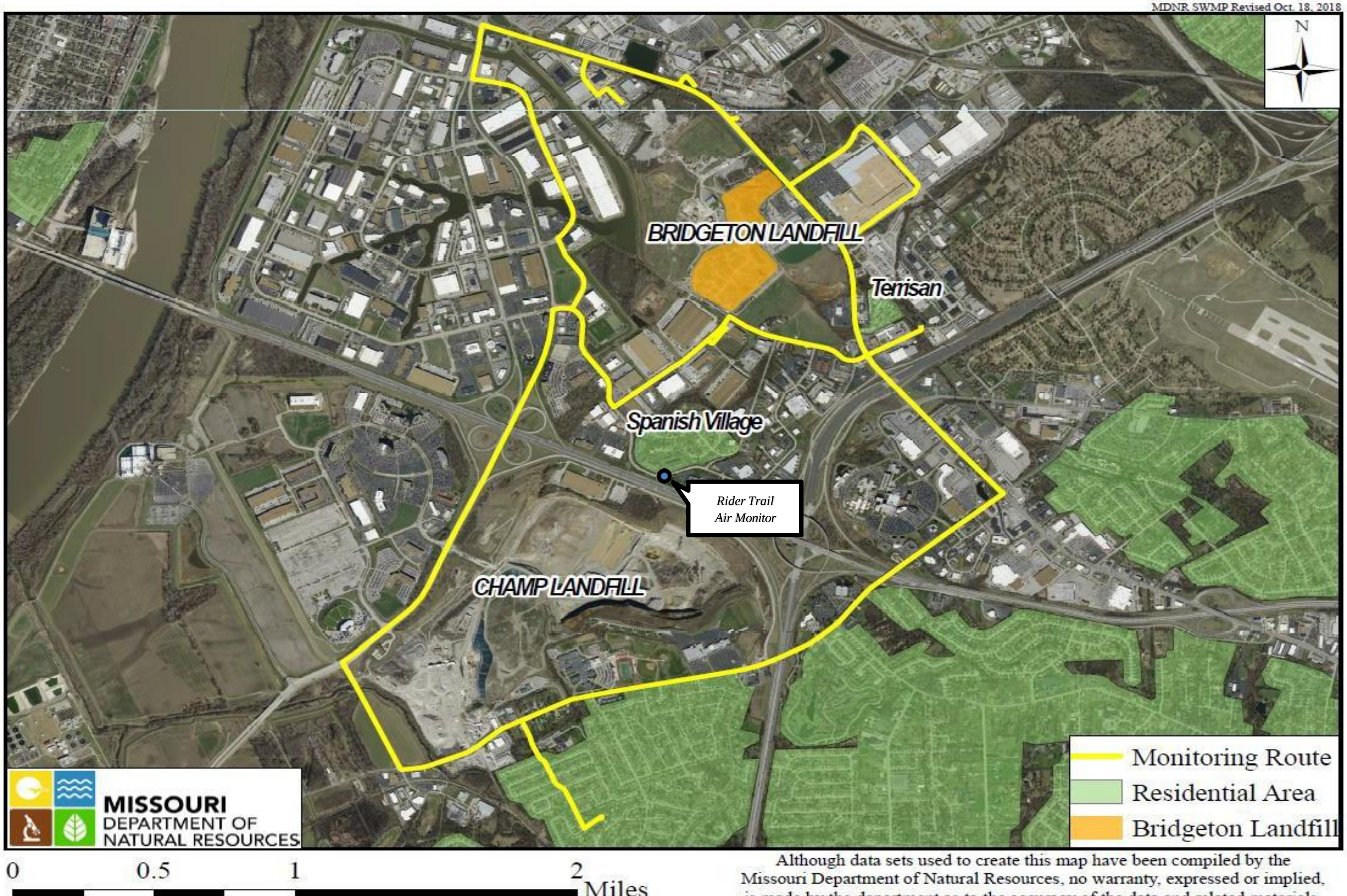


Figure 4. Map of MDNR's Routine Surveillance Path



Aerial Imagery Source: St. Louis Imagery Consortium 2016 6-inch Imagery Collection

Although data sets used to create this map have been compiled by the Missouri Department of Natural Resources, no warranty, expressed or implied, is made by the department as to the accuracy of the data and related materials. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by the department in the use of these data or related materials.

3.6 EPA Ambient Air Monitoring and Sampling

In 2014-2015, EPA conducted ambient air monitoring and sampling to characterize general ambient air trends in the Bridgeton area. EPA's ambient air monitoring/sampling approach is summarized in Table 3. Four air monitoring stations were located up to a mile from the landfill (Figure 5). The fifth air monitoring station was located approximately 2.3 miles from the landfill in St. Charles County to estimate urban/suburban "background" conditions. As shown in the wind rose plot in Figure 5, the fifth station was often upwind of the landfill.

From June 2014 to January 2015, EPA monitored ambient air quality in the Bridgeton area using continuous air monitors (AreaRAE®, RAE Systems, Inc.). The AreaRAE® monitors were operated 24-hours per day, 7 days per week to measure concentrations of H_2S, SO_2, and carbon monoxide in the ambient air. Like the MDNR AreaRAE® sensors, the EPA AreaRAE® sensors measured concentrations of those chemicals in air at 100 ppb or more, in 100 ppb increments, and were subject to interference from other chemicals. EPA contractors did not regularly monitor the AreaRAE® sensors and, therefore, did not omit data that may have been influenced by sensor drift or weather extremes. Because EPA's AreaRAE® data were heavily confounded by these and other factors, the data were reviewed but not used further in this evaluation.

From May 2014 to March 2015, EPA collected ambient air samples for laboratory analysis. For laboratory determination of concentrations of VOCs, ambient air samples were collected from May to December 2014 using SUMMA® canisters and from December 2014 to March 2015 using Radiello® passive samplers. For laboratory determination of concentrations of H_2S, ambient air samples were collected from December 2014 to March 2015 using Radiello® passive samplers. The SUMMA® canister samples were collected over a 24-hour period on a weekly basis. The Radiello® samples were generally collected over a period of 7 days.[17]

Reports containing EPA's air monitoring and sampling results are posted online at: https://semspub.epa.gov/src/collection/07/SC31560.

[17] In one sampling event in January 2015, samples were collected over a 14-day period rather than a 7-day period. The results of the 14-day sampling event did not significantly differ from 7-day sampling events [Tetra Tech 2015b].

Table 3. Summary of EPA's Monitoring/Sampling Approach Bridgeton Area, 2014-2015

Monitoring/ Sampling Method	Chemical/ Chemical Class	Monitoring Sampling Locations	Approximate Number of Samples	Sample Duration	Monitoring/ Sampling Frequency	Monitoring/ Sampling Period
AreaRAE® Ambient Air Monitoring	Combined Reduced Sulfur Compounds[a]	5 fixed locations	Continuous	Instantaneous	1-3 minute, 24 hrs/day, 7 days/week	June 2014-January 2015
	Sulfur Dioxide[a]					
	Carbon Monoxide[a]					
SUMMA® canister ambient air sampling	VOCs[b]	5 fixed locations	194	24-hour	Weekly	May 2014-December 2014
Ambient air sampling using Radiello® passive sampling cartridges	VOCs and Hydrogen Sulfide[c]	5 fixed locations	66	7 day[d]	Weekly	December 2014-March 2015

[a] Combined RSCs, SO_2, and carbon monoxide were measured by AreaRAE® monitors at concentrations at or above 100 ppb, the detection limit of the AreaRAE® sensors. RSCs are H_2S and other RSCs that may interfere with the AreaRAE® H_2S sensor.
[b] VOCs were analyzed using EPA method TO-15. Thirty-eight VOCs were targeted in 33 sampling events. Laboratory reporting limits varied but were typically <1 ppb.
[c] VOCs were analyzed using EPA method TO-17. Fourteen VOCs were targeted in 11 sampling events. H_2S was analyzed using an extraction and colorimetric assay. Laboratory reporting limits varied but were typically <1 ppb.
[d] One sample set was collected over a 14-day period.

Figure 5. Map of EPA's Air Monitoring Stations in the Bridgeton Area

4 EXPOSURE EVALUATION AND CHEMICAL SCREENING ANALYSIS

4.1 Exposure Pathway Analysis

Not every release of a site-related contaminant negatively affects the health of an off-site community. For a contaminant to pose a health problem, an exposure must first occur. Using a process called pathway analysis, MDHSS and ATSDR evaluate site conditions to determine whether people are being or could be exposed to site-related contaminants. In pathway analyses, MDHSS and ATSDR identify whether exposure to contaminated media (e.g., soil, water, food, air, waste, or biota) has occurred, is occurring, or could occur. We define an exposure pathway as complete or potentially complete if exposures occurred, are occurring, or could occur. If there are no exposure possibilities, the pathway is eliminated from further evaluation.

If ambient air monitors or samples are able to detect measurable levels of landfill gases in outdoor air, we consider people living or working nearby to be exposed and thus part of a completed exposure pathway. Breathing contaminants, however, does not always result in harmful health effects. The type and severity of health effects that a person might experience depend on the contaminant concentration in air; the frequency (how often) and duration (how long) of exposure; and other factors, such as pre-existing medical conditions like asthma and cardiovascular disease. Once a person is exposed, characteristics such as age, sex, nutritional status, genetic factors, lifestyle, and health status could influence how the contaminant is absorbed, distributed, metabolized, and excreted. An environmental concentration is not the sole indicator of adverse health outcomes. The likelihood that adverse health outcomes will occur depends on site-specific conditions, individual health status and lifestyle, and genetic factors that affect the route, magnitude, and duration of actual exposure.

4.1.1 Conceptual Exposure Model

This health consultation assesses the potential public health impacts of breathing landfill gases and odors in ambient air. The sources of Bridgeton Landfill gases and odors in the ambient air are fugitive emissions and point source emissions (such as flare stacks emissions) from the landfill.

Flares are used to control organic compound emissions from the landfill. Through the combustion process, flares convert reduced sulfur compounds and VOCs including methane to SO_2 and other combustion products.[18] Because of their high release point (40-45 feet above ground), stack emissions are unlikely to have contributed substantially to the total ground-level emissions near the landfill property boundary. Along with other point source emissions in the Bridgeton area, they may however contribute to ambient air pollution in the area. Because point-source emissions are addressed by MDNR air permits, they are not considered to be within the scope of this public health consultation. They are addressed only in as much as they contributed to the monitoring or sampling results evaluated in this report, including the results from EPA's monitoring stations and MDNR's Rider Trail monitoring station in the Bridgeton area.

[18] Flare/stack emissions are addressed by MDNR air permits based on engineered designs and approved modelling to verify and ensure protection of public health and the environment.

Fugitive gases are gases that are not captured by the landfill's gas extraction system and are released directly into the ambient air at the ground level. After the onset of the SSE in December 2010 and prior to completion of corrective actions at the landfill in 2014, fugitive emissions were likely a substantial percentage of total ground-level emissions from the landfill. MDNR's monitoring and sampling network was located between the landfill and nearby receptor populations (or within nearby residential communities) to measure primarily fugitive emissions rather than flare stack emissions leaving the landfill.

Fugitive gas and odor emissions from the landfill can increase during isolated events such as invasive work or instances of equipment failure, as when extreme weather caused temporary failure of the gas and leachate collection systems.

Gases emitted into the air may persist for varying amounts of time, depending on the chemical, time of day, and season. Landfill gases heavier than air (such as H_2S, SO_2, and many VOCs) may accumulate in low-lying areas, especially in the nighttime, evening, and early morning hours when atmospheric conditions tend to be most stable. Chemical concentrations are generally expected to decrease with increasing distance downwind. Studies indicate that fugitive chemical emissions concentrations may decrease by approximately ten-fold within 0.6 miles of emissions sources [Liu et al 2014; Pohl et al 2017]; however, dispersion rates depend on emission rates and meteorological conditions, including temperature, dew point, wind direction, wind speed, cloud cover, ceiling height, and precipitation.

4.1.2 Evidence of Exposure

Evidence of people's exposure to gases emitted from Bridgeton Landfill includes the periodic perception of distinctive, offensive odors in residential and commercial areas surrounding the landfill. Beginning in 2012, community members frequently complained about noxious odors emanating from the landfill. MDNR also detected distinctive odors in the vicinity of the landfill. During routine surveillance around the perimeter of West Lake Landfill and in residential and commercial areas within two miles of the site, MDNR reported Nasal Ranger® odor readings that were greater than 2:1 dilution in:

- 512 of 6,600 surveillance measurements (7.8%) in 2013,
- 345 of 9,620 measurements (3.6%) in 2014,
- 154 of 9,749 measurements (1.5%) in 2015,
- 104 of 10,220 measurements (1.0%) in 2016,
- 34 of 10,689 measurements (0.3%) in 2017, and
- 3 of 5,469 measurements (less than 0.1%) in 2018.

From 2013 to 2018, the frequency of odor detection by MDNR staff decreased by over 98%. This is a statistically significant decrease ($p<0.00001$ per the chi-square test for trend.)[19]

[19] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

According to MDNR's daily surveillance reports, odors characteristic of the landfill were particularly intense in surrounding areas prior to (and sometimes during) corrective actions at the landfill in 2013 and 2014. Corrective measures at the landfill included reconstruction of the gas and leachate extraction system that was no longer functioning as designed and was allowing the escape of fugitive landfill gases and odors (May-June 2013); installation of an engineered cap to help prevent the release of fugitive gases and odors from the south quarry of the landfill (June-September 2013); and construction of an onsite leachate storage and pretreatment system (March-July 2014) [MDNR 2014]. Particularly offensive odors were also reported during occasional instances of equipment failure that resulted in leachate or gas release [MDNR 2014].

A variety of chemicals produced by the breakdown of organic matter in the landfill likely contributed to the odors emanating from the landfill. Sulfur-based compounds have relatively low odor thresholds and could be responsible for much of that odor. Sulfur-based compounds are commonly detected in urban/suburban air due to their release from multiple sources, including landfills:

- **H_2S and other RSCs**: Landfills are a common source of H_2S and other RSCs, which can be perceived as offensive odor at low concentrations in ambient air [ATSDR 2014a].[20] H_2S was detected in the Bridgeton Landfill source gas. Other RSCs detected in the Bridgeton Landfill source gas include methyl mercaptan, dimethyl disulfide, and dimethyl sulfide.

- **SO_2**: Landfills are a common source of SO_2 in ambient air, in part due to the combustion of sulfur-based compounds to SO_2 by landfill flares and other emissions control equipment.

Table 4 shows sulfur-based compound odor thresholds and typical concentrations in ambient air in the United States. As discussed in the *Landfill Odors* section, people's sensitivity to odors can vary. Some people tend to notice or be bothered by odors at lower threshold concentrations than others. Typically, H_2S and SO_2 concentrations are below odor thresholds.

[20] Other common sources of H_2S in ambient air include petrochemical plants, coke oven plants, paper mills, viscose rayon manufacturing plants, sulfur production plants, iron smelters, food processing plants, manure treatment facilities, textile plants, wastewater treatment facilities, and tanneries [ATSDR 2014a].

Table 4. Sulfur-Based Compound Odor Thresholds

Chemical	Odor Threshold (ppb)	Odor Threshold Definition	Typical Ambient Air Concentration (ppb)	Typical Ambient Air Definition
H_2S[a]	0.5-10	odor thresholds (Ruth 1986)	≤1	typical concentrations in urban air (ATSDR 2014a)
	8	geometric mean odor threshold (Amoore 1985)	2.8-6.3	maximum concentrations in urban air (ATSDR 2014a)
	30	threshold of odor detection by 83% of population and bothersome odor for 40% of population (Cal EPA 2000, 2008)	>90	concentrations in air near some industrial sources (ATSDR 2014a)
Methyl Mercaptan	0.01-2.1	odor detection and recognition thresholds (AIHA 1999)	unknown	
Dimethyl Disulfide	0.01-7.5	odor detection and recognition thresholds (AIHA 1996)	unknown	
Dimethyl Sulfide	1-63	odor thresholds (AIHA 2004)	unknown	
SO_2	450-4,800	odor thresholds (Ruth 1986)	9-37	2010-2018 annual 99th percentile of daily maximum 1-hour average concentrations in St. Louis area (EPA 2019a)
	330-8,000	odor thresholds (AIHA 2013)		

[a] Other odor threshold reviews report threshold values as low as 0.04 ppb or as high as 300 ppb [AIHA 2013; ATSDR 2014a; Guidotti 1994]

4.2 Screening of Chemicals in Ambient Air

In assessing public health risks, MDHSS and ATSDR initially compare chemical concentrations to health-based screening levels and guidelines to identify chemicals of potential public health concern that may need more in-depth evaluation. Screening levels are media-specific concentrations, such as air concentrations, and are not thresholds for harmful health effects; rather, they are conservative (health-protective) values that are set well below levels shown or anticipated to cause adverse health effects. Screening levels are values unlikely to cause adverse health effects, even among sensitive populations. A chemical concentration at or below appropriate screening levels can reasonably be considered safe.

Exceedance of a screening level does not mean that exposures will result in health impacts or that all people will get sick if they are exposed. Rather, screening level exceedance means potential exposures warrant further investigation to determine whether people are at risk of harmful effects. The screening process enables MDHSS and ATSDR to safely eliminate contaminants below levels of health concern from further consideration and to further evaluate potentially harmful contaminants that exceed screening levels. Screening levels are not intended to define clean-up or action levels.

Odor thresholds are chemical concentrations at which a chemical's odor may be perceived or clearly defined. Odor threshold values for a chemical are generally different from the screening level values for that chemical. The perception of an odor does not mean that health effects will occur as a result of exposure to the chemical. Conversely, the absence of odor does not mean that health effects will not occur. At certain odor threshold levels, however, odors can be bothersome and can be associated with physiological responses such as headache and nausea and can reduce the quality of life.

In this section, we define the screening levels and odor thresholds used in this health consultation and summarize exceedances of those values in ambient air near the landfill and in the Bridgeton area. We discuss the frequency of exceedances, and we identify exceedances unlikely to be attributable to emissions from the landfill. Several factors likely contributed to differences in chemical concentrations detected near the landfill and in the Bridgeton area, including sampling distance from landfill, differences in the proximity of various other sources of air pollution, instrument detection limits, sampling duration, sampling times, and wind direction.

4.2.1 Screening Levels and Odor Thresholds

Health-based screening levels used in this health consultation include:

- ATSDR's minimal risk levels (MRLs), which are estimates of air concentrations below which non-cancerous effects are unlikely. ATSDR has developed MRLs for chronic (365 or more days) exposure, intermediate (15 to 364 days) exposure, and acute (0 to14 days) exposure.

- California EPA's (Cal EPA's) reference exposure levels (RELs), which are acute or repeated 8-hour exposure levels not anticipated to cause non-cancerous health effects.

- EPA's reference concentrations (RfCs), which are chronic exposure levels unlikely to pose appreciable risk of harm over a lifetime. RfCs are developed for health effects other than cancer.

- ATSDR's cancer risk evaluation guides (CREGs) and EPA's cancer regional screening levels (cancer RSLs), which are concentrations unlikely to result in more than one additional cancer case in an exposed population of a million people over a lifetime.

Screening levels and odor thresholds are developed for evaluation of single chemical exposures and their odors. Screening levels are generally not available for evaluating exposures to multiple chemicals, which can have a combined effect if they target the same tissue or organ.

> **Screening Combined RSCs:** To screen combined RSCs measured by the AreaRAE® monitors, we compared combined RSC concentrations to the screening levels and guidelines for H_2S, as health-based screening levels are not available for evaluating multiple RSCs or many other single RSCs, including the primary RSCs in the landfill source gas (dimethyl sulfide, dimethyl disulfide, and methyl mercaptan). The toxicity of H_2S is well established [EPA 2017a]. If H_2S is more toxic than the combination of RSCs in ambient air near the landfill, this is a conservative (health- protective) approach that may overestimate potential health risks.

To screen the odors of combined RSCs, we compared combined RSC concentrations to an objectionable odor threshold for combined RSCs (385 ppb) that MDHSS derived from the American Industrial Hygiene Association's (AIHA's) Emergency Response Planning Guideline-1 (ERPG-1) values for individual RSCs (Appendix C).[21, 22] The ERPG-1 values for methyl mercaptan, dimethyl disulfide, and dimethyl sulfide are based on odor threshold values. The ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

Appendix D shows all results of our screening analysis, in which we compared chemical concentrations in ambient air near the landfill and in the Bridgeton area to available health-based screening levels and odor thresholds. Exceedances of screening levels and odor thresholds are summarized in the following sections.

4.2.2 Exceedance of Acute Screening Levels and Odor Thresholds

Table 5 summarizes exceedances of acute screening levels and odor thresholds in ambient air near the landfill and in the Bridgeton area.[23] Shown are the number of exceedances of acute screening levels and odor thresholds at MDNR's surveillance and monitoring locations, MDNR's sampling locations upwind and downwind of the landfill, and EPA's monitoring/sampling stations in the Bridgeton and St. Charles (background) areas.

[21] MDHSS's site-specific odor threshold is based on the percent distribution of dimethyl sulfide, dimethyl disulfide, and methyl mercaptan in the landfill source gas and the assumption that ambient air contains the same percent distribution of those compounds. AIHA's screening level values for dimethyl sulfide, dimethyl disulfide, and methyl mercaptan are based on ERPG-1 values of 5 ppb (methyl mercaptan), 10 ppb (dimethyl disulfide), and 500 ppb (dimethyl sulfide) [AIHA 1996, 1999, 2004].

[22] MDHSS/ATSDR assumed that the AreaRAE® hydrogen sulfide sensor is sensitive to dimethyl sulfide, dimethyl disulfide, methyl mercaptan, and other RSCs in the ambient air. Chemicals similar to hydrogen sulfide may interfere with the AreaRAE® hydrogen sulfide sensor. The sensor has been shown to be nearly as sensitive to methyl mercaptan at high concentrations [RAE Systems 2015] and may be sensitive to others RSCs as well.

[23] Chemicals not listed in Table 5 were either not detected in ambient air or were detected at concentrations below available odor thresholds and noncancer screening levels for acute exposure. Also not shown are exceedances that only occurred upwind of the landfill.

Table 5. Exceedance of Acute Screening Levels & Odor Thresholds
Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2018

Chemical	Instrument Detection Limit (ppb)	Number of Detections/ Number of Measurements	Detected Concentrations (ppb)		Acute Screening Level[a] (ppb)	Odor Threshold[b] (ppb)	Number of Exceedances of Acute Screening Level[c]	Number of Exceedances of Odor Threshold[c]
H_2S and Benzene: MDNR Surveillance with Hand-held Meters[d]								
Hydrogen Sulfide	3	25,965/50,811	ND-45.5 Median: 3 ppb		70 ATSDR MRL 30 Cal EPA REL	8	1 Cal EPA REL	146
Benzene	50	17/50,811	ND-500 Median: Below DL		9 ATSDR MRL	61,000 EPA	16*	Not exceeded
Sulfur-based Compounds: MDNR AreaRAE® Monitoring[e]								
Combined Reduced Sulfur Compounds	100	Continuous measurement	ND- 3,700		70 ATSDR MRL 30 Cal EPA REL	385 MDHSS	17,295*	656
Sulfur Dioxide	100	Continuous measurement	ND-1,600		10 ATSDR MRL	330 AIHA	8,418*	20
Aldehydes: MDNR Sorbent Tube Sampling[f]								
		Downwind	***Upwind***	***Downwind***				
Valeraldehyde	<1	11/44	ND-10.8 Median: Below DL	ND-3.9 Median: Below DL	N/A	0.4 AIHA	N/A	2 upwind 2 downwind
VOCs: MDNR SUMMA® Canister Sampling[g]								
		Downwind	***Upwind***	***Downwind***				
Acetone	<1	475/481	ND-1,400 Median: 3.9	ND-440 Median: 4.2	26,000 ATSDR MRL	400 AIHA	Not exceeded	2 upwind 1 downwind
Benzene	<1	247/481	ND-2.0 Median: Below DL	ND-32.5 Median: 0.16	9 ATSDR MRL	61,000 EPA	2 downwind	Not exceeded
Carbon Disulfide	<1	18/437	ND-7.2 Median: Below DL	ND-18 Median: Below DL	1,990 Cal EPA REL	16 AIHA	Not exceeded	1 downwind
Ethanol	<1	462/481	ND-480 Median: 3.2	ND-150 Median: 3.2	N/A	90 AIHA	N/A	5 upwind 2 downwind

Chemical	Instrument Detection Limit (ppb)	Number of Detections/ Number of Measurements	Detected Concentrations (ppb)		Acute Screening Level[a] (ppb)	Odor Threshold[b] (ppb)	Number of Exceedances of Acute Screening Level[c]	Number of Exceedances of Odor Threshold[c]
VOCs: MDNR SUMMA® Canister Sampling[g]								
		Downwind	***Upwind***	***Downwind***				
Ethylbenzene	<1	71/481	ND-5 Median: Below DL	ND-4.5 Median: Below DL	5,000 ATSDR MRL	2 AIHA	Not exceeded	4 upwind 3 downwind
Propene	<1	41/44	ND-2.9 Median: 0.93	ND-12.1 Median: 0.88	N/A	10.1 AIHA	N/A	1 downwind
VOCs: EPA SUMMA® Canister Sampling[h]								
			St. Charles	***Bridgeton***				
PCE	<1	19/163	ND-2.8 Median: Below DL	ND-12.7 Median: Below DL	6 ATSDR MRL	47,000 EPA	1 Bridgeton area	Not exceeded

[a] Screening levels and health guidelines are ATSDR's MRLs for acute (0-14 days) exposure and California EPA's RELs for acute exposure. If an MRL for acute exposure has not been established, concentrations are compared to the Cal EPA acute REL, if available. For combined RSCs, we used H_2S screening levels and guidelines [ATSDR's MRL for acute exposure to H_2S (70 ppb) and California EPA's REL for acute (1-hour) exposure to H_2S (30 ppb)], because comparison values are not available for evaluating multiple RSCs or many other single RSCs, including the primary RSC components of the landfill source gas (dimethyl sulfide, dimethyl disulfide, and methyl mercaptan). Chemicals exceeding screening levels and health guidelines and identified as being of potential concern in relevant exposure scenarios are analyzed further by comparison to toxicologic and epidemiologic data. This in-depth evaluation is conducted to determine whether an exposure could cause harmful health effects.

[b] Odor thresholds reported in the scientific literature can vary widely due to differences in experimental methodology and human variability. Shown are geometric mean thresholds from EPA (1992), low thresholds from AIHA (2013), a threshold for potentially bothersome H_2S odors [Amoore 1985], and a site-specifically derived threshold for combined RSCs.

[c] Not shown are exceedances that only occurred upwind of the landfill.

[d] Instantaneous concentrations measured twice daily at locations up to 2 miles from the landfill. The detection limit of the UltraRAE® (benzene) meter was 50 ppb. The detection limit of the Jerome® (H_2S) meter was 3 ppb.

[e] Concentrations measured every 1-3 minutes at fixed AreaRAE® locations up to ½ mile from the landfill. The lower detection limit of the monitors was 100 ppb.

[f] Concentrations in 4-hour samples collected up to ½ mile upwind and downwind of the landfill on 20 days in 2013. Laboratory detection limits varied but were typically <0.5 ppb.

[g] Concentrations in 4-hour samples collected up to ½ mile upwind and downwind of the landfill on 264 days in 2013-2018. Laboratory detection limits varied but were typically <1 ppb.

[h] Concentrations in 24-hour ambient air samples collected for EPA in May-December 2014 using SUMMA canisters. Air samples were collected in fixed locations up to 1 mile from the landfill and in a "background" location in St. Charles County 2.3 miles from the landfill. Laboratory reporting limits varied but were typically <1 ppb.

ppb = parts per billion; ND = not detected; N/A = not available/not applicable

*Screening level below lower detection limit; the number of actual exceedances cannot be determined.

As shown in Table 5, chemicals that exceeded acute health-based screening levels were sulfur-based compounds (H_2S, combined RSCs, and SO_2) and benzene.[24] Sulfur-based compounds, an aldehyde (valeraldehyde), and VOCs occasionally exceeded odor thresholds. In one instance, PCE exceeded an acute screening level in the Bridgeton area. What follows is our evaluation of these exceedances.

H_2S near Bridgeton Landfill

Instantaneous H_2S concentrations measured with a hand-held meter during routine surveillance were as high as 45.5 ppb. In 146 instances (110 in 2013; 36 in 2014-2017), instantaneous concentrations met or exceeded 8 ppb, a geometric mean odor threshold at which approximately 11% of the population may be bothered by the odor [Amoore 1985]. In one instance in 2013, an instantaneous concentration exceeded Cal EPA's acute REL (30 ppb), which is based on the 1-hour California Ambient Air Quality Standard (CAAQS) for H_2S and an odor threshold at which H_2S odor can be detected by 83% of the population and can cause discomfort in 40% of the population [Cal EPA 2000, 2008].

The median concentration of H_2S measured during routine surveillance near the landfill was 3 ppb. In 2010-2015, the 50^{th} percentile of H_2S concentrations at urban air quality monitoring sites in the United States was 1 ppb [ATSDR 2014a]. Therefore, the frequency of H_2S detection above 3 ppb (the lower detection limit of the Jerome® meter) near the landfill (approximately 51%) was higher than expected and indicative of a local emissions source. Industrial and other sources of H_2S are common in urban/suburban areas. Bridgeton Landfill likely contributed to H_2S concentrations measured in the ambient air near the landfill.

Most instantaneous concentrations of H_2S measured with the Jerome® meter (i.e., >95% of detected concentrations) were between 3 ppb and 6 ppb, which is similar to maximum concentrations commonly detected in urban areas in the United States (2.8 ppb to 6.3 ppb) [ATSDR 2014a]. In at least 146 measurements, H_2S concentrations near the landfill exceeded maximum H_2S concentrations in urban areas in the United States.

The potential health impacts of breathing H_2S odors in ambient air near the landfill are further analyzed in the *Public Health Implications* section.

Combined RSCs and SO_2 near Bridgeton Landfill

Concentrations of combined RSCs and SO_2 measured by AreaRAE® monitors near the landfill were as high as 3,700 ppb and 1,600 ppb, respectively. Concentrations of combined RSCs and SO_2 exceeded ATSDR's acute MRL for H_2S (70 ppb) and ATSDR's acute MRL for SO_2 (10 ppb). However, the frequencies of exceedance of the acute MRLs are not known, because the lower detection limit of the AreaRAE® H_2S and SO_2 monitors (100 ppb) exceeded those screening levels. Combined RSCs and SO_2 were frequently below detection.

[24] Not included in Table 5 are EPA's AreaRAE® monitoring results. AreaRAE® measurements of combined RSCs (reported as H_2S), SO_2, and carbon monoxide at EPA's monitoring stations occasionally exceeded reporting threshold levels of 2 parts per million (ppm) H_2S, 2 ppm SO_2, and 10 ppm carbon monoxide (i.e., 20% of calibration gas concentrations). Reported concentrations far exceeded health-based screening levels and odor thresholds. However, exceedances of reporting thresholds were determined to be associated with sensor drift, weather extremes, or other interferences [Tetra Tech 2015a].

In 656 instances, combined RSC concentrations exceeded MDHSS's site-specific odor threshold value for combined RSCs (385 ppb). In 20 instances, SO_2 concentrations exceeded a lower odor threshold value for SO_2 (330 ppb).

The potential health impacts of breathing RSCs and SO_2 and their odors in ambient air near the landfill are further analyzed in the *Public Health Implications* section.

Benzene near Bridgeton Landfill

Instantaneous benzene concentrations measured with a hand-held meter during routine surveillance were as high as 500 ppb. In 16 instances (12 in 2013 and four in 2014), benzene concentrations exceeded ATSDR's acute MRL (9 ppb) during routine surveillance. However, the frequency of exceedance is not known, because the lower detection limit of the UltraRAE® meter (50 ppb) exceeded that screening level.

Four-hour average benzene concentrations in air samples collected downwind of the landfill were as high as 32.5 ppb. In two sampling events (one in 2013 and one in 2014), 4-hour average concentrations of benzene downwind of the landfill exceeded ATSDR's acute MRL (9 ppb).

Benzene was detected in the Bridgeton Landfill source gas and has often been found at increased concentrations in landfill gas at other smoldering landfills [Thalhamer 2015]. Hazardous waste sites and gas stations are common sources of benzene in ambient air [ATSDR 2007].[25]

The potential health impacts of breathing benzene in ambient air near the landfill are further analyzed in the *Public Health Implication* section.

Odor Threshold Exceedances

In nine sampling events, downwind 4-hour average concentrations of valeraldehyde, acetone, ethanol, ethylbenzene, carbon disulfide, or propene exceeded odor thresholds. Carbon disulfide and propene were only detected downwind of the landfill at concentrations exceeding their odor thresholds. Valeraldehyde, acetone, ethanol, and ethylbenzene were detected upwind and downwind of the landfill and may have been emitted from other sources.

Potential health effects associated with breathing offensive odors are discussed in the *Landfill Odors* section.

PCE in Bridgeton Area

In one sampling event, a 24-hour average concentration of PCE sample exceeded ATSDR's acute MRL (6 ppb). The sample was collected at EPA's monitoring station 2, located 0.6 miles northwest of the landfill.

PCE was detected by MDNR in some landfill source gas samples and occasionally in ambient air samples collected up to ½ mile from the landfill. However, concentrations in MDNR's ambient air samples were below ATSDR's acute MRL. While the landfill may have been a source of PCE in ambient air, multiple industrial sources were likely also important contributors. Apart from the

[25] Other common sources of benzene in ambient air include vehicle exhaust and industry, especially petroleum refineries and petrochemical, coke, coal, or tire manufacturing [ATSDR 2007].

one PCE concentration spike in EPA's air samples from the Bridgeton area (12.7 ppb), and the one smaller spike in a background sample from St. Charles County (2.8 ppb), 24-hour average concentrations of PCE were similar in Bridgeton and St. Charles County, 2.3 miles from the landfill. Average concentrations at the Bridgeton area monitoring stations were not statistically significantly different from background concentrations ($p=0.78$, monitoring station 1; $p=0.08$, monitoring station 2; $p=0.81$, monitoring station 3; $p=0.75$ monitoring station 4).[26] Median concentrations at the Bridgeton and background locations were below the laboratory reporting limit (0.04 ppb).

4.2.3 Exceedance of Intermediate, Chronic, and Cancer Screening Levels

Table 6 summarizes exceedances of intermediate, chronic, or cancer screening levels in ambient air near the landfill and in the Bridgeton area.[27] Shown are exceedances of intermediate, chronic, and cancer screening levels at MDNR's surveillance and monitoring locations, MDNR's sampling locations upwind and downwind of the landfill, and EPA's monitoring/sampling stations in the Bridgeton and St. Charles (background) areas.

[26] Bridgeton area and background concentrations were compared using the two-sample t-test in ProUCL, following regression on order statistics (ROS) imputation of sample values below laboratory reporting limits [EPA 2016]. Average (mean) concentrations were 0.03 ppb (monitoring station 1), 0.56 ppb (monitoring station 2); 0.02 ppb (monitoring station 3); 0.04 ppb (monitoring station 4); and 0.11 ppb (background station).

[27] Chemicals not listed in Table 6 were either not detected in ambient air or were detected at concentrations below available intermediate, chronic, or cancer screening levels.

Table 6. Exceedance of Intermediate, Chronic, and Cancer Screening Levels Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2018

Chemical	Instrument Detection Limit (ppb)	Number of Detections/ Number of Measurements	Detected Concentrations (ppb)		Intermediate Screening Level[a] (ppb)	Chronic Screening Level[a] (ppb)	Cancer Screening Level[a] (ppb)	Screening Level Exceedances
H_2S: MDNR Surveillance with Hand-held Meters[b]								
Hydrogen Sulfide	3	25,965/50,811	ND-45.5 Median: 3 ppb		20 ATSDR MRL	1.4 EPA RfC	N/A	Intermediate, Chronic
Benzene	50	17/50,811	ND-500 Median: Below DL		6 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Intermediate, Chronic, Cancer
Sulfur-based Compounds: MDNR AreaRAE® Monitoring[c]								
Combined Reduced Sulfur Compounds	100	Continuous measurement	ND-3,700		20 ATSDR MRL	1.4 EPA RfC	N/A	Intermediate, Chronic
Aldehydes: MDNR Sorbent Tube Sampling[d]								
		Downwind	***Upwind***	***Downwind***				***Downwind***
Acetaldehyde	<1	41/44	ND-5.2 Median: 0.32	ND-2.7 Median: 0.39	160 Cal EPA REL	5 EPA RfC	0.25 ATSDR CREG	Cancer
Formaldehyde	<1	35/44	ND-11.2 Median: 0.55	ND-5.4 Median: 0.59	30 ATSDR MRL	8 ATSDR MRL	0.063 ATSDR CREG	Cancer
VOCs: MDNR SUMMA® Canister Sampling[e]								
		Downwind	***Upwind***	***Downwind***				***Downwind***
1,1,2-Trichloroethane	<1	2/481	ND-0.09 Median: Below DL	ND-0.11 Median: Below DL	2 ATSDR MRL	N/A	0.011 ATSDR CREG	Cancer
1,2-Dichloroethane	<1	12/481	ND-1.6 Median: Below DL	ND-4.1 Median: Below DL	N/A	600 ATSDR MRL	0.0095 ATSDR CREG	Cancer
1,2-Dichloropropane	<1	4/481	ND-0.4 Median: Below DL	ND-2.7 Median: Below DL	2 ATSDR MRL	0.87 EPA RfC	N/A	Intermediate, Chronic
1,3-Butadiene	<1	1/481	ND-0.7 Median: Below DL	ND-0.4 Median: Below DL	4 Cal EPA REL	0.9 EPA RfC	0.015 ATSDR CREG	Cancer
1,4-Dichlorobenzene	<1	2/481	ND-3.4 Median: Below DL	ND-0.5 Median: Below DL	200 ATSDR MRL	10 ATSDR MRL	0.04 EPA RSL	Cancer
1,4-Dioxane	<1	10/481	ND-5.5 Median: Below DL	ND-6.4 Median: Below DL	200 ATSDR MRL	30 ATSDR MRL	0.055 ATSDR CREG	Cancer

Chemical	Instrument Detection Limit (ppb)	Number of Detections/ Number of Measurements	Detected Concentrations (ppb)		Intermediate Screening Level[a] (ppb)	Chronic Screening Level[a] (ppb)	Cancer Screening Level[a] (ppb)	Screening Level Exceedances
Benzene	<1	247/481	ND-2.0 Median: Below DL	ND-32.5 Median: 0.16	6 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Intermediate, Chronic Cancer
Bromoform	<1	1/481	ND	ND-0.6 Median: Below DL	N/A	N/A	0.088 ATSDR CREG	Cancer
Carbon Tetrachloride	<1	16/481	ND-0.1 Median: Below DL	ND-0.1 Median: Below DL	30 ATSDR MRL	30 ATSDR MRL	0.026 ATSDR CREG	Cancer
Chloroform	<1	11/481	ND-0.2 Median: Below DL	ND-0.5 Median: Below DL	50 ATSDR MRL	20 ATSDR MRL	0.0089 ATSDR CREG	Cancer
Ethyl Benzene	<1	71/481	ND-5 Median: Below DL	ND-4.5 Median: Below DL	2,000 ATSDR MRL	60 ATSDR MRL	0.25 EPA RSL	Cancer
Methylene Chloride	<1	76/481	ND-35 Median: Below DL	ND-181 Median: Below DL	300 ATSDR MRL	300 ATSDR MRL	18 ATSDR CREG	Cancer
PCE	<1	12/481	ND-1.4 Median: Below DL	ND-3.1 Median: Below DL	6 ATSDR MRL	6 ATSDR MRL	0.57 ATSDR CREG	Cancer
TCE	<1	9/481	ND-4.7 Median: Below DL	ND-0.3 Median: Below DL	0.4 ATSDR MRL	0.4 ATSDR MRL	0.04 ATSDR CREG	Cancer
VOCs: EPA SUMMA® Canister Sampling[f]								
		Bridgeton	***Background***	***Bridgeton***				
1,2-Dichloroethane	<1	1/163	ND-0.1 Median: Below DL	ND-0.05 Median: Below DL	N/A	600 ATSDR MRL	0.0095 ATSDR CREG	Cancer
1,4-Dichlorobenzene	<1	9/163	ND-0.08 Median: Below DL	ND-0.25 Median: Below DL	200 ATSDR MRL	10 ATSDR MRL	0.04 EPA RSL	Cancer
Benzene	<1	152/163	ND-0.38 Median: 0.13	ND-0.41 Median: 0.14	6 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Cancer
Carbon Tetrachloride	<1	157/163	ND-0.09 Median: 0.07	ND-0.2 Median: 0.07	30 ATSDR MRL	30 ATSDR MRL	0.026 ATSDR CREG	Cancer
Chloroform	<1	58/163	ND-0.2 Median: Below DL	ND-0.34 Median: Below DL	50 ATSDR MRL	20 ATSDR MRL	0.0089 ATSDR CREG	Cancer

Chemical	Instrument Detection Limit (ppb)	Number of Detections/ Number of Measurements	Detected Concentrations (ppb)		Intermediate Screening Level[a] (ppb)	Chronic Screening Level[a] (ppb)	Cancer Screening Level[a] (ppb)	Screening Level Exceedances
Hexachlorobutadiene	<1	1/163	ND-0.1 Median: Below DL	ND-0.1 Median: Below DL	N/A	N/A	0.0043 ATSDR CREG	Cancer
TCE	<1	31/163	ND-0.32 Median: Below DL	ND-0.39 Median: Below DL	0.4 ATSDR MRL	0.4 ATSDR MRL	0.04 ATSDR CREG	Cancer
PCE	<1	19/163	ND-2.8 Median: Below DL	ND-12.7 Median: Below DL	6 ATSDR MRL	6 ATSDR MRL	0.57 ATSDR CREG	Intermediate, Chronic Cancer
VOCs: EPA Radiello® Sampling[g]								
		Bridgeton	***Background***	***Bridgeton***				
TCE	<1	3/55	ND	ND-0.07 Median: Below DL	0.4 ATSDR MRL	0.4 ATSDR MRL	0.04 ATSDR CREG	Cancer

[a] The lowest (i.e., most conservative/health-protective) screening levels and guidelines established by ATSDR and EPA. If an MRL for chronic (>1 year) exposure has not been established, concentrations are compared to the RfC, if available. For combined RSCs, we used H_2S guidelines because health-based screening levels are not available for evaluating multiple RSCs or many other single RSCs, including the primary RSC components of the landfill source gas (dimethyl sulfide, dimethyl disulfide, and methyl mercaptan). Chemicals exceeding screening levels and health guidelines and identified as being of potential concern in relevant exposure scenarios are analyzed further by comparison to toxicologic and epidemiologic data. This in-depth evaluation is conducted to determine whether an exposure could cause harmful health effects.

[b] Concentrations of all instantaneous concentrations measured by meter surveillance in 2013-2018. The detection limit of the UltraRAE® (benzene) meter was 50 ppb. The detection limit of the Jerome® (H_2S) meter was 3 ppb.

[c] Concentrations measured every 1-3 minutes at fixed AreaRAE® locations up to ½ mile from the landfill. The lower detection limit of the monitors was 100 ppb.

[d] Concentrations in 4-hour samples collected upwind and downwind of the landfill on 20 days in 2013. Laboratory reporting limits varied but were typically <0.5 ppb.

[e] Concentrations in 4-hour samples collected upwind and downwind of the landfill on 264 days in 2013-2018. Laboratory reporting limits varied but were typically <1 ppb.

[f] Concentrations in 24-hour ambient air samples collected for EPA on 34 days in May-December 2014. Air samples were collected in the Bridgeton area up to 1 mile from the landfill and in a "background" location in St. Charles County 2.3 miles from the landfill. Laboratory reporting limits varied but were typically <1 ppb.

[g] Concentrations in 7- to 14-day air samples collected for EPA in December 2014-March 2015. Air samples were collected in the Bridgeton area up to 1 mile from the landfill and in a "background" location in St. Charles County 2.3 miles from the landfill. The laboratory reporting limits were typically below 1 ppb.

ppb = parts per billion; N/A = not available/not applicable; ND = not detected

As shown in Table 6, chemicals that exceeded intermediate, chronic, or cancer screening levels were sulfur-based compounds (H_2S and combined reduced sulfur compounds), aldehydes (acetaldehyde, formaldehyde), and VOCs including benzene.

H_2S near Bridgeton Landfill

In four instances (two in 2013, one in 2014, and one in 2016), instantaneous concentrations of H_2S measured with a hand-held meter during routine surveillance exceeded ATSDR's screening level for intermediate exposure (20 ppb). However, exceedances did not occur consecutively and are not expected to have lasted 15 – 364 days (the intermediate exposure period). Instantaneous H_2S concentrations also exceeded EPA's RfC (1.4 ppb). The frequency of exceedance is not known, because the lower detection limit of the surveillance meter (3 ppb) exceeded EPA's RfC. H_2S was frequently below detection.

The potential health impacts of breathing H_2S in ambient air near the landfill are further analyzed in the *Public Health Implications* section.

Combined RSCs near Bridgeton Landfill

Concentrations of combined RSCs measured by AreaRAE® monitors near the landfill exceeded ATSDR's intermediate MRL (20 ppb) and EPA's RfC for H_2S (1.4 ppb). The frequencies of exceedance are not known, because the lower detection limit of the AreaRAE® H_2S monitor (100 ppb) exceeded those screening levels. Combined RSCs were frequently below detection.

The potential health impacts of breathing RSCs in ambient air near the landfill are further analyzed in the *Public Health Implications* section.

Aldehydes near Bridgeton Landfill

Four-hour average concentrations of acetaldehyde and formaldehyde in samples collected downwind of the landfill frequently exceeded cancer screening levels. To estimate average long-term exposures to acetaldehyde and formaldehyde downwind of the landfill, MDHSS/ATDSR calculated 95 percent upper confidence limits of arithmetic mean concentrations (95UCLs) [ATSDR 2019].[28] The 95UCLs of acetaldehyde and formaldehyde downwind of the landfill were:

- 0.6 ppb acetaldehyde, exceeding the one in a million cancer screening level
- 1.2 ppb formaldehyde, exceeding the one in a million cancer screening level

As shown in Table 7, the acetaldehyde and formaldehyde 95UCLs were below typical concentrations in urban/suburban air. In 2013, the annual average concentrations in St. Louis City were 1.1 ppb acetaldehyde and 2.6 ppb formaldehyde [EPA 2021]. Multiple regional sources likely contribute to the acetaldehyde and formaldehyde concentrations in ambient air.[29]

[28] 95UCLs were calculated using ProUCL software [EPA 2016]. The 95UCL is an estimated value that equals or exceeds the actual arithmetic mean 95 percent of the time [ATSDR 2019]. It may be lower or higher than the actual arithmetic mean; however, it is highly unlikely (i.e., there is no more than 5 percent probability) that the 95UCL is lower than the actual arithmetic mean.

[29] Aldehydes are a class of chemicals that have natural and man-made sources and are generated when organic materials such as wood and fossil fuels are burned [ATSDR 2010a]. Common sources in outdoor air include vehicle emissions.

Benzene near Bridgeton Landfill

In 16 instances (12 in 2013 and four in 2014), instantaneous concentrations of benzene measured with a hand-held meter during routine surveillance exceeded ATSDR's intermediate MRL (6 ppb) and chronic MRL (3 ppb). The frequency of exceedance is not known, because the lower detection limit of the surveillance meter (50 ppb) exceeded those screening levels. Benzene was frequently below detection.

In three sampling events (two in 2013 and one in 2014), 4-hour average benzene concentrations in samples collected downwind of the landfill exceeded ATSDR's intermediate MRL. In nine sampling events (six in 2013 and three in 2014), downwind benzene concentrations exceeded ATSDR's chronic MRL (3 ppb). Downwind benzene concentrations also exceeded the cancer screening level.

MDHSS/ATSDR calculated 95UCLs to estimate average long-term exposures to benzene downwind of the landfill. As fugitive gas emission amounts likely varied over time, we calculated 95UCLs for three periods of time: before and during reconstruction of the gas and leachate extraction system at the landfill, when fugitive gas emissions were likely highest; during non-invasive corrective actions at the landfill, when fugitive gas emissions had likely decreased; and after completion of corrective action at the landfill, when fugitive gas emissions had likely further decreased. The 95UCLs of benzene downwind of the landfill were:

- 2.6 ppb before and during reconstruction of the gas and leachate extraction system in the south quarry of the landfill (April – June 2013), exceeding the one in a million cancer screening level but not intermediate or chronic screening levels
- 1.2 ppb during capping of the south quarry of the landfill and construction of an onsite leachate storage and pretreatment system (July 2013 – July 2014), exceeding the one in a million cancer screening level but not intermediate or chronic screening levels
- 0.22 ppb following corrective actions at the landfill (August 2014 – July 2018), exceeding the one in a million cancer screening level but not intermediate or chronic screening levels

Before and during reconstruction of the gas and leachate extraction system in the south quarry of the landfill (April – June 2013), benzene concentrations downwind of the landfill (2.6 ppb) were significantly higher than upwind concentrations ($p=0.001$) and significantly higher than the annual average benzene concentration in St. Louis City ($p=0.0002$).[30] In 2013, the average concentration of benzene in St. Louis City was 0.19 ppb [EPA 2021].

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[30] Upwind and downwind concentrations were compared using the two-sample t-test in ProUCL, following ROS imputation of sample values below laboratory reporting limits [EPA 2016]. Downwind concentrations were compared to the 2013 average concentration in St. Louis City using the one-sample t-test in ProUCL, following ROS imputation of non-detected values. Average (mean) concentrations were 1.9 ppb (downwind) and 0.43 ppb (upwind) in April-June 2013; 0.67 ppb (downwind) and 0.16 ppb (upwind) in July 2013-July 2014; and 0.18 ppb (downwind) and 0.14 ppb (upwind) in August 2014-July 2018.

Following reconstruction of the gas and leachate extraction system, downwind concentrations were higher than upwind concentrations, but neither upwind nor downwind concentrations were significantly different than the average concentration in St. Louis City ($p=0.05$, July 2013-July 2014; $p=0.88$, August 2014-July 2018).

The potential health impacts associated with breathing benzene in ambient air near the landfill are further analyzed in the *Public Health Implications* section.

What are Typical Concentrations of Benzene in Ambient Air?

Typical Benzene Concentrations[a]	
Concentration (ppb)	**Definition**
0.26	annual average concentration in urban/suburban air in the United States in 2013 (EPA 2017b)
0.19	annual average concentration in air in St. Louis City in 2013 (EPA 2021)
≤34	maximum concentrations common in urban outdoor air (ATSDR 2007)

[a] Exposures to benzene may also occur indoors, particularly where people smoke cigarettes. Average benzene concentrations in indoor air have been found to be 3.3 ppb in homes of smokers and up to 11.3 ppb in smoke-filled bars, compared to 2.3 ppb in homes of non-smokers [ATSDR 2007].

Other VOCs near Bridgeton Landfill

Other VOCs were infrequently detected downwind of the landfill (i.e., less than 20% frequency).

In a single 4-hour sampling event, a concentration of 1,2-dichloropropane exceeded intermediate and chronic screening levels downwind of the landfill. All other concentrations of that chemical were below those screening levels. In over 80% of samples, concentrations were below the detection limit (typically <1 ppb). Long-term concentrations are not expected to have exceeded intermediate or chronic screening levels over intermediate or chronic durations of exposure.

Maximum concentrations of 12 VOCs (1,1,2-trichloroethane, 1,2-dichloroethane, 1,3-butadiene, 1,4-dichlorobenzene, 1,4-dioxane, bromoform, carbon tetrachloride, chloroform, ethyl benzene, methylene chloride, TCE, and PCE) exceeded cancer screening levels downwind of the landfill. Concentrations of 1,3-butadiene, bromoform, and methylene chloride exceeded cancer screening levels in single sampling events only and are, therefore, not expected to pose substantial cancer risks. At least 95% of concentrations of the other chemicals were below detection (typically <1 ppb).

Generally, concentrations were similar upwind and downwind of the landfill, indicative of the presence of other sources. Multiple regional sources likely contribute to the concentrations of those VOCs in ambient air.

Benzene, Carbon Tetrachloride, and Chloroform in the Bridgeton Area

Maximum concentrations of benzene, carbon tetrachloride, and chloroform exceeded cancer screening levels in air samples collected for EPA in the Bridgeton area. Because benzene, carbon tetrachloride, and chloroform were frequently detected in air, MDHSS/ATSDR calculated

95UCLs to estimate average long-term exposures to those chemicals. The 95UCLs in the Bridgeton area were:

- 0.17-0.19 ppb benzene, exceeding the one in a million cancer screening level
- 0.08 ppb carbon tetrachloride, exceeding the one in a million cancer screening level
- 0.04-0.06 ppb chloroform, exceeding the one in a million cancer screening level

As shown in Table 7, benzene, carbon tetrachloride, and chloroform 95UCLs were similar to typical concentrations in urban/suburban air. Multiple regional sources likely contributed to the concentrations of those VOCs in ambient air.

<u>Other VOCs in the Bridgeton Area</u>

In a single sampling event, PCE exceeded intermediate and chronic screening levels in an air sample collected for EPA in the Bridgeton area. All other concentrations of PCE were below those screening levels. Long-term concentrations are not expected to have exceeded screening levels over intermediate or chronic durations of exposure. TCE and PCE concentrations also exceeded cancer screening levels in the Bridgeton area. However, 95^{th} percentiles of concentrations in the Bridgeton area (0.09 ppb TCE; 0.07 ppb PCE) were below the 95^{th} percentiles of concentrations in background samples (0.21 ppb TCE; 0.18 ppb PCE).

Maximum concentration of three other VOCs (1,2-dichloroethane, 1,4-dichlorobenzene, hexachlorobutadiene) exceeded cancer screening levels in the Bridgeton area.
However, at least 95% of concentrations were below reporting limits (0.05 ppb 1,2-dichloroethane; 0.06 ppb 1,4-dichlorobenzene; 0.04 ppb hexachlorobutadiene) and below the 95^{th} percentiles of concentrations in background samples (0.07 ppb 1,4-dichlorobenzene). The 95^{th} percentiles of background 1,2-dichloroethane and hexachlorobutadiene concentrations were also below reporting limits.

Multiple regional sources likely contributed to the concentrations of those VOCs in ambient air.

<u>What are Typical Aldehyde and VOC Concentrations in Air?</u>

Acetaldehyde[a,c]	0.91 ppb, 1.1 ppb	Carbon Tetrachloride[a,c]	0.08 ppb, 0.1 ppb
Formaldehyde[a,c]	2.6 ppb	Chloroform[b,c]	0.02 - 0.05 ppb, 0.05 ppb
1,2-Dichloroethane[b]	0.1 - 1.5 ppb	Ethylbenzene[b,c]	0.62 ppb, 0.06 ppb
1,2-Dichloropropane[b]	unknown	Hexachlorobutadiene[b,c]	<0.01 ppb
1,3-Butadiene[a,c]	0.07 ppb, 0.03 ppb	Methylene chloride[c]	0.48 ppb
1,4-Dichlorobenzene[b,c]	0.01 - 1.0 ppb, 0.02 ppb	PCE[a,c]	0.02 ppb
1,4-Dioxane[b]	unknown	TCE[c]	0.01 ppb
Benzene[a,c]	0.26 ppb, 0.19 ppb	trans-Dichloroethylene[c]	not detected
Bromoform[b,c]	<0.01 ppb		

[a] 2013 average concentration in urban/suburban air [EPA 2017b]
[b] Typical air concentration from ATSDR Toxicological Profiles [ATSDR 1989, 1997, 2001, 2005b, 2006, 2010b, 2012]
[c] 2013 average concentration in St. Louis City [EPA 2021]

Table 7. Estimated Long-Term Exposure Concentrations
Ambient Air Sampling, Bridgeton Landfill and Bridgeton Area, 2013-2018

Chemical	Estimated Long-Term Exposure Concentration[a] (ppb)	Screening Level (ppb)	Typical Concentration in Ambient Air (ppb)
Aldehydes: MDNR Sorbent Tube Sampling Downwind of the Landfill			
Acetaldehyde	0.6	0.25 ATSDR CREG	0.91 - United States 1.1 - St. Louis
Formaldehyde	1.2	0.063 ATSDR CREG	2.6 – St. Louis and United States
VOCs: MDNR SUMMA® Canister Sampling Downwind of the Landfill			
Benzene			
April - June 2013	2.6	0.04 ATSDR CREG	0.26 - United States 0.19 - St. Louis
July 2013 - July 2014	1.2		
August 2014 - July 2018	0.22		
VOCs: EPA SUMMA® Canister Sampling in the Bridgeton Area			
Benzene	0.17-0.19	0.04 ATSDR CREG	0.26 - United States 0.19 - St. Louis
Carbon Tetrachloride	0.08	0.026 ATSDR CREG	0.08 - United States 0.1 - St. Louis
Chloroform	0.04-0.06	0.0089 ATSDR CREG	0.02-0.05 - United States 0.05 - St. Louis

[a] 95% Upper Confidence Limits (UCLs) of the arithmetic mean calculated using ProUCL software [EPA 2016]. Values are lognormal or nonparametric 95% Percentile Bootstrap UCLs, per ATSDR guidance [ATSDR 2019].
Exceedance of a screening level and typical ambient air concentration indicates a need for further analysis.

4.2.4 Other Sources of Chemicals and Odors in Ambient Air

Bridgeton Landfill is located 15 miles northwest of St. Louis, Missouri, in an urban/suburban environment where people breathe air impacted by chemical and odor emissions from many sources.[31] Other sources of chemicals and odors in the air may be equally (or even more) significant with increasing distance from the landfill, as the landfill gases are diluted and dispersed. Over time, other sources may have also become equally (or more) significant as emissions from the landfill decreased and landfill gas concentrations in ambient air approached levels typical for urban/suburban air. It is difficult to accurately apportion responsibility for air pollutants in areas where there are multiple sources located in close proximity, especially when concentrations in the air are relatively low.

[31] In addition to automobile service stations and vehicle exhaust, other potentially significant sources of chemicals and odors in ambient air in the Bridgeton area include the waste transfer station located within the boundaries of West Lake Landfill and a Metropolitan St. Louis Sewer District sewage lift station located near the landfill boundary. Champ Landfill and a nearby asphalt plant are located approximately 1 mile south-southwest of Bridgeton Landfill in Maryland Heights, Missouri. In August 2016, Champ Landfill, LLC, under a settlement with EPA, agreed to the implementation of several measures to decrease landfill gas emissions and associated odors into the ambient air.

4.3 Further Analysis

In the *Public Health Implications* section, the potential public health impacts of breathing gas emissions from the landfill are further evaluated by comparison of concentrations of chemicals of potential concern to levels at which adverse health effects have been observed in animal, clinical, and epidemiological studies. Evaluation of the ambient air data in relation to observed effect levels allows MDHSS/ATSDR to assess the likelihood of public health impacts. Potential health risks are evaluated for the general public, including the most sensitive groups of individuals whose health may be impacted by breathing those chemicals. The increased cancer risks of breathing chemicals that exceeded cancer risk screening levels are also evaluated.

In addition, the potential health impacts of exposure to landfill odors are further evaluated. While many chemicals likely contributed to odors emanating from the landfill, sulfur-based compounds frequently exceeded their odor thresholds and could be responsible for much of the odor.

5 PUBLIC HEALTH IMPLICATIONS

The public health impacts of breathing chemical emissions in ambient air include toxicological effects. Some individuals may also experience symptoms and quality of life effects when chemicals with offensive odors are below known levels of toxicity. Symptoms from short-term exposure to offensive odors can be physiologically normal responses, while repeated or long-term exposure to offensive odors can trigger more serious health effects. The potential for health effects varies among individuals due to differences in sensitivity, whether those effects occur by toxicological or odor-related mechanisms. In this health consultation, MDHSS/ATSDR evaluate the public health impacts associated with both of those mechanisms.

5.1 Sulfur-Based Compounds

5.1.1 Hydrogen Sulfide

5.1.1.1 Response to Hydrogen Sulfide Odors

As shown in Table 8, H_2S concentrations detected in ambient air typically fell within a range of low odor thresholds reported for H_2S (i.e., thresholds of odor perception or recognition, ranging from 0.5 ppb to 10 ppb). It is, therefore, expected that H_2S contributed to odors perceived by people living or working near the landfill and in the Bridgeton area. Because people's sensitivities to odor vary, because H_2S concentrations typically fell within a range of low odor thresholds, and because there are multiple sources of odors in ambient air, it is unlikely that everyone would have smelled H_2S distinctly or continuously. H_2S smells like rotten eggs.

Occasionally, the odors of H_2S emissions from the landfill may have bothered sensitive individuals living or working near the landfill. In a total of 146 instances in 2013-2018, instantaneous H_2S concentrations measured by the Jerome® meter met or exceeded 8 ppb, a geometric mean odor threshold at which approximately 11% of the population may be bothered by the odor [Amoore 1985]. In 110 instances (i.e., 75% of the 146 instances), those exceedances occurred in 2013, prior to completion of corrective actions at the landfill. On many of those days,

H_2S concentrations exceeded 8 ppb at multiple surveillance locations. If exposures to those concentrations occurred for sufficient time periods on those days, sensitive individuals living or working in that area may have considered H_2S odors offensive and may have experienced adverse neurological effects such as headache and nausea.

On one day in 2013, an instantaneous concentration of H_2S exceeded Cal EPA's acute REL for H_2S (30 ppb; the 1-hour CAAQS for H_2S), which is based on an odor threshold level at which approximately 40% of the population may be bothered by the odor and experience headache and nausea [Cal EPA 2008].

H_2S concentrations measured with the Jerome® meter did not exceed the ATSDR acute MRL of 70 ppb and were, therefore, not likely to cause adverse toxicological effects.

Table 8. Estimated Intensity of Hydrogen Sulfide Odors in Ambient Air Bridgeton Landfill and Surrounding Areas, 2013-2018

Year	Range of Concentrations (ppb)	Number of Detections/ Number of Measurements	Frequency of Detection (%)	Number of Detections ≥8 ppb	Relative Odor Intensity[a]
H_2S: MDNR Jerome® Meter Surveillance [b]					
2013	ND-6 typical 45.5 maximum	4,426/6,491	68	110	Potential odor for some people; more frequently bothersome to sensitive individuals
2014	ND-6 typical 23.3 maximum	4,576/9,370	49	5	Potential odor for some people; less frequently bothersome to sensitive individuals
2015	ND-6 typical 13.9 maximum	3,793/9,806	39	8	
2016	ND-6 typical 22.6 maximum	3,948/9,879	40	9	
2017	ND-6 typical 10.2 maximum	7,223/9,914	73	14	
2018	ND-6 typical 6.8 maximum	1,999/5,351	37	0	

[a] At H_2S concentrations ranging from 0.5 ppb to 10 ppb, some people may be able to perceive an odor [ATSDR 2014a; Ruth 1986]. At a concentration of 8 ppb, approximately 11% of the population may be bothered by the odor [Amoore 1985]. At a concentration of 30 ppb, approximately 40% of the population may be bothered by the odor [Cal EPA 2008].

[b] Instantaneous meter measurements during routine surveillance up to 2 miles from the landfill in 2013-2018. The lower detection limit of the Jerome® meter was 3 ppb.

ppb = parts per billion; ND = not detected

5.1.1.2 Toxicological Effects of Chronic Exposure to Hydrogen Sulfide

To assess the potential health impacts of chronic exposure to H_2S in ambient air, MDHSS/ATSDR compared instantaneous concentrations of H_2S measured with the Jerome® meter to the effect level used to derive EPA's RfC. EPA's RfC for H_2S is based on olfactory effects observed in animal studies and is an estimate of a concentration of H_2S unlikely to pose appreciable risk over a lifetime of exposure.

- EPA's RfC (1.4 ppb) is based on a study that showed exposure of rats to H_2S for six hours per day for ten weeks caused olfactory neuron loss [Brenneman et al. 2000]. In derivation of the RfC for H_2S, an exposure level shown to have no adverse effects (NOAEL) in rats was converted to a human-equivalent NOAEL ($NOAEL_{animal}$ = 10 ppm or 10,000 ppb; human-equivalent NOAEL = 460 ppb). The human-equivalent NOAEL was then divided by an uncertainty factor of 300 to account for possible differences in animal and human sensitivity and the variability in individuals' response to low concentrations of H_2S [EPA 2003]. The same study identified a human-equivalent lowest observed adverse effect level (LOAEL) of 1,363 ppb.

H_2S concentrations were typically below 6 ppb (Table 8), well below an exposure level anticipated to have no adverse effects in humans (human-equivalent NOAEL = 460 ppb) and even further below the human-equivalent LOAEL identified from the same study (human-equivalent LOAEL = 1,363 ppb). Because concentrations were well below the human-equivalent NOAEL and human-equivalent LOAEL (typically a difference of 100- to 200-fold, or two orders of magnitude), it is unlikely that chronic H_2S exposures would have caused adverse olfactory effects in people living or working near the landfill.

This conclusion is supported by comparison to the ATSDR intermediate MRL for H_2S (20 ppb), which is based on the same study and applies to exposures of 15 – 364 days. As discussed in section 4.2.3, *Exceedance of Intermediate, Chronic, and Cancer Screening Levels*, most measured H_2S concentrations were below the intermediate MRL. On the few occasions when the intermediate MRL was exceeded, the duration of exposure was not long enough to cause harmful olfactory effects.

5.1.2 Reduced Sulfur Compounds

Maximum H_2S concentrations detected by MDNR's fixed AreaRAE® H_2S monitors near the landfill (3,700 ppb in 2013; 1,600 ppb in 2014; 400 ppb in 2015; 200 ppb in 2016, 2017, and 2018) were substantially higher than annual maximum concentrations of H_2S measured by the Jerome® meter around the landfill (6.8 ppb to 45.5 ppb).

The difference between the maximum AreaRAE® measurements and maximum Jerome® meter readings may be due to differences in the instruments' sensitivities and susceptibilities to interference, including chemical interference.[32] Chemicals that may interfere with both the Jerome® and AreaRAE® H_2S sensor readings include mercaptans, a group of RSCs [Arizona Instrument LLC 2014; RAE Systems 2015]. The AreaRAE® H_2S sensor has been shown to be sensitive to methyl mercaptan at high concentrations [RAE Systems 2015] and may be quite sensitive to other RSCs as well. Because the AreaRAE® H_2S monitor is prone to chemical

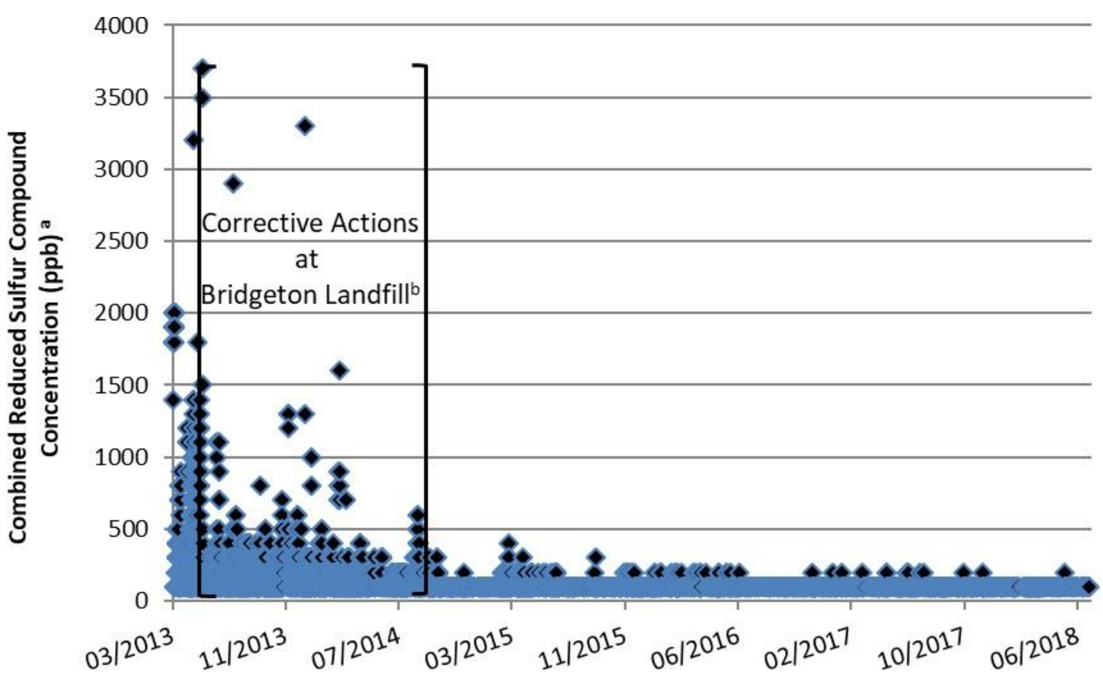
[32] The AreaRAE® sensors are designed to measure high concentrations of chemicals for emergency response, while the Jerome meter is designed to measure hydrogen sulfide at low concentrations. The detection range of the Jerome meter is 3 ppb to 50 ppm. The detection range of the AreaRAE® hydrogen sulfide sensor is 0.1 ppm (100 ppb) to 100 ppm.

interference by other RSCs, in this health consultation MDHSS/ATSDR refer to the AreaRAE® H_2S measurements as combined RSC concentrations.

Because the AreaRAE® monitors continuously measured concentrations in ambient air, they may also have captured concentration spikes of H_2S and other reduced sulfur compounds like mercaptans that the twice-daily surveillance readings with the Jerome® meter did not capture. Assuming AreaRAE® H_2S sensor measurements reflect the distribution of RSCs detected in the landfill source gas (which was found to contain approximately 1.6% H_2S), the estimated peak concentration of H_2S detected by the AreaRAE® monitors (3,700 ppb × 1.6% = 59.5 ppb H_2S) is close to the peak concentration detected by the Jerome meter (45.5 ppb H_2S).

Figure 6 shows daily maximum concentrations of combined RSCs measured every 1-3 minutes by the AreaRAE® monitors near the landfill in 2013-2018. Concentrations tended to be highest prior to and during corrective actions to mitigate gas and odor emissions from the landfill.

Figure 6. Daily Maximum Reduced Sulfur Compound Concentrations MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018



[a] Maximum concentrations of combined RSCs detected by AreaRAE® monitors near the landfill. Measurements were taken every 1-3 minutes.

[b] Corrective actions from May 2013 to June 2014 included reconstruction of the gas and leachate extraction system that was allowing the escape of fugitive gas and odors (May-June 2013), installation of an engineered landfill cap over the south quarry of the landfill (June-September 2013), and replacement of small tanks with 1-million gallon tanks for storage of pre-treated leachate (March-July 2014) [MDNR 2014].

Table 9 and Figure 7 show the annual frequencies of AreaRAE® detections of combined RSCs in ambient air near the landfill. In 2013, combined RSCs were detected at least once in 22.9% -

33.2 % of total monitoring hours, depending on the location of the AreaRAE® monitor. In subsequent years, the frequencies of detection of combined RSCs tended to decrease, except at the monitoring location at the southwest corner of the landfill (near the MSD lift station) where detection frequencies varied slightly.[33] In 2017-2018, combined RSCs were detected at least once in 3.7% to 12.6% of total monitoring hours. From 2013 to 2018, the annual average frequencies of detection of combined RSCs at all three AreaRAE® monitoring locations near the landfill decreased by 74.6%, which was a statistically significant decrease ($p<0.00001$ per the chi-square test for trend).[34]

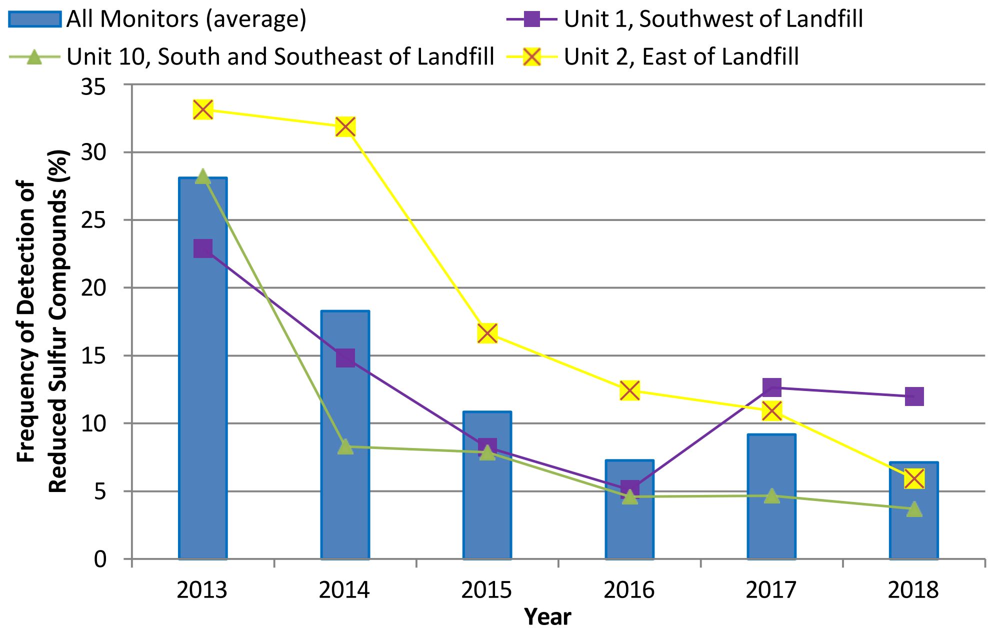
Table 9. Number and Frequency of Detections of Reduced Sulfur Compounds MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018

Year	AreaRAE® Unit 1[a] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 1[a] Frequency of Detection (%)	AreaRAE® Unit 10[d] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 10[d] Frequency of Detection (%)	AreaRAE® Unit 2[e] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 2[e] Frequency of Detection (%)
2013	1,524/6,656	22.9	1,889/6,688	28.2	2,208/6,660	33.2
2014	1,135/7,658	14.8	688/8,305	8.3	2,572/8,070	31.9
2015	670/8,121	8.3	645/8,193	7.9	1,312/7,880	16.6
2016	412/8,050	5.1	379/8,256	4.6	956/7,688	12.4
2017	888/7,020	12.6	371/7,974	4.7	758/6,944	10.9
2018	487/4,063	12.0	160/4,321	3.7	241/4,060	5.9

[a] Southwest of the landfill
[b] Number of detections of combined RSC concentrations in ambient air near the landfill. Shown are the number of times that hourly maximum combined RSC concentrations equaled or exceeded 100 ppb (the AreaRAE® sensor detection limit). Measurements were taken every 1-3 minutes.
[c] Number of hours that the AreaRAE® RSC monitors were operational
[d] South and southeast of the landfill
[e] East of the landfill

[33] AreaRAE® monitor proximity to emissions sources and differences in AreaRAE® unit sensor drift may have contributed to variability in annual detection frequencies. The AreaRAE® monitors at the southwest corner of the landfill were immediately adjacent to the landfill and MSD lift station. At that location, there was little distance between the monitors and emissions sources. Sensor drift could have been affected by multiple factors, including temperature, humidity, precipitation, and age/continual operation of the AreaRAE® units.
[34] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

Figure 7. Annual Average Frequency of Detection of Reduced Sulfur Compounds MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018



[a] The number of hours in which combined reduced sulfur compounds were detected at least once by MDNR's AreaRAE® monitors are shown as a percentage of the total number of hours that data were collected each year. Shown are the annual frequencies of detection at each monitoring site and the annual average frequencies of detection at all three monitoring sites.

5.1.2.1 Response to Reduced Sulfur Compound Odors

The perception of odors of mixtures of multiple chemicals in air is complex and not well understood. Odors may be perceived at or above the odor thresholds of individual chemicals in the mixture. Odors may be perceived below the odor thresholds of individual chemicals if combined chemical concentrations reach an individual threshold. Some odors might also enhance or mask other odors.

MDHSS's site-specifically derived threshold value (385 ppb) is an estimate of the threshold concentration at which people living or working near the landfill may have been able to smell a mixture of several RSCs in ambient air (see calculation in Appendix C). Assuming that the odors of single RSCs can be perceived at their individual odor thresholds, some people living or working near the landfill may have been able to smell objectionable odors of sulfur compounds below that combined odor threshold. For example, methyl mercaptan could have possibly been perceived at AreaRAE® measurements as low as 100 ppb, the detection limit for this instrument:

- Reduced sulfur in the landfill source gas was found to consist of approximately 4.8% methyl mercaptan. Based on that percentage, methyl mercaptan (with an odor threshold of 5 ppb) may have been perceived as objectionable above combined RSC concentrations of 104 ppb (5 ppb ÷ 4.8% methyl mercaptan = 104 ppb), measured by AreaRAE® monitors at 100 ppb.[35]

Table 10 shows the annual frequencies of detection of combined RSCs at concentrations meeting or exceeding odor thresholds for single and multiple RSCs. At the lower detection limit of the AreaRAE® monitors (100 ppb), people may have perceived objectionable odors of some single RSCs with low odor thresholds including methyl mercaptan. At AreaRAE® measurements exceeding MDHSS's odor threshold for multiple RSCs (385 ppb), people more likely perceived objectionable odors of a mixture of RSCs. If exposures to those concentrations occurred for sufficient time periods on those days for odors to become bothersome, individuals may have experienced adverse neurological effects such as headache and nausea.

RSC odors were most likely bothersome in 2013 and 2014, when combined RSCs were detected 28.1% and 18.3% of the time and when combined RSC concentrations exceeded the odor threshold for multiple RSCs (385 ppb) 3.1% and 0.2% of the time, respectively. In subsequent years, the frequency of combined RSC detections at single and combined RSC odor thresholds significantly decreased ($p<0.00001$ per chi-square tests for trend).[36]

Table 10. Estimated Intensity of Reduced Sulfur Compound Odors in Ambient Air Bridgeton Landfill, 2013-2018

Year	Range of Concentrations (ppb)	Number of Detections at Single RSC Odor Threshold[a]/ Number of Measurements[b]	Frequency of Detection (%)	Number of Detections at a Combined RSC Odor Threshold[a] / Number of Measurements[b]	Frequency of Detection (%)	Relative Odor Intensity
Combined RSCs: MDNR AreaRAE® Monitoring						
2013	ND - 3,700	5,621/20,004	28.1	619/20,004	3.1	Odor more frequently bothersome
2014	ND - 1,600	4,395/24,033	18.3	36/24,033	0.2	
2015	ND - 400	2,627/24,194	10.9	1/24,194	<0.1	Odor less frequently bothersome
2016	ND - 200	1,747/23,994	7.3	0/23,994	0	
2017	ND – 200	2,017/21,938	9.2	0/21,938	0	
2018	ND – 200	888/12,444	7.1	0/12,444	0	

[a] Number of times that hourly maximum AreaRAE® measurements met individual RSC odor thresholds (≥100 ppb) or exceeded MDHSS's odor threshold for combined RSCs (385 ppb). Measurements were taken every 1-3 minutes.
[b] Number of hours that the AreaRAE® monitors were operational
ppb = parts per billion; ND = not detected

[35] AIHA ERPG-1 value for methyl mercaptan (5 ppb) is based on an odor threshold below which individuals are unlikely to perceive a clearly defined, objectionable odor [AIHA 1996; AIHA 1999]. The AreaRAE® H_2S monitor measures concentrations in 100 ppb increments.
[36] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

5.1.2.2 Uncertainty in Odor Thresholds

There are several limitations to evaluating the impacts of breathing RSC odors emitted from the landfill. As discussed, the odor thresholds of mixtures of multiple chemicals in air are not well studied or understood. In addition, the odor thresholds of single chemicals are often based on limited data and are often reported over wide concentration ranges due to differences in testing methodology and in people's ability to perceive odors. For example, AIHA's ERPG-1 for dimethyl sulfide (500 ppb) is based on odor thresholds from a single study, in which individuals perceived a faint odor at a concentration of 84 ppb and easily noticed odor at a concentration of 1,900 ppb [AIHA 2004]. As shown in Table 4, numerous other studies show much lower odor thresholds for dimethyl sulfide, ranging from 1 ppb to 63 ppb [Leonardos et al. 1969; Nishida et al. 1979; Sullivan and Krieger 1992]. The exact concentrations at which RSC odors become objectionable are poorly understood and vary within a population.

Odor thresholds are often not well defined. Studies indicate there is a 2- to 10-fold difference between a chemical's lowest odor threshold (i.e., the concentration at which at least one person in a study perceived an odor) and 100% recognition odor threshold (i.e., the concentration at which everyone perceived an odor) [Ruth 1986] and reported odor thresholds are not always defined as a low odor threshold or a 100% recognition odor threshold. Without estimates of the lowest and 100% recognition odor thresholds, the difference between those values is not known, and it is difficult to estimate the percentage of the population potentially bothered by an odor.

5.1.2.3 Toxicological Effects of Acute Exposure to Reduced Sulfur Compounds

To assess the potential health impacts of acute exposure to combined RSCs in ambient air near the landfill, MDHSS/ATSDR compared combined RSC concentrations to the effect level used to derive the acute MRL for H_2S.[37] In comparing combined RSCs to health guideline and effect levels specific to H_2S, MDHSS/ATSDR are taking a conservative health assessment approach that assumes H_2S and the combination of RSCs have similar toxicity levels. While little is known about the toxicity of combined RSCs, the toxicity of H_2S is well established.

ATSDR's acute MRL for H_2S is based on respiratory effects observed in a human clinical study and is an estimated concentration of H_2S unlikely to pose appreciable risk over a specific period of exposure (<2 weeks):

- ATSDR's acute MRL (70 ppb) for H_2S is based on a study in which some people with mild to moderate asthma exhibited measurable narrowing of airways (bronchoconstriction) following 30 minutes exposure to H_2S [Jappinen et al 1990]. In the study, some people also complained of headache, which was not addressed by the MRL.

  Thirty minutes of exposure to 2,000 ppb H_2S was the lowest effect level shown in the study to cause measurable bronchoconstriction. ATSDR derived the acute MRL by

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[37] Lacking critical studies of the toxicities of methyl mercaptan, dimethyl sulfide, and dimethyl disulfide, neither ATSDR nor EPA has established health-based screening levels for those RSCs, which were detected at higher concentrations than hydrogen sulfide in the Bridgeton Landfill source gas.

dividing the LOAEL of 2,000 ppb by an uncertainty factor of 27 to account in part for variability in individuals' response to low concentrations of H_2S [ATSDR 2014a].

Table 11 shows the annual frequencies of AreaRAE® detections at concentrations at or above 200 ppb (a concentration an order of magnitude below the LOAEL). Generally, as combined RSC concentrations exceeded 200 ppb and approached the LOAEL, sensitive individuals, including people with chronic respiratory disease such as asthma, were increasingly likely to experience adverse respiratory effects. Highly sensitive individuals, including people with severe asthma, were more likely to experience adverse respiratory effects than less sensitive individuals or the general population. If concentrations exceeded the LOAEL, adverse health effects were more likely to occur in the general population.

In 2013, people living or working near the landfill were most likely to have experienced aggravated respiratory symptoms from acute exposures to combined RSCs in ambient air. In that year, 13.7% of hourly maximum concentrations in residential and commercial areas near the landfill approached or exceeded the LOAEL. After implementation of corrective actions at the landfill in 2013 and 2014 to reduce fugitive landfill gas emissions, the frequency of combined RSC detections exceeding 200 ppb significantly decreased ($p<0.00001$ per the chi-square test for trend) to only 15 of the almost 22,000 measurements (<0.1%) in 2017.[38] In 2018, combined RSC concentrations in ambient air near the landfill were well below the LOAEL, reaching 200 ppb in only one monitoring hour through July of that year.

Table 11. Potential Public Health Impacts of Breathing Reduced Sulfur Compounds Bridgeton Landfill, 2013-2018

Year	Range of Combined RSC Concentrations (ppb)	Number of Detections at Concentrations ≥200 ppb[a]/ Number of Measurements[b]	Frequency of Detection at Concentrations ≥200 ppb (%)	Likelihood of Public Health Impacts
Combined RSCs: MDNR AreaRAE® Monitoring				
2013	ND - 3,700	2,743/20,004	13.7	More likely to cause respiratory effects
2014	ND - 1,600	720/24,003	3.0	
2015	ND – 400	94/24,194	0.4	Less likely to cause respiratory effects
2016	ND – 200	24/23,994	0.1	
2017	ND – 200	15/21,938	<0.1	
2018	ND – 200	1/12,444	<0.1	

[a] Number of times that hourly maximum combined RSC concentrations equaled or exceeded 200 ppb (i.e., approached or exceeded the LOAEL of 2,000 ppb). Measurements were taken every 1-3 minutes.
[b] Number of hours that the AreaRAE® RSC monitors were operational.
ppb = parts per billion; ND = not detected

Due to the uncertainty of individual response to mixtures of reduced sulfur compounds, some sensitive individuals may experience adverse respiratory effects from acute exposures to combined RSC concentrations below 200 ppb. However, because the lower detection limit of the AreaRAE® H_2S sensor (100 ppb) exceeded ATSDR's acute MRL (70 ppb), the potential for sensitive individuals to have experienced adverse respiratory effects from low level exposures is

[38] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

not known. The lack of data on low-level exposures precludes a detailed assessment of the public health impacts of breathing low concentrations of RSCs in ambient air near the landfill, especially among sensitive individuals.

Note on adverse respiratory effects from chemical exposures

People may experience adverse respiratory effects, such as chest tightness or breathing discomfort, in response to chemical exposures whether or not they perceive an odor in the air. If people do experience adverse respiratory effects during periods of objectionable odor, those effects may not subside when the odors dissipate [ATSDR 2014a].

5.1.2.4 Toxicological Effects of Long-Term Exposure to Reduced Sulfur Compounds

To assess the potential health impacts of long-term exposure to combined RSCs in ambient air near the landfill, MDHSS/ATSDR compared combined RSC concentrations to the effect level used to derive the intermediate and chronic health guidelines for H_2S. ATSDR's intermediate MRL for H_2S and EPA's RfC for H_2S are based on olfactory effects observed in animal studies and estimate the concentrations of H_2S unlikely to pose appreciable risk over long-term periods of exposure.

- ATSDR's intermediate MRL (20 ppb) for H_2S is based on a study that showed exposure of rats to H_2S for six hours per day for ten weeks caused olfactory neuron loss [Brenneman et al. 2000]. In establishing the MRL, ATSDR derived a human-equivalent concentration of the NOAEL in rats ($NOAEL_{animal}$ = 10,000 ppb; human-equivalent $NOAEL_{ADJ}$ = 460 ppb). The same study identified a human-equivalent concentration of the LOAEL in rats ($LOAEL_{animal}$ = 30,000 ppb; human-equivalent $LOAEL_{ADJ}$ = 1,380 ppb).

- EPA's RfC (1.4 ppb) is based on the same study showing exposure to H_2S may result in olfactory neuron loss in rats [Brenneman et al. 2000; EPA 2003].

- Derivations of the intermediate MRL and RfC for H_2S were based in part on the possibility that sensitive individuals might experience adverse health effects from exposure to concentrations well below the adverse effect levels observed in animal studies. The human-equivalent NOAEL (460 ppb) was divided by uncertainty factors of 30 (in derivation of the intermediate MRL) or 300 (in derivation of the RfC) to account for possible differences in animal and human sensitivity and the variability in individuals' response to low concentrations of H_2S [ATSDR 2014a; EPA 2003].

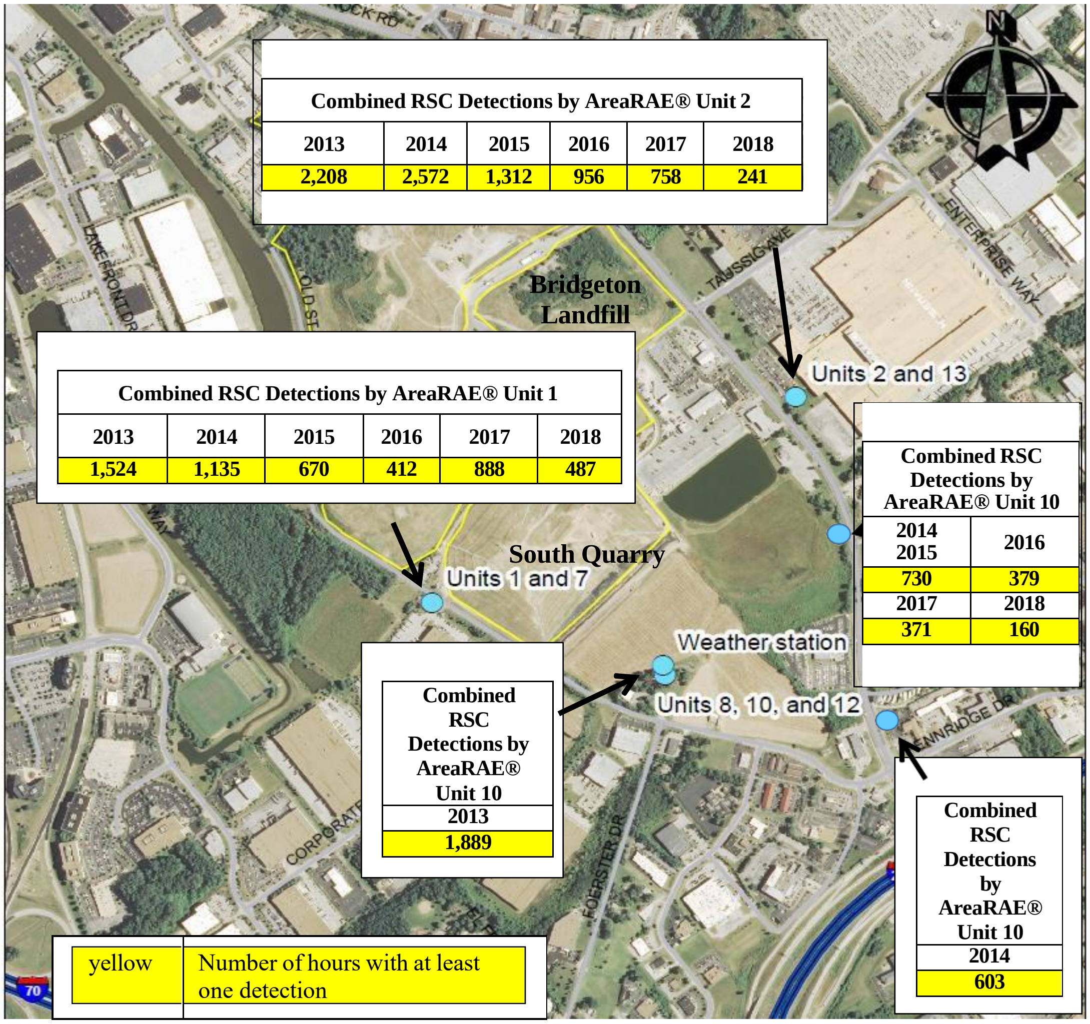
Due to differences in the nasal anatomy of rats and humans, the physiological effects of long-term exposure to low concentrations of RSCs in humans requires further study [Brenneman et al. 2000]. However, observations of olfactory neuron loss in animals exposed to high concentrations of a chemical may explain why humans breathing much lower concentrations might experience changes in their perception of smell [Kilburn et al. 2010]. The offensive odors of chemical emissions may also modify olfactory function and cause loss of smell [Miner 1980].

In 2013, combined RSC concentrations exceeded the human-equivalent NOAEL for H_2S at least once in approximately 2.5% of total monitoring hours and were not consistently elevated for long periods (e.g., weeks or months). In subsequent years, combined RSC concentrations rarely or never exceeded the NOAEL. However, because the lower detection limit of the AreaRAE® H_2S sensor (100 ppb) far exceeded health guidelines for intermediate and chronic exposure to H_2S, the likelihood of long-term exposures to RSCs having caused changes in olfactory function is not known. The need for additional studies on olfactory function and the lack of data on long-term low-level exposures preclude a detailed assessment of the public health impacts of intermediate or chronic exposure to RSCs, especially among sensitive individuals.

5.1.2.5 Distribution of Reduced Sulfur Compounds Near Bridgeton Landfill

Figure 8 shows the number of detections of combined RSCs at monitoring locations near the landfill: a commercial area southwest of the landfill (unit 1), residential areas south and southeast of the landfill (unit 10), and a commercial area east of the landfill (unit 2). Shown are number of hours in which combined RSCs were detected at least once (highlighted in yellow). Combined RSC detections occurred most frequently in 2013-2014. After 2013, the frequency of detection of combined RSCs tended to be highest in the commercial areas east and southwest of the landfill (units 1 and 2).

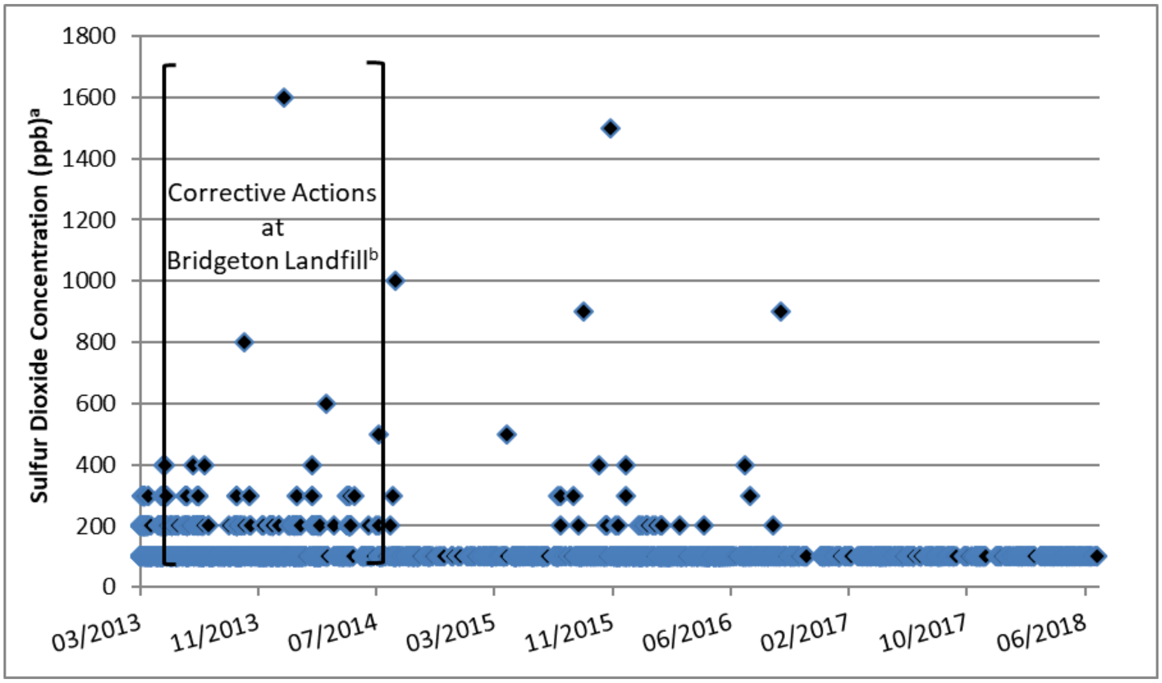
Figure 8. Map of the Number of Detections of Reduced Sulfur Compounds in Ambient Air Bridgeton Landfill, 2013-2018



5.1.3 Sulfur Dioxide

Figure 9 shows daily maximum concentrations of SO_2 measured by the AreaRAE® monitors every 1-3 minutes near the landfill in 2013-2018. SO_2 concentrations were typically less than or equal to 200 ppb, although peak concentrations were as high as 800 ppb in 2013, 1,600 ppb in 2014, 1,500 ppb in 2015, and 900 ppb in 2016. SO_2 was most frequently detected at concentrations above 200 ppb prior to and during the corrective actions to mitigate gas and odor emissions from the landfill. In 2017 and 2018, SO_2 concentrations did not exceed 100 ppb.

Figure 9. Daily Maximum Sulfur Dioxide Concentrations
MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018



[a]Daily maximum concentrations of SO_2 detected by AreaRAE® monitors near the landfill. Measurements were taken by AreaRAE® monitors every 1-3 minutes.
[b]Corrective actions from May 2013 to June 2014 included reconstruction of the gas and leachate extraction system that was allowing the escape of fugitive gas and odors (May-June 2013), installation of an engineered landfill cap over the south quarry of the landfill (June-September 2013), and replacement of small tanks with 1-million gallon tanks for storage of pre-treated leachate (March-July 2014) [MDNR 2014].

Table 12 and Figure 10 show the annual frequencies of AreaRAE® detections of SO_2 in ambient air near the landfill. In 2013, SO_2 was detected at least once in 4.0% - 32.6% of total monitoring hours, depending on the location of the AreaRAE® monitor. In subsequent years, the frequencies of detection of SO_2 in ambient air tended to decrease, although detection frequencies near the southwest corner of the landfill (near the MSD lift station) somewhat varied.[39] From 2013 to 2018, the annual average frequencies of detection of SO_2 at all three AreaRAE® monitoring locations near the landfill decreased by 92.3%. This was a statistically significant decrease ($p<0.00001$ per chi-square test for trend).[40]

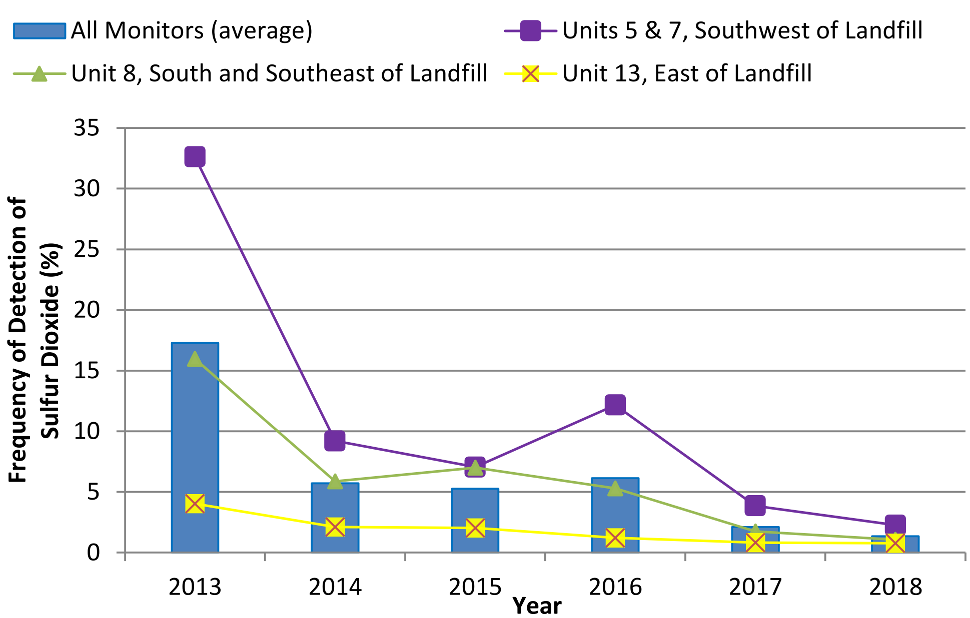
[39] AreaRAE® monitor proximity to emissions sources and differences in AreaRAE® unit sensor drift may have contributed to variability in annual detection frequencies. The AreaRAE® monitors at the southwest corner of the landfill were immediately adjacent to the landfill and MSD lift station. At that location, there was little buffer between the monitors and emissions sources. Sensor drift was affected by multiple factors, including temperature, humidity, precipitation, and age/continual operation of the AreaRAE® units.
[40] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

Table 12. Number and Frequency of Detection of Sulfur Dioxide in Ambient Air MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018

Year	AreaRAE® Unit 5&7[a] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 5&7[a] Frequency of Detection (%)	AreaRAE® Unit 8[d] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 8[d] Frequency of Detection (%)	AreaRAE® Unit 13[e] Number of Detections[b] / Number of Measurements[c]	AreaRAE® Unit 13[e] Frequency of Detection (%)
2013	2,145/6,576	32.6	1,108/6,942	16.0	278/6,919	4.0
2014	767/8,337	9.2	493/8,382	5.9	176/8,378	2.1
2015	509/7,219	7.1	586/8,364	7.0	171/8,432	2.0
2016	971/7,984	12.2	441/8,329	5.3	101/8,307	1.2
2017	298/7,730	3.9	141/8,124	1.7	66/8,108	0.8
2018	90/3,990	2.3	44/4,200	1.0	33/4,318	0.8

[a] Southwest of the landfill
[b] Number of detections of SO_2 concentrations in ambient air near the landfill. Shown are the number of times that hourly maximum SO_2 concentrations equaled or exceeded 100 ppb (the AreaRAE® sensor detection limit). Measurements were taken every 1-3 minutes.
[c] Number of hours that the AreaRAE® SO_2 monitors were operational
[d] South and southeast of the landfill
[e] East of the landfill

Figure 10. Annual Average Frequency of Detection of Sulfur Dioxide in Ambient Air MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2018



[a] The number of hours in which sulfur dioxide was detected at least once by MDNR's AreaRAE® monitors, shown as a percentage of the total number of hours that data were collected each year. Shown are the annual frequencies of detection at each monitoring site and the annual average frequencies of detection all three monitoring sites.

5.1.3.1 Response to Sulfur Dioxide Odors

SO_2 odor may have been occasionally perceptible to people living or working near the landfill. Table 13 shows the annual frequencies of detection of SO_2 at concentrations approaching or exceeding an odor threshold for SO_2 (330 ppb). That odor threshold is the lower value in a range of odor thresholds at which people may be able to perceive SO_2 odor. If exposures to concentrations above the odor threshold occurred for sufficient time periods for odors to become bothersome, individuals may have experienced adverse neurological effects such as headache and nausea.

SO_2 may have occasionally contributed to landfill odors in 2013, when SO_2 concentrations approached or exceeded its odor threshold 0.5% of the time. In subsequent years, the frequencies of detection of SO_2 decreased. In 2017-2018, concentrations of SO_2 near the landfill were well below the odor threshold. This decrease is statistically significant ($p<0.00001$ per the chi-square test for trend).[41] In 2016-2018, concentrations of SO_2 at the Rider Trail monitoring location ¾ of a mile south of the landfill were also well below the odor threshold.

Table 13. Estimated Intensity of Sulfur Dioxide Odors in Ambient Air Bridgeton Landfill, 2013-2018

Year	Range of SO_2 Concentrations (ppb)	Number of Detections above Odor Threshold[a] / Number of Measurements[b]	Frequency of Exceedance of Odor Threshold[c] (%)	Odor Intensity[d]
SO_2: MDNR AreaRAE® Monitoring[e]				
2013	ND – 800	102/20,437	0.5	Potential odor for some people
2014	ND – 1,600	16/25,097	0.06	
2015	ND – 1.500	9/24,015	0.04	
2016	ND – 900	3/24,620	0.01	
2017	ND 100	0/23,962	0	No odor
2018	ND 100	0/12,508	0	
SO_2: Pulsed-Fluorescence Monitoring at Rider Trail-I-70[f]				
2016	ND – 16.5	0/4,925	0	No odor
2017	ND – 21	0/8,176	0	
2018	ND – 29.1	0/4,275	0	

[a] Number of times that SO_2 concentrations equaled or exceeded 300 ppb, nearing or exceeding the lower value in a range of odor thresholds (330 ppb). The AreaRAE® results are the number of hourly maximum concentrations equal to or greater than 300 ppb. AreaRAE® measurements are taken every 1-3 minutes. The pulsed fluorescence results are 1-hour concentrations.
[b] Number of hours that SO_2 monitors were operational
[c] Frequency of detection of SO_2 at concentrations ≥300 ppb, nearing or exceeding an odor threshold of 330 ppb.
[d] At an SO_2 concentration of 330 ppb, some people may be able to perceive an odor [AIHA 2013].
[e] AreaRAE® SO_2 concentrations are detected at 100 ppb or more in 100 ppb increments.
[f] Pulsed Fluorescence SO_2 concentrations are detected in ranges of 0 ppb - 50 ppb or 0 ppb -1000 ppb
ppb = parts per billion; ND = not detected

5.1.3.2 Toxicological Effects of Acute Exposure to Sulfur Dioxide

To assess the potential health impacts of acute exposure to SO_2 in ambient air near the landfill, MDHSS/ATSDR compared SO_2 concentrations to the effect level used to derive the acute MRL for

SO_2. ATSDR's acute MRL is based on respiratory effects observed in a human clinical study and is an estimated concentration of SO_2 unlikely to pose appreciable risk over a specific period of exposure:

- ATSDR's acute MRL (10 ppb) is based on a clinical study in which some people with mild asthma exhibited measurable airway resistance during 10 minutes of exercise and exposure to 100 ppb SO_2 [Sheppard et al. 1981]. In establishing the MRL, ATSDR divided the LOAEL (100 ppb) for increased airway resistance by an uncertainty factor of 9, in part to address the possibility that breathing lower concentrations of SO_2 may aggravate respiratory illnesses in other sensitive individuals such as people with severe asthma [ATSDR 1998].

MDHSS/ATSDR also compared SO_2 concentrations to EPA's Air Quality Index (AQI), which provides additional public health information on acute exposure to SO_2.[42] The AQI for SO_2 is based on data from multiple clinical and epidemiological studies that associate SO_2 exposures with adverse respiratory effects. It is divided by breakpoint concentration values into six color-coded categories representing different levels of potential health concern [EPA 2016]. Table 14 summarizes EPA's guide on the potential public health risks of breathing SO_2 in ambient air.

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[41] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

Table 14. Summary of EPA's Air Quality Index for Sulfur Dioxide

Air Quality	SO_2 Concentration[a] (ppb)	Potential Health Effects from Acute Exposure	Community Members at Risk
Good	0 – 49 1-hour	No symptoms expected	None
Moderate	50 – 75 1-hour	Possible aggravation of respiratory symptoms (chest tightness, wheezing, breathing discomfort)	Highly sensitive individuals[b] during periods of activity
Unhealthy for Sensitive Groups[b]	76 – 185 1-hour	Increasing likelihood of aggravated respiratory symptoms	Sensitive individuals[b] during periods of activity
Unhealthy for General Population	186 – 300 1-hour	Everyone may begin to experience respiratory effects; sensitive groups may experience more serious health effects	General population, especially sensitive individuals[b] during periods of activity
Very Unhealthy for General Population	301 – 600 24-hour	The entire population is increasingly likely to experience respiratory effects	General population
Hazardous	>601 24 hour	The entire population is likely to experience respiratory effects	General population

[a] "Good", "moderate" and "unhealthy" air quality categories are based on the 99^{th} percentile of 1-hour average concentrations, while the "very unhealthy" and "hazardous" categories are based on 24-hour average concentrations.
[b] Sensitive individuals include children, elderly adults, and people with asthma or other chronic respiratory disease. Highly sensitive individuals are individuals who may be particularly sensitive to acute exposures, such as people with severe asthma.

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[42] The Air Quality Index is a tool EPA uses to track and report air quality in the United States, as determined by concentrations of common air pollutants regulated by the Clean Air Act, including SO_2 [EPA 2016]. EPA uses specific and rigorous monitoring and analytical methods for evaluation of ambient air quality. Thus, AreaRAE monitoring results are not typically appropriate for comparison to the AQI. However, in this health consultation, MDHSS has compared the AreaRAE® monitoring results to EPA's AQI to provide a general understanding of how they might be interpreted according to a commonly used air quality index.

Table 15 shows the annual frequencies of AreaRAE® detections of SO_2 at concentrations at or above 100 ppb, the LOAEL at which some people with mild asthma exhibited measurable airway resistance during exercise; and 200 ppb, an AQI concentration in the "unhealthy for the general population" category. Exposure to 200 ppb SO_2 over a sufficient exposure period could cause adverse respiratory effects in the general population, especially in sensitive individuals during periods of activity. Generally, as SO_2 concentrations increase, the general population becomes more likely to experience symptoms, and sensitive individuals become increasingly likely to experience more severe effects. Highly sensitive individuals, including people with severe asthma, are more likely to experience adverse respiratory effects than less sensitive individuals.

In 2013, people living or working near the landfill were most likely to have experienced respiratory symptoms from acute exposures to SO_2 in ambient air near the landfill. In that year, 17.3% of hourly maximum concentrations met or exceeded 100 ppb, and 2.6% of hourly maximum concentrations met or exceeded 200 ppb. Following implementation of corrective action at the landfill, the frequency of SO_2 detections decreased. In 2017 and 2018, SO_2 concentrations in ambient air near the landfill did not exceed 200 ppb. This decrease in detections of SO_2 at concentrations at or above 200 ppb is statistically significant ($p<0.00001$ per the chi-square test for trend).[43]

Table 15. Potential Public Health Impacts of Breathing Sulfur Dioxide Bridgeton Landfill 2013-2018

Year	Number of Detections at Concentrations ≥100 ppb[a]/ Number of Measurements[b]	Frequency of Detection at Concentrations ≥100 ppb (%)	Number of Detections at Concentrations ≥200 ppb[a]/ Number of Measurements[b]	Frequency of Detection at Concentrations ≥200 ppb (%)	Likelihood of Public Health Impacts[c]
SO_2: MDNR AreaRAE® Monitoring[d]					
2013	3,531/20,437	17.3	521/20,437	2.6	More likely to cause respiratory effects in the general population, especially sensitive individuals
2014	1,436/25,097	5.7	151/25,097	0.6	Less likely to cause respiratory effects in the general population, including sensitive individuals
2015	1,266/24,015	5.3	18/24,015	0.07	
2016	1,513/24,620	6.1	15/24,620	0.06	
2017	505/23,962	2.1	0/23,962	0	
2018	167/12,508	1.3	0/12,508	0	
SO_2: MDNR Pulsed-Fluorescence Monitoring at Rider Trail-I-70[e]					
2016	0/4,925	0	0/4,925	0	Good air quality
2017	0/8,176	0	0/8,176	0	
2018	0/4,275	0	0/4,275	0	

[a] Number of times that SO_2 concentrations equaled or exceeded the LOAEL used to derive ATSDR's acute MRL (100 ppb) or AQI concentration unhealthy for the general population (200 ppb). AreaRAE® measurements were taken every 1-3 minutes. The pulsed fluorescence results are 1-hour concentrations.
[b] Number of hours that SO_2 monitors were operational

[43] Chi-square test for trend statistics were calculated using Epi Info™ [Dean et al. 2019].

[c] EPA's AQI defines 99th percentile 1-hour average concentrations within a range of 186 ppb – 300 ppb as "unhealthy" for the general population.
[d] AreaRAE® SO_2 concentrations are detected at 100 ppb or more in 100 ppb increments.
[e] In 2016-2018, 1-hour average SO_2 concentrations were ≤29.1 ppb. Pulsed Fluorescence SO_2 concentrations are detected in ranges of 0 ppb - 50 ppb or 0 ppb -1000 ppb
ppb = parts per billion; ND = not detected

Some sensitive individuals, particularly people with asthma, may experience adverse respiratory effects from acute SO_2 exposures at AQI concentrations defining "moderate" air quality [i.e., concentrations in yellow (50 ppb - 75 ppb)] or air quality "unhealthy for sensitive groups" [i.e., concentrations in orange (76 ppb -185 ppb)]. However, because the lower detection limit of the AreaRAE® SO_2 sensor (100 ppb) exceeded those AQI breakpoint values (50 ppb and 76 ppb), as well as ATSDR's MRL for acute exposure to SO_2 (10 ppb), the likelihood of sensitive individuals having experienced adverse respiratory effects from low level exposures is not known. The lack of data on low level exposures precludes a detailed assessment of the public health impacts of breathing low concentrations of SO_2 in ambient air near the landfill, especially among sensitive individuals.

In 2016-2018, 1-hour average SO_2 concentrations at the Rider Trail regional monitoring location (¾ of a mile from the landfill) were 29.1 ppb or less, well below the human LOAEL (100 ppb) and AQI values defined as unhealthy, or potentially unhealthy, for sensitive individuals (50 ppb – 185 ppb). In 2017-2019 and 2018-2020, the 99th percentile of 1-hour average SO_2 concentrations at the Rider Trail location were 14 ppb and 12 ppb, respectively [MDNR 2021], well below EPA's 1-hour primary National Ambient Air Quality Standard for SO_2 (75 ppb). Twenty-four-hour averages of SO_2 concentrations were 5.7 ppb or less [EPA 2021], not exceeding the World Health Organization's Air Quality Guideline of 7.6 ppb for 24-hour exposures to SO_2 [WHO 2006].

5.1.3.3 Toxicological Effects of Long-term Exposure to Sulfur Dioxide

Health guidelines for intermediate or chronic exposure to SO_2 have not been established by either ATSDR or EPA. Long-term exposure to SO_2 may aggravate respiratory illness, especially in sensitive individuals including people with asthma, children, and elderly individuals with chronic respiratory disease [EPA 2014]. However, additional studies are needed to determine concentrations that, over the long term, might have those effects.

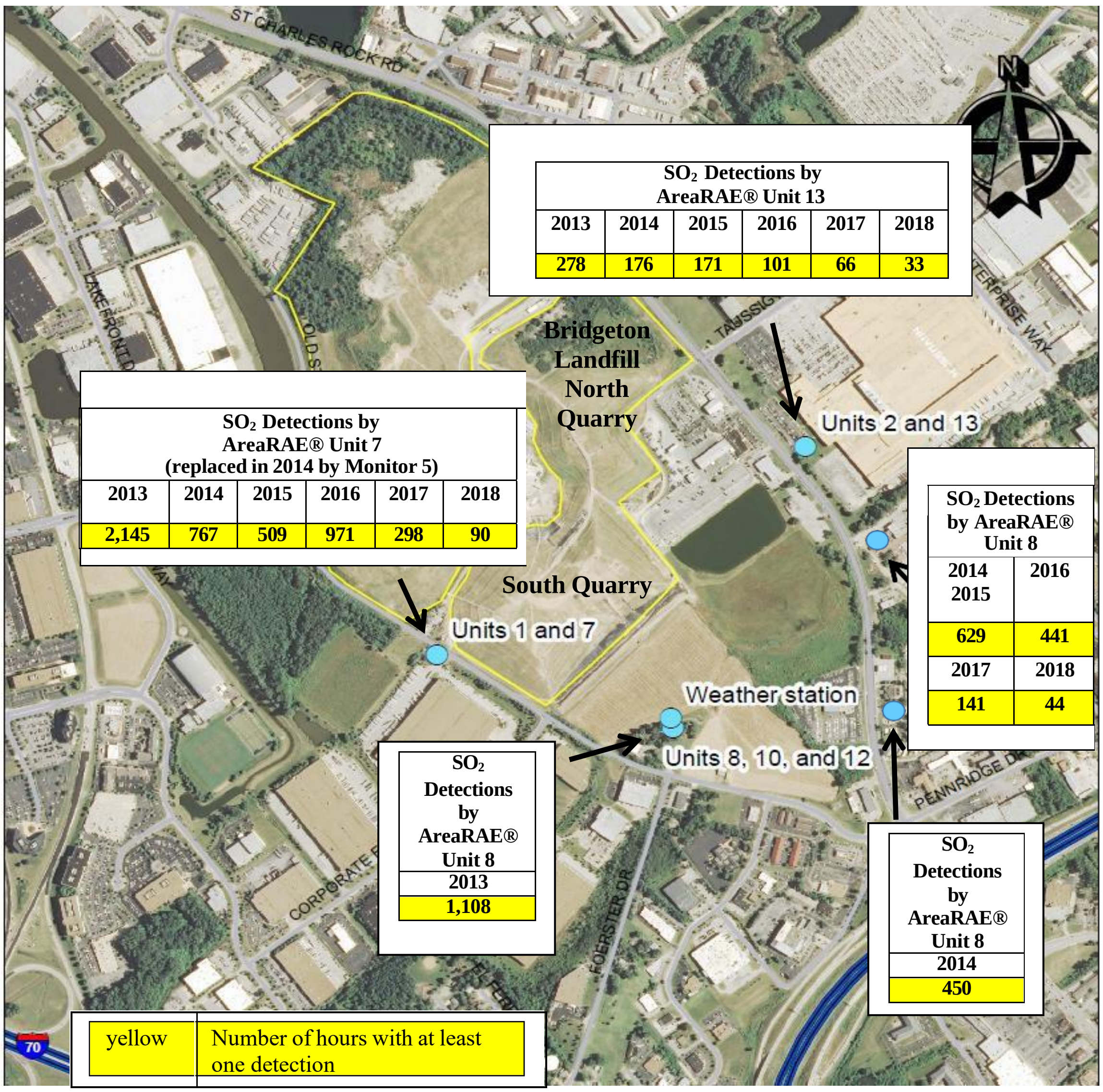
5.1.3.4 Distribution of Sulfur Dioxide Near Bridgeton Landfill

Figure 11 shows the number of detections of SO_2 at AreaRAE® monitoring locations near the landfill: the commercial area southwest of the landfill (unit 7), residential areas south and southeast of the landfill (unit 8), and a commercial area east of the landfill (unit 13). Shown are number of hours in which SO_2 was detected at least once (highlighted in yellow). SO_2 detections occurred most frequently in 2013 in the commercial area southwest of the landfill. After 2013, the frequency of detection of SO_2 tended to be highest in the commercial area southwest of the landfill, possibly due to its proximity to the landfill and other potential sources including the MSD lift station.

5.1.3.1 Ambient Air Quality in the St. Louis Region

The AQI is reported daily for the St. Louis region and many other regions throughout the country [EPA 2019b]. Based on all air quality monitoring station results in the St. Louis area, EPA reported air quality in the St. Louis region as "good" or "moderate" on most days in 2013-2018 [EPA 2021]. Occasionally, because of elevations of one of the four criteria pollutants (ground-level ozone, particulate matter, carbon monoxide, or SO_2) above a national ambient air quality standard, regional air quality was reported as "unhealthy for sensitive groups". The current AQI by zip code can be viewed online at https://airnow.gov. The zip code of Bridgeton, Missouri, is 63044.

Figure 11. Map of Numbers of Detections of Sulfur Dioxide in Ambient Air Bridgeton Landfill 2013-2018



5.1.4 Supporting Community Studies

5.1.4.1 Acute exposures

In 2016, the St. Louis County Department of Public Health (SLCDPH) conducted a survey to evaluate the health of residents living near the landfill [SLCDPH 2016]. In the survey, people living within a 2-mile radius of the landfill were asked about the occurrence of respiratory illness in their households and the occurrence of respiratory or other health symptoms within the previous 12 months. The prevalence of asthma and chronic obstructive pulmonary disease (COPD) was not significantly elevated compared to households farther away from the landfill, but "other respiratory conditions" including attacks of shortness of breath were significantly higher. The frequency of odor perception and worry about neighborhood environmental issues in residents living near the landfill was also higher. It is important to remember that the 2016 survey was conducted after completion of corrective actions in 2013-2014 at Bridgeton Landfill to reduce fugitive gas emissions from the landfill.

The following studies in other communities support the possibility that some individuals living or working near Bridgeton Landfill may have experienced respiratory effects (such as chest tightness, wheezing, or difficulty breathing) and neurological symptoms (such as headache and nausea) as a result of acute exposures to mixtures of low concentrations of H_2S and other RSCs in the ambient air, whether by toxicological or odor-related mechanisms. The studies also support the possibility that sensitive individuals, including children and elderly adults, may have been particularly susceptible to adverse respiratory effects.

- In a study of community exposure to reduced sulfur compounds emitted from an animal slaughter and tanning facility in Nebraska, 30-minute rolling-average exceedance of a threshold value of 30 ppb total reduced sulfur (TRS) was shown to be associated with increased numbers of unplanned hospital visits for respiratory illnesses, including asthma, in children [Campagna et al 2004]. In the study, total reduced sulfur (TRS) concentrations were combined H_2S, dimethyl sulfide, dimethyl disulfide, and methyl mercaptan concentrations. TRS was measured in concentrations as high as ~800 ppb (maximum 1-minute concentrations) that contained 10%-50% H_2S.

  In that study, the researchers found a positive association between elevated TRS concentrations and increased visits for asthma in children but not adults, suggesting that children may be particularly susceptible to the adverse effects of breathing reduced sulfur compounds.

- In a study of community exposure to emissions from an oil refinery in California, residential exposures to low concentrations of RSCs were associated with neurological symptoms such as headache and nausea [Kilburn and Warshaw 1995]. One-week average concentrations of RSCs in indoor air were 10 ppb H_2S with periodic peaks of 100 ppb H_2S, 4 ppb dimethyl disulfide, and 2 ppb mercaptans, although different exposure levels at different duration times may have contributed to symptoms.

- In studies of community exposures to sulfur compounds emitted from sulfur-producing pulp mills in Finland, acute exposures to low TRS concentrations were associated with increased risks of respiratory and neurological effects [Haahtela et al. 1992; Marttila et al. 1995]. In one of the studies, a higher prevalence of symptoms followed exposures to 25 ppb and 30 ppb H_2S and unknown concentrations of other malodorous sulfur-based compounds over two days, when H_2S concentration peaks, measured in 4-hour increments, were as high as 100 ppb [Haahtela et al. 1992]. In that study, 23 percent of community members reported neurological symptoms such as headache and nausea, and 35 percent of community members reported breathlessness.

The AQI for SO_2 is based on multiple studies including epidemiological studies that show associations between SO_2 exposures and emergency department visits and hospital admissions for respiratory effects [EPA 2010]. They include the following studies, where 99th percentile 1-hour average SO_2 concentrations ranged from 78 ppb to 150 ppb (which are concentrations within the AQI category defined as "unhealthy for sensitive groups"):

- In a study of hospital admissions in two cities in Connecticut and Washington, common air pollutants including ozone, particulate matter, and SO_2 were associated with increased admissions of elderly adults for respiratory symptoms [Schwartz 1995].

- In studies of emergency department visits in New York City, common air pollutants SO_2, ozone, particulate matter, and nitrogen dioxide were associated with increased numbers of visits for asthma [NYDOH 2006; Ito 2007].

5.1.4.2 Long-term Exposures

The following community studies support the possibility that some individuals living or working near Bridgeton Landfill may have experienced upper respiratory and olfactory effects upon long-term continuous or repeated exposures to low concentrations of H_2S, other RSCs, and SO_2 in ambient air.

- In studies of community exposures to sulfur compounds emitted from sulfur-producing pulp mills in Finland, long-term exposure to low concentrations of TRS has been associated with increased risk of upper respiratory infection (common cold and bronchitis) and nasal irritation (runny or stuffy nose) [Jaakkola et al. 1999; Marttila et al. 1994; Partti-Pellinen et al. 1996]. In one study, a higher prevalence of respiratory infections and reports of respiratory and neurological symptoms occurred in a community where the 1-year average TRS concentration was approximately 4 ppb and where, 4.3% of the time over a four-week period, 1-hour average TRS concentrations ranged from 14 ppb to 110 ppb [Jaakkola et al. 1999]. In other studies, respiratory and neurological effects were seen in children [Jaakkola et al. 1991; Marttila et al. 1994].

- In a study of the respiratory and neurological impacts of long-term exposures to malodorous emissions from a confined animal feeding operation in Ohio, impaired neurological functions in community members living near the operation included a decreased sense of smell [Kilburn 2012]. Average concentrations of H_2S in indoor air were as high as 30 ppb, with concentration spikes as high as 2,100 ppb.

In addition to upper respiratory and olfactory effects, long-term or repeated exposures to low concentrations of malodorous sulfur-based compounds may increase stress levels resulting in potential stress-related health effects. Changes in mood have often been reported in communities with long-term or repeated exposures to malodorous sulfur emissions, including increased anxiety, tension, anger, confusion, and depression [Haahtela et al. 1992; Heaney et al. 2011; Kilburn and Warshaw 1995; Legator et al. 2001].

5.1.4.3 Uncertainty in Community Studies

The SLCDPH community survey did not show a causal link between sulfur-based compound exposures and adverse health effects. There are many causes of illness and several factors that contribute to an adverse response or development of a disease. Breathing cigarette smoke, for instance, can trigger asthma attacks and is a contributing factor in the development of chronic respiratory diseases. In their community survey, SLCDPH found slightly higher rates of smoking in households within a 2-mile radius of the landfill than in households they surveyed elsewhere in St. Louis County [SLCDPH 2016]. Because smoking is a cause of respiratory diseases and contributes to respiratory symptoms, it is a confounding factor in environmental exposure studies.

Whether sulfur-based compound emissions from the landfill posed health risks similar to those observed in other community studies is furthermore uncertain, as the composition of sulfur-based compounds in the landfill emissions may have differed from the composition of sulfur compounds in ambient air in other communities. Differences in the mixture of sulfur-based compounds could contribute to differences in toxicities and odor thresholds.

- The average percentage of H_2S in the Bridgeton Landfill source gas (approximately 1.6%) was lower than percentages of H_2S reported in air in other community studies discussed in this health consultation, and maximum instantaneous concentrations of H_2S detected with the Jerome® meter near the landfill (6.8 ppb to 45.5 ppb) were lower than peak concentrations in the other community studies. However, instantaneous concentrations of H_2S near the landfill were often within the range of 30-minute average H_2S concentrations that Campagna et al. (2003) detected in ambient air (3 ppb to 15 ppb).[44]

- The average percentage of other RSCs in Bridgeton Landfill source gas samples (approximately 98.4%) was higher than percentages of other RSCs reported in air in community studies discussed in this health consultation, and maximum concentrations of combined RSCs detected with AreaRAE® monitors near the landfill were often higher than concentrations reported in those community studies. Bridgeton Landfill source gas contained approximately 76.5% dimethyl sulfide, which some laboratory studies indicate is less toxic than other RSCs.[45] However, toxicological studies are currently inadequate

[44] 30 ppb total reduced sulfur × 10% H_2S = 3 ppb H_2S; 30 ppb total reduced sulfur × 50% H_2S = 15 ppb H_2S

[45] In one study, while methyl mercaptan and dimethyl sulfide were both shown to inhibit metabolic activity in the liver and brain, dimethyl sulfide was shown to have less inhibitory effect than methyl mercaptan [Vahlkamp et al. 1979]. In another study, the lethal concentration of dimethyl sulfide in rats was shown to be approximately 100-times greater than the lethal concentrations of other RSCs, including hydrogen sulfide [Tansy et al. 1981].

for assessing the relative public health risks of exposure to dimethyl sulfide and many other RSCs.

In summary, combined RSC exposure concentrations and durations that might cause adverse respiratory and neurological effects cannot currently be determined from epidemiological studies. However, epidemiological studies associate adverse effects with short- or long-term exposures to low concentrations of combined RSCs in ambient air. In the community studies discussed in this health consultation, adverse respiratory and neurological effects are associated with low level exposures to combined RSCs (i.e., concentrations below effect levels observed in critical studies of H_2S toxicity, including the LOAEL of 2,000 ppb used to derive ATSDR's acute MRL and the human-equivalent NOAEL of 460 ppb used to derive ATSDR's intermediate MRL and EPA's RfC). Additional studies are needed to better understand the relative toxicities of RSCs and mixtures of RSCs.

5.2 Benzene

To assess the potential noncancer health impacts of acute and intermediate exposure to benzene in ambient air near the landfill, MDHSS/ATSDR compared benzene concentrations to effect levels used to derive the acute and intermediate MRLs for benzene. ATSDR's acute and intermediate MRLs are based on immunological effects observed in animal studies and are estimated concentrations of benzene unlikely to pose appreciable risk over a specific period of exposure.

- ATSDR's acute MRL (9 ppb) is based on an animal study in which mice exposed to benzene for six hours per day for six consecutive days exhibited decreased or delayed immune response [ATSDR 2007; Rosenthal and Snyder 1987; Rozen et al. 1984]. In calculating the acute MRL, ATSDR adjusted the exposure to 24 hours and derived a human-equivalent LOAEL of 2,550 ppb for mild immunological effects.

- ATSDR's intermediate MRL (6 ppb) is based on an animal study in which mice exposed to benzene for 6 hours per day and 5 days per week for 20 weeks exhibited a depressed immune response [ATSDR 2007]. In calculating the intermediate MRL, ATSDR adjusted the exposure to 24 hours and derived a human-equivalent LOAEL of 1,800 ppb for mild immunological effects.

- Because estimated average long-term exposures (95UCLs) to benzene downwind of the landfill did not exceed ATSDR's chronic MRL (3 ppb), we did not evaluate the health impacts of chronic exposure to benzene.

Because benzene concentrations in air samples collected near the landfill (≤32.5 ppb) were well below the LOAELs derived for acute and intermediate exposure (i.e., at least two orders of magnitude below the human-equivalent LOAELs), and because benzene was not detected regularly on the routine surveillance path around the perimeter and up to 2 miles from the landfill, it is unlikely that individuals would have been exposed to benzene at sufficient concentrations and over sufficient time periods for adverse immune response.

5.3 Multiple Chemical Exposures

Breathing multiple chemicals in ambient air can have combined adverse health effects if they target the same tissue or organ. As discussed in Appendix E, several chemicals that may jointly target the respiratory or neurological systems were detected in ambient air near the landfill in 2013-2018. Mixtures of sulfur-based compounds were found to have the greatest potential for causing combined adverse effects. Concentrations of other (non-sulfur based) chemicals were below levels that might jointly affect those systems and were, therefore, unlikely to cause combined adverse effects.

5.4 Cancer Risks

5.4.1 Benzene

Air pollutants in urban/suburban environments in the United States sometimes exceed cancer screening values like ATSDR's CREGs, which are values representative of concentrations unlikely to increase cancer rates in an exposed population.[46] As discussed in section 4.2, *Screening of Chemicals in Ambient Air,* several chemicals in air downwind of the landfill and in the Bridgeton area exceeded CREG values. However, only benzene was frequently detected downwind of the landfill and at long-term average concentrations exceeding typical ambient air concentrations.

5.4.2 Estimated Cancer Risk from Exposure to Benzene in Ambient Air

The National Toxicology Program (NTP) classifies benzene as a known human carcinogen, based on studies linking benzene exposure to various forms of leukemia in humans [NTP 2016]. Animal studies have shown that benzene exposures may cause a variety of cancers, including skin, lung, and lymphoid tumors [NTP 2016].

Table 16 shows estimated cancer risk values for two exposure scenarios:

- Lifetime exposure to benzene in ambient air downwind of Bridgeton Landfill starting with the onset of the subsurface smoldering event in December 2010.

- Lifetime exposure to benzene commonly found in urban/suburban air in the United States

Cancer risk estimations are typically expressed as a single number that represents a proportion of an adult population potentially affected by a carcinogen over a long period of time. For example, an estimated cancer risk of 1×10^{-6} predicts no more than 1 additional cancer case in 1 million people over a lifetime of continuous exposure to a carcinogen.

MDHSS/ATSDR estimate that, starting in December 2010, lifetime exposure to benzene in ambient air near Bridgeton Landfill poses an increased cancer risk of 7.3×10^{-6}, or

[46] CREG values are concentrations estimated to pose increased cancer risks of no more than 1×10^{-6}, or one cancer case in a population of 1 million.

approximately 7 extra cancer cases in a population of 1 million. That estimate is based on the assumption of residential exposure to estimated long-term average (95UCL) benzene concentrations downwind of the landfill over a standard residential occupancy period (33 years), followed by exposure to benzene concentrations measured in the Bridgeton and St. Louis City areas over the remainder of a lifetime (45 years) for a total of 78 years. Calculation of cancer risk values is described in Appendix F.

For comparison, we also estimated cancer risk based on typical background levels of benzene in urban/suburban areas in the United States. MDHSS/ATSDR estimate that exposure to typical ambient air concentrations of benzene in urban/suburban environments poses a lifetime increased risk of 6.5×10^{-6}, or approximately 7 extra cancer cases in a population of 1 million (Appendix F). That estimate is based on the 2013 average benzene concentration at air quality monitoring stations in the United States [EPA 2017b] and the assumption of lifetime exposure over 78 years. Benzene in air in urban/suburban environments is attributable to emissions from multiple common sources, including vehicle and industrial emissions.

Even though outdoor air benzene concentrations were elevated for several years near Bridgeton Landfill, estimated lifetime cancer risks (about 7 cases per million people) from living and breathing air near Bridgeton Landfill are similar to cancer risks from living in other urban/suburban environments in the United States.

Table 16. Estimated Cancer Risks from Exposure to Benzene in Ambient Air

Exposure Scenario	Increased Cancer Risk Values	Approximate Number of Extra Cancer Cases
Lifetime Exposure Downwind of Bridgeton Landfill	7.3×10^{-6}	7 cases in 1 million
Lifetime Exposure to a National Average Concentration in Urban/Suburban Air[a]	6.5×10^{-6}	7 cases in 1 million

[a] Assuming lifetime exposure to 0.26 ppb benzene (the 2013 national average concentration in urban/suburban air) [EPA 2017b].

For comparison, the National Cancer Institute estimates that 1.5% of men and women in the United States, or 15 thousand people in a population of 1 million, will develop leukemia in their lifetimes [NCI 2018].[47] Breathing benzene in ambient air near Bridgeton Landfill compared to other urban/suburban areas could, therefore, increase the number of people with leukemia from 15,000 to 15,001 cases in a population of 1 million.[48]

Cancer risk values are extrapolated from observed effect levels from occupational or laboratory animal studies, in which cancers are linked to exposures to very high doses of a chemical. Cancer risk estimates assume that even the smallest exposure to the chemical will cause a slight increase in people's risk of developing cancer. In toxicological reports on benzene, chronic exposure effect levels have ranged from 300 ppb to 200,000 ppb in occupational settings [ATSDR 2007].

[47] https://seer.cancer.gov/statfacts/

[48] 7.3×10^{6} extra cases (Bridgeton area) – 6.5×10^{6} extra cases (urban/suburban areas) = 0.8×10^{6} extra cases, or approximately 1 extra case in a population of 1 million

While cancer risk estimates assume that continuous exposures to much lower concentrations of benzene could also cause cancer, the true or actual cancer risks from breathing low concentrations (like typical ambient air concentrations) are not known and could be higher or lower, or even zero.

5.5 Landfill Odors

People can often smell chemicals well before they have reached a concentration that might cause a toxic effect. Thus, the perception of offensive odor does not necessarily mean that the chemical(s) causing the odor pose(s) a toxic threat to people's health. However, offensive odors can quickly become a nuisance and may be the direct cause of some health symptoms even at chemical concentrations below levels of toxicity [Schiffman and Williams 2005].

Chemicals with offensive odors can affect health by more than one mechanism [Schiffman and Williams 2005]. Odors are detected when the odorous chemical stimulates the olfactory nerve in the nasal passage. If odors are considered offensive, this mechanism may be associated with headache, nausea, or vomiting [Schiffman et al. 1995]. If malodorous chemicals are present at higher concentrations (i.e., generally, concentrations one to two orders of magnitude above the odor threshold), stimulation of other cranial nerves may cause irritation, including a burning, stinging, or itching sensation in the eyes, nose, or throat. Irritation of the respiratory tract may be accompanied by changes in respiration, including changes in breathing rate, or increased airflow resistance in the upper or lower respiratory tract [Schiffman et al. 2000; Schiffman and Williams 2005]. Combinations of low concentrations of malodorous chemicals may also cause irritation. The irritation levels of mixtures of malodorous chemicals are not well studied or understood.

With repeated exposures to a malodorous chemical, people can develop learned responses to the odor of that chemical [Schiffman and Williams 2005]. For example, if breathing malodorous sulfur-based compounds at sufficient exposure levels previously caused an asthma attack, perception of the odor of those compounds may subsequently trigger an attack. Repeated exposure to irritating, malodorous chemicals (in combination with other environmental air pollutants including particulate matter, nitrogen oxides, and ozone) may induce chronic respiratory illnesses including asthma, especially in children and elderly adults, although the relevant pollutant mixtures and exposures are not well understood [Clark et al. 2010; Schiffman and Williams 2005; Tétreault et al. 2016]. Repeated exposure to offensive odors perceived as unpredictable or uncontrollable may also add significantly to individuals' stress levels and affect quality of life [Schiffman and Williams 2005]. Chronic stress can harm people's health in a variety of ways, as discussed in the following section.

Generally, symptoms subside once odors dissipate and do not require medical attention. However, symptoms may last longer if odors are persistent or if malodorous chemicals reach irritation levels. Respiratory symptoms that may not subside include shortness of breath, chest tightness, or breathing discomfort, especially in people with chronic cardiopulmonary disease or chronic respiratory disease, such as asthma [ATSDR 2014b]. MDHSS/ATSDR recommend that individuals seek medical advice for any acute respiratory symptoms such as difficulty breathing or for any persistent symptoms that do not subside when the odors dissipate.

People's perception of odors and their responses to those perceptions may vary. Factors that can influence olfaction and the perception of odors include genetics, gender, and age [Greenberg et al 2013]. Women tend to be more sensitive than men to odors, and younger people tend to be more sensitive than older people to odors. Pregnant women may be more likely to experience nausea in response to offensive odors. Sensitivity to odors may also be influenced by an individual's health. Individuals with chronic respiratory diseases like asthma, for example, may be more likely to experience chest tightness or difficulty breathing in response to offensive odors [ATSDR 2014b].

Numerous community studies have found chronic exposure to malodorous sulfur emissions may cause adverse health effects, negative emotions, and decreased quality of life [Campagna et al. 2004; Haahtela et al. 1992; Kilburn and Warshaw 1995; Jaakkola et al. 1999; Legator et al. 2001; Marttila et al. 1994; Partti-Pellinen et al. 1996], including in communities downwind of landfills [Heaney et al. 2011].

MDHSS/ATSDR expect that odors were more likely to persist in areas around Bridgeton Landfill and more likely affect people in neighborhoods close to Bridgeton Landfill when winds were relatively calm. Atmospheric conditions tend to be more stable in the early morning, evening, and nighttime hours. Odors may have been more dilute and less intense and traveled a longer distance from Bridgeton Landfill when the winds were stronger.

5.6 Stress

Individuals living near hazardous waste sites are at increased risk of experiencing stress and the negative health effects associated with chronic stress. Offensive odors that are perceived as unpredictable or uncontrollable raise individuals' stress levels. Other causes of stress can include frustration with lengthy cleanup times at sites and the perception that health threats do not diminish over time. Individuals may be stressed by uncertainties regarding their current or future health, the current or future health of their children, and the impact of environmental exposures on their health.

Increased stress can be accompanied by a variety of negative emotions, including anxiety, depression, anger, and confusion [Schiffman et al. 1995; Schiffman and Williams 2005]. Over a long period of time, stress and the negative emotions that are generated from increased stress can affect people's health in a variety of ways, due to the interaction of the central nervous, immune, and endocrine systems in the body [Glaser and Kiecolt-Glaser 2005]. Health issues induced by chronic stress can include impaired immune response, increasing susceptibility to infection or severity of infectious disease, or increased inflammatory responses that may be associated with many common diseases such as coronary artery disease and irritable bowel syndrome [Glaser and Kiecolt-Glaser 2005]. Indirect effects of stress (e.g., poor sleep, poor eating habits, less exercise, increased smoking and alcohol consumption) put people at even greater risk of developing health problems.

Stress can also affect children. Children can take stress cues from others, including their families and communities, and manifest stress in different ways depending on their age, previous experiences, and coping behavior. To learn more about the importance of self-care, common stress responses in children, and ways parents and others can help children cope with stress, visit ATSDR's Community Stress Resource Center at: https://www.atsdr.cdc.gov/stress/index.html.

Individuals are advised to seek out ways to manage their stress as much as possible, for themselves and their families. Improving nutrition, getting enough sleep, and following an exercise regimen can help to manage stress. Social support is also important for managing stress. People at risk of chronic stress are advised to seek advice on developing a comprehensive stress management plan.

5.7 Children's Respiratory Health Considerations

In general, children are especially susceptible to air pollution, as their respiratory and immune systems are still developing and they have more frequent respiratory infections that can be aggravated by air pollution. Children may also have higher exposures to outdoor air pollution because they tend to spend more time outdoors and have higher activity levels with higher breathing rates. Some children are more susceptible than others. Children with chronic respiratory disease, such as asthma, or with higher exposures to indoor air pollutants, such as tobacco smoke, may be especially susceptible to the effects of outdoor air pollution [WHO 2005].

Children living near Bridgeton Landfill, therefore, may have been at greater risk than adults of experiencing respiratory discomfort, aggravation of chronic respiratory disease such as asthma, or more frequent or severe asthma attacks from breathing landfill emissions and their odors. In several studies in other communities, exposures to a variety of pollutants including sulfur-based compounds in air have been associated with adverse respiratory outcomes in children.

Air pollution is considered in general to be a risk factor for respiratory symptoms/illness and reduced lung function in children [WHO 2005]. In polluted environments and specifically in high traffic areas, children may be at increased risk of developing asthma. However, scientific studies of the effects of environmental exposures on the development of asthma are limited, and the relevant pollutant mixtures and exposure levels are not well understood. Based on current scientific knowledge, MDHSS/ATSDR cannot assess the likelihood of children having developed chronic respiratory disease as a result of exposure to emissions from the landfill.

6 COMMUNITY HEALTH CONCERNS

MDHSS worked closely with MDNR to review air data and evaluate the impact of landfill gas emissions and odors on local public health and wellbeing. In a consolidated effort, MDHSS and MDNR and several local agencies also worked to ensure public safety in the event that gas emissions from the landfill approached levels that threaten public health. Those efforts involved regular interagency meetings and development of response plans. Much time was also devoted to addressing public and individual community members' health concerns. MDHSS and MDNR fielded phone calls and emails from community members and met with local business leaders, at their invitation, to speak about their concerns. MDHSS and MDNR also addressed community concerns in public meetings/public availability sessions hosted by EPA and in a live public webinar held on June 17, 2013. In addition, MDHSS staff members were available to answer questions at numerous other community gatherings.

Below are answers to common questions for MDHSS raised at the public meetings and webinar:

What is the role of MDHSS?

MDHSS works in cooperation with ATSDR and closely with communities and other state, federal, and local environmental government agencies to evaluate the public health risks of exposure to environmental contaminants. Specifically, MDHSS addresses public health concerns regarding potential exposures to hazardous substances, educates communities about possible adverse health effects from exposure to those substances, and makes recommendations for public health protective actions. This is done by:

- Determining if there are human health risks from exposure to hazardous substances
- Developing recommendations to reduce risk of exposure
- Informing the community of possible health risks from exposure
- Addressing community health concerns
- Educating the community on how to reduce exposure to hazardous substances

In several ways, we attempted to keep the community updated on the potential public health impacts of gas and odor emissions from the site:

- From February 2013 to July 2018, we issued over 800 messages reviewing MDNR's data and providing recommendations to people for protection of their health. During excavation of the reinforced concrete pipes at the landfill in 2013, those messages reviewing the continuous air monitoring data were issued daily. Later, they were issued twice per week. Messages reviewing the air sampling were generally issued on a weekly basis following laboratory analysis of the samples. As noted in the *Site Description and Background* section, the messages were posted on MDNR's and MDHSS's Bridgeton Landfill website pages (www.health.mo.gov/bridgeton and https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill). Bridgeton Landfill also posted the messages on their website, www.bridgetonlandfill.com.
- We participated in weekly multi-agency conference calls that included a member of the Community Advisory Group.
- We participated in monthly Community Advisory Group (CAG) meetings, Community Dialogue meetings, and EPA listening sessions.
- In May 2016, we held a conference call with community leaders to share the findings of the health consultation and hear their public health concerns.
- In January 2019, we held a public meeting and availability session to share the findings of the health consultation, answer community members' questions, and hear comments about the findings.

What are the risks to individuals with asthma who live or work near the landfill?

Asthma is an increasingly common respiratory disease. People with asthma are especially sensitive to airborne particles and pollutants, such as cigarette smoke, dust mites, mold, and chemicals. They, therefore, have been the subject of many toxicological studies, including human clinical studies used by ATSDR and EPA to derive health guidelines for H_2S and SO_2.

Offensive odors can also aggravate asthma. When odors from the landfill are objectionable, people with asthma should stay indoors as much as possible, avoid outdoor exercise, and seek medical advice for any acute symptoms. In addition, MDHSS/ATSDR recommend the following:

- Know your asthma triggers and learn how to avoid them, if possible. If you have asthma, an asthma attack can happen when you are exposed to "asthma triggers." Your triggers can be very different from those of someone else with asthma.
- Avoid cigarette smoke and keep your children away from cigarette smoke.
- Recognize early signs and symptoms (e.g., a child coughing) before an asthma attack occurs.
- Take medications when needed or make sure your child is correctly inhaling his/her asthma medication.
- Inform school nurses, day care, and other caregivers of your child's asthma and potential triggers.
- Develop a plan of care with your doctor for your child's asthma and treatment.
- Visit the MDHSS asthma website for tips on reducing triggers, various reports, and statewide and St. Louis-specific data, available at http://health.mo.gov/living/healthcondiseases/chronic/asthma/index.php

How are public health impacts evaluated? Are screening levels and guidelines appropriate for elderly adults and children?

As described in section 4.2, *Screening of Chemicals in Ambient Air*, MDHSS/ATSDR compare chemical concentrations to health-based screening levels and health guidelines established by ATSDR, EPA, and other government agencies. Screening levels and health guidelines are based on data from numerous animal laboratory, clinical, and/or occupational exposure studies described in chemical-specific toxicological profiles. When agencies derive a screening level or health guideline, the lowest appropriate exposure concentration from the best study (or studies) is divided by uncertainty factors typically ranging from 10 to 1,000. Uncertainty factors ensure that screening levels and health guidelines are well below levels shown or anticipated to cause adverse health effects in humans. Chemical concentrations at or below screening levels or health guidelines are unlikely to cause harm to people's health, including the health of sensitive individuals such as children or elderly adults.

Often multiple health guidelines are available that may represent acceptable concentrations for varying exposure times and levels of effect. In this health consultation, concentrations of chemicals in ambient air near the landfill are compared to the most conservative (health-protective) screening levels or health guideline developed by ATSDR, EPA, and (for evaluation of acute effects) Cal EPA.

As described in section 5, *Public Health Implications*, chemicals exceeding screening levels and health guidelines and identified as being of potential concern are further analyzed by comparison to toxicologic and epidemiologic data, including observed effects levels used in derivation of health guidelines. Comparing concentrations to effect levels is done to determine where they lie in relation to those effect levels and assess the likelihood of adverse health effects in relevant exposure scenarios.

Is increased stress a public health concern at the site?

Community members living or working near the landfill often expressed worry and frustration regarding the intensity and frequency of offensive odors emanating from the landfill, the unpredictability of those odors, and uncertainty regarding the toxicity of the chemicals causing those odors. Over time, those worries and frustrations may have resulted in increased levels of stress and potentially led to stress-related illnesses, as discussed in the *Landfill Odors* and *Stress* sections of this health consultation.

7 UNCERTAINTIES AND LIMITATIONS

MDHSS/ATSDR identified the following limitations to assessing the public health risks of exposure to gas emissions from Bridgeton Landfill.

Monitoring and Sampling Uncertainties and Limitations

- A wide range of chemicals were targeted in ambient air monitoring and sampling approaches used by MDNR and EPA to evaluate the landfill gas and odor emissions. However, some chemicals emitted from the landfill may not have been included in standard analytical methods or may have been present in ambient air at concentrations below instrument detection or laboratory reporting limits. In addition, because the landfill is located in an urban/suburban environment, multiple emissions sources likely contributed low concentrations of a variety of chemicals in the air.
- Routine ambient air monitoring and sampling data are not available for 2011 and 2012, following the onset of the SSE. In 2012, MDNR began receiving odor complaints indicative of increased gas emissions from the landfill. MDNR began routine monitoring and sampling near the landfill in 2013.
- MDHSS/ATSDR use conservative health-based screening levels and guidelines to evaluate the public health impacts of emissions of gases from the landfill. While most detection or laboratory reporting limits were below those screening levels and guidelines, the detection limits of the AreaRAE® H_2S and SO_2 sensors (100 ppb) exceeded many screening levels and guidelines for H_2S and SO_2. The AreaRAE® monitors are not designed to measure low concentrations of chemicals in the ambient air. This precludes a detailed assessment of the public health impacts of breathing low concentrations of sulfur-based compounds in ambient air, especially among sensitive individuals.

- The AreaRAE® sensors and Jerome® H_2S meter may be sensitive to other, similar chemicals that may be present in the air. The AreaRAE® H_2S sensor may be especially prone to chemical interference by mercaptans and perhaps other RSCs. Because reduced sulfur in the landfill source gas was found to consist of multiple RSCs (including dimethyl sulfide, dimethyl disulfide, methyl mercaptan, and H_2S), MDHSS/ATSDR refer to the AreaRAE® H_2S sensor measurements as combined RSC concentrations in this health consultation.
- Because AreaRAE® monitors detected concentrations in 100 ppb increments, the AreaRAE® measurements were not exact readings of actual chemical concentrations in the ambient air.
- MDNR located their fixed AreaRAE® monitors near the landfill (i.e., a few hundred feet to approximately ½ mile from the landfill) to capture the highest concentrations of fugitive gas emissions from the landfill. It is assumed in this health consultation that MDNR's AreaRAE® monitoring results are representative of the highest exposure point concentrations of chemicals released in fugitive emissions from the landfill. Not everyone living or working in the Bridgeton area would have been exposed to those concentrations. Unless winds are very calm, concentrations of chemicals tend be higher downwind than upwind of an emissions source and become more dilute as they travel downwind from the landfill.
- MDNR collected air samples for determination of VOC, aldehyde, and sulfur-based compound concentrations upwind and downwind of the landfill during daylight hours. Samples were usually collected on a weekly basis. MDNR also performed twice-daily surveillance of odors and meter measurements of H_2S and benzene concentrations in ambient air during daylight hours, usually once in the mid to late morning and once in the afternoon.
    - As often as possible, MDNR targeted time periods or areas when/where the odors were considered most offensive and, therefore, when/where the chemical concentrations may have been highest. Those results may, therefore, represent worst-case exposure levels during those time periods and may not represent what everyone in the area was breathing during the day.
    - Daytime sampling and surveillance may have missed spikes in emissions, which may or may not be associated with transient odors. Many VOCs, aldehydes, and sulfur-based compounds are heavier than air and tend to accumulate at ground level, especially in the early morning, evening, and nighttime hours when winds are generally calmer. Therefore, results may not represent worst-case conditions.
- When chemical-specific analyses were conducted, sulfur-based compounds were not detected in air samples collected by MDNR upwind or downwind of the landfill. Standard analytical methods of laboratory analysis are complicated by the instability and reactivity of sulfur-based compounds.
- Weather conditions may have periodically interfered with the AreaRAE® monitor readings. High humidity levels can cause false positive readings or fog the monitor lamp and cause decreased sensitivity. MDNR used handheld meters to try to confirm false positive AreaRAE® readings. MDHSS/ATSDR did not evaluate AreaRAE® monitor readings that MDNR has determined to be invalid.

Screening Level Uncertainties and Limitations

- Health-based screening levels and guidelines are available for many but not all chemicals detected in ambient air, including many RSCs, such as dimethyl sulfide, dimethyl disulfide, and methyl mercaptan. Scientific studies of the health effects of multiple chemical exposures are also limited.
- Because screening levels and guidelines are not available for many RSCs, concentrations of combined RSCs are compared to screening levels and guidelines for H_2S, a minor component of the landfill source gas (1.6%). Comparison of combined reduced sulfur concentrations to H_2S guidelines is a conservative approach that may overestimate potential health risks if H_2S is more toxic than the combination of RSCs in air near the landfill.
- The relative toxicities of individual RSCs are not well studied or understood. The distribution of RSCs in the landfill source gas differs from the distribution of RSCs reported in the community studies discussed in this evaluation.
- The availability of odor thresholds of many chemicals is limited. The odor thresholds of some chemicals are reported over wide concentration ranges due to differences in testing methodology, odor threshold definitions, and people's ability to perceive odors.
- Chemicals that exceed CREGs are not necessarily site-related but are often common pollutants in ambient urban air.

Despite these uncertainties and limitations, MDHSS/ATSDR are confident that the data collected and evaluated in this health consultation are of sufficient quantity and quality to make several important conclusions and recommendations on exposure to chemicals and odors in ambient air near the landfill.

8 CONCLUSIONS

MDHSS/ATSDR have reached the following conclusions in this health consultation:

Conclusion 1

Before completion of corrective actions at the landfill in 2014, breathing sulfur-based compounds (i.e., RSCs and SO_2) at concentrations detected in ambient air near the landfill may have harmed the health of people living or working near the landfill by aggravating chronic respiratory disease (e.g., asthma), aggravating chronic cardiopulmonary disease, or causing adverse respiratory effects such as chest tightness or difficulty breathing especially in sensitive individuals (e.g., children, elderly adults). Breathing the odors of sulfur-based compounds may have also caused headache, nausea, or fatigue. Sulfur-based compounds were most frequently detected at concentrations that might cause those effects in 2013, prior to completion of corrective actions at the landfill in 2014.

From February 2013 to July 2018, MDNR continuously monitored combined RSCs and SO_2 in ambient air at three fixed AreaRAE® monitoring locations up to ½ mile from the landfill. Occasionally, concentrations of combined RSCs and SO_2 were detected at or above 100 ppb (the lower detection limit of AreaRAE® monitors), exceeding conservative health guidelines for respiratory or neurological effects and sometimes exceeding concentrations shown in human clinical studies to cause adverse respiratory effects. Maximum concentrations of combined RSCs detected by AreaRAE® monitors near the landfill were as high as 3,700 ppb. Maximum concentrations of SO_2 detected by AreaRAE® monitors near the landfill were as high as 1,600 ppb.

Depending on the toxicities of the individual RSCs in ambient air, breathing combined RSCs at concentrations detected in ambient air near the landfill for sufficient time periods may have caused acute respiratory or neurological effects such as chest tightness, wheezing, breathing discomfort, headache, or nausea, especially in sensitive individuals. Breathing SO_2 at concentrations detected in ambient air near the landfill for sufficient time periods may have also caused acute respiratory effects such as chest tightness, wheezing, or breathing discomfort, especially in sensitive individuals. People with asthma and other pre-existing chronic respiratory or cardiopulmonary conditions, as well as children and elderly adults, may be especially sensitive to RSCs and SO_2 in the ambient air.

Respiratory and neurological symptoms including shortness of breath, wheezing, headache, and/or nausea have been reported by residents living up to two miles from the landfill and in numerous studies of exposures to malodorous sulfur compound emissions in other communities.

AreaRAE® detections of sulfur-based compounds in ambient air near the landfill occurred most frequently in 2013, when combined RSCs were detected at least once in 28.1% of total monitoring hours and SO_2 was detected at least once in 17.5% of total monitoring hours. Sulfur-based compounds were detected less frequently in subsequent years, following implementation of corrective measures in 2013-2014 to control landfill gas and odor emissions associated with the SSE (e.g., re-engineering of the gas and leachate extraction system, capping of the south quarry with an impermeable liner, and active extraction and onsite pretreatment of leachate from the landfill). From 2013 to 2018, the frequency of detection of sulfur-based compounds decreased significantly by 74.6% (combined RSCs) and 92.3% (SO_2).

Conclusion 2

Before completion of corrective actions at the landfill in 2014, long-term or repeated exposures to sulfur-based compounds and their odors in ambient air near the landfill may have harmed the health or affected the quality of life of people living or working near the landfill by increasing stress, impairing mood, or increasing the risk of respiratory infection.

Landfill gases can have objectionable odors at low concentrations. Offensive odors alone, not just the toxicity of the chemicals causing the odors, may induce health effects. With repeated exposures, offensive odors may aggravate chronic respiratory disease, such as asthma. Long-lasting feelings of helplessness and frustration regarding the intensity and frequency of offensive odors, the unpredictability of the onset of offensive odors, and uncertainty regarding the toxicity of the chemicals causing those odors may increase levels of stress and potentially lead to stress-related illness.

In Spring 2012, when the SSE began to intensify, Bridgeton area residents began submitting complaints about noxious odors emanating from the landfill. MDNR staff conducted routine surveillance of odors from April 2013 to July 2018 and most frequently reported offensive odors in the area in 2013, prior to implementation of corrective measures to control gas and odor emissions.

A variety of chemicals produced by the decomposition of organic matter in the landfill likely contributed to those odors. Sulfur-based compounds have relatively low odor thresholds and could have been responsible for much of the odor. In numerous studies in other communities, long-term or repeated exposures to malodorous sulfur emissions have been associated with changes in mood, including increased anxiety, tension, anger, confusion, and depression. Long-term exposures to malodorous sulfur-based compounds have also been associated with increased risk of acute respiratory infection (common cold, bronchitis).

Conclusion 3

Fugitive gas emissions from the landfill decreased significantly as a result of corrective actions at the landfill in 2013 and 2014 and breathing sulfur-based compounds in ambient air near the landfill is currently unlikely to harm people's health. However, the odors of low concentrations of sulfur-based compounds may occasionally be bothersome and affect the quality of life of people living or working near the landfill.

From 2013 to 2018, the frequency of detection of combined RSCs in ambient air near the landfill significantly decreased. In 2018, maximum concentrations of combined RSCs detected by MDNR's AreaRAE® monitors (200 ppb) were well below a hydrogen sulfide (H_2S)

concentration shown in a human clinical study to cause adverse respiratory effects in people with asthma (2,000 ppb).

From 2013 to 2018, the frequency of detection of SO_2 in ambient air near the landfill also significantly decreased. In 2018, maximum SO_2 concentrations detected by MDNR's AreaRAE® monitors occasionally reached a concentration shown in a human clinical study to cause adverse respiratory effects in people with asthma (100 ppb). However, the majority of detections occurred at the monitoring location in a commercial area only a few hundred feet from the landfill.

In 2016, MDNR installed a pulsed fluorescence SO_2 monitor at their Rider Trail air quality monitoring station located ¾ of a mile south of the landfill. The monitor is a part of a state-wide network of sensitive SO_2 monitors that provides ambient air quality data to EPA's Air Quality System. The 99^{th} percentiles of daily maximum 1-hour average SO_2 concentrations at that location have been similar to values from other monitoring stations in St. Louis County, which have been well below EPA's primary NAAQS for SO_2 (75 ppb). Twenty-four hour average SO_2 concentrations at that location (≤5.7 ppb) have also been below the World Health Organization's 24-hour Air Quality Guideline (7.6 ppb).

From 2013 to 2018, the frequency with which MDNR detected offensive odors in the vicinity of the landfill decreased significantly by more than 98%. Still, sulfur-based compound odors may occasionally be objectionable, especially during periods of construction or other invasive work at the landfill or in instances of landfill equipment malfunction. Children and individuals with chronic respiratory diseases, such as asthma, are particularly sensitive to odors.

Conclusion 4

Breathing other (i.e., non-sulfur based) chemicals detected in ambient air is not expected to have harmed people's health.

In 2013-2015, MDNR oversaw landfill gas and air sampling at five comprehensive sampling events to characterize the landfill source gas and emissions. In those events, samples were collected for determination of concentrations of a broad range of chemicals in gas, onsite air, and ambient air [e.g., aldehydes, amines, carboxylic acids, dioxins/furans, PAHs, and VOCs, in addition to sulfur-based compounds]. In ambient air, some aldehydes and VOCs were occasionally detected at concentrations exceeding health-based screening levels and guidelines and were, therefore, targeted for routine ambient air monitoring/sampling. Like sulfur-based compounds, carbon monoxide is a common landfill gas that can be toxic at low concentrations and was, therefore, targeted for routine ambient air monitoring/sampling.

From February 2013 to July 2018, MDNR continuously monitored carbon monoxide (as well as sulfur-based compound) emissions from the landfill. MDNR also conducted routine ambient air sampling upwind and downwind of the landfill to monitor aldehyde and VOC (as well as sulfur-based compound) emissions from the landfill. In three air samples collected a few hundred feet downwind of the landfill in 2013-2014, concentrations of benzene (a VOC) exceeded conservative health guidelines for immunological effects. In those air samples, benzene concentrations were as high as 32.5 ppb. However, they were well below levels shown in animal studies to cause those effects. Concentrations of carbon monoxide measured by AreaRAE® monitors near the landfill did not exceed health guidelines.

In this health consultation, the potential health impacts of single and multiple chemical exposures are evaluated. Experimental studies have shown that exposure to low concentrations of multiple chemicals can sometimes have combined adverse health effects if they target the same tissue or organ. Many chemicals that may jointly target the respiratory or neurological systems, including sulfur and non-sulfur based compounds, were detected in ambient air near Bridgeton Landfill. However, concentrations of other (non-sulfur based) chemicals were below levels that might jointly affect those systems and were therefore, unlikely to cause combined adverse effects.

Conclusion 5

Estimated cancer risks from living and breathing VOCs near Bridgeton Landfill are similar to cancer risks from living in other urban/suburban environments in the United States.

Concentrations of acetaldehyde (an aldehyde), formaldehyde (an aldehyde), and several VOCs including benzene occasionally exceeded ATSDR's Cancer Risk Evaluation Guide (CREG) values. CREG values are screening values that represent concentrations expected to result in no more than 1 extra cancer case in a population of 1 million exposed for a lifetime.

Chemicals in urban/suburban air sometimes exceed CREG values. Of those chemicals that exceeded CREG values in air near the landfill, only benzene was frequently detected downwind of the landfill and at long-term average concentrations exceeding ambient air concentrations typical in other urban/suburban areas in the United States. Before and during reconstruction of the gas and leachate extraction system at the landfill, the long-term average concentration of benzene downwind of the landfill was significantly higher than the average concentration in St. Louis City. However, after completion of those corrective actions, long-term average concentrations were similar to the average concentration in St. Louis City.

Based on the assumption of lifetime exposure to benzene from living in the Bridgeton area, MDHSS/ATSDR estimate an increased cancer risk of 7.3×10^{-6}, or slightly more than 7 extra cancer cases in a population of 1 million. Lifetime exposure to typical benzene concentrations in ambient air in urban/suburban areas in the United States poses a similar increased risk of approximately 7 extra cancer cases in a population of 1 million.

9 RECOMMENDATIONS

In this section, we provide recommendations for the protection of public health. Although fugitive gas emissions from the landfill are currently unlikely to harm people's health, sensitive individuals living or working near the landfill may continue to be occasionally affected by odors (such as during invasive work or instances of equipment failure) while the SSE continues to occur.

1. MDHSS/ATSDR recommend that, during periods of objectionable odor, sensitive individuals including children, elderly adults, and people with asthma or other chronic respiratory conditions stay indoors as much as possible and avoid outdoor exercise.

2. MDHSS/ATSDR recommend that individuals seek immediate medical advice for any acute respiratory symptoms such as difficulty breathing. Sensitive individuals including children, elderly adults, and people with asthma or other chronic respiratory conditions may be particularly likely to experience acute respiratory symptoms. Symptoms may be associated with objectionable odors, although individuals may experience symptoms without perceiving objectionable odors.

3. MDHSS/ATSDR recommend that individuals seek medical advice for any persistent symptoms that do not subside when the odors dissipate. Objectionable odor may aggravate chronic respiratory diseases such as asthma. Persistent or repeated offensive odors may also increase stress, which can be associated with or lead to a variety of health issues including anxiety, mental depression, impaired immune responses, or increased inflammatory responses. Children can take stress cues from others, including their families and communities, and manifest stress in different ways depending on their age, previous experiences, and coping behavior.

4. MDHSS/ATSDR recommend that individuals take health-protective measures to combat the effects of stress, as much as possible. Important preventive measures include following recommended nutrition guidelines and getting regular exercise. Individuals at risk of chronic stress are advised to seek advice on developing a comprehensive stress management plan.

5. MDHSS/ATSDR recommend that any future data allow MDHSS or other responsible agencies to evaluate the potential health impacts of breathing chemicals in ambient air in residential and commercial areas near the landfill. Future data should be provided to MDHSS or other responsible agencies in a timely manner so that the potential public health impacts of acute exposures can be adequately communicated and addressed.

10 PUBLIC HEALTH ACTION PLAN

The Public Health Action Plan (PHAP) for the Bridgeton Landfill site contains a description of actions to be taken by MDHSS, ATSDR, and other involved parties. The purpose of the PHAP is to ensure that this health consultation not only identifies public health hazards but provides an action plan to mitigate and prevent adverse human health effects resulting from past, present, and future exposures to hazardous substances at or near the site. Included is a commitment from MDHSS and/or ATSDR to follow up on this plan to ensure that it is implemented.

1. MDHSS will review any additional monitoring/sampling data collected by MDNR or other agencies as they become available or as appropriate.

2. MDHSS will coordinate with MDNR and other agencies to address community health concerns and questions as they arise by providing health professional and community education as requested.

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APPENDICES

Appendix A: Comprehensive Sampling Results

In 2013-2015, Republic Services, under the oversight of MDNR, conducted five comprehensive sampling events at Bridgeton Landfill. In those events, multiple landfill source gas, onsite air, and ambient air samples were collected. Ambient air samples were collected upwind and downwind of the landfill for analysis of up to 183 chemical compounds, including aldehydes, amines, ammonia, carboxylic acids, dioxins/furans, hydrogen chloride, hydrogen cyanide, mercury (elemental), individual RSCs, sulfur dioxide, PAHs, and individual VOCs.

Table A-1 summarizes the results of upwind and downwind ambient air sampling in those comprehensive sampling events. In samples collected downwind of the landfill, some aldehydes and VOCs were occasionally detected at concentrations exceeding health-based screening levels. As a result, MDNR targeted those chemical groups for further investigation. Benzene concentrations in downwind samples were substantially higher than in upwind samples.

Sulfur-based compounds and carbon monoxide were not detected in upwind or downwind ambient air samples. However, because they are typical components of landfill gas [ATSDR 2001] and may be harmful to human health at low concentrations, MDNR also targeted sulfur-based compounds and carbon monoxide for further investigation.

Carboxylic acids, dioxins/furans, and PAHs were occasionally detected in ambient air samples collected upwind or downwind of the landfill, but they did not exceed health-based screening levels. Amines, ammonia, hydrogen chloride, hydrogen cyanide, other permanent gases (hydrogen, carbon dioxide), and mercury were not detected in upwind or downwind samples.

Screening of Dioxins/Furans

Using the standard approach for evaluating the human health risks of exposure to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) and dioxin-like compounds, concentrations of dioxins and furans detected in ambient air downwind of the landfill (expressed in picograms per cubic meter or pg/m^3) were converted to toxicity equivalence (TEQ) values [EPA 2013]. Total TEQ values for each air sample were then compared to EPA's RfC for 2,3,7,8-TCDD (0.074 pg/m^3).

Concentrations are converted to TEQs using toxicity equivalency factors (TEFs), which are measures of toxicity relative to 2,3,7,8-TCDD.

Equation:

$$\mathbf{TEQ\ (pg/m^3) = Concentration\ (pg/m^3) \times TEF}$$

where TEQ = toxicity equivalence
TEF = toxicity equivalency factor for each compound

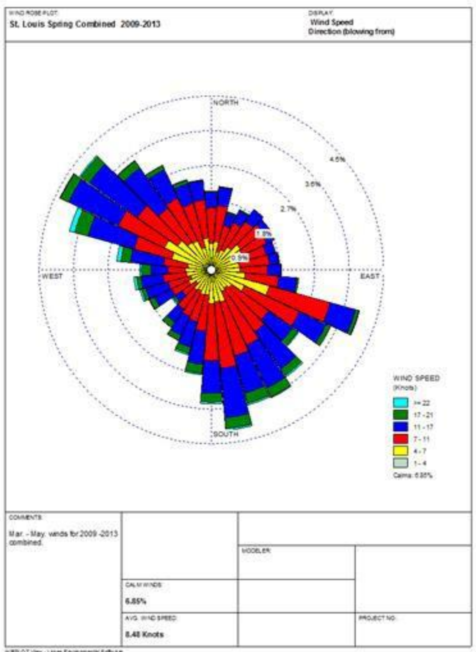
Table A-1. Exceedance of Screening Levels in Comprehensive Sampling Events
Bridgeton Landfill, 2013-2015

Chemical/ Chemical Group	Range of Concentrations[a]	Screening Levels Available ?	Screening Level Exceedances ?	Chemical with Screening Level Exceedance[b]	Upwind Concentration (ppb)	Downwind Concentration (ppb)	Screening Level (ppb)	Number of Exceedances[d]
Aldehydes	ND - 11.0	Yes[c]	Yes	Formaldehyde	0.8-9.4	0.6-11.0	8 ATSDR MRL	1 upwind 2 downwind
Amines	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
Ammonia	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
Carboxylic Acids	ND – 9.0	No	N/A	N/A	N/A	N/A	N/A	N/A
Dioxins/ Furans	0.0003 - 0.064	Yes[c]	No	N/A	N/A	N/A	N/A	N/A
Permanent Gases	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
Hydrogen Chloride	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
Hydrogen Cyanide	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
Mercury	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
PAHs	0.00008 - 0.011	Yes[c]	No	N/A	N/A	N/A	N/A	N/A
Sulfur-based Compounds	ND	Yes	No	N/A	N/A	N/A	N/A	N/A
VOCs	ND – 130	Yes[c]	Yes	Acrolein	ND-0.31	ND-1.4	0.0087 EPA RfC	3 upwind 7 downwind
				Benzene	ND-0.61	ND-21.8	3 ATSDR MRL	2 downwind
				Carbon Tetrachloride	ND-0.11	ND-0.51	0.026 ATSDR CREG	10 upwind 13 downwind
				Ethylbenzene	ND-0.4	ND-1.14	0.25 Cancer RSL	4 upwind 5 downwind
				Naphthalene	ND	ND-0.25	0.02 Cancer RSL	3 downwind
				Trichloroethylene	ND-0.23	ND-0.23	0.040 ATSDR CREG	1 upwind 1 downwind

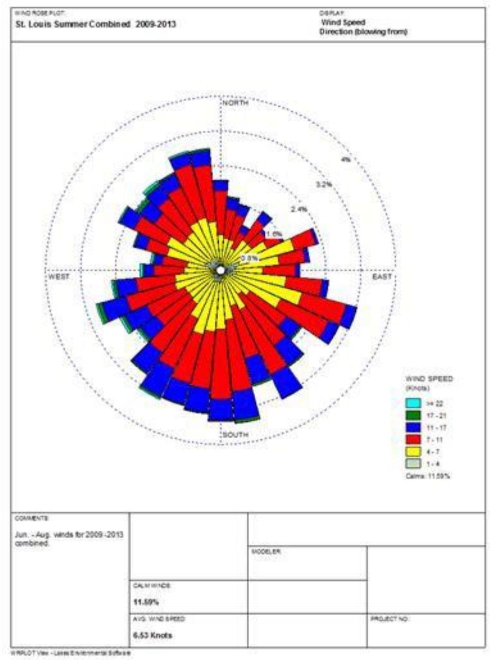
[a] Concentrations of dioxins/furans were converted to total toxic equivalency (TEQ) values, shown in picograms per cubic meter (pg/m^3). Shown for dioxins/furans is the range of TEQs from samples collected downwind of the landfill. Concentrations of other chemicals/chemical groups are individual chemical concentrations from samples collected upwind and downwind of the landfill, shown in parts per billion (ppb).
[b] Listed are individual chemicals that exceeded available health-based screening levels in samples collected downwind of the landfill. Shown are upwind and downwind concentration ranges for those chemicals and the number of times those concentrations exceeded noncancer screening levels or, if noncancer screening levels were not exceeded, cancer screening levels. Screening levels are cancer screening levels or the most conservative non-cancer screening levels developed by ATSDR, EPA, or California EPA.
[c] Screening levels for individual aldehydes and VOCs are listed in Appendix D. Dioxin/furan total TEQs were compared to EPA's RfC for 2,3,7,8-TCDD (0.074 pg/m^3). One PAH (naphthalene) detected in ambient air had available screening levels. EPA's RfC (0.57 ppb) was used as a comparison value.
[d] Yellow highlights indicate exceedances of the screening level for that chemical or chemical group.

Appendix B: Wind Rose Plots

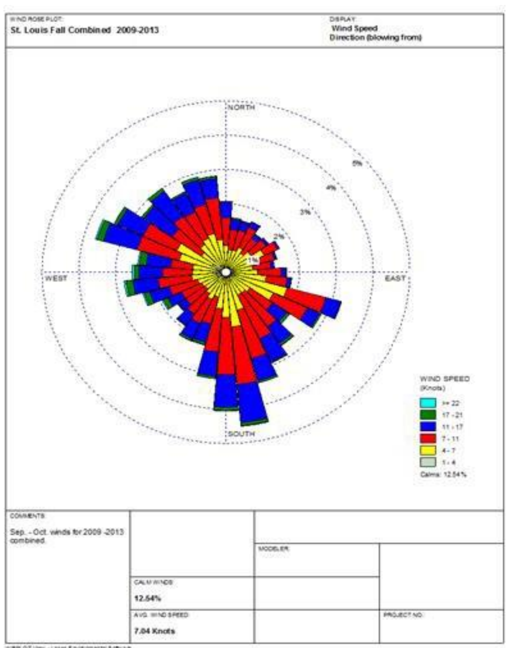
Wind roses show the general direction winds blew from, wind speeds and how often winds blew.



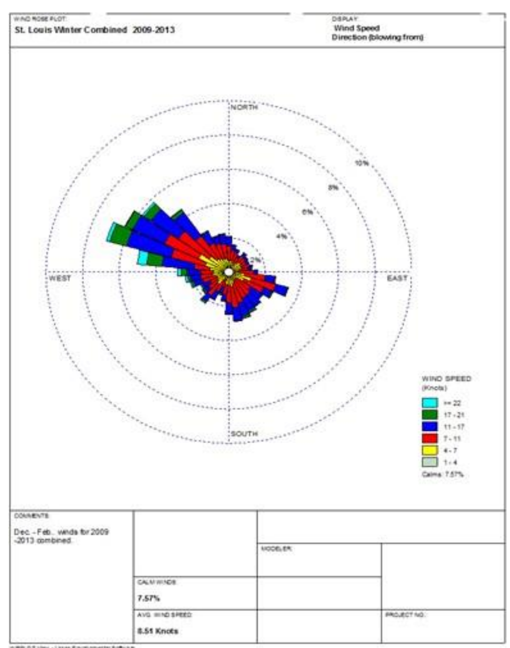
Spring Wind Rose Plot (source: MDNR)



Summer Wind Rose Plot (source: MDNR)



Fall Wind Rose Plot (source: MDNR)



Winter Wind Rose Plot (source: MDNR)

Appendix C: Calculation of an Odor Threshold for Combined RSCs

MDHSS derived an odor threshold for combined RSCs in ambient air. The threshold is based on compound-specific odor-based guidelines for RSCs produced by the landfill (i.e., compounds found in gas samples from under the landfill liner) and the relative amounts of those compounds in the landfill source gas. In April 2013, total reduced sulfur compounds under the landfill liner were composed of 76.5% dimethyl sulfide, 8.2% dimethyl disulfide, 4.8% methyl mercaptan, and 10.5% other reduced sulfur compounds including 1.6% H_2S. The threshold value is an estimate of the concentration at which some people might be able to smell a mixture of several RSCs in ambient air and, after a sufficient exposure period, perceive that odor as objectionable.

Equation:

Screening Level = $(F_{DMS} \times GV_{DMS}) + (F_{DMDS} \times GV_{DMDS}) + (F_{MM} \times GV_{MM}) + (F_{OTH} \times GV_{OTH})$

Table C-1. List of Variables

Variables	Description	Value	Units
F_{DMS} [a]	Dimethyl Sulfide Fraction	0.765	unitless
F_{DMDS} [a]	Dimethyl Disulfide Fraction	0.082	unitless
F_{MM} [a]	Methyl Mercaptan Fraction	0.048	unitless
F_{OTH} [a]	Other Reduced Sulfur Fraction	0.105	unitless
GV_{DMS} [b]	Acute Guideline Value for Dimethyl Sulfide	500	ppb
GV_{DMDS} [b]	Acute Guideline Value for Dimethyl Disulfide	10	ppb
GV_{MM} [b]	Acute Guideline Value for Methyl Mercaptan	5	ppb
GV_{OTH} [c]	Acute Guideline Value for Other Reduced Sulfur Compounds	5	ppb
Screening Level $_{TRS}$	**Total Reduced Sulfur Screening Level**	**385**	**ppb**

[a] Expressed as a fraction of TRS in landfill gas from under the landfill liner, April 2013. Similar results were obtained in repeated sampling of landfill gas in July 2014.
[b] American Industrial Hygiene Association (AIHA) Emergency Response Planning Guidelines (ERPGs) [AIHA 1996; AIHA 1999; AIHA 2004]. The ERPG-1s for these reduced sulfur compounds are based on odor thresholds and are maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without perceiving a clearly defined, objectionable odor or experiencing more than mild, transient adverse health effects.
[c] The most conservative AIHA acute guideline value available for reduced sulfur compounds included in the laboratory analysis

Calculation of Site-Specifically Derived Screening Level:

Objectionable Odor Threshold Level = $(0.765 \times 500 \text{ ppb}) + (0.082 \times 10 \text{ ppb}) + (0.048 \times 5 \text{ ppb}) + (0.105 \times 5 \text{ ppb}) = 385 \text{ ppb}$

Appendix D: Ambient Air Monitoring and Sampling Results

Table D-1: Exceedance of Odor Thresholds and Health-Based Screening Levels
MDNR Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2018

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Aldehydes in Downwind Sorbent Tube Samples[f]							
Acetaldehyde	41/44	ND-2.7	67 EPA GM	260 Cal EPA REL	5 EPA RfC	0.25 ATSDR CREG	Cancer
Acetone	44/44	0.2-7.3	400 AIHA Low	26,000 ATSDR MRL	13,000 ATSDR MRL	N/A	Not exceeded
Acrolein	0/44	ND	1,800 EPA GM	3 ATSDR MRL	0.0087 EPA RfC	N/A	ND
Benzaldehyde	9/44	ND-0.5	1.5 AIHA Low	N/A	N/A	N/A	Not exceeded
Crotonaldehyde	30/44	ND-3.4	20 AIHA Low	N/A	N/A	N/A	Not exceeded
Formaldehyde	35/44	ND-5.4	27 AIHA Low	40 ATSDR MRL	8 ATSDR MRL	0.063 ATSDR CREG	Cancer
Hexaldehyde	3/44	ND-12.7	N/A	N/A	N/A	N/A	N/A
MEK (2-Butanone) & Butyraldehyde	42/44	ND-2.7	17,000 EPA GM for MEK	1,000 ATSDR MRL for MEK	1,700 EPA RfC For MEK	N/A	Not exceeded
Methacrolein	14/44	ND-0.4	N/A	N/A	N/A	N/A	N/A
m-Tolualdehyde	9/44	ND-1.3	N/A	N/A	N/A	N/A	N/A
Propionaldehyde	7/44	ND-1.3	40 EPA GM	N/A	3.4 EPA RfC	N/A	Not exceeded
Valeraldehyde	11/44	ND-3.9	0.4 AIHA Low	N/A	N/A	N/A	Odor
Benzene and H_2S Measured with Hand-held Meters during Routine Surveillance[g]							
Benzene	17/50,811	ND-500	61,000 EPA GM	9 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Acute, Chronic, Cancer
Hydrogen Sulfide	25,965/50,811	ND-45.5	8	30 Cal EPA REL 70 ATSDR MRL	1.4 EPA RfC	N/A	Odor, Acute, Chronic
Carbon Monoxide Detected by AreaRAE® Monitors[h]							
Carbon Monoxide	Continuous	ND-13,200	N/A	20,000 Cal EPA REL	N/A	N/A	Not exceeded
Sulfur-Based Compounds Detected by AreaRAE® Monitors[i]							
Combined Reduced Sulfur Compounds	Continuous	ND-3,700	385 MDHSS	70 ATSDR MRL for H_2S	1.4 EPA RfC for H_2S	N/A	Odor, Acute, Chronic

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Sulfur Dioxide	Continuous	ND-1,600	330 AIHA Low	10 ATSDR MRL	N/A	N/A	Odor, Acute
Sulfur Dioxide Detected by Pulsed-Fluorescence Monitor at Rider Trail-I-70[j]							
Sulfur Dioxide	Continuous	ND-29.1	330 AIHA Low	75 1-hour NAAQS	N/A	N/A	Not exceeded
Sulfur-Based Compounds in Downwind SUMMA® Canister Samples[k]							
2-Methylthiophene	0/78	ND	N/A	N/A	N/A	N/A	ND
3-Methylthiophene	0/78	ND	N/A	N/A	N/A	N/A	ND
Bromothiophene	0/78	ND	N/A	N/A	N/A	N/A	ND
Carbon Disulfide	0/78	ND	16 AIHA Low	1,990 Cal EPA REL	300 ATSDR MRL	N/A	ND
Carbonyl Sulfide	0/78	ND	100 EPA GM	269 Cal EPA REL	N/A	N/A	ND
Diethyl Disulfide	0/78	ND	N/A	N/A	N/A	N/A	ND
Diethyl Sulfide	0/78	ND	N/A	N/A	N/A	N/A	ND
Dimethyl Disulfide	0/78	ND	0.3 AIHA Low	N/A	N/A	N/A	ND
Dimethyl Sulfide	0/78	ND	0.12 AIHA Low	N/A	N/A	N/A	ND
Ethyl Mercaptan	0/78	ND	0.01 AIHA Low	N/A	N/A	N/A	ND
Hydrogen Sulfide	0/78	ND	8	30 Cal EPA REL 70 ATSDR MRL	1.4 EPA RfC	N/A	ND
Isobutyl Mercaptan	0/78	ND	N/A	N/A	N/A	N/A	ND
Isopropyl Mercaptan	0/78	ND	N/A	N/A	N/A	N/A	ND
Methyl Mercaptan	0/78	ND	5.1×10^{-10} AIHA Low	N/A	N/A	N/A	ND
Methylethylsulfide	0/78	ND	N/A	N/A	N/A	N/A	ND
n-Butyl Mercaptan	0/78	ND	2.7×10^{-3} AIHA Low	N/A	N/A	N/A	ND
n-Propyl Mercaptan	0/78	ND	N/A	N/A	N/A	N/A	ND
sec-Butyl Mercaptan	0/78	ND	N/A	N/A	N/A	N/A	ND
Sulfur Dioxide	0/78	ND	330 AIHA Low	10 ATSDR MRL	N/A	N/A	ND
tert-Butyl Mercaptan	0/78	ND	0.003 AIHA Low	N/A	N/A	N/A	ND
Tetrahydrothiophene	0/78	ND	N/A	N/A	N/A	N/A	ND
Thiophene	0/78	ND	N/A	N/A	N/A	N/A	ND
Thiophenol	0/78	ND	N/A	N/A	N/A	N/A	ND

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Volatile Organic Compounds in Downwind SUMMA® Canister Samples[l]							
1,1,1-Trichloroethane	0/481	ND	385,000 EPA GM	2,000 ATSDR MRL	700 ATSDR MRL*	N/A	ND
1,1,2,2-Tetrachloroethane	0/481	ND	7,300 EPA GM	N/A	N/A	0.006 EPA RSL	ND
1,1,2-Trichloroethane	2/481	ND-0.11	N/A	30 ATSDR MRL	2.0 ATSDR MRL*	0.011 ATSDR CREG	Cancer
1,1-Dichloroethane	0/481	ND	49,000 AIHA Low	N/A	N/A	0.37 EPA RSL	ND
1,1-Dichloroethene	0/481	ND	277,000 AIHA Low	18 Cal EPA REL	0.60 ATSDR MRL	N/A	ND
1,2,4-Trichlorobenzene	0/481	ND	2,960 AIHA Low	N/A	N/A	N/A	ND
1,2,4-Trimethylbenzene	60/481	ND-3.4	6 AIHA Low	N/A	12 EPA RfC	N/A	Not exceeded
1,2-Dibromoethane	0/481	ND	10,000 AIHA Low	N/A	1.2 EPA RfC	0.00022 ATSDR CREG	ND
1,2-Dichlorobenzene	0/481	ND	N/A	N/A	N/A	N/A	ND
1,2-Dichloroethane	12/481	ND-4.1	26,000 EPA GM	N/A	600 ATSDR MRL	0.0095 ATSDR CREG	Cancer
1,2-Dichloropropane	4/481	ND-2.7	260 EPA GM	20 ATSDR MRL	0.87 EPA RfC	N/A	Chronic
1,3,5-Trimethylbenzene	27/481	ND-1.2	N/A	N/A	12 EPA RfC	N/A	Not exceeded
1,3-Butadiene	1/481	ND-0.4	450 EPA GM	300 Cal EPA REL	0.9 EPA RfC	0.015 ATSDR CREG	Cancer
1,3-Dichlorobenzene	0/481	ND	N/A	N/A	N/A	N/A	ND
1,4-Dichlorobenzene	2/481	ND-0.5	120 EPA GM	2,000 ATSDR MRL	10 ATSDR MRL	0.04 EPA RSL	Cancer
1,4-Dioxane	10/481	ND-6.4	22,000 EPA GM	2,000 ATSDR MRL	30 ATSDR MRL	0.055 ATSDR CREG	Cancer
2,2,4-Trimethylpentane	50/481	ND-35	N/A	N/A	N/A	N/A	N/A
2-Butanone (MEK)	170/481	ND-28	17,000 EPA GM	1,000 ATSDR MRL	1,700 EPA RfC	N/A	Not exceeded
2-Hexanone	3/481	ND-4.3	24 AIHA Low	N/A	7.3 EPA RfC	N/A	Not exceeded
2-Propanol (IPA)	180/481	ND-300	1,000 AIHA Low	1,300 Cal EPA REL	N/A	N/A	Not exceeded
4-Ethyltoluene	31/481	ND-1.5	N/A	N/A	N/A	N/A	N/A
4-Methyl-2-Pentanone	34/481	ND-9.4	880 EPA GM	N/A	730 EPA RfC	N/A	Not exceeded
Acetone	475/481	ND-440	400 AIHA Low	26,000 ATSDR MRL	13,000 ATSDR MRL	N/A	Odor

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Acrylonitrile	0/44	ND	1,600 EPA GM	100 ATSDR MRL	0.92 EPA RfC	0.0068 ATSDR CREG	ND
Allyl Chloride	0/44	ND	480 AIHA Low	N/A	0.32 EPA RfC	0.15 EPA RSL	ND
Benzene	247/481	ND-32.5	61,000 EPA GM	9 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Acute, Chronic, Cancer
Benzyl Chloride	0/481	ND	41 EPA GM	46 Cal EPA REL	N/A	0.01 EPA RSL	ND
Bromodichloromethane	0/481	ND	N/A	N/A	N/A	0.01 EPA RSL	ND
Bromoform	1/481	ND-0.6	190 AIHA Low	N/A	N/A	0.088 ATSDR CREG	Cancer
Bromomethane	0/481	ND	N/A	N/A	1.0 ATSDR MRL	N/A	ND
Carbon Disulfide	18/437	ND-18	16 AIHA Low	1,990 Cal EPA REL	300 ATSDR MRL	N/A	Odor
Carbon Tetrachloride	16/481	ND-0.1	250,000 EPA GM	300 Cal EPA REL	30 ATSDR MRL	0.026 ATSDR CREG	Cancer
Chlorobenzene	0/481	ND	1,300 EPA GM	N/A	N/A	N/A	ND
Chlorodifluoromethane	44/44	0.3-0.7	2×10^8 AIHA Low	N/A	14,000 EPA RfC	N/A	Not exceeded
Chloroethane	0/481	ND	3,800 AIHA Low	15,000 ATSDR MRL	3,800 EPA RfC	N/A	ND
Chloroform	11/481	ND-0.5	192,000 EPA GM	100 ATSDR MRL	20 ATSDR MRL	0.0089 ATSDR CREG	Cancer
Chloromethane	53/481	ND-1.0	10 AIHA Low	500 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded
cis-1,2-Dichloroethene	0/481	ND	4,300 AIHA Low	N/A	N/A	N/A	ND
cis-1,3-Dichloropropene	0/481	ND	260 AIHA Low	N/A	7 ATSDR MRL	0.055 ATSDR CREG	ND
Cumene	1/437	ND-0.2	32 EPA GM	N/A	81 EPA RfC	N/A	Not exceeded
Cyclohexane	40/481	ND-4.9	520 AIHA Low	N/A	1,700 EPA RfC	N/A	Not exceeded
Dibromochloromethane	6/481	ND-31	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane (Freon 12)	408/481	ND-0.8	2×10^5 AIHA Low	N/A	N/A	N/A	Not exceeded
Dichlorofluoromethane	0/44	ND	N/A	N/A	N/A	N/A	ND
Dichlorotetrafluoroethane (Freon 114)	6/481	ND-0.6	N/A	N/A	N/A	N/A	N/A
Ethanol	462/481	ND-150	90 AIHA Low	N/A	N/A	N/A	Odor

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Ethyl Acetate	11/44	ND-5.9	90 AIHA Low	N/A	N/A	N/A	Not exceeded
Ethylbenzene	71/481	ND-4.5	2 AIHA Low	5,000 ATSDR MRL	60 ATSDR MRL	0.25 EPA RSL	Odor, Cancer
Heptane	137/481	ND-2.8	410 AIHA Low	N/A	N/A	N/A	Not exceeded
Hexachlorobutadiene	0/481	ND	N/A	N/A	N/A	0.0043 ATSDR CREG	ND
Hexane	201/481	ND-7.4	426 AIHA Low	N/A	600 ATSDR MRL	N/A	Not exceeded
Methanol	44/44	5.9-97.2	160,000 EPA GM	21,000 Cal EPA REL N/A	15,000 EPA RfC	N/A	Not exceeded
Methyl tert-Butyl Ether	2/481	ND-2.8	30 AIHA Low	2,000 ATSDR MRL	700 ATSDR MRL	3.1 EPA RSL	Not exceeded
Methylene Chloride	76/481	ND-181	144,000 EPA GM	600 ATSDR MRL	300 ATSDR MRL	18 ATSDR CREG	Cancer
Propene	41/44	ND-12.1	10.1 AIHA Low	N/A	N/A	N/A	Odor
Propylbenzene	3/437	ND-0.3	N/A	N/A	N/A	N/A	N/A
Styrene	15/481	ND-0.9	150 EPA GM	5,000 ATSDR MRL	200 ATSDR MRL	N/A	Not exceeded
Tetrachloroethylene (PCE)	12/481	ND-3.1	47,000 EPA GM	6 ATSDR MRL	6.0 ATSDR MRL	0.57 ATSDR CREG	Cancer
Tetrahydrofuran	31/481	ND-18	92 AIHA Low	N/A	680 EPA RfC	N/A	Not exceeded
Toluene	308/481	ND-70	2,800 EPA GM	2,000 ATSDR MRL	1,000 ATSDR MRL	N/A	Not exceeded
trans-1,2-Dichloroethylene	4/481	ND-1.7	277,000 AIHA Low	200 ATSDR MRL	200 ATSDR MRL*	N/A	Not exceeded
trans-1,3-Dichloropropene	0/481	ND	990 AIHA	N/A	7 ATSDR MRL	0.055 ATSDR CREG	ND
Trichloroethylene (TCE)	9/481	ND-0.3	82,000 EPA GM	N/A	0.40 ATSDR MRL	0.040 ATSDR CREG	Cancer
Trichlorofluoromethane (Freon 11)	461-481	ND-1.0	5,000 AIHA Low	N/A	N/A	N/A	Not exceeded
Trichlorotrifluoroethane (Freon 113)	11/481	ND-0.12	N/A	N/A	N/A	N/A	N/A
Vinyl Acetate	0/44	ND	110 EPA GM	N/A	57 EPA RfC	N/A	ND
Vinyl Bromide	0/44	ND	N/A	N/A	0.69 EPA RfC	N/A	ND
Vinyl Chloride	0/481	ND	203 AIHA Low	500 ATSDR MRL	39 EPA RfC	0.044 ATSDR CREG	ND
Xylenes (mixture of m- and p-xylene)	115/481	ND-12	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded

Chemical	Frequency of Detection	Range of Concentrations (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
o-Xylene	61/481	ND-3.3	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded

ATSDR MRL = Agency for Toxic Substances and Disease Registry's Minimal Risk Level
Cal EPA REL = California Environmental Protection Agency's Reference Exposure Level
EPA RfC = Environmental Protection Agency's Reference Concentration
EPA RSL = Environmental Protection Agency's Regional Screening Level
ATSDR CREG = Agency for Toxic Substances and Disease Registry's Cancer Risk Evaluation Guide
N/A = not available/not applicable; ND = not detected
Below RL = the screening level is below the laboratory reporting limit (RL); therefore, the health risks of chronic exposure cannot be accurately evaluated.
*Intermediate MRL is used, because a chronic MRL is not available.

[a] Odor thresholds reported in the scientific literature can vary widely due to differences in experimental methodology and human variability. Shown for H_2S is the geometric mean odor threshold at which approximately 11% of the population may be bothered by the odor [Amoore 1985]. Shown for VOCs are geometric mean (GM) odor thresholds reported by EPA (1992), considered by EPA to be "best estimates" of odor thresholds. If the GM is not available for a particular chemical, shown are the lowest odor thresholds reported by AIHA (2013).
[b] Screening levels are ATSDR's MRLs for acute (0-14 days) exposure and California EPA's RELs for acute exposure. If an MRL for acute exposure has not been established, concentrations are compared to the Cal EPA acute REL, if available.
[c] The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR and EPA. If an MRL for chronic (>1 year) exposure has not been established, concentrations are compared to the intermediate MRL or RfC, if available.
[d] Cancer risks are evaluated by comparison to ATSDR's CREGs or, if CREGs are not available, EPA's cancer RSLs.
[e] Yellow highlights indicate exceedances of the screening level(s) for that chemical or chemical group.
[f] Aldehyde concentrations are four-hour average concentrations from 44 four-hour ambient air samples collected by MDNR up to ½ mile downwind of the landfill on 20 days in April-August 2013. The laboratory reporting limits were typically below 0.5 ppb.
[g] Benzene and H_2S concentrations are instantaneous concentrations measured twice per day by MDNR up to 2 miles from the landfill in 2013-2018. The detection limit of the Ultra RAE® meter used to measure benzene was 50 ppb. The detection limit of the Jerome® meter used to measure H_2S concentrations was 3 ppb.
[h] Carbon monoxide concentrations are 1-hour average concentrations measured by continuous AreaRAE® monitors up to ½ mile from the landfill, 24 hours per day, 7 days per week in 2013-2018. The detection limit of the AreaRAE monitors was 100 ppb. The Cal EPA REL is a 1-hour REL.
[i] Concentrations of sulfur-based compounds are 1-3 minute concentrations measured by continuous AreaRAE® monitors up to ½ mile from the landfill, 24 hours per day, 7 days per week in 2013-2018. The detection limit of the AreaRAE® monitors was 100 ppb.
[j] Sulfur dioxide concentrations are 1-hour average concentrations measured by the pulsed fluorescence monitor at the Rider Trail monitoring site ¾ of a mile from the landfill, 24 hours per day, 7 days per week in 2016-2018.
[k] MDNR collected 4-hour samples on 20 days from April to August 2013 and 45-50 minute samples on 18 days from April 2015 to December 2016 up to ½ mile upwind and downwind of the landfill for determination of sulfur-based compound concentrations. The laboratory reporting limits were typically below 20 ppb.
[l] VOC concentrations are four-hour average concentrations from 44-481 ambient air samples collected by MDNR up to ½ mile downwind of the landfill in 2013-2018. The laboratory reporting limits were typically below 1 ppb.

Table D-2: Exceedance of Odor Thresholds and Health-Based Screening Levels EPA Ambient Air Sampling Results, 2014-2015

Chemical	Frequency of Detection	Range of Concentration (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
H_2S in Radiello® Samples[f]							
Hydrogen Sulfide	35/55	ND-0.44	8	30 Cal EPA REL 70 ATSDR MRL	1.4 EPA RfC	N/A	Not exceeded
Volatile Organic Compounds in SUMMA® Canister Samples[g]							
1,1,1-Trichloroethane	0/163	ND	385,000 EPA GM	2,000 ATSDR MRL	700 ATSDR MRL*	N/A	ND
1,1,2,2-Tetrachloroethane	0/163	ND	7,300 EPA GM	N/A	N/A	0.006 EPA RSL	ND
1,1,2-Trichloroethane	0/163	ND	N/A	30 ATSDR MRL	2.0 ATSDR MRL*	0.11 ATSDR CREG	ND
1,1-Dichloroethane	1/163	ND-0.1	49,000 AIHA Low	N/A	N/A	0.37 EPA RSL	Not exceeded
1,1-Dichloroethene	1/163	ND-0.05	277,000 AIHA Low	18 Cal EPA REL	0.6 ATSDR MRL	N/A	Not exceeded
1,2,4-Trichlorobenzene	0/163	ND	2,960 AIHA Low	N/A	N/A	N/A	ND
1,2,4-Trimethylbenzene	31/163	ND-0.16	6 AIHA Low	N/A	12 EPA RfC	N/A	Not exceeded
1,2-Dibromoethane	0/163	ND	10,000 AIHA Low	N/A	1.2 EPA RfC	0.00022 ATSDR CREG	ND
1,2-Dichlorobenzene	1/163	ND-0.18	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	1/163	ND-0.05	26,000 EPA GM	N/A	600 ATSDR MRL	0.0095 ATSDR CREG	Cancer
1,2-Dichloropropane	0/163	ND	260 EPA GM	20 ATSDR MRL	0.87 EPA RfC	N/A	ND
1,3,5-Trimethylbenzene	0/163	ND	N/A	N/A	12 EPA RfC	N/A	ND
1,3-Dichlorobenzene	2/163	ND-0.08	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	9/163	ND-0.25	120 EPA GM	2,000 ATSDR MRL	10 ATSDR MRL	0.04 EPA RSL	Cancer
Benzene	152/163	ND-0.41	61,000 EPA GM	9 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	Cancer
Benzyl Chloride	0/163	ND	41 EPA GM	46 Cal EPA REL	N/A	0.01 EPA RSL	ND

Chemical	Frequency of Detection	Range of Concentration (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
Bromomethane	15/163	ND-0.1	N/A	N/A	1.0 ATSDR MRL	N/A	Not exceeded
Carbon Tetrachloride	157/163	ND-0.2	250,000 EPA GM	300 Cal EPA MRL	30 ATSDR MRL	0.026 ATSDR CREG	Cancer
Chlorobenzene	0/163	ND	1,300 EPA GM	N/A	N/A	N/A	ND
Chloroethane	31/163	ND-0.34	3,800 AIHA Low	15,000 ATSDR MRL	3,800 EPA RfC	N/A	Not exceeded
Chloroform	58/163	ND-0.34	192,000 EPA GM	100 ATSDR MRL	20 ATSDR MRL	0.0089 ATSDR CREG	Cancer
Chloromethane	162/163	ND-2.42	10 AIHA Low	500 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded
cis-1,2-Dichloroethene	1/163	ND-0.1	4,300 AIHA Low	N/A	N/A	N/A	Not exceeded
cis-1,3-Dichloropropene	0/163	ND	260 AIHA Low	N/A	7 ATSDR MRL	0.055 ATSDR CREG	ND
Dichlorodifluoromethane (Freon 12)	163/163	0.16-0.63	N/A	N/A	N/A	N/A	N/A
Dichlorotetrafluoroethane (Freon 114)	0/163	ND	N/A	N/A	N/A	N/A	ND
Ethylbenzene	48/163	ND-0.14	2 AIHA Low	5,000 ATSDR MRL	60 ATSDR MRL	0.25 EPA RSL	Not exceeded
Hexachlorobutadiene	1/163	ND-0.1	N/A	N/A	N/A	0.0043 ATSDR CREG	Cancer
Methylene Chloride	81/163	ND-4.0	144,000 EPA GM	600 ATSDR MRL	300 ATSDR MRL	18 ATSDR CREG	Not exceeded
Styrene	16/163	ND-0.8	150 EPA GM	5,000 ATSDR MRL	200 ATSDR MRL	N/A	Not exceeded
Tetrachloroethylene (PCE)	19/163	ND-12.7	47,000 EPA GM	6 ATSDR MRL	6 ATSDR MRL	0.57 ATSDR CREG	Acute, Chronic, Cancer
Toluene	136/163	ND-4.0	2,800 EPA GM	2,000 ATSDR MRL	1,000 ATSDR MRL	N/A	Not exceeded
trans-1,3-Dichloropropene	0/163	ND	990 AIHA	N/A	7 ATSDR MRL	0.055 ATSDR CREG	ND
Trichloroethylene (TCE)	31/163	ND-0.39	82,000 EPA GM	N/A	0.4 ATSDR MRL	0.04 ATSDR CREG	Cancer
Trichlorofluoromethane (Freon 11)	163/163	0.16-0.41	5,000 AIHA Low	N/A	N/A	N/A	Not exceeded
Trichlorotrifluoroethane (Freon 113)	163/163	0.05-0.16	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	0/163	ND	203 AIHA Low	500 ATSDR MRL	39 EPA RfC	0.044 ATSDR CREG	ND

Chemical	Frequency of Detection	Range of Concentration (ppb)	Odor Threshold[a] (ppb)	Acute Screening Level[b] (ppb)	Chronic Screening Level[c] (ppb)	Cancer Screening Level[d] (ppb)	Exceedances[e]
m- and p-Xylene	84/163	ND-0.41	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded
o-Xylene	66/163	ND-0.15	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded
Volatile Organic Compounds in Radiello® Samples[h]							
1,2,4-Trimethylbenzene	5/55	ND-0.07	6 AIHA Low	N/A	12 EPA RfC	N/A	Not exceeded
1,3,5-Trimethylbenzene	0/55	ND	N/A	N/A	12 EPA RfC	N/A	ND
Benzene	0/21	ND	61,000 EPA GM	9 ATSDR MRL	3 ATSDR MRL	0.04 ATSDR CREG	ND
cis-1,2-Dichloroethene	0/55	ND	277,00 AIHA	N/A	N/A	N/A	ND
trans-1,2-Dichloroethene	0/55	ND	277,00 AIHA	200 ATSDR MRL	200 ATSDR MRL*	N/A	ND
Ethylbenzene	15/55	ND-0.07	2 AIHA Low	5,000 ATSDR MRL	60 ATSDR MRL	0.25 EPA RSL	Not exceeded
Isopropylbenzene (Cumene)	0/55	ND	32 EPA GM	N/A	81 EPA RfC	N/A	ND
Methyl t-butyl ether	0/55	ND	30 AIHA Low	2,000 ATSDR MRL	700 ATSDR MRL	3.1 EPA RSL	ND
Tetrachloroethylene (PCE)	2/55	ND-0.07	47,000 EPA GM	6 ATSDR MRL	6 ATSDR MRL	0.57 ATSDR CREG	Not exceeded
Toluene	6/22	ND-0.15	2,800 EPA GM	2,000 ATSDR MRL	1,000 ATSDR MRL	N/A	Not exceeded
Trichloroethylene (TCE)	3/55	ND-0.07	82,000 EPA GM	N/A	0.4 ATSDR MRL	0.04 ATSDR CREG	Cancer
Vinyl chloride	0/55	ND	203 AIHA Low	500 ATSDR MRL	39 EPA RfC	0.044 ATSDR CREG	ND
m- and p - Xylene	17/55	ND-0.23	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded
o-Xylene	15/55	ND-0.08	730-5,400 EPA GM	2,000 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded

ATSDR MRL = Agency for Toxic Substances and Disease Registry's Minimal Risk Level
Cal EPA REL = California Environmental Protection Agency's Reference Exposure Level
EPA RfC = Environmental Protection Agency's Reference Concentration
EPA RSL = Environmental Protection Agency's Regional Screening Level
ATSDR CREG = Agency for Toxic Substances and Disease Registry's Cancer Risk Evaluation Guide
N/A = not available/not applicable; ND = not detected
*Intermediate MRL is used, because a chronic MRL is not available.

[a] Odor thresholds reported in the scientific literature can vary widely, likely due to differences in experimental methodology and human variability. Shown for H_2S is the geometric mean odor threshold at which approximately 11% of the population may be bothered by the odor [Amoore 1985]. Shown for VOCs are geometric mean (GM) odor thresholds reported by EPA (1992), considered by EPA to be "best estimates" of odor thresholds. If the GM is not available for a particular chemical, shown are the lowest odor thresholds reported by AIHA (2013).
[b] Screening levels are ATSDR's MRLs for acute (0-14 days) exposure and California EPA's RELs for acute exposure. If an MRL for acute exposure has not been established, concentrations are compared to the Cal EPA acute REL, if available.
[c] The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR and EPA. If an MRL for chronic (>1 year) exposure has not been established, concentrations are compared to the intermediate MRL or RfC, if available.
[d] Cancer risks are evaluated by comparison to ATSDR's CREGs or, if CREGs are not available, EPA's cancer RSLs.
[e] Yellow highlights indicate exceedances of the screening level(s) for that chemical or chemical group.
[f] H_2S concentrations are 7- to 14-day average concentrations in ambient air samples collected for EPA from four monitoring stations ¼ mile to 1 mile from the landfill. Samples were collected from each monitoring station on a weekly basis from December 2014-March 2015. The laboratory reporting limits were typically below 1 ppb.
[g] VOC concentrations are 24-hour average concentrations in ambient air samples collected for EPA at four monitoring stations ¼ mile to 1 mile from the landfill. Samples were collected on a weekly basis from May-December 2014. The laboratory reporting limits were typically below 1 ppb.
[h] VOC concentrations are 7- to 14-day average concentrations in ambient air samples collected for EPA from four monitoring stations ¼ mile to 1 mile from the landfill. Samples were collected from each monitoring station on a weekly basis from December 2014-March 2015. The laboratory reporting limits were typically below 1 ppb.

Appendix E: Evaluation of Multiple Chemical Exposures

Toxicological studies are generally performed to better understand the health effects of exposures to individual chemicals. However, single chemical exposures are not necessarily the cause of illness or disease. Adverse health effects can result from the combined action of multiple chemicals that are metabolized in similar ways and target the same tissue or organ. Multiple chemical exposures can happen as a result of air emissions from hazardous waste sites but also occur in daily encounters with numerous chemicals in the air, including other air pollutants, vehicle emissions, cigarette smoke, pesticides, and fumes from cleaning supplies, treated fabrics, paints, and building supplies. There are an infinite number of mixtures of low concentrations of chemicals that people breathe.

Toxicological data are not available for many of the chemicals to which people are exposed, including many chemicals detected at low concentrations in air at hazardous waste sites. While information on the toxicities of many individual chemicals is lacking, there is even less detailed knowledge of the metabolic interactions of those chemicals. A standard, health-protective approach to assessing the risks of multiple chemical exposures is to assume that the effects are additive (i.e., the effect of multiple chemical exposures is equal to the sum of the effects of individual chemical exposures).

The potential health risks of the additive effects of multiple chemical exposures may be evaluated by calculation of "hazard quotients" (HQs), which are ratios of chemical concentrations to their screening levels, and a "hazard index" (HI), which is the sum of HQs for chemicals that target a particular organ or tissue. An HI greater than "1" indicates that more in-depth evaluation of the potential for additive effects may be warranted.

$$HI = \frac{chemical\ concentration}{screening\ level} + \frac{chemical\ concentration}{screening\ level} + \cdots$$

Estimation of Multiple Chemical Exposure Risks near Bridgeton Landfill

Many of the chemicals detected in ambient air near Bridgeton Landfill have been shown in occupational or clinical studies to individually target the respiratory or nervous systems. Lists of chemicals known to affect those systems are included on ATSDR's website at www.atsdr.cdc.gov/substances/ToxOrganSystems.asp. Shown in Table E-1 are short-term concentration ranges and HQs of those chemicals that were detected in ambient air near the landfill. Among the chemicals listed, sulfur-based compounds (SO_2 and RSCs) have the highest HQs, indicating they had the greatest potential to cause acute respiratory or neurological effects.

Also shown are in Table E-1 are the concentration endpoints (NOAELs or LOAELs) that were used to derive the acute screening levels and whether chemical concentrations in ambient air exceeded those adverse effect levels. Individual chemical concentrations (other than the maximum combined RSC and SO_2 concentrations) were at least an order of magnitude below their respective adverse effect levels (i.e., less than 1/10th of the adverse effect level). Because those chemical concentrations were well below their adverse effect levels, the potential for significant additive or interactive effects from multiple chemical exposures is expected to be low and not significantly increase the adverse effects of sulfur-based chemicals.

For acute effects to be additive, people living or working near the landfill must have been exposed to the multiple chemicals at one time. Because the chemicals listed were detected at varying concentrations on different days, the potential for significant additive effects from multiple chemical exposures is furthermore expected to be low.

Table E-1. Chemicals that May Jointly Affect Respiratory or Nervous Systems Bridgeton Landfill, 2013-2018

Target System	Chemical[a]	Range of Concentrations[b] (ppb)	Acute Screening Level (ppb)	Acute Hazard Quotient	Acute Effect Level (ppb)[c]	Exceedance of 1/10th of Acute Effect Level?
Respiratory System	Hydrogen Sulfide*	ND-45.5	70	≤0.65	2,000	No
	Combined RSCs*	ND-3,700	70	≤52.86	2,000	Yes
	Formaldehyde	ND-5.4	40	≤0.14	400	No
	1,2-Dichloropropane	ND-2.7	20	≤0.14	1,800	No
	2-Butanone	ND-28	1,000	≤0.03	99,150	No
	Sulfur Dioxide*	ND-1,600	10	≤160	100	Yes
	Tetrachloroethylene	ND-3.1	6	≤0.52	1,700	No
Nervous System	Hydrogen Sulfide*	ND-45.5	70	≤0.65	2,000	No
	Combined RSCs*	ND-3,700	70	≤52.86	2,000	Yes
	Benzene	ND-32.5	9	≤3.61	2,550	No
	Xylenes	ND-12	2,000	<0.01	50,000	No
	1,1,2-Trichloroethane	ND-0.11	30	<0.01	7,500	No
	Methylene Chloride	ND-181	600	≤0.30	60,000	No
	1,2-Dichloropropane	ND-2.7	20	≤0.14	1,800	No
	2-Hexanone	ND-4.3	N/A	N/A	N/A	N/A
	Acetone	ND-440	26,000	≤0.02	237,000	No
	Carbon Tetrachloride	ND-0.1	300	<0.01	5,000	No
	Chloroform	ND-0.5	100	≤0.01	3,000	No
	Chloromethane	ND-1	500	<0.01	50,000	No
	Ethylbenzene	ND-4.5	5,000	<0.01	154,200	No
	n-Hexane	ND-7.4	N/A	N/A	N/A	N/A
	Styrene	ND-0.9	5,000	<0.01	49,000	No
	Tetrachloroethylene	ND-3.1	6	≤0.52	1,700	No
	Toluene	ND-70	2,000	≤0.04	15,000	No

[a] Chemicals included in ATSDR's list of substances that target the respiratory and nervous systems (available online at: www.atsdr.cdc.gov). Not listed are substances not being monitored but common in urban air (e.g., ozone, nitrogen oxides, particulate matter).
[b] H_2S concentrations are instantaneous concentrations detected by the Jerome® meter up to 2 miles from the landfill. Combined RSC and sulfur dioxide concentrations are instantaneous concentrations detected by AreaRAE® monitors up to ½ mile from the landfill. VOC concentrations are from 4-hour samples collected up to ½ mile downwind of the landfill. The detection limits of the Jerome® meter and AreaRAE® monitors were 3 ppb and 100 ppb, respectively. Laboratory detection limits for VOCs varied but were typically <1 ppb.
[c] Effect levels used to establish acute screening levels and shown to have respiratory or nervous system effects.
*H_2S, combined RSC, and sulfur dioxide concentrations are instantaneous concentrations and, as such, are more likely to be higher than the 4-hour average concentrations of the other chemicals listed. Combined RSCs are

compared to H_2S screening and effect levels, as the toxicities of individual or combined RSCs are not well studied or understood. This is a conservative approach that may overestimate potential health risks if H_2S is more toxic than combined RSCs in air near the landfill.

Limitations

Evaluating the potential health impacts of multiple chemicals is generally limited by the availability of toxicological data. There is a lack of information on the toxicological effects of many chemicals and a lack of understanding of the combined effects of exposures to multiple chemicals that may target the same tissue or organ. VOCs and RSCs, for instance, may jointly affect the respiratory or neurological systems, but the combined effect of breathing those chemicals has yet to be adequately studied.

In community exposure studies, identifying pollutants responsible for respiratory effects is generally complicated by the fact that there are often multiple air pollutants from multiple sources. Other air pollutants that may contribute to respiratory and other health problems and that are common in urban/suburban settings include ozone, nitrogen dioxide, and particulate matter. Common respiratory irritants also include radon, gasoline, and fuel oil fumes. Community studies can also be complicated by smoking prevalence and exposures to secondhand smoke, which contribute to respiratory and other health problems.

In addition, the cumulative health risks of multiple chemical exposures and exposures to non-chemical stressors are not well studied or understood.

Increased Cancer Risks

Cancer risks can also increase if individuals are exposed to multiple chemicals that target the same tissue or organ. For example, because formaldehyde and acetaldehyde have each been shown in animal studies to cause nasal tumors, long-term exposure to both chemicals could theoretically increase the incidence of that cancer.

Appendix F: Cancer Risk Calculations

Calculation of Increased Cancer Risks Associated with Breathing Benzene

The cancer risk values for benzene are estimates of the extra risk of developing cancer associated with benzene inhalation. MDHSS/ATSDR calculated cancer risk values for two exposure scenarios:

1) lifetime exposure to benzene in ambient air downwind of the landfill, assuming continuous residential exposure to long-term average (95UCL) concentrations downwind of the landfill over a standard residential occupancy period (33 years) and over the remainder of a lifetime (45 years) at concentrations measured in the Bridgeton and St. Louis City areas, and

2) lifetime exposure to benzene commonly found in urban/suburban air in the United States (0.26 ppb in 2013) [EPA 2017b].

We assumed the following exposure conditions when estimating cancer risk for residents who live near Bridgeton Landfill:

- 2.5 years exposure to 2.6 ppb benzene [the downwind 95UCL before and during reconstruction of the gas and leachate extraction system in the south quarry of the landfill (April - June 2013)],
- 1 year exposure to 1.2 ppb benzene [the downwind 95UCL during capping of the south quarry of the landfill and construction of an onsite leachate storage and pretreatment system (July 2013 – July 2014)],
- 29.5 years exposure to 0.22 ppb benzene [the downwind 95UCL after completion of corrective actions at the landfill (August 2014 – July 2018)], and
- 45 years exposure to 0.19 ppb benzene (the 95UCL in the Bridgeton area and the average concentration in St. Louis City) [EPA 2021].

The residential occupancy period is assumed to be 33 years [EPA 2011]. We also assumed that, over a 78-year lifespan, residents continue to live in the Bridgeton or St. Louis areas for the remainder of their lives (45 years).

$$\textbf{Cancer Risk Value} = C\ (\mu g/m^3) \times IUR \times EF; \quad C\ (\mu g/m^3) = \frac{C\ (ppb) \times MW}{24.45}; \quad EF = \frac{ED}{AT}$$

where C = average concentration; EF = exposure factor
MW = molecular weight; ED = exposure duration
IUR = inhalation unit risk factor; AT = averaging time

Table F-1. Cancer Risk Values for Benzene

Benzene[a] Exposure Scenario	Time and Place of Exposure	Benzene Concentration (ppb)	Benzene Concentration ($\mu g/m^3$)	Exposure Duration (yrs)	Averaging Time[b] (yrs)	Cancer Risk Value
Downwind of the landfill	After onset of the SSE and before reconstruction of gas/leachate extraction system, downwind	2.6	8.31	2.5	78	2.1×10^{-6}
	During capping and construction of leachate storage system, downwind	1.2	3.83	1		3.8×10^{-7}
	After corrective actions, downwind	0.22	0.70	29.5		2.1×10^{-6}
	Bridgeton area	0.19	0.61	45		2.7×10^{-6}
					Total	7.3×10^{-6}
Urban/suburban locations in the United States in 2013[c]		0.26	0.83	78	78	6.5×10^{-6}

[a] The molecular weight of benzene is 78.11 g/mol; the inhalation unit risk factor for benzene is 7.8×10^{-6} $(\mu g/m^3)^{-1}$
[b] Averaging time = average lifetime of 78 years
[c] [EPA 2017b]
ppb = parts per billion; g/mol = grams per mole; $\mu g/m^3$ = micrograms per cubic meter; yrs = years

Example calculation for urban/suburban locations in the United States:

$$\text{Cancer Risk}_{(\text{national average})} = 0.26 \text{ ppb} \times (78.11 \text{ g/mol} / 24.45) \times 7.8 \times 10^{-6} (\mu g/m^3)^{-1} \times 78 \text{ yrs}/78 \text{ yrs}$$

Estimated Increased Cancer Risk = 6.5×10^{-6}

Appendix G: Public Comments and MDHSS/ATSDR Responses to Comments

The September 2018 Bridgeton Sanitary Landfill Health Consultation was available for public review and comment from September 21, 2018, to January 18, 2019. During the public comment period, the public comment version of the document was available for viewing at the St. Louis Public Library, Bridgeton Trails Branch, in Bridgeton, Missouri. The document and associated fact sheets were also available for viewing and downloading from MDHSS's and ATSDR's webpages.

When the public comment version was released in September 2018, MDHSS met with community leaders, state legislators, and public health partners to discuss the findings of the document. MDHSS announced the release of the document and subsequent public meeting to discuss the findings of the document to area media outlets and on social media. MDHSS shared and discussed the findings of the document with community members at a public meeting and availability session held on January 7, 2019, at the Bridgeton Banquet Hall in Bridgeton. Copies of the report and fact sheets summarizing the findings were provided to the community at the meeting.

During the public comment period, MDHSS received the following comments relating to the document. We received written comments from 4 organizations and 32 written comments from private citizens. Comments from organizations and comments/questions from private citizens are shown in **bold text**. MDHSS/ATSDR responses to those comments are shown in *italicized text*.

Comments from organizations are summarized. We included, as far as possible while protecting personally identifiable information (PII), verbatim comments received from private citizens. Several of the comments from private citizens contained PII such as individual medical histories or addresses of residence, which were removed. Insertions by MDHSS/ATSDR are indicated in brackets. Obvious typographical errors were corrected and are not marked.

<u>Center for Health, Environment & Justice (CHEJ)</u>

PC-CHEJ-1

State and federal agencies failed to share their findings about air emissions from Bridgeton Landfill with the public, most importantly the residents who live around the landfill.

MDHSS/ATSDR response: Please see Section 6, "Community Health Concerns", for a description of our past efforts to keep the community updated on the potential public health impacts of breathing increased fugitive gas and odor emissions from Bridgeton Landfill.

PC-CHEJ-2

MDHSS/ATSDR failed to include the increased cancer risk from benzene levels in ambient air in the key findings of the Health Consultation Report.

MDHSS/ATSDR response: Estimated cancer risk from continuous residential exposure to benzene in ambient air near the landfill is similar to the risk from exposure to typical concentrations of benzene in urban/suburban air in the United States. For clarification, we have revised Conclusion 5 "Basis of Decision" and the "Cancer Risks" section to include estimated *cancer risk values from lifetime exposure to benzene in the Bridgeton area and other urban/suburban areas.*

PC-CHEJ-3
MDHSS/ATSDR's use of screening guidelines to evaluate the air sampling data is suspect.

MDHSS/ATSDR response: Screening levels and health guidelines developed by ATSDR, EPA, and other government agencies are based on the best available scientific studies and are estimates of exposure likely to be without appreciable risk of adverse health effects. Screening levels undergo rigorous review processes. They are reviewed by expert panels of internal and external peer reviewers, and they are submitted for public comment before being finalized.

As estimated values, screening levels and health guidelines contain some degree of uncertainty. Some uncertainty comes from the lack of precise toxicological information on the sensitivity of vulnerable individuals (e.g., children, elderly adults, and people with pre-existing illnesses) to the effects of hazardous substances. Uncertainty can also come from a lack of information on the sensitivity of humans to chemical doses administered to animals in experimental studies. To address uncertainties, government agencies including ATSDR and EPA apply uncertainty factors to observed effect levels from scientific studies that can result in derivation of screening values and health guidelines up to 1,000-times below those effect levels. This is a conservative (i.e., health-protective) approach to addressing uncertainty.

- **MDHSS/ATSDR use available health screening guides inconsistently. Often it seemed that MDHSS/ATSDR moved from one screening [guideline] to another when it was convenient and consistent with its efforts to dismiss an ambient air finding that exceeded a screening level.**

MDHSS/ATSDR response: In this health consultation, we followed ATSDR's public health assessment guidance [ATSDR 2005a]. The public health assessment process has multiple steps, which include a health effects evaluation that involves a screening analysis (see section 4.2, "Screening of Chemicals in Ambient Air") followed by more in-depth analysis of chemicals that exceed screening levels and health guidelines (see section 5, "Public Health Implications"). In the screening analysis, chemical concentrations are compared to screening levels to identify chemicals for further toxicological evaluation. In further analysis, chemicals identified at levels warranting further review are compared to toxicologic and epidemiologic data, including observed effects levels, from scientific studies. Chemical concentrations are compared to observed effect levels to determine where they lie in relation to those effect levels and to assess the likelihood of adverse health effects in relevant exposure scenarios. In both sections (sections 4.2 and 5), we have added and reformatted text to make it easier to follow the steps of a health effects evaluation.

- **As a scientific community, we know very little about what specific level of exposure to a single chemical will result in an adverse health outcome in a person.**

MDHSS/ATSDR response: Our public health assessments evaluating the potential public health impacts of exposure to chemicals in the environment are based on the best available science. As *discussed in the "Uncertainties and Limitations" section and in Appendix E, "Evaluation of Multiple Chemical Exposures", public health assessments can be limited by the lack of scientific information on some individual chemicals and on multiple chemical exposures, including the contribution of non-chemical stressors to health effects. However, there is sufficient information, including air sample and toxicological data, on chemicals of concern at this site to draw conclusions about their potential public health impacts.*

Public health consultations and public health assessments assess the risk of public health impacts of environmental exposures at a site. They are not designed to predict the potential health impacts on individuals. We recommend individuals speak to their healthcare providers to discuss any personal health issues or concerns.

PC-CHEJ-4
MDHSS/ATSDR's public health evaluation including its analysis and conclusions is not transparent and is based on limited environmental data collected primarily by MDNR.

- **How did MDNR avoid confounding factors such as weather extremes and sensor drift that could affect the AreaRAE® data?**

MDHSS/ATSDR response: From April 2013 to July 2018, MDNR staff were stationed near the site and regularly checked the AreaRAE® readings with handheld meters (see footnote 13 in the "MDNR Continuous Ambient Air Monitoring" section and the main text in the "Uncertainties and Limitations" section). For additional details on data quality assurance, please see MDNR's Quality Assurance Project Plan for Bridgeton Landfill at: *https://dnrservices.mo.gov/env/swmp/facilities/docs/bridgetonslfqapp.pdf*

- **It is not clear how the data from samples collected by Republic Services (see Appendix A) were used in the analysis, or how they are different from the data shown in Table 1.**

MDHSS/ATSDR response: We have revised section 3.1 "Chemicals Targeted for Routine Air Monitoring/Sampling" and the text in Appendix A to clarify how the comprehensive sampling data collected by Republic Services were used.

- **In the results tables in Appendix D, Tables D-2 and D-4 only show average chemical concentrations. The highest readings are not presented. Evaluating potential adverse chronic effects and cancer risks based on the average rather than the highest concentrations limits understanding of the risks posed by gas and odors coming from the landfill.**

MDHSS/ATSDR response: We have consolidated the tables in Appendix D. They now show the range of concentrations of chemicals in air alongside acute, chronic, and cancer screening levels and health guidelines.

Chemical concentrations are compared to screening levels and health guidelines appropriate to the exposure duration. Health guidelines include ATSDR's MRLs, which are derived for acute

(0-14 days), intermediate (15 to 364 days), and chronic (365 days or longer) durations of exposure. We compared instrument measurements to acute screening and health guideline values, and we compared estimates of long-term exposure to chronic screening and health guideline values. Following ATSDR's 2019 exposure point concentration guidance, we calculated 95UCLs of the mean to estimate average long-term exposures to chemicals frequently detected in air.

- **It is difficult to understand which sampling locations are upwind and which sampling locations are downwind. Without a clear understanding of which monitoring/sampling locations are downwind of the landfill, it's not possible to independently verify the analysis presented in this report.**

MDHSS/ATSDR response: Some of the data reviewed in this report, including the AreaRAE® and routine surveillance data, were collected at fixed or stationary locations that were not always upwind or downwind of the landfill and are, therefore, not identified as such. However, the wind rose plots in Appendix B show the fixed AreaRAE® monitors were often downwind of the landfill. The AreaRAE® data were collected at residential and commercial locations as close to the landfill as possible to measure the highest emissions of gases coming from the landfill. Based on those measurements, we conclude in this report that people living or working near the landfill, regardless of location, may have breathed sulfur-based compounds over sufficient time periods for adverse health effects. We do not assume that the risk of adverse health effects was greater or less in one residential area than another.

The data obtained by MDNR by laboratory analysis were always from samples that were designated by MDNR as collected upwind or downwind of the landfill (see section 3.3 "MDNR Ambient Air Sampling for Laboratory Analysis"). Data exceeding a screening level at sampling locations upwind and/or downwind of the landfill are identified as such in Tables 5 and 6 and Appendix D.

- **Data presented in the report do not represent what people who live around the landfill breathe daily.**

MDHSS/ATSDR response: No single monitoring or sampling method provides a complete picture of what people were breathing. Therefore, MDNR and EPA used a variety of air monitoring and sampling approaches to evaluate the nature and extent of gas emissions from the landfill and assess air quality in the Bridgeton area. Evaluating those data as a whole over an extended period of time, we were able to observe patterns in the data (e.g., downward trends in AreaRAE® detections of sulfur-based compounds) that allowed us to draw several conclusions about the potential public health impacts of breathing gas and odor emissions from the landfill.

- **Why did MDHSS/ATSDR limit its analysis to data collected through 2016?**

MDHSS/ATSDR response: We did not include MDNR's 2017-2018 data in our September 2018 public comment version of this report, because processing those data for the report (including laboratory analysis of air samples, compilation and evaluation of the sample data, and comprehensive peer-review of the evaluation) would have delayed its release. We believed the

2013-2016 data included in the report were sufficient for assessment of the past and current health impacts of breathing gas and odor emissions from the landfill. We did not expect that waiting for additional data would change our conclusions about the current health impacts.

In this final version of the document, we evaluate the complete set of ambient air data collected by MDNR in 2013-2018, while the landfill was under MDNR's oversight. Addition of the 2017-2018 data did not change the findings presented in the public comment version of this report.

- **Exposure to fugitive emissions are likely to be underestimated, given the limited number of monitoring locations and the inconsistent wind patterns.**

MDHSS/ATSDR response: Several monitoring and sampling uncertainties and limitations, for various reasons, may have resulted in overestimation or underestimation of exposures to fugitive gas emissions near the landfill (see section 7, "Uncertainties and Limitations"). However, we do not consider the number of AreaRAE® monitoring locations to be a major limitation to assessing the public health risks of exposure to fugitive gases emitted from the landfill. Data collected by multiple monitoring and sampling methods (the AreaRAE® data as well as upwind and downwind sample data and twice-daily surveillance data) were used to estimate fugitive landfill gas exposures. We believe that, together, those data are adequate and sufficient to support the conclusions of this report.

- **Not considering flare stack emissions resulted in significant underestimation of the emissions coming from the landfill.**

MDHSS/ATSDR response: The purpose of this health consultation is to assess the public health impacts of fugitive landfill gas emissions into ambient (outdoor, offsite) air. In this report, we did not review the onsite landfill flare/stack emissions, which are addressed by MDNR air permits based on engineered designs and approved modeling to verify and ensure protection of public health and the environment. However, we did review data collected to characterize the impacts gas emissions have on ambient air quality in the Bridgeton area (e.g., the Rider Trail monitoring station data). Those data are used to assess the air quality impacts of multiple regional emissions sources, including fugitive and flare stack emissions from the landfill.

- **Break-through events are not included in the conceptual exposure model.**

MDHSS/ATSDR response: We have revised section 4.1.1 "Conceptual Exposure Model" to emphasize that gas emissions from the landfill may increase during isolated events such as invasive work or instances of equipment failure. The data evaluated in this report include ambient air data collected during instances of equipment failure during extreme weather events.

- **Does MDHSS/ATSDR consider vapor intrusion as a potential source of exposure?**

MDHSS/ATSDR response: The purpose of this health consultation is to assess the public health impacts of fugitive landfill gas emissions into ambient (outdoor, offsite) air. In this report, we did not evaluate the potential for underground gas migration or potential subsequent intrusion of those gases into homes or businesses. To prevent offsite gas migration, MDNR enforces *regulations on methane gas concentrations in soil at landfill property boundaries, including Bridgeton Landfill. If those concentrations exceed allowable limits, MDNR requires the responsible party (1) to notify surrounding property owners/occupants of the potential for landfill gas migration, (2) to conduct an investigation of the extent of migration, and (3) to propose corrective actions to bring methane gas concentrations to within safe levels.*

Methane levels at the perimeter of Bridgeton Landfill are actively monitored. MDNR has not found evidence of offsite soil gas migration threatening to public health (https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill).

PC-CHEJ-5
MDHSS/ATSDR fails to conduct an analysis of how only using existing available data impacts its evaluation of the public health risks posed by the Bridgeton Landfill. MDHSS/ATSDR should discuss the limitations of the data, especially in the context of whether they are adequate and sufficient to properly evaluate the public health risks posed by the landfill.

MDHSS/ATSDR response: Several uncertainties and limitations, for various reasons, may have resulted in overestimation or underestimation of exposures to fugitive gas emissions near the landfill (see section 7, "Uncertainties and Limitations"). Despite those uncertainties and limitations, we believe there are adequate and sufficient data to support the conclusions of this report.

PC-CHEJ-6
MDHSS/ATSDR failed to consider cumulative risks in this health evaluation.

MDHSS/ATSDR response: In Appendix E, we quantitatively evaluate the combined risk of exposure to multiple chemicals detected in ambient air near the landfill that may target the respiratory or nervous systems. We also discuss the limitations to understanding the public health impacts of multiple chemical exposures and the contribution of non-chemical stressors to health effects.

PC-CHEJ-7
Despite limitations in the data available to MDHSS/ATSDR, the agenc(ies) still found that some of the contaminants detected in ambient air near the landfill likely caused adverse health effects for members in the community.

- **However, MDHSS/ATSDR attempts to dismiss these findings as being "in the past" without recognition or acknowledgement that these effects even if in the past can cause long-lasting adverse effects on the people who were impacted.**

MDHSS/ATSDR response: In this health consultation, we conclude that prior to completion of corrective actions at the landfill, exposure to sulfur-based compounds in ambient air near the landfill may have harmed people's health. Harmful health effects may have included aggravation of chronic respiratory disease or acute respiratory effects such as chest tightness, wheezing, or *breathing discomfort. After corrective actions were completed at the landfill in 2013 and 2014, the frequency of detection of those compounds in ambient air decreased significantly. Currently, fugitive emissions of sulfur-based compounds are unlikely to harm people's health. However, landfill odors may continue to be objectionable, especially during periods of construction or other invasive work at the landfill or in instances of landfill equipment malfunction, and affect the quality of life of people living or working near the landfill.*

In the "Stress" section of this report, we discuss the potential for individuals to experience increased stress from living near the landfill, including long-term or repeated exposures to malodorous emissions from the landfill. We discuss the potential for negative health effects associated with chronic stress. Health issues that can be induced by chronic stress include anxiety, mental depression, or impaired immune response, which can be long-lasting or increase the persistence or severity of some illnesses. Stress can also affect children. Children can manifest stress in different ways depending on their age, previous experiences, and coping behavior.

PC-CHEJ-8
MDHSS/ATSDR's third conclusion of the health consultation report is internally inconsistent and seems to contradict itself.

MDHSS/ATSDR response: We conclude in this report that breathing sulfur-based compounds in ambient air near the landfill is currently unlikely to harm people's health but that the odors of those compounds may be occasionally bothersome and affect the quality of life of people living or working near the landfill. Odors from the landfill may be objectionable during invasive work or instances of landfill equipment malfunction at the landfill. As discussed in the "Landfill Odors" section, perception of offensive odors in not necessarily an indication of a threat to health. However, offensive odors can become bothersome and cause symptoms such as headache or nausea, even if chemicals causing the odors are at concentrations below levels of toxicity.

PC-CHEJ-9
MDHSS/ATSDR defined its objectives for the health consultation without consulting with community leaders.

MDHSS/ATSDR response: MDHSS and ATSDR conduct public health assessments upon request. In 2013, MDHSS received a request for three health consultations from the Director of the St. Louis County Department of Public Health (SLCDPH), which defined the concerns that MDHSS and ATSDR have addressed in those health assessments/consultations. SLCDPH requested health consultations on "the area surrounding the West Lake/Bridgeton Landfill due to the odors/emissions caused by the recent subsurface smoldering event", "the area surrounding the West Lake/Bridgeton Landfill due to the radiological waste improperly deposited years ago in the West Lake Landfill Superfund Site", and "the Coldwater Creek area in North St. Louis County due to the radiological waste improperly deposited years ago". This health consultation was written in response to their request for an evaluation regarding odors/emissions caused by the subsurface smoldering event. In 2015, ATSDR completed the West Lake Landfill Operable Unit 1 Health Consultation in response to their request for an evaluation regarding radiological waste deposited at West Lake Landfill. In April 2019, ATSDR completed the Evaluation of

Community Exposures Related to Coldwater Creek Public Health Assessment in response to their request for an evaluation regarding radiological waste at Coldwater Creek.

MDHSS and ATSDR invite agencies or community members to submit requests for public health assessments/consultations to address concerns about additional exposure scenarios at any time.

Stantec Consulting Services, on behalf of Bridgeton Landfill, LLC

PC-Stantec-1

Conclusions 1, 2, and part of 3 are overstated. Ambient air around Bridgeton Landfill did not in the past pose unacceptable risk of adverse health effects to people working and living nearby. Conclusions 4, 5 and the remainder of 3 are accurate.

- **Conclusion 1 ignores laboratory analytical data which prove that, even in 2013, ambient concentrations of sulfur-based compounds were below screening levels for protection of human health.**

MDHSS/ATSDR response: Individual sulfur-based compounds were not detected in the air samples collected by MDNR upwind and downwind of the landfill for laboratory analysis (Appendix D). However, we cannot conclude from the laboratory data alone that sulfur-based compound concentrations in ambient air near the landfill were below levels potentially harmful to human health. Standard analytical methods of laboratory analysis are complicated by the instability and reactivity of sulfur-based compounds. In addition, as discussed in the "Uncertainties and Limitations" section, MDNR's air samples were collected over 45-50 minute or 4-hour time periods during the day (once per week or month) and may not have captured emission spikes or accumulation of gases that can occur near ground level in the evening, nighttime, and early morning hours when winds tend to be calmer.

- **Discrete one-minute interval detections by AreaRAE® sensors do not represent continuous exposure over longer periods of time and do not show conditions of exposure where health effects have been observed in people. MDHSS/ATSDR point to limited and infrequent detections above screening levels, but most of the data are well below screening levels.**

MDHSS/ATSDR response: All sulfur-based compound measurements by the AreaRAE® monitors were above health-based screening levels and guidelines, because the lower detection limits of the AreaRAE® H_2S and SO_2 sensors (100 ppb) were above those screening levels and guidelines [ATSDR's acute and intermediate MRLs for H_2S (70 ppb and 20 ppb, respectively), Cal EPA's acute REL for H_2S (30 ppb), EPA's RfC for H_2S (1.4 ppb), and ATSDR's acute MRL for SO_2 (10 ppb)]. Sulfur-based compounds were most frequently detected by the AreaRAE® monitors near the landfill in 2013, prior to the completion of corrective actions at the landfill. Our conclusions on past exposures are based on a detailed toxicological evaluation, including review of the frequency of detection of sulfur-based compounds at concentrations exceeding health guidelines, and are predicated on the assumption that people may have breathed sulfur-based compounds for sufficient time periods for adverse health effects to have occurred.

- **A recent study by SLCDPH and the St. Louis University College for Public Health published in a peer reviewed journal (Kret et al. *A Respiratory Health Survey of a Subsurface Smoldering Landfill*, Environmental Research, 2018) shows there was no actual harm to the health of nearby residents. The study concludes that people living near the Bridgeton Landfill do not have elevated respiratory or related illness**.

MDHSS/ATSDR response: Kret et al. (2018) found no significant difference in the prevalence of asthma or COPD in households within a 3.2-kilometer (2 mile) radius of the landfill, compared to other households surveyed. In other words, they did not find a significantly higher proportion of households with one or more individuals ever diagnosed with asthma or COPD. However, their findings do not contradict our conclusion that individuals living or working near the landfill may have experienced aggravation of a chronic respiratory disease, such as asthma, or other respiratory symptoms prior to the implementation of corrective actions at the landfill in 2013-2014, a few years prior to the survey.

PC-Stantec-2
Conclusions 1, 2, and 3 are inter-related rather than separate conclusions that conflate health effects caused by exposure to RSCs and SO_2 with symptoms associated with unpleasant odors.

MDHSS/ATSDR response: For the sake of brevity, we did not draw separate conclusions about the potential health effects of exposures to sulfur-based compounds and their odors. Potential health effects included aggravation of chronic respiratory disease or other respiratory effects that may occur by toxicologic or odor-related mechanisms. They also included increased risk of respiratory illness observed in other community studies of exposure to malodorous sulfur-based compounds. Whether increased risk of respiratory illness is related to a toxicologic, odor-related, or stress-related response is not well studied or understood.

PC-Stantec-3
A fundamental flaw in the health consultation is MDHSS/ATSDR's reliance on, and misinterpretation, of readings from the MDNR AreaRAE® sensor measurements of H_2S and SO_2 to infer community level exposures to sulfur-based compounds in ambient air.

- **Because the AreaRAE® data are central to Conclusions 1, 2, and 3 regarding health effects, it is important to discuss the limitation of these instruments and the alternative analytical data for reduced sulfur compounds in ambient air.**

MDHSS/ATSDR response: Several monitoring and sampling uncertainties and limitations, for various reasons, may have resulted in overestimation or underestimation of exposures to fugitive gas emissions near the landfill (see section 7). We have revised section 7 to clarify that AreaRAE® monitors are not designed to measure low concentrations of chemicals in the ambient air. We have also revised that section to emphasize that standard analytical methods of laboratory analysis of sulfur-based compounds are complicated by the instability and reactivity of those compounds. Despite uncertainties and limitations, we believe there are adequate and sufficient data to support the conclusions of this report.

- **Using an AreaRAE®, there is no way to discriminate methyl mercaptan from H_2S in ambient air. This is significant because their toxicities are not equivalent.**

MDHSS/ATSDR response: We agree that AreaRAE® H_2S sensors may be prone to chemical interference by mercaptans (section 7), and, therefore, the monitor readings do not discriminate between methyl mercaptan and H_2S in ambient air. Because methyl mercaptan and other RSCs were detected in the landfill source gas (76.5% dimethyl sulfide, 8.2% dimethyl disulfide, 4.8% methyl mercaptan, 1.6% H_2S), we assume the AreaRAE® H_2S sensor readings are likely to be measurements of a combination of RSCs in the ambient air near the landfill.

While individual RSCs cause similar health effects, the concentrations required to cause those effects may be different. However, the toxicities of individual RSCs and combinations of multiple RSCs are not well understood. The toxicity of H_2S is well established [EPA 2017a]. Our assumption that combined RSCs are as toxic as H_2S is a conservative/health-protective approach that may overestimate potential health risks.

We have revised section 5.1.4.3 "Uncertainty in Community Studies" to clarify that combined RSC exposure concentrations and durations that might cause adverse respiratory and neurological effects cannot currently be determined from epidemiological studies. Despite that limitation, several studies show associations between short- and long-term exposures to mixtures of low concentrations of RSCs in ambient air and adverse respiratory and neurological effects in affected communities and support the conclusions of this report.

- **Although there are some other RSCs that may elicit a response, the AreaRAE® is designed to detect H_2S because of the acute hazard associated with that gas. The assumption that the H_2S AreaRAE® sensors are recording the level of all reduced sulfur compounds is not accurate and not consistent with the purpose of the instrument.**

MDHSS/ATSDR response: As discussed in section 7 "Uncertainties and Limitations", the AreaRAE® H_2S sensor may be prone to chemical interference by methyl mercaptan and perhaps other RSCs. Because reduced sulfur in the landfill source gas was found to consist of multiple RSCs (e.g., dimethyl sulfide, dimethyl disulfide, methyl mercaptan, and H_2S), we assume that the AreaRAE® H_2S sensors were measuring not only H_2S but a combination of RSCs in the ambient air.

- **MDHSS/ATSDR acknowledge potential issues with the MDNR AreaRAE® monitors including sensor drift, weather extremes, and MDNR failure to conduct routine checks of the sensors. They state that although some of those early AreaRAE® measurements were likely biased high, they treated all reported data as valid. This is an important statement because the conclusions about exposure to RSCs and SO_2 and health effects in 2013-2014 are largely based on data from the MDNR AreaRAE® monitors that may not have been valid.**

MDHSS/ATSDR response: MDNR staff began routine monitoring for AreaRAE® sensor drift in April 2013. Considering all prior AreaRAE® measurements (i.e., the February-March 2013 *measurements) invalid would not change our findings that AreaRAE® measurements of sulfur-based compounds (which exceeded health-based screening levels and guidelines) occurred most frequently in 2013 and that those detections decreased significantly after corrective actions at the landfill were completed in 2014. From April 2013 to July 2018, annual frequencies of detection of sulfur-based compounds decreased significantly by 74.8% (combined RSCs) and 91.8% (SO_2).*

PC-Stantec-4

MDHSS/ATSDR state "Concentrations of H_2S in ambient air in urban areas in the United States are typically at or below 1 ppb (ATSDR, 2014). Maximum concentrations have ranged from 2.8 ppb to 6.3 ppb in urban areas…." This directly supports the conclusion that H_2S concentrations detected in ambient air near the landfill are consistent with concentrations observed in ambient air in urban settings.

MDHSS/ATSDR response: We have revised section 4.2.2, "H_2S near Bridgeton Landfill", to emphasize that the median concentration of H_2S measured with the Jerome® meter near the landfill (3 ppb) was higher than expected for an urban area in the United States and indicative of a local emissions source. In 2010-2015, the median H_2S concentrations in urban areas in the United States was approximately 1 ppb. Most instantaneous concentrations of H_2S in air near the landfill (i.e., >95% of detected concentrations) were similar to maximum concentrations detected in urban areas. In 146 instances (mostly occurring in 2013, prior to completion of corrective actions at the landfill), instantaneous H_2S concentrations in air near the landfill met or exceeded 8 ppb (Table 5), an odor threshold at which approximately 11% of the population may be bothered by the odor.

PC-Stantec-5

MDHSS/ATSDR's statement that "evidence of people's exposure to Bridgeton Landfill gases includes the periodic perception (by MDNR) of distinctive, offensive odors in residential and commercial areas surrounding the landfill" would suggest that odors were sporadic/episodic and not sustained over long periods of time, and by inference exposures were sporadic.

MDHSS/ATSDR response: MDNR staff periodically reported distinctive, offensive landfill odors during their twice-daily surveillance of the landfill and nearby areas. MDNR's reports did not include information on the persistence of those odors. We therefore cannot assume that those odors were not sustained over sufficient periods of time to be bothersome to people living or working near the landfill. In fact, MDNR received numerous complaints from community members indicating odors were persistent and bothersome.

PC-Stantec-6

Although people may be able to observe the odor at very low at concentrations, these concentrations are not representative of concentrations that may cause toxic exposures.

MDHSS/ATSDR response: We agree that the perception of offensive odor does not necessarily mean that the chemical(s) causing the odor pose(s) a toxic threat to people's health. Please see the first paragraph in section 5.5, "Landfill Odors".

PC-Stantec-7

Since the RSCs and SO_2 are common landfill gases, it cannot be concluded that Bridgeton Landfill would have been the only source of the odors (and inferential exposures). It should be noted that the MDNR AreaRAE® sensors were placed in locations where other sources of SO_2 and H_2S were likely to be present in ambient air at ground level; within 10 feet of the St. Louis Metropolitan Sewer District lift station vault, the intersection of busy roads (car exhaust can be a common source of SO_2 and H_2S), and in a mobile home neighborhood.

MDHSS/ATSDR response: Bridgeton Landfill is in an urban/suburban area with multiple sources of airborne pollutants. In section 4.2.4, "Other Sources of Chemicals and Odors in Ambient Air", we discuss the presence of other nearby sources of chemicals in the air. However, downward trends in the frequency of detection of odors, in the frequency of detection of sulfur-based compounds at nearby AreaRAE® monitoring locations, and in downwind benzene concentrations following implementation of corrective actions at the landfill indicate the smoldering landfill was a significant source of pollutants in the ambient air.

PC-Stantec-8

Since ATSDR MRLs are used to support some of the conclusions about adverse health effects, it is important to understand the definition of those screening levels. It is important to note that MRLs are not intended to define clean up or action levels.

MDHSS/ATSDR response: It is correct that MRLs are not intended to define clean up or action levels. When MRLs are exceeded, we conduct further toxicological evaluation to determine whether people are at risk of harmful effects. We have revised sections 4.2, "Screening of Chemicals in Ambient Air", and 4.2.1, "Screening Levels and Odor Thresholds", to include this point and to define MRLs and other health guidelines.

PC-Stantec-9

Comparing instantaneous concentrations of H_2S measured by MDNR with the Jerome® meter to Cal EPA's acute REL or ATSDR's acute and intermediate MRLs (which are protective of health from exposures over longer periods of time) is not warranted and is misleading.

MDHSS/ATSDR response: Sulfur-based compounds are chemicals that can cause irritant effects in a short period of time. It is therefore important to determine whether brief exposures to sulfur-based compounds might cause harmful effects. Cal EPA's acute REL and ATSDR's MRLs are health guidelines that help us make that determination.

The time it takes for an odor to become bothersome is not well studied or understood. Therefore, our conclusions on sulfur-based compound odors are based on the assumption that people may have been exposed for sufficient time periods for odors to become offensive. In 146 instances, *instantaneous H_2S concentrations met or exceeded 8 ppb (Table 5), an odor threshold at which approximately 11% of the population may be bothered by the odor.*

PC-Stantec-10
Sporadic one-minute readings from AreaRAE® sensors do not equate to sustained exposure and causation of illness.

MDHSS/ATSDR response: In this health consultation, we conclude that before completion of corrective action at the landfill, breathing sulfur-based compounds in ambient air near the landfill may have been harmful to people's health. This conclusion is not based solely on exceedance of health guidelines but rather our detailed toxicological evaluation including review of the frequency of detection of sulfur-based compounds at concentrations exceeding health guidelines. It assumes that people may have breathed sulfur-based compounds for sufficient time periods for adverse health effects to have occurred.

PC-Stantec-11
MDHSS/ATSDR state "In 2013-2016, MDNR detected H_2S approximately 47% of the time during their twice-daily routine surveillance with hand-held meters to 2 miles from the landfill. It is therefore expected that people living or working near the landfill and in the Bridgeton area may have occasionally been able to smell H_2S in ambient air." And, "If exposures to those concentrations occurred for a sufficient period of time on those days, sensitive individuals living or working in that area may have considered H_2S concentrations offensive and may have experienced adverse neurological effects such as headache and nausea." These statements and subsequent conclusions are not supported by the facts at the site. H_2S is a very small percentage of the reduced sulfur compounds detected in Bridgeton Landfill source gas (1.6% according to MDHSS). H_2S has a distinctive rotten egg odor that has not been observed on the landfill or in downwind monitoring locations. Dimethyl sulfide was the dominant RSC contributing to the Bridgeton Landfill odor.

MDHSS/ATSDR response: Although H_2S was detected in the landfill source gas in relatively low amounts (1.6% of total RSCs; Appendix C), H_2S concentrations measured with the Jerome® meter in ambient air near the landfill were often within a range of low odor detection thresholds. In 110 instances in 2013, prior to the completion of corrective actions at the landfill, H_2S was detected at concentrations that could be considered bothersome (Table 8).

We have revised section 5.1.1.1, "Responses to Hydrogen Sulfide Odors", to clarify that people were unlikely to smell H_2S distinctly or continuously but that H_2S likely contributed to odors perceived by people in the Bridgeton area. Multiple RSCs, including H_2S and dimethyl sulfide, likely contributed to the odors associated with the landfill.

<u>West Lake Landfill/Bridgeton Landfill Community Advisory Group (CAG)</u>
PC-CAG-1
Did MDHSS/ATSDR consider the health effects of breathing particulates?

MDHSS/ATSDR response: The datasets that we evaluate in this health consultation do not include data on particulate matter (PM) in ambient air. PM is a common air pollutant in urban/suburban environments. Most particulates are formed in the atmosphere as a result of complex chemical reactions involving chemical emissions from vehicle, industrial, or other sources. There are multiple secondary sources of PM in the air in the Bridgeton area. See the "Landfill Odors" section and Appendix E, "Evaluation of Multiple Chemical Exposures", for discussion of the contribution of particulate matter to respiratory illness.

PC-CAG-2
Were the synergetic effects of the combinations of chemicals in the air taken into account? If not, is this something that can and should be considered? Why or why not?

MDHSS/ATSDR response: In Appendix E, "Evaluation of Multiple Chemical Exposures", we quantitatively evaluate the combined risk of exposure to multiple chemicals detected in ambient air near the landfill that may target the respiratory or nervous systems. We also discuss the limitations to understanding the public health impacts of multiple chemical exposures and the contribution of non-chemical stressors to health effects.

PC-CAG-3
Combined RSCs were detected most frequently at the AreaRAE® monitoring location east of the landfill. Is there a separate health risk rating for people living in that direction? If not, can you add this to the report?

MDHSS/ATSDR response: In total, sulfur-based compounds (RSCs and SO_2 combined) were detected most frequently in the commercial area southwest of the landfill (at least once in 12% of total monitoring hours). Total sulfur-based compounds were detected less frequently at the residential location south/southeast of the landfill and the commercial location northeast/east of the landfill (at least once in 8% and 10% of total monitoring hours, respectively). Sulfur-based compound exposures may cause adverse respiratory effects. Their odors may cause headache or other adverse effects, especially in individuals who are sensitive to odors.

The AreaRAE® monitors were placed at residential and commercial locations as close to the landfill as possible to measure the highest emissions of gases from the landfill. As shown by the wind rose plots in Appendix B, those locations were often downwind of the landfill. The southwest monitoring location, where sulfur-based compounds were most frequently detected, was immediately adjacent to the landfill and MSD lift station. At that location, there was little buffer between the monitors and emissions sources. The monitoring locations south/southeast and northeast/east of the landfill were approximately ½ mile from the landfill.

Before completion of corrective actions at the landfill, people living or working downwind of the landfill, regardless of location, may have breathed sulfur-based compounds over sufficient time periods for adverse health effects. Although the total number of detections of sulfur-based compounds varied by monitoring location, we did not assume that the risk of adverse health effects was greater or less in one downwind monitoring location than another.

PC-CAG-4

In the past, MDHSS has issued odor alerts, etc. With the Settlement between Republic Services and the State of Missouri, the State of Missouri is no longer directly monitoring the air around the landfills, and MDNR has stated that the new monitors run by Republic Services are to be collected by Republic Services every 2 weeks and then analyzed by Republic Services for an additional 30 days before being released to MDNR. What is MDHSS doing to monitor and alert our communities in real-time should a release of toxic gases occur?

MDHSS/ATSDR response: In "Next Steps" and "Recommendations" sections, we recommend that future data should be provided to MDHSS or other responsible agency in a timely manner so that public health impacts can be adequately communicated and addressed. We will continue to explore ways to issue health alerts.

Missouri Coalition for the Environment (MCE)

PC-MCE-1

Landfill workers are at the greatest risk of negative health impacts, considering their direct proximity to the flares and emissions that escape through rips in the landfill cover. Rips and tears in the EVOH cap occur regularly as the smoldering causes the landfill to settle. Workers are required to repair these rips and are often seen without personal protective equipment. MCE requests the MDHSS include landfill workers in the risk assessment and require Republic Services to provide the final report to all current and past employees who worked at the landfill dating back to December 2010.

MDHSS/ATSDR response: The purpose of this health consultation is to assess the public health impacts of fugitive landfill gas emissions into ambient (outdoor, offsite) air. We assessed the potential health implications for people living or working near the landfill but not for workers on the landfill.

MDHSS and ATSDR invite agencies or community members to submit requests for public health assessments/consultations to address concerns about additional exposure scenarios at any time. However, requests for worker exposure evaluations are typically referred to the federal Occupational Safety and Health Administration (OSHA) or National Institute for Occupational Safety and Health (NIOSH).

PC-MCE-2

The health consultation should acknowledge potential health risks during periods of objectionable odors before MDNR started monitoring ambient air near the landfill.

MDHSS/ATSDR response: Routine ambient air monitoring and sampling data are not available from December 2010, when the SSE began, to 2013, when MDNR began routine monitoring and sampling near the landfill. We have revised the "Uncertainties and Limitations" section to note the lack of those data. If chemical emissions were similar to what was measured in ambient air in 2013, the health risks of living or working near the landfill were likely similar. During that time, MDNR began receiving odor complaints, indicative of increased gas emissions from the landfill.

PC-MCE-3
Based on the comments received by MDHSS during the community meeting, MCE recommends further detailing how the odor threshold was established. Community members at the meeting were clearly frustrated that it shows 656 exceedances of the odor threshold. Community members want to know why there was not a greater sense of urgency from MDHSS to communicate these exceedances with them in real-time.

MDHSS/ATSDR response: MDHSS developed a site-specific odor threshold for evaluation of the odors of combined RSCs measured by MDNR's AreaRAE® monitors near the landfill. As shown in Table 5, AreaRAE readings (lasting 1 to 3 minutes) exceeded that odor threshold 656 times in 2013-2018. If those exceedances occurred for sufficient periods of time, sensitive individuals living or working in that area may have considered RSC odors offensive. Calculation of the odor threshold is described in Appendix C.

We have revised the "Community Health Concerns" section to include details of our past efforts to keep the community updated on the potential public health impacts of breathing increased fugitive gases and odors emitted from the landfill. Those efforts included release of over 500 air monitoring review messages on MDHSS's and MDNR's websites that included standing recommendations for limiting exposures to odors and responding to symptoms associated with odors. Please see the "Recommendations" section for recommendations regarding odors.

PC-MCE-4
Please indicate which studies are referenced in the last paragraph of Conclusion 2, including a reference for the claim that "long-term exposures have also been associated with increased risk of acute respiratory infection (common cold, bronchitis)."

MDHSS/ATSDR response: Please see the references in section 5.1.4.2, "Long-term Exposures", which is a part of the "Supporting Community Studies" section, for discussion of the potential link between long-term exposures to malodorous sulfur-based compounds and increased risk of common respiratory illnesses like the common cold. As discussed in the "Stress" section, constant exposure to malodorous emissions can contribute to people's stress, and chronic stress can increase people's susceptibility to illness.

PC-MCE-5
MDHSS/ATSDR should acknowledge in Conclusion 5 that air testing did not begin until several months following calls reporting increased odors from the landfill. MDHSS should include data from odor reports as it relates to chronic stress.

MDHSS/ATSDR response: We have revised the Conclusion 5 "Basis of Decision" to include a cancer risk value that is based, in part, on an assumption that increased benzene exposures occurred after the onset of the SSE in December 2010 and before the start of air sampling in April 2013.

In the Conclusion 2 "Basis for Decision", we note that community members began submitting odor complaints in 2012 and discuss odors as a contributing factor to stress that, over time, can lead to stress-related illness.

PC-MCE-6
The last paragraph on page 13 should note the constant settlement of the landfill can compromise the landfill gas collection infrastructure and puncture the EVOH cap. The landfill also experiences problems during intense weather events, such as the polar vortex at the beginning of 2014.

MDHSS/ATSDR response: We have revised the "Site Description and Background" section to include mention of issues that have complicated landfill gas and leachate collection, including settlement of the landfill and extreme weather events.

PC-MCE-7
MDHSS/ATSDR should consider the community is likely under-reporting odors for a variety of reasons, including mistrust of the landfill owner Republic Services now that it is responsible for collecting air data, reporting fatigue after more than six years of random odors impacting their lives, and that many individuals who accepted legal settlement compensation from Republic Services were likely required to sign nondisclosure agreements, increasing the fear of violating the terms of the settlement and the landfill company's legal team if they were to file an odor complaint.

MDHSS/ATSDR response: In this health consultation, we note that odor complaints from the community accompanied the SSE (see Conclusion 2). In this report, we do not otherwise evaluate the odor complaint data collected by MDNR.

Comments from private citizens

Citizen Comment-1
I live in [PII removed]. I smell the odors coming from the landfill every day and experience headaches every day and was just diagnosed with migraines. So the smells are not helping with controlling the headaches. I know when I go to St. Charles or to Webster Groves my headaches are not as bad. I also am dealing with sinus and asthma issues and would love to be able to open my windows with the cooler weather coming in but really can't cause if I do then I get sicker. Thank You. (sent 9/23/2018)

MDHSS/ATSDR response: Please follow up with your primary care provider to have your headaches and other health conditions evaluated. As discussed in section 5.5, "Landfill Odors", some people may experience adverse effects including headaches from objectionable odors.

Citizen Comment-2
My wife and I bought our home in [PII removed]. Within 3 years after we moved in, I suffered from repetitive sinus infections and still do to this day. After approximately 10 years of living here, I was diagnosed with Chronic Obstructive Pulmonary Disease (COPD).

My biggest fear is that I, my [family], as well as the community, have been and continue to be slowly poisoned by the toxic byproducts of combustion from the Bridgeton Landfill. It's

my opinion that the Bridgeton Landfill is a major contributor to the unhealthy air quality in and around the area on a 24/7/365 basis.

I'm very thankful to the women of Just Moms STL for working so hard for so many years to bring truth and awareness to so many about West Lake Landfill/Bridgeton Landfill. Thank you. (sent 10/2/2018)

MDHSS/ATSDR response: Please follow up with your primary care provider for treatment of your health conditions. As you know, COPD has a number of causes (https://www.lung.org/lung-health-and-diseases/lung-disease-lookup/copd/symptoms-causes-risk-factors/what-causes-copd.html). Short-term exposures to air pollutants evaluated in this report have not been associated with causing COPD. However, short-term exposures to air pollutants may irritate COPD. Long-term exposure to air pollution may play a role in the development of COPD, although the vast majority of COPD cases (85-90%) are primarily related to smoking.

Citizen Comment-3
Is [the] state actually going to take anything seriously or the EPA you would rather go around this entire state and closed down junk yards because you said they're leaking oil and antifreeze into the soil but yeah we have a landfill with radioactive waste leaking into the Earth and you're doing nothing about it nothing about it you keep putting it off because somebody keeps putting money in people's pockets this is utterly ridiculous that these people living up there I lived up there I was in that landfill have to put up with this every day you had a chance to put that fire out a guy came up here and looked at it and you think you're going to do what you want to do cover it with a tarp one of them out there ain't working have you got that through your head yet it ain't working so it needs to be cleaned up like Times Beach was!!! (sent 10/5/2018)

MDHSS/ATSDR response: This report does not evaluate health risks associated with radiologically impacted materials at West Lake Landfill. EPA is currently planning remedial actions to excavate and remove those materials from the landfill. Please visit their webpage for information on cleanup of the site:
https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039

Citizen Comment-4
My observations mirror the conclusions of your report. That is at the onset of the SSE, 2012-13, there was great concern and anxiety over the obnoxious odors which were frequent occurrences. As the remediation work by Republic Services progressed the odor events gradually decreased. At this time although not completely gone they are infrequent. Not mentioned in your report are the other sources of odors such as the active Fred Weber Sanitary Landfill in the vicinity. The reality of this is that the residents and the thousands of people that work, shop, play, and do business in Bridgeton have been largely unaffected by this issue. This of course may not be apparent to non-residents. As has been noted many times extremist[s] in environmental groups have sensationalized events using overblown scare tactics that are not necessarily supported by science. The media seems to focus on reporting this side of the story only.

I will not deny that some very sensitive people may have experienced adverse effects. However as your report states, individuals may have been affected, however with remediation measures largely in place it is unlikely breathing the surrounding air would have adverse effects. I agree with this totally.

Offsetting this was the recent TV coverage of a prominent landfill figure which gave the impression that they knew all along that the landfill's emissions were taking a terrible toll on people's health and that odors were so bad that going outdoors was not possible. Media coverage and the fact that not many will wade through your 53 page report will make it likely that this view will prevail.

In further support of my observations I have also noticed that attendance at the landfill meetings has markedly decreased over the last year or so, the exception being the broad interest in the proposed EPA remedy for the West Lake radioactive materials waste removal. Your work is appreciated. I am pleased to have the opportunity to comment. (sent 10/8/2018)

MDHSS/ATSDR response: Thank you for your comment.

Citizen Comment-5
I can taste the air…that's never a good thing. (sent 10/23/2018)

MDHSS/ATSDR response: What we think of as taste (flavor) is actually a combination of smell, taste, and other factors. Our olfactory receptors, which sense odors, and taste buds are in close proximity to each other in the oral cavity. Please see section 5.5, "Landfill Odors", where we discuss the adverse effects some people may experience from exposure to objectionable odors.

Citizen Comment-6
The State of Missouri needs to step up and protect its citizens in the area of the Bridgeton Landfill. The odors and toxic emissions are unacceptable. Bad enough to breathe the stink, worse yet to inhale carcinogens. No one should think putting perfume in the air is a sufficient response. These citizens of our state are stuck with these terrible conditions and need help. We, as Missourians, are in this together. Thank you. (sent 11/15/2018)

MDHSS/ATSDR response: Please see section 2, "Site Description and Background", for a description of the corrective actions that were taken to reduce emissions of gases and odors from Bridgeton Landfill. Those actions were conducted by Republic Services under the oversight of MDNR. Also, please visit EPA's webpage on West Lake Landfill for information on their plans to excavate and remove radiologically impacted materials from the site: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039

Citizen Comment-7
I live in [PII removed]. I am emailing you in regards to the smell in the air and now in our home. My husband and I have complained many times about the smell in the air and to our Landlord about the smell in this house. My husband was diagnosed with Prostate Cancer and went through Radiation treatments and surgery for his prostate to be removed. Since

then, he is having other issues I believe due to the smell in the area and house. His nervous system is now giving him some problems and he is now having to go to the doctor for this and not able to work some of the time as his legs are giving him problems as well where he falls and become weak. I too have headaches most of the time for the past year and a half that is very rare for me. My eyes, nose burn when the house reeks of the odors. I also have ovarian cysts that have formed that wasn't there at first. It's like I'm scared to have on my air or heat cause it circulates throughout our home. I have also worked in this area for over 10 years where the smell is all the way past the Hollywood Casino. Former coworkers have also been affected as well, whether it was being diagnosed with cancer or something else.

I constantly have to air our house out by opening up windows and I use a ton of Pinesol to kill the odor that we smell most of the time since the Landfill has been capped off. These houses around me are all full of horrible smells that have been going on now for at least a couple of years or so, from what I have been told by my neighbors. I believe that the smell in this house is doing something to us and our bodies. Even with airing out the house the smell from outside gets in as well. There is not any escape from these smells. People in this area have families, kids, grandkids, pets that are or could be affected by this. Children go to school around here and play outside breathing this horrible air and live in these homes that reek of unimaginable smells, Deadly if you ask me. If something can be done about this it should. Shouldn't anyone have to live like this in this area where it is dangerous for us our families, children and our pets.

They need to stop sweeping it under the rug and do something. Lives are at stake and it is a shame that nothing further is being done about any of this. Yes, they capped off the Landfill but at what costs? Now it is in our homes all of the time strong like a bagged up sewer that is something to behold, ghastly if you ask me. All big business when we are all dying inside of this smoldering infested nest of a community that claims to care for all of us and when in all reality we are ponds in a vicious game of chess and seemingly all expendable. Shame on all of them!! I just wonder how many of us and not to mention our children that this will have a long term effect on in the coming years from this horrible odor! Thanks for your time in this matter. (sent 11/20/2018)

MDHSS/ATSDR response: Please follow up with your primary care provider for treatment of your health conditions. Some people may have experienced adverse respiratory effects prior to and during corrective actions at Bridgeton Landfill (see Conclusions 1 and 2 of this report). In addition, as discussed on p. 60 in section 5.5, "Landfill Odors", some people may experience headaches or other effects from breathing objectionable odors.

In section 2, "Site Description and Background", we describe the corrective actions taken to reduce emissions of gases and odors from Bridgeton Landfill. While subsurface smoldering at the landfill continues to occur, it is possible that odors will continue to be occasionally bothersome to people living near the landfill. Odors might increase during construction projects or instances of equipment failure on the landfill.

EPA is currently planning remedial actions to excavate and remove radiologically impacted materials from West Lake Landfill. Once that work begins, there may be an increase in the frequency of offensive odors being emitted from the landfill.

Citizen Comment-8

I am writing to comment on the emissions resulting from the smoldering fire (that was an actual fire a couple of weeks ago) at West Lake Landfill. First, the report put out by the MO DHSS regarding "Evaluation of Exposure to Landfill Gases in Ambient Air" does not address the increase in respiratory illness causing and cancer causing agents that will be released into the air during excavation and removal of the radioactive materials under the recent EPA decision. Also, I still strongly feel the EPA solution to this mess should include a buyout for the residents living near the landfill. (sent 11/23/2018)

MDHSS/ATSDR response: EPA is currently planning remedial actions to excavate and remove radiologically impacted materials from West Lake Landfill. During excavation and removal, EPA will be monitoring contaminant concentrations in the air. Those data will be evaluated to assess the potential impacts of emissions on public health. Please visit EPA's webpage for information on cleanup of the site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039. Please provide your feedback on remedies, including buyouts, directly to EPA.

Citizen Comment-9

I live in St. Charles and can often smell the landfill stink at my house. The smell is so bad when driving on highway 70 by Earth City that I often try to find a different way to drive. This smell is horrendous and needs to be taken care of. (sent 11/26/2018)

MDHSS/ATSDR response: Please see section 2, "Site Description and Background", for a description of the corrective actions that were taken to reduce gases and odors being emitted from Bridgeton Landfill. While subsurface smoldering at the landfill continues to occur, it is possible that odors will continue to be occasionally offensive, especially during construction or instances of equipment failure at the landfill. In addition, people may be bothered by other sources of odors in the area, including Champ Landfill and a nearby asphalt plant in Maryland Heights.

Citizen Comment-10

Early environmental exposures of children to toxic, carcinogenic and genetic or fetal disease-causing substances is especially concerning when considering what to do about West Lake Landfill. Children are prone to put things in their mouths, causing far greater exposure than in adults. They transform the ambient air into a bodies' building materials, in greater volume and more quickly than adults. The European Union has developed strong policies to reduce exposure of this kind, in spite of chemical company opposition. Plastics making up the bulk of solid waste, are endocrine disrupters, these will hamper normal growth. Pituitary and thyroid gland disruption is life threatening. Heated plastics become dioxin. This is one of the world's most toxic chemicals. Remember the Blessy company paving streets of a new town, that had to be closed down entirely out west on Route 66?

Please take every precaution to handle disposal of these materials safely. Consult scientists familiar with appropriate disposal of chemicals. Thank you for your consideration. (sent 11/30/2018)

MDHSS/ATSDR response: As discussed in Appendix A, dioxins were occasionally detected at low concentrations in ambient air samples collected upwind and downwind of Bridgeton Landfill. Dioxins are typically found at low concentrations in ambient air due to commercial and industrial releases and long-distance transport from forest fires. Concentrations downwind of the landfill did not exceed health-based screening levels and guidelines. We did not find harmful dioxin concentrations in the data we reviewed for this site.

During the excavation and removal of radiologically impacted materials from West Lake Landfill, EPA will be monitoring concentrations of contaminants in the air. Please visit EPA's webpage for information on excavation and removal activities at the West Lake Landfill site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039.

Citizen Comment-11
I am very concerned about the air quality for residents who live near the West Lake Landfill during the excavation period. Please encourage all necessary parties to [do] what is needed to protect our citizens. (sent 12/21/2018)

MDHSS/ATSDR response: Thank you for your comment. Please visit EPA's webpage for information on the cleanup of the West Lake Landfill site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039. While conducting remedial work at the landfill, EPA will be monitoring air quality and taking steps to minimize emissions into the air. We will evaluate relevant data, as appropriate, to assess the potential public health impacts of emissions into ambient air.

Citizen Comment-12
Thank you for the opportunity to comment on the emissions resulting from the fire at West Lake Landfill. I support the calls to arrange a buyout for residents living near the landfill, who appear to face significant exposure to further health risks.

I have reviewed the West Lake emissions report and am concerned that it does not address the increase in agents that will be released into the air during excavation and removal of radioactive materials at the site. Repeated exposure to harsh chemicals (and other environmental air pollutants including particulate matter, nitrogen oxides, and ozone) may induce chronic respiratory illnesses including asthma, especially in children and elderly adults. Respiratory symptoms that may not subside include shortness of breath, chest tightness, or breathing discomfort, especially in people with chronic cardiopulmonary disease or chronic respiratory disease such as asthma. Children may be especially susceptible to air pollutants, including gases emitted from the landfill.

Thank you for your concern and attention. (sent 12/21/2018)

MDHSS/ATSDR response: Thank you for your comment. EPA is currently developing a remedial design plan for excavation and removal of radioactive materials from West Lake Landfill. They are taking steps to limit emissions of landfill gases into the air, such as creating modeled designs for areas of excavation and limiting construction times. They will also be monitoring contaminant concentrations in the air. Those data will be evaluated to assess the potential impacts of emissions on public health. Please visit EPA's webpage for more information on cleanup of the site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039. Please provide your feedback on remedies, including buyouts, directly to EPA.

Citizen Comment-13

I am submitting my public comments about the atrocity that is West Lake Landfill. A buyout of the residents living near the landfill is the ONLY acceptable option for so many reasons. Among them:

- **Respiratory and neurological symptoms including shortness of breath, wheezing, headache, and nausea have been reported by residents living up to two miles from the landfill.**
- **Of the chemicals exceeding CREG values in samples collected near the landfill, only benzene was detected at concentrations noticeably higher downwind than upwind of the landfill and exceeding typical ambient air concentrations in the United States. The NTP classifies benzene as a known human carcinogen, based on studies linking benzene exposure to various forms of leukemia in humans [NTP 2016]. Animal studies have shown that benzene exposures may cause a variety of cancers, including skin, lung, and lymphoid tumors [NTP 2016].**
- **Repeated exposure to irritating, malodorous chemicals (and other environmental air pollutants including particulate matter, nitrogen oxides, and ozone) may induce chronic respiratory illnesses including asthma, especially in children and elderly adults. Respiratory symptoms that may not subside include shortness of breath, chest tightness, or breathing discomfort, especially in people with chronic cardiopulmonary disease or chronic respiratory disease such as asthma.**
- **Children may be especially susceptible to air pollutants, including gases emitted from the landfill, as their respiratory and immune systems are still developing. Children may also have higher exposures to those air pollutants, because they tend to spend more time outdoors and their high activity levels can result in higher breathing rates.**
- **Long-term or repeated exposures to sulfur-based compounds and their odors in ambient air near the landfill may have harmed the health or affected the quality of life of people living or working near the landfill by increasing stress, impairing mood, or increasing the risk of respiratory infection. Offensive odors alone, not just the toxicity of the chemicals causing the odors, may induce health effects.**

This whole debacle just makes me sick to think our government is making them suffer through no fault of their own. (sent 12/26/2018)

MDHSS/ATSDR response: Benzene was often higher downwind than upwind of the landfill prior to completion of corrective actions at the landfill. Benzene often exceeds the CREG in urban/suburban areas and, in the Bridgeton area, poses cancer risks similar to the risks in other urban/suburban areas (see Conclusion 5 of this report). We agree that malodorous and irritating chemicals can cause respiratory irritation and worsen existing respiratory conditions.

EPA is currently planning remedial actions at West Lake Landfill. When conducting remedial work, EPA takes steps to minimize potential impacts to workers and nearby residents. Please visit EPA's webpage for information on cleanup of the West Lake Landfill site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039. Please provide your feedback about remedies, including buyouts, directly to EPA.

Citizen Comment-14
It is so disappointing to learn that people, especially children are suffering from shortness of breath and other breathing issues as a result of air pollution coming from the Bridgeton landfill. This is a ridiculous situation and it needs to be remedied. In addition to breathing issues there are also emissions of hazardous chemicals, such as formaldehyde. The St. Louis area needs to clean up its act. It needs to start with cleaning up the mess at Bridgeton. The current level of irresponsibility is just one example of why it is so hard to get new businesses into our area. GET IT FIXED! (sent 12/29/2018)

MDHSS/ATSDR response: Thank you for your comment. Please see section 2, "Site Description and Background", for a description of the corrective actions that were taken to reduce emissions of gases and odors from Bridgeton Landfill.

Citizen Comment-15
I am a resident of St. Louis County, Missouri. I believe that the residents living near the West Lake Landfill should be bought out. During excavation of the removal of the radioactive materials, there will be an increase in respiratory-illness-causing and cancer-causing agents that will be released into the air. This will increase the illnesses that residents near the Landfill have suffered. Long-term or repeated exposures to malodorous sulfur emissions have been associated with long-lasting changes in mood, including increased anxiety, tension, anger, confusion, and depression. Long-term exposures have also been associated with increased risk of acute respiratory infection (common cold, bronchitis). I urge the State of Missouri to buy out all residents in the West Lake Landfill area who wish to be bought out. (sent 12/31/2018)

MDHSS/ATSDR response: Thank you for your comment. Health agencies assess public health hazards at a site but do not have a role in enforcement negotiations with responsible parties for site remedies, including buyouts. Please provide your feedback about remedies directly to EPA (see https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039).

Citizen Comment-16
I would like to comment on the plan for the West Lake Landfill. The comment is simple. For reasons of public health, today and in the future, this toxic problem needs to be totally cleaned up. I know that that would be expensive. I'm not convinced that the amount of

money being appropriated is enough to really keep this problem from rising its destructive head in the future. Why not be honest and do what's right and totally clean it up. It will save lives and also money in the future. (sent 12/31/2018)

MDHSS/ATSDR response: Thank you for your comment. Please provide feedback on the cleanup of West Lake Landfill directly to EPA: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039.

Citizen Comment-17
I'm writing to express my concerns about the effects that nearby residents will experience during the remediation efforts undertaken at West Lake Landfill.

It is logical to assume that during the years of excavation, those living locally will not only continue to experience the same bad health effects they have long been subjected to, but will be exposed to increased problems resulting from the increase of releases of odors and toxins into the surrounding air. In the current situation, residents living up to two miles from the landfill have reported respiratory and neurological symptoms. Invasive work at the landfill will surely contribute to toxic and malodorous emissions and contribute to already chronic conditions if not be the source of entirely new bad health effects.

In the 2016 St. Louis County Department of Public Health survey, it was reported that a significantly higher percentage of households within a 2-mile radius of West Lake experienced shortness of breath compared to other areas studied in the County.
But respiratory illnesses are the tip of the iceberg. Among the many dangerous chemicals present at the landfill is benzene. Benzene exposure can result in a raft of cancers, from skin cancer to leukemia to an assortment of malignant tumors.

And not only are the air pollutants significant, but so are the actual particles released through excavation and construction.

So I am writing to ask, that in addition to the important work of excavation and removal of wastes of the site, the residents within the 2-mile radius be offered buyouts and removal as well. And that families with children or the elderly be first on the buyout list. When it comes to these exposures, children are the most vulnerable population as they are still developing.

The offer of a buyout is the only just and moral remedy. It was the federal government that was responsible for the creation and the dispersal of these highly toxic radioactive wastes. It is the federal government's responsibility to protect these citizen victims from the results of improper and reckless handling of atomic bomb wastes. The government has evaded and even denied its responsibility for decades. It is a great relief that the situation is finally being addressed. Now it needs to be fully addressed.

Thank you for the opportunity to express my concerns. (sent 12/31/18)

MDHSS/ATSDR response: Thank you for your comment. Please see our response to Citizen Comment-15.

Citizen Comment-18

We live in Chesterfield and on nice days we cannot open our windows because of the fumes. ..this is not what citizens expect from OUR government and the truth needs to be addressed now, we expect to hear all about the real information obtained by contractors!! (sent 1/7/2019)

MDHSS/ATSDR response: Please see section 2, "Site Description and Background", for a description of the corrective actions that were taken to reduce gases and odors being emitted from Bridgeton Landfill. While subsurface smoldering at Bridgeton Landfill continues to occur, it is possible that odors will continue to be occasionally offensive, especially during construction or instances of equipment failure at the landfill. The odors may also have other sources, including Champ Landfill and a nearby asphalt plant in Maryland Heights.

Citizen Comment-19

The people in this area should be offered health screening, free of charge to monitor for future cancers. No one who lives here should have to pay for these and neither should their insurance companies. We did not know about this hell hole we were living next to. **(1/7/2019 public meeting comment card submission)**

MDHSS/ATSDR response: In 2018, the Bridgeton Landfill Community Project Fund was established to support initiatives that "contribute to the betterment of the environment, health, and safety of the communities" near the landfill (https://stlgives.org/nonprofits/bridgeton-landfill-community-project-fund/). Initiatives include improving people's access to healthcare. The fund was established from a legal settlement between the State of Missouri and Republic Services, Allied Services, and Bridgeton Landfill, LLC.

Citizen Comment-20

I live at the trailer park across from the landfill. I come in late and walk my dog late at night. Smells real bad. Graph shows 2015-2016, not 2017 & 2018. Was real bad smell also. I know because I live across from landfill.

Friday of June 2018, road was closed down on the St. Charles Rock Road. Was a big fire. But wasn't on TV. Why? What's taking so long! Give money to move out. Thank you. (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: In 2013-2014, corrective actions were taken to reduce gases and odors being emitted from Bridgeton Landfill (see section 2, "Site Description and Background"). However, while subsurface smoldering continues to occur, it is possible that odors will continue to be occasionally offensive, especially during construction or instances of equipment failure at the landfill. In those instances, please try to avoid the odors as much as possible.

Citizen Comment-21

This reported evening was a HUGE waste of any time. You are <u>NOT</u> of any help to the people OLD or YOUNG and everyone in between. Another useless govt. agency. (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Thank you for your comment.

Citizen Comment-22
When will the rad waste be removed so it is safe for my children (1 with 2x leukemia) to come back to my family businesses? (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Please visit EPA's webpage for information on the excavation and removal of radiologically impacted materials from West Lake Landfill and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039

Citizen Comment-23
You have a serious communication problem. You need to immediately communicate data collected that shows harmful effects to the people that it affects; otherwise, it is not effective. Along the lines of an amber alert that is specific to this landfill. It is a conflict of interest and is inappropriate that Republic Services Waste Management collects data on any harmful effects of the landfill. (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Thank you for your comment. From 2013 to 2018, MDHSS issued over 500 messages that included information on health effects associated with odors. Those messages were posted on MDNR's and MDHSS's Bridgeton Landfill websites (see www.health.mo.gov/bridgeton and https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill). However, we understand that not everyone has internet access and that, in some situations, an alert system might be a better form of communication. We will continue to explore ways to issue health alerts.

Citizen Comment-24
If you are charged to care for community health, then the community needs surveillance of air quality in real time and communication of risk or non-risk in real time. And community health is made up of many things related to properties like the landfill - like what goes into the air, water, etc. So why wasn't your concern more integral? Public health? I recognize that the study(ies) as interpreter of generated data are relevant mostly in retrospect. We need not to generate papers so much as we need real services to the community in real time. I understand the scope of this agency's work. It just doesn't seem too relevant to the health of this community. It's disappointing. (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Thank you for your comment. The purpose of this health consultation is to assess the public health impacts of fugitive landfill gas emissions into ambient air. From 2013 to 2018, MDHSS issued over 500 messages on the ambient air data, including information on health effects associated with odors. Those messages were posted on MDNR's and MDHSS's Bridgeton Landfill websites (see www.health.mo.gov/bridgeton and https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill). We will *continue to explore ways to communicate our messages in real time to everyone concerned, including issuing health alerts.*

Please visit EPA's webpage for information on cleanup of the West Lake Landfill site and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039. In addition to planning for excavation and removal of radiologically impacted materials, EPA is currently investigating groundwater at the site.

Citizen Comment-25
Please clarify why the data collection method was limited to air sampling only and not other sampling methods like ground water sampling. Is this the only landfill in the St. Louis Region that we should be concerned with? If this landfill was used for "normal" waste from Republic, what about the other landfills in the region? (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: This report addresses concerns about the public health impacts of increased gas and odor emissions resulting from a subsurface smoldering event at Bridgeton Landfill. Therefore, in this report we only evaluate air data. However, MDNR and EPA do collect other environmental samples at the site, including groundwater and soil gas. MDNR has not found evidence of offsite migration of soil gas threatening to public health (https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill). EPA is currently evaluating groundwater at the site (https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039).

Bridgeton Landfill is the only permitted solid waste landfill in the region found to have an ongoing subsurface smoldering event. However, other landfills including Champ Landfill can be a source of offensive odors in the area.

Citizen Comment-26
Announcing these meetings needs to improve and be made in a way for the Bridgeton community [to] be notified timely. Facebook is not a good way to communicate and announce these meetings. It appears that Bridgeton is trying to hide something. (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Thank you for your comment. We try to use multiple outlets to announce public meetings. In December 2018, we issued a press release announcing the January 2019 public meeting about this report. Local media outlets, including the St. Louis Post Dispatch and Fox 2 News, announced the date, time, and location of the meeting. We also included a notice on our webpage at https://health.mo.gov/bridgeton. We will continue to explore ways to communicate our messages in a timely manner to everyone concerned.

Citizen Comment-27
The study did not include data for cumulative risks & no risk level for continuous exposure so can we assume there is a flaw & cancer risk would be greater than 6.5 per million? (1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: As discussed in Conclusion 5, cancer risk from continuous exposure to benzene in the ambient air near Bridgeton Landfill is similar to the risk from exposure to benzene in other urban/suburban areas in the United States. Concentrations of other potential carcinogens were below typical urban/suburban concentrations. We, therefore, do not expect cumulative cancer risks from breathing multiple chemicals in the air to be greater than those in other urban/suburban environments in the United States.

Citizen Comment-28

1. **Report doesn't address risks to workers**
2. **Report doesn't consider risks from 2010 to early 2013**
3. **DNR/DHSS should better describe its response time to odor complaints**
4. **Please acknowledge that chronic stress remains. Odor events can trigger concerns/stress even if odor events have decreased. Settlement means DNR will not be at the landfill as frequently. Conclusion #2 (stress) based on DNR confirmed odors. How will MDNR/DHSS assess this risk in a meaningful way moving forward to ensure Republic Services doesn't increase odors released into the community?**
5. **This report supports relocation of fenceline residents.**

(1/7/2019 public meeting comment card submission)

MDHSS/ATSDR response: Thank you for your comments.

1. MDHSS and ATSDR invite agencies or community members to submit requests for public health assessments/consultations that address concerns about additional exposure scenarios at any time. However, worker exposure evaluations are typically conducted by the federal Occupational Safety and Health Administration (OSHA) or National Institute for Occupational Safety and Health (NIOSH).

2. MDNR did not begin routine air monitoring near the landfill until 2013, after they began receiving odor complaints from the community. In this report, we have revised the "Uncertainties and Limitations" section to note the lack of routine air monitoring and sampling in 2011 and 2012, following the onset of the SSE. We have also revised the Conclusion 5 "Basis of Decision" to include a cancer risk value that is based, in part, on an assumption that benzene exposures occurred during that time.

3. From 2013 to 2018, MDHSS issued over 500 messages that included standing recommendations on odors. Those messages were posted on MDNR's and MDHSS's Bridgeton Landfill websites (see www.health.mo.gov/bridgeton and https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill). We will continue to explore ways to communicate our messages to communities in a timely manner.

4. Odors contribute to stress that, over time, can lead to stress-related illness. In the "Stress" section, we discuss the potential for individuals living near the landfill to experience increased stress due to long-term or repeated exposures to malodorous emissions from the landfill. We also discuss the potential for negative health effects associated with chronic *stress. Chronic stress can cause anxiety, mental depression, or impaired immune response, which can be long-lasting or increase the persistence or severity of some illnesses. MDNR continues to take odor complaints at https://dnr.mo.gov/bridgeton/concern.htm.*

5. Relocation of residents is outside the purview of MDHSS as a health agency. Please see our response to Citizen Comment-15 and provide regulatory and enforcement feedback directly to EPA.

Citizen Comment-29

Please clarify why your report and study chose to not collect drinking water samples from the local area. On page 3 of your report, you mention "a separate public health consultation on radiation in groundwater and air at the site was written by ATSDR in 2015." But your report fails to mention if any follow-up data collection or oversight of ATSDR on their groundwater and drinking water data collection methods continued or poses a risk to public health. I think this should be addressed in your final report since its now 2019 and four years later. Are you relying on the local water utility to evaluate drinking water for possible contamination? And if so, did you validate if they are capable of testing for the 200 chemicals you are assessing for with air sampling? Please advise. (sent 1/8/2019)

MDHSS/ATSDR response: We wrote this health consultation in response to community concerns and a request by St. Louis County Department of Public Health that we assess the public health impacts of increased fugitive gas emissions from Bridgeton Landfill. This report is therefore based on our evaluation of air data.

EPA is currently investigating groundwater at the West Lake Landfill site. Please visit EPA's webpage for information on their investigation and updates as their work progresses: https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0701039.

Citizen Comment-30

Please clarify how the Bridgeton Landfill compares to other landfills for ambient air and groundwater/drinking water health hazards. Your report fails to compare your analysis of Bridgeton against any other existing landfills near populated areas, whether in Missouri or within the US. You could reach out to other state public health agencies or even the CDC or other federal agencies for comparative landfills to reference in your report. We, the public, have nothing to compare your report to. I think you tried to do this on page 8 of your report, but I can't tell since you say "typical ambient air concentrations in the United States..." What is your source, that is vague? (sent 1/8/2019)

MDHSS/ATSDR response: The purpose of this health consultation is to assess the public health impacts of fugitive gas emissions from Bridgeton Landfill into ambient air. A comprehensive study of the health hazards generally associated with landfills is beyond the scope of this report.

As a part of our screening analysis in section 4, we compare chemical concentrations in air near the landfill to concentrations typically found in ambient air in St. Louis and urban/suburban areas in the United States. We have revised that section to include tables that highlight typical *chemical concentrations and reference the sources of those values. Chemical concentrations in ambient air in other communities are also included in section 5.1.4, "Supporting Community Studies". In that section, we review epidemiological studies evaluating community exposures to malodorous sulfur-based compounds in the ambient air.*

Citizen Comment-31
What is your method of notifying the public for data samples exceeding the tolerance threshold for public health hazards as mentioned in Table 4, page 34? (sent 1/8/2019)

MDHSS/ATSDR response: From 2013 to 2018, MDHSS issued over 800 data review messages on MDNR's and MDHSS's websites (see www.health.mo.gov/bridgeton and https://dnr.mo.gov/waste-recycling/sites-regulated-facilities/closed-inactive-landfills/bridgeton-sanitary-landfill), including over 500 air monitoring review messages that included information on odors and standing recommendations for mitigating exposures to odors. Please see Section 6, "Community Health Concerns", for additional details of our efforts to keep the community updated on the potential public health impacts of Bridgeton Landfill.

Citizen Comment-32
Why is this report or the information your agency is learning about the hazards associated with landfills not easily accessible to the public on your agency website? For instance, on your "Licensing & Regulations" tab of your agency website, you mention nothing about landfills. As a suggestion, you should display the information and lessons learned from your study to your agency website prominently so the general public can access it without having to search for it in multiple folders. (sent 1/8/2019)

MDHSS/ATSDR response: Thank you for your comment. When the public comment version of this report was released in September 2018, it was posted on ATSDR's website at https://www.atsdr.cdc.gov/ (see Public Health Assessments/Health Consultations) and MDHSS's website at www.health.mo.gov/bridgeton. We also issued a press release about the report. Local media outlets, including the St. Louis Post Dispatch, KDSK, and St. Louis Public Radio, provided links to the report. On our website, we have recently added a link to the report and fact sheets from our "Hazardous Waste Sites – Reports, Fact Sheets and Consultations" webpage (https://health.mo.gov/living/environment/hazsubstancesites/reportsconsults.php). We will continue to explore ways to communicate effectively.