Letter Health Consultation

AMBIENT HYDROGEN SULFIDE NEAR MUSHROOM COMPOSTING OPERATIONS

LONDON GROVE AND NEW GARDEN TOWNSHIPS
CHESTER COUNTY, PENNSYLVANIA

Public Health Evaluation of 2021-2022 Hydrogen Sulfide (H_2S) Ambient Air Monitoring Data in Southern Chester County

March 21, 2024

pennsylvania
DEPARTMENT OF HEALTH

Bureau of Epidemiology, Division of Environmental Health Epidemiology
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Pennsylvania Department of Health
Division of Environmental Health Epidemiology

March 21, 2024

The Honorable Christina Sappey
Willowdale Town Center
698 Unionville Rd
Kennett Square, PA 19348

Dear Representative Sappey:

The Pennsylvania Department of Health (PADOH) prepared this letter health consultation (LHC) to evaluate hydrogen sulfide (H_2S) in outdoor air based on August 2021-December 2022 hourly data collected by the Pennsylvania Department of Environmental Protection's (PADEP) Bureau of Air Quality (BAQ). BAQ collected these data in response to your March 6, 2020, request for an air quality study for New Garden Township. You and members of your constituency expressed concern of possible negative health effects such as headaches and effects on asthma perceived to be resulting from emissions of area mushroom composting operations. Residents also complained of corroding outdoor air conditioning units.

BAQ shared the data with PADOH in February 2023. PADOH evaluated these data using public health assessment methods of the Agency for Toxic Substances and Disease Registry (ATSDR) to determine whether detected outdoor H_2S levels could harm public health. **Based on our evaluation, outdoor H_2S at the Landenberg and West Grove monitors may have been an acute public health hazard for short-term respiratory effects in certain individuals, particularly sensitive populations (such as children or older adults) and/or people with chronic respiratory conditions such as asthma**. Acute health hazards indicate the potential for health effects from exposures lasting less than or equal to 14 days. On certain days of the highest H_2S peaks, hourly H_2S concentrations at the West Grove and Landenberg monitors approached effect levels found in the scientific literature to negatively affect adults with asthma from exposures of 30 minutes. Therefore, certain people exposed to the hourly levels on these dates may have experienced worsening of asthma, chest tightness, difficulty breathing, or similar effects. As a percentage of the overall data, the highest hourly peaks were relatively infrequent and nearly all peaks occurred at night or during the early morning hours. Nonetheless, if **current H_2S levels (and peaks) are ongoing and similar to the 2021-2022 levels, an acute health hazard remains for the above effects, particularly for sensitive individuals.**

Additionally, area nuisance odors may be leading to stress or health symptoms such as headache, nausea, fatigue, or similar symptoms in some people. Not everyone responds to odors the same way, and the levels at which people smell H_2S in air vary considerably, but common H_2S odor thresholds were regularly exceeded.

Intermediate (15-364 days) and chronic exposures (a year or more) to detected H_2S are unlikely to produce longer-term health effects. Our exposure estimates exceeded ATSDR and U.S. Environmental Protection Agency (EPA) screening values and health guidelines for H_2S exposures in air of intermediate (15-364 days) and chronic duration (a year or longer). However, our exposure estimates were lower than the human-equivalent health effect levels that serve as the basis for these guidelines. There is currently limited scientific understanding of the potential for adverse human health impacts from longer-term low-dose exposures to H_2S in air. Therefore, PADOH acknowledges a degree of uncertainty in our conclusion on community H_2S exposures of longer duration and the potential for longer-term health effects.

PADOH recommends that:

1. Facilities suspected of high H_2S emissions engage in best practices and engineering controls to reduce odors, which might include an air monitoring plan to see if best practices or engineering controls are resulting in lower H_2S emissions.
2. Efforts be made to significantly reduce area H_2S of this region to lower levels, and/or ensure H_2S emissions are located away from residential areas. Ideally, year-round/lifetime daily averages should be at or below 1.4 parts per billion (ppb), which is EPA's reference concentration (RfC) and would protect against lifetime health risk and common odor thresholds.
3. Entities or community partners consider outdoor air monitoring to see if odor and health effect levels are being exceeded near homes, or at workplaces. Continued area monitoring may be useful to understand if engineering controls are effective and reduce area H_2S levels in future years. Further, any collected data should be shared with stakeholders and the community to understand trends in H_2S levels and whether common odor and health effect levels are being approached or exceeded.
4. Residents consult their physicians if experiencing adverse health effects. Though it can be difficult to reduce exposures to environmental odors, residents can try staying indoors when outdoor environmental conditions are bothersome, exercising indoors instead of outdoors on days of more odors, or leaving the area for a few hours, if possible. Residents should also continue reporting occurrences of environmental odors to PADEP (complaints line: 484-250-5991; 24-hour line: 484-250-5990, or electronically at https://greenport.pa.gov/obPublic/EnvironmentalComplaintForm/) and health concerns from H_2S emissions to PADOH (phone: 717-787-3350, or electronically at: https://forms.health.pa.gov/environmental-health-concern).

Limitations

1. PADOH's conclusions are based on averaged hourly data. Very high levels of H_2S (>27 parts per million, ppm) of short exposure duration (<1 hour) can cause severe health effects. Hourly levels at the monitoring stations were well below more severe health effect levels. If available in the future, PADOH may consider a review of additional quality-assured data for this area, including data of shorter exposure durations, if deemed representative of community exposures.
2. PADOH's conclusions do not account for monitor-specific meteorological data such as wind-direction, wind speed, or relative humidity, which might provide further insight on the episodic peaks of H_2S. PADOH recently received and will review monitor-specific meteorological data from BAQ and will provide a follow-up letter health consultation if needed.
3. Although the dataset PADOH received is robust and of sufficient quality, each monitor had several days or weeks of invalid hourly data, most commonly the West Grove monitor. Occurrences of invalid data are common for hourly monitoring. There were hours in which monitor data were invalid due to machine malfunctions, power failures, quality assurance results, maintenance/routine repairs, or daily automated calibration checks. PADOH did not include invalid data for this assessment.

4. Our conclusions are based on ambient H_2S levels and not other compounds (such as other sulfur compounds) that are often present in air with H_2S and can also affect health. PADOH received ammonia data from BAQ that we will consider assessing for a follow-up report. Ammonia was sampled less frequently using a monitor that was unable to detect it at low concentrations.
5. Our conclusions are based on BAQ August 2021 – December 2022 data in this region. PADOH may consider a review of additional data or data taken more recently if deemed representative of community exposures and will provide a follow-up letter health consultation if needed.

Public Health Action Plan

1. PADOH may consider a review of additional data for this site if deemed representative of community exposures and will provide a follow-up letter health consultation if needed.
2. PADOH will share the results of this letter health consultation with interested site stakeholders.
3. PADOH intends to participate in meetings with stakeholders, community members, and/or interagency partners, if requested, to discuss ambient H_2S levels, data sources, efforts to reduce emissions, and/or additional updates or concerns in this area.

Attached to this letter ("Attachment A") is the assessment supporting our findings as well as on additional community concerns. Please contact the Pennsylvania Department of Health at 717-787-3350 or by email at dehe@pa.gov if you have any questions.

Sincerely,

The Pennsylvania Department of Health
Division of Environmental Health Epidemiology

Attachment A

Contents

1. Site Background and Community Concerns

On March 6, 2020, your office informed the Pennsylvania Department of Health (PADOH) that New Garden Township residents were concerned of odors and health effects such headaches and effects on asthma perceived to be coming from a nearby mushroom composting facility. Residents also raised concerns of corroding metals at an accelerated rate affecting outdoor air conditioning units and resident vehicles. In October 2022, PADOH was notified of a New Garden resident who lived near a mushroom composting facility and expressed concerns of recurring lung nodules.

Nearly two-thirds of all U.S. mushroom production occurs in Southeastern Pennsylvania (CCAD 2022). In 2021-2022, Chester County produced 321 million of the U.S.'s 680 million pounds of the Agaricus ("white button") mushroom, which is the most popular commercial mushroom in the U.S. (USDA 2022). Chester County ranks first among U.S. counties in mushroom production and in 2021-2022 its growing area increased 22 percent from the previous season (USDA 2022; CCADC 2017). Chester County's mushroom production is part of a rich agricultural landscape that ranks second among Pennsylvania counties in agricultural products sold (CCPC 2023). In southern Chester County, the earliest mushroom farming dates back more than 120 years (Mowday 2008).

The mushroom growing process involves creating a substrate and compost favorable to mushrooms at the exclusion of competing fungi and bacteria (PADEP 2012). Mushrooms are grown indoors and require nutrient-rich substrate to grow; mushroom compost remains afterward. The exact contents of mushroom substrate are up to the farmer, but common main ingredients include a mixture of corncobs, hay, straw, straw-bedded horse manure, and poultry manure. These ingredients are pre-conditioned, piled, and softened to ensure they are optimal prior to being combined into the substrate. The substrate is then lined in rows (often called "ricks") of 5-7 ft (width) by 5-8 ft (height) size that are turned and watered every few days to maintain aerobic (oxygen-containing) and optimal conditions selective for mushroom growing. This process generally lasts 7-16 days and results in a brown substrate containing 68-74% moisture. Further details on the composting process are provided in PADEP 2012.

Odors can occur during the composting process and are most common during substrate formation. The contents of the substrate allow for favorable bacteria to grow and reproduce. These bacteria require sufficient oxygen, however, without it, anaerobic conditions can result (PSU 2008). The anaerobic conditions create gases, including hydrogen sulfide (H_2S) and other sulfur compounds (Derikx et al. 1991; Noble et al. 2001) that have rotten egg-like odors. Maintaining aerobic conditions and adding water to the substrate is critical; too little water can limit the growth of productive fungi. Too much water, however, can lead to more anaerobic bacteria and increased odors (PADEP 2012; PSU 2008). Other processes such as thoroughly mixing and frequently turning of the substrate, and other aeration techniques are also needed to avoid anaerobic conditions that can produce odors (PSU 2008).

Compost used to produce agricultural commodities is not subject to Pennsylvania air quality regulations and thus the Pennsylvania Department of Environmental Protection (PADEP) has limited authority under Pennsylvania's Air Pollution Control Act to address odors or other emissions from composting facilities (PADEP and PADOH 1999). In response to community concerns, PADEP's Bureau of Air Quality (BAQ) conducted continuous ambient air monitoring at community locations near area composting facilities and shared the results with PADOH (discussed in section 3).

2. Previous Investigation

PADOH and PADEP previously evaluated this general site area and released a report in 1999. The agencies received rotten-egg odor and health complaints in 1997 and 1998 from residents living near mushroom composting facilities in London Grove Township.

PADOH and PADEP did not find a consistent association between H_2S levels and health symptoms; however, the agencies acknowledged the existence of a chronic odor problem affecting quality of life of residents near the operations. **Appendix A** has additional details on PADEP and PADOH's 1998-1999 investigation.

3. PADEP 2021-2022 Environmental Monitoring

3.1. BAQ Air Monitoring of H_2S

In response to community concerns raised by your office in 2020, BAQ conducted continuous ambient environmental air monitoring for H_2S.

H_2S has a very low odor threshold. BAQ measured it using a Teledyne T101 H_2S Analyzer, which is able to detect low (parts per billion) concentrations. This analyzer is an established method to monitor ambient H_2S.

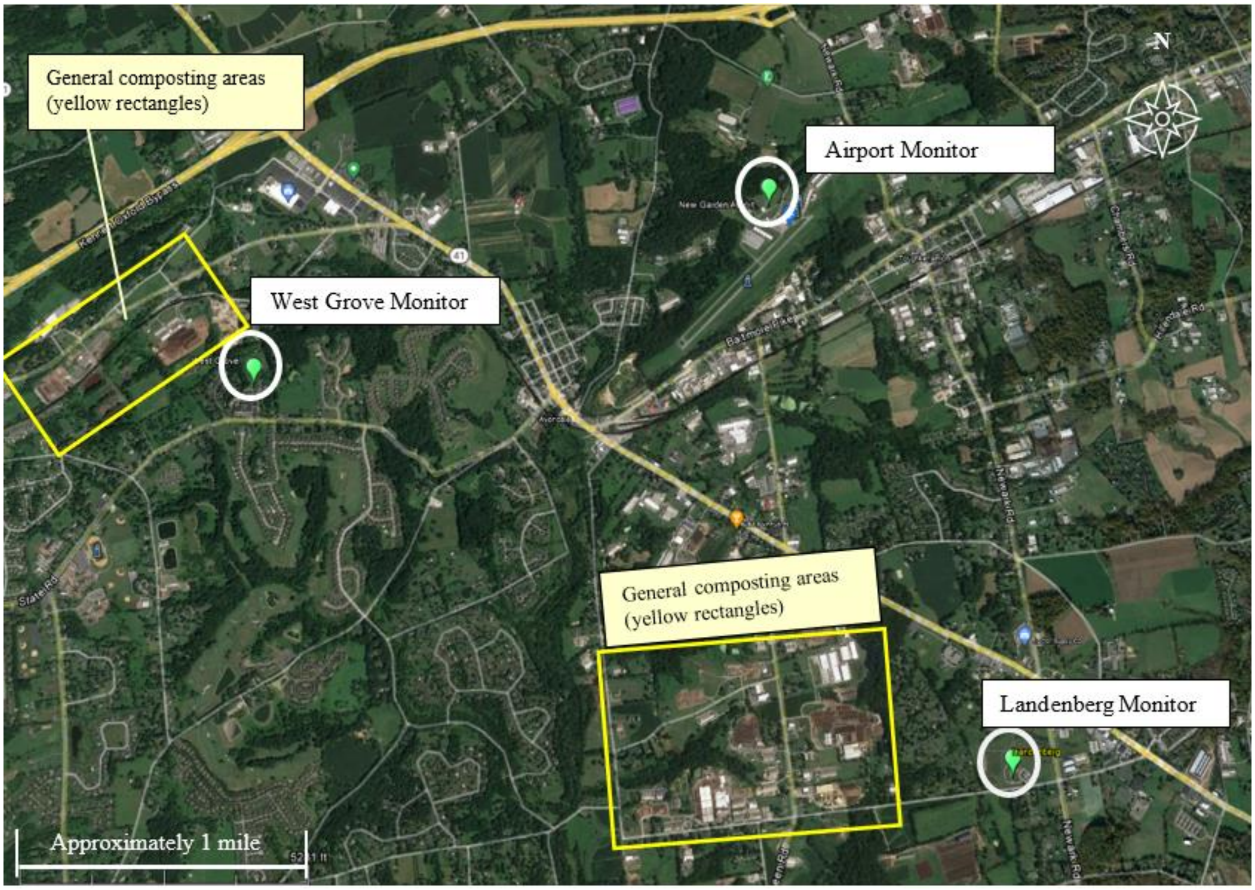
BAQ measured ambient H_2S at three locations (Figure 1):

1. Avon Grove Charter School, London Grove Township **("West Grove monitor")**
2. New Garden Township Town Hall, New Garden Township **("Landenberg monitor")**
3. New Garden Airport **("Airport monitor")**

BAQ designated the Airport monitor as the "background" location, presumed to be largely unaffected by composting emissions. BAQ informed PADOH that the two monitors near sources of emissions - i.e., the "near source" West Grove and Landenberg monitors - met relevant siting criteria (40 CFR Part 58) and were downwind and representative of community exposures. Recently, BAQ shared monitor-specific meteorological data that PADOH will review in the near future. In the absence of review of this monitor-specific meteorological data, a nearby weather monitor in Kennett Square, New Garden Township (approximately 1.7 miles northeast of the Landenberg monitor) supports BAQ's assessment that the monitors are generally downwind of mushroom agricultural facilities (Iowa Environmental Mesonet of Iowa State University 2023).

Monitor locations and their relation to general mushroom composting areas are shown in Figure 1.

Figure 1. Location of the three monitoring stations (labeled in white circles) and their relative proximity to general areas of mushroom composting operations (within the yellow rectangles)



This Letter Health Consultation evaluates the ambient air monitoring that took place from August 2021 through December 2022.

3.2. H_2S Measurements and Data Quality

H_2S was measured continuously and reported as hourly averages. Though the dataset was robust, not all data were valid: at each monitor, the Teledyne instrument underwent automatic calibration checks nearly each day, and precision checks each week. The daily calibration checks occurred at noon and 1 pm to ensure the instrument met specific performance criteria; data generated during these periods were invalid.[1] If the instrument did not "pass" these daily checks, the site operator investigated and repaired the equipment. There were monitored hours for which the instrument data were invalid due to quality assurance results, instrument malfunctions, maintenance/routine repairs, power failures, or the daily automated checks. Occurrences of invalid data are common for hourly monitoring.

[1] Typically, daily calibration checks within BAQ's monitoring network occur between the hours of midnight and 4am. However, because the highest peaks of area H_2S occurred in the nighttime or early morning hours, calibration checks were scheduled to occur during 12 pm and 1 pm to ensure any peaks that may have occurred during nighttime/early morning hours were captured.

Occasionally a field issue was reported, such as excess heat, in which the data were still valid. PADOH only assessed valid data.

There were also valid negative values. These values represented competing interferences which is in line with the instrument's monitoring process. Negative values were small and infrequent, as constituting approximately 1% of all valid hours in the dataset, and did not impact overall results. Though some data were invalid, we consider the dataset overall as robust, sufficient and representative of community exposures.

The monitors had 7,094 (West Grove), 9,823 (Landenberg) and 10,332 (Airport) valid hourly concentrations during the study period. Table 1 summarizes the monitoring data.

Table 1. Overview of Ambient Air H_2S Data

Monitor Name	West Grove	Landenberg	Airport
Type of Monitor	Near-Source	Near-Source	Background
Address	Avon Grove Charter School 110 State Rd West Grove, PA 19390	New Garden Township Town Hall 299 Starr Rd Landenberg, PA 19350	New Garden Airport 1235 Newark Rd Toughkenamon, PA 19374
Monitor Location Municipality	London Grove	New Garden	New Garden
General Monitoring Period	Oct 2021 – Nov 2022	Aug 2021 – Dec 2022	Aug 2021 – Dec 2022
Number Valid Hourly Entries, Aug. 2021-Dec. 2022	7,094	9,823	10,332
Range of all valid entries (ppb)	-1.6-943.3	-0.8-1236.6	-0.1-196.1
Arithmetic mean of all valid hourly entries (ppb)	13.3	20.6	3.8
Median of all valid hourly entries (ppb) (25^{th}, 75^{th}, 90^{th}, 95^{th}, and 97.5^{th} percentiles)	1.8 (0.7, 9.1, 30.2, 65.6, 109.9)	1.5 (0.9, 9.5, 45.6, 104.4, 183.5)	1.0 (0.7, 2.6, 9.1, 16.8, 26.4)
Mode of all valid hourly entries	0.6	1.1	0.7

BAQ shared the quality-assured dataset with PADOH in February 2023, which PADOH analyzed to determine the potential for adverse health effects. PADOH also assessed the ambient H_2S data for each monitor location using the openair package in R to evaluate any daily, weekly, or monthly trends in the detected H_2S (Carslaw and Ropkins 2012).

Our analysis is based on August 2021-December 2022 hourly data that PADOH received. At the time of this report's release, BAQ's H_2S air monitoring in this area has concluded; the West Grove monitor was taken offline on December 31, 2022, and the Landenberg and New Garden Airport monitors were taken offline on October 31, 2023.

4. PADOH Exposure Pathway Analysis, Exposure Unis and Estimates, Screening, and Health Assessment Process

To determine whether August 2021-December 2022 ambient H_2S concentrations could harm health, PADOH followed public health assessment guidelines of the Agency for Toxic Substances and Disease Registry (ATSDR 2023), discussed below.

4.1 Exposure Pathway Analysis

PADOH first conducted an exposure pathway analysis to determine whether resident exposure to H_2S emissions is occurring, may have occurred in the past, or may occur in the future. An exposure pathway is a link between an environmental release or source to the point in which people might come into contact with, or be exposed to, the environmental contaminant (ATSDR 2023). Figure 2 shows a generic example of potential exposure pathways from a release of a contaminant into the environment - in the example below, from an oil drum spill. Exposure pathways and the potential for human exposure will vary based on the specific characteristics of an environmental release and surrounding areas.

Figure 2. Generic Example of Exposure Pathways from an Environmental Contaminant's Release

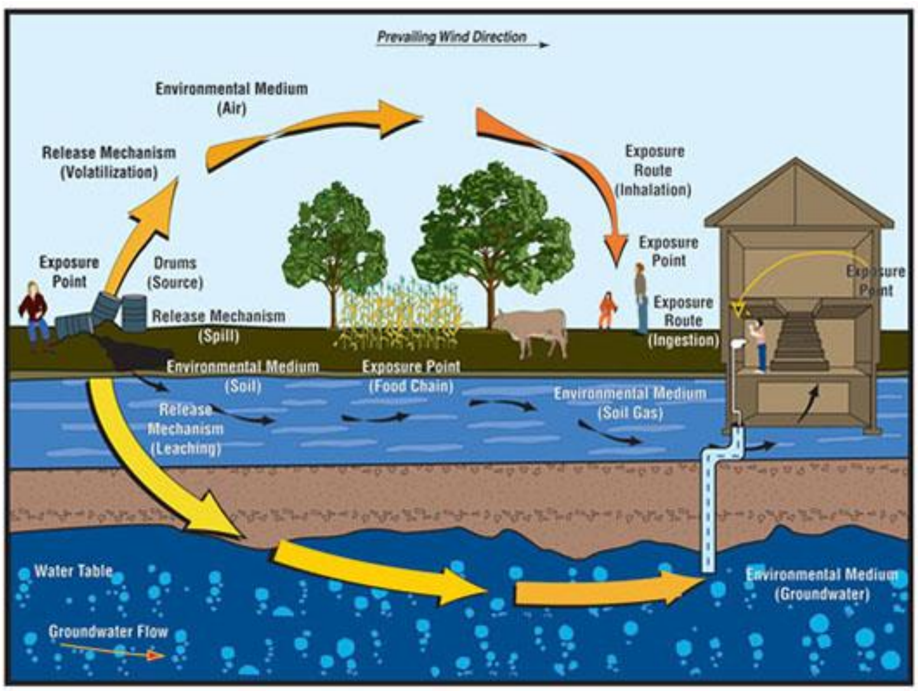


Image source: ATSDR 2023

Being exposed to a contaminant does not mean a person will get sick; whether a person gets sick depends on many factors including the properties and toxicity of a contaminant, the levels of a contaminant, the duration and frequency of exposure, the route of exposure (breathing, ingesting, or making skin contact with a chemical), and the age, genetics, and the overall health of a person (ATSDR 2023).

An exposure pathway consists of:

1. **A contaminant source,** such as an industrial facility, a landfill, or other facility
2. **Environmental fate and transport**, which evaluates whether and how contaminants migrate once released
3. **An exposure point,** which is the location in which people come in contact with site contaminants such as air, drinking water, or soil
4. **An exposure route**, such as inhalation, ingestion, or dermal contact, and
5. **A receptor population** that is exposed to contaminants.

Exposure pathways with all 5 criteria are designated as "completed." If one or more criteria are missing but cannot be eliminated, the pathway is "potential." If one or more criteria are absent and will never be present, the pathway is considered "eliminated." Contaminants in "completed" or "potential" pathways are examined further.

PADOH deemed the exposure pathway for this area as "completed" for past, present, and future exposures for London Grove and New Garden Township residents living near composting operations (Table 2). We attributed mushroom composting as the source of emissions due to historical investigations of composting facilities and odors in this region (PADEP and PADOH 1999) and because odors and H_2S are part of natural processes involving anaerobic bacteria and can occur during operations. We determined that past exposures were occurring because some facilities have operated for several decades. Because operations are ongoing, PADOH determined that present and future exposures are occurring. PADOH next designated exposure units for these communities, discussed in section 4.2 below.

Table 2. PADOH Exposure Pathway Analysis for H_2S Ambient Air Emissions in the Site Area

Source	Environmental Fate and Transport	Exposure Point	Exposure Route	Receptor Population	Designation	Timeline
Nearby Mushroom composting operations	Ambient H_2S emissions that migrate into nearby residential areas	Contact with contaminated air	Inhalation	Residents, workers, and visitors	Completed	Past, present, and future

4.2. Exposure Units

An exposure unit is a geographical area within "completed" or "potential" exposure pathways where a receptor population comes into contact with a contaminant (ATSDR 2023). PADOH deemed residential areas near each of the three monitors as separate exposure units due to their proximity to the monitors and composting operations (Figure 1). As shown in Figure 1, there are residences within a half-mile to a mile of the three monitors as well as residences within this distance to the nearest composting operations. PADOH assessed and compared H_2S levels among exposure units.

4.3. Screening Process and Screening Results

PADOH then screened hourly H_2S levels within each exposure unit against ATSDR comparison values (CVs). CVs are chemical concentrations in a specific medium (e.g., air, soil, or water) at or below which human exposure is unlikely to harm health. CVs rely on default exposure assumptions and are not site-specific. Exceedance of a CV does not indicate that harmful health effects will occur but that a contaminant is further evaluated.

There are cancer and non-cancer CVs. H_2S has only non-cancer CVs because it is not classified as a human carcinogen. ATSDR H_2S inhalation CVs include:

- **Environmental Media Evaluation Guides (EMEGs**) for acute (≤14 days) and intermediate (15-364 day) exposures. EMEGs are derived from ATDSR Minimal Risk Levels (MRLs), which is an estimate of daily human exposure to a contaminant that is not expected to cause harmful non-cancer health effects.
- **Reference Media Evaluation Guides (RMEGs)** for chronic (1 year or more) exposures. RMEGs are derived from U.S. Environmental Protection Agency (EPA) Reference Concentrations (RfCs) representing daily concentrations of a contaminant that are not expected to result in harmful non-cancer health effects over the course of a lifetime.

For each monitor, PADOH compared H_2S maximum levels, maximum 15-day averages, and full monitoring period averages to acute, intermediate, and chronic CVs, respectively. If levels of a contaminant in the environment exceed a CV, it is deemed a "potential contaminant of concern" and further evaluated.

In the case of the three monitors, *maximum* H_2S levels and *full monitoring period averages* exceeded ATSDR acute and chronic CVs (Table 3); **thus, H_2S is a potential contaminant of concern.** At two of three monitors (Landenberg and West Grove) maximum 15-day averages also exceeded ATSDR's intermediate CV. ATSDR H_2S inhalation CVs are set at the same thresholds as ATSDR and EPA H_2S health guidelines. Therefore, ambient H_2S also exceeded ATSDR's acute and intermediate health guidelines, and EPA's chronic health guideline (Table 3). We discuss these guidelines further in sections 4.5 and 5.

Table 3. August 2021 – December 2022 Hourly H_2S Concentrations at the three southern Chester County monitoring locations compared to ATSDR H_2S Comparison Values (CVs)

Monitor	Max* (ppb)	Max Value Exceeds aEMEG? CV / MRL = 70 ppb	Max 15-day avg (ppb)**	Max 15-day avg exceeds iEMEG? CV / MRL = 20 ppb	Full monitoring period avg (ppb) ***	Full monitoring period avg exceeds RMEG? CV / RfC = 1.4 ppb
West Grove	943.3	Yes	37.2	Yes	13.3	Yes
Landenberg	1236.6	Yes	60.9	Yes	20.6	Yes
Airport	196.1	Yes	8.4	No	3.8	Yes

*The maximum hourly average. **Maximum 15-day averages were calculated to assess intermediate (15-364 day) exposures; this is discussed further in section 4.4. ***The average of all hourly averages from each monitor. Avg = average; CVs = Comparison Values; aEMEG = acute Environmental Media Evaluation Guide (EMEG) CV; iEMEG = intermediate EMEG CV; Max = maximum; MRL = Minimal Risk Level; ppb = parts for billion; RfC = EPA's Reference Concentration; RMEG = Reference Media Evaluation Guide

4.4. Estimating Community Exposures to the Potential Contaminant of Concern (H_2S)

PADOH identified H_2S as a potential Contaminant of Concern and assessed it further to determine whether levels occurred long enough, were high enough, or were frequent enough to harm health. This process first involves calculating exposure estimates for the community that adequately represent acute (≤14 days), intermediate (15-364 days), and chronic exposures (a year or longer). The estimates are then compared to acute, intermediate, and chronic health guidelines and effect levels (discussed further in section 4.5) to determine whether exposures at these durations can harm health.

Typically, acute exposure estimates to chemicals (exposures lasting ≤14 days) are adjusted to assume these exposures occur continuously for 24 hours a day during this period (ATSDR 2016a). H_2S has an acute health guideline that is derived from a study for which exposure occurred for 30 minutes (ATSDR 2016b). When assessing the potential for acute health effects, H_2S is one of several point of contact irritants for which short-term exposures are not adjusted to assume continuous 24 hour exposures, because doing so may omit shorter-term (i.e., less than 24 hour) peaks characteristic of H_2S's potential irritant properties and that serve as the basis for ATSDR's acute health guideline (ATSDR 2022a, ATSDR 2016b). Thus, to assess the potential for health effects from **acute** exposures, PADOH assessed the **frequency** of hours at each monitor that exceeded the acute H_2S MRL and approached health effect levels from which this MRL is derived.

Conversely, ATSDR's intermediate health guideline is based on effects for continuous exposures of 24 hours per day during an intermediate exposure period (15-364 days). Thus, to assess the potential for health effects from **intermediate** exposures (15 days up to a year), PADOH calculated **15-day H_2S averages** of the daily averages reported at each monitor during the monitoring period (August 2021 – December 2022). PADOH compared these averages to ATSDR's intermediate H_2S MRL and health effect levels from which it is derived.

EPA's chronic health guideline for H_2S also assumes that exposures occur continuously for 24 hours a day for a year or longer. To assess the potential for health effects from **chronic** exposures (a year or longer), PADOH used the **average** H_2S detected at each monitor **for the entire sampling duration** and compared it to EPA's chronic H_2S RfC and health effect levels from which it is derived.

Due to the time series nature of the dataset, PADOH also evaluated data trends by season, time of day, day of week, and month (Appendices B and C).

4.5. Health Assessment Process

To determine the potential for health effects, PADOH first compared acute, intermediate, and chronic exposure estimates to ATSDR MRLs and EPA RfCs. MRLs and RfCs are non-cancer health guidelines for human exposures to specified contaminants. For inhaled H_2S, ATSDR has MRLs for acute (≤14 day) and intermediate exposures (15-364 days). EPA has an RfC for chronic/lifetime exposures.

As mentioned in section 4.3, MRLs and RfCs are daily estimates at or below which harmful non-cancer human health effects are **not** expected to occur over a specified period (acute, intermediate, or chronic exposures). They have built-in uncertainty factors to account for sensitive populations such as young children, pregnant people, older adults, and people with chronic conditions. They undergo extensive scientific peer-review and are derived from "principal studies" that represent the most sensitive and human-relevant health endpoints based on a contaminant's toxic and chemical properties. As part of this process, EPA and ATSDR identify the principal study's lowest concentrations at which noticeable harmful effects occur. These are called the Lowest Observed Adverse Effect Level (LOAEL). Sometimes, no effects occur at a given concentration; these thresholds are identified as the No Observed Adverse Effect Level (NOAEL). The point of departure, which can be a NOAEL, LOAEL, benchmark dose, or effective dose, is the value selected or calculated from the principal study for later extrapolations or analyses to determine a chemical-specific MRL or RfC.

Often, laboratory animal studies, such as those using mouse or rat models, are used to derive MRLs and RfCs because relevant human studies are lacking (ATSDR 2018). In setting final MRLs or RfCs, ATSDR and EPA apply uncertainty factors (UFs) to a study LOAEL or NOAEL, which are meant to account for factors such as using an animal study to derive the MRL, differences in human variability (e.g., children compared to adults), and other variables. MRLs and RfCs can be as much as a 100-fold below levels found to be non-toxic in laboratory animals.

For non-cancer health effects, an exposure estimate for a chemical that exceeds an MRL or RfC produces a hazard quotient (HQ) above 1. Our exposure estimates for ambient H_2S in southern Chester County produced HQs >1. An exceedance of an MRL or RfC (an HQ >1) does not necessarily mean that harmful health effects will occur, but that a toxicological evaluation is conducted to determine whether harmful health effects are possible. Therefore, to determine the potential for health effects, we conducted a toxicological evaluation by comparing the acute, intermediate, and chronic exposure estimates to the "principal studies" used to derive these H_2S health guidelines. As mentioned, H_2S is not classified as a cancer-causing chemical; therefore, we only assessed the potential for non-cancer effects. We also evaluated exceedances of H_2S odor thresholds and briefly evaluated peer-reviewed epidemiological studies of other communities that live near H_2S sources.

Our toxicological evaluation is provided in section 5.

5. Public Health Implications of Ambient H_2S in Southern Chester County

5.1. H_2S Overview

H_2S is a flammable, colorless gas that smells like rotten eggs (ATSDR 2016b). Natural sources include gases from volcanoes, sulfur springs, swamps and bogs, areas of high geothermal activity, crude petroleum, and natural gas. Bacteria, fungi, and actinomycetes (a type of mostly anaerobic bacteria) also release H_2S when sulfur-containing proteins decompose (ATSDR 2016b). Industrial sources include but are not limited to landfilling, municipal sewage pumping and treatment plants, manure treatment facilities, pulp and paper production, petroleum refining, coke production plants, and food processing plants. The human body also makes small amounts by natural bacteria in the mouth and when bacteria breaks down some types of proteins in the gut.

The level at which people can smell H_2S in air, also referred to as an odor threshold, varies widely and ranges from 0.0005-0.3 parts per million (ppm), or 0.5-300 parts per billion (ppb). People are primarily exposed to H_2S by breathing it, and since it naturally occurs in the environment, the general population will have some exposures. Typically, these exposures are low; concentrations in urban air are generally less than 1 ppb (ATSDR 2016b). People who live near places like farms with manure storage, landfills, pulp or paper mills, oil and gas operations or wastewater treatment plants might have higher levels of exposure. People who work in these types of industries can also have higher exposures. H_2S lasts in air for approximately 1 day in summer to 42 days in winter (ATSDR 2016b). Once inhaled, it's primarily absorbed in the lungs and then distributed in the bloodstream throughout the body. It's primarily converted to sulfate before it's excreted by urine. It's removed from the body rapidly (ATSDR 2016b).

H_2S is a respiratory irritant and human and animal studies have consistently shown that the respiratory and neurological systems are most sensitive to its toxicity (ATSDR 2016b). Typical environmental levels are not likely to cause health effects, but studies of communities and occupations near sources of H_2S pollution have reported increases in respiratory symptoms such as nasal symptoms, cough, throat irritation, shortness of breath, worsening of asthma symptoms, and alterations in lung function (ATSDR 2016b). Generally, lung function alterations have not been significant, but there is some evidence suggesting that people with asthma may be a sensitive population (ATSDR 2016b). Some human studies have also found subclinical neurological effects such as alterations in balance, reaction time, verbal recall, and memory, or physiological effects such as fatigue, irritability, poor memory, headaches, and stress (ATSDR 2016c). In most community studies, environmental monitoring is limited, and people in these settings were also exposed to compounds such as ammonia, methyl mercaptan, methyl sulfides, or sulfur dioxide. H_2S gas is also an eye irritant (ATSDR 2016b).

Exposures to high levels of H_2S (≥ 100 ppm or 100,000 ppb) can lead to olfactory paralysis, meaning you can no longer smell H_2S. Brief (less than an hour) human exposures of approximately 500 ppm (500,000 ppb) H_2S and higher have resulted in unconsciousness (known as "knockdown") or death, which has been observed in case reports of accidental H_2S poisonings. In most cases, following prompt removal of exposure, the person recovers and regains consciousness without any other effects. However, in some individuals after knockdown, there may be permanent or long-term effects such as headaches, poor attention span, poor memory, and poor motor function (ATSDR 2016b). Most fatal cases have occurred in confined spaces such as sewers, animal processing plants, tanks, cesspools, as well as plumbing system failures that allow sewer gas to flow back into a home or building.

H_2S has not been shown to cause cancer in humans, and animal data are inadequate to make a cancer determination.

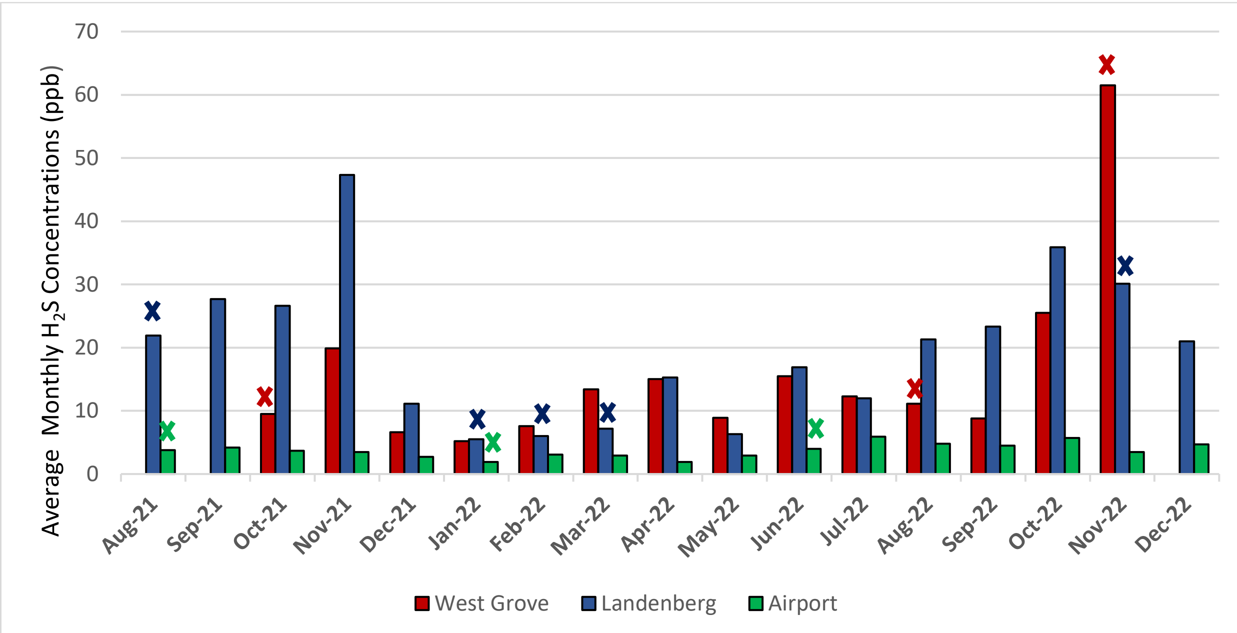
5.2. Overview of H_2S levels detected at three monitoring sites

The Landenberg monitor had the highest H_2S concentrations (range: -0.8-1236.6 ppb; average: 20.6 ppb), followed by the West Grove monitor (range: -1.6-943.3 ppb; average: 13.3 ppb) and the Airport/background monitor (range: -0.1-196.1 ppb; average: 3.8 ppb; Tables 1 and 3). Maximum concentrations at all three monitors exceeded ATSDR's acute (70 ppb) and intermediate MRL (20 ppb) as well as EPA's RfC (1.4 ppb). Average concentrations at the three monitors were also above EPA's RfC of 1.4 ppb. In addition, at one of the three monitors (Landenberg), average H_2S for the sampling period (20.6 ppb) exceeded ATSDR's intermediate MRL (20 ppb).

Median and mode values were notably lower than averages, indicating wide variability and fluctuations in H_2S concentrations, characterized by episodic peaks on certain nights and early mornings that raised averages overall, with generally lower values during the day. Although medians were notably lower (range: 1.0-1.8 ppb) they exceeded U.S. background levels for urban air, which are generally less than 1 ppb (ATSDR 2016b). Higher levels of ambient air H_2S at ≥ 0.09 ppm (90 ppb) have been observed in communities near industries releasing H_2S or near natural sources of H_2S (ATSDR 2016b).

General data trends are provided in **Appendix B (as tables)** and **C (as graphs).** At the West Grove and Landenberg monitors, nearly all of the highest H_2S values occurred between 10 pm and 7am (Appendix Table B1). The highest averages were found during fall months (Figure 3; Appendix Table B2).

Figure 3. Monthly average H_2S concentrations (ppb) at each monitor, August 2021-December 2022



Note: X symbols in Figure 3 denote that the average encompasses less than 80% of days for that month of valid hourly data. Calculated monthly averages only include days in which there were 80% or more (20 hours or more) of valid data available. Monitoring started in mid-August 2021, therefore all monitors had less than 80% valid days in August 2021. The West Grove monitor had <1 day of valid hourly data in August 2021, <5 days of valid monitor data in August and November 2022, and no days of valid data in September 2021 and December 2022. Appendix Table B2 provides the number of valid days of data per month.

Even on days of the highest nighttime or early-morning H_2S levels, mid-morning, midday and afternoon levels were usually much lower – generally around 2-5 ppb (Appendix C). PADOH notes that the lowest H_2S levels shown as occurring around 12 pm and 1 pm (Appendix C) are biased low, as they are based on very limited data. As mentioned, the Teledyne instrument had automated calibration checks nearly every day during these hours, which rendered most data during these hours as invalid.

Appendix C shows graphs and trends of the data, including a display of all valid hourly averages (Figure C1) and the daily averages at each monitor during the monitoring period (Figures C2-C4). Near-source H_2S averages were highest in October and November 2021-2022 and on Tuesdays and Fridays (Figure C5). H_2S averages tended to decrease on Saturdays and Sundays before rising again on Tuesdays, with the highest averages at nighttime or in the early morning before decreasing to lower levels during the day.

Compared to fall months, H_2S levels were moderately lower in spring and summer, and lowest in January and February. Mushroom growing occurs year-round; thus, these patterns in H_2S levels are likely also influenced by seasonal changes in weather such as temperature, wind speed and wind direction, and/or temperature inversions that could affect H_2S dispersion in addition to or in combination with facility operations. In addition, many 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 (MDHSS 2022). The present analysis does not account for monitor-specific meteorological data; BAQ recently sent PADOH monitor-specific meteorological data that PADOH will review as part of a follow-up report if necessary.

Medians at the 2 near-source monitors were usually much lower than averages, at roughly 1-2 ppb. H_2S 95^{th} percentiles were far higher and almost always occurred in the nighttime and early morning as described above (Figures C6-C8).

H_2S levels at the Airport background monitor generally followed the above trends but had much lower levels. Its highest levels were in July (Figures C5, C8).

In addition to examining H_2S trends, we assessed the potential to cause health effects, discussed below.

5.3. Potential for Health Effects from Acute (≤14 day) Exposures

Acute exposures are defined as lasting less than or equal to 14 days (ATSDR 2023). As mentioned in section 4.4, H_2S acute exposure estimates are not adjusted to assume exposures last for 24 hours a day during this period because doing so may omit shorter-term peaks characteristic of H_2S's potential irritant properties that are the basis for ATSDR's H_2S acute Minimal Risk Level (MRL). To assess the potential for health effects from acute exposures, we evaluated the hours in which outdoor H_2S exceeded ATSDR's acute MRL of 70 ppb and approached the health effect level from which this MRL is derived. As shown in Table 4 below, approximately 7%, 5%, and 0.3% of hourly concentrations at the Landenberg, West Grove, and New Garden Airport monitors, respectively, exceeded ATSDR's **acute** inhalation MRL of 0.07 ppm (70 ppb).

Table 4. Frequency of hourly H_2S averages that exceeded ATSDR's acute Minimal Risk Level (MRL), August 2021-December 2022

Monitor	Number (%) exceedances of ATSDR's acute MRL (70 ppb)
West Grove	332 / 7094 (4.7%)
Landenberg	695 / 9823 (7.1%)
New Garden Airport (Background)	31 / 10332 (0.3%)

MRL = Minimal Risk Level; ppb = parts per billion

ATSDR's acute MRL of 70 ppb is derived from the selected principal study on adults with asthma by Jappinen et al. 1990 (ATSDR 2016b). In this study, ten adults with bronchial asthma (though none had severe asthma) were exposed to 2 ppm (2,000 ppb) H_2S in a sealed chamber (known as a "controlled exposure study") for 30 minutes. When evaluated as a group, there were no statistically significant differences in airway resistance (Raw), specific airway conductance (SGaw), forced vital capacity (FVC), forced expiratory volume (FEV), and forced expiratory flow. However, two of ten adults had >30% changes in Raw and SGaw, suggestive of bronchial obstruction, and three adults reported headaches (ATSDR 2016b). The study's acute LOAEL was 2 ppm (2,000 ppb) based on the effects suggestive of bronchial obstruction. ATSDR applied a total uncertainty factor (UF) of 27, where x3 UF was applied for use of a LOAEL, x3 UF was applied to account for human variability, and x3 UF was applied for database deficiencies. ATSDR's final acute inhalation MRL is 0.07 ppm (2 ppm_{LOAEL} / 27_{UF} = 0.07 ppm), or **70 ppb** (2,000 ppb_{LOAEL}/27_{UF} = 70 ppb).

Acute H_2S exposures that exceed 70 ppb do not necessarily indicate that adverse effects will occur. However, as H_2S exposures increase and approach effect levels of the principal study (2,000 ppb H_2S), the risk for these acute effects increases, particularly to more susceptible people including those with chronic respiratory disease, such as asthma. People with severe asthma are more likely to experience respiratory effects compared to the general public or compared to people with less severe respiratory conditions (MDHSS 2022).

The highest hourly H_2S averages at the 2 near-source monitors were 1,236.6 ppb (Landenberg) and 943.3 ppb (West Grove). The highest hourly averages did not exceed the LOAEL of the Jappinen et al. 1990 study of 2,000 ppb, but were within an order of magnitude, or at or within 10 times of this LOAEL, on 2.2% and 0.9% of respective hours (Table 5). At such levels – 200 ppb and above – the risk of acute health effects increases, particularly for sensitive individuals. In addition, the acute MRL is based on a 30-minute exposure study in humans. Because the data used for this assessment are hourly averages, it is possible that 30-minute H_2S concentrations at the two near-source monitors were higher than their hourly averages, and potentially higher than the Jappinen et al. principal study LOAEL of 2,000 ppb. The Jappinen et al. 1990 study only included adults with asthma, not children or people with severe asthma; these people might be more sensitive at H_2S concentrations below 2,000 ppb.

Table 5. Acute exposures: Frequency of hourly H_2S averages that exceeded 200 ppb, August 2021-December 2022

Monitor	Number (%) of detections ≥200 ppb (≤10 times less than the human equivalent LOAEL of 2,000 ppb used to derive ATSDR's acute MRL)
West Grove	62 / 7094 (0.9%)
Landenberg	221 / 9823 (2.2%)
New Garden Airport (Background)	0 / 10332 (0.0%)

MRL = ATSDR Minimal Risk Level; LOAEL = Lowest Observed Adverse Effect Level of Jappinen et al. (1990); ppb = parts per billion

Therefore, acute exposures to H_2S levels during certain hours and days may have been a health hazard to certain people living and working near the Landenberg and West Grove monitors, particularly sensitive individuals such as children, older adults, or people with respiratory conditions. These sensitive populations may have experienced acute respiratory effects such as narrowed airways, chest tightness, or difficulty breathing. On certain days the levels detected may have also aggravated asthma or other chronic respiratory conditions. There is some epidemiological support for asthma exacerbations from short-term H_2S exposures; a brief review is provided in Section 6.

The peaks at or above 200 ppb at the West Grove and Landenberg monitors were relatively infrequent – above the 97.5^{th} percentile of H_2S levels at each monitor (Table 1). However, it is possible they posed an acute health risk. Additionally, nearly all of the highest H_2S levels occurred during the nighttime or very early morning on certain days (Appendix Table B1). People are less likely to be outside during these hours but could still be exposed if opening windows at night during episodes of higher H_2S. Appendix

Figures C9 and C10 show dates, shaded purple, in which maximum hourly concentrations exceeded 200 ppb. On these days, risk for the effects described above may have been elevated, especially for sensitive individuals.

It is important to note that elevated *risk* does not guarantee that people will experience or have experienced these effects on the above dates when H_2S concentrations were highest. Elevated risk means there is a higher ***probability*** or likelihood that adverse health effects may be experienced. Whether an exposure produces an adverse health outcome is influenced by characteristics of exposure but also factors such as age, sex, nutritional status, developmental stage, genetic factors, or existing underlying conditions.

5.4. Potential for Health Effects from Intermediate (15-364 Day) Exposures

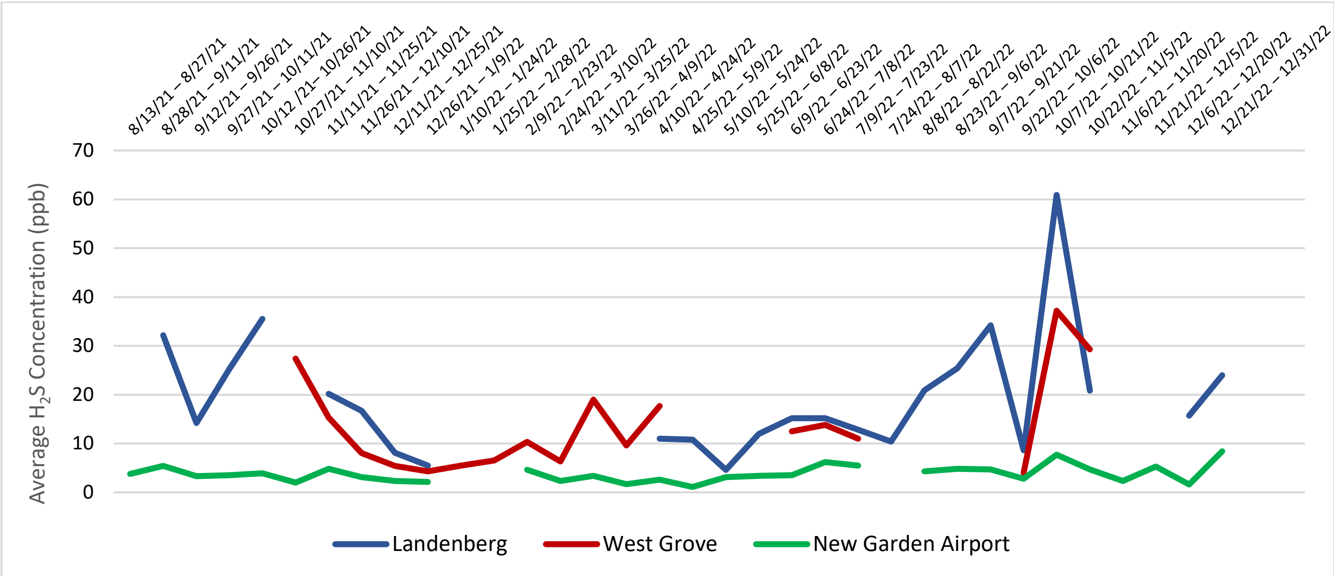
Intermediate exposures are defined as exposures lasting between 15 and 364 days (ATSDR 2023). For H_2S and other compounds, it is assumed that these exposures occur continuously during this period (24 hours a day), under a residential exposure scenario (ATSDR 2022a).

ATSDR's intermediate MRL is 20 ppb. It is derived from a study by Brenneman et al. 2000 that found that rats exposed to H_2S for six hours a day for ten weeks experienced nasal lesions and olfactory neuron loss (ATSDR 2016b; MDHSS 2022). Rats in groups of 12 were exposed to H_2S in air at 0 ppm, 10 ppm, 30 ppm and 80 ppm (0 ppb, 10,000 ppb, 30,000 ppb, or 80,000 ppb) during the 10-week period. Evidence for olfactory neuron loss and nasal lesions first occurred at 30 ppm (30,000 ppb), the study's LOAEL. No effects occurred at 10 ppm (10,000 ppb), the study's NOAEL.

ATSDR adjusted the study's NOAEL (10 ppm, or 10,000 ppb) to account for continuous exposures of 24 hours per day rather than the 6-hour intermittent exposures of the principal study. This resulted in an adjusted NOAEL of 2.5 ppm (2,500 ppb). ATSDR then applied an EPA dosimetric model to adjust for differences in rat and human breathing rates and surface area. ATSDR's final NOAEL representing *human-equivalent concentrations* (HECs) was 0.46 ppm (460 ppb). ATSDR divided this NOAEL by a total UF of 30: x3 UF for extrapolating a rat study to humans after using a dosimetric model, and x10 UF for human variability. ATSDR's final inhalation intermediate MRL for H_2S is 0.02 ppm (20 ppb) (ATSDR 2016b).

To estimate intermediate exposures in southern Chester County, PADOH calculated 15-day H_2S averages for each monitor, beginning at the start of the monitoring period (August 13, 2021). PADOH only included 15-day periods that had at least 12 days (12/15 = 80%) of valid data. We only included days that had at least 20 valid hours (≥ 80% of hours) as part of the calculation. Results are shown in Figure 4.

Figure 4. 15-Day H_2S average concentrations (ppb) at each monitor, August 2021-December 2022



Note: Breaks in the data in Figure 4 indicate lack of valid data during the respective 15-day period.

As shown in Figure 4, the highest 15-day average was 60.9 ppb at the Landenberg monitor, from 10/7/2022 – 10/21/2022. Although exceeding ATSDR's intermediate MRL of 20 ppb, this maximum 15-day average is below the human-equivalent NOAEL of 460 ppb from the Brenneman et al. 2000 study, which was the point-of departure value that was used to derive ATSDR's intermediate MRL. **Therefore, adverse health effects (nasal lesions and evidence of olfactory neuron loss) are unlikely to occur from H_2S exposures of intermediate duration (15-364 days).** PADOH notes that the highest average overall within a 15-day period was 104.6 ppb at the Landenberg monitor, between 10/27/2021 – 11/10/2021; however, 5 days during this 15-day period were missing complete (≥ 80%) hourly data (Appendix Table B3).

Assessing different 15-day periods than that which was assessed in Figure 4 could result in different intermediate exposures which could change the likelihood of intermediate effects. However, PADOH found that rolling 2 week averages that account for any consecutive 15-day period of valid data were similar to the concentrations shown in Figure 4 above.

While further study is needed on intermediate-duration exposures to H_2S, particularly in humans, it is unlikely that the principal study effect of nasal lesions and olfactory neuron loss would occur, based on our exposure estimates for southern Chester County.

Although these effects are unlikely, PADOH acknowledges a degree of uncertainty with this conclusion because the highest 15-day (60.9 ppb; Figure 4) and monthly H_2S averages (47.3 ppb; Appendix Table B2), while lower than the principal study NOAEL of 460 ppb, were within the margin of uncertainty factors used to derive ATSDR's much lower intermediate MRL of 20 ppb. To significantly lower risk of intermediate health effects from H_2S, any average or rolling average H_2S concentration of 15-364 days' duration should be at or below ATSDR's intermediate MRL of 20 ppb.

5.5. Potential for Health Effects from Chronic (1 year or longer) Exposures

Chronic exposures are defined as lasting a year or longer (ATSDR 2023). For H_2S and other compounds, it is assumed that these exposures occur continuously (24 hours a day) during this period, under a residential exposure scenario (ATSDR 2022a).

ATSDR lacks a chronic inhalation MRL for H_2S. EPA, however, has a chronic RfC of 0.002 milligrams per cubic meter (mg/m^3), which equates to 1.4 parts per billion (1.4 ppb) for lifetime exposures. EPA's RfC is derived from the Brenneman et al. 2000 study that found nasal lesions and olfactory neuron loss in rats. This is the same study that ATSDR used to derive its intermediate MRL for H_2S. EPA adjusted the study's NOAEL and LOAEL for continuous exposures and applied a rat to human dosimetric adjustment, resulting in human-equivalent concentrations of 1.9 mg/m^3 (LOAEL[2]) and 0.64 mg/m^3 (NOAEL).[3] EPA selected the study NOAEL of 0.64 mg/m^3 as the point of departure; a NOAEL of 0.64 mg/m^3 is the same as 640 micrograms per cubic meter ($\mu g/m^3$), or approximately 460 ppb. To determine the RfC, EPA divided the NOAEL by a total UF of 300, where x10 UF was applied for use of a subchronic study to derive its chronic RfC, x10 UF was applied to account for sensitive populations, and x3 UF was applied to account for interspecies extrapolation from rat to human after dosimetric adjustment. EPA's final RfC is 0.002 mg/m^3 ($0.64\ mg/m^3{}_{NOAELHEC} / 300_{UF} = 0.002\ mg/m^3$; EPA 2003). In parts per billion (ppb), an RfC of 0.002 mg/m^3 is the same as 2 $\mu g/m^3$, or 1.4 ppb.

We estimated chronic exposure using each monitor's average during the monitoring period. Average H_2S concentrations at all three monitors exceeded EPA's RfC of 1.4 ppb (Table 1). Median concentrations (1-1.8 ppb) were more comparable to EPA's RfC (Table 1).

Daily concentrations of H_2S should be at or below EPA's RfC of 1.4 ppb to significantly reduce lifetime risk when area H_2S is present. As shown in Appendix Figures C2-C4, this was often **not** the case for the Landenberg and West Grove monitors, and to a much lesser extent, the Airport monitor. However, each monitor's average H_2S concentrations for the entire monitoring period (Airport: 3.8 ppb, West Grove: 13.3 ppb, and Landenberg: 20.6 ppb; Table 1) were below the NOAEL (460 ppb) from the principal study that was used to derive EPA's RfC. **Therefore, adverse health effects (nasal lesions and olfactory neuron loss) are unlikely to occur from H_2S exposures of chronic duration.**

5.6. Potential for Health Symptoms from H_2S Odors

5.6.1. Overview of Odors, Health Symptoms, and Stress

Some people perceive and are more sensitive to environmental odors than others. Generally, younger people, women, and people with chronic respiratory conditions tend to be more sensitive to environmental odors. Pregnant women may also be more likely to suffer nausea from odors (MDHSS 2022). H_2S has an objectionable odor that people can detect at low levels relative to many other compounds. Detectable odors in outdoor air for most compounds including H_2S are below levels known to produce a toxic effect or cause serious long-term effects (ATSDR 2015; ATSDR 2017). However, a

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[2] An H_2S LOAEL of 1.9 mg/m^3 is 1,363 parts per billion (ppb).

[3] In deriving an RfC in mg/m^3 from the Brenneman et al. 2000 principal study, EPA first adjusted the study's NOAEL of 10 ppm to 13.9 mg/m^3 and the study's LOAEL of 30 ppm to 41.7 mg/m^3. In making these conversions, EPA assumed a molecular weight of 34.08 g/mol H_2S at 25°C and 760 mmHg. EPA then made the conversion to assume continuous exposures with a rat-to-human dosimetric adjustment. Further details are provided in EPA 2003.

substantial body of research shows that offensive odors can cause temporary health symptoms – most commonly headache and nausea (PADOH 2019; ATSDR 2015). Other effects might include dizziness, watery eyes, irritated throat, coughing or wheezing especially among people with asthma or chronic lung problems, and sleep problems due to respiratory irritation (ATSDR 2015; ATSDR 2017). Usually, symptoms resolve when the odor goes away, but in sensitive people, odors can worsen chronic medical conditions or produce symptoms that last longer (PADOH 2019). Some individuals develop learned responses to certain odors such that repeated perceptions of that odor may trigger symptoms, such as asthma attacks in people with asthma (MDHSS 2022).

H_2S is unique in that people can smell it as low as 0.0005 ppm (0.5 ppb), but at very high levels (≥ 100 ppm or 100,000 ppb) individuals might not be able to smell it due to olfactory paralysis (ATSDR 2016b).

Regardless of whether odors cause acute health symptoms, they can affect quality of life. Environmental odors can cause stress, particularly if they are viewed as unpredictable or uncontrollable (MDHSS 2022). Chronic stress can lead to a number of conditions including anxiety, depression, increased inflammatory responses, susceptibility to infection, or impaired immune responses (MDHSS 2022). Stress can also lead to behaviors that increase risk of health problems such as poorer sleep or nutrition, lack of exercise, or increased smoking or alcohol consumption (MDHSS 2022).

5.6.2. H_2S Odor Exceedances in Southern Chester County

In the scientific literature, H_2S odor detection is highly variable at 0.0005-0.3 ppm (0.5-300 ppb) (ATSDR 2016b). There have been varied estimates of its detection threshold for the general population. The World Health Organization suggested that to avoid odor annoyance, a 30-minute average H_2S should not exceed 0.005 ppm (5 ppb) (WHO 1981). A 1985 report by Amoore reviewed 26 published reports that assessed average odor detection thresholds for H_2S (Amoore 1985). Averages showed wide variation and from these averages, Amoore calculated a geometric mean (which he noted as numerically equal to the median) of 0.008 ppm (8 ppb). At this threshold, Amoore suggested that H_2S might be bothersome to 11% of a population. Amoore also reported that the true odor detection threshold is likely between 0.005 and 0.12 ppm (5-12 ppb) (Amoore 1985). Amoore reported that at 0.03 ppm (30 ppb), the odor could be detected by 83% of a population and bothersome to 40%, and at 0.04 ppm (40 ppb), the odor might be bothersome to half of a population (Amoore 1985). The state of California set a 1-hour recommended exposure limit (REL) for H_2S at 0.03 ppm (30 ppb) based on Amoore's 1985 study and reports of physiological headache, nausea, and other symptoms at this threshold (OEHHA 2008; MDHSS 2022). California's Air Resources Board suggests that on a population basis, average H_2S odor detection is between 0.03-0.05 ppm (30-50 ppb) (CARB, n.d.).

Table 6 shows number of hourly H_2S concentrations that exceeded reported odor thresholds of 0.008 ppm (8 ppb) and 0.03 ppm (30 ppb) at the three monitors.

Table 6. Number of hourly H_2S concentrations at or above 8 and 30 ppb odor thresholds at each of the three monitors, August 2021-December 2022

Monitor	Number (%) of detections ≥ an 8 ppb odor threshold*	Number (%) of detections ≥ a 30 ppb odor threshold**
West Grove	2028 / 7094 (28.6%)	717 / 7094 (10.1%)
Landenberg	2609 / 9823 (26.6%)	1339 / 9823 (13.6%)
Airport (Background)	1188 / 10332 (11.5%)	205 / 10332 (2.0%)

*8 ppb = H_2S concentration thought to be bothersome to approximately 11% of the population (Amoore 1985); **30 ppb = Threshold H_2S concentration thought to be detected by 83% of the population and bothersome to 40% (Amoore 1985; MDHSS 2022); ppb = parts per billion

Not everyone reacts the same way to environmental odors. Some people might not detect odors at or above 30-ppb H_2S, find them a nuisance, or experience health symptoms. **Nonetheless, the data for southern Chester County show that common H_2S odor thresholds are regularly exceeded, indicating a chronic nuisance odor problem for this community. H_2S levels routinely reached odor thresholds that have been reported to result in headaches, nausea, and other physiological symptoms (Table 6).** Odor threshold exceedances were most frequent at the West Grove and Landenberg monitors. An odor threshold of 30 ppb was commonly exceeded in the nighttime or very early morning, and occasionally during mid-morning or mid-afternoon hours.

Appendix Figures C4-C6 and C13-C15 show average and maximum H_2S concentrations for each day of monitoring, respectively. As levels increase a greater percentage of people will detect the odor and/or be affected. In the figures, days of average H_2S concentration of 30 ppb and above are shaded orange, with higher levels shaded red and purple.

There were also multiple 15-day periods and months in which average H_2S levels exceeded 8 ppb, or less commonly, 30 ppb (Figures 3 and 4; Appendix Tables B2 and B3), which further underscores the chronic nuisance odor problem in this community.

5.7. Summary of Potential Health Effects from H_2S in Southern Chester County

PADOH found that August 2021-December 2022 acute H_2S exposures near the West Grove and Landenberg monitors may have posed a public health hazard for acute respiratory health effects such as chest tightness, difficulty breathing, or narrowed airways, particularly in people with asthma or other respiratory conditions, or other sensitive populations. On certain days at the Landenberg and West Grove monitors, peak hourly H_2S levels approached thresholds that are capable of producing bronchial obstruction in adults with asthma who were exposed for 30 minutes. **If current H_2S levels (and peaks) at these locations are similar to levels of August 2021-December 2022, their concentrations remain a health hazard for acute effects in certain people, particularly for sensitive individuals.**

PADOH found that intermediate and chronic adverse health effects (nasal lesions and olfactory neuron loss) were unlikely to occur. Our exposure estimates for area H_2S, when averaged over longer time periods, exceeded ATSDR and EPA health guidelines for intermediate and chronic/lifetime exposures, of 20 ppb and 1.4 ppb, respectively. However, our estimates were below human-equivalent concentrations of 460 ppb (the principal study's NOAEL) that serve as the basis for these guidelines, at which no effects are estimated to occur from continuous, 24 hour per day exposures of intermediate (15-364 days) and chronic (a year or longer) duration. Our estimates were also below the principal study's effect level for nasal lesions and olfactory neuron loss (at a human-equivalent LOAEL of 1.9 mg/m^3, or 1,363 ppb) from continuous, longer-term exposures.

Long-time residents of an area can have acute, intermediate, or chronic exposures; they are not mutually exclusive. The August 2021-December 2022 H_2S data for southern Chester County are characterized by acute, episodic peaks. These episodes reach higher H_2S levels and then often drop to lower levels, as opposed remaining continuous at higher levels. Hence, short-term and/or repeated acute health effects during these episodic peaks are more likely to occur for nearby residents than effects from continuous intermediate or chronic exposures.

Although intermediate and chronic health effects are unlikely to occur, PADOH acknowledges a degree of uncertainty in this conclusion. Our intermediate and chronic exposure estimates were lower than the continuous threshold at which no adverse human health effects are estimated to occur (460 ppb); however, they were within the margins of uncertainty used to derive ATSDR and EPA's much lower intermediate and chronic H_2S health guidelines, of 20 ppb and 1.4 ppb, respectively – including within the margins of uncertainty factors that seek to account for human variability and/or sensitive populations. In addition, due in part to limitations in epidemiological studies (discussed further in section 6), there is currently limited scientific understanding on the potential for human health effects from low-dose intermediate or chronic H_2S exposures.

As mentioned in section 5.1., brief exposures to very high levels of H_2S in air, at approximately 500,000 ppb and above, can cause loss of consciousness or be fatal under certain circumstances. Hourly H_2S levels at the monitoring locations were much lower than these severe effect levels. Other disabling effects from H_2S exposures less than an hour duration are estimated to occur above 27 ppm (27,000 ppb), depending on the duration of exposure.[4] PADOH may consider a review of additional quality-assured data for this area, including data representing shorter exposure durations (i.e., less than an hour), if deemed representative of community exposures.

PADOH found that common odor thresholds are regularly exceeded, indicating a chronic nuisance odor problem that could result in headaches, nausea, stress, or similar symptoms among community members.

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[4] This estimate of above 27 ppm is a Level 2 Acute Exposure Guideline Level (AEGL-2) for 1 hour exposures. AEGLs are used by emergency planners and responders as guidance in dealing with rare and usually accidental releases of chemicals into the air (EPA 2024). They are calculated for shorter exposures (10 minutes, 30 minutes, an hour, 4 hours, and 8 hours) and are predictions of short-term exposures to a chemical that could harm the general population and susceptible individuals. AEGLs are expressed in 3 levels: 1) Level 1 (AEGL-1) for discomforting and irritating effects, but reversible effects once exposure stops; 2) Level 2 (AEGL-2) for irreversible, disabling, or other lasting health effects, or an impaired ability to escape, and 3) Level 3 (AEGL-3) for life-threatening health effects. AEGL-2s for H_2S range from 17-41 ppm (i.e., above 17,000 ppb to above 41,000 ppb), at 17 ppm (8-hour exposure), 20 ppm (4 hour exposure), 27 ppm (1 hour exposure), 32 ppm (30 minute exposure), and 41 ppm (10 minute exposure).

6. Summary of epidemiological studies on community exposures to nearby ambient H_2S

As discussed in sections 5.4 and 5.5, EPA and ATSDR intermediate and chronic health guidelines for inhaled H_2S are derived from the same animal study. The current epidemiological evidence is limited due to factors such inadequate exposure assessment and co-exposures to other chemicals (ATSDR 2016b). Still, there have been a few studies of communities living near H_2S sources.

Generally, acute effects from community H_2S exposures have been most commonly reported. Most findings of elevated risk are for effects such as asthma exacerbations, respiratory ailments (cough, sore throat, nasal irritation, difficulty breathing), headache, and/or neurological or neurobehavioral changes (Jaakkola et al. 1990; Kilburn 2012; Batterman et al. 2023). Reports of nuisance odors were common in the studies.

A notable study by ATSDR of Dakota and Sioux City, Nebraska (Campagna et al. 2004) found that days with one or more 30-minute rolling average of ≥30 ppb H_2S was associated with following-day hospital visits for all respiratory diseases, including asthma, in children (ATSDR 2016b). When evaluating asthma solely, a statistically significant association was found for adults but not children. The primary sources of H_2S were a beef slaughter facility and leather tanning facility; total reduced sulfur (TRS) compounds were also measured. There was no individual level data collected in this study, and it is not possible to determine whether a 30 ppb cut-off is a threshold for population response to H_2S (MDHSS 2006). Yet the results suggest that children with asthma or people with respiratory conditions might be particularly susceptible to acute H_2S exposures, lending support to the notion that people with asthma might be more affected. The 30-minute rolling average of ≥30 ppb H_2S used in this study is below ATSDR's acute MRL of 70 ppb.

Not all studies have found associations, including some of the larger studies assessing chronic exposures and health outcomes, such as neurobehavioral effects, lung function, asthma or wheezing, or peripheral nerve function (Bates et al. 2013, 2015; Reed et al. 2014; Pope et al. 2017; Inserra et al. 2004). Differences in findings are likely attributable to contrasting measurement methods, study populations, and statistical analyses.

As noted by reviews by ATSDR (2016b) and Batterman et al. (2023), many long-term studies remain limited due to co-pollutant exposures, exposure measurement limitations, small sample sizes, and concerns of study representativeness. More long-term studies are needed to confirm findings at lower exposures and to refine exposure guidelines (Batterman et al. 2023).

7. Assessing H_2S Concentrations and Community Concerns

7.1. Odors, Asthma, and Headache

In March 2020, your office informed PADOH that residents were complaining of odors, headaches, and effects on asthma. As mentioned, based on the August 2021-December 2022 ambient H_2S data, PADOH found that common odor thresholds are being exceeded that could lead to headaches, nausea, fatigue, and other effects common from environmental odors. These thresholds were most frequently exceeded at the Landenberg and West Grove monitors. PADOH also found that the highest hourly H_2S levels at the Landenberg and West Grove monitors approached thresholds that could lead to narrowed airways, chest tightness, or difficulty breathing, particularly in people sensitive or susceptible to these effects and/or people with respiratory conditions such as asthma.

7.2. Corroding metals affecting the function of outdoor air conditioning units

Residents have complained that ambient H_2S has corroded outdoor air conditioning units. PADOH acknowledges this complaint, but this concern is not a health complaint. Therefore, PADOH is not the entity qualified to address this complaint.

7.3. Lung nodules

In October 2022, PADOH received a concern of a resident living near a mushroom composting operation who experienced recurring lung nodules.

A lung nodule is a small growth on the lung that is more dense than normal lung tissue. According to the American Thoracic Society, it appears as a white spot on a CT scan and is usually caused by scar tissue, a healed infection, or some irritant in the air (American Thoracic Society 2020). Nodules are found in up to half of adults who get a chest x-ray or CT scan and most are about a half inch in size. Generally, they do not cause any noticeable problems (American Thoracic Society 2020). Most lung nodules are not cancer, but for a small amount of people, they can turn out to be an early stage of lung cancer (American Thoracic Society 2020).

H_2S is a respiratory irritant that is absorbed in the lung and bloodstream; however, it is not classified as a carcinogen, and current scientific literature is too limited to determine whether H_2S causes lung nodules. A study by Dorman et al. 2004 on laboratory rats found lung lesions (bronchiolar epithelial hypertrophy and hyperplasia) in rats exposed to H_2S at least 30,000 ppb and higher for 6 hours a day for 90 days (ATSDR 2016b). Additional study and evidence are needed on the association between human exposure to H_2S and occurrence of lung nodules.

8. Conclusions and Recommendations

Currently, the PADEP's BAQ's air monitoring of this area has concluded. Based on our review of BAQ's hourly ambient H_2S data of Southern Chester County from August 2021-December 2022, PADOH has reached the following conclusions:

1. **Ambient H_2S at the Landenberg and West Grove monitors may have been a public health hazard for acute respiratory effects in certain individuals, particularly sensitive populations (such as children or older adults) and/or those with chronic respiratory conditions such as asthma**. Certain residents living near the Landenberg and West Grove monitors may have experienced worsening of asthma, chest tightness, difficulty breathing, or similar effects on certain days of the highest H_2S levels (nearly all of which happened at night or very early morning). These hourly peaks, though constituting a small percentage of the data overall, approached effect levels that have been found in the scientific literature to affect adults with bronchial asthma from 30-minute exposures. **If H_2S current levels (and peaks) are ongoing and similar to 2021-2022 levels, an acute health hazard remains for the above effects, particularly for sensitive individuals.**

2. **Intermediate and chronic exposures to detected H_2S are unlikely to produce longer-term health effects.** PADOH estimates exceeded ATSDR and EPA health guidelines for these exposures but were lower than human-equivalent effect levels (nasal lesions and olfactory neuron loss) that serve as the basis for them. Based on the nature of the H_2S data for southern Chester County, repeated, acute exposures based on episodic peaks in H_2S levels are more likely to increase risk health risk than continuous intermediate or chronic exposures for which ATSDR and EPA health guidelines are based. PADOH however acknowledges a degree of uncertainty with this conclusion. There is currently limited scientific understanding of the potential for adverse human health impacts from longer-term low-dose exposures to H_2S in air.
3. **Common H_2S odor thresholds are routinely being exceeded, indicating a chronic nuisance odor problem that might be affecting quality of life for residents** and may be leading to symptoms such as headache, nausea, fatigue, or similar symptoms.

PADOH does not have enough information to evaluate the occurrence of lung nodules and H_2S exposure. There are currently not enough laboratory animal or epidemiological studies on occurrence of pulmonary nodules from H_2S exposures. PADOH also acknowledges the community's corrosion complaints; however, since this is not a health concern, PADOH is not the entity qualified to investigate this type of complaint.

Limitations

1. PADOH's conclusions are based on averaged hourly data. Very high levels of H_2S (>27 parts per million, ppm) of short exposure duration (<1 hour) can cause severe health effects. Hourly levels at the monitoring stations were well below more severe health effect levels. If available in the future, PADOH may consider a review of additional quality-assured data for this area, including data of shorter exposure durations, if deemed representative of community exposures.
2. PADOH's conclusions do not account for monitor-specific meteorological data such as wind-direction, wind speed, or relative humidity, which might provide further insight on the episodic peaks of H_2S. PADOH recently received and will review monitor-specific meteorological data from BAQ and will provide a follow-up letter health consultation if needed.
3. Although the dataset PADOH received is robust and of sufficient quality, each monitor had several days or weeks of invalid hourly data, most commonly the West Grove monitor. Occurrences of invalid data are common for hourly monitoring. There were hours in which monitor data were invalid due to machine malfunctions, power failures, quality assurance results, maintenance/routine repairs, or daily automated calibration checks. PADOH did not include invalid data for this assessment.
4. Our conclusions are based on ambient H_2S levels and not other compounds (such as other sulfur compounds) that are often present in air with H_2S and can also affect health. PADOH received ammonia data from BAQ that we will consider assessing for a follow-up report. Ammonia was sampled less frequently using a monitor that was unable to detect it at low concentrations.
5. Our conclusions are based on BAQ August 2021 – December 2022 data in this region. PADOH may consider a review of additional data or data taken more recently if deemed representative of community exposures and will provide a follow-up letter health consultation (LHC) if needed.

PADOH recommends that:

1. Facilities suspected of high H_2S emissions engage in best practices and engineering controls to reduce odors, which might include an air monitoring plan to see if best practices or engineering controls are resulting in lower H_2S emissions.
2. Efforts be made to significantly reduce area H_2S of this region to lower levels, and/or ensure H_2S emissions are located away from residential areas. Ideally, year-round/lifetime daily averages should be at or below 1.4 ppb, which is EPA's RfC and would protect against lifetime health risk and common odor thresholds.
3. Entities or community partners consider outdoor air monitoring to see if odor and health effect levels are being exceeded near homes, or at workplaces. Continued area monitoring may be useful to understand if engineering controls are effective and reduce area H_2S levels in future years. Further, any collected data should be shared with stakeholders and the community to understand trends in H_2S levels and whether common odor and health effect levels are being approached or exceeded.
4. Residents consult their physicians if experiencing adverse health effects. Though it can be difficult to reduce exposures to environmental odors, residents can try staying indoors when outdoor environmental conditions are bothersome, exercising indoors instead of outdoors on days of more odors, or leaving the area for a few hours, if possible. Residents should also continue reporting occurrences of environmental odors to BAQ (complaints line: 484-250-5991; 24-hour line: 484-250-5990, or electronically at: https://greenport.pa.gov/obPublic/EnvironmentalComplaintForm/) and health concerns from H_2S emissions to PADOH (phone: 717-787-3350, or electronically at: https://forms.health.pa.gov/environmental-health-concern).

Public Health Action Plan

1. PADOH may consider a review of additional data for this site if deemed representative of community exposures and provide a follow-up letter health consultation if needed.
2. PADOH will share the results of this letter health consultation with interested site stakeholders.
3. PADOH intends to participate in meetings with stakeholders, community members, and/or interagency partners, if requested, to discuss ambient H_2S levels, data sources, efforts to reduce emissions, and/or additional updates or concerns in this area.

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Appendix A. Previous Hydrogen Sulfide Investigations of Southern Chester County

A.1. Overview

PADOH and PADEP have previously evaluated this site area. In 1997 and 1998 the agencies received odor complaints and health concerns from residents living near mushroom composting operations in London Grove Township. Residents were concerned of ambient hydrogen sulfide (H_2S), which is a colorless gas produced from natural and man-made activity that has an odor of rotten eggs. PADOH and PADEP collaborated on a study to determine whether adverse health effects were possible from area H_2S.

A.2. PADEP Air Monitoring

Between the spring of 1998 and summer of 1999, PADEP conducted ambient air monitoring at two elementary schools, at Avon Grove Elementary in London Grove Township located near composting operations, and at Kemblesville Elementary, a "background school" located away from the operations in Franklin Township. PADEP also monitored for H_2S in London Grove Township at a community location where malodors were reported (West Borough Garage), a private residence on Meadow Wood Lane (also located near potential sources of emissions) and a private residence on Holly Drive (a "background" location away from emissions).

Both indoor and outdoor air monitoring occurred at the "near-source" school (Avon Grove) and private residence (Meadow Wood Lane). At other locations, only outdoor monitoring occurred. One-hour, 5-minute, and 1-minute H_2S averages were reported, in parts per billion (ppb). As shown in Table A1, monitoring periods and samplers used varied during the study period. H_2S concentrations were highest at the private residence and were generally higher at near-source than at background locations.

The 1998 study evaluated exceedances of Pennsylvania's 1- and 24-hour standards of 0.1 ppm and 0.005 ppm, respectively. The standards were originally adopted in the 1960s to prevent malodors and damage to paints, not on the potential for health effects (PADEP and PADOH 1999). Exceedances of these standards in 1998-1999, along with the maximum average concentrations, are also shown in Table A1.[5] Table A1 is adapted from data presented in the 1999 report (PADEP and PADOH 1999).

[5] The 1998-1999 ambient H_2S study utilized an outdated interpretation of the H_2S ambient air standards set forth in Title 25 of the Pennsylvania Code, § 131.3 (relating to Ambient air quality standards). PADEP currently uses a comparison threshold of 149 ppb to determine an exceedance of the 1-hour H_2S standard. In addition, current data handling protocols accord that each 1-hour concentration greater than 149 ppb constitutes a unique exceedance of the 1-hour standard, regardless of other exceedances occurring on the same day, or the number of 1-hour averages available for the day.

Table A1. 1998-1999 H_2S Ambient Air Monitoring Results for London Grove Township

Monitor Site	Monitor Location	Indoor or Outdoor	Monitoring Instrument (H_2S detection range)	Operating Dates	N exceedances of PA 1-hour H_2S standard[1,3] (max 1 h average)	N exceedances of PA 24-hour H_2S standard[2,3] (max 24 h average)	Max 1-minute / 5-minute averages
Avon Grove Elementary School	Near-source	Outdoor	TEI 0-1000 ppb	4/8/98-6/16/99	1 (129 ppb)	18 (20 ppb)	828 ppb / 512 ppb
-	-	Indoor	TEI 0-1000 ppb	4/8/98-12/2/98 12/2/98-2/8/99 2/8/99-6/16/99	-	6 (11 ppb)	243 ppb / 227 ppb
Meadow Wood Lane	Near-source (residence)	Outdoor	TEI 0-5000 ppb	4/8/98-5/26/99	31 (607 ppb)	45 (51 ppb)	4888 ppb / 3667 ppb
-	-	Indoor	SPM 53-1500 ppb	6/12/98-10/29/98	7 (417 ppb[4])	-	1493 ppb[4] / 1456 ppb[4]
West Grove Borough Garage	Near-source	Outdoor	SPM 53-1500 ppb	6/5/98-8/27/98	11 (378 ppb)	-	1040 ppb / 947 ppb
Kemblesville Elementary School	Background	Outdoor	SPM 2-90 ppb	4/10/98-4/22/98 5/18/98-6/12/98 8/27/98-11/4/98	-	-	15 ppb / 15 ppb
Holly Drive	Background (residence)	Outdoor	SPM 53-1500 ppb	4/8/98-10/29/98	3 (408 ppb)	-	1307 ppb / 1102 ppb

ppb = parts per billion; TEI = Thermo Environmental Inc. (TEI) Continuous SO_2/H_2S monitor
SPM = SPM Tape Sampler, manufactured by Zellweger Analytics
[1] PA's 1-hour H_2S standard: 0.1 parts per million
[2] PA's 24-hour H_2S standard: 0.005 parts per million
[3] The 1998-1999 ambient H_2S study utilized an outdated interpretation of the H_2S ambient air standards set forth in Title 25 of the Pennsylvania Code, § 131.3 (relating to Ambient air quality standards). PADEP currently uses a comparison threshold of 149 ppb to determine an exceedance of the 1-hour H_2S standard. In addition, current data handling protocols accord that each 1-hour concentration greater than 149 ppb constitutes a unique exceedance of the 1-hour standard, regardless of other exceedances occurring on the same day, or the number of 1-hour averages available for the day.
[4] PADEP noted that the instrument upper limit range was exceeded and thus the actual average may have been higher. The range of the monitor was exceeded during this period.

A.3. PADOH School and Community Health Symptom Evaluation

During PADEP's ambient air monitoring, PADOH conducted school and community health surveys, between the spring and fall of 1998.

For the school survey, PADOH compared spring (April 20-June 5, 1998) and fall (August 31-October 30, 1998) school nurse-reported student respiratory symptoms and medical conditions between the school "near-source" to operations (Avon Grove), and a "background/control group" elementary school (Kemblesville). Permission and consent to conduct the surveys were obtained through the school districts and administrators, and student parents and guardians. The surveys were self-reported by students as part of their visits to the school nurses, including whether they were experiencing respiratory symptoms, whether they were on prescribed medication, whether they were informed by a doctor of several medical conditions, and whether any medical conditions had worsened. Monitored symptoms included eye irritation or burning, dry or sore throat, skin irritation or rash, chest tightness, runny nose, worsening of asthma, cough, wheezing, dizziness, headache, nausea or vomiting, or other symptoms. Monitored medical conditions included asthma, hay fever and pollen allergies, chronic bronchitis, chronic sinus problems, skin allergies and dermatitis, and other allergies.

Between May 18-June 30, 1998, PADOH also conducted a community health survey examining these conditions. In May 1998, PADOH mailed packages to residents within 2 miles of the Avon Grove school or on Holly Drive. The packages contained information about the study, study consent forms, and the survey questionnaire. A second mailing occurred to residents who did not respond to the first mailing. For households that completed surveys, PADOH compared responses from "exposed group" households (within ¼ mile of Avon Grove Elementary School) to the "control group" households located further away from emissions (located outside of ¼ mile of the school, or on Holly Drive).

A.3.1. School Results

Study survey participation was far higher at the two schools (95-96% during April-June 1998 and 86-87% during August-October 1998) than for the community portion of the study (45% from May 18-June 30, 1998).

PADOH compared spring and fall surveys between the "near-source" (Avon Grove) and "background/control" (Kemblesville) elementary schools. In the spring survey, PADOH found that near-source school students reported significantly more symptoms (n=16) and conditions (n=9) than the "control school" students (n=10 and n=3, respectively); however, they did not correlate with H_2S concentrations at the school. PADOH used a 1-hour threshold of 10 parts per billion as a screening value for symptoms (1/10 of Pennsylvania's 1-hour standard of 0.1 parts per million), and a greater percentage of elevated symptoms occurred at Avon Grove on days in which ambient H_2S was below 10 ppb. There was no consistent pattern identified.

In the fall survey, PADOH found a greater number of symptoms (n=33) and conditions (n=20) at the control school than the near-source school (n=1 and n=0, respectively). There were no elevated symptoms or conditions at the near-source school on days of the highest measured H_2S concentrations. This finding was opposite of what would be expected based on the study's hypothesis. As shown in Table A1, H_2S concentrations at the school were low overall, rarely exceeding Pennsylvania's 24- and 1-hour standards.

A.3.2. Community Results

In the community portion of the survey (May 18 – June 30, 1998), PADOH found that 2 symptoms ("other symptoms" and any combination of symptoms) were significantly elevated among the "exposure group" households compared to "control group" households. These symptoms also occurred during 2 of

3 days in which PA's ambient 24-hour (0.005 parts per million) and 1-hour (0.1 parts per million) standards were also exceeded (Meadow Wood Lane monitor). PADOH noted that there were 8 days overall in which these standards were exceeded during the study period. Thus, there were some significant results of increased symptoms in accordance with ambient H_2S levels. PADOH noted that the finding should be viewed with caution due to the low participation rate among households (45% of contacted households participated, 36% for the "exposed group" households and 51% for the "control group" households).

A.4. 1998-1999 Conclusion

PADOH and PADEP released their findings in a 1999 report. PADOH "noted that the results do not support a consistent association between exposure to low levels of hydrogen sulfide and the appearance of symptoms." However, both PADOH and PADEP acknowledged the chronic odor problem within the community as affecting the quality of life of residents near mushroom composting operations. PADEP agreed to provide financial support for the Penn State University's research efforts to reduce odors and H_2S emissions from mushroom composting activities (PADOH and PADEP 1999).

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Appendix B. Monthly and Hourly Trends in Hydrogen Sulfide (H_2S) (ppb) Concentrations by Monitor

Table B1. Hours in which the highest H_2S concentrations were detected (above ≥ 200 ppb)*

Starting Hour Time	West Grove	Landenberg
Midnight	4	20
1 am	5	20
2 am	2	16
3 am	1	20
4 am	3	21
5 am	13	19
6 am	10	23
7 am	8	14
8 am	3	4
9 am	-	-
10 am	-	-
11 am	-	-
12 pm**	-	-
1 pm**	-	-
2 pm	-	-
3 pm	-	-
4 pm	-	-
5 pm	-	-
6 pm	-	5
7 pm	-	4
8 pm	1	8
9 pm	5	11
10 pm	3	17
11 pm	4	19
Total Hours with Averages above 200 ppb	**62**	**221**

***** Results for 2 near-source monitors are displayed (West Grove and Landenberg) because no values exceeded 200 ppb at the New Garden Airport monitor.

****** Data were largely invalid at 12pm and 1pm, during which the Teledyne H_2S monitoring device went through auto calibration checks; however, invalid data on these dates did not exceed 200 ppb.

Table B2. Monthly averages of H_2S in parts per billion (ppb) based on hourly data at the three monitors, August 2021-December 2022

	West Grove Monitor Monthly Average (ppb)	West Grove Monitor Valid Days*	Landenberg Monitor Monthly Average (ppb)	Landenberg Monitor Valid days*	Airport Monitor Monthly Average (ppb)	Airport Monitor Valid Days*
Aug 2021	-	0/31	21.9**	16/31	3.8**	18/31
Sept 2021	-	0/30	27.7	30/30	4.2	30/30
Oct 2021	9.5**	8/31	26.9	27/31	3.7	24/31
Nov 2021	19.9	30/30	**47.3**	29/30	3.5	29/30
Dec 2021	6.6	31/31	11.1	31/31	2.7	31/31
Jan 2022	5.2	31/31	5.5**	18/31	1.9**	11/31
Feb 2022	7.6	26/28	6.0**	18/28	3.1	28/28
Mar 2022	13.4	30/31	7.2**	16/31	2.9	28/31
Apr 2022	15.0	24/30	16.0	24/30	1.9	29/30
May 2022	8.9	25/31	6.3	28/31	2.9	31/31
Jun 2022	15.5	29/30	16.9	30/30	4.0	30/30
Jul 2022	12.3	28/31	12.0	31/31	5.9**	24/31
Aug 2022	11.1**	1/31	21.3	31/31	4.8	27/31
Sept 2022	8.8**	11/30	23.3	30/30	4.5	30/30
Oct 2022	25.5	29/31	35.9	31/31	5.7	31/31
Nov 2022	61.5**	3/30	30.1**	20/30	3.5	30/30
Dec 2022	-	0/31	21.0	25/31	4.7	31/31

Averages expressed as arithmetic means in parts per billion (ppb). *Valid days = days that had at least 20 hours of valid H_2S concentrations. ** = Listed average is based on a month in which there were fewer than 80% of valid days of valid data for that month. **Bold** = highest monthly average found at a monitor of at least 80% of valid hours/days. Calculated monthly averages only include valid days (i.e., days with at least 20 hours or more of valid H_2S concentrations).

Table B3. Fifteen-day H_2S average concentrations in parts per billion (ppb) for each monitor, August 2021-December 2022

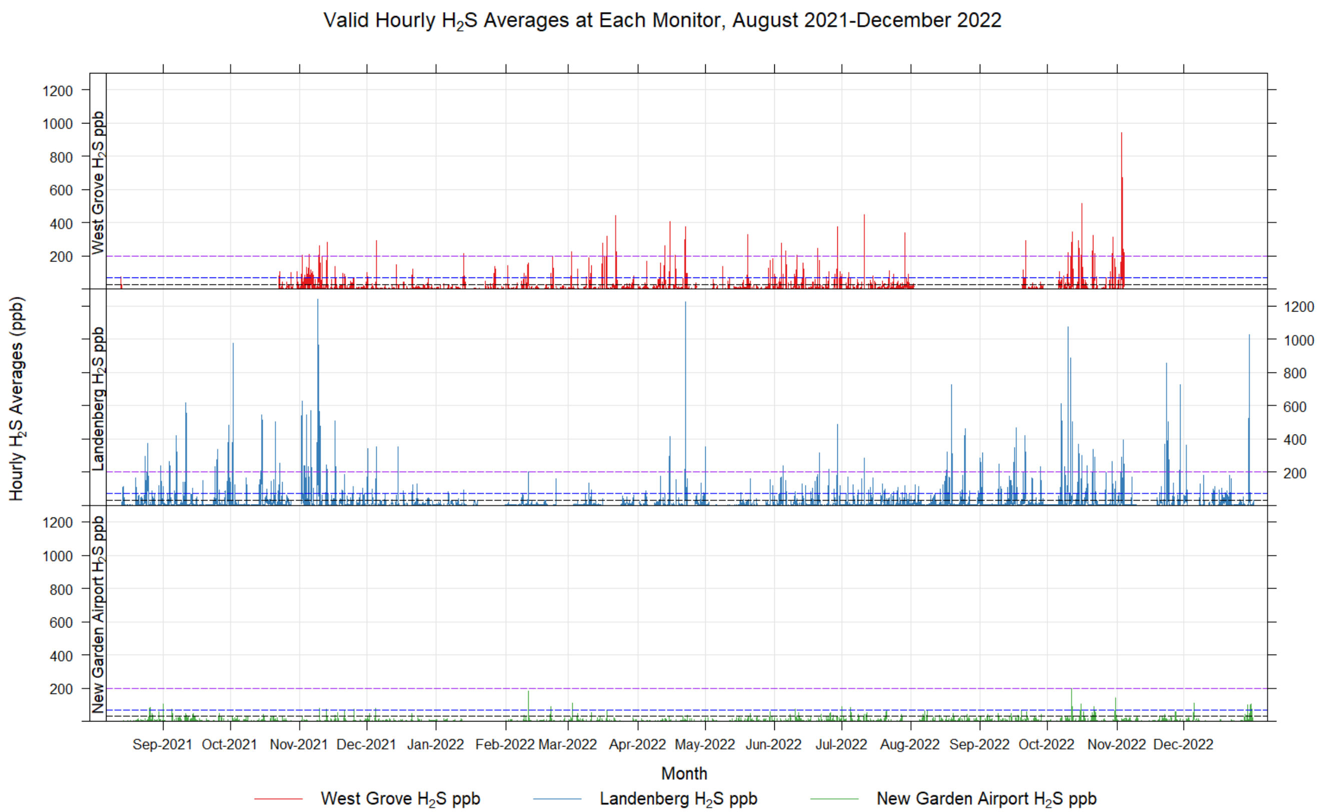
	West Grove Monitor 15 Day Average (ppb)	West Grove Monitor Valid Days* per 15 day period	Landenberg Monitor 15 Day Average (ppb)	Landenberg Monitor Valid Days per 15 day period	New Garden Airport Monitor 15 Day Average (ppb)	New Garden Airport Monitor Valid Days per 15 day period
2021						
8/13/21 – 8/27/21	24.2**	<1/15	25.0	12/15	3.8	14/15
8/28/21 – 9/11/21	-	-	32.2	15/15	5.4	15/15
9/12/21 – 9/26/21	-	-	14.2	15/15	3.3	15/15
9/27/21 – 10/11/21	-	-	25.3	15/15	3.5	14/15
10/12/21– 10/26/21	7.7**	4/15	35.5	15/15	3.9	12/15
10/27/21 – 11/10/21	27.4	14/15	104.6**	10/15	2.0**	11/15
11/11/21 – 11/25/21	15.3	15/15	20.2	15/15	4.8	15/15
11/26/21 – 12/10/21	8.0	15/15	16.7	15/15	3.1	15/15
12/11/21 – 12/25/21	5.4	15/15	8.1	15/15	2.3	15/15
12/26/21 – 1/9/22	4.3	15/15	5.5	15/15	2.1	15/15
2022						
1/10/22 – 1/24/22	5.5	15/15	4.8**	9/15	1.4**	2/15
1/25/22 – 2/8/22	6.5	15/15	4.3**	8/15	1.5**	8/15
2/9/22 – 2/23/22	10.3	13/15	7.3**	10/15	4.5	15/15
2/24/22 – 3/10/22	6.3	14/15	4.5**	7/15	2.3	14/15
3/11/22 – 3/25/22	19.0	15/15	9.7**	5/15	3.4	13/15
3/26/22 – 4/9/22	9.6	15/15	8.5**	8/15	1.7	15/15
4/10/22 – 4/24/22	17.7	15/15	11.0	14/15	2.6	14/15
4/25/22 – 5/9/22	4.6**	8/15	10.8	12/15	1.1	15/15
5/10/22 – 5/24/22	8.4	15/15	4.6	15/15	3.1	15/15
5/25/22 – 6/8/22	17.1**	11/15	12.0	15/15	3.4	15/15
6/9/22 – 6/23/22	12.5	15/15	15.2	15/15	3.5	15/15
6/24/22 – 7/8/22	13.8	14/15	15.2	15/15	6.2	15/15
7/9/22 – 7/23/22	11.0	15/15	12.8	15/15	5.5	14/15
7/24/22 – 8/7/22	17.4**	9/15	10.4	15/15	7.1**	5/15
8/8/22 – 8/22/22	-	-	20.9	15/15	4.3	15/15
8/23/22 – 9/6/22	-	-	25.4	15/15	4.8	15/15
9/7/22 – 9/21/22	31.4**	2/15	34.2	15/15	4.7	15/15
9/22/22 – 10/6/22	4.0	15/15	8.6	15/15	2.8	15/15
10/7/22 – 10/21/22	37.2	14/15	**60.9**	15/15	7.7	15/15
10/22/22 – 11/5/22	29.3	12/15	20.8	15/15	4.7	15/15
11/6/22 – 11/20/22	-	-	12.3**	5/15	2.3	15/15
11/21/22 – 12/5/22	-	-	41.0**	11/15	5.3	15/15
12/6/22 – 12/20/22	-	-	15.7	13/15	1.6	15/15
12/21/22 – 12/31/22	-	-	24.0	11/11	8.4	11/11

Cells marked as "-" = no days of valid data. *Valid days = days that had at least 80% (12/15 days) of valid hourly concentrations. ** = did not meet the 80%, 15-day threshold of valid hourly data (e.g., there were fewer than 12 of 15 days of valid data during this period, or fewer than 9 of 11 days from 12/21/22-12/31/22); ppb = parts per billion; **Bold =** highest 15-day average (of valid data) among the 3 stations.

Appendix C. Plots of the Valid Hydrogen Sulfide (H_2S) Data for Southern Chester County

Figure C1. Full Dataset of Hourly Averages for the three monitors, August 2021-December 2022

Figure C1. West Grove, Landenberg and New Garden Airport Monitor Hourly H_2S Averages (ppb) during the monitoring period. The dotted black line = 30 ppb (an odor threshold) . The dotted blue line = 70 ppb (ATSDR's acute Minimal Risk Level (MRL)). The dotted purple line = 200 ppb (above ATSDR's acute MRL and approaching health effect levels of the acute MRL principal study; further discussed in section 5.3 of the main report). Figure was prepared using the openair package in R.



Figures C2-C4. H_2S Daily Averages for the Three Monitors, August 2021-December 2022

Figure C2. Landenberg Monitor Daily H_2S Averages (ppb) by date. Daily averages are shown in which hourly data exists for at least 80% or more for each 24-hour day (20 hours or more). Days that are blank/white = not enough data (less than 80% of valid hours on that date). Figure was prepared using the openair package in R.

Landenberg Monitor Daily H_2S Averages (ppb), August 2021-December 2022

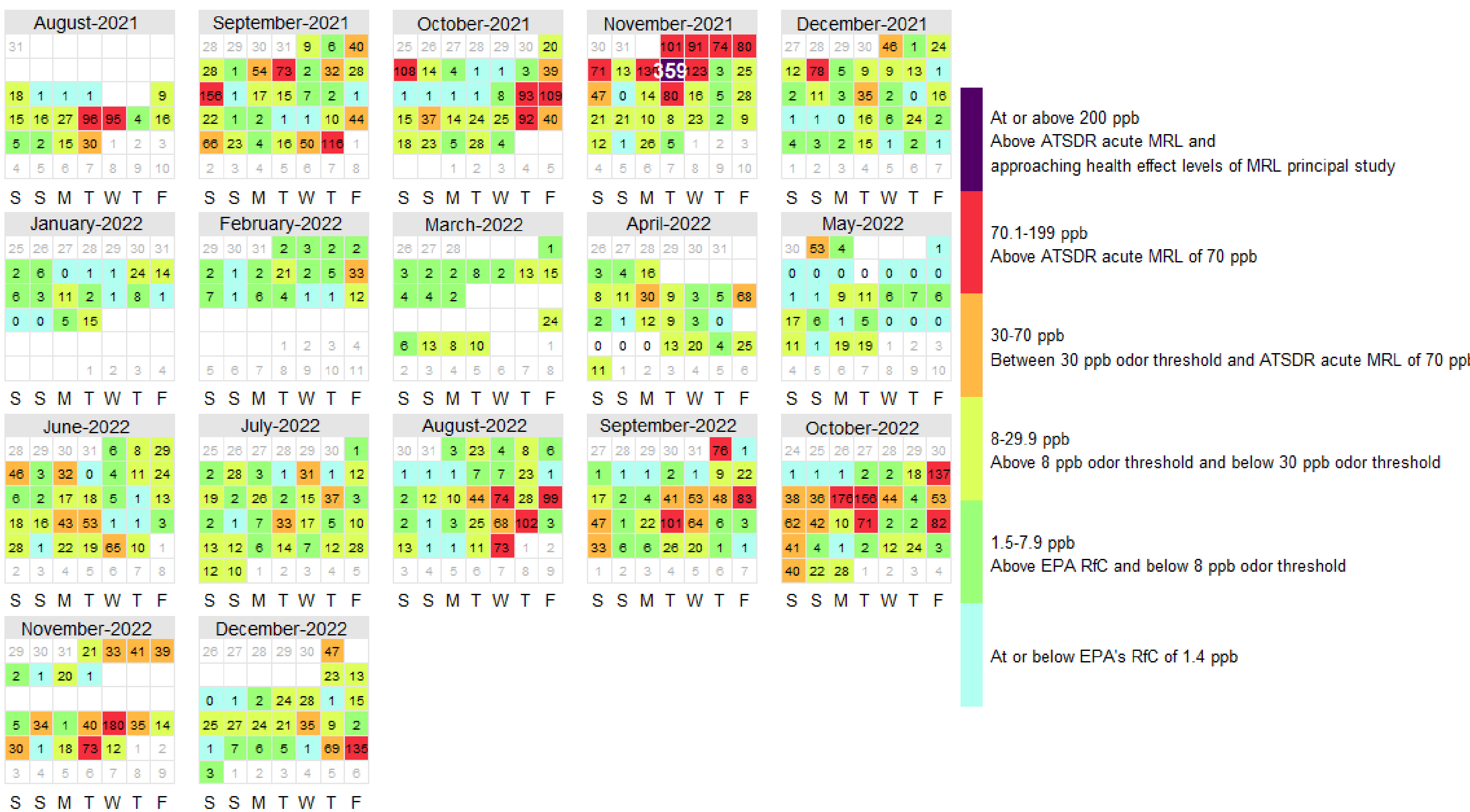


Figure C3. West Grove Monitor Daily H_2S Averages (ppb) by date. Daily averages are shown in which hourly data exists for at least 80% or more for each 24-hour day (20 hours or more). Days that are blank/white = not enough data (less than 80% of valid hours on that date). **For this monitor, there were no valid data days from August 2021 to Mid-October 2021, or from mid-November to December 2022.** Figure was prepared using the openair package in R.

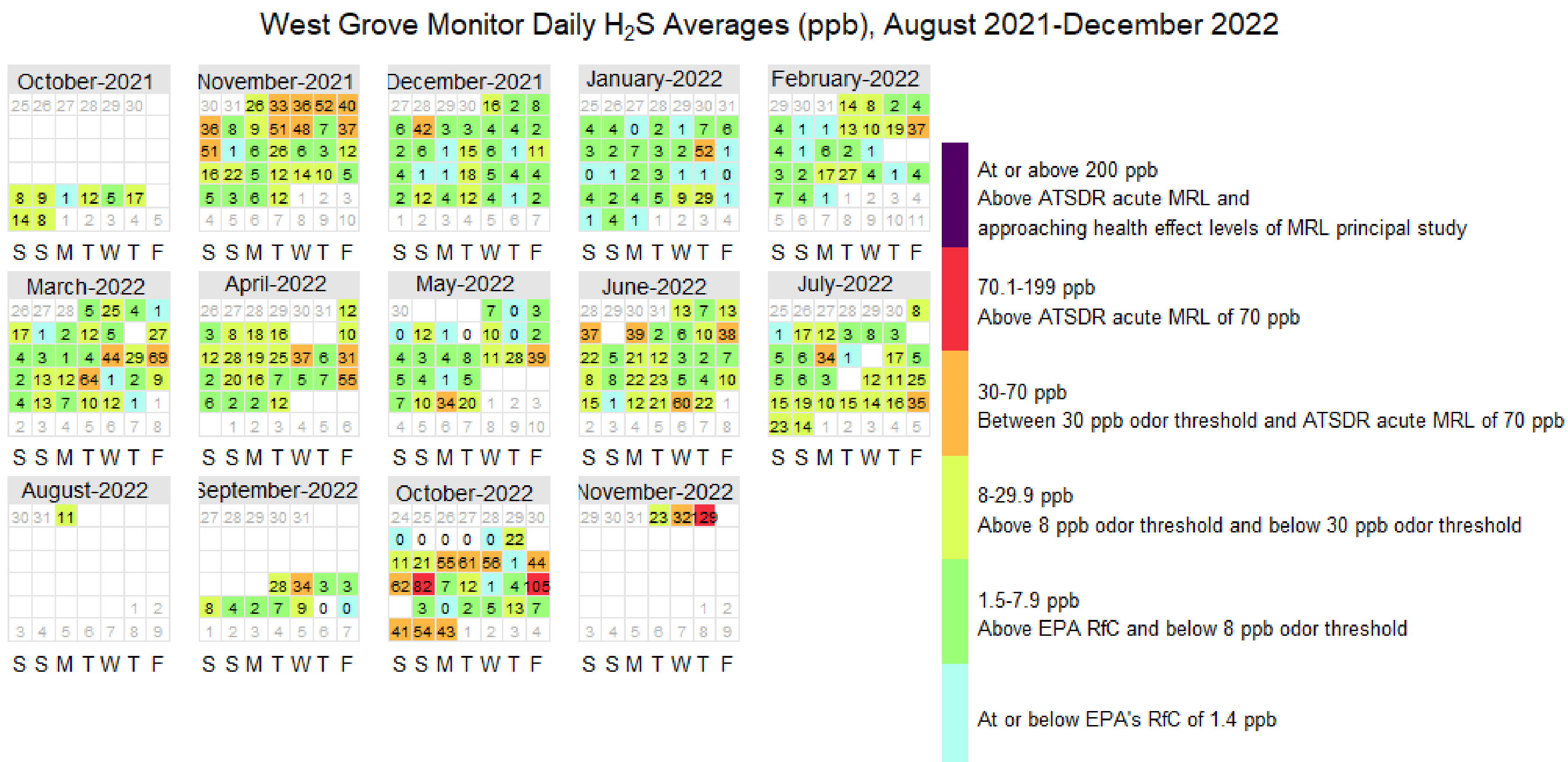


Figure C4. New Garden Airport Monitor Daily H_2S Averages (ppb) by date. Daily averages are shown in which hourly data exists for at least 80% or more for each 24-hour day (20 hours or more). Days that are blank/white = not enough data (less than 80% of valid hours on that date). Figure was prepared using the openair package in R.

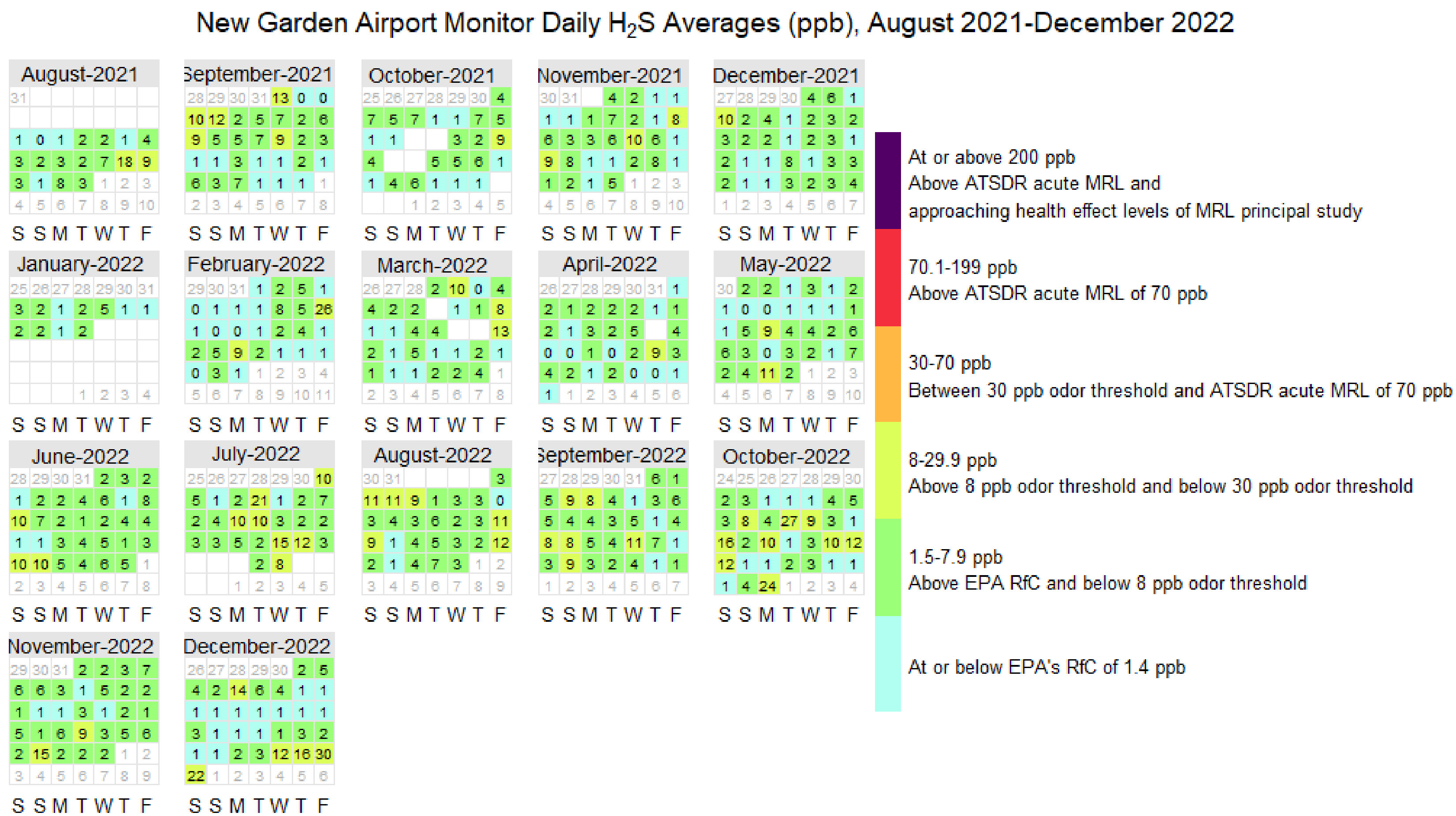
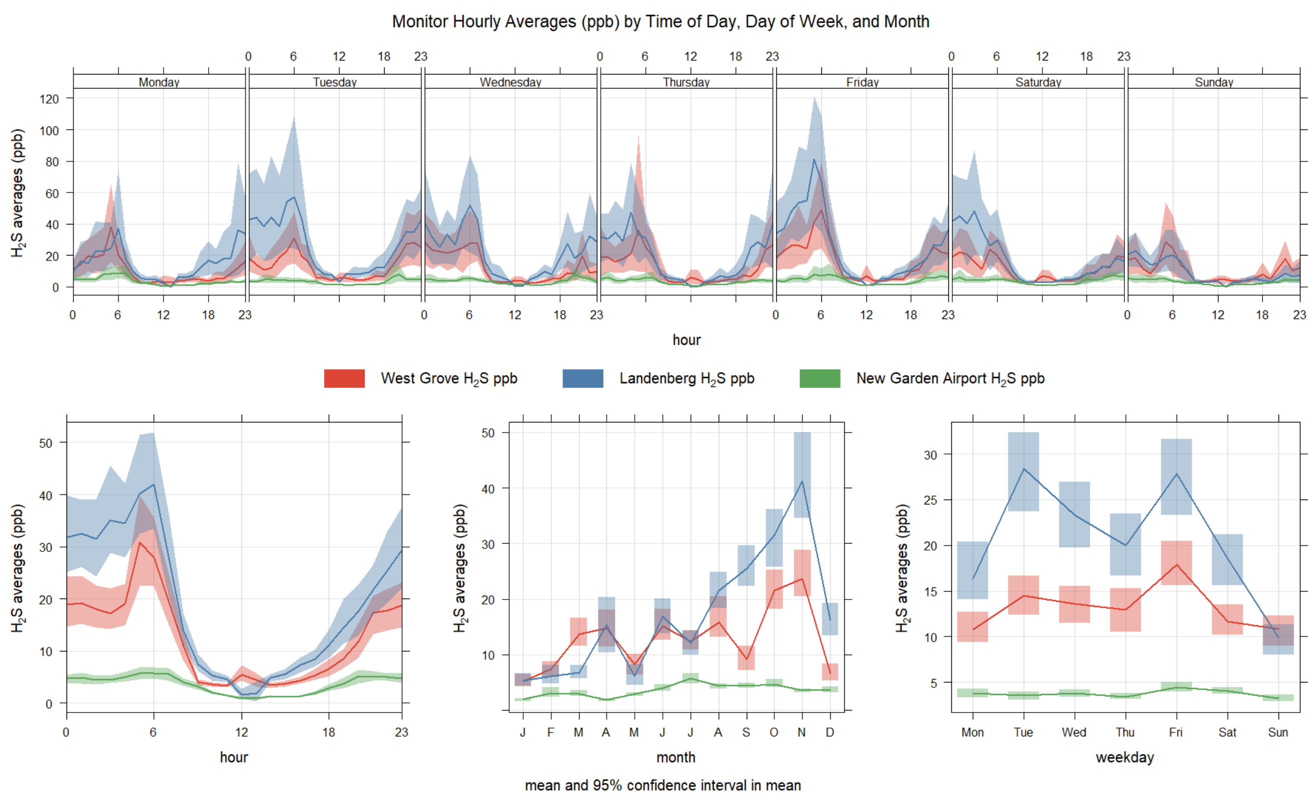


Figure C5. Hourly Averages (ppb) by Time of Day, Day of Week, and Month

Figure C5. Comparison of West Grove, Landenberg, and New Garden Airport Monitor H_2S Averages (ppb) and 95% Confidence Intervals by hour of day, day of week, and month of year. The data show that the two near-source monitors (Landenberg and West Grove) had the highest averages overall and had higher averages than the background monitor (New Garden Airport). The highest averages at the two near-source monitors (West Grove and Landenberg) occurred in October through November, and on Tuesdays and Fridays. Note: for the West Grove monitor, there was a lack of valid daily averages during most of August - October 2021, August - September 2022, and for November 2022, and there were no valid data days at this monitor for December 2022; the December data in the plot for West Grove represents December 2021. The lighter portions of the plots are the 95% confidence intervals of the mean. Daily averages plotted below encompass days with 80% or more valid data (20 hours or more). The Teledyne H_2S instrument had automated calibration checks nearly every day at 12 and 1 pm; therefore, the low values during these hours are based on very limited data. Figure was prepared using the openair package in R.



Figures C6-C8. Median H_2S (ppb) by Time of Day, Day of Week, and Month

Figure C6. Landenberg Monitor H_2S medians (ppb) by hour of day, day of week, and month of year. The data show that compared to averages (Figure C5), medians (represented by the solid lines) were low. However, 95^{th} percentiles of the data were much higher (represented by the lightest pink shading) and these peaks occurred in very early morning or nighttime hours, on Fridays, and in September through November. Medians plotted below encompass days with 80% or more valid data (20 hours or more). Figure was prepared using the openair package in R.

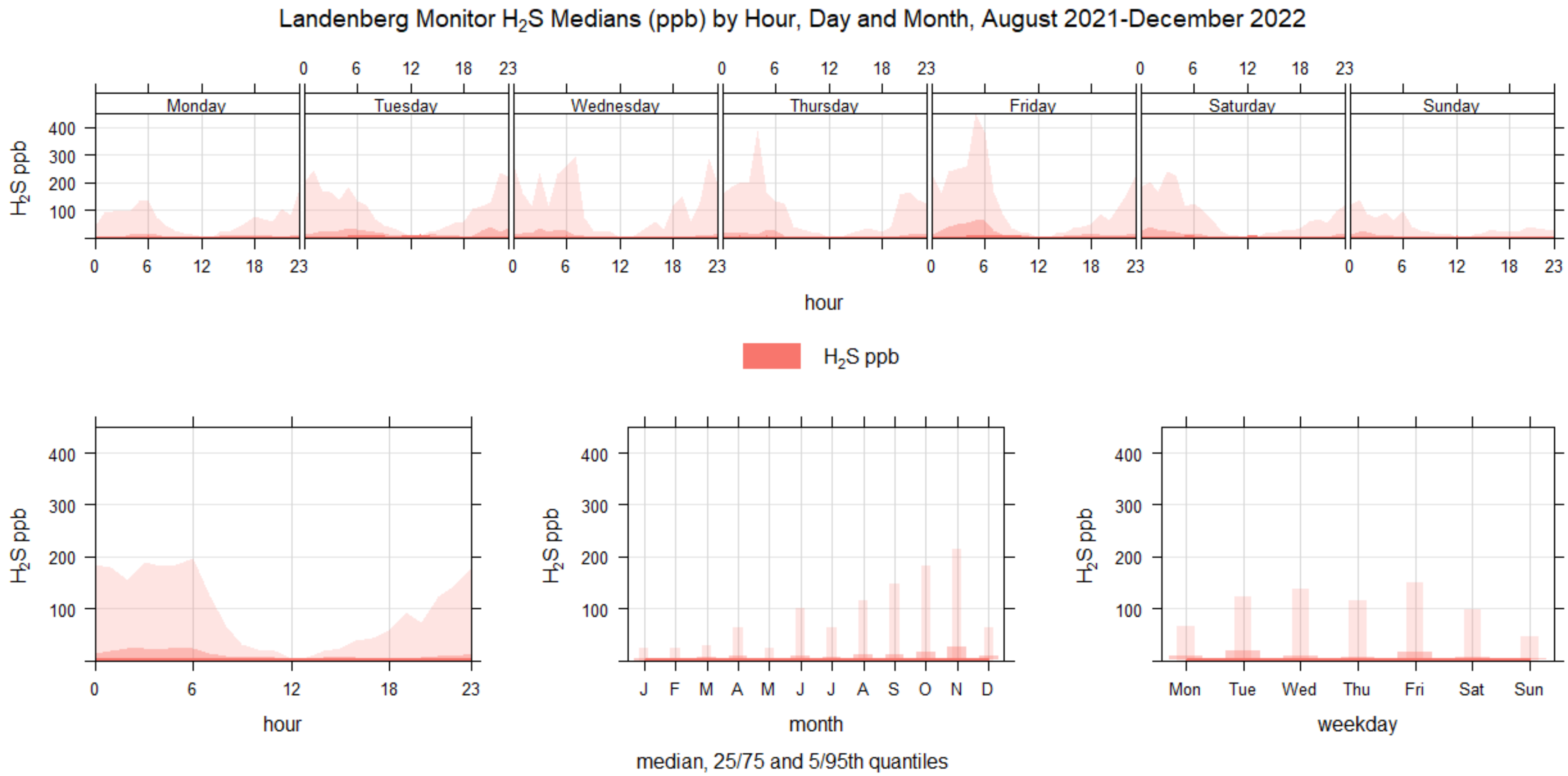


Figure C7. West Grove Monitor H_2S medians (ppb) by hour of day, day of week, and month of year. The data show that compared to averages (Figures C5), medians (represented by the solid lines) were low. However, 95th percentiles of the data were much higher (represented by the lightest pink shading) and these peaks occurred in the very early morning or nighttime hours, on Fridays, and in October and November. Medians plotted below encompass days with 80% or more valid data (20 hours or more). Figure was prepared using the openair package in R.

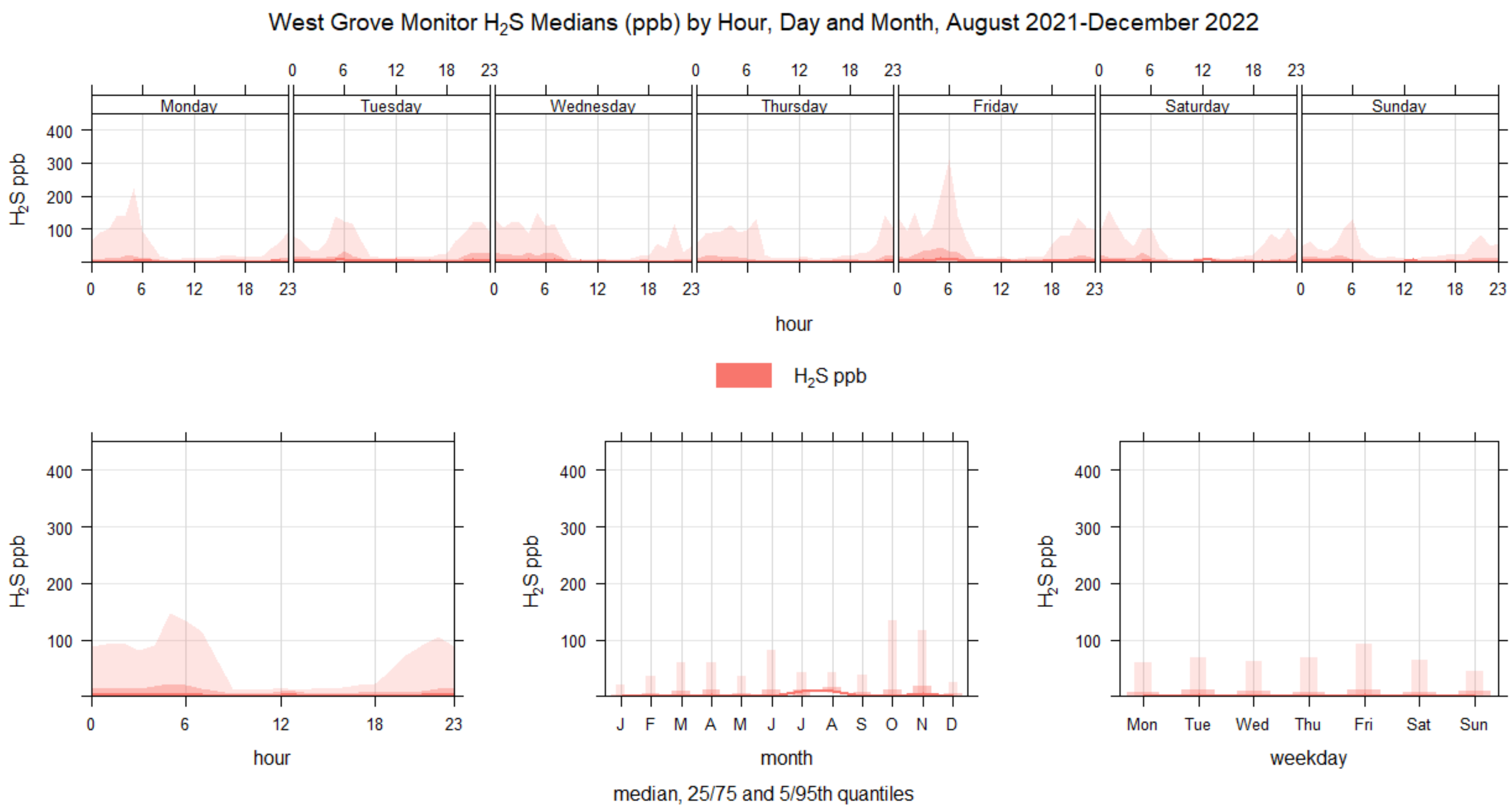
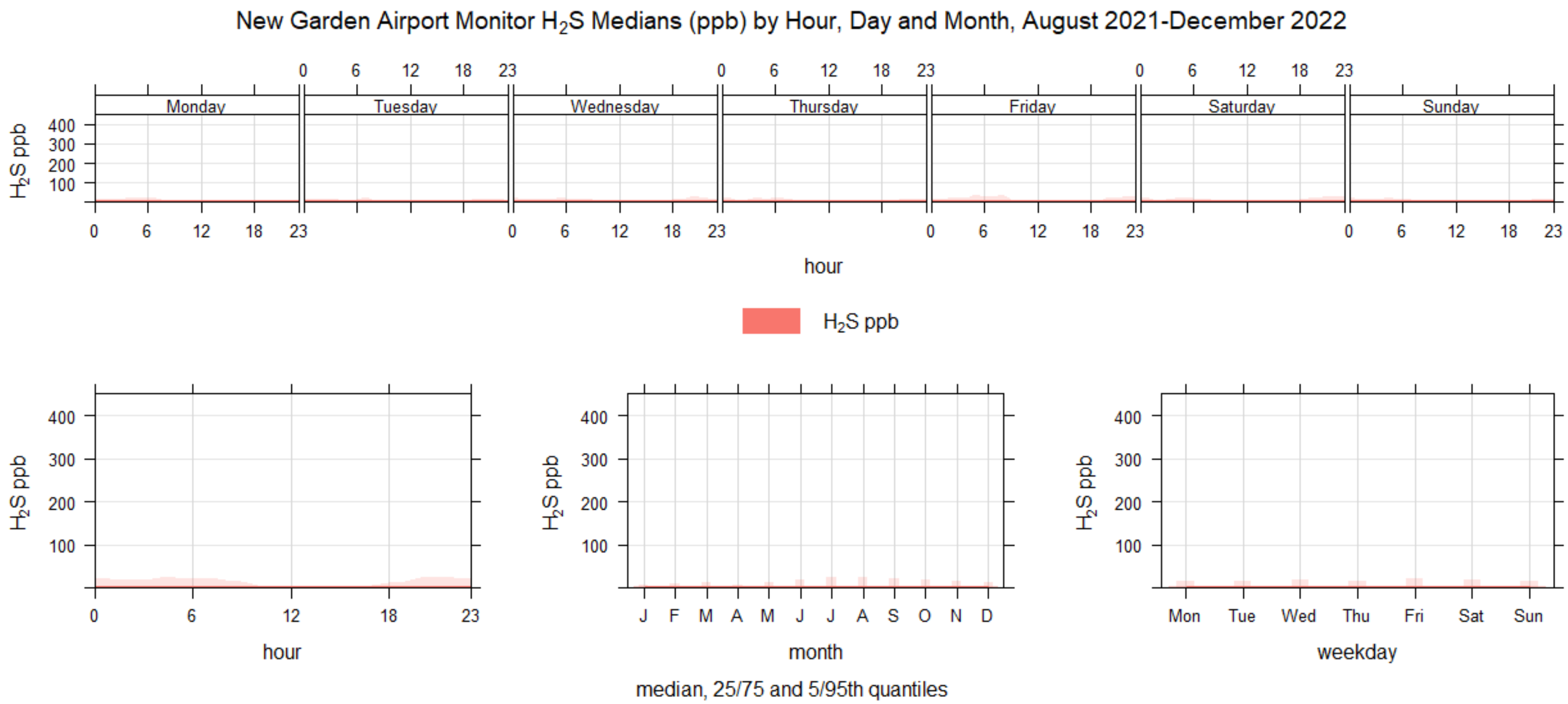


Figure C8. New Garden Airport Monitor H_2S medians (ppb) by hour of day, day of week, and month of year. The same y-axis scale is shown for this monitor as for the Landenberg (Figure C6) and West Grove Monitor (Figure C7). The data show that 95th percentiles (represented by the light pink shading) of the Airport data were much lower than the 95th percentiles of the two near-source monitors. Medians plotted below encompass days with 80% or more valid data (20 hours or more). Figure was prepared using the openair package in R.



Figures C9-C11. Daily Hourly Maximums at the Three Monitors, August 2021-December 2022

Figure C9. Landenberg Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). The data show that the highest values were most often found in August through November in both 2021 and 2022. The rest of this plot is shown on the next page. Figure was prepared using the openair package in R.

Landenberg Monitor Maximum Hourly H_2S detected (ppb) each day, August 2021-December 2022

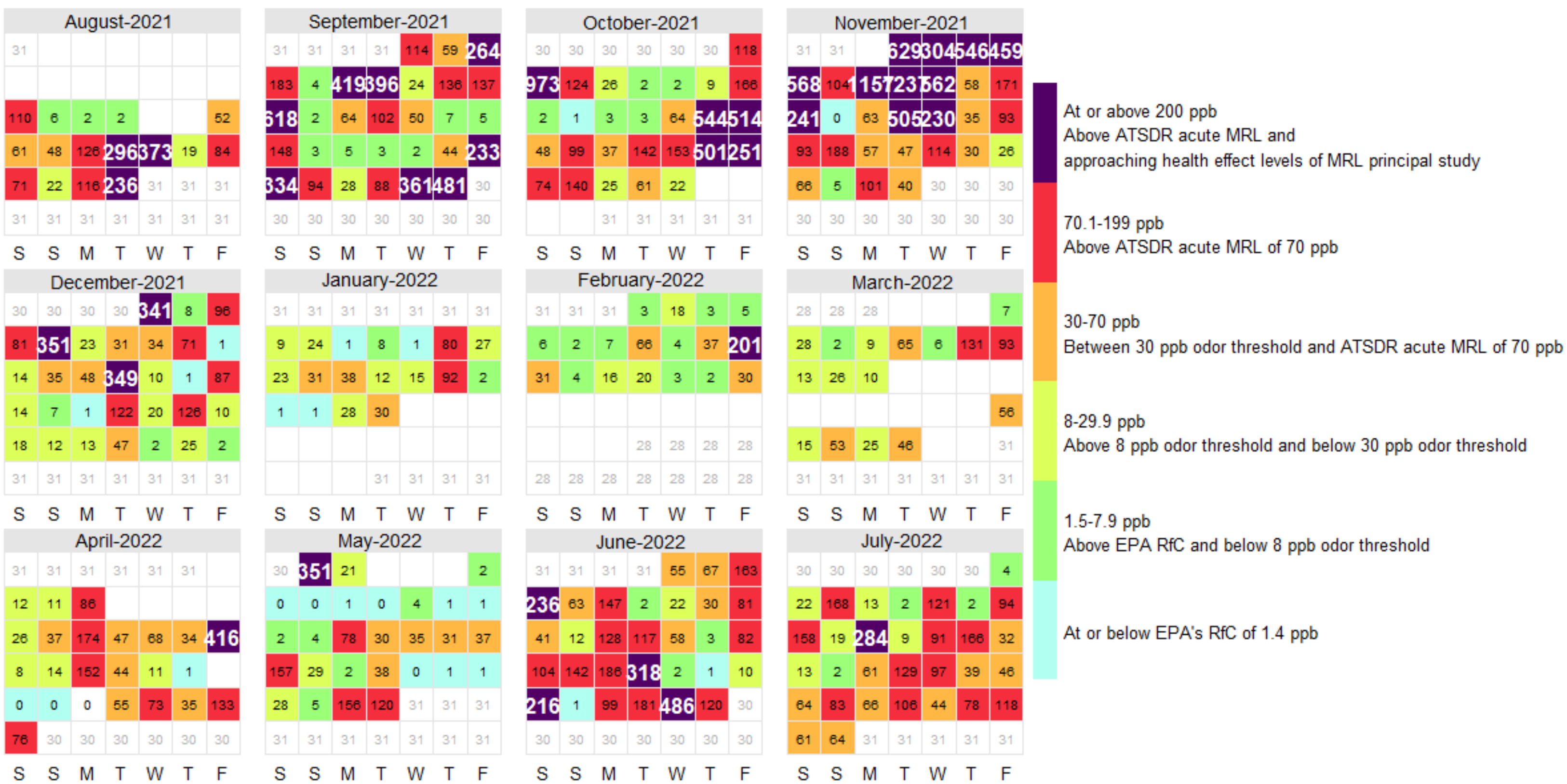


Figure C9 (Continued). Landenberg Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). The data show that the highest values were most often found in August through November in both 2021 and 2022. Figure was prepared using the openair package in R.

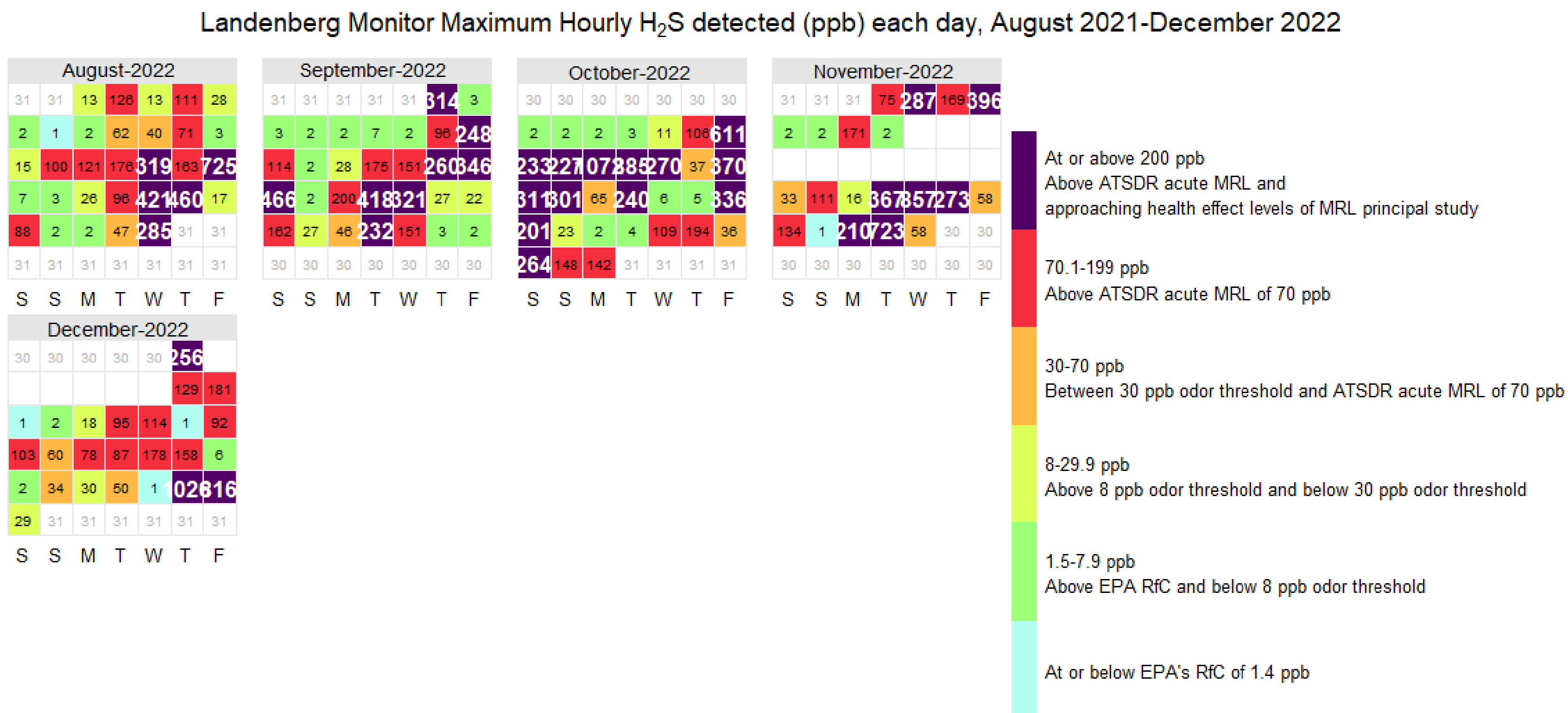


Figure C10. West Grove Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). The data show that the highest values were most often found in November 2021 and 2022, June 2022, and October 2022. The rest of this plot is shown on the next page. Figure was prepared using the openair package in R.

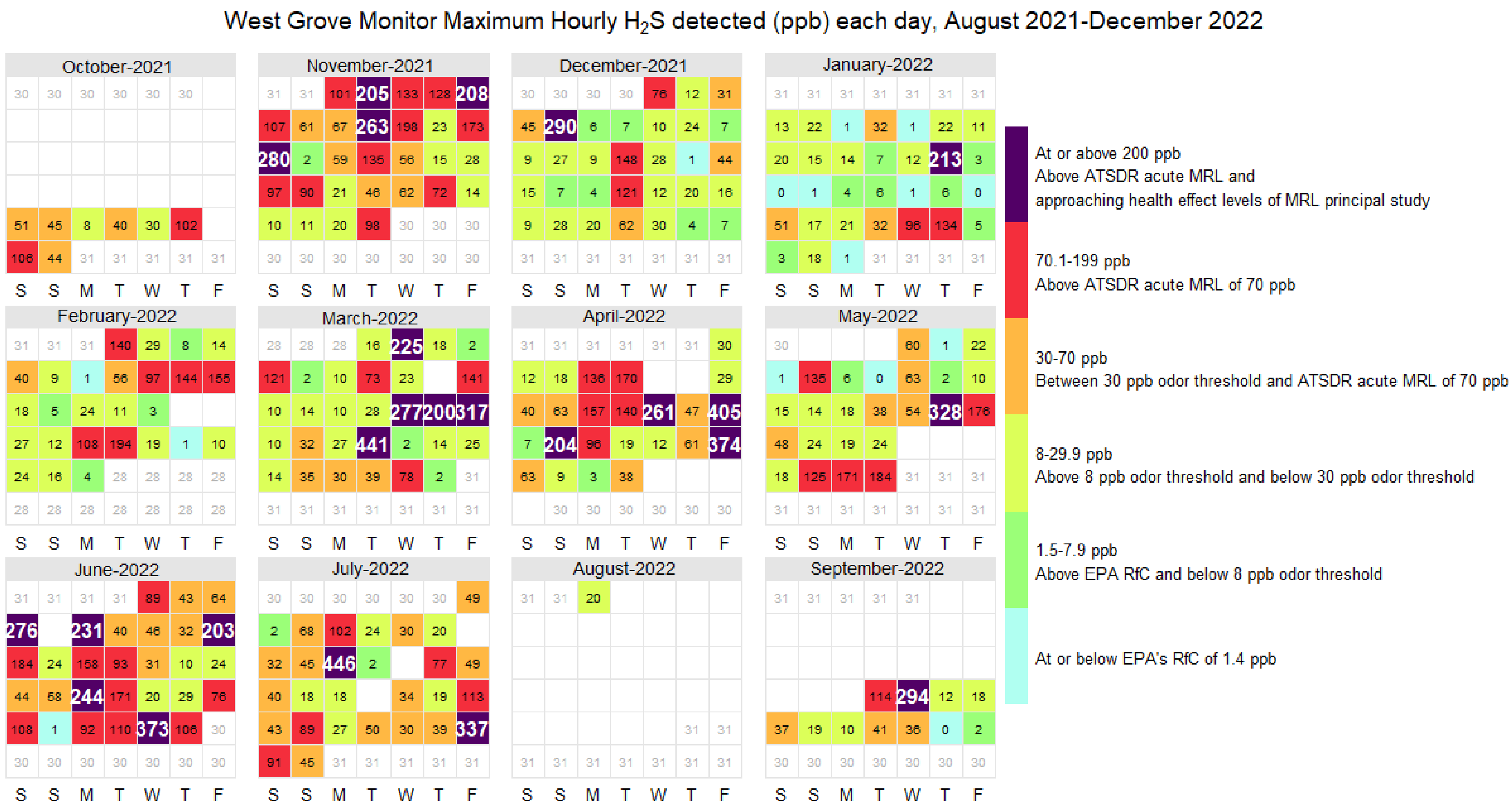


Figure C10 (Continued). West Grove Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). The data show that the highest values were most often found in November 2021 and 2022, June 2022, and October 2022. Figure was prepared using the openair package in R.

West Grove Monitor Maximum Hourly H_2S detected (ppb) each day, August 2021-December 2022

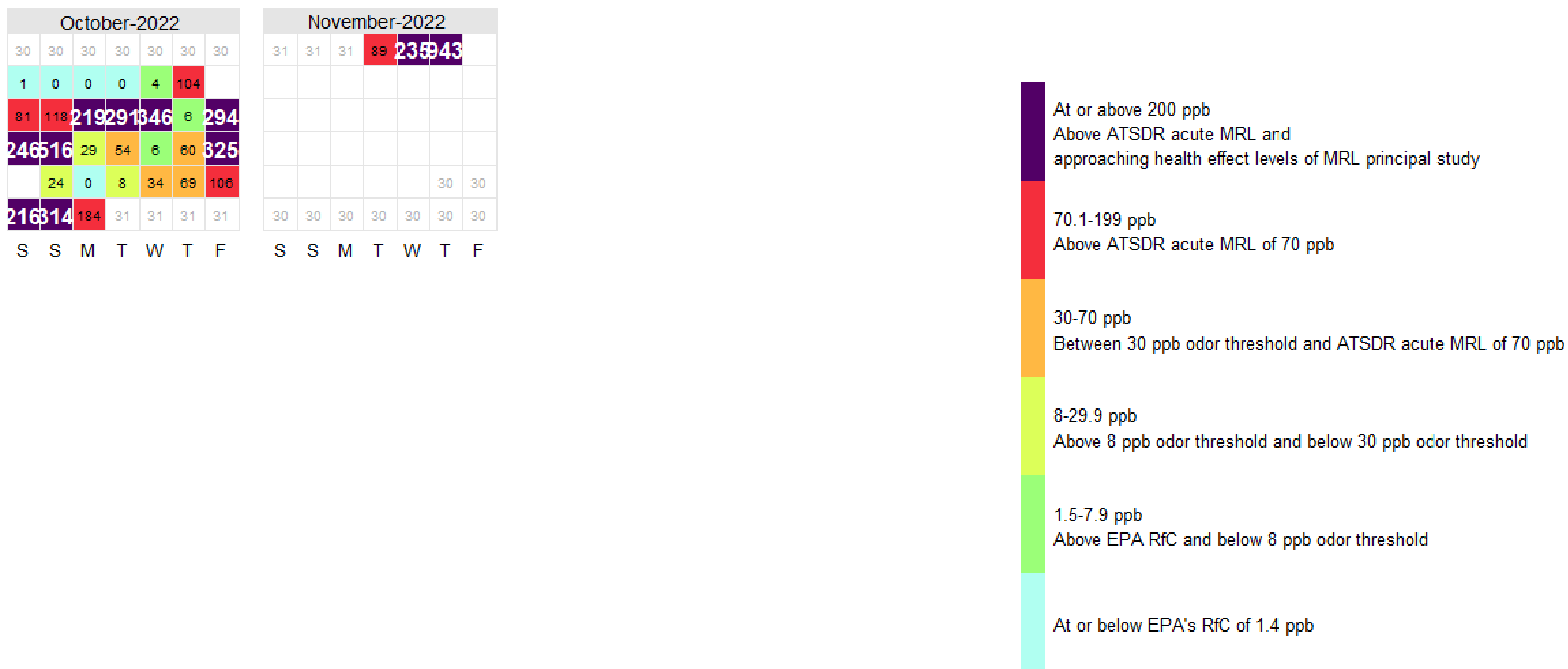


Figure C11. New Garden Airport Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). The rest of this plot is shown on the next page. Figure was prepared using the openair package in R.

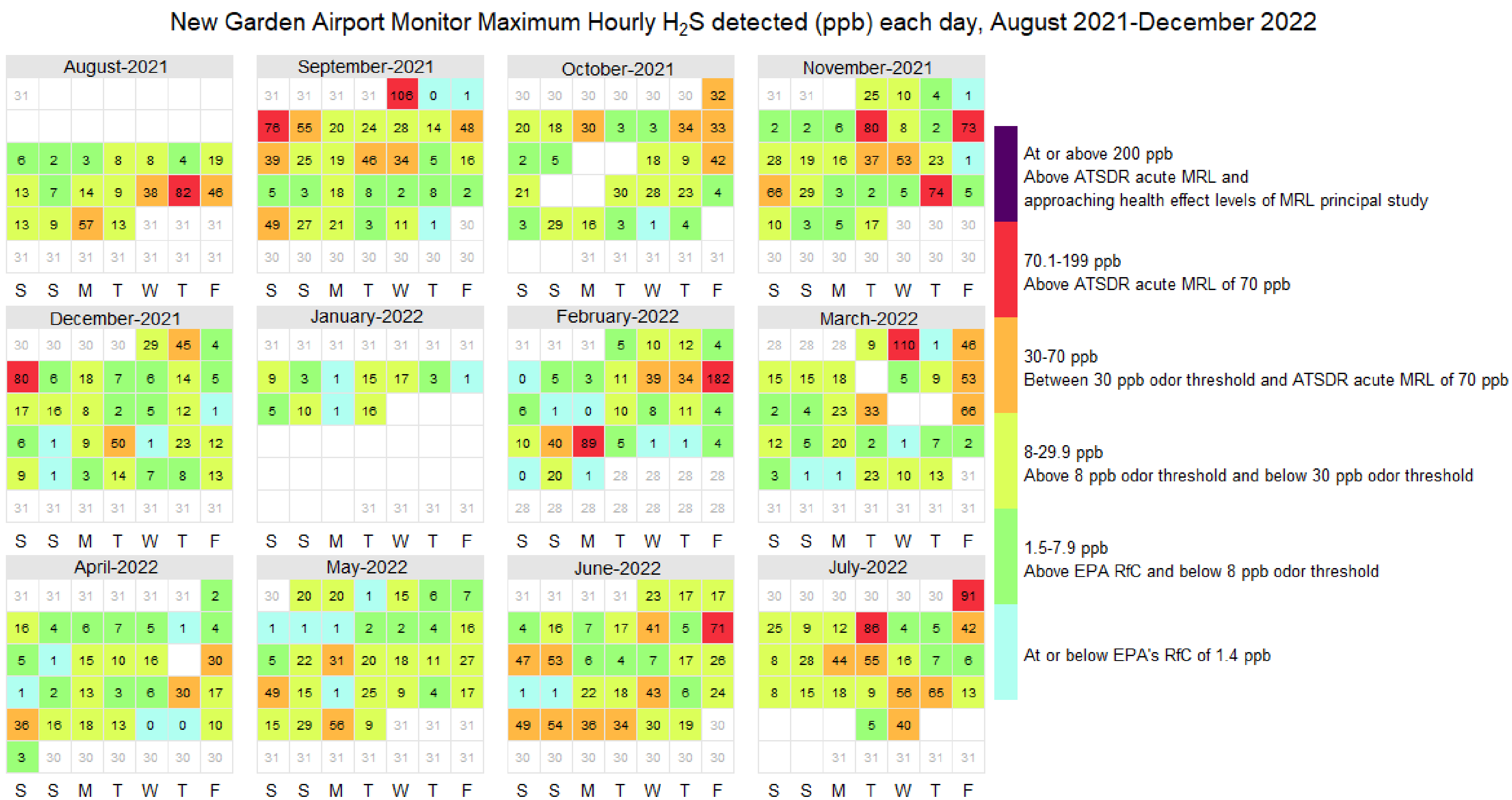


Figure C11 (Continued). New Garden Airport Monitor Maximum Hourly H_2S concentrations (ppb) by date. Days that are blank/white = not enough data to be considered (less than 80% of valid hours on that date). Figure was prepared using the openair package in R.