Health Consultation

PUBLIC COMMENT VERSION

Evaluation of Exposure to Landfill Gases in Ambient Air

BRIDGETON SANITARY LANDFILL

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

Prepared by:
Missouri Department of Health and Senior Services

SEPTEMBER 21, 2018

COMMENT PERIOD ENDS: NOVEMBER 20, 2018

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners 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 or ATSDR's Cooperative Agreement Partner 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: http://www.atsdr.cdc.gov

HEALTH CONSULTATION

PUBLIC COMMENT VERSION

Evaluation of Exposure to Landfill Gases in Ambient Air

BRIDGETON SANITARY LANDFILL

BRIDGETON, ST LOUIS COUNTY, MISSOURI

Prepared By:

Missouri Department of Health and Senior Services
Division of Community and Public Health
Section for Environmental Public Health
Bureau of Environmental Epidemiology
Under a Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

Foreword

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 under a cooperative agreement [*Funding Opportunity CDC-RFA-TS17-1701*] with the federal Agency for Toxic Substances and Disease Registry (ATSDR). The 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 would like to provide comments on the Bridgeton Health Consultation public comment report, please provide written comments by November 20, 2018 through these methods:

- Online: Email to BridgetonComments@health.mo.gov

- Postal Mail: Lorena Locke
  Bureau of Environmental Epidemiology
  Missouri Department of Health and Senior Services
  P.O. Box 570
  Jefferson City, MO 65102

If you have questions about this report, we encourage you to contact us at (573) 751-6102 or (866) 628-9891 or email at BridgetonComments@health.mo.gov.

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 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, which has 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. Since February 2013, the Missouri Department of Natural Resources (MDNR) has monitored chemical contaminant and odor levels in ambient air near the boundary of the south quarry of Bridgeton Landfill, where the smoldering is currently contained. Since 2014, MDNR and the United States Environmental Protection Agency (EPA) have also monitored ambient air quality in the Bridgeton area. In this health consultation, MDHSS evaluated both sets of air data to assess the potential public health implications of breathing Bridgeton Landfill gas emissions and their associated odors. MDHSS 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.

Conclusions

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

Conclusion 1

In the past, 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 remedial work at the landfill.

Basis for Decision

Since 2013, MDNR has 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 have been detected at or above 100 parts per billion (ppb; the lower detection limit of AreaRAE® monitors), exceeding conservative health-based guidelines for respiratory and neurological effects and sometimes exceeding concentrations shown in clinical studies to cause adverse respiratory effects.[2,3] Maximum concentrations of combined RSCs detected by AreaRAE® monitors near the landfill have been as high as 3,700 ppb. Maximum concentrations of SO_2 detected by AreaRAE® monitors near the landfill have been 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 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.

---

[1] MDNR's AreaRAE® monitors are equipped with sensors for detection of concentrations of hydrogen sulfide (H_2S) and sulfur dioxide, as well as carbon monoxide, oxygen, total volatile organic compounds (VOCs), and combustible gases and vapors in air. The AreaRAE® H_2S sensor may detect not only H_2S but other RSCs in the air [RAE Systems 2015]. Reduced sulfur in Bridgeton Landfill source gas was found to consist of multiple RSCs, including 76.5% dimethyl sulfide, 8.2% dimethyl disulfide, 4.8% methyl mercaptan, and 10.5% other RSCs including 1.6% H_2S. MDHSS, therefore, refers to the AreaRAE® H_2S sensor measurements as combined RSC concentrations.

[2] Health-based guidelines include ATSDR's minimum risk levels (MRLs) for acute (<14 day) 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 critical 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 critical clinical study to have adverse respiratory effects in people with asthma [ATSDR 2014a]. Some sensitive individuals may experience adverse effects at lower concentrations. Even though hydrogen sulfide is a small fraction of all RSCs produced by subsurface smoldering in the landfill, combined RSCs detected in ambient air near the landfill are considered in this health consultation to be as toxic as H_2S, because the toxicity of many RSCs is not well understood. The toxicity of H_2S is well established [EPA 2017a]. If H_2S is more toxic than the combination of RSCs in air near the landfill, this is a conservative/health-protective approach that may overestimate potential health risks.

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 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). In 2016, the frequency of detection of sulfur-based compounds had decreased by approximately 74% (combined RSCs) and 64% (SO_2).

Conclusion 2

In the past, 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

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.

Landfill gases can have objectionable odors at low concentrations. Bridgeton area residents have frequently complained about noxious odors emanating from the landfill. MDNR has also occasionally reported offensive odors in the vicinity of the landfill, most frequently before implementation of corrective measures in 2013-2014 to control the landfill gas and odor emissions.

A variety of chemicals produced by the decomposition of organic matter in the landfill likely contributes to those odors. Sulfur-based compounds have relatively low odor thresholds and could be responsible for much of the odor. In numerous community studies, 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 have also been associated with increased risk of acute respiratory infection (common cold, bronchitis).

Conclusion 3	**Currently, fugitive emissions from the landfill have decreased significantly, and breathing sulfur-based compounds in ambient air near the landfill is unlikely to harm people's health. However, the odors of low concentrations of sulfur-based compounds may occasionally affect the health or quality of life of people living or working near the landfill.**
Basis for Decision	From 2013 to 2016, the frequency of detection of combined RSCs in ambient air near the landfill significantly decreased. In 2016, 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 critical clinical study to cause adverse respiratory effects in people with asthma (2,000 ppb). From 2013 to 2016, the frequency of detection of SO_2 in ambient air near the landfill also decreased. Maximum SO_2 concentrations detected by MDNR's AreaRAE® monitors occasionally met or exceeded a concentration shown in a critical 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 ambient 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. During that year, the 99th percentile of daily maximum 1-hour average SO_2 concentrations at that location was 14 ppb, similar to the results from other monitoring stations in St. Louis County and 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 (≤3.4 ppb) were also below the World Health Organization's 24-hour Air Quality Guideline (7.6 ppb). From 2013 to 2016, the frequency with which MDNR detected odors in the vicinity of the landfill decreased by more than 80%, and their frequency of detection of combined RSCs at concentrations at which individuals may perceive bothersome odors (≥100 ppb) decreased by 74%. Still, the odors of RSCs may occasionally be objectionable, especially during periods of construction or other invasive work at the landfill or in instances of landfill equipment malfunction.
Conclusion 4	**Breathing other (i.e., non-sulfur based) chemicals that have been detected in ambient air is not expected to harm people's health.**

[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.

Basis for Decision

Since 2013, MDNR has overseen 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 ambient air [e.g., aldehydes, amines, carboxylic acids, dioxins/furans, fixed gases, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs), in addition to sulfur-based compounds]. Some aldehydes and VOCs were occasionally detected at concentrations exceeding health-based screening levels and were selected for further investigation. Because they are common landfill gases that can be toxic at low concentrations, carbon monoxide (as well as sulfur-based compounds) was also selected for further investigation.

Since 2013, MDNR has conducted routine air sampling upwind and downwind of the landfill to determine the concentrations of aldehydes and VOCs (as well as sulfur-based compounds) in ambient air. In three samples collected a few hundred feet downwind of the landfill in 2013-2014, benzene concentrations exceeded conservative health-based guidelines for immunological effects.[5] During routine surveillance with hand-held meters, MDNR also occasionally detected benzene at concentrations exceeding health-based guidelines. However, benzene concentrations were well below levels that might be expected to cause those effects.[6] Concentrations of carbon monoxide measured by AreaRAE® monitors near the landfill did not exceed health-based guidelines.

MDHSS also evaluated the potential health effects of multiple chemical exposures. Exposure to low concentrations of multiple chemicals can have combined adverse health effects if they target the same tissue or organ. Many VOCs that may jointly target the respiratory or neurological systems have been detected in ambient air near the landfill. However, concentrations of those chemicals were below levels expected to significantly increase the adverse effects of sulfur-based chemicals on those systems.

Downwind of the landfill, concentrations of four VOCs (carbon disulfide, ethanol, ethylbenzene, propene) and one aldehyde (valeraldehyde) occasionally exceeded their odor thresholds and may contribute to offensive odors.

---

[5] Health-based guidelines include ATSDR's minimum risk levels (MRLs) for acute exposure (<14 day) and intermediate exposure (2 weeks to 1 year) to benzene (9 ppb and 6 ppb, respectively).

[6] ATSDR based its acute MRL on a lowest adverse effect level (LOAEL) of 2,550 ppb for 24-hour exposure to benzene and its intermediate MRL on an LOAEL of 1,800 ppb for seven day exposure to benzene [ATSDR 2007].

Conclusion 5	**Current cancer risks from breathing VOCs near the landfill are similar to those in other urban environments in the United States. Over the long term, people living or working near the landfill are likely breathing ambient air concentrations similar to national average concentrations.**
Basis for Decision	Average concentrations of acetaldehyde (an aldehyde), formaldehyde (an aldehyde), 1,2-dichloroethane (a VOC), benzene, carbon tetrachloride (a VOC), and chloroform (a VOC) in ambient air slightly exceeded ATSDR's Cancer Risk Evaluation Guide (CREG) values. CREG values are screening level values that represent concentrations expected to result in no more than 1 excess cancer case in a population of 1 million. Of those chemicals detected in ambient air from the landfill, only benzene was detected at higher concentrations downwind than upwind of the landfill and at concentrations exceeding typical ambient air concentrations in the United States. In 2013, the average concentration downwind of the landfill (1.2 ppb) exceeded the average concentration in ambient air at urban locations in the United States (0.26 ppb). However, in 2014-2016, after completion of remedial actions at the landfill, annual average benzene concentrations downwind of the landfill fell below the national average concentration and were similar to upwind concentrations. Lifetime exposure to typical benzene concentrations in ambient air in urban areas in the United States poses an estimated slight increased risk of approximately 7 excess cancer cases in a population of 1 million.
Next Steps	MDHSS recommends that responsible parties continue gathering appropriate air data in the Bridgeton area while the SSE and/or remedial work on the landfill continues to occur. Future data should allow MDHSS or other responsible agencies to evaluate the potential public health impacts of breathing chemicals in ambient air from the landfill in nearby residential and commercial areas. 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 have 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 has been captured by ambient air monitoring and sampling efforts. Multiple monitoring and sampling approaches have been 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 has used conservative health-based screening levels 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, the detection limits of the AreaRAE® H_2S and SO_2 monitors exceed screening levels 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 distribution of RSCs in emissions sources differs at each site, and the relative toxicities of individual RSCs are not well understood.

Health-based screening levels 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.

TABLE OF CONTENTS

Figures

Tables

1 PURPOSE AND HEALTH ISSUES

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.

Since 2013, MDNR has conducted air monitoring and sampling near the landfill for evaluation of the nature and extent of landfill gas and odor emissions. MDNR continues to monitor contaminant and odor levels in ambient air to the present day, as subsurface smoldering at the landfill has persisted.[7] The United States Environmental Protection Agency (EPA) has also conducted air monitoring and sampling to characterize ambient air quality in the Bridgeton area. Both MDNR's and EPA's ambient air data are evaluated in this health consultation.

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 Bridgeton 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, a mixture of soil and low-level radioactive waste generated by the Mallinckrodt Chemical Company during the World War II and Cold War eras was used as daily landfill cover material 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

[7] Due to a settlement agreement that the State of Missouri reached with Republic Services on June 29, 2018, ambient air monitoring is currently transitioning to Republic Services.

may pose a health threat to West Lake Landfill workers, if the contaminated soil is disturbed, but that radiological contamination does not pose a threat to people living or working near the landfill [ATSDR 2015].

The portions of West Lake Landfill found to contain radioactive materials have been designated Areas 1 and 2 of Operable Unit 1 (OU-1) of the site by EPA. 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 portions of West Lake Landfill not reported to have received radioactive waste have been designated areas of Operable Unit 2 (OU-2). OU-2 includes Bridgeton Landfill. 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.

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 concentrations and increased carbon monoxide concentrations.[8] 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].

MDNR has overseen efforts by Republic Services to control the SSE and minimize its effects on local air quality. In 2013-2014, efforts by Republic Services 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].[9] In 2014, an odor neutralizing system was also installed at the perimeter of the landfill.

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 measures, odors from the landfill have been occasionally offensive. The magnitude of the SSE has complicated efforts to control landfill gas and odors emissions, as when the leachate pumps have failed resulting in leachate release and intensified odors.

[8] Municipal solid waste landfills typically produce 45% to 60 % methane 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 has been composed of approximately 7%-12% methane. Other compounds produced by the SSE at Bridgeton Landfill include 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).

[9] 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.

Since 2013, MDHSS has worked closely with MDNR, EPA, and other agencies to assess the public health impacts of gas and odor emissions from the landfill. MDHSS regularly evaluates MDNR's air monitoring and sampling data to determine the potential public health risks of acute (short-term) exposure to chemicals in ambient air near the landfill.[10] MDHSS's air monitoring and sampling reviews are posted online by MDNR (www.dnr.mo.gov/bridgeton) and MDHSS (www.health.mo.gov/bridgeton).

2.1 Demographics

Bridgeton Landfill is surrounded mostly by commercial and light industrial areas. A residential area is located approximately ½ mile south-southwest of the landfill, immediately north of Interstate-70. Another residential area 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 has received 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 of 1 mile or more from the landfill. According to the 2010 U.S. census, 1,933 people live within a 1-mile radius of West Lake/Bridgeton Landfill. In this 1-mile radius, approximately 94% of the population is white, 5% is African American, and 1% is composed of other races [U.S. Census 2010]. According to the 2010 census, 43,290 people (83% white, 11% African American, and 6% other races) live within a 3-mile radius of the landfill. Approximately 43-44% of the surrounding population is composed of potentially sensitive groups (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 also be especially sensitive to contaminants in air. Several hundred more people work in commercial and industrial zones around the perimeter of the landfill.

Figure 2 shows locations of community gathering facilities at various distances from the landfill. There is one park within ½ mile of the landfill. There are 5 community gathering facilities within a 1-mile radius of the landfill: 1 school, 1 college/university, and 3 parks. There are 43 community gathering facilities, including schools, parks, and daycare centers, within a 3-mile radius of the landfill. Thirty-four health and emergency facilities, including hospitals and long-term care centers, are located within a 5-mile radius of the landfill (not shown).

[10] As noted above, MDNR air monitoring is currently transitioning to Republic Services.

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

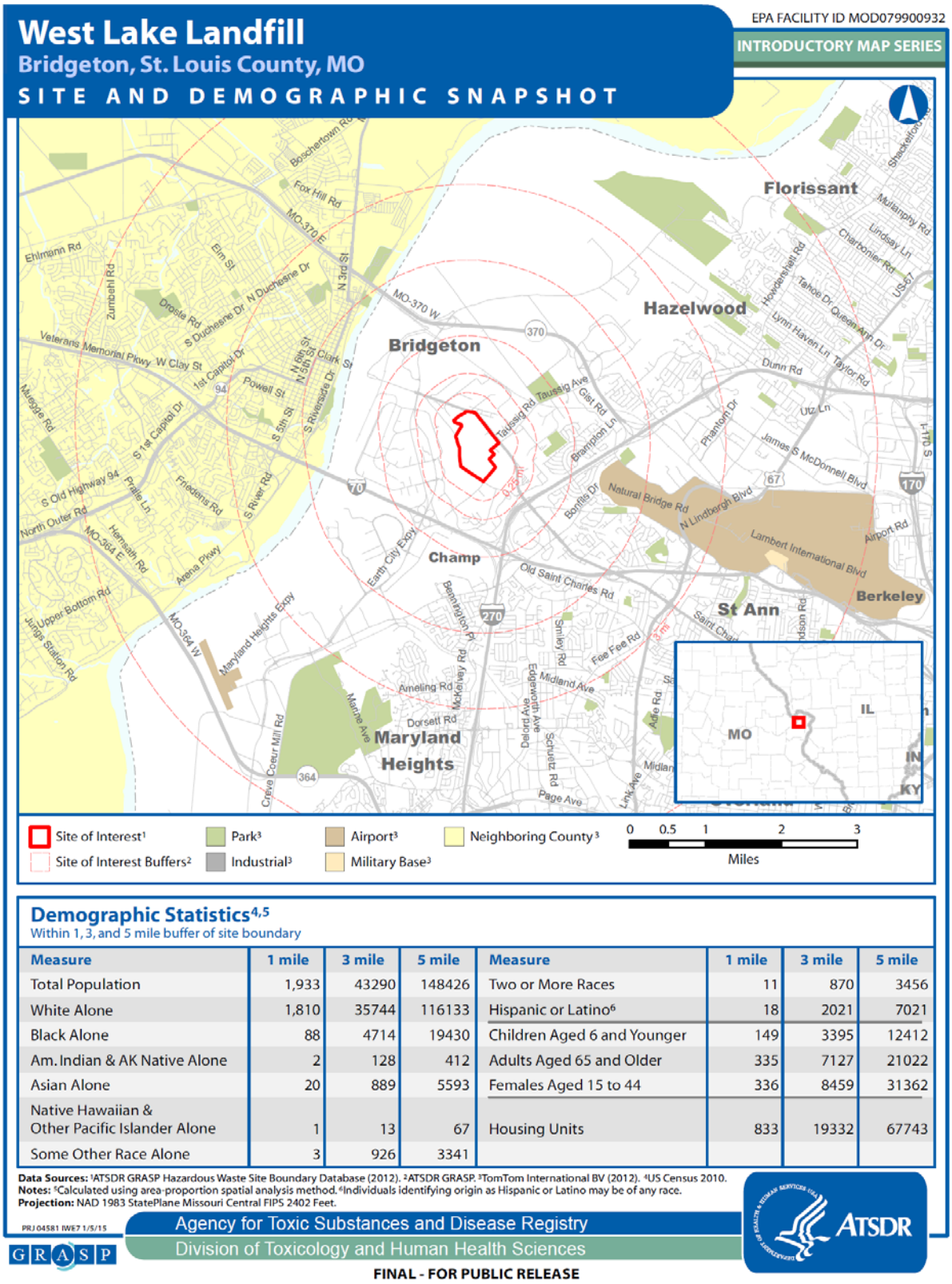
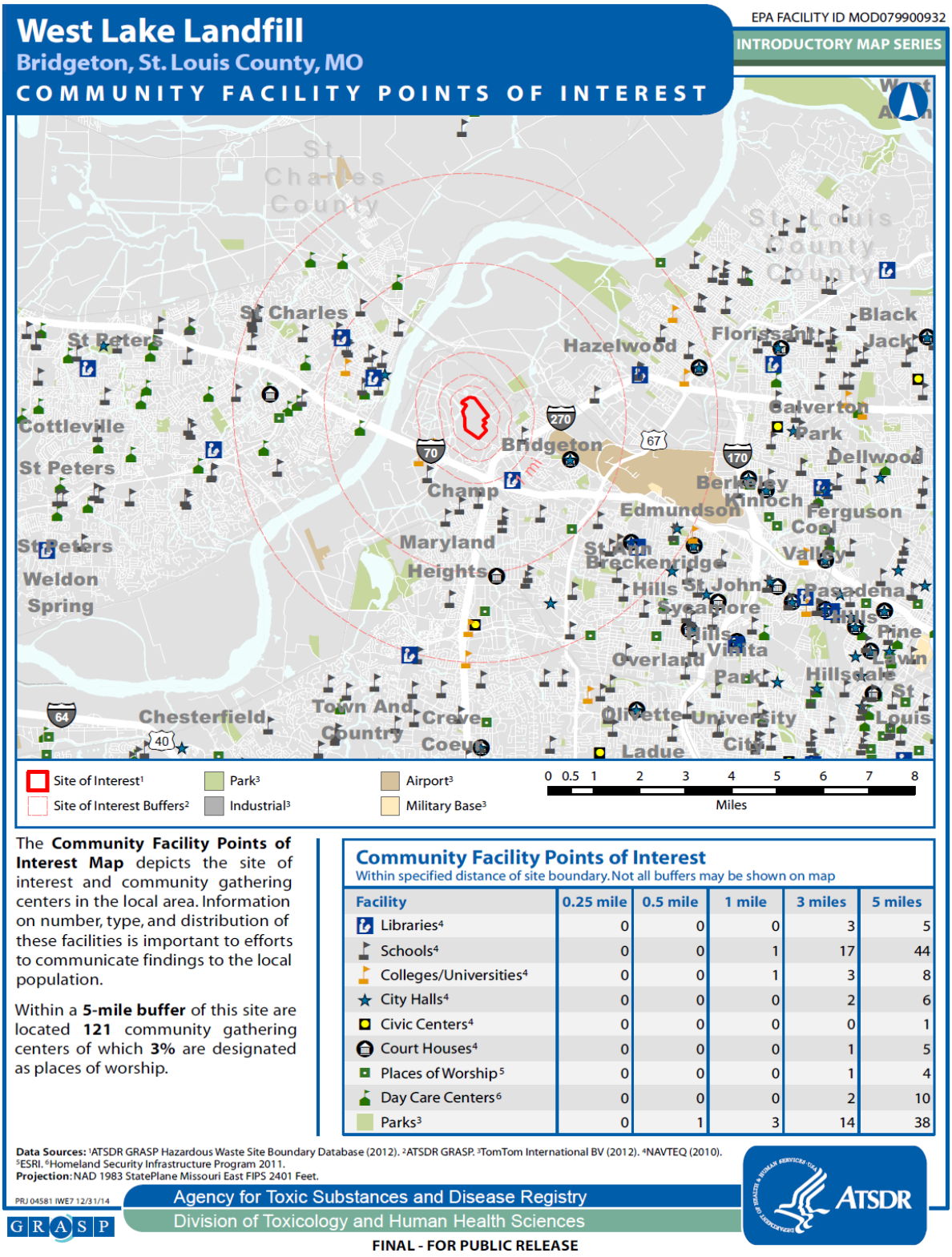


Figure 2. Map of Community Facilities near West Lake/Bridgeton Landfill



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 **5-mile buffer** of this site are located **121** community gathering centers of which **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	0.25 mile	0.5 mile	1 mile	3 miles	5 miles
Libraries[4]	0	0	0	3	5
Schools[4]	0	0	1	17	44
Colleges/Universities[4]	0	0	1	3	8
City Halls[4]	0	0	0	2	6
Civic Centers[4]	0	0	0	0	1
Court Houses[4]	0	0	0	1	5
Places of Worship[5]	0	0	0	1	4
Day Care Centers[6]	0	0	0	2	10
Parks[3]	0	1	3	14	38

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.

PRJ 04581 IWE7 12/31/14

GRASP

Agency for Toxic Substances and Disease Registry
Division of Toxicology and Human Health Sciences

ATSDR

FINAL - FOR PUBLIC RELEASE

3 INVESTIGATIONS OF GAS AND ODOR EMISSIONS IN AMBIENT AIR

3.1 MDNR Comprehensive Sampling for Laboratory Analysis

Since 2013, Republic Services, under MDNR's oversight, has conducted comprehensive sampling for the characterization of the landfill source gas and landfill gas emissions. In five comprehensive sampling events, source gas samples were collected from under the landfill liner and air samples were collected onsite and upwind and downwind of the landfill for determination of concentrations of a wide range of chemicals in landfill gas and air, including aldehydes, amines, ammonia, carboxylic acids, carbon monoxide and other fixed gases, 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). MDNR used the results of the comprehensive sampling events to identify chemicals (or classes of chemicals) of possible concern in landfill gas emissions. The results of ambient air sampling at upwind and downwind locations during those sampling events are summarized in Appendix A, Table A-1.

Because some aldehyde and VOC concentrations in ambient air occasionally exceeded conservative health-based screening levels, both chemical groups (aldehydes and VOCs) were targeted by MDNR for routine ambient air monitoring/sampling, as summarized in Table 1 and described below. Concentrations of other chemicals were generally similar in samples collected upwind and downwind of the landfill and were, thus, unlikely being emitted from the landfill; most of those chemicals were therefore not selected for further analysis.

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 in low concentrations, sulfur-based compounds and some fixed gases were also targeted by MDNR for routine ambient air monitoring/sampling, as summarized in Table 1 and described below.

Table 1. Summary of MDNR's Ambient Air Monitoring/Sampling Approach Bridgeton Landfill, 2013-2016

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 (2-6 million)	Instantaneous	1-3 minutes, 24 hrs/day, 7 days/week	February 2013-December 2016[b]
	Sulfur dioxide[a]					
	Carbon Monoxide[a]					
Pulsed Fluorescence Ambient Air Quality Monitoring	Sulfur dioxide[c]	Rider Trail at I-70	Continuous	Instantaneous	24 hrs/day, 7 days/week	May 2016-December 2016[b]
SUMMA® canister ambient air sampling	VOCs[d]	upwind and downwind of the landfill	800	4-hour	Weekly	April 2013-December 2016[b]
Ambient air sampling using sorbent tubes	Aldehydes[e]	upwind and downwind of the landfill	80	4-hour	Weekly	April 2013-August 2013
SUMMA® canister ambient air sampling	Sulfur-Based Compounds[f]	upwind and downwind of the landfill	116	4-hour	Weekly	April 2013-August 2013
				45-50 minute	Monthly	April 2015-December 2016[b]
Surveillance with hand-held meters	Benzene[g]	multiple locations in surveillance loop around the landfill	33,000	Instantaneous	Twice-daily	April 2013-December 2016[b]
	Hydrogen sulfide[g]					

[a]Combined RSCs, SO_2, and carbon monoxide are measured by AreaRAE® monitors at concentrations at or above 100 ppb, the detection limit of the AreaRAE® sensors. Combined RSCs are H_2S and other RSCs detected by the AreaRAE® H_2S sensor.
[b]Data continue to be collected; only data collected through December 2016 are evaluated in this document.
[c]SO_2 is measured by pulsed fluorescence at concentrations ranging from 0 ppb - 50 ppb or 0 ppb -1000 ppb.
[e]Volatile organic compounds (VOCs) are analyzed using EPA method TO-15. Seventy-seven VOCs were targeted in 198 sampling events. Detection limits varied but were typically <1 ppb.
[f]Aldehydes are analyzed using EPA method TO-11A. Twelve aldehydes were targeted in 20 sampling events. Detection limits varied but were typically <0.5 ppb.
[g]Sulfur-based compounds are analyzed using ASTM method D-5504. Twenty-three sulfur-based compounds were targeted in 38 sampling events. Detection limits varied but were typically <20 ppb.
[h]Benzene and H_2S concentrations are measured using hand-held meters during routine surveillance. The detection limit of the UltraRAE® (benzene) meter is 50 ppb. The detection limit of the Jerome® (H_2S) meter is 3 ppb.

3.2 MDNR Continuous Ambient Air Monitoring

Since February 2013, MDNR has conducted continuous ambient air monitoring at three fixed locations near the landfill (Table 1). The continuous ambient air monitoring data are collected in residential and commercial areas close to the landfill (i.e., from a few hundred feet to ½ mile from the landfill) in an attempt to characterize potential community exposures to gases being emitted from the landfill. Continuous operation of the monitors (24-hours per day, 7 days per week) allows rapid air quality assessment and response. The monitors are equipped with sensors for measurement of concentrations of hydrogen sulfide (H_2S), SO_2, and carbon monoxide in ambient air.[11,12] Those sensors measure concentrations in air at 100 parts per billion (ppb) or more, in 100 ppb increments, every 1 to 3 minutes.

The continuous 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 may be nearly as sensitive to methyl mercaptan and potentially to other RSCs that have been detected in the landfill source gas, MDHSS refers to the AreaRAE® H_2S measurements as "combined RSC concentrations" in this health consultation. Chemical interference is discussed further in the *Public Health Implications* section.

As shown in Table 2, multiple AreaRAE® monitors are located at each monitoring station, so that at least one AreaRAE® monitor at each of the three fixed monitoring locations is equipped with a sensor for measurement of H_2S (i.e., combined RSCs), SO_2, or carbon monoxide. Figure 3 is a map of the usual locations of the AreaRAE® monitors.

Table 2. AreaRAE® Unit Sensors at Monitoring Locations near the Landfill
Bridgeton Landfill 2013-2016

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	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.

Placement of the AreaRAE® monitors was based on multiple considerations, including proximity to the landfill, seasonal wind direction, the location of residential areas, and logistical concerns. The air monitors have occasionally been relocated in an attempt to measure the highest emissions of gases from the landfill. The monitors were initially located east (units 2 and 13),

[11] AreaRAE® hydrogen sulfide, SO_2, and carbon monoxide sensor specifications: detection ranges: 0-100 ppm (hydrogen sulfide), 0-20 parts per million (ppm; sulfur dioxide), 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 is 0.1 ppm (100 ppb).

[12] this health consultation, MDHSS did not evaluate AreaRAE® measurements of oxygen, total combustible gases, total VOCs, and gamma radiation, which are monitored by MDNR for emergency response purposes.

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 these fixed monitors were temporarily relocated to the north of the landfill when the winds were predominantly from the south (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. In October 2014, monitor 7 stopped functioning and was replaced with monitor 5.

In 2013, MDNR also installed a weather station near the landfill to monitor meteorological conditions (Figure 3). In December 2013, the weather station was moved from a location south of the landfill to a location east of the landfill. Data collected include 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.

MDNR reports hourly maximum values and 1-hour average values on data sheets posted online at www.dnr.mo.gov/bridgeton.[13]

3.3 MDNR Ambient Air Sampling for Laboratory Analysis

Since February 2013, MDNR has regularly collected ambient air samples upwind and downwind of the landfill for laboratory analysis (Table 1). Since that time, samples have been collected for determination of individual VOC concentrations in ambient air near the landfill. From April through August 2013, samples were collected for determination of individual aldehyde and sulfur-based compound concentrations in ambient air near the landfill. From September 2013 through March 2015, because aldehydes and sulfur-based compounds had not been detected in downwind ambient air samples at concentrations of concern, samples were collected for VOC analysis only. Since April 2015, samples have again been collected for determination of individual sulfur-based compound concentrations.

In each sampling event, samples are collected concurrently at locations directly upwind and downwind of the landfill within ½ mile of the West Lake Landfill boundary. Sampling has generally been 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. Since April 2015, samples for sulfur-based compounds have been collected on a monthly basis. Some sampling times and locations are selected in an attempt to capture peak concentrations of chemicals in ambient air, which may coincide with offensive odors.

[13] Since mid-2013, MDNR staff members have been stationed near the landfill to monitor the AreaRAE® sensors. MDNR omits 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 does not review the omitted data. In early 2013, MDNR did not do routine AreaRAE® sensor checks. Although some of those early AreaRAE® measurements were likely biased high, MDHSS has treated all reported data as valid data.

The laboratory reporting limits are typically at or below 1 ppb for VOCs, 0.5 ppb for aldehydes, and 20 ppb for sulfur-based compounds. Sampling reports are posted online at www.dnr.mo.gov/bridgeton.

3.4 MDNR Routine Surveillance

MDNR uses hand-held meters to regularly check the fixed AreaRAE® monitor readings. Since April 2013, MDNR has also performed twice-daily surveillance of instantaneous H_2S and benzene concentrations in ambient air in commercial and residential locations near the landfill and surrounding areas, using a Jerome® meter for H_2S measurements and an UltraRAE® meter for benzene measurements (Table 1).[14] MDNR has also monitored odor levels using a Nasal Ranger® olfactometer for measurement of odor intensity.[15] Figure 4 shows MDNR's routine surveillance monitoring path around the perimeter of the landfill and in residential and commercial areas up to 2 miles south of the landfill.

H_2S is measured at concentrations as low as 3 ppb, and benzene is measured at concentrations as low as 50 ppb. Surveillance reports provided to MDHSS are posted online at www.dnr.mo.gov/bridgeton.

3.5 MDNR Regional Ambient Air Quality Monitoring

MDNR operates several continuous ambient air monitors in St. Louis and other regions of the state for EPA's Air Quality System. MDNR's regional ambient air quality monitors are able to 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 (Table 1).[16] The Rider Trail monitoring station is one of three regional ambient air quality monitoring stations currently located in St. Louis City or County. The purpose of the 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 "background" concentrations typical of the area. SO_2 concentrations detected by the Rider Trail monitor could be attributed 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.

---

[14] Jerome® J605 meter specifications: detection range: 0.003 ppm-10 ppm hydrogen sulfide, 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

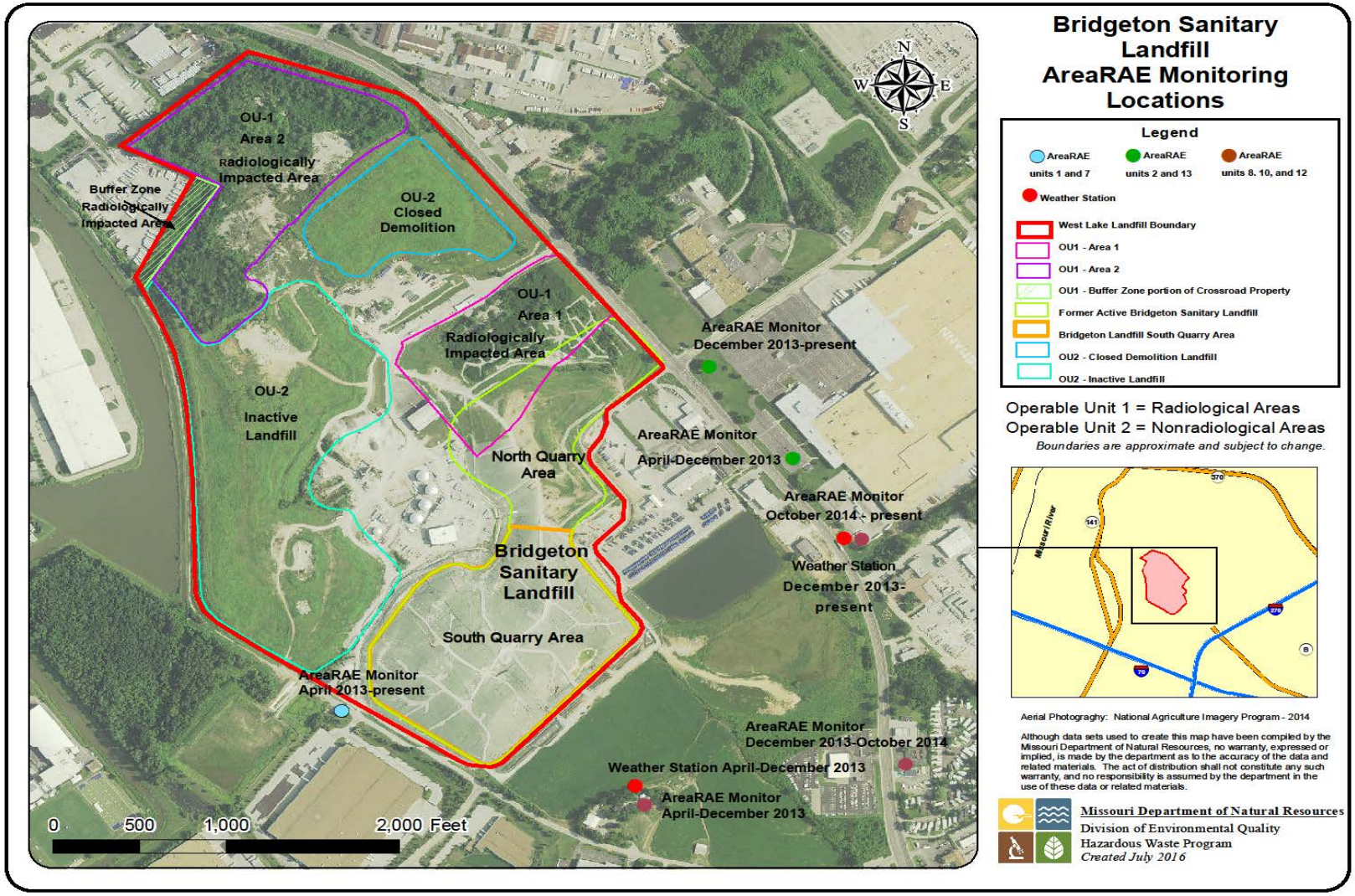
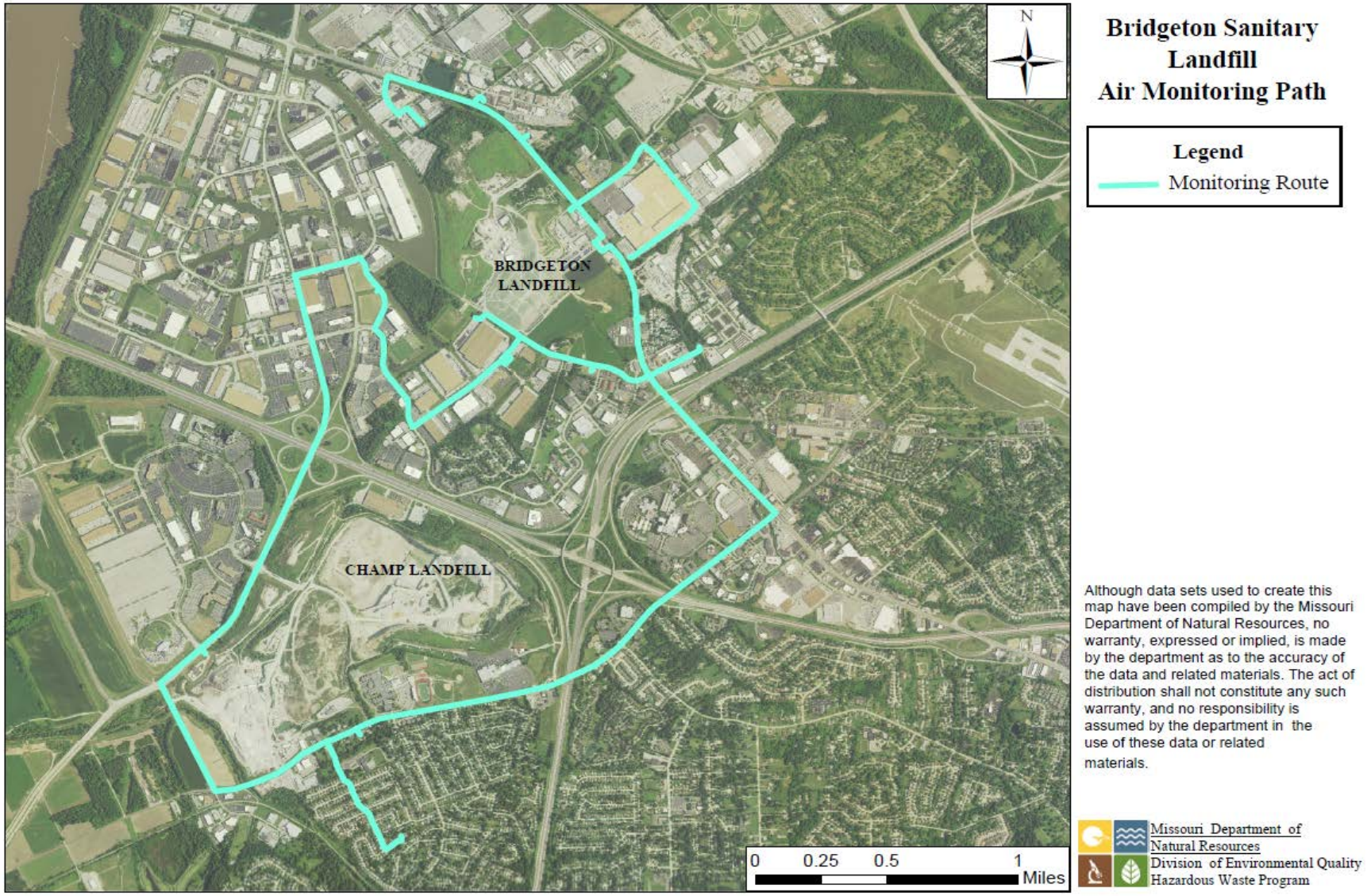


Figure 4. Map of MDNR's Routine Surveillance Path



3.6 EPA Ambient Air Monitoring and Sampling

In 2014-2015, EPA conducted continuous ambient air monitoring and periodic ambient air sampling at five air monitoring stations to assess ambient air quality in the Bridgeton area, as 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 "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 a sampling period 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					
	Carbon Monoxide					
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 are 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] Volatile organic compounds (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 to Landfill Gas Emissions

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

For environmental contamination at a hazardous waste site to be considered a potential public health risk, there must be direct evidence or, at least, a strong likelihood that people may come into contact with contaminants from the site [ATSDR 2005].

Exposure does not always result in harmful health effects. The type and severity of health effects that a person might experience depend on the dose, which is based on the person's age at exposure, the exposure rate (how much), the frequency (how often) or duration (how long) of exposure, the route or pathway of exposure (breathing, eating, drinking, or skin contact), and other factors (such as a combination of contaminants). Once a person is exposed, characteristics such as age, sex, nutritional status, genetic factors, lifestyle, and health status influence how the contaminant is absorbed, distributed, metabolized, and excreted. An environmental concentration alone will not cause an adverse health outcome; the likelihood that adverse health outcomes will actually occur depends on site-specific conditions, individual lifestyle, and genetic factors that affect the route, magnitude, and duration of actual exposure.

4.1.1 Conceptual Exposure Model

The sources of exposure to Bridgeton Landfill gases in ambient air are fugitive emissions and point source emissions (such as flare stacks emissions) from the landfill. Flares are used to control nonmethane organic compound emissions from the landfill, and as a part of that they also convert reduced sulfur compounds and VOCs such as methane to SO_2 and other combustion products.[18] Because of their high release point, stack emissions are unlikely to have contributed substantially to concentrations detected near the landfill property boundary. Along with other point source emissions, they do however contribute to ambient air quality pollution in the area. As such, they are not considered to be within the scope of this public health consultation. Point-source emissions are addressed only inasmuch as they contribute to the monitoring or sampling results evaluated in this public health consultation, including the results from the Rider Trail monitoring station.

[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 have not been 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 and prior to completion of corrective action at the landfill in 2013-2014, fugitive emissions were likely a substantial percentage of total emissions from the landfill. Fugitive emissions are likely captured by MDNR's monitoring and sampling network, which was located between the landfill and nearby receptor populations (or within nearby residential communities).

Gases emitted into the air may persist for varying amounts of time, depending on the chemical and time of year. For example, it is estimated that H_2S released into the environment will persist in ambient air for about one day in the summertime and as long as 42 days in the wintertime before degrading [ATSDR 2014a]. Landfill gases heavier than air, including H_2S, SO_2, and many VOCs, may accumulate in low-lying areas in the evening and early morning hours, when atmospheric conditions tend to be more stable. However, those gases are generally expected to disperse during daytime hours, and concentrations are expected to decrease with increasing distance downwind. Studies indicate that fugitive chemical concentrations may decrease by an order of magnitude or so within 0.6 miles of emissions sources [Liu et al 2014; Pohl et al 2018]. Dispersion rates depend on emission rates, as well as 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 Bridgeton Landfill gases includes the periodic perception of distinctive, offensive odors in residential and commercial areas surrounding the landfill. Since 2012, community members have frequently complained about noxious odors emanating from the landfill. Since 2013, MDNR has also detected distinctive odors in the vicinity of the landfill. MDNR reported detecting landfill odors at 7.8% of all surveillance stops in 2013, 3.6% of stops in 2014, 1.5% of stops in 2015, and 1.0% of stops in 2016. From 2013 to 2016, their frequency of odor detection decreased by over 80%.

According to MDNR's daily surveillance reports, odors characteristic of the landfill were particularly intense in surrounding areas prior to (and sometimes during) remedial work on the landfill in 2013 and 2014. Corrective measures at the landfill included reconstruction of the gas and leachate extraction system, with abandonment of reinforced concrete pipes that were no longer functioning as designed and were allowing the escape of fugitive landfill gases and odors (May-June 2013); installation of a 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 have also been reported during occasional instances of equipment failure that result in leachate or gas release [MDNR 2014].

A variety of chemicals produced by the breakdown of organic matter in the landfill likely contributes 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 air due to their release from multiple sources, including landfills:

- Landfills are a common source of H_2S, which can be perceived as an offensive odor in low concentrations in ambient air [ATSDR 2014a].[19] Concentrations of H_2S in ambient air in urban areas in the United States are typically at or below 1 ppb [ATSDR 2014a]. Maximum concentrations have ranged from 2.8 ppb to 6.3 ppb in urban areas, while higher concentrations (exceeding 90 ppb) have been measured in air in communities located near industries that emit H_2S into the air [ATSDR 2014a].

  Odor thresholds of H_2S have been found to range from 0.5 ppb-10 ppb, depending on individual sensitivities [Ruth 1986]. Other reviews report thresholds as low as 0.04 ppb or as high as 300 ppb [AIHA 2013; ATSDR 2014a; Guidotti 1994]. A geometric mean odor threshold is 8 ppb [Amoore 1985]. A H_2S concentration of 30 ppb is the 1-hour California Ambient Air Quality Standard (CAAQS) for H_2S, which is based on an odor threshold level that can be detected by 83% of the population and can cause discomfort in 40% of the population [Cal EPA 2000, 2008].

- Landfills are also a common source of other RSCs, which can be perceived as offensive odors in low concentrations in ambient air [ATSDR 2014a]. Other RSCs detected in the Bridgeton Landfill source gas include methyl mercaptan, dimethyl disulfide, and dimethyl sulfide. Odor thresholds for methyl mercaptan have been reported to range from 0.01 ppb (odor detection) to 2.1 ppb (odor recognition) [AIHA 1999]. Odor thresholds for dimethyl disulfide have been reported to range from 0.01 ppb (odor detection) to 7.5 ppb (odor recognition) [AIHA 1996]. Odor thresholds for dimethyl sulfide have been reported to range from 1 ppb to 63 ppb [AIHA 2004].

  The American Industrial Hygiene Association's (AIHA's) Emergency Response Planning Guideline-1 (ERPG-1) values for methyl mercaptan, dimethyl disulfide, and dimethyl sulfide are based on odor thresholds, below which most people are not expected to perceive clearly defined, objectionable odors. ERPG-1 values are 5 ppb (methyl mercaptan), 10 ppb (dimethyl disulfide), and 500 ppb (dimethyl sulfide) [AIHA 1996, 1999, 2004].

- 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. MDNR's Air Pollution Control Program monitors SO_2 concentrations in ambient air in regional areas throughout the state. In 2013-2016, the 99th percentile of 1-hour average concentrations of SO_2 in ambient air in the St. Louis area ranged from 9 ppb to 42 ppb [MDNR 2017].

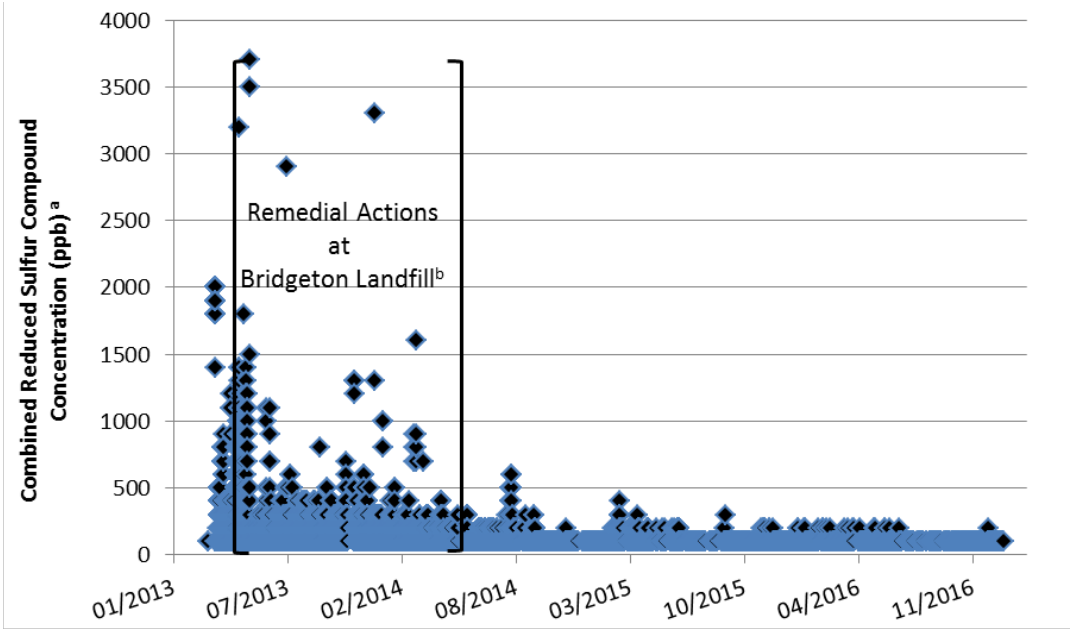
  Odor thresholds of SO_2 have been reported to range from 450 ppb – 4,800 ppb [Ruth 1986] or 330 ppb – 8,000 ppb [AIHA 2013].

Evidence of people's potential exposures to Bridgeton Landfill gases also includes the detection of sulfur-based compounds at MDNR's AreaRAE® monitoring locations near the landfill.

[19] 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, waste water treatment facilities, and tanneries [ATSDR 2014a].

Figure 6 shows daily maximum concentrations of combined RSCs in ambient air near the landfill in 2013-2016. Concentrations tended to be highest prior to and during the remedial work that was done from May 2013 to July 2014 to control gas and odor emissions from the landfill.

Figure 6. Daily Maximum Reduced Sulfur Compound Concentrations MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016



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

[b]Remedial actions from May 2013 to June 2014 included abandonment of concrete pipes that were 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-millions gallon tanks for storage of pre-treated leachate (March-July 2014) [MDNR 2014].

4.2 Screening of Chemicals in Ambient Air

As a first step in evaluating exposures, MDHSS health assessors compare contaminant concentrations to health-based screening levels to identify chemicals of potential public health concern that may need more in-depth evaluation. Screening levels are not thresholds for harmful health effects; rather they are conservative (health-protective) levels that are unlikely to cause adverse health effects, even among sensitive populations. They are developed by ATSDR and other government agencies to ensure the protection of human health.

Concentrations at or below the screening level can reasonably be considered safe. Exceedance of a screening level means potential exposures warrant further investigation. It does not necessarily mean that exposures will result in health impacts or that all people will get sick if they are exposed. This screening process enables MDHSS to safely eliminate from further consideration contaminants not of health concern and to further evaluate potentially harmful contaminants.

Non-cancer screening levels include ATSDR's minimal risk levels (MRLs), which are estimates of exposure that are not likely to have adverse, non-carcinogenic health effects. ATSDR has developed MRLs for chronic (more than 365 days) exposure, intermediate (14 to 365 days) exposure, and acute (less than 14 days) exposure. Non-cancer screening levels also include California EPA's (Cal EPA's) reference exposure levels (RELs) for acute or 8-hour (repeated) exposure. EPA's reference concentrations (RfCs) are chronic inhalation exposure levels unlikely to cause harm in humans over a lifetime. ATSDR's cancer risk evaluation guides (CREGs) and EPA's cancer regional screening levels (cancer RSLs) are concentrations unlikely to result in more than one additional cancer case in an exposed population of a million people over a lifetime.

In this health consultation, MDHSS compares H_2S measurements by the Jerome® meter and Radiello® passive samplers to screening levels for H_2S, including ATSDR's acute MRL (70 ppb), ATSDR's intermediate MRL (20 ppb), and EPA's RfC (1.4 ppb). MDHSS also compares combined RSC concentrations measured by AreaRAE® monitors to H_2S screening levels, as health-based screening levels are not available for many other RSCs, including the primary RSC components of 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. Unfortunately, the lower detection limit of AreaRAE® monitors (100 ppb) exceeds screening levels for H_2S. Therefore, whenever combined RSCs are detected by the AreaRAE® monitors, those measured concentrations exceed H_2S screening levels.

Odor-based screening levels are available for H_2S and several other RSCs, including dimethyl sulfide, dimethyl disulfide, and methyl mercaptan. H_2S concentrations measured by the Jerome® meter and Radiello® passive samplers are compared to odor thresholds for H_2S. Combined RSC concentrations measured by AreaRAE® monitors are compared to an odor threshold (385 ppb) that MDHSS derived from AIHA's ERPG-1 values for individuals RSCs.[20, 21] MDHSS's calculation of the odor threshold is shown in Appendix C.

MDHSS compares SO_2 measurements by AreaRAE® monitors to available health-based screening levels and odor thresholds for SO_2. However, as with combined RSCs, the lower detection limit of AreaRAE® monitors (100 ppb) exceeds some conservative screening levels, including ATSDR's acute MRL for SO_2 (10 ppb). Whenever SO_2 is detected by the AreaRAE® monitors, those measured concentrations exceed the acute MRL. To evaluate SO_2 odors in ambient air, MDHSS used the lower odor threshold from a range of odor threshold values reported by AIHA (330 ppb) [AIHA 2013].

[20] MDHSS's threshold is based on the percent distribution of dimethyl sulfide, dimethyl disulfide, and methyl mercaptan in the landfill source gas and assumes 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 odor threshold data that indicate dimethyl sulfide has an odor threshold much higher than the other RSCs [AIHA 1996, 1999, 2004].

[21] MDHSS assumes that the AreaRAE® hydrogen sulfide sensor is equally 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 [RAE Systems 2015] and may be highly sensitive to others RSCs as well.

MDHSS compares concentrations of other targeted chemicals, including aldehydes, carbon monoxide, and VOCs, to available health-based screening levels and odor thresholds. Comparison of concentrations of all targeted compounds to available health-based screening levels and odor thresholds is included as Appendix D.

The following section summarizes exceedances of health-based screening levels and/or odor thresholds. Table 4 summarizes exceedances of acute and intermediate screening levels and odor thresholds in ambient air.[22] Table 5 summarizes exceedances of chronic or cancer screening levels in ambient air.[23] Chemicals exceeding screening levels are evaluated further in Section 5 of the document.

Several factors contributed to differences in chemical concentrations detected by MDNR near the landfill (i.e., AreaRAE® monitoring, sampling, and surveillance data collected up to ½ mile from the landfill) and ambient air quality data collected 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.[24]

4.2.1 Exceedance of Acute and Intermediate Screening Levels

As shown in Table 4, instantaneous concentrations of H_2S measured by MDNR with the Jerome® meter exceeded Cal EPA's acute REL in only one instance (in 2013). They did not exceed ATSDR's acute MRL. In four instances (two in 2013, one in 2014, and one in 2016), H_2S concentrations exceeded ATSDR's screening level for intermediate exposure (20 ppb). However, exceedances of the intermediate screening level did not occur consecutively and are not expected to have lasted 14 – 365 days (the intermediate exposure period). Concentrations are measured twice daily at surveillance locations up to 2 miles from the landfill.

Whenever sulfur-based compounds (combined RSCs and SO_2) were detected by MDNR's AreaRAE® monitors, concentrations exceeded ATSDR's acute MRL (70 ppb) and intermediate MRL (20 ppb) for H_2S and ATSDR's acute MRL for SO_2 (10 ppb). The frequencies of exceedance of those MRLs are not known, because the lower detection limit of the AreaRAE® H_2S and SO_2 monitors (100 ppb) exceeds those screening levels. MDNR AreaRAE® monitors are located at fixed locations up to ½ mile from the landfill.

In ambient air samples collected by MDNR downwind of the landfill, only benzene was detected at concentrations exceeding acute or intermediate screening levels. In two sampling events (one in 2013 and one in 2014), benzene concentrations exceeded ATSDR's acute MRL (9 ppb). In three sampling events (two in 2013 and one in 2014), benzene concentrations exceeded ATSDR's intermediate MRL (6 ppb). Samples are collected up to ½ mile upwind and downwind

[22] Chemicals not listed in Table 4 were either not detected in ambient air or were detected at concentrations below available odor thresholds and noncancer screening levels for acute or intermediate exposure. Also not shown are exceedances that only occurred upwind of the landfill. See Appendix D for a full list of exceedances.
[23] Chemicals not listed in Table 5 were either not detected in ambient air or were detected at concentrations below available chronic or cancer screening levels. See Appendix D for a full list of exceedances.
[24] EPA collected air samples at fixed locations in the Bridgeton area that were not necessarily downwind from the landfill. Also, those air samples were collected in 2014-2015 only, over 24-hour and 7-day periods that were less likely than MDNR's instantaneous measurements or 4-hour samples to capture spikes in concentration.

of the landfill. The samples with exceedances were collected within a few hundred feet of the landfill.

In 16 instances (12 in 2013 and four in 2014), MDNR detected benzene in ambient air using the UltraRAE® meter. Whenever concentrations were measured, those concentrations exceeded ATSDR's acute and intermediate screening levels (9 ppb and 6 ppb). The frequencies of exceedance of those screening levels are not known, because the lower detection limit of the UltraRAE® meter (50 ppb) exceeds those levels. Concentrations are measured twice daily at surveillance locations up to 2 miles from the landfill.

- Benzene 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 average concentration of benzene in ambient air sampled at 137 monitoring stations in the United States steadily decreased from 0.47 ppb in 2003 to 0.26 in 2013 [EPA 2017b]. However, benzene concentrations up to 34 ppb have been found in urban areas [ATSDR 2007].

  Exposures to benzene may also occur indoors, particularly where people smoke cigarettes. Average benzene concentrations in indoor air has 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].

In ambient air samples collected by EPA in the Bridgeton area, only tetrachloroethylene (PCE) was detected at concentrations exceeding acute or intermediate screening levels. PCE was detected in one 24-hour air sample at a concentration that exceeded ATSDR's acute and intermediate MRLs. That sample was collected 0.6 miles northwest of the landfill at monitoring station 2. Exceedances of the intermediate screening level did not occur consecutively and are not expected to have lasted for 14 – 365 days (the intermediate exposure period).

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 ambient air were below ATSDR's MRLs. While the landfill may have been a source of PCE, industrial sources common in urban areas likely contributed to PCE in the ambient air. Apart from the 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 in Bridgeton area air samples were similar to average concentrations in background samples from St. Charles County, 2.3 miles from the landfill.

4.2.2 Exceedance of Odor Thresholds

As shown in Table 4, H_2S concentrations measured by MDNR with the Jerome® meter were often within a range of concentrations at which people may perceive an odor (0.5 ppb – 10 ppb). In less than 20 instances, H_2S was measured in ambient air near the landfill at slightly higher concentrations, up to 45.5 ppb.

[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].

Combined RSC concentrations detected by the AreaRAE® monitors at MDNR's monitoring locations near the landfill frequently exceeded MDHSS's site-specifically derived odor threshold (385 ppb). SO_2 concentrations detected by the AreaRAE® monitors occasionally exceeded the lower value in a range of odor thresholds (330 ppb).

In ambient air samples collected by MDNR downwind of the landfill, valeraldehyde, ethanol, ethylbenzene, carbon disulfide, and propene occasionally exceeded their odor thresholds (0.4 ppb – 90 ppb). Carbon disulfide and propene were only detected downwind of the landfill at concentrations exceeding their odor thresholds. Valeraldehyde, ethanol, and ethylbenzene were also detected upwind of the landfill at concentrations exceeding their odor thresholds, indicating they may have been emitted from other sources.

Table 4. Exceedance of Short-term Screening Levels & Odor Thresholds
Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2016

Chemical	Range of Concentrations (ppb)		Health-Based Screening Level[a] (ppb)	Odor Threshold[b] (ppb)	Number of Exceedances[c]	
					Screening Level	Odor Threshold
H_2S and Benzene: MDNR Surveillance with Hand-held Meters[d]						
Hydrogen Sulfide	ND-45.5		70 ATSDR Acute MRL 30 Cal EPA Acute REL 20 ATSDR Int. MRL	0.5-10 Low Range	1 Acute REL 4 Int. MRL	Often within low range
Benzene	ND-500		9 ATSDR Acute MRL 6 ATSDR Int. MRL	61,000 EPA	Below DL	Not exceeded
Sulfur-based Compounds: MDNR AreaRAE® Monitoring[e]						
Combined Reduced Sulfur Compounds	ND- 3,700		70 ATSDR Acute MRL 30 Cal EPA Acute REL 20 ATSDR Int. MRL (hydrogen sulfide)	385 MDHSS	Below DL	656
Sulfur Dioxide	ND-1,600		10 ATSDR Acute MRL	330 AIHA	Below DL	20
Aldehydes: MDNR Sorbent Tube Sampling[f]	***upwind***	***downwind***				
Valeraldehyde	ND-10.8	ND-3.9	N/A	0.4 AIHA	N/A	2 upwind/ downwind
VOCs: MDNR SUMMA® Canister Sampling[g]	***upwind***	***downwind***				
Benzene	ND-2.0	ND-32.5	9 ATSDR Acute MRL 6 ATSDR Int. MRL	61,000 EPA	2 Acute MRL 3 Int. MRL downwind	Not exceeded

Carbon Disulfide	ND-7.2	ND-18	1,990 Cal EPA Acute REL	16 AIHA	Not exceeded	1 downwind
Ethanol	ND-480	ND-150	N/A	90 AIHA	N/A	5 upwind 2 downwind
Ethylbenzene	ND-3.7	ND-2.2	5,000 ATSDR Acute MRL	2 AIHA	Not exceeded	2 upwind 2 downwind
Propene	ND-2.9	ND-12.1	N/A	10.1 AIHA	N/A	1 downwind
VOCs: EPA SUMMA® Canister Sampling[h]						
	St. Charles	***Bridgeton***				
PCE	ND-0.29 typical 2.8 Maximum	ND-0.25 typical 12.7 maximum	6 Acute and Intermediate ATSDR MRLs	47,000 EPA	1 Bridgeton area	Not exceeded

[a]The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR, EPA, and Cal EPA
[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 low threshold range for H_2S [Ruth 1986], and a site-specifically derived threshold for combined RSCs.
[c]Not shown are exceedances that only occurred upwind of the landfill.
[d]Concentrations are instantaneous concentrations measured twice daily at locations up to 2 miles from the landfill.
[e]Concentrations are measured every 1-3 minutes by continuous air monitoring at fixed locations up to ½ mile from the landfill.
[f]Concentrations are from 4-hour samples collected up to ½ mile upwind and downwind of the landfill on 20 days in 2013.
[g]Concentrations are from 4-hour samples collected up to ½ mile upwind and downwind of the landfill on 198 days in 2013-2016.
[h]Concentrations are from 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.
ppb = parts per billion; ND = not detected; N/A = not available/not applicable
Below DL = screening level below lower detection limit; the number of exceedances cannot be determined.

Not included in Table 4 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 and 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].

4.2.3 Exceedance of Chronic and Cancer Screening Levels

As shown in Table 5, the 4-year average of H_2S concentrations measured by MDNR at surveillance locations up to 2 miles from the landfill in 2013-2016 slightly exceeded EPA's RfC for chronic exposure to H_2S (1.4 ppb).

Four-month average concentrations of acetaldehyde and formaldehyde in air samples collected by MDNR downwind of the landfill in 2013 and 4-year average concentrations of 1,2-dichloroethane and benzene in air samples collected by MDNR downwind of the landfill in

2013-2016 exceeded cancer screening levels (0.0095 ppb – 0.25 ppb). Average concentrations of acetaldehyde, formaldehyde, and 1,2-dichloroethane were similar upwind and downwind of the landfill, indicating they may have been emitted from other sources.[26]

Seven-month average concentrations of benzene, carbon tetrachloride, and chloroform in ambient air samples collected by EPA in 2014 in the Bridgeton area exceeded cancer screening levels (0.0089 ppb – 0.04 ppb). While the landfill may have been a source of those chemicals in the ambient air, industrial and other sources of those chemicals are common in urban areas. Average concentrations of benzene, carbon tetrachloride, and chloroform in Bridgeton area air samples were similar to average concentrations in background samples from St. Charles County, 2.3 miles from the landfill.

Table 5. Exceedance of Chronic and Cancer Screening Levels
Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2016

Chemical	Average Concentration (ppb)		Chronic Health-Based Screening Levels[a] (ppb)	Cancer Screening Level (ppb)	Exceedances[b]	
					Chronic Screening Level	Cancer Screening Level
H_2S: MDNR Surveillance with Hand-held Meters[c]						
Hydrogen Sulfide	1.9		1.4 EPA RfC	N/A	Exceeded	N/A
Aldehydes: MDNR Sorbent Tube Sampling[d]	***upwind***	***downwind***				
Acetaldehyde	0.48	0.48	5 EPA RfC	0.25 ATSDR CREG	Not exceeded	Exceeded up and down wind
Formaldehyde	0.94	0.95	8 ATSDR Chronic MRL	0.063 ATSDR CREG	Not exceeded	Exceeded up and down wind
VOCs: MDNR SUMMA® Canister Sampling[e]	***upwind***	***downwind***				
1,2-Dichloroethane	0.03	0.02	1.8 EPA RfC	0.0095 ATSDR CREG	Not exceeded*	Exceeded up and down wind
Benzene	0.11	0.39	3 ATSDR Chronic MRL	0.04 ATSDR CREG	Not exceeded	Exceeded up and downwind
VOCs: EPA SUMMA® Canister Sampling[f]	***St. Charles***	***Bridgeton***				
Benzene	0.15	0.16	3 ATSDR Chronic MRL	0.04 ATSDR CREG	Not Exceeded	Exceeded - Bridgeton and Background
Carbon Tetrachloride	0.07	0.07	16 EPA RfC	0.026 ATSDR CREG	Not Exceeded	Exceeded - Bridgeton and Background
Chloroform	0.02	0.05	20 ATSDR Chronic MRL	0.0089 ATSDR CREG	Not Exceeded	Exceeded - Bridgeton and Background

[a]The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR and EPA

[26] 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 2010]. Common sources in outdoor air include vehicle emissions.

[b]Not shown are exceedances that may have only occurred upwind of the landfill
[c]The concentration is the average of all instantaneous concentrations measured by meter surveillance in 2013-2016.
[d]Concentrations are averages from 4-hour samples collected up and downwind of the landfill on 20 days in 2013.
[e]Concentrations are averages from 4-hour samples collected up and downwind of the landfill on 198 days in 2013-2016.
[f]Concentrations are averages from all 24-hour ambient air samples collected for EPA on 34 days in May-December 2014 using SUMMA canisters. 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.
ppb = parts per billion; N/A = not available/not applicable; *laboratory reporting limit approached the RfC

Not included in Table 5 are average concentrations of combined RSCs detected by MDNR's AreaRAE® monitors near the landfill. The extent to which RSC exposures may exceed the RfC for H_2S is not known, as the lower detection limit of the AreaRAE® monitors exceeds the RfC.

4.2.4 Other Sources of Chemicals and Odors in Ambient Air

Bridgeton Landfill is located in an urban environment, where people breathe air impacted by chemical and odor emissions from many sources. 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 also become equally or more significant as emissions from the landfill decrease and chemical concentrations in ambient air near landfill approach levels typical for urban air. However, 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.

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, MO. 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

The public health risks of exposure to chemicals of potential concern are further evaluated in the *Public Health Implications* section of this health consultation by comparison of chemical concentrations to the levels at which adverse health effects have been observed in critical clinical and/or epidemiological studies. Potential health risks are evaluated not only for the general public but also for the most sensitive groups of individuals whose health may be impacted as a result of breathing those chemicals.

Cancer risks are also discussed in the *Public Health Implications* section of this health consultation.

5 PUBLIC HEALTH IMPLICATIONS

The public health impacts of breathing chemical emissions from the landfill include toxicological effects. In addition, some individuals may experience health effects when chemicals with offensive odors are below known levels of toxicity. Health effects 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 has evaluated 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

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. As shown in Table 6, H_2S was detected most frequently in 2013. Nearly all instantaneous concentrations of H_2S measured with the Jerome® meter (i.e., 99.9% of detected concentrations) were between 3 ppb (the lower detection limit of the Jerome® meter) and 10 ppb. Those concentrations fall 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 people living or working near the landfill and in the Bridgeton area may have occasionally been able to smell H_2S in ambient air. Because people's sensitivities to odor varies, and because H_2S concentrations were often below 3 ppb, it is unlikely that everyone would have smelled H_2S continuously.

In a total of 134 instances on 42 days in 2013-2016, instantaneous H_2S concentrations measured by the Jerome® meter exceeded 8 ppb, a geometric mean odor threshold at which approximately 11% of the population may be bothered by the odor [Amoore 1985]. Approximately 84% of those exceedances occurred in 2013. On many of those days, H_2S concentrations exceeded 8 ppb at multiple surveillance locations. 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.

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 odor-related physiological effects including headache and nausea [Cal EPA 2008].

Table 6. Estimated Intensity of Hydrogen Sulfide Odors in Ambient Air Bridgeton Landfill and Surrounding Areas, 2013-2016

Year	Range of Concentrations (ppb)	Number of Detections/ Number of Measurements	Frequency of Detection (%)	Number of Detections ≥8 ppb	Estimated Odor Intensity[a]
H_2S: MDNR Jerome® Meter Surveillance[b]					
2013	ND-10 typical 45.5 maximum	4,458/6,587	68	113	Potential odor; occasionally bothersome to sensitive individuals
2014	ND-10 typical 23.3 maximum	4,669/9,621	49	5	Potential odor; rarely bothersome to sensitive individuals
2015	ND-10 typical 13.9 maximum	3,761/9,748	39	7	
2016	ND-10 typical 22.6 maximum	4,081/10,220	40	9	

[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, Cal EPA's acute REL, approximately 40% of the population may be bothered by the odor [Cal EPA 2008]. Concentrations of H_2S in ambient air in urban areas in the United States are typically <1 ppb [ATSDR 2014a].
[b]Instantaneous meter measurements taken by MDNR during routine surveillance up to 2 miles from the landfill in 2013-2016.
ppb = parts per billion; ND = not detected

5.1.1.2 Adverse Effects of Breathing Hydrogen Sulfide

Breathing H_2S in ambient air near the landfill is not expected to have caused adverse respiratory or olfactory effects that were observed in the clinical studies used to derive ATSDR's MRLs for H_2S.

Instantaneous concentrations of H_2S measured with the Jerome® meter were below ATSDR's MRL for acute exposure to H_2S (70 ppb), which is based on respiratory effects and estimates a concentration of H_2S unlikely to pose appreciable risk of those effects, even in sensitive individuals. Instantaneous concentrations were also typically below ATSDR's MRL for intermediate exposure (20 ppb), which is based on a study that showed intermediate exposures to high concentrations of H_2S may result in olfactory neuron loss in animals [Brenneman et al. 2000]. Concentrations exceeding the intermediate MRL were detected only briefly in four isolated instances.

The 4-year average of instantaneous H_2S concentrations (1.9 ppb) only slightly exceeded EPA's RfC for H_2S (1.4 ppb). EPA's RfC is also based on the study that showed high concentrations of H_2S may result in olfactory neuron loss in animals [Brenneman et al. 2000; EPA 2003]. The average concentration of H_2S in ambient air near the landfill was far below exposure levels shown in that study to have no adverse effects (i.e., $NOAEL_{animal}$ = 10 ppm or 10,000 ppb; human equivalent NOAEL = 460 ppb). EPA's RfC is a concentration unlikely to pose appreciable risk over a long-term period of exposure, even in sensitive individuals.

In Radiello® air samples collected by EPA in the Bridgeton area in 2014-2015, seven-day average concentrations of H_2S were below health-based screening levels and were similar to concentrations commonly detected in urban air (i.e., <1 ppb; ATSDR 2014a).

5.1.2 Reduced Sulfur Compounds

Maximum H_2S concentrations detected by the MDNR 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) were substantially higher than maximum concentrations of H_2S measured by the Jerome® meter around the landfill.

The difference between the maximum AreaRAE® measurements and maximum Jerome® meter readings may be due to differences in the instruments' susceptibilities to interference, including chemical interference.[27] 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 nearly as sensitive to methyl mercaptan [RAE Systems 2015] and may be quite sensitive to other RSCs as well. Because the AreaRAE® H_2S monitor is particularly prone to chemical interference, MDHSS refers to the AreaRAE® H_2S measurements as combined RSC concentrations.

Because the AreaRAE® monitors continuously monitor concentrations in ambient air, they may also have captured concentration spikes of H_2S that the twice-daily surveillance readings with the Jerome® meter did not. However, 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 peak concentration of H_2S detected by the AreaRAE® monitors (3,700 ppb × 1.6% = 59.5 ppb H_2S) is not much higher than the peak concentration detected by the Jerome meter (45.5 ppb H_2S).

Table 7 shows the number and frequency 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 each subsequent year, the frequency of detection of combined RSCs in ambient air decreased. From 2013 to 2016, the average frequency of detection of combined RSCs at the three AreaRAE® monitoring locations near the landfill decreased by approximately 74%, which was a statistically significant decrease ($p= 0.006$).

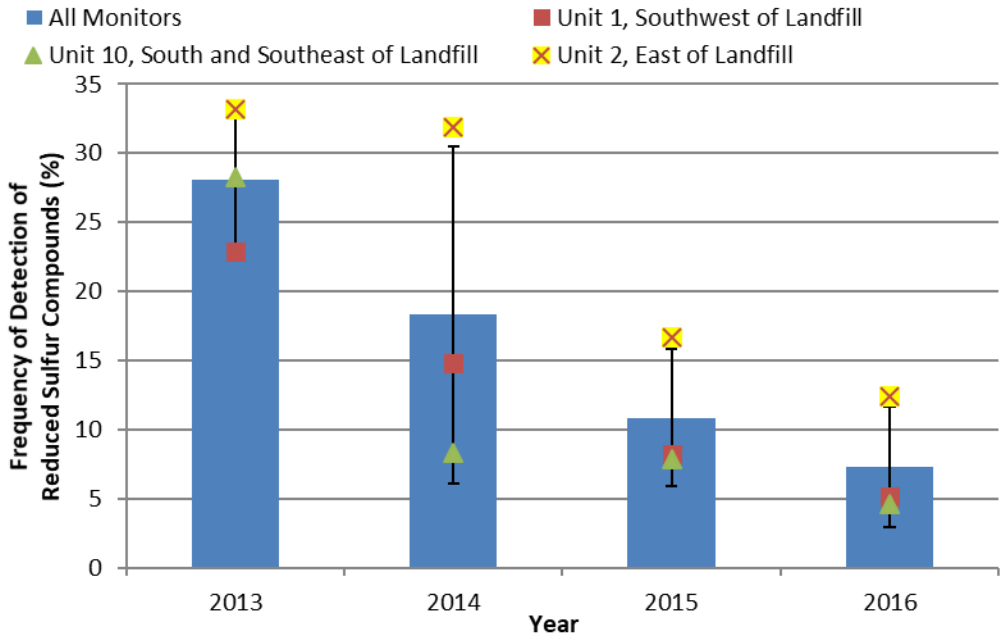
[27] The AreaRAE® monitors are designed to measure multiple types of chemicals concurrently, while the Jerome meter is designed to measure hydrogen sulfide specifically. The detection range of the Jerome meter is 3 ppb to 50 ppm. The detection range of the AreaRAE® hydrogen sulfide sensor is 0.1 ppm (100 ppb) to 100 ppm.

Table 7. Number and Frequency of Detections of Reduced Sulfur Compounds MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016

Year	AreaRAE® Unit 1 Southwest of the Landfill		AreaRAE® Unit 10 South, Southeast of the Landfill		AreaRAE® Unit 2 East of the Landfill	
	Number of Detections[a] / Number of Measurements[b]	Frequency of Detection (%)	Number of Detections[a] / Number of Measurements[b]	Frequency of Detection (%)	Number of Detections[a] / Number of Measurements[b]	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

[a]Number of detections of combine 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 are taken every 1-3 minutes.
[b]Number of hours that the AreaRAE® RSC monitors were operational

Figure 7. Annual Average Frequency of Detection of Reduced Sulfur Compounds MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016



[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 average frequencies of detection at all three monitoring sites. Error bars show the standard deviation from the mean frequency of detection at the three monitoring sites.

5.1.2.1 Response to Reduced Sulfur Compound Odors

The odor thresholds of mixtures of odorous chemicals are not well understood. Odors might be perceived at the odor thresholds of individual chemicals in a mixture. Odors might be perceived

below the odor thresholds of individual chemicals, if combined chemical concentrations reach an individual threshold. Odors might also enhance or mask other odors.

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 clearly defined, objectionable odors at AreaRAE® monitor measurements of:

- 100 ppb. Reduced sulfur in the landfill source gas was found to consist of approximately 4.8% methyl mercaptan and 8.2% dimethyl sulfide. Based on those percentages, methyl mercaptan (with an odor threshold of 5 ppb) and dimethyl sulfide (with an odor threshold of 10 ppb) may have been perceived as objectionable above combined RSC concentrations of 104 ppb (5 ppb ÷ 4.8% methyl mercaptan = 104 ppb) and 121 ppb (10 ppb ÷ 8.2% dimethyl disulfide = 121 ppb), measured by AreaRAE® monitors at 100 ppb.[28]

- 500 ppb. Reduced sulfur in the landfill source gas was found to consist of approximately 1.6% hydrogen sulfide. Based on that percentage, hydrogen sulfide (with an odor threshold of 8 ppb) may have been perceived as objectionable at AreaRAE® monitor measurements of 500 ppb (8 ppb ÷ 1.6% H_2S = 500 ppb).[29]

- 600 ppb. Reduced sulfur in the landfill source gas was found to consist of approximately 76.5% dimethyl sulfide. Based on that percentage, dimethyl sulfide (with an odor threshold of 500 ppb) may have been perceived as objectionable at combined RSC concentrations above 653 ppb (500 ppb ÷ 76.5% dimethyl sulfide = 653 ppb), measured by AreaRAE® monitors at 600 ppb.[30]

MDHSS's site-specifically derived threshold value (385 ppb) is an estimate of the 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).

Table 8 shows frequencies of detection of combined RSCs by MDNR's AreaRAE® monitors at odor thresholds for single and multiple RSCs. At the monitor detection limit (100 ppb), people may have been bothered by the odors of single RSCs, including methyl mercaptan and dimethyl disulfide. At AreaRAE® measurements of 300 ppb, as concentrations approached or exceeded MDHSS's threshold value (385 ppb), people may have been bothered by additional RSCs.

RSC odors were most likely bothersome in 2013, when combined RSCs were detected approximately 28% of the time and when combined RSC concentrations equaled or exceeded

[28] AIHA ERPG-1 values for dimethyl disulfide (10 ppb) and methyl mercaptan (5 ppb) are based on odor thresholds 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.

[29] A geometric mean odor threshold for H_2S is 8 ppb [Amoore 1985].

[30] AIHA ERPG-1 value for dimethyl sulfide (500 ppb) is based on an odor threshold below which individuals are unlikely to perceive a clearly defined, objectionable odor [AIHA 2004]. The AreaRAE® H_2S monitor measures concentrations in 100 ppb increments.

300 ppb approximately 6% of the time. With each subsequent year, the frequency of combined RSC detections decreased. From 2013 to 2016, the frequency of detection of combined RSCs decreased by approximately 74%.

When people living or working near the landfill perceived objectionable odor, they may have experienced health effects associated with the perception of those odors, including neurological effects such as headache and nausea.

Table 8. Estimated Intensity of Reduced Sulfur Compound Odors in Ambient Air Bridgeton Landfill, 2013-2016

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 (%)	Estimated Odor Intensity
Combined RSCs: MDNR AreaRAE® Monitoring						
2013	ND - 3,700	5,621/20,004	28.1	1,191/20,004	6.0	More frequently bothersome
2014	ND - 1,600	4,395/24,033	18.3	149/24,033	0.6	Less frequently bothersome
2015	ND - 400	2,627/24,194	10.9	8/24,194	<0.1	
2016	ND - 200	1,747/23,994	7.3	0/23,994	0	

[a]Number of times that hourly maximum AreaRAE® measurements met individual RSC odor thresholds (≥100 ppb) or MDHSS's odor threshold for combined RSCs (≥300 ppb). Measurements are taken every 1-3 minutes.
[b]Number of hours that the AreaRAE® monitors were operational
ppb = parts per billion; ND = not detected

5.1.2.2 Uncertainty in Odor Thresholds

Odor thresholds for some chemicals are often reported over wide concentration ranges due to differences in testing methodology and in people's ability to perceive odors. Odor thresholds are also often based on limited data. 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].

In addition, 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]. Reported odor thresholds are not always defined as a low odor threshold or a 100% recognition odor threshold. Without both values, the span between them is not known, and it is difficult to estimate the percentage of the population who might be bothered by an odor.

5.1.2.3 Adverse Effects of Acute Exposure to Reduced Sulfur Compounds

To assess the potential for adverse respiratory effects from acute exposure to combined RSCs detected by AreaRAE® monitors in ambient air near the landfill, MDHSS compared combined

RSC concentrations to health-based screening levels for H_2S.[31] In comparing combined RSCs to screening levels specific to H_2S, MDHSS has taken a conservative health assessment approach that assumes H_2S and the other RSCs have similar toxicity levels. While little is known about the toxicity of other RSCs, the toxicity of H_2S is well established.

ATSDR's acute MRL for H_2S is based on respiratory effects observed in clinical studies and estimates a concentration of H_2S unlikely to pose appreciable risk over a specific period of exposure:

- 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.

  The lowest observed adverse effect level (LOAEL) for H_2S (2,000 ppb) is the lowest concentration shown in the study to cause bronchoconstriction. ATSDR derived the acute MRL by 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].

Generally, as combined RSC concentrations approach the LOAEL, sensitive individuals, including people with chronic respiratory disease such as asthma, become increasingly likely to experience adverse respiratory effects. Highly sensitive individuals, including people with severe asthma, may be more likely to experience adverse respiratory effects than less sensitive individuals. If concentrations exceed the LOAEL, adverse health effects in the general public become more likely to occur.

In 2013, people living or working near the landfill were most likely to have experienced aggravated respiratory illnesses or respiratory symptoms from acute exposure to combined RSCs in ambient air. As shown in Table 9, in that year 13.7% of hourly maximum concentrations approached or exceeded the LOAEL (i.e., concentrations were ≥200 ppb, exceeding or falling within an order of magnitude of the LOAEL). In subsequent years, the frequency of combined RSC detections decreased. In 2016, combined RSC concentrations in ambient air near the landfill were generally well below the LOAEL, reaching 200 ppb in only 24 monitoring hours during the year.

[31] 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.

Table 9. Potential Public Health Impacts of Breathing Reduced Sulfur Compounds Bridgeton Landfill, 2013-2016

Year	Range of Combined RSC Concentrations[a] (ppb)	Number of Detections at Concentrations ≥200 ppb[a]/ Number of Measurements[b]	Frequency of Detection at Concentrations ≥200 ppb (%)	Potential Public Health Impact
Combined RSCs: MDNR AreaRAE® Monitoring[c]				
2013	ND - 3,700	2,743/20,004	13.7	Occasionally unhealthy
2014	ND - 1,600	720/24,003	3.0	
2015	ND – 400	94/24,194	0.4	Rarely unhealthy
2016	ND – 200	24/23,994	0.1	

[a]Number of times that hourly maximum combined RSC concentrations equaled or exceeded 200 ppb. Measurements are 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, some sensitive individuals may experience adverse respiratory effects from acute exposures to combined RSC concentrations below 200 ppb. The lower detection limit of the AreaRAE® H_2S sensor (100 ppb) exceeds ATSDR's acute MRL (70 ppb) and, as a result, precludes a detailed assessment of the public health impacts of breathing low concentrations of RSCs in ambient air near the landfill. MDHSS cannot estimate the frequency with which sensitive individuals living or working near the landfill may have experienced adverse respiratory effects.

People may experience adverse respiratory effects, such as chest tightness or breathing discomfort, 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 Adverse Effects of Long-Term Exposure to Reduced Sulfur Compounds

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 establishment of the MRL, ATSDR derived a human-equivalent concentration of the no observed adverse effect level (NOAEL) in rats ($NOAEL_{animal}$ = 10,000 ppb; human equivalent NOAEL = 460 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 could experience adverse health effects from exposure to concentrations well below the adverse effect levels observed in critical 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].

In 2013, combined RSC concentrations exceeded the NOAEL for H_2S at least once in approximately 2.5% of total monitoring hours. In subsequent years, combined RSC concentrations rarely or never exceeded the NOAEL. The lower detection limit of the AreaRAE® H_2S sensor (100 ppb) exceeds screening levels for intermediate and chronic exposure to H_2S and, as a result, precludes a detailed assessment of the public health impacts of intermediate or chronic exposure to RSCs, especially among sensitive individuals.

Due to differences in the nasal anatomy of rats and human, 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 could experience changes in their perception of smell [Kilburn et al. 2010]. The offensive odors of chemical emissions may modify olfactory function [Miner 1980].

5.1.2.5 Distribution of Reduced Sulfur Compounds Near Bridgeton Landfill

Figure 8 shows the distribution of 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).

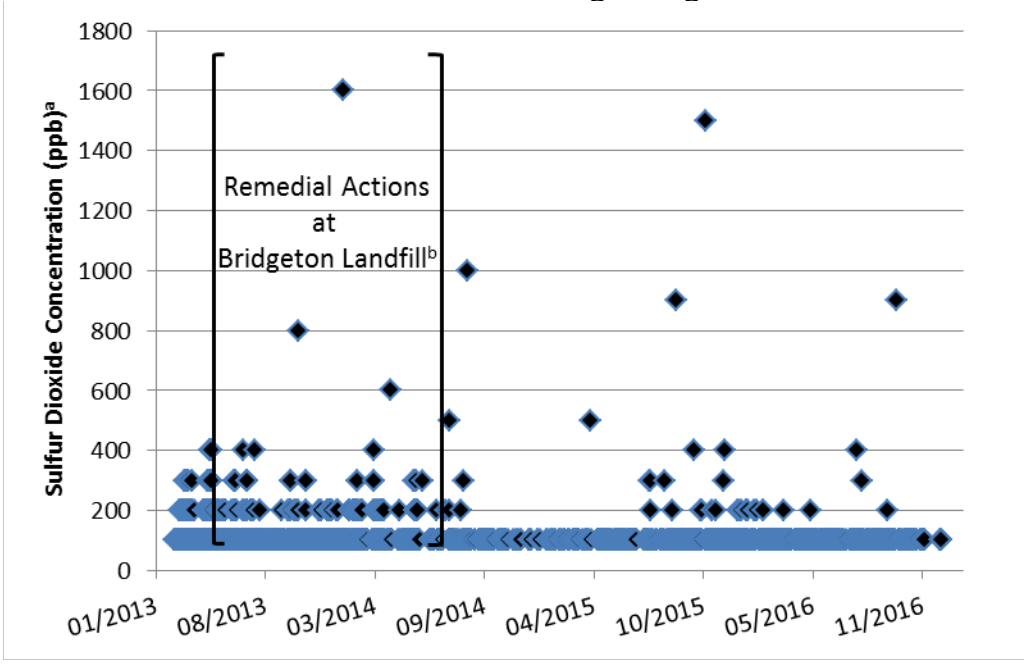
At locations south and southwest of the landfill (units 1 and 10), the numbers of detections of combined RSCs were highest in 2013. East of the landfill (unit 2), the numbers of detections were highest in 2013 and 2014. Combined RSCs were most frequently detected in the commercial area east of the landfill.

Figure 8. Map of the Number of Detections of Reduced Sulfur Compounds in Ambient Air Bridgeton Landfill, 2013-2016

5.1.3 Sulfur Dioxide

Figure 9 shows daily maximum concentrations of SO_2 detected by MDNR AreaRAE® monitors near the landfill in 2013-2016. 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 of 200 ppb or more prior to and during the remedial work that was done from May 2013 to July 2014 to control gas and odor emissions from at the landfill.

Figure 9. Daily Maximum Sulfur Dioxide Concentrations
MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016



[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]Remedial actions from May 2013 to June 2014 included abandonment of concrete pipes that were 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-millions gallon tanks for storage of pre-treated leachate (March-July 2014) [MDNR 2014].

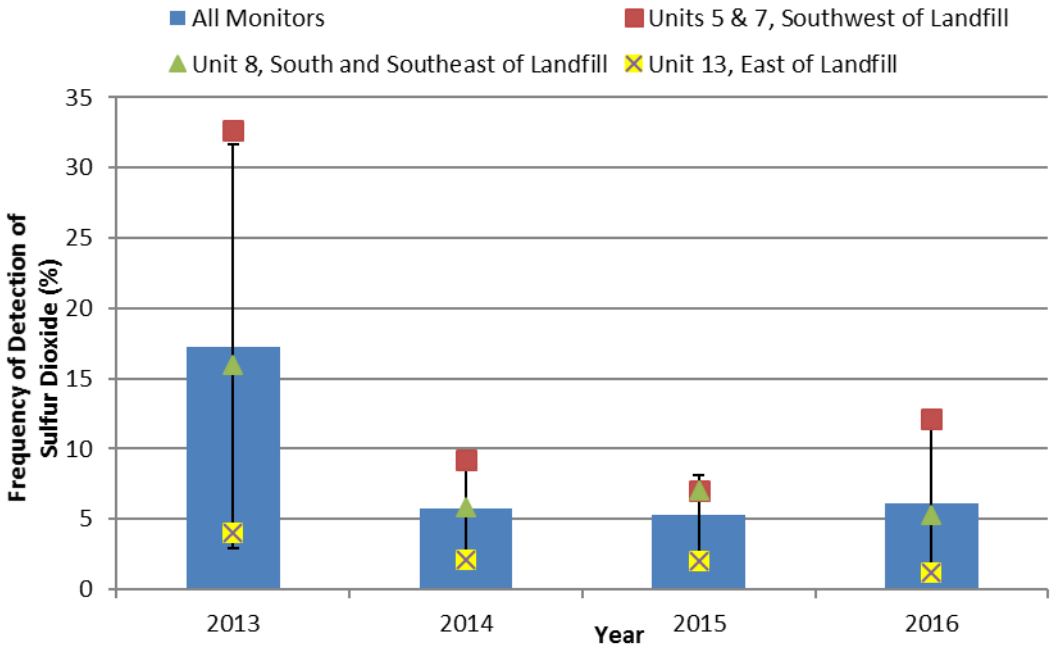
Table 10 shows the number and frequency of detections of SO_2 in ambient air at AreaRAE® monitoring locations near the landfill. In 2013, SO_2 was detected at least once in 4.0% - 32.6% of total monitoring hours. In subsequent years, the frequency of detection of SO_2 generally decreased, although detection frequencies near the southwest corner of the landfill (near the MSD lift station) somewhat varied. From 2013 to 2016, the average frequency of detection of SO_2 at the three AreaRAE® monitoring sites near the landfill decreased by approximately 64%. However, because concentrations varied so much by location, that decrease was not statistically significant ($p = 0.27$).

Table 10. Number and Frequency of Detection of Sulfur Dioxide in Ambient Air MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016

Year	AreaRAE® Units 5&7 Southwest of Landfill		AreaRAE® Unit 8 South/Southeast of Landfill		AreaRAE® Unit 13 East of Landfill	
	Number of RSC Detections[a] / Number of Measurements[b]	Frequency of Detection (%)	Number of RSC Detections[a] / Number of Measurements[b]	Frequency of Detection (%)	Number of RSC Detections[a] / Number of Measurements[b]	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

[a]Number of times that hourly maximum SO_2 concentrations equaled or exceeded 100 ppb (the AreaRAE® sensor detection limit). Measurements are taken every 1-3 minutes.
[b]Number of hours that the AreaRAE® SO_2 monitors were operational

Figure 10. Annual Average Frequency of Detection of Sulfur Dioxide in Ambient Air MDNR Continuous Ambient Air Monitoring, Bridgeton Landfill, 2013-2016



[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. Error bars show standard deviation from the mean frequency of detection at the three monitoring locations. The detection limit of the AreaRAE® monitors is 100 ppb.

5.1.3.1 Response to Sulfur Dioxide Odors

People living or working near the landfill were not likely bothered by SO_2 odors. Table 11 shows estimated intensities of SO_2 odors near the landfill. In 2013, SO_2 concentrations in ambient air near the landfill rarely exceeded 300 ppb, approaching or exceeding the lower value in a range of odor thresholds (330 ppb) only 0.5% of the time. In subsequent years, the frequencies of

detection of SO_2 at those concentrations were even lower. In 2016, 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 11. Estimated Intensity of Sulfur Dioxide Odors in Ambient Air Bridgeton Landfil, 2013-2016

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] (%)	Estimated Odor Intensity[d]
SO_2: MDNR AreaRAE® Monitoring[e]				
2013	ND – 800	102/20,437	0.5	Possible occasional perception of odor
2014	ND – 1,600	16/25,097	0.06	Rare perception of odor
2015	ND – 1.500	9/24,015	0.04	
2016	ND – 900	3/24,620	0.01	
SO_2: Pulsed-Fluorescence Monitoring at Rider Trail-I-70[f]				
2016	ND – 16.5	0/8,736	0	No odor

[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 Adverse Effects of Acute Exposure to Sulfur Dioxide

To assess the physiological effects of acute exposure to SO_2 in ambient air near the landfill, MDHSS has compared SO_2 concentrations to ATSDR's acute MRL for SO_2. ATSDR's MRL is a concentration unlikely to pose appreciable risk over a period of exposure of 14 days or less, based on observations of respiratory effects in a critical clinical study.

> ATSDR's acute MRL (10 ppb) is based on a clinical study in which some people with mild asthma exposed to 100 ppb SO_2 exhibited measurable airway resistance during 10 minutes of exercise [Sheppard et al. 1981]. In establishment of the MRL, ATSDR applied uncertainty factors to the LOAEL (100 ppb), 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].

EPA's Air Quality Index (AQI) can be referenced for an indication of the effects that different concentrations of SO_2 in ambient air may have on people's health.[32] The AQI for SO_2 is based

[32] 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.

on data from multiple clinical and epidemiological studies that associate SO_2 exposures with adverse respiratory effects. The AQI is divided by breakpoint concentration values into six color-coded categories representing different levels of potential health concern [EPA 2016]. At low concentrations, SO_2 is not expected to harm people's respiratory health. Generally, as concentrations increase, the general population becomes more likely to experience symptoms, and sensitive individuals become increasingly likely to experience more severe effects. Table 12 summarizes EPA's delineation of the potential public health impacts of breathing SO_2 in ambient air.

Table 12. 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 99th 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.

Due to the uncertainty of individual response, some individuals may experience adverse respiratory effects from acute SO_2 exposures below the LOAEL (100 ppb) and that, in the AQI, define "moderate" air quality [i.e., concentration in yellow (50 ppb - 75 ppb)] or air quality unhealthy for sensitive groups [(concentrations in orange (76 ppb – 185 ppb)]. The lower detection limit of the AreaRAE® SO_2 sensor (100 ppb) exceeds those AQI breakpoint values, as well as ATSDR's MRL for acute exposure to SO_2, precluding 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.

As shown in Table 13, SO_2 concentrations detected in ambient air near Bridgeton Landfill were occasionally at or above 200 ppb, falling primarily within an AQI concentration range that, over

sufficient time periods, could cause adverse respiratory effects in the general population, especially in sensitive individuals, during periods of activity [i.e., concentrations in red (186 ppb – 300 ppb)]. In 2013, only 2.6% of hourly maximum concentrations fell within AQI concentration ranges where the general population may begin to feel respiratory effects. In subsequent years, SO_2 was rarely detected within those ranges.

The pulsed fluorescence monitor at the Rider Trail monitoring location ¾ of a mile from the landfill is sensitive to low concentrations of SO_2 in ambient air. It was installed at that location in 2016 to characterize ambient air trends in the region, rather than the landfill's contribution to chemicals in ambient air. In 2016, 1-hour average SO_2 concentrations detected at that location (16.5 ppb or less) were well below the LOAEL (100 ppb) and AQI values defined as unhealthy, or potentially unhealthy, for sensitive individuals (50 ppb – 185 ppb). The 99th percentile of 1-hour average SO_2 concentrations was 14 ppb. If concentrations remain at that level over a three-year averaging period, SO_2 in ambient air at that location will be 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 3.4 ppb or less. Twenty-four average concentrations did not exceed the World Health Organization's Air Quality Guideline of 7.6 ppb for 24-hour exposures to SO_2 [WHO 2006].

Table 13. Potential Public Health Impacts of Breathing Sulfur Dioxide in Ambient Air Bridgeton Landfill 2013-2016

Year	Number of Detections at Concentrations ≥200 ppb[a]/ Number of Measurements[b]	Frequency of Detection at Concentrations ≥200 ppb (%)	Potential Public Health Impact[c]
SO_2: MDNR AreaRAE® Monitoring[d]			
2013	521/20,437	2.6	Occasionally unhealthy
2014	151/25,097	0.6	Rarely unhealthy
2015	18/24,015	0.07	
2016	15/24,620	0.06	
SO_2: MDNR Pulsed-Fluorescence Monitoring at Rider Trail-I-70[e]			
2016	0/8,736	0	Good air quality

[a]Number of times that SO_2 concentrations equaled or exceeded 200 ppb, concentrations that might be considered unhealthy for the general population. The AreaRAE® results are the number of hourly maximum concentrations equal to or greater than 200 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]EPA's AQI defines 99th percentile 1-hour average concentrations within a range of 186 ppb – 300 ppb as "unhealthy" for the general population.
[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

As with RSCs, people may have experienced adverse respiratory effects, such as chest tightness or breathing discomfort, from exposure to SO_2 over sufficient time periods, whether or not they perceived an odor in the air. If respiratory effects occur during periods of objectionable odor, those effects may not subside when the odors dissipate.

5.1.3.3 Adverse Effects of Long-term Exposure to Sulfur Dioxide

Health-based 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 diseases [EPA 2014]. However, additional studies are need to determine concentrations that, over the long term, might have those effects.

5.1.3.4 Distribution of Sulfur Dioxide Near Bridgeton Landfill

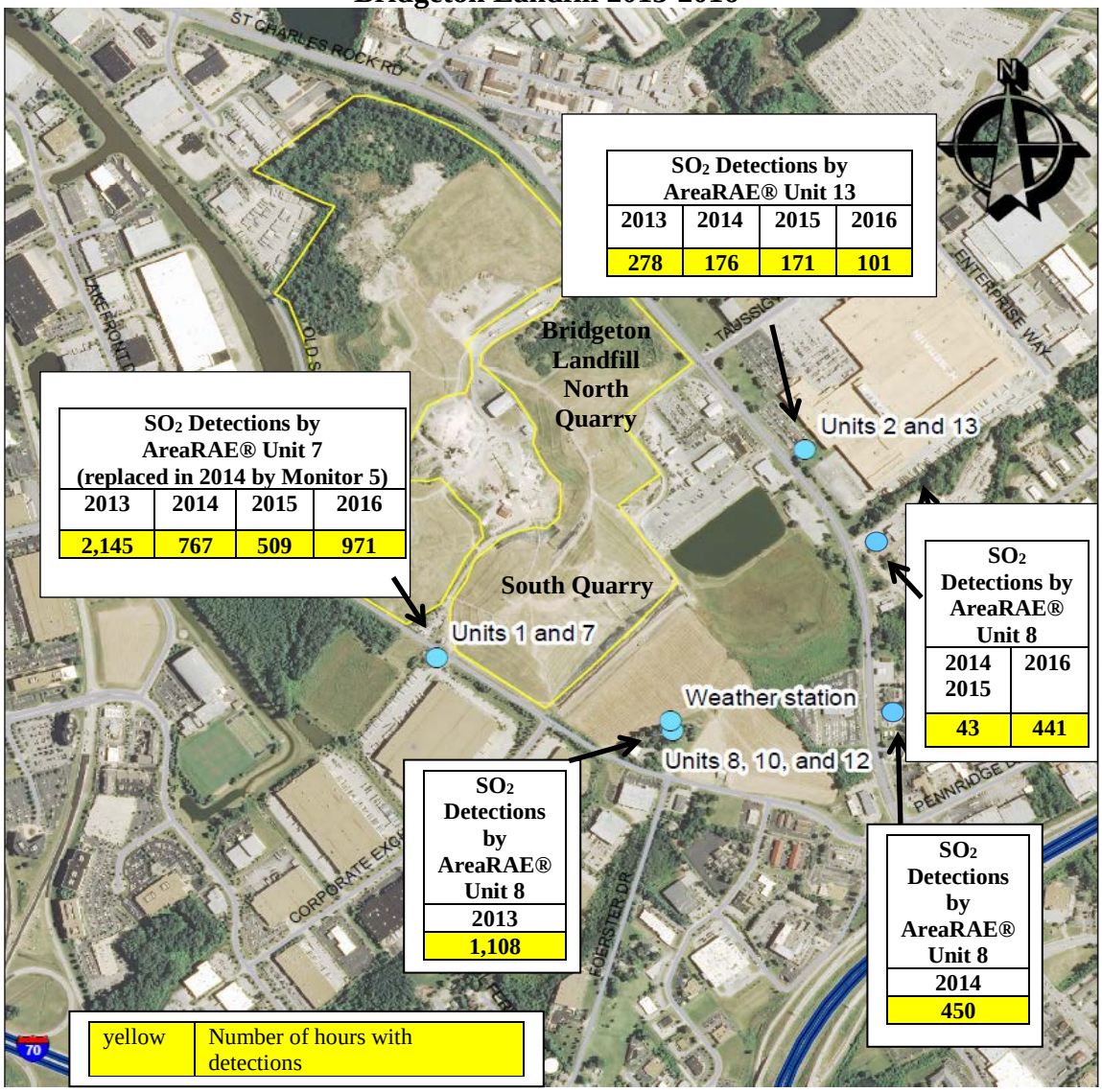
Figure 11 shows the distribution of the number of detections of SO_2 at AreaRAE® monitoring locations near the landfill: the commercial area southwest of the landfill (unit 7), residential areas south and southeast of the landfill (unit 8), and a commercial area east of the landfill (unit 13). Shown are number of hours in which SO_2 was detected at least once.

At all locations, SO_2 was detected most frequently in 2013. In all years, SO_2 was detected most frequently in the commercial area southwest of the landfill (units 5 and 7). SO_2 was less frequently detected in the commercial area east of the landfill and residential area southeast of the landfill (unit 8 in 2014-2016; unit 13), possibly due to the distance of those monitoring locations from the landfill (approximately ½ mile from the landfill waste).

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 2016]. 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 2013-2016 [EPA 2016]. 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 AQI can be viewed online at http://www.airnow.gov.

Figure 11. Map of Numbers of Detections of Sulfur Dioxide in Ambient Air Bridgeton Landfill 2013-2016



5.1.4 Supporting Community Studies

5.1.4.1 Acute exposures

In February and March 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 that survey, a significantly higher percentage of households within a 2-mile radius of the landfill reported residents having experienced shortness of breath within the previous 12 months, compared to households in the study's reference area elsewhere in St. Louis County. More residents within that radius also reported having experienced wheezing, cough, headache, nausea, and fatigue within the previous 12 months, although those results were not statistically significant.

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 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 for exposure to RSCs (30 ppb) 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 numbers of 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 H2S, 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 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 association between SO_2 exposures and emergency department visits and hospital admissions for respiratory effects [EPA 2010]. They include the following studies, where 99^{th} percentile 1-hour average concentrations ranged from 78 ppb to 150 ppb, within the category defined as "unhealthy for sensitive groups" [EPA 2010].

- 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 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 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), as well as respiratory and neurological symptoms [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, although concentration spikes were as high as 2,100 ppb.

In addition to upper respiratory and olfactory effects, long-term or repeated exposures to the 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].

In 2013-2016, RSCs were most frequently detected at AreaRAE® monitoring locations near the landfill at concentrations of 100 ppb, the lower detection limit of the AreaRAE® monitor. That concentration is similar to peak ambient air concentrations in several communities where long-term exposure to low concentrations of TRS has been associated with increased risk of neurological and respiratory effects and impaired mood.

5.1.4.3 Uncertainty in Community Studies

The SLCDPH community survey supports the conclusions of this health consultation that sulfur-based compound emissions from the landfill may have posed health risks to people living or working near the landfill in the past. However, it does 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 the 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 RSC emissions from the landfill pose health risks similar to those observed in other community studies is furthermore uncertain, as the distribution of RSCs in the landfill emissions may differs from the distribution of RSCs in ambient air in other communities, and the relative toxicities and odor thresholds of RSCs are not well understood.

The average percentage of H_2S in the Bridgeton Landfill source gas (approximately 1.6%) is lower than percentages of H_2S reported in some of the community studies discussed above. Concentrations of H_2S detected with the Jerome® meter near the landfill were often within the range of 30-minute average H_2S concentrations that Campagna et al. (2003) detected in ambient air (30 ppb × 10% = 3 ppb; 30 ppb × 50% = 15 ppb). However, peak concentrations of H_2S in ambient air near the landfill were lower than peak concentrations in those community studies. MDNR's instantaneous Jerome meter concentrations did not exceed 45.5 ppb. If AreaRAE® measurements reflect the distribution of RSCs detected under the landfill liner, H_2S concentrations detected by the AreaRAE® H_2S monitor did not exceed 59.2 ppb (3,700 ppb × 1.6%).

On the other hand, the average percentage of other RSCs in Bridgeton Landfill source gas samples (approximately 98.4%) is much higher than percentages of other RSCs reported in the community studies discussed above. Concentrations of other RSCs in ambient air near the landfill were also higher. If AreaRAE® measurements reflect the distribution of RSCs detected under the landfill liner, concentrations of methyl mercaptan were as high as 178 ppb (3,700 ppb × 4.8%), concentrations of dimethyl disulfide were as high as 303 ppb (3,700 ppb × 8.2%), and concentrations of dimethyl sulfide were as high as 2,830 ppb (3,700 ppb × 76.5%). Fortunately, laboratory studies indicate that dimethyl sulfide is less toxic than other RSCs.[33] Also, the odor thresholds reported for dimethyl sulfide are greater than the odor thresholds of other RSCs.

[33] 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].

5.2 Volatile Organic Compounds

5.2.1 Benzene

The landfill was a likely source of benzene during this period, which MDNR occasionally detected in ambient air. Benzene concentrations in two 4-hour air samples collected in a commercial location a few hundred feet downwind of the landfill (32.5 ppb in 2013; 10 ppb in 2014) exceeded ATSDR's acute MRL (9 ppb). Benzene concentrations in those samples and another 4-hour air sample collected at that location (6.3 ppb in 2013) exceeded ATSDR's intermediate MRL (6 ppb). During routine surveillance on those days, MDNR detected landfill odors but did not detect benzene with the UltraRAE® meter (which has a lower detection limit of 50 ppb). In 12 additional instances in 2013 and 4 additional instances in 2014, MDNR detected benzene at instantaneous concentrations of 50 ppb to 500 ppb at surveillance locations up to 2 miles from the landfill.

ATSDR's acute MRL is based on animal studies 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 calculation of the acute MRL, ATSDR derived an LOAEL for 24-hour human exposure of 2,550 ppb for immunological effects.

ATSDR's intermediate MRL is based on animal studies 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 calculation of the intermediate MRL, ATSDR derived an LOAEL for 24-hour, 7-day human exposure of 1,800 ppb for immunological effects.

Because benzene concentrations in air samples near the landfill were well below the LOAELs derived for acute and intermediate human exposure (i.e., two orders of magnitude below the LOAELs), and because benzene was not detected consecutively on surveillance routes, it is unlikely that individuals would have been exposed to benzene at sufficient concentrations and over sufficient time periods for adverse immune response.

5.2.2 Tetrachloroethylene

In 2014, a PCE concentration in one 24-hour sample that EPA collected at a monitoring station approximately 0.6 miles from the landfill exceeded ATSDR's acute and intermediate MRLs (6 ppb). Although the landfill may have been a source of PCE in the ambient air, other emissions sources were likely major contributors to concentrations in the Bridgeton area.

ATSDR's acute and intermediate MRLs are based on an occupational study in which workers exposed to PCE exhibited changes in color vision following an average exposure time of 106 months [ATSDR 2014c; Cavalerri et al. 1994]. Workers exhibited decreased abilities to distinguish color, especially in the blue-yellow range. The acute and intermediate MRLs were developed by converting the mean concentration of PCE in air of 7.2 ppm (7,200 ppb) to a continuous concentration of 1.7 ppb and further dividing that LOAEL by an uncertainty factor of 300 to account for database deficiencies, use of the LOAEL, and variability in individuals' response [ATSDR 2014c]. Because the PCE concentration in the ambient air sample in the

Bridgeton area (12.7 ppb) was well below the LOAEL in that study (1,700 ppb; a difference of two orders of magnitude), it is unlikely that PCE exposures in the Bridgeton area would have caused that adverse effect.

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 VOCs that may jointly target the respiratory or neurological systems were detected in ambient air near the landfill in 2013-2016. However, concentrations of those chemicals were below levels expected to significantly increase the adverse effects of sulfur-based chemicals on those systems.

5.4 Cancer Risks

5.4.1 Chemicals Exceeding CREG Values

Air pollutants in urban environments in the United States often exceed CREG values, which are values representative of concentrations unlikely to increase cancer rates in an exposed population above what would be expected. Table 14 shows average concentrations of chemicals that exceeded CREG values, compared to concentrations commonly detected in urban air. Some aldehydes and VOCs exceeded CREGs in air samples collected by MDNR near the landfill, and some VOCs exceeded CREGs in air samples collected by EPA in the Bridgeton area.

Average concentrations of acetaldehyde and formaldehyde in air samples collected near the landfill exceeded ATDSR's CREG values. The National Toxicology Program (NTP) lists acetaldehyde as reasonably anticipated to be a human carcinogen, based on studies showing inhalation of acetaldehyde can cause certain respiratory tract tumors, including nasal and pharynx cancers, in animals [NTP 2016]. NTP classifies formaldehyde as a known human carcinogen, based on studies linking formaldehyde exposure and increased risks of certain respiratory tract cancers and myeloid leukemia [NTP 2016].

- Average concentrations of acetaldehyde and formaldehyde were the same or similar at sampling locations upwind and downwind of the landfill, indicating they are air pollutants not necessarily emitted from the landfill. Both chemicals are pollutants commonly found in low concentrations in urban air. Average concentrations near the landfill were below average concentrations in ambient air in the United States in 2013 [EPA 2018].

Average concentrations of 1,2-dichloroethane in air samples collected near the landfill exceeded ATDSR's CREG value. NTP lists 1,2-dichloroethane as reasonably anticipated to be a human carcinogen [NTP 2016]. Animal studies have shown that 1,2-dichloroethane exposures may cause a variety of cancers, including liver, kidney, and reproductive system cancers [NTP 2016].

- Average concentrations were similar at sampling locations upwind and downwind of the landfill, indicating 1,2-dichloroethane is an air pollutant not necessarily emitted from the landfill. It is a chemical commonly found in low concentrations in urban air.

Concentrations near the landfill were below concentrations commonly detected in urban air [ATSDR 2001].

In air samples collected by EPA at monitoring stations in the Bridgeton area, average concentrations of carbon tetrachloride and chloroform exceeded ATSDR's CREG. NTP lists carbon tetrachloride as reasonably anticipated to be a human carcinogen, based on studies showing inhalation and other routes of exposure to carbon tetrachloride can cause liver and mammary gland tumors in animals [NTP 2016]. NTP lists chloroform as reasonably anticipated to be a human carcinogen, based on studies showing chloroform can cause liver and kidney tumors in animals [NTP 2016]. Exposure routes causing liver and kidney tumors in animals include inhalation.

- Average concentrations of carbon tetrachloride and chloroform were the same or similar in the Bridgeton and St. Charles areas. Carbon tetrachloride concentrations were slightly below 2013 national average concentrations [EPA 2018]. Concentrations of chloroform were below concentrations commonly detected in urban air [ATSDR 1997].

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].

- In 2013, the average concentration downwind of the landfill (1.2 ppb) exceeded the average concentration in ambient air at urban locations in the United States (0.26 ppb) [EPA 2018]. In 2014-2016, after completion of remedial actions at the landfill, annual average concentrations (0.10 ppb to 0.19 ppb) fell slightly below the national average concentration. Average concentrations upwind of the landfill (0.11 ppb in 2013-2016) and in the Bridgeton area (0.15 ppb to 0.16 ppb in 2014) were also slightly below the national average concentration.

Table 14. Chemicals Exceeding Cancer Risk Evaluation Guidelines Bridgeton and Surrounding Areas, 2013-2016

Chemicals Detected above CREG Values	Average Concentrations (ppb)		Typical Ambient Air Concentrations in the United States[a] (ppb)	ATSDR CREG (ppb)
MDNR SUMMA® Canister Sampling[b]				
	Upwind	***Downwind***		
Acetaldehyde	0.48	0.48	0.90	0.25
Formaldehyde	0.94	0.95	2.61	0.063
1,2-Dichloroethane	0.03	0.02	0.1-1.5	0.0095
Benzene 2013-2016	0.11	0.39	0.26	0.04
2013	0.20	1.2		
2014	0.06	0.19		
2015	0.11	0.10		
2016	0.11	0.19		
EPA SUMMA® Canister Sampling[c]				
	Background	***Bridgeton***		
Benzene	0.15	0.16	0.26	0.04
Carbon Tetrachloride	0.07	0.07	0.09	0.0089
Chloroform	0.02	0.05	0.2-0.5	0.029

[a]Concentrations of acetaldehyde, formaldehyde, benzene, and carbon tetrachloride are 2013 national average ambient air concentrations reported by EPA [EPA 2018]. Concentrations of 1,2-dichloroethane and chloroform are concentration ranges in common in urban environments [ATSDR 2001].
[b]Concentrations of acetaldehyde and formaldehyde are 4-month averages of 4-hour concentrations in samples collected upwind and downwind of the landfill on 20 days in April-August 2013. Concentrations of 1,2-dichloroethane and benzene are 4-year averages of 4-hour concentrations in samples collected upwind and downwind of the landfill on 198 days in 2013-2016. Also shown for benzene are annual averages of 4-hour concentrations in samples collected upwind and downwind of the landfill.
[c]Concentrations are averages of 24-hour concentrations in weekly samples collected in May-December 2014. Air samples were collected up to 1 mile from the landfill and in a "background" location in St. Charles County 2.3 miles from the landfill.

5.4.2 Estimated Cancer Risk of Lifetime Exposure to Benzene in Ambient Air

CREG values are concentrations estimated to pose increased cancer risks of no more than 1×10^{-6}. 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. An estimated 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.

Of the chemicals that exceeded their CREG values, only benzene was detected at concentrations that exceeded typical ambient air concentrations in urban environments in the United States. However, annual average concentration trends indicate that benzene emissions were mitigated by remedial actions at the landfill in 2013-2014 and that those exceedances were temporary. Over the long-term, people living or working near the landfill are likely breathing concentrations of

VOCs in ambient air that are similar to typical urban air concentrations. Current cancer risks from breathing VOCs are, therefore, expected to be similar to those in other urban environments in the United States.

Lifetime exposure to typical benzene concentrations in ambient air in urban areas in the United States poses an estimated slight increased risk of 6.5×10^6, or approximately 7 excess cancer cases in a population of 1 million (Appendix F). That value is considered to represent a low level of increased risk (i.e., risk that is in addition to the risk of developing cancer due to other reasons). For comparison, the American Cancer Society estimates that slightly more than a third of men and women in the United States (i.e., approximately 38.4%) will develop some form of cancer in their lifetimes [ACS 2018].[34] In other words, typical urban air concentrations of benzene (like what is expected at this area) could raise the chances of developing cancer by 0.0007%.

Cancer risk factors 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]. While cancer risk estimates assume that continuous exposures to much lower concentrations of benzene could also cause cancer, the true or actual 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 in 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 in 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 health effects of breathing mixtures of malodorous chemicals are not well 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

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

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 (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, 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 recommends that individuals seek medical advice 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 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 expects that odors more likely persist in areas around the landfill and more likely affect people in neighborhoods adjacent to the landfill when winds are relatively calm. Atmospheric conditions tend to be more stable in the early morning, evening, and nighttime hours. Odors may become more dilute and less intense and travel a longer distance from the landfill when the winds are stronger. Individuals are advised to seek medical advice for acute symptoms and symptoms that do not subside when the odors dissipate.

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 increased susceptibility to infection, increased severity of infectious diseases, 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.

Individuals are advised to seek out ways to manage their stress as much as possible. 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 Health Considerations

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.

Children exposed to sulfur-based compounds emitted from the landfill may have been at increased risk of acute respiratory illness or development of chronic respiratory disease, such as asthma. Children with asthma or other chronic respiratory disease may have been especially sensitive to emissions of those chemicals and their odors. Children with asthma may have been at greater risk of experiencing respiratory discomfort or more frequent and severe asthma attacks. In several studies in other communities, airborne particulates and a variety of chemicals including sulfur-based compounds in air have been implicated in adverse health outcomes in children.

6 COMMUNITY HEALTH CONCERNS

Since February 2013, MDHSS has 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 have also worked to ensure public safety in the event that gas emissions from the landfill approach levels that threaten public health. This has involved regular interagency meetings and development of response plans. Much time has also been devoted to addressing public and individual community members' health concerns. MDHSS and MDNR have fielded phone calls and emails from community

members and have 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 have been 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 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

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 and, therefore, have been the subject of many toxicological studies, including the primary studies of ATSDR and EPA's screening levels 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 recommends 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 appropriate for elderly adults and children?

As a first step in evaluating chemical exposures, MDHSS compares chemical concentrations to health-based screening levels established by ATSDR, EPA, and other government agencies. Concentrations at or below screening levels are unlikely to cause adverse health effects and can reasonably be considered to be no risk or very low risk to people's health. Concentrations that exceed screening levels do not necessarily pose health threats but indicate the need for further investigation.

Health-based screening levels are based on data from numerous animal laboratory studies, clinical studies, and/or documented occupational exposures. 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 are below concentrations that might cause adverse health effects in humans, including sensitive individuals such as children or elderly adults.

Often multiple health-based 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 developed by ATSDR, EPA, and (for evaluation of acute effects) Cal EPA.

Is increased stress a public health concern at the site?

Community members living or working near the landfill have 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 lead to stress-related illnesses, as discussed in the *Landfill Odors* and *Stress* sections of this health consultation.

7 UNCERTAINTIES AND LIMITATIONS

MDHSS has 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 have been 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 be included in standard analytical methods or may be present in ambient air at concentrations below instrument detection or laboratory reporting limits. In addition, because the landfill is located in an urban environment, multiple emissions sources likely contribute low concentrations of a variety of chemicals in the air.

- MDHSS has used conservative health-based screening levels 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, the detection limits of the AreaRAE® H_2S and SO_2 monitors exceed many screening levels for H_2S and SO_2. This precludes a detailed assessment of the public health impacts of breathing sulfur-based compounds in ambient air, especially among sensitive individuals.
- The AreaRAE® H_2S monitors 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 refers to the AreaRAE® H_2S sensor measurements as combined RSC concentrations.
- Because AreaRAE® monitors detect concentrations in 100 ppb increments, the AreaRAE® measurements may differ from actual concentrations of chemical concentrations in the ambient air.
- MDNR located its AreaRAE® monitors near the landfill (i.e., a few hundred feet to approximately ½ mile from the landfill) to capture the highest concentrations of chemical emissions from the landfill. This health consultation assumes 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.
- The AreaRAE® monitors near the landfill may have not always captured maximum gas concentrations emitted from the landfill flares. Landfill gases including SO_2 released from landfill flares at higher elevations may have bypassed the AreaRAE® monitors.
- 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, chemical concentrations may have been highest. Those results may, therefore, represent worst-case exposure levels during those time periods, not what everyone in the area was breathing during the day.
    - However, spikes in emissions, which may or may not be associated with transient odors, may have been missed. 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 do not represent worst-case conditions.

- Weather conditions may periodically interfere with the AreaRAE® monitor readings. High humidity levels can cause false positive readings or fog the monitor lamp and cause decreased sensitivity. MDNR uses handheld meters to try to confirm false positive AreaRAE® readings. MDHSS does not evaluate AreaRAE® monitor readings that MDNR has determined to be invalid.

Screening Level Limitations

- Health-based screening levels 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.
- Because screening levels are not available for many RSCs, concentrations of combined RSCs were compared to screening levels for H_2S, a minor component of the landfill source gas (1.6%). Comparison of combined reduced sulfur concentrations to screening levels for H_2S 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.
- Combined RSC concentrations detected by the AreaRAE® monitors in ambient air near the landfill exceeded some RSC concentrations associated in community studies with adverse respiratory and neurological effects. Whether RSC emissions from the landfill pose health risks similar to those observed at other sites remains uncertain, however, as the composition of the landfill gas differs from the distribution of RSCs in ambient air in those communities, and the relative toxicities of individual RSCs are not well understood.
- 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 is confident that the data collected and evaluated in this health consultation is of sufficient quantity and quality to make several important conclusions and recommendations on exposure to chemicals in ambient air near the landfill.

8 CONCLUSIONS

MDHSS has reached the following conclusions in this health consultation:

Conclusion 1

In the past, 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 remedial work at the landfill.

Since 2013, MDNR has 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 have been detected at or above 100 ppb (the lower detection limit of AreaRAE® monitors), exceeding many conservative guidelines based on respiratory or neurological effects and sometimes exceeding concentrations shown in clinical studies to cause adverse respiratory effects. Maximum concentrations of combined RSCs detected by AreaRAE® monitors near the landfill have been as high as 3,700 ppb. Maximum concentrations of SO_2 detected by AreaRAE® monitors near the landfill have been 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 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.

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 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). In 2016, the frequency of detection of sulfur-based compounds had decreased by approximately 74% (combined RSCs) and 64% (SO_2).

Conclusion 2

In the past, 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. 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.

Landfill gases can have objectionable odors at low concentrations. Bridgeton area residents have frequently complained about noxious odors emanating from the landfill. MDNR has also occasionally reported offensive odors in the vicinity of the landfill, most frequently before implementation of corrective measures in 2013-2014 to control the landfill gas and odor emissions.

A variety of chemicals produced by the decomposition of organic matter in the landfill likely contributes to those odors. Sulfur-based compounds have relatively low odor thresholds and could be responsible for much of the odor. In numerous community studies, 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 have also been associated with increased risk of acute respiratory infection (common cold, bronchitis).

Conclusion 3

Currently, fugitive emissions from the landfill have decreased significantly, and breathing sulfur-based compounds in ambient air near the landfill is unlikely to harm people's health. However, the odors of low concentrations of sulfur-based compounds may occasionally affect the health or quality of life of people living or working near the landfill.

From 2013 to 2016, the frequency of detection of combined RSCs in ambient air near the landfill significantly decreased. In 2016, 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 critical clinical study to cause adverse respiratory effects in people with asthma (2,000 ppb).

From 2013 to 2016, the frequency of detection of SO_2 in ambient air near the landfill also decreased. In 2016, maximum SO_2 concentrations detected by MDNR's AreaRAE® monitors occasionally met or exceeded a concentration shown in a critical 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 ambient 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. During that year, the 99th percentile of daily maximum 1-hour average SO_2 concentrations at that location was 14 ppb, similar to the results from other monitoring stations in

St. Louis County and well below EPA's primary NAAQS for SO_2 (75 ppb). Twenty-four hour average SO_2 concentrations at that location (≤3.4 ppb) were also below the World Health Organization's 24-hour Air Quality Guideline (7.6 ppb).

From 2013 to 2016, the frequency with which MDNR detected odors in the vicinity of the landfill decreased by more than 80%, and their frequency of detection of sulfur-based compounds at concentrations at which individuals may perceive bothersome odors (≥100 ppb) decreased by 74%. Still, the odors of RSCS may occasionally be objectionable, especially during periods of construction or other invasive work at the landfill or in instances of landfill equipment malfunction.

Conclusion 4

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

Since 2013, MDNR has overseen 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 ambient air [e.g., aldehydes, amines, carboxylic acids, dioxins/furans, fixed gases, PAHs, and VOCs, in addition to sulfur-based compounds]. Some aldehydes and VOCs were occasionally detected at concentrations exceeding health-based screening levels and were selected for further investigation. Because they are common landfill gases that can be toxic at low concentrations, carbon monoxide (as well as sulfur-based compounds) was also selected for further investigation.

Since 2013, MDNR has conducted routine air sampling upwind and downwind of the landfill to determine the concentrations of aldehydes and VOCs (as well as sulfur-based compounds) in ambient air. In three samples collected a few hundred feet downwind of the landfill in 2013-2014, benzene concentrations exceeded conservative health-based guidelines for immunological effects. During routine surveillance with hand-held meters, MDNR also occasionally detected benzene at concentrations exceeding health-based guidelines. However, benzene concentrations were well below levels that might be expected to cause those effects. Concentrations of carbon monoxide measured by AreaRAE® monitors near the landfill did not exceed health-based guidelines.

MDHSS also evaluated the potential health effects of multiple chemical exposures. Exposure to low concentrations of multiple chemicals can have combined adverse health effects if they target the same tissue or organ. Many VOCs that may jointly target the respiratory or neurological systems have been detected in ambient air near the landfill. However, concentrations of those chemicals were below levels expected to significantly increase the adverse effects of sulfur-based chemicals on those systems.

Downwind of the landfill, concentrations of four VOCs (carbon disulfide, ethanol, ethylbenzene, propene) and one aldehyde (valeraldehyde) occasionally exceeded their odor thresholds.

Conclusion 5

Current cancer risks from breathing VOCs near the landfill are similar to those in other urban environments in the United States. Over the long term, people living or working near the landfill are likely breathing ambient air concentrations similar to national average concentrations.

Average concentrations of acetaldehyde, formaldehyde, 1,2-dichloroethane, and benzene in ambient air near the landfill and average concentrations of benzene, carbon tetrachloride, and chloroform in ambient air in the Bridgeton area exceeded ATSDR's CREG values. CREG values are screening level values that represent concentrations expected to result in 1 excess cancer case in a population of 1 million.

Of those chemicals detected in ambient air from the landfill, only benzene was detected at higher concentrations downwind than upwind of the landfill and at concentrations exceeding typical ambient air concentrations in the United States. In 2013, the average concentration downwind of the landfill (1.2 ppb) exceeded the average concentration in ambient air at urban locations in the United States (0.26 ppb). However, in 2014-2016, after completion of remedial actions at the landfill, annual average benzene concentrations downwind of the landfill fell below the national average concentration and were similar to upwind concentrations. Lifetime exposure to typical benzene concentrations in ambient air in urban areas in the United States poses an estimated slight increased risk of approximately 7 excess cancer cases in a population of 1 million.

9 RECOMMENDATIONS

1. MDHSS recommends 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 recommends 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 recommends 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 in turn can lead to a variety of health issues including anxiety, mental depression, impaired immune responses, or increased inflammatory responses.

4. MDHSS recommends 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 recommends that responsible parties continue gathering air data in the Bridgeton area while the SSE and/or remedial work on the landfill continues to occur. Future data should 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.

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 the MDHSS, the 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 sampling data collected by MDNR or other agencies as they become available or as appropriate.

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

11 REFERENCES

[ACS] American Cancer Society. 2018. Lifetime risk of developing or dying from cancer. [updated 2018 January 4; accessed 2018 January]. Available online at: https://www.cancer.org/cancer/cancer-basics/lifetime-probability-of-developing-or-dying-from-cancer.html

Arizona Instrument LLC. 2013. Jerome® J605 hydrogen sulfide analyzer: operation manual. www.azic.com

[AIHA] American Industrial Hygeine Association. 1996. Emergency Response Planning Guideline (ERPG) for dimethyl disulfide. www.aiha.org

[AIHA] American Industrial Hygeine Association. 1999. Emergency Response Planning Guideline (ERPG) for methyl mercaptan. www.aiha.org

[AIHA] American Industrial Hygeine Association. 2004. Emergency Response Planning Guideline (ERPG) for dimethyl sulfide. www.aiha.org

[AIHA] American Industrial Hygeine Association. 2013. Odor thresholds for chemicals with established health standards. 2nd Edition. Fairfax, VA: American Industrial Hygeine Association.

Amoore JD. 1985. The perception of hydrogen sulfide odor in relation to setting an ambient standard. California Air Resources Board. Contract A4-046-33. Available online at http://www.arb.ca.gov/research/apr/past/a4-046-33.pdf

[ATSDR] Agency for Toxic Substances and Disease Registry. 1997. Toxicological profile for chloroform. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 1998. Toxicological profile for sulfur dioxide. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 1999. Toxicological profile for formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2001. Toxicological profile for 1,2-dichloroethane. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2001. Landfill gas primer: an overview for environmental health professionals. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services. Available online at https://www.atsdr.cdc.gov/hac/landfill/html/intro.html

[ATSDR] Agency for Toxic Substances and Disease Registry. 2005. Public health assessment guidance manual (update). Atlanta: U. S. Department of Health and Human Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2007. Toxicological profile for benzene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2010. Addendum to the Toxicological profile for formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2014a. Draft toxicological profile for hydrogen sulfide and carbonyl sulfide. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2014b. Environmental odors. Atlanta, GA [updated 2014 April 24; accessed 2015 August 25]. Available online at: http://www.atsdr.cdc.gov/odors

[ATSDR] Agency for Toxic Substances and Disease Registry. 2014c. Draft toxicological profile for tetrachloroethylene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2015. West Lake Landfill Operable Unit 1: an evaluation of radiation in groundwater and air. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services.

Brenneman et al. 2000. Olfactory neuron loss in adult male CD rates following subchronic inhalation exposure to hydrogen sulfide. Toxicol Pathol 28(2):326-333.

[Cal EPA] California Environmental Protection Agency. 2000. Hydrogen sulfide: evaluation of current California air quality standards with respect to protection of children.

[Cal EPA] California Environmental Protection Agency. 2008. Technical support document for the derivation of noncancer reference exposure levels. Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment (OEHHA), Oakland, California. Available online at: www.oehha.ca.gov

Campagna D et al. 2004. Ambient hydrogen sulfide, total reduced sulfur, and hospital visits for respiratory diseases in northeast Nebraska, 1998-2000. J Expo Anal Environ Epidemiol 14: 180-187.

Cavalerri et al. 1994. Perchloroethylene exposure can induce colour vision loss. Neurosci Lett 179:162-166.

Clark NA et al. 2010. Effect of early life exposure to air pollution on development of childhood asthma. Environ Health Perspect 118(2): 284-290.

[EPA] U. S. Environmental Protection Agency. 1992. Reference guide to odor thresholds for hazardous air pollutants listed in the Clean Air Act amendments of 1990. Washington, D.C.: Office of Research and Development. EPA/600/R-92/047. March 1992.

[EPA] U. S. Environmental Protection Agency. 2003. Toxicological review of hydrogen sulfide: In support of summary information on the integrated risk information system (IRIS). EPA/635/R-03/005. June 2003.

[EPA] U.S. Environmental Protection Agency. 2010. Primary national ambient air quality standard for sulfur dioxide. Final Rule. Federal Register Vol. 75, Number 119.

[EPA] U.S. Environmental Protection Agency. 2013. Use of dioxin TEFs in calculating dioxin TEQs at CERCLA and RCRA sites. May 2013.

[EPA] U.S. Environmental Protection Agency. 2014. Air quality index: a guide to air quality and your health. EPA-456/F-14-002. February 2014.

[EPA] U.S. Environmental Protection Agency. 2015. National Priorities List (NPL) site narrative for West Lake Landfill. Washington, DC [updated 2015 December 29; accessed 2016 January 6]. Available online at: www.epa.gov/superfund/sites/npl/nar1289

[EPA] U.S. Environmental Protection Agency. 2016. AirNow: the air quality index. Washington DC [updated 2016 January; accessed 2016 January]. Available online at http://www.airnow.gov

[EPA] U.S. Environmental Protection Agency. 2017a. Toxic Release Inventory (TRI) list of toxic chemicals. Washington, DC [updated 2017 January 12; accessed 2017 January]. Available online at https://www.epa.gov/toxics-release-inventory-tri-program

[EPA] U.S. Environmental Protection Agency. 2017b. Ambient concentrations of selected air toxics. Washington, DC [accessed 2017 January]. Available online at: https://cfpub.epa.gov/roe/indicator.cfm?i=90

[EPA] U.S. Environmental Protection Agency. 2018. Report on the environment. Washington, DC [updated 2017 July 28; accessed 2018 February]. Available online at https://www.epa.gov/roe/

Glaser R. and Kiecolt-Glaser J.K. 2005. Stress-induced immune dysfunction: implications for health. Nat Rev Immun 5(3):243-251.

Greenberg et al. 2013. The perception of odor is not a surrogate marker for chemical exposure: a review of factors influencing human odor perception. Clinical Toxicol. 51:70-76.

Guidotti TL. 1994. Occupational exposure to hydrogen sulfide in the sour gas industry: some unresolved issues. Int Arch Occup Environ Health 66:153-160.

Haahtela et al. 1992. The South Karelia air pollution study: acute health effects of malodorous sulfur air pollutants released by a pulp mill. Am J Public Health 82:603-605.

Heaney CD et al. 2011. Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill. Environ Res 111: 847-852.

Ito et al. 2007. Characterization of $PM_{2.5}$, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. J Expo Sci Envrion Epidemiol 17(2): S45-60.

Jaakkola et al. 1991. Low level air pollution and upper respiratory effects in children. Am J Public Health 81(8): 1060-1063.

Jaakkola et al. 1999. The South Karelia air pollution study: changes in respiratory health in relative to emission reduction of malodorous sulfur compounds from pulp mills. Arch Environ Health 54(4): 254-263.

Jappinen et al. 1990. Exposure to hydrogen sulfide and respiratory function. Br J Intern Med 47:824-828.

Kilburn, KH. 2012. Human impairment from living near confined animal (hog) feeding operations. J. Environ. Public Health 2012, 565690.

Kilburn KH and Warshaw RH. 1995. Hydrogen sulfide and reduced sulfur gases adversely affect neurophysiological functions. Toxicol Ind Health 11(2): 185-197.

Kilburn et al. 2010. Low-level hydrogen sulfide and central nervous system dysfunction. Toxicol Ind Health 26(7):387-405.

Legator et al. 2001. Health effects from chronic low-level exposure to hydrogen sulfide. Arch Environ Health 56(2): 123-131.
Liu et al. 2014. Ammonia and hydrogen sulfide emissions from swine production facilities in North America: a meta-analysis. J Anim Sci 92: 1656-1665.

Marttila et al. 1994. Sourth Karelia air pollution study: the effects of malodorous sulfur compounds from pulp mills on respiratory and other symptoms in children. Environ Res 66:152-159.

Marttila et al. 1995. South Karelia air pollution study: daily symptom intensity in relation to exposure levels of malodorous sulfur compounds from pulp mills. Environ Res 71: 122-127.

[MDNR] Missouri Department of Natural Resources (MDNR). 2014. Site Background - Bridgeton Sanitary Landfill. MDNR Solid Waste Management Program, Jefferson City, MO [updated 2014 September 28; accessed 2014 December]. Available online at: www.dnr.mo.gov/bridgeton.

[MDNR] Missouri Department of Natural Resources (MDNR). 2017. Common air pollutants. MDNR Air Pollution Control Program, Jefferson City, MO [updated 2017 June 19; accessed 2017 June]. Available online at: https://dnr.mo.gov/env/apcp/airpollutants.htm.

Miner, JR. 1980. Controlling odors from livestock production facilities: state-of-the-art. Livestock waste, a renewable resource. American Society of Agricultural Engineers, St. Joseph, MI: 297-301.

[NTP] National Toxicology Program. 2016. Report on carcinogens, fourteenth edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. https://ntp.niehs.nih.gov/pubhealth/roc/index-1.html

[NYDOH] New York State Department of Health. 2006. A study of ambient air contaminants and asthma in New York City. New York State Energy Research and Development Authority. May 2006.

[OSHA] Occupational Safety and Health Administration. 2007. Chemical sampling information for dimethyl sulfide. United States Department of Labor. Available online at: www.osha.gov

Partti-Pellinen et al. 1996. The South Karelia air pollution study: effects of low-level exposure of malodorous sulfur compounds on symptoms. Arch Environ Health 51(4):315-320.

Pohl et al. 2017. Modeling emissions from CAFO poultry farms in Poland and evaluating potential risk to surrounding populations. Regul Toxicol Pharmacol 84:18-25.

RAE Systems. 2010. UltraRAE 3000 user's guide, revision 3. www.raesystems.com

RAE Systems. 2015. Technical note TN-114: Sensor specifications and cross-sensitivities. [updated 2015 May 8; accessed 2015 December] Available online at: www.raesystems.com

Rosenthal GJ and Snyder CA. 1987. Inhaled benzene reduces aspects of cell-mediated tumor surveillance in mice. Toxicol Appl Pharmacol 88: 35-43.

Rozen MG et al. 1984. Depression in B- and T-lymphocyte mitogen-induced blastogenesis in mice exposed to low concentrations of benzene. Toxicol Lett 20: 343-349.

Ruth JH. 1986. Odor thresholds and irritation levels of several chemical substances: a review. Am Ind Hyg Assoc J 47:142-151.

Schiffman SS, Williams CM. 2005. Science of odor as a potential health issue. J Environ Qual 34: 129-138.

Schiffman SS et al. 1995. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Res Bull 37(4): 369-375.

Schiffman SS et al. 2000. Potential health effects of odor from animal operations, wastewater treatment, and recycling of byproducts. J. Agromedicine 7(1): 7-81.

Schwartz J. 1995. Short-term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. Thorax 50:531-538.

Sheppard et al. 1981. Exercise increases sulfur dioxide – induced bronchoconstriction in asthmatic subjects. Am Rev Respir Dis 123: 486-491.

[SLCDPH] St. Louis County Department of Public Health. 2016. Community Respiratory Health Survey to Compare Residents near Bridgeton Landfill and Matched Populations in St. Louis County, Missouri. June 2016. Available online at: https://www.stlouisco.com/

Tansy et al. 1981. Acute and subchronic toxicity studies of rats exposed to vapors of methyl mercaptan and other reduced-sulfur compounds. J Toxicol Environ Health 8:71-88.

Tetra Tech 2015a. Interim data summary of AreaRAE measurements during ongoing baseline off-site air monitoring: West Lake Landfill site, Bridgeton, Missouri. Superfund Technical Assessment and Response Team 4, Kansas City, MO. March 2015.

Tetra Tech. 2015b. Interim data summary of ongoing baseline off-site air monitoring via sampling for volatile organic compounds and HYDROGEN SULFIDE by application of passive/diffusive sampling methods: West Lake Landfill site, Bridgton, Missouri. Superfund Technical Assessment and Response Team 4, Kansas City, MO. May 2015.

Tétreault et al. 2016. Childhood exposure to ambient air pollutants and the onset of asthma: an administrative cohort study in Québec. Environ Health Perspect 124(8): 1276-1282.

Thalhamer, T. 2015. Expert Opinion of the Bridgeton Sanitary Landfill Incident. September 2015. Available online at: www.dnr.mo.gov/bridgeton

U.S. Census Bureau. 2010. Census 2010, Bridgeton, Missouri. [accessed October 2013]. Available online at: http://www.census.gov/

Vahlkamp T et al. 1979. Inhibition of mitochondrial electron transfer in rats by ethanethiol and methanethiol. Clinical Science 56:147-156.

[WHO] World Health Organization. 2006. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: summary of risk assessment. Global update 2005. Available online at: http://apps.who.int/iris/

12 REPORT PREPARATION

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 under a cooperative agreement [*Funding Opportunity CDC-RFA-TS17-1701*] with the federal Agency for Toxic Substances and Disease Registry (ATSDR). The 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.

Author

Elizabeth Semkiw, PhD
Senior Epidemiology Specialist
Bureau of Environmental Epidemiology
Section for Environmental Public Health
Division of Community and Public Health
Missouri Department of Health and Senior Services

State Reviewers

Jeff Wenzel, Bureau Chief
Bureau of Environmental Epidemiology
Section for Environmental Public Health
Division of Community and Public Health
Missouri Department of Health and Senior Services

Jonathan Garoutte, Administrator
Section for Environmental Public Health
Division of Community and Public Health
Missouri Department of Health and Senior Services

ATSDR Cooperative Agreement Coordinator and Technical Project Officer

Trent D. LeCoultre, MSEH, REHS, CPH
CDR, US Public Health Service
Cooperative Agreement Coordinator (Acting)
Division of Community Health Investigations

Laura Frazier, MS
Technical Project Officer
Division of Community Health Investigations

ATSDR Regional Representative

Erin Evans, MPH
LCDR, U.S. Public Health Service
Regional Representative, ATSDR Region 7

APPENDICES

Appendix A: Comprehensive Sampling Results
Appendix B: Wind Rose Plot
Appendix C: Calculation of an Odor-Based Screening Level for RSCs
Appendix D: Ambient Air Monitoring and Sampling Results
Appendix E: Evaluation of Multiple Chemical Exposures
Appendix F: Cancer Risk Calculations

Appendix A: Comprehensive Sampling Results

In 2013-2016, 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, fixed gases, 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 fixed 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:

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

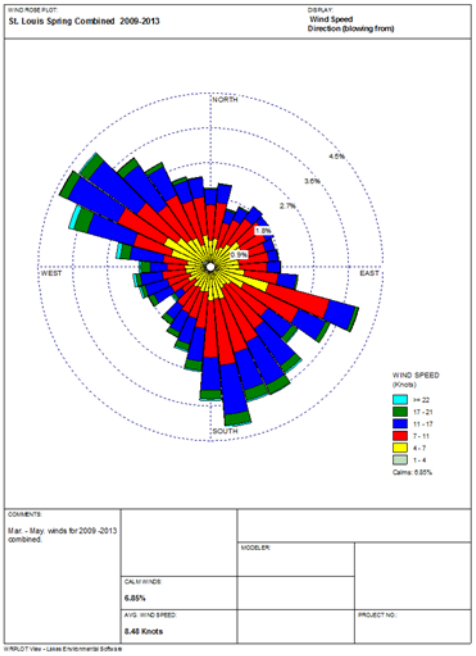
where TEQ = toxicity equivalence
TEF = toxicity equivalency factor for each compound

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

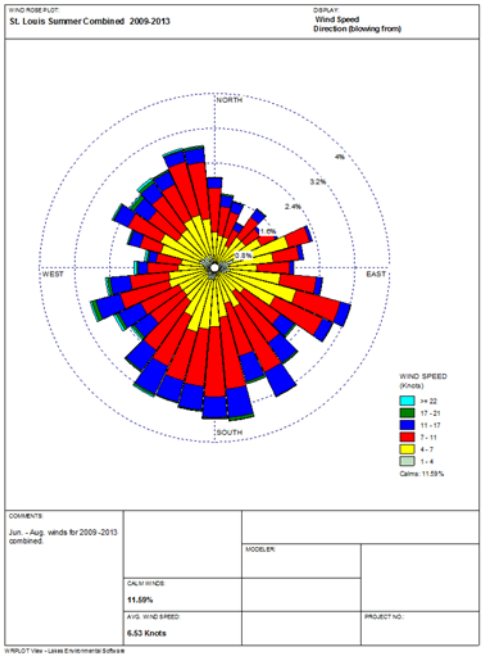
Chemical/ Chemical Group	Range of Concentrations[a]	Screening Levels Available ?	Screening Level Exceedances ?	Screening Level Exceedances[b]				
				Chemical	Upwind Concentration (ppb)	Downwind Concentration (ppb)	Screening Level (ppb)	Number of Exceedances
Aldehydes	ND - 11.0	Yes[c]	Yes	Formaldehyde	0.8-9.4	0.6-11.0	7 Cal EPA REL (8 hr)	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
Fixed 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	0.009 EPA RfC	3 upwind 7 downwind
				Benzene	ND-0.61	ND-21.8	3 EPA RfC	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	0.22 cancer RSL	4 upwind 5 downwind
				Naphthalene	ND	ND-0.25	0.02 cancer RSL	3 downwind
				Trichloroethylene	ND-0.23	ND-0.23	0.041 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 individuals chemicals that exceeded available health-based screening levels in samples collected downwind of the landfill. Shown are upwind and downwind concentrations 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.

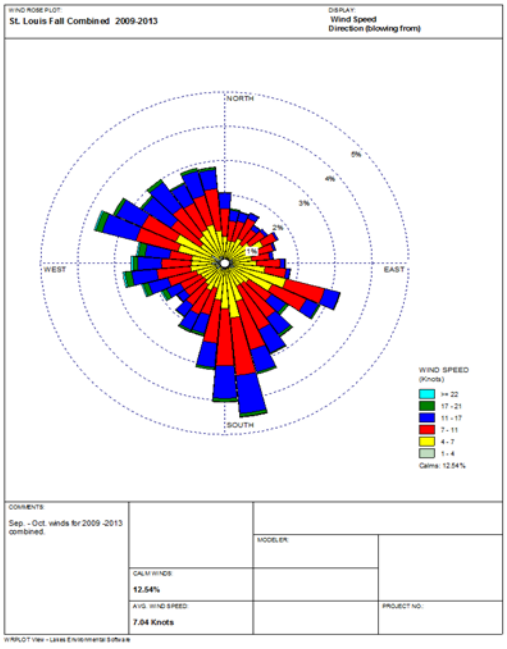
Appendix B: Wind Rose Plots



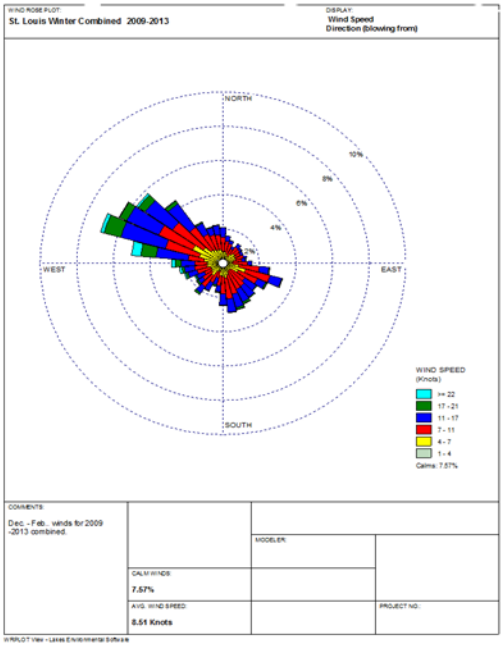
Spring Wind Rose Plot (source: MDNR)



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 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.
[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:

Threshold Level = (0.765 × 500 ppb) + (0.082 × 10 ppb) + (0.048 × 5 ppb) + (0.105 × 5 ppb)

= 385 ppb

Appendix D: Ambient Air Monitoring and Sampling Results

Table D-1: Number of Exceedances of Short-term Screening Levels and Odor Thresholds
MDNR Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2016

Chemical	Range of Concentrations (ppb)	Health-Based Screening Levels[a]		Odor Threshold[b] (ppb)	Number of Exceedances	
		Acute (ppb)	Intermediate (ppb)		Screening Levels	Odor Threshold
Aldehydes in Sorbent Tube Samples[c]						
Acetaldehyde	ND-5.2	260 Cal EPA REL	160 (8-hr) Cal EPA REL	67 EPA GM	Not exceeded	Not exceeded
Acetone	0.9-7.3	26,000 ATSDR MRL	13,000 ATSDR MRL	400 AIHA Low	Not exceeded	Not exceeded
Acrolein	ND	1 Cal EPA REL	0.04 ASTDR MRL	1,800 EPA GM	Below RL	Not exceeded
Benzaldehyde	ND-1.3	N/A	N/A	1.5 AIHA Low	N/A	Not exceeded
Crotonaldehyde	ND-4.0	N/A	N/A	20 AIHA Low	N/A	Not exceeded
Formaldehyde	ND-11.2	40 ATSDR MRL	7 (8-hr) Cal EPA REL	27 AIHA Low	1 (REL) (upwind)	Not exceeded
Hexaldehyde	ND-34.0	N/A	N/A	N/A	N/A	N/A
MEK & Butyraldehyde	ND-5.8	4,500 Cal EPA REL for MEK	N/A	17,000 EPA GM for MEK	Not exceeded	Not exceeded
Methacrolein	ND-0.4	N/A	N/A	N/A	N/A	N/A
m-Tolualdehyde	ND-3.0	N/A	N/A	N/A	N/A	N/A
Propionaldehyde	ND-2.8	N/A	N/A	40 EPA GM	N/A	Not exceeded
Valeraldehyde	ND-10.8	N/A	N/A	0.4 AIHA Low	N/A	2 (upwind, downwind)
Benzene and H_2S Measured with Hand-held Meters during Routine Surveillance[d]						
Benzene	ND-500	9 ATSDR MRL	6 ATSDR MRL	61,000 EPA GM	Below DL	Not exceeded
Hydrogen Sulfide	ND-45.5	30 Cal EPA REL 70 ATSDR MRL	20 ATSDR MRL	0.5-10 Low Range	1 Acute REL 4 Inter. MRL	Often within low range
Carbon Monoxide Detected by AreaRAE® Monitors[e]						
Carbon Monoxide	ND-13.2	20,000 Cal EPA REL	N/A	N/A	Not exceeded	N/A
Sulfur-Based Compounds Detected by AreaRAE® Monitors[f]						
Combined Reduced Sulfur Compounds	ND-3,700	70 ATSDR MRL for hydrogen sulfide	20 ATSDR MRL for hydrogen sulfide	385 MDHSS	Below DL	656
Sulfur Dioxide	ND-1,600	10 ATSDR MRL	N/A	330 AIHA Low	Below DL	20
Sulfur Dioxide Detected by Pulsed-Fluorescence Monitors at Rider Trail-I-70[d]						
Sulfur dioxide	ND-16.5	75 1-hour NAAQS	N/A	330 AIHA	Not exceeded	Not exceeded
Sulfur Based Compounds in SUMMA® Canister Samples[g]						
2-Methylthiophene	ND	N/A	N/A	N/A	N/A	N/A

Chemical	Range of Concentrations (ppb)	Health-Based Screening Levels[a]		Odor Threshold[b] (ppb)	Number of Exceedances	
		Acute (ppb)	Intermediate (ppb)		Screening Levels	Odor Threshold
3-Methylthiophene	ND	N/A	N/A	N/A	N/A	N/A
Bromothiophene	ND	N/A	N/A	N/A	N/A	N/A
Carbon Disulfide	ND	1,990 Cal EPA REL	N/A	16 AIHA Low	Not exceeded	Below RL
Carbonyl Sulfide	ND	70 ATSDR MRL*	20 ATSDR MRL*	100 EPA GM	Not exceeded	Not exceeded
Diethyl Disulfide	ND	N/A	N/A	N/A	N/A	N/A
Diethyl Sulfide	ND	N/A	N/A	N/A	N/A	N/A
Dimethyl Disulfide	ND	N/A	N/A	0.3 AIHA Low	N/A	Below RL
Dimethyl Sulfide	ND	N/A	N/A	0.12 AIHA Low	N/A	Below RL
Ethyl Mercaptan	ND	N/A	N/A	0.01 AIHA Low	N/A	Below RL
Hydrogen Sulfide	ND	70 ATSDR MRL	20 ATSDR MRL	0.5-10 Low Range 30 CAAQS	Not exceeded	Below RL
Isobutyl Mercaptan	ND	N/A	N/A	N/A	N/A	N/A
Isopropyl Mercaptan	ND	N/A	N/A	N/A	N/A	N/A
Methyl Mercaptan	ND	N/A	N/A	5.1×10^{-10} AIHA Low	N/A	Below RL
Methylethylsulfide	ND	N/A	N/A	N/A	N/A	N/A
n-Butyl Mercaptan	ND	N/A	N/A	2.7×10^{-3} AIHA Low	N/A	Below RL
n-Propyl Mercaptan	ND	N/A	N/A	N/A	N/A	N/A
sec-Butyl Mercaptan	ND	N/A	N/A	N/A	N/A	N/A
Sulfur Dioxide	ND	10 ATSDR MRL	N/A	330 AIHA Low	Below RL	Not exceeded
tert-Butyl Mercaptan	ND	N/A	N/A	0.003 AIHA Low	N/A	Below RL
Tetrahydro-thiophene	ND	N/A	N/A	N/A	N/A	N/A
Thiophene	ND	N/A	N/A	N/A	N/A	N/A
Thiophenol	ND	N/A	N/A	N/A	N/A	N/A
Volatile Organic Compounds in SUMMA® Canister Samples[h]						
1,1,1-Trichloroethane	ND-0.5	2,000 ATSDR MRL	700 ATSDR MRL	385,000 EPA GM	Not exceeded	Not exceeded
1,1,2,2-Tetrachloroethane	ND	N/A	N/A	7,300 EPA GM	N/A	N/A
1,1,2-Trichloroethane	ND-0.1	N/A	N/A	N/A	N/A	Not exceeded
1,1-Dichloroethane	ND-0.2	N/A	N/A	49,000 AIHA Low	N/A	Not exceeded
1,1-Dichloroethene	ND-0.2	N/A	20 ATSDR MRL	277,000 AIHA Low	Not exceeded	Not exceeded
1,2,4-Trichlorobenzene	ND	N/A	N/A	2,960 AIHA Low	N/A	Not exceeded
1,2,4-Trimethylbenzene	ND-4.2	N/A	N/A	6 AIHA Low	N/A	Not exceeded
1,2-Dibromoethane	ND-0.2	N/A	N/A	10,000 AIHA Low	N/A	Not exceeded
1,2-Dichlorobenzene	ND-12	N/A	N/A	N/A	N/A	N/A

Chemical	Range of Concentrations (ppb)	Health-Based Screening Levels[a]		Odor Threshold[b] (ppb)	Number of Exceedances	
		Acute (ppb)	Intermediate (ppb)		Screening Levels	Odor Threshold
1,2-Dichloroethane	ND-1.6	N/A	N/A	26,000 EPA GM	N/A	Not exceeded
1,2-Dichloropropane	ND-2.7	50 ATSDR MRL	7 ATSDR MRL	260 EPA GM	Not exceeded	Not exceeded
1,3,5-Trimethylbenzene	ND-7.7	N/A	N/A	N/A	N/A	N/A
1,3-Butadiene	ND-1.7	300 Cal EPA REL	4 (8-hr) Cal EPA REL	450 EPA GM	Not exceeded	Not exceeded
1,3-Dichlorobenzene	ND-0.9	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	ND-3.4	2,000 ATSDR MRL	200 ATSDR MRL	120 EPA GM	Not exceeded	Not exceeded
1,4-Dioxane	ND-6.4	800 Cal EPA REL	200 ATSDR MRL	22,000 EPA GM	Not exceeded	Not exceeded
2,2,4-Trimethylpentane	ND-35	N/A	N/A	N/A	N/A	N/A
2-Butanone (MEK)	ND-910	4,500 Cal EPA REL	N/A	17,000 EPA GM	Not exceeded	Not exceeded
2-Hexanone	ND-1	N/A	N/A	24 AIHA Low	N/A	Not exceeded
2-Propanol (IPA)	ND-300	1,300 Cal EPA REL	N/A	1,000 AIHA Low	Not exceeded	Not exceeded
4-Ethyltoluene	ND-3.2	N/A	N/A	N/A	N/A	N/A
4-Methyl-2-Pentanone	ND-6.7	N/A	N/A	880 EPA GM	N/A	Not exceeded
Acetone	ND-1,400	26,000 ATSDR MRL	13,000 ATSDR MRL	400 AIHA Low	Not exceeded	2 (upwind)
Acrylonitrile	ND	100 ATSDR MRL	N/A	1,600 EPA GM	Not exceeded	N/A
Allyl Chloride	ND	N/A	N/A	480 AIHA Low	N/A	Not exceeded
Benzene	ND-32.5	9 ATSDR MRL	6 ATSDR MRL	61,000 EPA GM	3 (downwind)	Not exceeded
Benzyl Chloride	ND	46 Cal EPA REL	N/A	41 EPA GM	Not exceeded	Not exceeded
Bromodichloro-methane	ND	N/A	N/A	N/A	N/A	N/A
Bromoform	ND-0.62	N/A	N/A	190 AIHA Low	N/A	Not exceeded
Bromomethane	ND-0.29	50 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded	N/A
Carbon Disulfide	ND-18	1,990 Cal EPA REL	N/A	16 AIHA Low	Not exceeded	1 (downwind)
Carbon Tetrachloride	ND-0.24	300 Cal EPA REL	30 ATSDR MRL	250,000 EPA GM	Not exceeded	Not exceeded
Chlorobenzene	ND-12	N/A	N/A	1,300 EPA GM	N/A	Not exceeded
Chlorodifluoro-methane	0.32-0.66	N/A	N/A	2×10^8 AIHA Low	N/A	Not exceeded
Chloroethane	ND	15,000 ATSDR MRL	N/A	3,800 AIHA Low	Not exceeded	Not exceeded
Chloroform	ND-0.46	30 Cal EPA REL	50 ATSDR MRL	192,000 EPA GM	Not exceeded	Not exceeded
Chloromethane	ND-1.9	500 ATSDR MRL	200 ATSDR MRL	10 AIHA Low	Not exceeded	Not exceeded

Chemical	Range of Concentrations (ppb)	Health-Based Screening Levels[a]		Odor Threshold[b] (ppb)	Number of Exceedances	
		Acute (ppb)	Intermediate (ppb)		Screening Levels	Odor Threshold
cis-1,2-Dichloroethene	ND-1.9	N/A	N/A	4,300 AIHA Low	N/A	Not exceeded
cis-1,3-Dichloropropene	ND	N/A	8 ATSDR MRL	260 AIHA Low	Not exceeded	Not exceeded
Cyclohexane	ND-12	N/A	N/A	520 AIHA Low	N/A	Not exceeded
Dibromochloro-methane	ND	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoro-methane	ND-0.82	N/A	N/A	2×10^5 AIHA Low	N/A	Not exceeded
Dichlorofluoro-methane (Freon 12)	ND	N/A	N/A	N/A	N/A	N/A
Dichlorotetrafluoro-ethane (Freon 114)	ND	N/A	N/A	N/A	N/A	N/A
Ethanol	1-480	N/A	N/A	90 AIHA Low	N/A	5 (upwind) 2 (downwind)
Ethyl Acetate	ND-5.9	N/A	N/A	90 AIHA Low	N/A	No exceedance
Ethylbenzene	ND-3.7	5,000 ATSDR MRL	2,000 ATSDR MRL	2 AIHA Low	Not exceeded	2 (upwind) 2 (downwind)
Heptane	ND-4.0	N/A	N/A	410 AIHA Low	N/A	Not exceeded
Hexachloro-butadiene	ND	N/A	N/A	N/A	N/A	N/A
Hexane	ND-32	21,000 Cal EPA REL	N/A	426 AIHA Low	Not exceeded	Not exceeded
Methanol	7.3-70.1	21,000 Cal EPA REL	N/A	160,000 EPA GM	Not exceeded	Not exceeded
Methyl te-butyl ether	ND-0.8	2,000 ATSDR MRL	700 ATSDR MRL	30 AIHA Low	Not exceeded	Not exceeded
Methylene Chloride	ND-181	600 ATSDR MRL	300 ATSDR MRL	144,000 EPA GM	Not exceeded	Not exceeded
Propene	ND-12.1	N/A	N/A	10.1 AIHA Low	N/A	1 (downwind)
Styrene	ND-1.5	5,000 ATSDR MRL	N/A	150 EPA GM	Not exceeded	Not exceeded
Tetrachloro-ethylene (PCE)	ND-1.4	6 ATSDR MRL	6 ATSDR MRL	47,000 EPA GM	Not exceeded	Not exceeded
Tetrahydrofuran	ND-18	N/A	N/A	92 AIHA Low	N/A	Not exceeded
Toluene	ND-44	2,000 ATSDR MRL	N/A	2,800 EPA GM	Not exceeded	Not exceeded
Trans-1,2-dichloroethylene	ND-2.2	200 ATSDR MRL	200 ATSDR MRL	277,000 AIHA Low	Not exceeded	Not exceeded
Trans-1,3-dichloropropene	ND	N/A	8 ATSDR MRL	990 AIHA	Not exceeded	Not exceeded
Trichloroethylene (TCE)	ND-4.7	N/A	0.4 ATSDR MRL	82,000 EPA GM	3 (upwind)	Not exceeded
Trichlorofluoro-methane (Freon 11)	ND-1.0	N/A	N/A	5,000 AIHA Low	N/A	Not exceeded

Chemical	Range of Concentrations (ppb)	Health-Based Screening Levels[a]		Odor Threshold[b] (ppb)	Number of Exceedances	
		Acute (ppb)	Intermediate (ppb)		Screening Levels	Odor Threshold
Trichlorotrifluoro-ethane (Freon 113)	ND-0.2	N/A	N/A	N/A	N/A	N/A
Vinyl acetate	ND	N/A	10 ATSDR MRL	110 EPA GM	Not exceeded	Not exceeded
Vinyl bromide	ND	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	ND	500 ATSDR MRL	30 ATSDR MRL	203 AIHA Low	Not exceeded	Not exceeded
Xylenes (o-, m-, and p-xylene)	ND-12	2,000 ATSDR MRL	600 ATSDR MRL	730-5,400 EPA GM	Not exceeded	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
N/A = not available/not applicable; ND = not detected
Below DL, Below RL = the screening level or odor threshold is below the detection limit (DL) or typical laboratory reporting limit (RL); therefore, the number of exceedances is not known.
*screening levels for hydrogen sulfide

[a]The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR and Cal EPA. Screening levels are ATSDR's MRLs for acute (<14 days) or intermediate (2 weeks – 1 year) exposure and California EPA's RELs for acute or 8-hour exposure. Cal EPA 8-hr RELs apply to 8-hour exposures that may be repeated.

[b]Odor thresholds reported in the scientific literature can vary widely due to differences in experimental methodology and human variability. Shown for H_2S are low range of odor thresholds [Ruth 1986] and the 1-hour California Ambient Air Quality Standard (CAAQS) for H_2S. 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).

[c]Aldehyde concentrations are four-hour average concentrations in 80 ambient air samples collected by MDNR upwind or downwind of the landfill on 20 days in April-August 2013. The laboratory reporting limits were typically below 0.5 ppb.

[d]Benzene and H_2S concentrations are instantaneous concentrations measured twice per day by MDNR up to 2 miles from the landfill in 2013-2016. The detection limit of the Ultra RAE® meter used to measure benzene is 50 ppb. The detection limit of the Jerome® meter used to measure H_2S concentrations is 3 ppb.

[e]Carbon monoxide concentrations 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 2013-2016. The detection limit of the AreaRAE monitors is 100 ppb.

[f]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 2013-2016. The detection limit of the AreaRAE® monitors is 100 ppb.

[g]Sulfur-based compound concentrations are 45-minute to four-hour average concentrations in 116 ambient air samples collected by MDNR up to ½ mile upwind or downwind of the landfill on 20 days in April-August 2013 and on 18 days from April 2015 to December 2016. The laboratory reporting limits were typically below 20 ppb.

[h]VOC concentrations are four-hour average concentrations in 800 ambient air samples collected by MDNR up to ½ mile upwind or downwind of the landfill in 2013-2016. The laboratory reporting limits were typically below 1 ppb.

Table D-2: Exceedance of Chronic and Cancer Screening Levels
MDNR Ambient Air Monitoring/Sampling, Bridgeton Landfill, 2013-2016

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
Aldehydes in Sorbent Tube Samples[c]						
Acetaldehyde	41/44	0.48	5 EPA RfC	0.25 ATSDR CREG	Not exceeded	Exceeded
Acetone	44/44	1.56	13,000 ATSDR MRL	N/A	Not exceeded	N/A
Acrolein	0/44	ND	0.009 EPA RfC	N/A	Below RL	N/A
Benzaldehyde	9/44	0.04	N/A	N/A	N/A	N/A
Crotonaldehyde	30/44	0.57	N/A	N/A	N/A	N/A
Formaldehyde	35/44	0.95	8 ATSDR MRL	0.063 ATSDR CREG	Not exceeded	Exceeded
Hexaldehyde	3/44	0.29	N/A	N/A	N/A	N/A
MEK & Butyraldehyde	42/44	0.40	1,700 EPA RfC For MEK	N/A	Not exceeded	N/A
Methacrolein	14/44	0.07	N/A	N/A	N/A	N/A
m-Tolualdehyde	9/44	0.06	N/A	N/A	N/A	N/A
Propionaldehyde	7/44	0.06	3.5 EPA RfC	N/A	Not exceeded	N/A
Valeraldehyde	11/44	0.13	N/A	N/A	N/A	N/A
Benzene and H_2S Measured with Hand-held Meters during Routine Surveillance[d]						
Benzene	17/36,191	<0.01	3 ATSDR MRL	0.04 ATSDR CREG	Below DL	Below DL
Hydrogen Sulfide	16,969/36,191	1.9	1.4 EPA RfC	N/A	Exceeded	N/A
Sulfur Dioxide Detected by Pulsed-Fluorescence Monitors at Rider Trail-I-70[d]						
Sulfur dioxide	4,925/8,736	3.1	N/A	N/A	N/A	N/A
Sulfur-Based Compounds in SUMMA® Canister Samples[e]						
2-Methylthiophene	0/62	ND	N/A	N/A	N/A	N/A

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
3-Methylthiophene	0/62	ND	N/A	N/A	N/A	N/A
Bromothiophene	0/62	ND	N/A	N/A	N/A	N/A
Carbon Disulfide	0/62	ND	220 EPA RfC	N/A	Not exceeded	N/A
Carbonyl Sulfide	0/62	ND	N/A	N/A	N/A	N/A
Diethyl Disulfide	0/62	ND	N/A	N/A	N/A	N/A
Diethyl Sulfide	0/62	ND	N/A	N/A	N/A	N/A
Dimethyl Disulfide	0/62	ND	N/A	N/A	N/A	N/A
Dimethyl Sulfide	0/62	ND	N/A	N/A	N/A	N/A
Ethyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Hydrogen Sulfide	0/62	ND	1.4 EPA RfC	N/A	Below RL	N/A
Isobutyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Isopropyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Methyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Methylethylsulfide	0/62	ND	N/A	N/A	N/A	N/A
n-Butyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
n-Propyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
sec-Butyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Sulfur Dioxide	0/62	ND	N/A	N/A	N/A	N/A
tert-Butyl Mercaptan	0/62	ND	N/A	N/A	N/A	N/A
Tetrahydrothiophene	0/62	ND	N/A	N/A	N/A	N/A
Thiophene	0/62	ND	N/A	N/A	N/A	N/A
Thiophenol	0/62	ND	N/A	N/A	N/A	N/A
Volatile Organic Compounds in SUMMA® Canister Samples[f]						
1,1,1-Trichloroethane	0/400	ND	700 ATSDR Int. MRL*	N/A	Not exceeded	N/A
1,1,2,2-Tetrachloroethane	0/400	ND	N/A	0.006 EPA RSL	N/A	Below RL
1,1,2-Trichloroethane	2/400	<0.01	0.04 EPA RfC	0.11 ATSDR CREG	Below RL	Below RL
1,1-Dichloroethane	0/400	ND	N/A	0.37 EPA RSL	N/A	Below RL
1,1-Dichloroethene	0/400	ND	20 ATSDR Int. MRL*	N/A	Not exceeded	N/A

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
1,2,4-Trichlorobenzene	0/400	ND	0.28 EPA RfC	N/A	Below RL	N/A
1,2,4-Trimethylbenzene	58/400	0.07	12.2 EPA RfC	N/A	Not exceeded	N/A
1,2-Dibromoethane	0/400	ND	1.2 EPA RfC	0.00022 ATSDR CREG	Not exceeded	Below RL
1,2-Dichlorobenzene	0/400	ND	35 EPA RfC	N/A	Not exceeded	N/A
1,2-Dichloroethane	12/400	0.02	1.8 EPA RfC	0.0095 ATSDR CREG	Not exceeded	Exceeded
1,2-Dichloropropane	4/400	0.01	0.87 EPA RfC	0.16 EPA RSL	Not exceeded	Below RL
1,3,5-Trimethylbenzene	26/400	0.02	N/A	N/A	N/A	N/A
1,3-Butadiene	1/400	<0.01	0.9 EPA RfC	0.015 ATSDR CREG	Not exceeded	Below RL
1,3-Dichlorobenzene	0/400	ND	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	2/400	<0.01	10 ATSDR MRL	0.04 EPA RSL	Not exceeded	Below RL
1,4-Dioxane	9/400	0.04	8.32 EPA RfC	0.056 ATSDR CREG	Not exceeded	Below RL
2,2,4-Trimethylpentane	49/400	0.20	N/A	N/A	N/A	N/A
2-Butanone (MEK)	130/400	0.6323	1,700 EPA RfC	N/A	Not exceeded	N/A
2-Hexanone	2/400	0.01	7.32 EPA RfC	N/A	Not exceeded	N/A
2-Propanol (IPA)	127/400	2.313	81.4 EPA RfC	N/A	Not exceeded	N/A
4-Ethyltoluene	30/400	0.02	N/A	N/A	N/A	N/A
4-Methyl-2-Pentanone	32/400	0.13	730 EPA RfC	N/A	Not exceeded	N/A
Acetone	394/400	5.492	13,000 ATSDR MRL	N/A	Not exceeded	N/A
Acrylonitrile	0/44	ND	0.92 EPA RfC	0.0068 ATSDR CREG	Below RL	Below RL
Allyl Chloride	0/44	ND	0.32 EPA RfC	0.13 EPA RSL	Below RL	Below RL

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
Benzene	220/400	0.3919	3 ATSDR MRL	0.04 ATSDR CREG	Not exceeded	Exceeded
Benzyl Chloride	1/400	<0.01	0.19 EPA RfC	0.01 EPA RSL	Below RL	Below RL
Bromodichloromethane	0/400	ND	N/A	0.01 EPA RSL	N/A	Below RL
Bromoform	1/400	<0.01	N/A	0.088 ATSDR CREG	N/A	Below RL
Bromomethane	0/400	ND	1.3 EPA RfC	N/A	Not exceeded	N/A
Carbon Disulfide	17/356	0.16	220 EPA RfC	N/A	Not exceeded	N/A
Carbon Tetrachloride	16/400	<0.01	16 EPA RfC	0.026 ATSDR CREG	Not exceeded	Below RL
Chlorobenzene	0/400	ND	11.3 EPA RfC	N/A	Not exceeded	N/A
Chlorodifluoromethane	44/44	0.3436	14,000 EPA RfC	N/A	Not exceeded	N/A
Chloroethane	0/400	ND	3,800 EPA RfC	N/A	Not exceeded	N/A
Chloroform	11/400	0.01	20 ATSDR MRL	0.0089 ATSDR CREG	Not exceeded	Below RL
Chloromethane	52/400	0.07	44 EPA RfC	N/A	Not exceeded	N/A
cis-1,2-Dichloroethene	0/400	ND	N/A	N/A	N/A	N/A
cis-1,3-Dichloropropene	0/400	ND	4.4 EPA RfC	0.055 ATSDR CREG	Not exceeded	Below RL
Cyclohexane	39/400	0.06	1,740 EPA RfC	N/A	Not exceeded	N/A
Dibromochloromethane	6/400	0.14	N/A	N/A	N/A	N/A
Dichlorodifluoromethane (Freon 12)	346/400	0.4222	20 EPA RfC	N/A	No exceedance	N/A
Dichlorofluoromethane	0/44	ND	N/A	N/A	N/A	N/A
Dichlorotetrafluoroethane (Freon 114)	6/400	0.01	N/A	N/A	N/A	N/A
Ethanol	385/400	6.415	N/A	N/A	N/A	N/A

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
Ethyl Acetate	11/44	0.1743	20 EPA RfC	N/A	Not exceeded	N/A
Ethylbenzene	70/400	0.08	60 ATSDR MRL	0.22 EPA RSL	Not exceeded	Not exceeded
Heptane	91/400	0.09	N/A	N/A	N/A	N/A
Hexachlorobutadiene	2/400	<0.01	N/A	0.0043 ATSDR CREG	N/A	Below RL
Hexane	153/400	0.1762	200 EPA RfC	N/A	Not exceeded	N/A
Methanol	44/44	27.37	15,262 EPA RfC	N/A	Not exceeded	N/A
Methyl tert-Butyl Ether	2/400	0.01	700 ATSDR MRL	3.1 EPA RSL	Not exceeded	Not exceeded
Methylene Chloride	70/400	0.63	170 EPA RfC	18 ATSDR CREG	Not exceeded	Not exceeded
Propene	41/44	1.575	1,800 EPA RfC	N/A	Not exceeded	N/A
Styrene	14/400	0.02	200 ATSDR MRL	N/A	Not exceeded	N/A
Tetrachloroethylene (PCE)	11/400	0.02	5.9 EPA RfC	0.57 ATSDR CREG	Not exceeded	Not exceeded
Tetrahydrofuran	30/400	0.16	678 EPA RfC	N/A	Not exceeded	N/A
Toluene	262/400	1.06	1,000 ATSDR MRL	N/A	Not exceeded	N/A
trans-1,2-Dichloroethylene	1/400	<0.01	0.87 EPA RfC	N/A	Not exceeded	N/A
trans-1,3-Dichloropropene	0/400	ND	4.4 EPA RfC	0.055 ATSDR CREG	Not exceeded	Below RL
Trichloroethylene (TCE)	9/400	<0.01	0.37 EPA RfC	0.041 ATSDR CREG	Not exceeded	Below RL
Trichlorofluoromethane (Freon 11)	384/400	0.24	N/A	N/A	Not exceeded	N/A
Trichlorotrifluoroethane (Freon 113)	11/400	<0.01	652 EPA RfC	N/A	Not exceeded	N/A

Chemical	Frequency of Detection	Average Concentration (ppb)	Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
					Chronic Screening Level	Cancer Screening Level
Vinyl Acetate	0/44	ND	10 ATSDR Int. MRL*	N/A	Not exceeded	N/A
Vinyl Bromide	0/44	ND	0.69 EPA RfC	0.02 EPA RSL	Below RL	Below RL
Vinyl Chloride	0/400	ND	30 ATSDR Int. MRL*	0.044 ATSDR CREG	Not exceeded	Below RL
Xylenes (mixture of m- and p-xylene)	107/400	0.25	23 EPA RfC	N/A	Not exceeded	N/A
o-Xylene	60/400	0.08	23 EPA RfC	N/A	Not exceeded	N/A

ATSDR MRL = Agency for Toxic Substances and Disease Registry's Minimal Risk 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]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. If neither a chronic/intermediate MRL nor an RfC has been established, concentrations are compared to EPA's noncancer Regional Screening Levels (noncancer RSLs) for evaluating non-cancer risks.
[b]Cancer risks are evaluated by comparison to ATSDR's CREGs or, if CREGs are not available, EPA's cancer RSLs.
[c]Aldehyde concentrations are 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.
[d]Benzene and hydrogen sulfide concentrations are averages of instantaneous concentrations measured twice per day by MDNR up to 2 miles from the landfill in 2013-2016. The detection limit of the Ultra RAE® meter used to measure benzene is 50 ppb. The detection limit of the Jerome® meter used to measure H_2S concentrations is 3 ppb.
[e]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.
[f]VOC concentrations are average concentrations from 44 to 400 four-hour ambient air samples collected by MDNR up to ½ mile downwind of the landfill in 2013-2016. The laboratory reporting limits were typically below 1 ppb.

Table D-3: Number of Exceedances of Short-term Screening Levels and Odor Thresholds
EPA Ambient Air Monitoring/Sampling Results, 2014-2015

Chemical	Range of Concentrations (ppb)		Health-Based Screening Levels[a] (ppb)		Odor Threshold[b] (ppb)	Number of Exceedances	
			Acute	Intermediate		Screening Levels	Odor Threshold
H_2S in Radiello® Samples[c]							
	Bridgeton	**Background**					
Hydrogen Sulfide	ND-0.44	ND-0.46	70 ATSDR MRL	20 ATSDR MRL	0.5-10 Low Range 30 CAAQS	Not exceeded	Not exceeded
VOCs in SUMMA® Canister Samples Collected[d]							
	Bridgeton	**Background**					
1,1,1-Trichloroethane	ND	ND	2,000 ATSDR MRL	700 ATSDR MRL	385,000 EPA GM	Not exceeded	Not exceeded
1,1,2,2-Tetrachloroethane	ND	ND	N/A	N/A	7,300 EPA GM	N/A	Not exceeded
1,1,2-Trichloroethane	ND	ND	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	ND-0.1	ND	N/A	N/A	49,000 AIHA Low	N/A	Not exceeded
1,1-Dichloroethene	ND-0.05	ND	N/A	20 ATSDR MRL	277,000 AIHA Low	Not exceeded	Not exceeded
1,2,4-Trichlorobenzene	ND-0.16	ND-0.13	N/A	N/A	2,960 AIHA Low	N/A	Not exceeded
1,2,4-Trimethyl-benzene	ND	ND-0.08	N/A	N/A	6 AIHA Low	N/A	Not exceeded
1,2-Dibromoethane	ND	ND	N/A	N/A	10,000 AIHA Low	N/A	Not exceeded
1,2-Dichloro-benzene	ND-0.18	ND	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	ND-0.05	ND-0.1	N/A	N/A	26,000 EPA GM	N/A	Not exceeded
1,2-Dichloropropane	ND	ND	50 ATSDR MRL	7 ATSDR MRL	260 EPA GM	Not exceeded	Not exceeded
1,3,5-Trimethyl-Benzene	ND	ND	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	ND-0.08	ND	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	ND-0.25	ND-0.08	2,000 ATSDR MRL	200 ATSDR MRL	120 EPA GM	Not exceeded	Not exceeded
Benzene	ND-0.41	ND-0.38	9 ATSDR MRL	6 ATSDR MRL	61,000 EPA GM	Not exceeded	Not exceeded
Benzyl Chloride	ND	ND	46 Cal EPA REL	N/A	41 EPA GM	Not exceeded	Not exceeded

Chemical	Range of Concentrations (ppb)		Health-Based Screening Levels[a] (ppb)		Odor Threshold[b] (ppb)	Number of Exceedances	
			Acute	Intermediate		Screening Levels	Odor Threshold
Bromomethane	ND-0.1	ND-0.04	50 ATSDR MRL	50 ATSDR MRL	N/A	Not exceeded	N/A
Carbon Tetrachloride	ND-0.2	ND-0.09	300 Cal EPA MRL	30 ATSDR MRL	250,000 EPA GM	Not exceeded	Not exceeded
Chlorobenzene	ND	ND	N/A	N/A	1,300 EPA GM	N/A	Not exceeded
Chloroethane	ND-0.34	ND-0.12	15,000 ATSDR MRL	N/A	3,800 AIHA Low	Not exceeded	Not exceeded
Chloroform	ND-0.34	ND-0.2	30 Cal EPA REL	50 ATSDR MRL	192,000 EPA GM	Not exceeded	Not exceeded
Chloromethane	ND-2.42	0.43-1.11	500 ATSDR MRL	200 ATSDR MRL	10 AIHA Low	Not exceeded	Not exceeded
cis-1,2-Dichloroethene	ND-0.1	ND	N/A	N/A	4,300 AIHA Low	N/A	Not exceeded
cis-1,3-Dichloropropene	ND	ND	N/A	8 ATSDR MRL	260 AIHA Low	Not exceeded	Not exceeded
Dichlorodifluoro methane (Freon 12)	0.16-0.63	0.16-0.57	N/A	N/A	N/A	N/A	N/A
Dichlorotetrafluor oethane (Freon 114)	ND	ND	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	ND-0.14	ND-0.18	5,000 ATSDR MRL	2,000 ATSDR MRL	2 AIHA Low	Not exceeded	Not exceeded
Hexachloro-butadiene	ND-0.1	ND-0.1	N/A	N/A	N/A	N/A	N/A
Methylene Chloride	ND-4.0	ND-1.21	600 ATSDR MRL	300 ATSDR MRL	144,000 EPA GM	Not exceeded	Not exceeded
Styrene	ND-0.8	ND-0.13	5,000 ATSDR MRL	N/A	150 EPA GM	Not exceeded	Not exceeded
Tetrachloro-ethylene (PCE)	ND-12.7	ND-2.8	6 ATSDR MRL	6 ATSDR MRL	47,000 EPA GM	1 (station 2)	Not exceeded
Toluene	ND-3.98	ND-4.51	2,000 ATSDR MRL	N/A	2,800 EPA GM	Not exceeded	Not exceeded
Trans-1,3-dichloropropene	ND	ND		8 ATSDR MRL	990 AIHA	Not exceeded	Not exceeded
Trichloroethylene (TCE)	ND-0.39	ND-0.32	N/A	0.4 ATSDR MRL	82,000 EPA GM	Not exceeded	Not exceeded

Chemical	Range of Concentrations (ppb)		Health-Based Screening Levels[a] (ppb)		Odor Threshold[b] (ppb)	Number of Exceedances	
			Acute	Intermediate		Screening Levels	Odor Threshold
Trichlorofluoro-methane (Freon 11)	0.16-0.41	0.18-0.30	N/A	N/A	5,000 AIHA Low	N/A	Not exceeded
Trichlorotrifluoro-ethane (Freon 113)	0.05-0.16	0.06-0.09	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	ND	ND	500 ATSDR MRL	30 ATSDR MRL	203 AIHA Low	Not exceeded	Not exceeded
m- and p - Xylene	ND-0.41	ND-0.53	2,000 ATSDR MRL	600 ATSDR MRL	730-5,400 EPA GM	Not exceeded	Not exceeded
o-Xylene	ND-0.15	ND-0.18	2,000 ATSDR MRL	600 ATSDR MRL	730-5,400 EPA GM	Not exceeded	Not exceeded

Volatile Organic Compounds in Radiello® Samples[e]

	Bridgeton	Background					
1,2,4-Trimethyl-benzene	ND-0.07	ND-0.09	N/A	N/A	6 AIHA Low	N/A	Not exceeded
1,3,5-Trimethyl-benzene	ND	ND	N/A	N/A	N/A	N/A	N/A
Benzene	ND	ND	9 ATSDR MRL	6 ATSDR MRL	61,000 EPA GM	Not exceeded	Not exceeded
cis-1,2-Dichloroethene	ND	ND	N/A	N/A	277,00 AIHA	N/A	Not exceeded
trans-1,2-Dichloroethene	ND	ND	200 ATSDR MRL	200 ATSDR MRL	277,00 AIHA	Not exceeded	Not exceeded
Ethylbenzene	ND-0.07	ND-0.09	5,000 ATSDR MRL	2,000 ATSDR MRL	2 AIHA Low	Not exceeded	Not exceeded
Isopropylbenzene (cumene)	ND	ND	N/A	N/A	32 EPA GM	N/A	Not exceeded
Methyl t-butyl-ether	ND	ND	2,000 ATSDR MRL	700 ATSDR MRL	30 AIHA Low	Not exceeded	Not exceeded
Tetrachloro-ethylene (PCE)	ND-0.07	ND-0.03	6 ATSDR MRL	6 ATSDR MRL	47,000 EPA GM	Not exceeded	Not exceeded
Toluene	ND-0.15	ND-0.10	2,000 ATSDR MRL	N/A	2,800 EPA GM	Not exceeded	Not exceeded
Trichloroethylene (TCE)	ND-0.09	ND	N/A	0.4 ATSDR MRL	82,000 EPA GM	Not exceeded	Not exceeded
Vinyl chloride	ND	ND	500 ATSDR MRL	30 ATSDR MRL	203 AIHA Low	Not exceeded	Not exceeded

Chemical	Range of Concentrations (ppb)		Health-Based Screening Levels[a] (ppb)		Odor Threshold[b] (ppb)	Number of Exceedances	
			Acute	Intermediate		Screening Levels	Odor Threshold
m- and p - Xylene	ND-0.23	ND-0.25	2,000 ATSDR MRL	600 ATSDR MRL	730-5,400 EPA GM	Not exceeded	Not exceeded
o-Xylene	ND-0.08	ND-0.09	2,000 ATSDR MRL	600 ATSDR MRL	730-5,400 EPA GM	Not exceeded	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
N/A = not available/not applicable; ND = not detected

[a]The lowest (i.e., most conservative/health-protective) screening levels established by ATSDR and Cal EPA. Screening Levels are ATSDR's MRLs for acute (<14 days) or intermediate (2 weeks – 1 year) exposure and California EPA's RELs for acute or intermediate exposure. Cal EPA 8-hr RELs apply to 8-hour exposures that may be repeated.

[b]Odor thresholds reported in the scientific literature can vary widely, likely due to differences in experimental methodology and human variability. Shown 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).

[c]H_2S concentrations are 7-day to 14-day average concentrations in ambient air samples collected for EPA from four monitoring stations up to1 mile from the landfill and one "background" monitoring station 2.3 miles 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.

[d]VOC concentrations are 24-hour average concentrations in ambient air samples collected for EPA from four monitoring stations up to1 mile from the landfill and in one "background" monitoring station 2.3 miles from the landfill. Samples were collected from each monitoring station on a weekly basis from May to December 2014. The laboratory reporting limits were typically below 1 ppb.

[e]VOC concentrations are 7-day to 14-day average concentrations in ambient air samples collected for EPA from four monitoring stations up to1 mile from the landfill and one "background" monitoring station 2.3 miles 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.

Table D-4: Exceedance of Chronic or Cancer Screening Levels
EPA Ambient Air Sampling Results, 2014-2015

Chemical	Frequency of Detection at Fixed Monitoring Stations		Average Concentration (ppb)		Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
							Chronic Screening Level	Cancer Screening Level
H_2S in Radiello® Samples[c]	**Bridgeton**	**Background**	**Bridgeton**	**Background**				
Hydrogen Sulfide	35/55	7/11	0.22	0.18	1.4 EPA RfC	N/A	Not exceeded	N/A
Volatile Organic Compounds in SUMMA® Canister Samples[d]	**Bridgeton**	**Background**	**Bridgeton**	**Background**				
1,1,1-Trichloroethane	0/163	0/31	ND	ND	700 ATSDR Int MRL*	N/A	Not exceeded	N/A
1,1,2,2-Tetrachloroethane	0/163	0/31	ND	ND	N/A	0.006 EPA RSL	N/A	Below RL
1,1,2-Trichloroethane	0/163	0/31	ND	ND	0.04 EPA RfC	0.11 ATSDR CREG	Below RL	Below RL
1,1-Dichloroethane	1/163	0/31	<0.01	ND	N/A	0.37 EPA RSL	N/A	Not exceeded
1,1-Dichloroethene	1/163	0/31	<0.01	ND	20 ATSDR Int MRL*	N/A	Not exceeded	N/A
1,2,4-Trichlorobenzene	0/163	1/31	ND	<0.01	0.28 EPA RfC	N/A	Below RL	N/A
1,2,4-Trimethylbenzene	31/163	6/31	0.02	0.02	12.2 EPA RfC	N/A	Not exceeded	N/A
1,2-Dibromoethane	0/163	0/31	ND	ND	1.2 EPA RfC	0.00022 ATSDR CREG	Not exceeded	Below RL
1,2-Dichlorobenzene	1/163	0/31	<0.01	ND	35 EPA RfC	N/A	Not exceeded	N/A
1,2-Dichloroethane	1/163	1/31	<0.01	<0.01	1.8 EPA RfC	0.0095 ATSDR CREG	Not exceeded	Below RL
1,2-Dichloropropane	0/163	0/31	ND	ND	0.87 EPA RfC	0.16 EPA RSL	Not exceeded	Below RL
1,3,5-Trimethylbenzene	0/163	0/31	ND	ND	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	2/163	0/31	<0.01	ND	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	9/163	3/31	0.01	0.01	10 ATSDR MRL	0.04 EPA RSL	Not exceeded	Below RL

Chemical	Frequency of Detection at Fixed Monitoring Stations		Average Concentration (ppb)		Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
							Chronic Screening Level	Cancer Screening Level
Benzene	152/163	30/31	0.16	0.15	3 ATSDR MRL	0.04 ATSDR CREG	Not exceeded	Exceeded (stations 1-4 & 5)
Benzyl Chloride	0/163	0/31	ND	ND	0.19 EPA RfC	0.01 EPA RSL	Below RL	Below RL
Bromomethane	15/163	1/31	<0.01	<0.01	1.3 EPA RfC	N/A	Not exceeded	N/A
Carbon Tetrachloride	157/163	30/31	0.07	0.07	16 EPA RfC	0.026 ATSDR CREG	Not exceeded	Exceeded (stations 1-4 & 5)
Chlorobenzene	0/163	0/31	ND	ND	11.3 EPA RfC	N/A	Not exceeded	N/A
Chloroethane	31/163	5/31	0.02	0.01	3,800 EPA RfC	N/A	Not exceeded	N/A
Chloroform	58/163	8/31	0.05	0.02	20 ATSDR MRL	0.0089 ATSDR CREG	Not exceeded	Exceeded (stations 1-4 & 5)
Chloromethane	162/163	31/31	0.66	0.63	44 EPA RfC	N/A	Not exceeded	N/A
cis-1,2-Dichloroethene	1/163	0/31	<0.01	ND	N/A	N/A	N/A	N/A
cis-1,3-Dichloropropene	0/163	0/31	ND	ND	4.4 EPA RfC	0.055 ATSDR CREG	Not exceeded	Below RL
Dichlorodifluoromethane (Freon 12)	163/163	31/31	0.44	0.44	20 EPA RfC	N/A	Not exceeded	N/A
Dichlorotetrafluoroethane (Freon 114)	0/163	0/31	ND	ND	N/A	N/A	N/A	N/A
Ethylbenzene	48/163	9/31	0.18	0.03	60 ATSDR MRL	0.22 EPA RSL	Not exceeded	Below RL
Hexachlorobutadiene	1/163	1/163	<0.01	<0.01	N/A	0.0043 ATSDR CREG	N/A	Below RL
Methylene Chloride	81/163	15/31	0.34	0.54	170 EPA RfC	18 ATSDR CREG	Not exceeded	Not exceeded
Styrene	16/163	2/31	0.01	0.01	200 ATSDR MRL	N/A	Not exceeded	N/A
Tetrachloroethylene (PCE)	19/163	5/31	0.09	0.10	5.9 EPA RfC	0.57 ATSDR CREG	Not exceeded	Not exceeded

Chemical	Frequency of Detection at Fixed Monitoring Stations		Average Concentration (ppb)		Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
							Chronic Screening Level	Cancer Screening Level
Toluene	136/163	27/31	0.41	0.70	1,000 ATSDR MRL	N/A	Not exceeded	N/A
Trans-1,3-dichloropropene	0/163	0/31	ND	ND	4.4 EPA RfC	0.055 ATSDR CREG	Not exceeded	Below RL
Trichloroethylene (TCE)	31/163	10/31	0.02	0.04	0.37 EPA RfC	0.041 ATSDR CREG	Not exceeded	Below RL
Trichlorofluoromethane (Freon 11)	163/163	31/31	0.24	0.23	N/A	N/A	Not exceeded	N/A
Trichlorotrifluoroethane (Freon 113)	163/163	31/31	0.08	0.07	652 EPA RfC	N/A	Not exceeded	N/A
Vinyl chloride	0/163	0/31	ND	ND	30 ATSDR Int MRL*	0.044 ATSDR CREG	Not exceeded	Below RL
m- and p-Xylene	84/163	16/31	0.11	0.13	23 EPA RfC	N/A	Not exceeded	N/A
o-Xylene	66/163	11/31	0.04	0.04	23 EPA RfC	N/A	Not exceeded	N/A

Volatile Organic Compounds in Radiello® Samples[e]

	Bridgeton	Background	Bridgeton	Background				
1,2,4-Trimethylbenzene	5/55	1/11	<0.01	<0.01	12.2 EPA RfC	N/A	Not exceeded	N/A
1,3,5-Trimethylbenzene	0/55	0/11	ND	ND	N/A	N/A	N/A	N/A
Benzene	0/21	0/4	ND	ND	3 ATSDR MRL	0.04 ATSDR CREG	Not exceeded	Not exceeded
cis-1,2-Dichloroethene	0/55	0/11	ND	ND	N/A	N/A	N/A	N/A
trans-1,2-Dichloroethene	0/55	0/11	ND	ND	N/A	N/A	N/A	N/A
Ethylbenzene	15/55	3/11	0.01	0.02	60 ATSDR MRL	0.22 EPA RSL	Not exceeded	Not exceeded
Isopropylbenzene (cumene)	0/55	0/11	ND	ND	81 EPA RfC	N/A	Not exceeded	N/A
Methyl t-butyl ether	0/55	0/11	ND	ND	700 ATSDR MRL	3 EPA RSL	Not exceeded	Not exceedd
Tetrachloroethylene (PCE)	2/55	1/11	<0.01	<0.01	5.9 EPA RfC	0.57 ATSDR CREG	Not exceeded	Not exceeded
Toluene	6/22	1/4	0.03	0.03	1,000 ATSDR MRL	N/A	Not exceeded	Not exceeded

Chemical	Frequency of Detection at Fixed Monitoring Stations		Average Concentration (ppb)		Chronic Health-Based Screening Level[a] (ppb)	Cancer Screening Level[b] (ppb)	Exceedances	
							Chronic Screening Level	Cancer Screening Level
Trichloroethylene (TCE)	3/55	0/11	<0.01	ND	0.37 EPA RfC	0.041 ATSDR CREG	Not exceeded	Not exceeded
Vinyl chloride	0/55	0/11	ND	ND	30 ATSDR Int MRL*	0.044 ATSDR CREG	Not exceeded	Not exceeded
m- and p - Xylene	17/55	4/11	0.06	0.05	23 EPA RfC	N/A	Not exceeded	N/A
o-Xylene	15/55	3/11	0.01	0.02	23 EPA RfC	N/A	Not exceeded	N/A

ATSDR MRL = Agency for Toxic Substances and Disease Registry's Minimal Risk 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]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. If neither a chronic/intermediate MRL nor an RfC has been established, concentrations are compared to EPA's noncancer Regional Screening Levels (noncancer RSLs) for evaluating non-cancer risks.
[b]Cancer risks are evaluated by comparison to ATSDR's CREGs or, if CREGs are not available, EPA's cancer RSLs.
[c]H_2S concentrations are average concentrations in ambient air samples collected for EPA from four monitoring stations ¼ mile to 1 mile from the landfill and one "background" monitoring station 2.3 miles 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.
[d]VOC concentrations are average concentrations from 163 24-hour ambient air samples collected for EPA at four monitoring stations ¼ mile to 1 mile from the landfill and from 31 24-hour ambient air samples collected at one "background" monitoring station 2.3 miles from the landfill. Samples were collected on a weekly basis from May-December 2014. The laboratory reporting limits were typically below 1 ppb.
[e]VOC concentrations are average concentrations in ambient air samples collected for EPA from four monitoring stations ¼ mile to 1 mile from the landfill and one "background" monitoring station 2.3 miles 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 urban air pollutants, vehicle emissions, cigarette smoke, pesticides, and fumes from cleaning supplies, treated fabrics, paints, and other 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 in low concentrations 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. Lacking detailed information on chemical interactions, 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 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 G-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 H_2S) 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 SO_2 concentration) 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.

In addition, 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 further expected to be low.

Table E-1. Chemicals that May Jointly Affect Respiratory or Nervous Systems
Bridgeton Landfill, 2013-2016

Target System	Chemical[a]	Short-Term Concentration[b] (ppb)	Acute Screening Level (ppb)	Acute Hazard Quotient	Acute Effect Level (ppb)[c]	Exceedance 1/10th of Acute Effect Level?
Respiratory System	Hydrogen Sulfide*	ND-45	70	≤0.64	2,000	No
	Formaldehyde	ND-11.2	44	≤0.25	440	No
	1,1-Dichloroethane	ND-0.2	N/A	N/A	N/A	N/A
	1,2-Dichloropropane	ND-2.7	50	≤0.054	50,000	No
	2-Butanone	ND-910	4,500	≤0.2	270,000	No
	Sulfur Dioxide*	ND-1,600	10	160	100	Yes
	Tetrachloroethylene	ND-1.4	6	≤0.23	1,700	No
Nervous System	Hydrogen Sulfide*	ND-45	70	≤0.64	2,000	No
	Benzene	ND-32.5	9	≤0.28	2,550	No
	Xylenes	ND-2.7	2,000	<0.01	50,000	No
	1,1,2-Trichloroethane					
	Methylene Chloride	ND-0.1	N/A	N/A	N/A	N/A
	1,2-Dichloropropane	ND-181	600	≤0.30	60,000	No
	2-Hexanone	ND-2.7	50	≤0.05	50,000	No
	Acetone	ND-1	N/A	N/A	N/A	N/A
	CarbonTetrachloride	ND-1,400	26,000	≤0.05	237,000	No
	Chloroform	ND-0.24	300	<0.01	5,000	No
	Chloromethane	ND-0.46	30	≤0.02	30,000	No
	Ethylbenzene	ND-1.9	500	<0.01	50,000	No
	n-Hexane	ND-3.7	5,000	<0.01	154,200	No
	Styrene	ND-32	N/A	N/A	N/A	N/A
	Tetrachloroethylene	ND-1.5	5,000	<0.01	49,000	No
	Toluene	ND-1.4	6	≤0.23	1,700	No
		ND-44	2,000	≤0.22	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 are 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. Sulfur dioxide concentrations are instantaneous concentrations detected by AreaRAE® monitors up to ½ mile from the landfill. Other chemical concentrations are from 4-hour samples collected up to ½ mile from the landfill at upwind or downwind locations.
[c]Effect levels used to establish acute screening levels and shown to have respiratory or nervous system effects.
*H_2S 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.

Limitations

The limitations of evaluation of multiple chemical exposures include the lack of toxicological data for many chemicals. Chemicals that may jointly affect the respiratory or neurological systems but lack toxicological reviews include many RSCs. As discussed in the *Public Health Implications* section, evidence that RSCs may jointly target those systems includes the results of community studies showing associations between total RSC exposures and increased reports of respiratory symptoms and increased hospital visits for respiratory illnesses in children [Campagna et al. 2004; Jaakkola et al. 1999; Jappinen et al. 1990] and reports of headache [Brenneman et al. 2000; Jappinen et al. 1990; Partti-Pellinen et al. 1996].

Furthermore, in community exposure studies, identifying pollutants responsible for respiratory effects is generally complicated by the fact that there are multiple air pollutants from multiple sources. Other air pollutants that may contribute to respiratory and other problems and that are common in urban settings include ozone, nitrogen dioxide, and particulate matter. Irritants also include radon, gasoline and fuel oil fumes, and creosols. Other chemical exposures at home that may contribute to those respiratory and other problems include breathing cigarette smoke and ingestion of alcohol. For example, studies have shown that alcohol consumption can increase the risk of adverse health effects of exposure to certain air contaminants, including H_2S and benzene.

Increased Cancer Risks

Cancer risks can 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 increase the incidence of that cancer.

Appendix F: Cancer Risk Calculations

Calculation of Increased Cancer Risks Associated with Breathing Benzene

In 2013-2016, the 4-year average of benzene concentrations in ambient air samples collected downwind of Bridgeton Landfill (0.39 ppb) slightly exceeded ATDSR's cancer risk evaluation guide (CREG) value. In 2013, the average concentration of benzene downwind of the landfill (1.2 ppb) also exceeded the average concentration in ambient air at urban locations in the United States (0.26 ppb in 2013) [EPA 2018]. Benzene concentrations downwind of the landfill were lower in 2014-2016, when annual averages (0.10 ppb to 0.19 ppb) fell slightly below the national average concentration. Concentrations upwind of the landfill (0.11 ppb in 2013-2016) and in the Bridgeton area (0.15 ppb to 0.16 ppb in 2014-2015) were also slightly below the national average concentration.

The following cancer risk estimate is based on the assumption of lifetime exposure to the 2013 national average benzene concentration in ambient air. It is an estimate of the excess risk of developing cancers associated with benzene inhalation.

Formula:

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

where C = average concentration (see Table F-1)
MW = molecular weight (see Table F-1)
IUR = inhalation unit risk factor (see Table F-1)

Table F-1. Chemical-Specific Values

	Average Concentration[a] (ppb)	Molecular Weight (g/mol)	Inhalation Unit Risk Factor $(\mu g/m^3)^{-1}$
Benzene	0.26	78.11	7.8×10^{-6}

[a]Average of concentrations
ppb = parts per billion
g/mol = grams per mole
$\mu g/m^3$ = micrograms per cubic meter

Example Calculation:

Cancer Risk (2013 national average) = 0.26 ppb x (78.11 g/mol / 24.45) × 7.8×10^{-6} $(\mu g/m^3)^{-1}$

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