Air Quality Study – New Garden Township

2023-2024

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Table of Contents

Introduction

Half of the fresh mushrooms produced in the United States originate from the fresh mushroom production (FMP) industry in Pennsylvania, which has a long-standing history in Chester County. Pennsylvania produced 643 million pounds of fresh mushrooms during the 2022-2023 growing season, which had a market share of 1.0 billion dollars (Gorgo-Simcox, 2024). FMP has grown significantly in this region and along with it, residents' concern for air quality and health due to the strong odors associated with the byproducts of composting, substrate generation, and fresh mushroom production.

Residents in New Garden Township and surrounding FMP facilities have lodged complaints about the risk of these emissions for decades. Among their concerns are health, inability to enjoy their property due to overwhelming smells, and metal corrosion observed on surfaces and equipment around their property. There is little research which studies residential well-being and the impact on health that chronic exposures to mushroom farming byproducts may have on human health.

Prior research suggests that there are recognizable hazards associated with FMP. For example, Cobb et al. (1995) conducted a pilot study in Chester and Lancaster Counties in Pennsylvania, which involved a 1-day sampling near compost facilities and documented symptoms within the resident population. The symptoms included tiredness, sinus trouble, eye irritation, joint pains, sore throat, cough, nasal congestion, and influenza-like symptoms. The short sampling campaign measured concentrations of hydrogen sulfide (H_2S), methane (CH_4), ammonia (NH_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), formaldehyde, and particulates. The brief campaign resulted in contaminant concentrations below the limits of detection (LOD) of the equipment and inability to attribute symptoms to a specific environmental toxicant. Moderately elevated nitrates were found in water samples. A state employee who went to the site to collect a sample of compost fell acutely ill with a cough and sore throat that lasted several days. The study report did not specify if the illness was caused from exposure at the FMP facility.

Velusami et al. (2013) monitored emissions of H_2S at two outdoor and two indoor locations in Europe where stored spent mushroom compost (SMC) was being removed for land application. They recorded H_2S concentrations released as high as 2,083 ppm when sampling near the SMC piles. Exposure to concentrations above 1000 ppm would cause rapid loss of consciousness and death within a few seconds (OSHA, 2024). When disturbed, indoor and outdoor SMC piles release high concentrations of H_2S above the face of the pile. Velusami et al. (2013) ultimately determined that concentrations of H_2S appear to be minimized when SMC is stored under cover in small heaps with low moisture content, and with moderate heat.

Sexsmith et al. (2022) investigated Latino/a employee concerns and perceptions of how the workplace environment shapes occupational safety and health. Their study examined whether and how those perceptions differ by gender and identified future areas for research on occupational safety and health in the mushroom industry. Researchers focused primarily on the perceptions of health and safety of the employees. Approximately one third of respondents had suffered an injury at work, and nearly half felt that there are workplace factors that affect their health and safety. This study did not investigate toxic gas exposures among the employees. This gap in knowledge demonstrates an opportunity to understand more about toxic gas exposures and the relationship between worker's job tasks and release of toxic gases.

Mushroom composting ingredients typically include wheat straw bedding, horse manure, hay, corn cobs, cottonseed hulls, poultry manure, brewer's grain, cottonseed meal, cocoa bean hulls, and gypsum. These ingredients are directly used in mushroom production and the main byproduct of mushroom cultivation is SMC. Furthermore, emissions from FMP facilities include toxic gases such as H_2S, CH_4, and NH_3. These gases are recognized byproducts of composting in FMP substrate generation (CoAS, 2008). Each gas poses its unique health concerns related to exposure. Besides air pollution, other recognizable concerns from mushroom composting processes include environmental contamination, water pollution, disposal issues, and odor complaints.

Gas Emissions

H_2S is a flammable gas which generates from the decay of organic matter. The gas settles close to the ground, smells like rotten eggs, and at low concentrations causes irritation of the eyes, nose, and respiratory tract. Exposure to the gas is dangerous and can create lethal conditions. The odor threshold of H_2S is 0.01-1.5 ppm (OSHA, 2024). Therefore, residents and workers near, or downwind of fugitive emissions from substrate composting and FMP facilities can often smell the rotten eggs odors when H_2S is released into the environment. Exposure to H_2S concentrations between 2.0 ppm and 20.0 ppm are known to cause fatigue, irritability, poor memory, nausea, dizziness, headaches, sleep disruption, respiratory and eye irritation including watery eyes, and airway constriction, especially among people who may be asthmatic. At concentrations between 20.0 ppm and 100 ppm, (in addition to worsening severity of previous symptoms) individuals exposed may develop a loss of appetite, digestive upset, and worsening eye and respiratory irritation. Conjunctivitis, inflammation of the cornea and conjunctiva, is known to occur at this concentration and is referred to as “gas eye”. Exposure to concentrations between 100 ppm and 150 ppm paralyzes the olfactory nerve and those exposed lose the ability to smell the gas which can be dangerous as individuals may assume this means they are no longer exposed. H_2S exposure at concentrations above 100 ppm creates lethal conditions. At concentrations as high as 300 ppm, exposed individuals will develop a buildup of fluid and swelling in their lungs, pulmonary edema, and increased severity of prior symptoms. Exposure to concentrations between 500 ppm-700 ppm is expected to cause death in as little as 30 minutes of exposure, and concentrations upwards of 1000-2000 ppm, nearly instantaneous death (OSHA, 2024). Due to the recognized health hazard and nuisances of H_2S exposure, federal, state, and local governments have established exposure limits on the amount of H_2S an individual should be exposed to within their respective environment.

At the federal level, the Occupational Safety and Health Administration (OSHA) enforces workplace safety and has established a general industry ceiling limit of 20 ppm in occupational settings which tasks employers with preventing employee exposures to H_2S more than 20 ppm at any point during the workday

(OSHA, 2024). The National Institute of Occupational Health and Safety (NIOSH), a division of the Centers for Disease Control and Prevention (CDC) recommends keeping workplace exposures to H_2S no higher than 10 ppm for 10 minutes (CDC, 2019). In the state of Pennsylvania, the Pennsylvania Department of Environmental Protection (PA DEP) is tasked with enforcing and monitoring H_2S exposure to the general population (25 Pa. Code § 131.3), and the ambient air quality standard limits H_2S concentrations to 0.005 ppm (5 ppb) averaged over 24 hours and 0.1 ppm (100 ppb) averaged over 1 hour.

Methane (CH_4) is a highly flammable, colorless, odorless, and potentially explosive gas. It is lighter than air and is a known greenhouse gas. CH_4 is not a byproduct of composting during aerobic conditions, however, it is produced during anerobic conditions, such as windrows saturated with excess water (CoAS, 2008). According to an OSHA standard interpretation on inert gases (including NH_3), OSHA does not recognize or enforce a standard for CH_4 for workers since it is not expected to cause systemic effects, though hazard assessments of compressed gases and flammable products are left to manufacturers to distinguish the health risks of exposure (OSHA, 1993). CH_4 can displace oxygen, it is known as a simple asphyxiant and is otherwise not expected to cause systemic health effects due to exposure, though a case study done in 2013 (Jo et al.) suggests there may be chronic lung injuries after recovering from exposure to asphyxiating concentrations. In contrast, neither OSHA nor NIOSH establish direct limits on CH_4 exposure in general industry settings, but air composition should not fall below 19.5% oxygen to avoid oxygen deficiency and potential asphyxiating conditions. Pennsylvania and the PA DEP do not establish ambient air quality standards for methane in the environment.

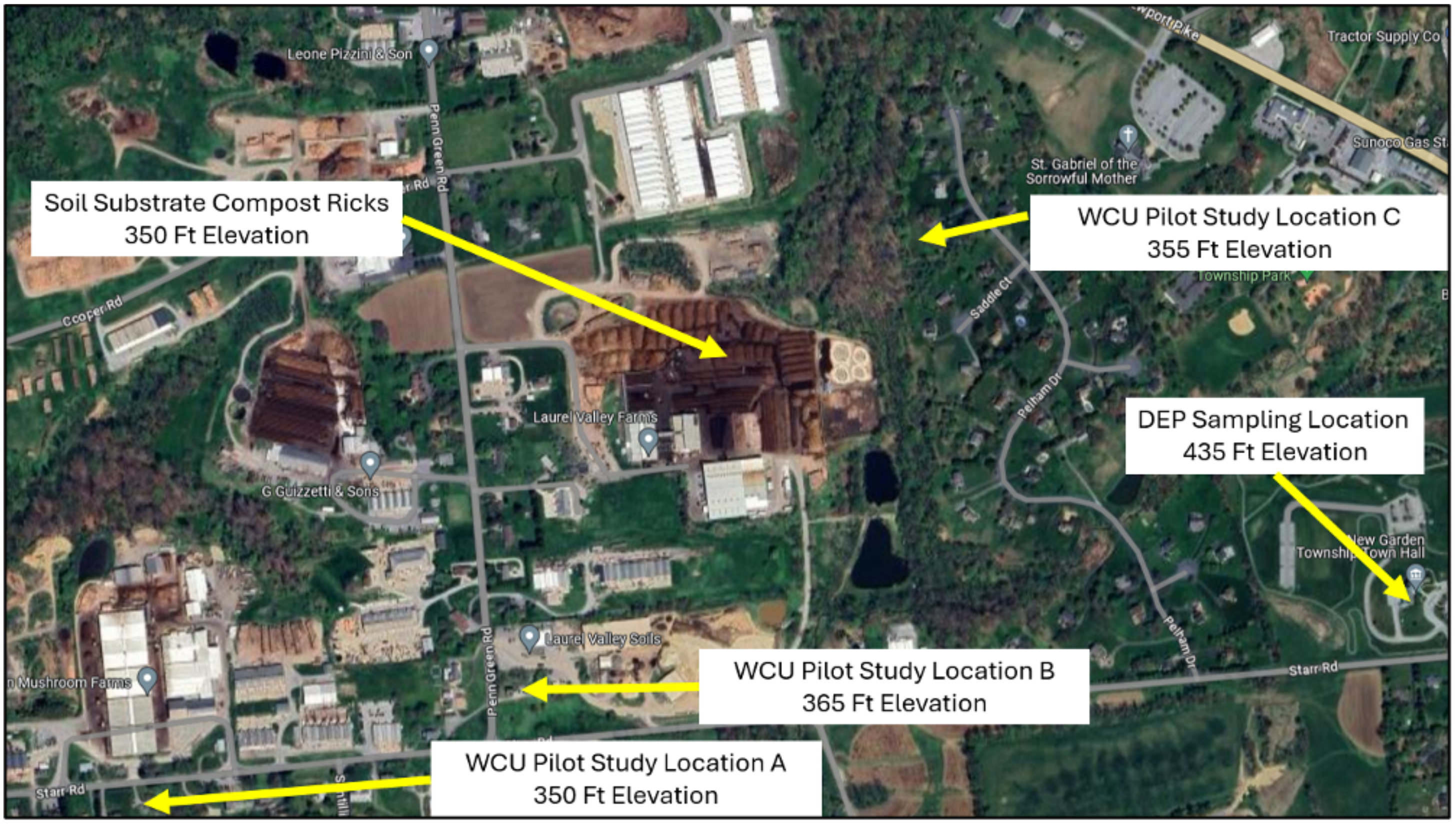
Ammonia (NH_3) is colorless, very pungent smelling, and is not a flammable gas. NH_3 is known for its corrosive properties due to lower alkalinity. NH_3 is a known byproduct of composting and substrate production and can be used as an indicator of successful substrate production (CoAS, 2008). Exposure to NH_3 can cause systemic health effects including irritation to the eyes, nose, and throat, difficulty breathing including wheezing and chest pain, pulmonary edema, and pink frothy sputum (CDC, 2019). Due to these recognized health effects, OSHA permits exposures in an occupational setting at 50 ppm as an 8-hour Time Weighted Average (NIOSH, 2019). NIOSH recommends no more than 25 ppm as a TWA, and no more than 35 ppm during a 15-minute TWA (NIOSH, 2019) known as a short-term exposure limit (STEL). Pennsylvania and the PA DEP do not establish ambient air quality standards for NH_3.

This pilot study focused on quantifying fugitive emission concentrations of H_2S, CH_4, and NH_3 near residential areas adjacent to FMP and substrate production facilities. Secondly, the pilot study evaluated the temporality of these concentrations in the outdoor environment. This pilot study will inform future research to delineate health concerns and nuisance concerns to respective point-sources during the FMP and mushroom substrate production procedures.

Materials and Methods

To evaluate these concerns, the pilot study sought to quantify gas concentrations that may exist in the residential community by installing three area monitors (G7 EXO, Blackline Safety Calgary, AB T2G 1P5, Canada). The area samplers and a weather monitoring station were located between 100 and 600 feet of distance of suspected sources of gases and at similar elevation (350-365 ft above sea level) of compost production facilities and mushroom farms (Figure 1). The area samplers logged environmental concentrations of NH_3, CH_4, and H_2S continuously for one year and reported data in ten second intervals, which was uploaded to Blackline Safety's servers. Gas data was downloaded from the servers once a month for analysis. Graphs were created for each device and the peak concentrations were recorded at daily, weekly, and monthly intervals for H_2S. Measurements were compared to environmental standards for occupational and ambient air quality. The lower limit of detection (LOD) of the devices was 0.5 ppm, with an upper LOD of 100 ppm. Figure 1 shows a map of the location of the West Chester University (WCU) samplers and the closest DEP monitoring station for comparison. All instruments were calibrated according to manufacturer' specifications which included device calibration every 180 days.

Figure 1: West Chester University and PA DEP Sampling Locations.



Results

The Pilot Study conducted by West Chester University has evaluated millions of data points related to the emissions of H_2S, CH_4, and NH_3 at the sampling locations (see Figure 1). The area monitors recorded levels of CH_4 and NH_3 below the limit of detection of 0.5 ppm during the sampling period therefore exposure to methane and ammonia were assumed negligible for this period. However, H_2S results showed elevated and irregular patterns through the area monitor readings during the study.

Location A:

The device (EXO-1525) stationed at location A collected ambient readings of H_2S, CH_4, and NH_3. During February 2023 through February 2024, concentrations of CH_4 and NH_3 were not detectable and below the lower LOD of the instrument during the sampling campaign. However, H_2S during this period was detected with variable concentrations.

During July 2023, (see Figure 2), the device identified H_2S concentrations that varied from 0.5 ppm and reached as high as 0.7 ppm over the course of an hour, in exceedance of the PA DEP Ambient Air Quality Standard of 0.1 ppm averaged over the course of an hour.

During December 2023, (see Figure 3) the device identified H_2S concentrations that varied from 0.5 ppm and reported irregular patterns as high as 100 ppm over the course of an hour, in exceed of the PA DEP ambient air quality standard of 0.1 ppm averaged over the course of an hour. When comparing these measured concentrations to the NIOSH (10 ppm as a STEL) and OSHA (20 ppm as a TWA) occupational regulations, location A was able to identify exceedance of these standards since the device identified spikes upwards of 100 ppm. The device was able to demonstrate that the PA DEP ambient air quality standards had been exceeded. However, concentrations at or above 100 ppm were only identified at this sampling location and appear atypical, indicating that the device may have been experiencing a sensor malfunction. H_2S concentrations at location A did not violate occupational standards, but did exceed ambient air quality standards established in Pennsylvania.

The complete data analysis for measurement recorded at Location A is included in Appendices A and B.

Figure 2 Location A July 10, 2023

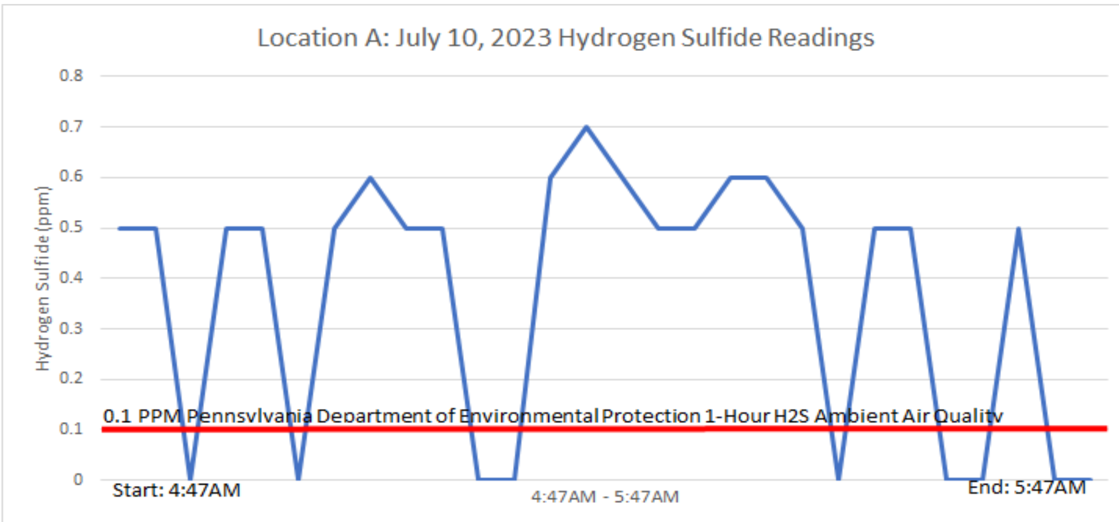
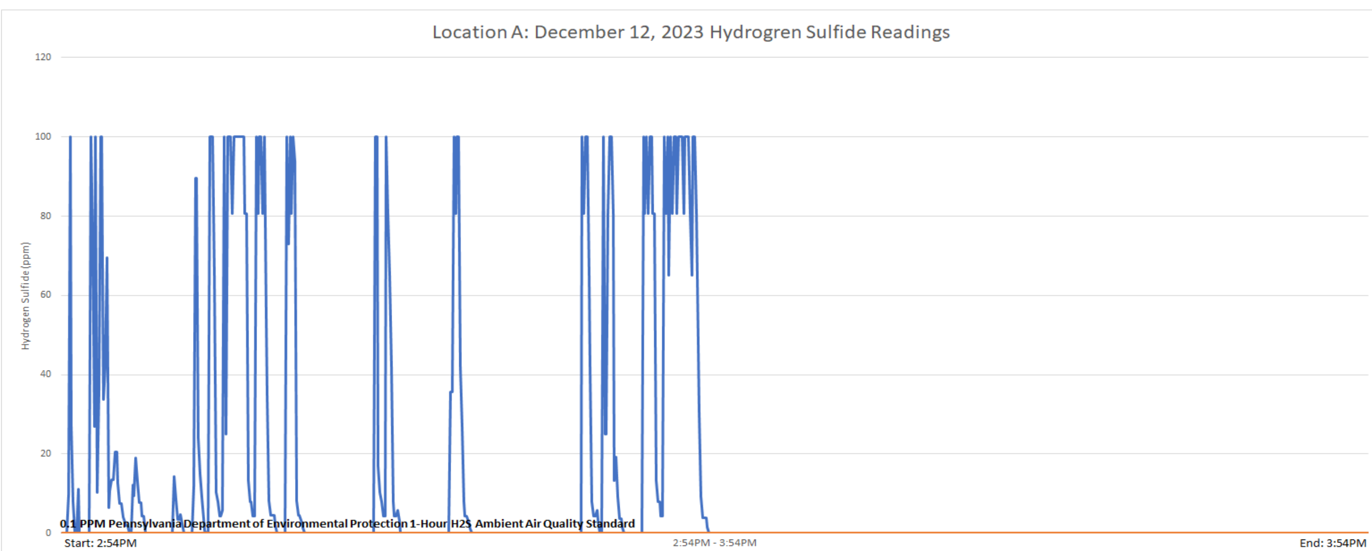


Figure 3 Location A December 12, 2023



Location B:

The device (EXO-1526) stationed at location B collected ambient readings of H_2S, CH_4, and NH_3. During February 2023 through February 2024, concentrations of CH_4 and NH_3 were not detectable and below the lower LOD of the instrument during the sampling campaign. However, H_2S during this period was detected with variable concentrations.

During July, 2023 (see Figure 4), the device identified H_2S concentrations that varied from 0.5 ppm and reached as high as 0.6 ppm over the course of an hour, in exceedance of the PA DEP ambient air quality standard of 0.1 ppm averaged over the course of an hour.

During December 2023, (See Figure 5) the device identified H_2S concentrations that varied from 0.5 ppm and reached as high as 1.2 ppm over the course of an hour, in exceedance of the PA DEP ambient air quality standard of 0.1 ppm averaged over the course of an hour.

The complete data analysis for measurement recorded at Location B is included in Appendices C and D.

Figure 4 Location B December 5, 2023

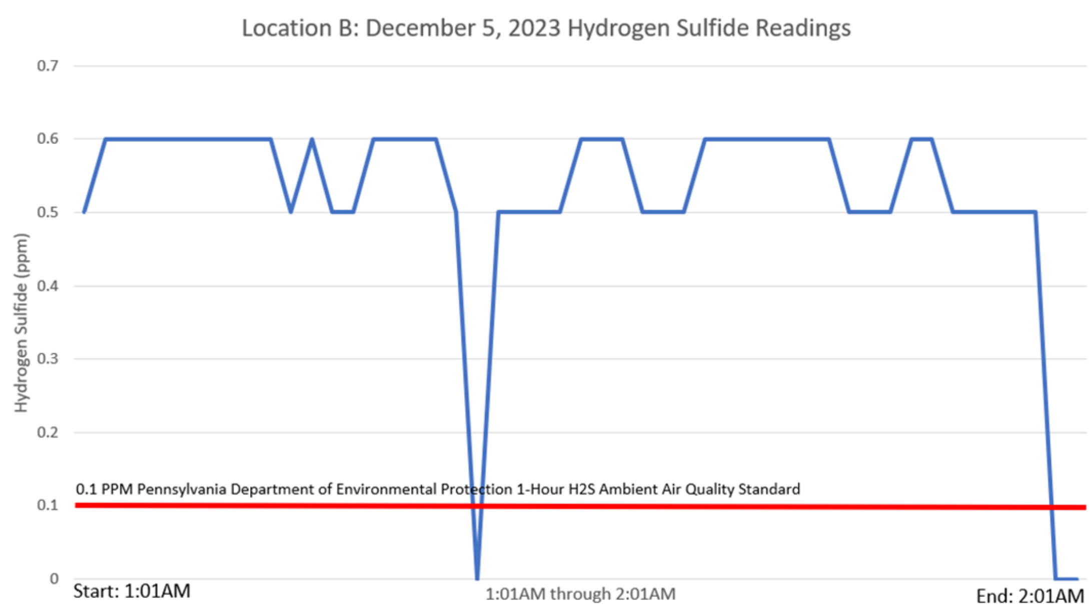
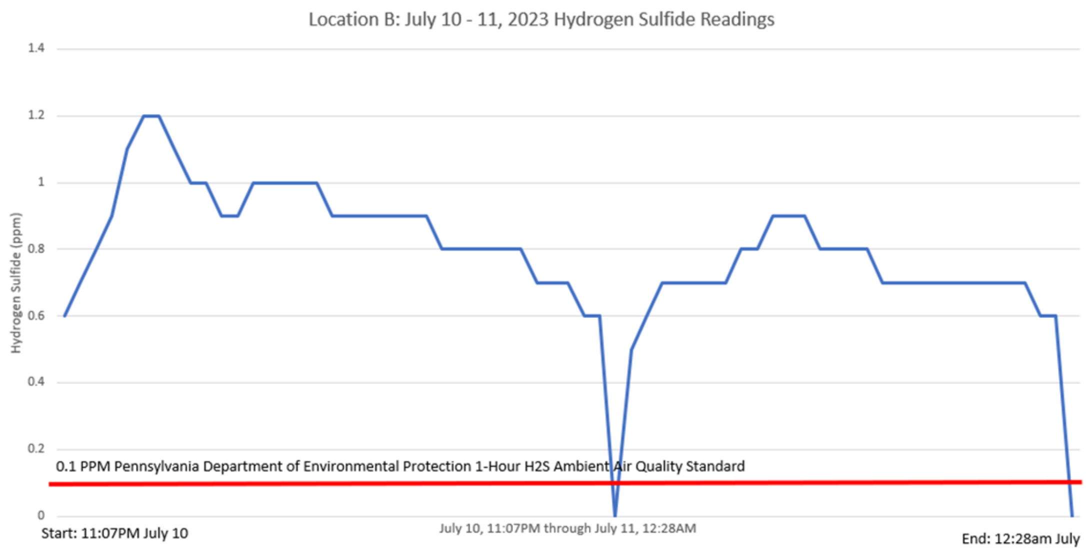


Figure 5 Location B July 10-11, 2023



Location C:

The device (EXO-1527) stationed at Location C collected ambient readings of H_2S, CH_4, and NH_3. During February 2023 through February 2024, concentrations of CH_4 and NH_3 were not detectable and below the lower LOD of the instrument during the sampling campaign. However, H_2S during this period was detected with variable concentrations.

During July 2023, (see Figure 6), the device identified hydrogen sulfide concentrations that varied from 0.5 ppm and reached as high as 1.6 ppm over the course of an hour, in exceedance of the PA DEP ambient air quality standard of 0.1 ppm averaged over the course of an hour.

During December 2023, (see Figure 7) the device identified hydrogen sulfide concentrations that varied from 0.5 ppm and reached as high as 3.6 ppm over the course of an hour, in exceed of the PA DEP ambient air quality standard of 0.1 ppm averaged over the course of an hour.

The complete data analysis for measurement recorded at Location C is included in Appendices E and F.

Figure 6 Location C July 7, 2023

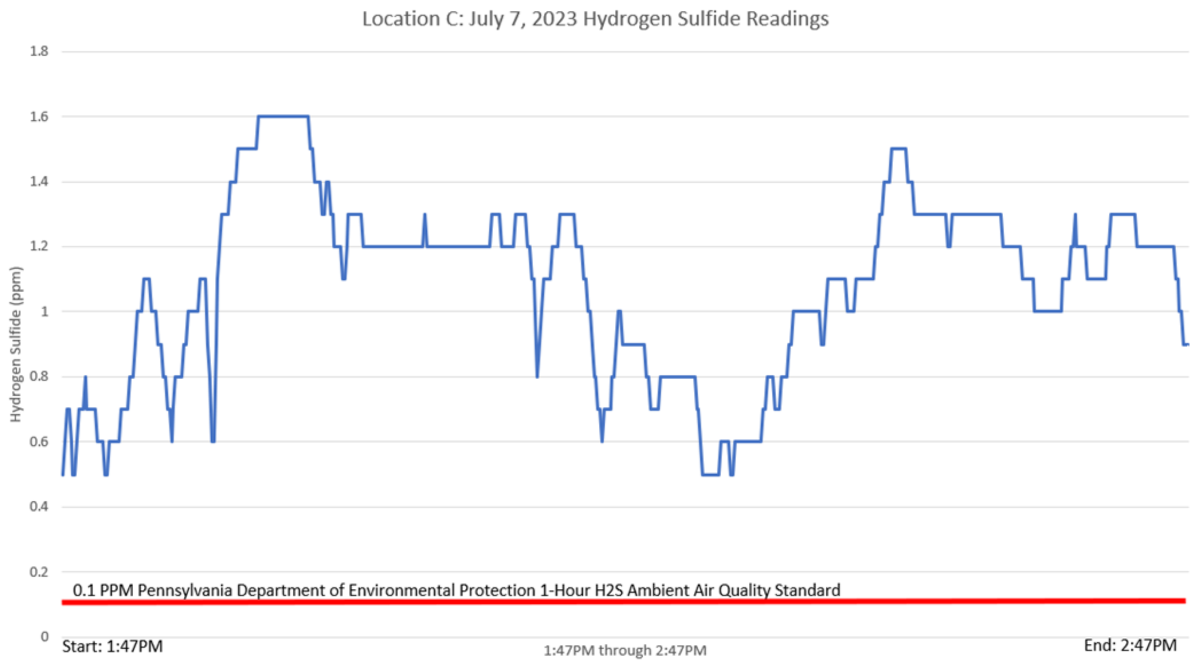
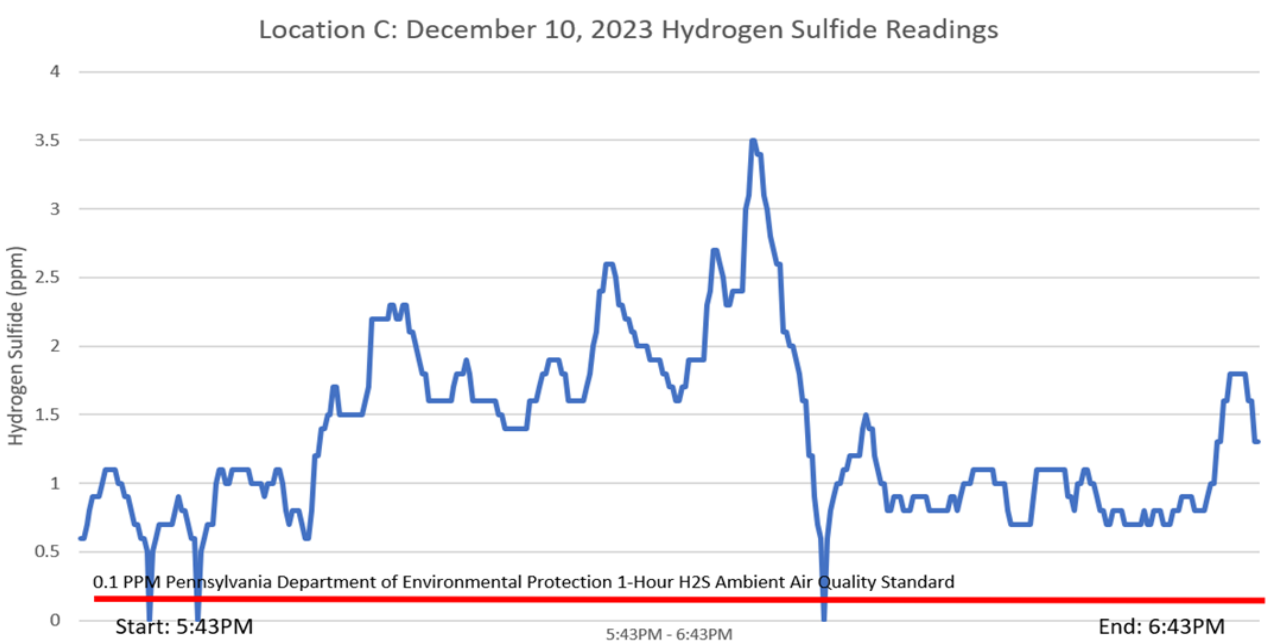


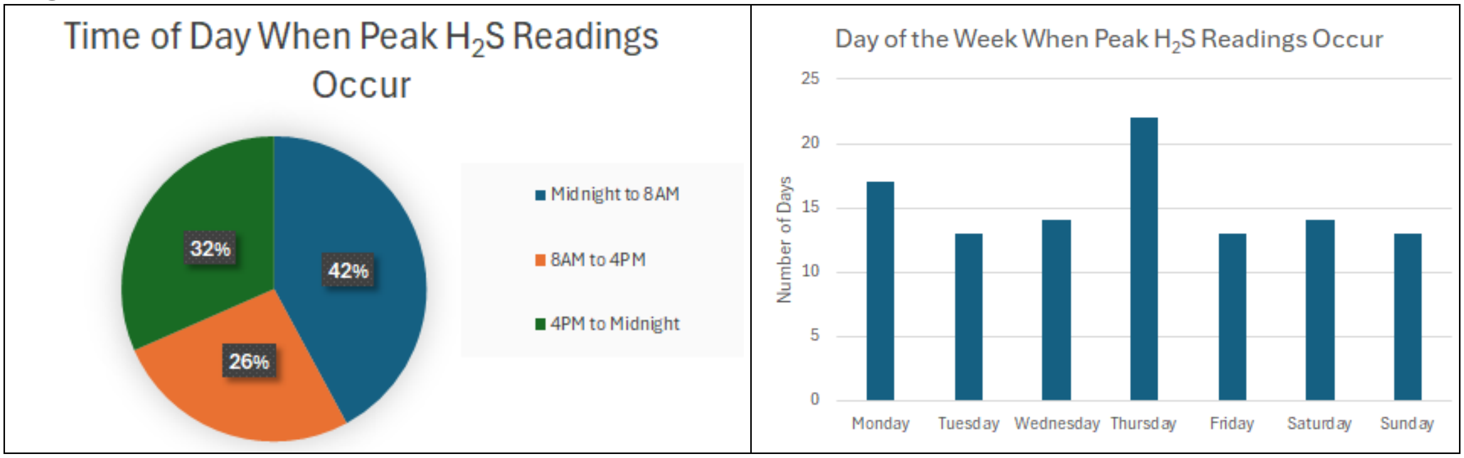
Figure 7 Location C December 10, 2023



Concentration Patterns

Throughout all three sampling locations, elevated concentrations of hydrogen sulfide were observed primarily from midnight until 8:00AM with 42% of peak readings occurring during this time of day. This suggests operations conducted overnight or in the early morning hours cause increases in H_2S levels in the residential community. In contrast, 26% of the peak readings were recorded between the times of 8AM and 4 PM. Additionally, the peak concentrations of hydrogen sulfide that occurred in each given week were more frequently observed on Thursdays followed by Mondays (see Figure 8).

Figure 8. Concentration Patterns.



Discussion

This study examined the environmental concentration of three gases with potential impact to chronic exposure to NH_3, CH_4 and H_2S. Since the study did not investigate the health of the community, this report cannot determine a potential relationship between H_2S exposure and negative health outcomes such as asthma, coughing, wheezing, or nasal congestion. However, these symptoms are typical among people exposed to H_2S and have been verified by the U.S. Department of Health and Human Services Agency for Toxic Substance and Disease Registry (ATSDR, 2016). Additional information is needed to understand the link between exposure, disease status, and nuisance symptoms. It is recommended that a future health and epidemiological study be conducted to evaluate health records and disease status to determine the impact of H_2S on residents' health in the community.

Point sources of metal corrosion were not investigated during this pilot study, but corrosion of metal bolts on the equipment deployed during this study was observed. The equipment was new and free of corrosion or damage when initially installed in February 2023, which suggests the observed oxidation and chemical deposits on equipment surfaces during the 1-year sampling campaign were more severe than the typical outdoor corrosion. It presented as severe rusting and a layer of black powdery material on the iron and copper surfaces. Literature has established that H_2S can react with oxygen molecules in the atmosphere and create sulfuric acid, which is known to accelerate rust and metal corrosion rates (EPA, 1991). Increased concentrations of H_2S in the community will increase the amount of sulfuric acid in the area, resulting in an accelerated rate of metal decomposition in the ambient and residential environments. Due to the inability to determine the sources of increased corrosion, a future study should investigate the presence of sulfuric acid and its conjugates in both the ambient environment, and the surface of metal materials.

One limitation of this pilot study was due to the limited number of devices available for use during the sampling campaign. Three area monitors were used. Using more area samplers during sampling will provide a more comprehensive representation of the area being studied, leading to a more accurate mapping of the ambient concentrations, a reduction in the margin of error and uncertainty, and a better understanding of the dispersion of gases through the environment and subsequently, the residential community. Furthermore, device 1525 (Location A) reported H_2S concentrations near the upper limit of the detection of the sensor (100 ppm) readings from August 2023 to December 2023. These gas readings do not follow conventional gas dispersion patterns and are assumed to be a result of sensor drift, which may be due to the sensor becoming faulty during the respective months of the sampling period. Due to the limited number of devices, redundancy of sampling to validate the readings in Location A was not possible. Having another area monitor to deploy near Location A could have helped draw clarity to the data being reported during August 2023 to December 2023 and ultimately establish the reliability of the sensor during this period. The data in Location A from August to December 2023 should be interpreted with caution.

An additional limitation of these devices was being unable to obtain readings below 0.5 ppm. The samplers began reporting data once a concentration of 0.5 ppm was reached. Readings between 0.1 and 0.5 ppm would still be above the PA DEP ambient air quality standard of 0.1 ppm averaged over 1 hour. Ultimately, this suggests the H_2S concentrations could have consistently been above the ambient air quality standard of 0.1 ppm even when beneath the equipment's lower LOD of 0.5 ppm.

Gas sampling was not able to be recorded within FMP facilities. Our samplers were deployed within 100-600 feet away from suspected point sources near FMP facilities. This limitation prevented more precise identification of sources within the FMPs. Gas diffusion through the ambient environment subsequently does not allow us to identify which components of FMP facilities are contributing to the increase of ambient H_2S levels. Further, it does not clarify the proportion these sources may have contributed to the detected concentration of H_2S. Since environmental parameters such as wind, thermal gradients, and pressure changes influence the diffusion of gases, concentrations that reached the samplers between 100-600 feet away do not imply there are not higher concentrations in other parts of the ambient or residential environments. Due to these limitations, a future study should investigate concentrations inside FMP facilities, additional sources within FMP facilities, and the relationship between worker or procedural tasks and the subsequent release of H_2S.

Conclusion

Hydrogen sulfide, methane, and ammonia are recognized toxic gases. Employees, residents, and the general population should be protected from exposure to these gases. Subsequently, exposure to these gases is known to cause deleterious effects to health and pose a nuisance concern at lower concentrations. This pilot study demonstrates significant exposure to hydrogen sulfide is occurring in residential communities surrounding the suspected point sources. The concentrations recorded are elevated enough to cause discernable and recognizable symptoms among individuals who may inhale H_2S. Since sampling was conducted on resident's properties, it follows that the residents in this area have been exposed to these concentrations over the sampling campaign.

This pilot study was not able to detect or indicate releases of methane or ammonia entering the residential communities surrounding the suspected FMP point sources at or above 0.5 ppm. While the concentrations were not elevated enough to be detected by the area monitors, there may be low-level concentrations that exist below the LOD of the devices. Further, the pilot study was unable to conclude the absence of these gases entirely as environmental parameters such as wind direction ultimately determine how these gases permeate into other areas of the environment.

The pilot study analysis determined that the Pennsylvania Department of Environmental Protection ambient air quality standard has periodically been violated in comparison to the established 0.1 ppm 1-hour average or 0.05 ppm 24-hour average. The National Institute of Occupational Safety and Health recommended exposure limit of 10 ppm over a 10-minute period may have been exceeded at Location A during the Fall and Winter months of 2023, though the data will require further sampling to validate the findings of this device during that period. Additionally, the Occupational Safety and Health Administration permissible exposure limit of 20 ppm as a time-weighted average may have been exceeded at Location A during the Fall and Winter months of 2023. Location B and C readings did not exceed either NIOSH or OSHA occupational exposure limits.

Recommendations

Due to the hazardous nature of hydrogen sulfide and concentrations measured on residential properties surrounding FMP facilities in New Garden Township, Pennsylvania, the following recommendations are made:

1. Evaluate the sources of the gas releases and quantify the concentrations released from the source within the FMP sites.

2. Remedy deficiencies in business operating procedures in comparison to the *Best Practices for Environmental Protection in the Mushroom Farm Community* published by the Pennsylvania Department of Environmental Protection (2012).
3. Inform residents and other stakeholders of chronic exposure to hydrogen sulfide and consequences to health.
4. Consult with a Professional Engineer and Certified Industrial Hygienist to evaluate business procedures and associated releases of gases.
5. Consult with health officials to determine the impact that chronic exposure has on resident's health and wellbeing.

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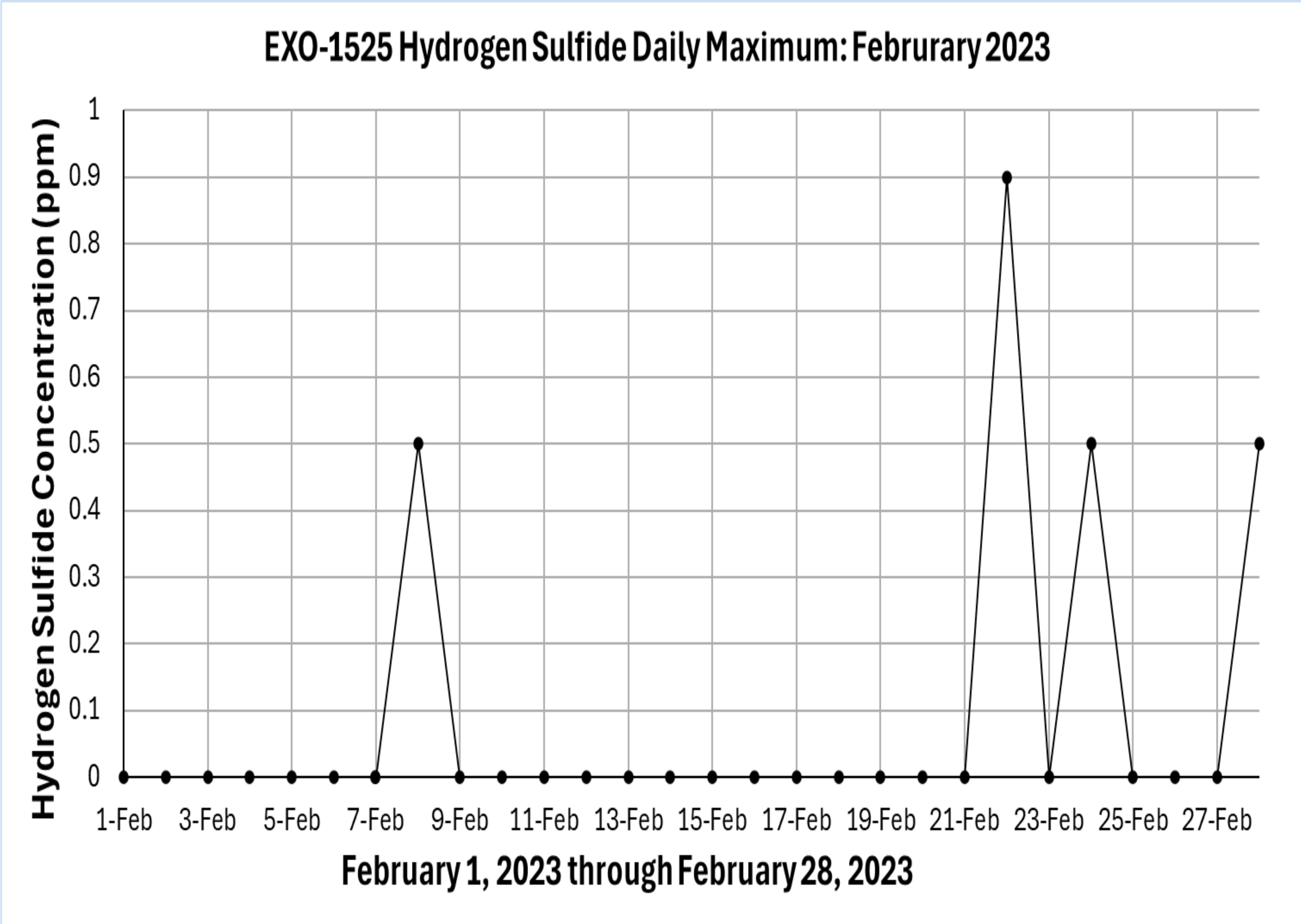
Appendices

APPENDIX A: Location A

EXO-1525 Daily Maximum Graphs


EXO-1525 Hydrogen Sulfide Daily Maximum: Februrary 2023
Hydrogen Sulfide Concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
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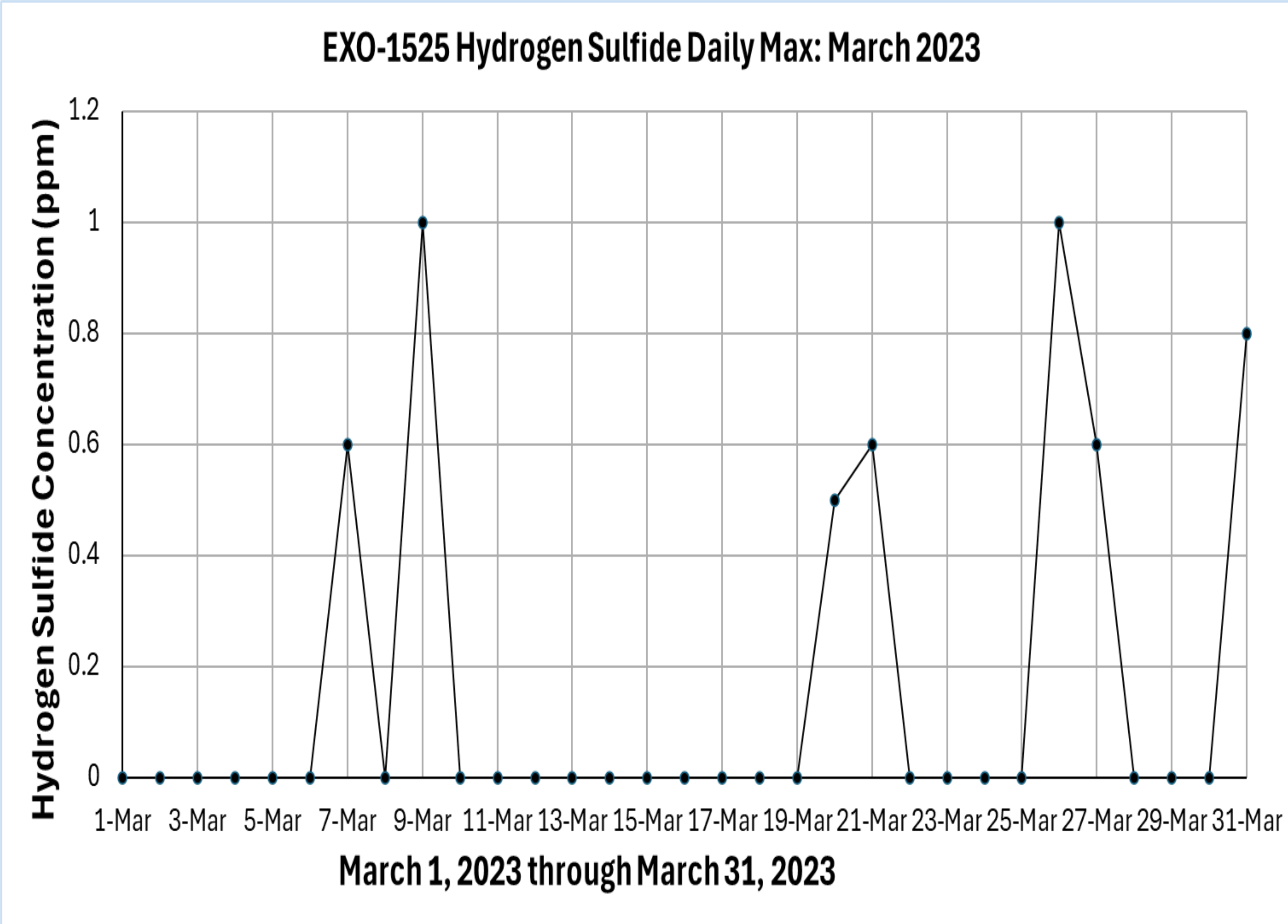
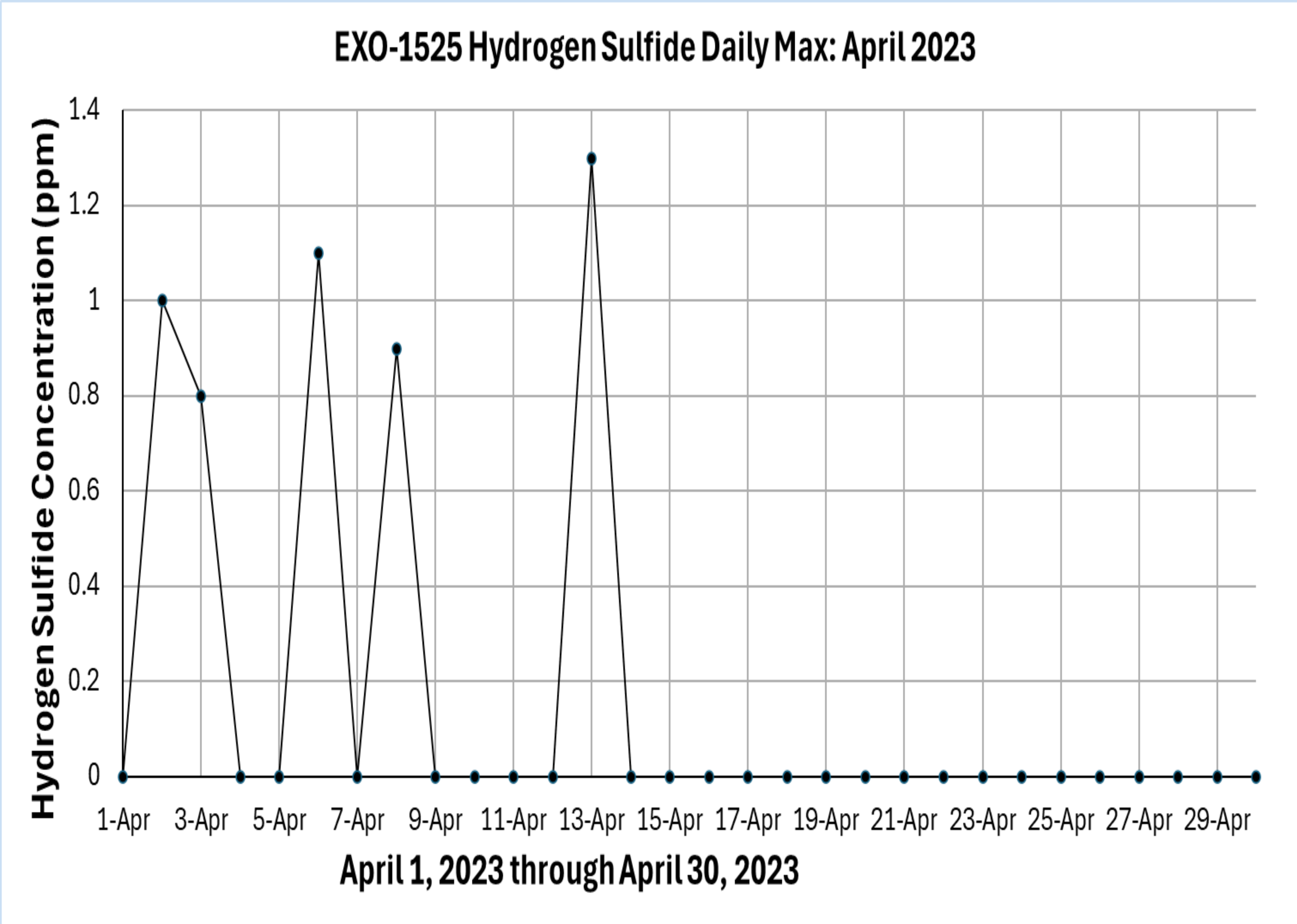
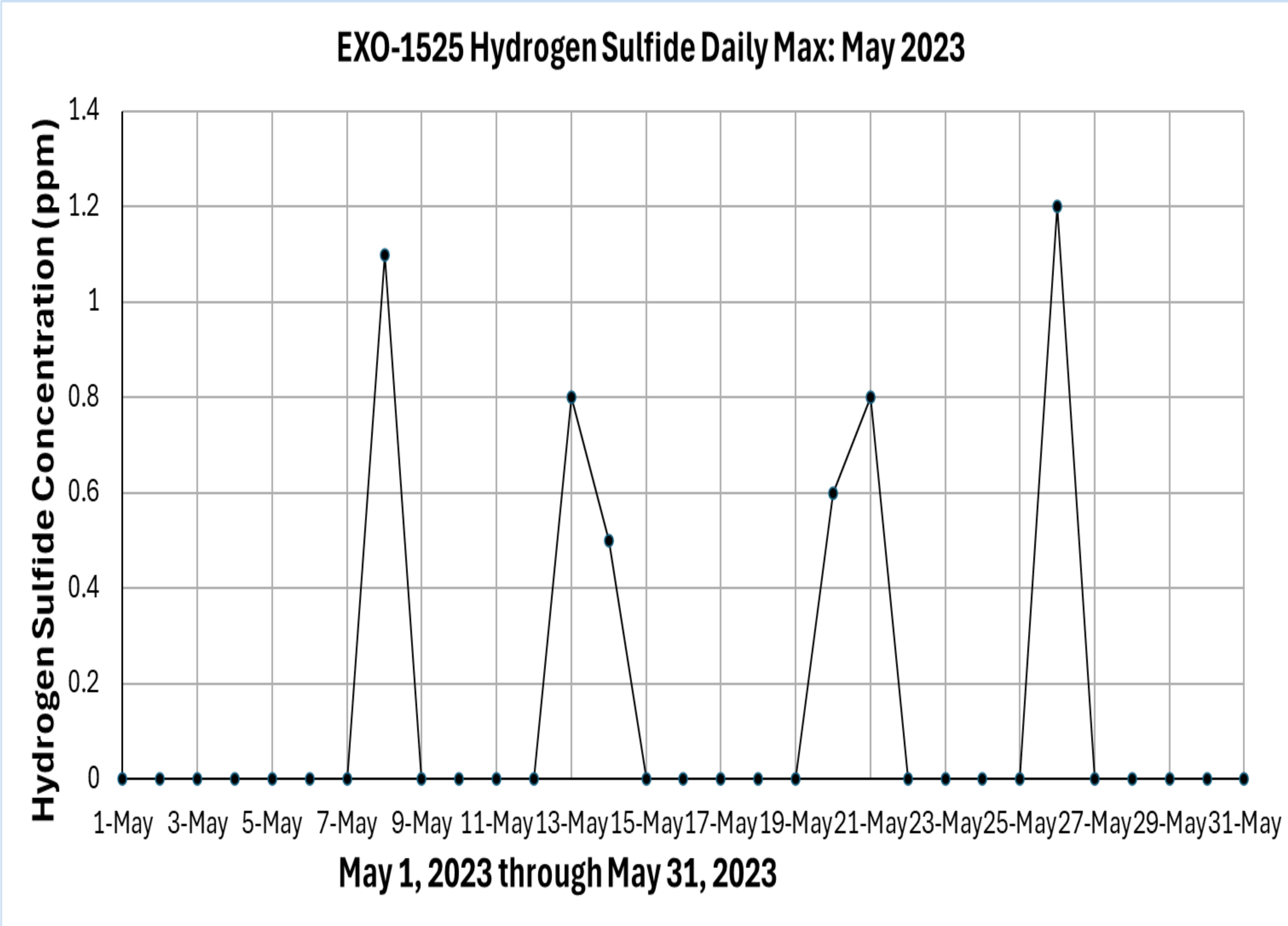
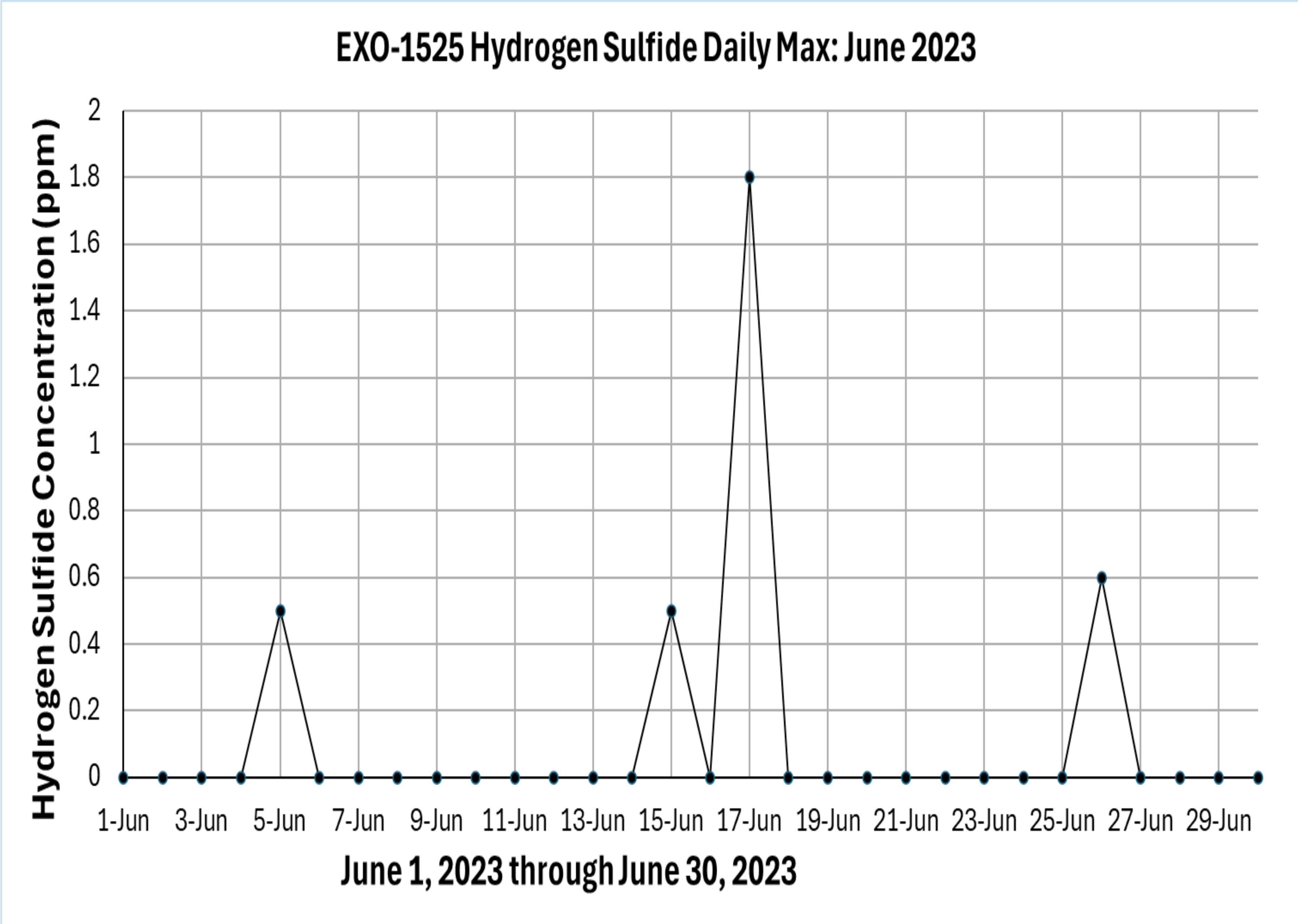
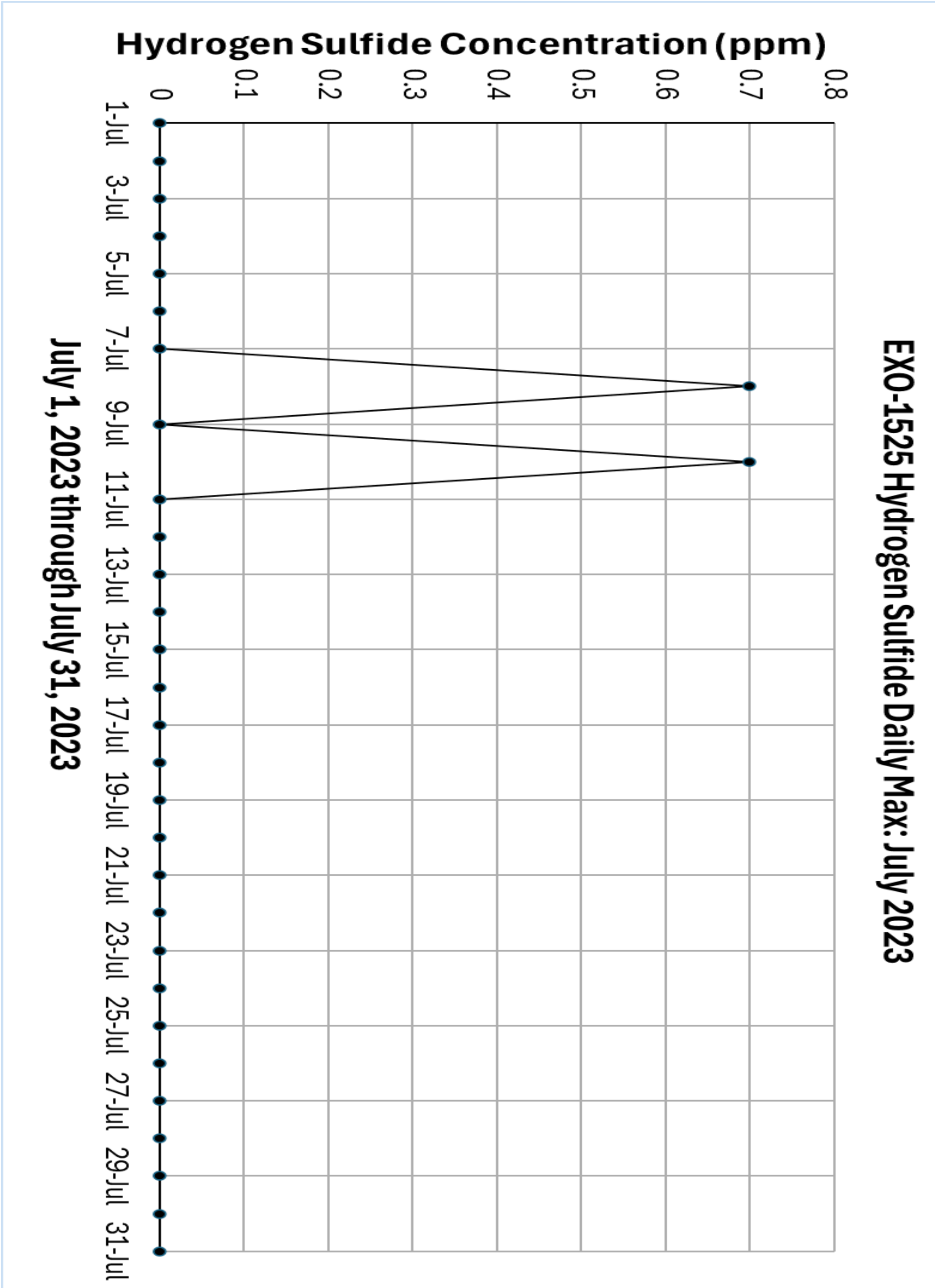
25-Feb
27-Feb
February 1, 2023 through February 28, 2023

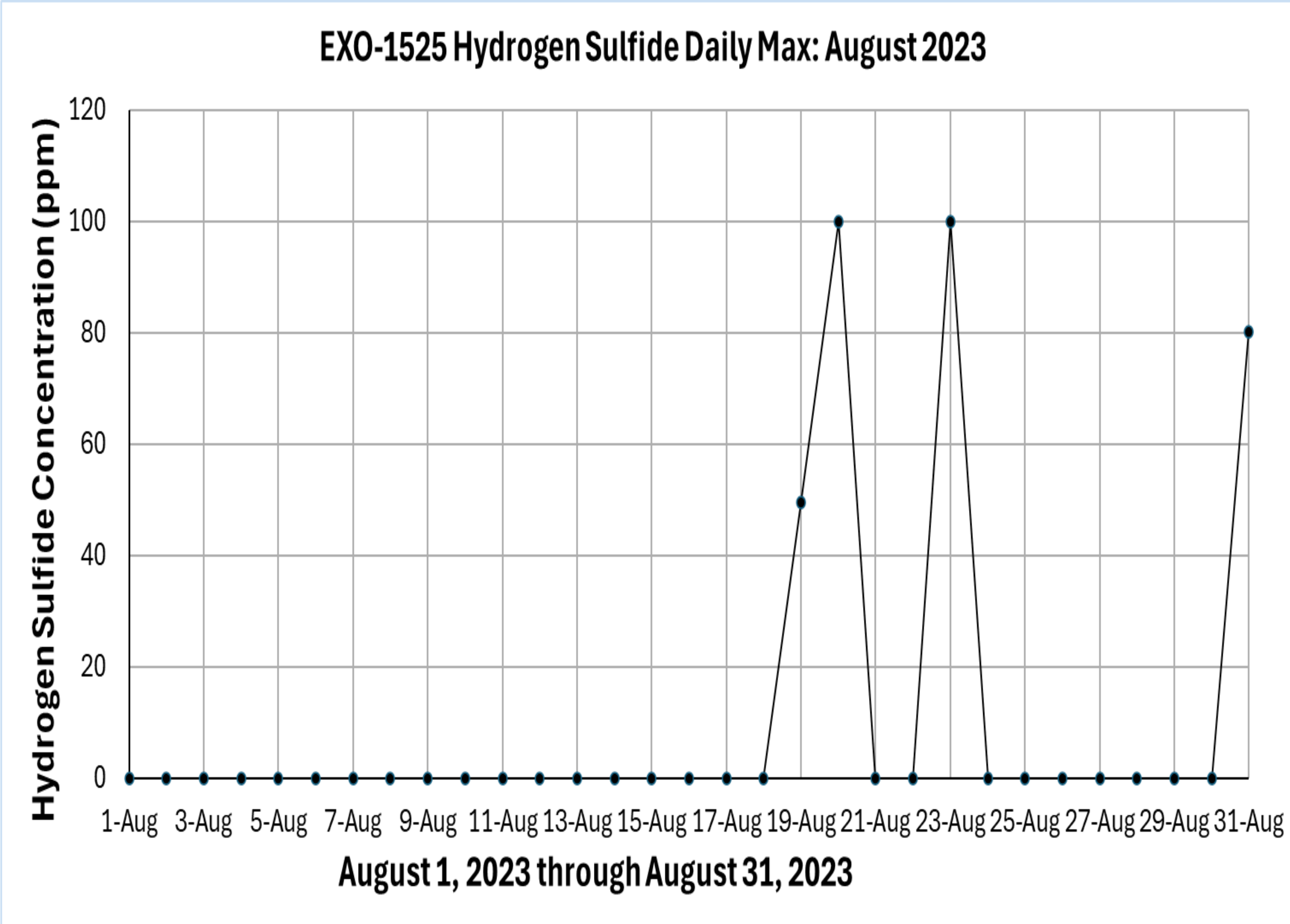

EXO-1525 Hydrogen Sulfide Daily Max: March 2023
Hydrogen Sulfide Concentration (ppm)
1.2
1
0.8
0.6
0.4
0.2
0
1-Mar
3-Mar
5-Mar
7-Mar
9-Mar
11-Mar
13-Mar
15-Mar
17-Mar
19-Mar
21-Mar
23-Mar
25-Mar
27-Mar
29-Mar
31-Mar
March 1, 2023 through March 31, 2023

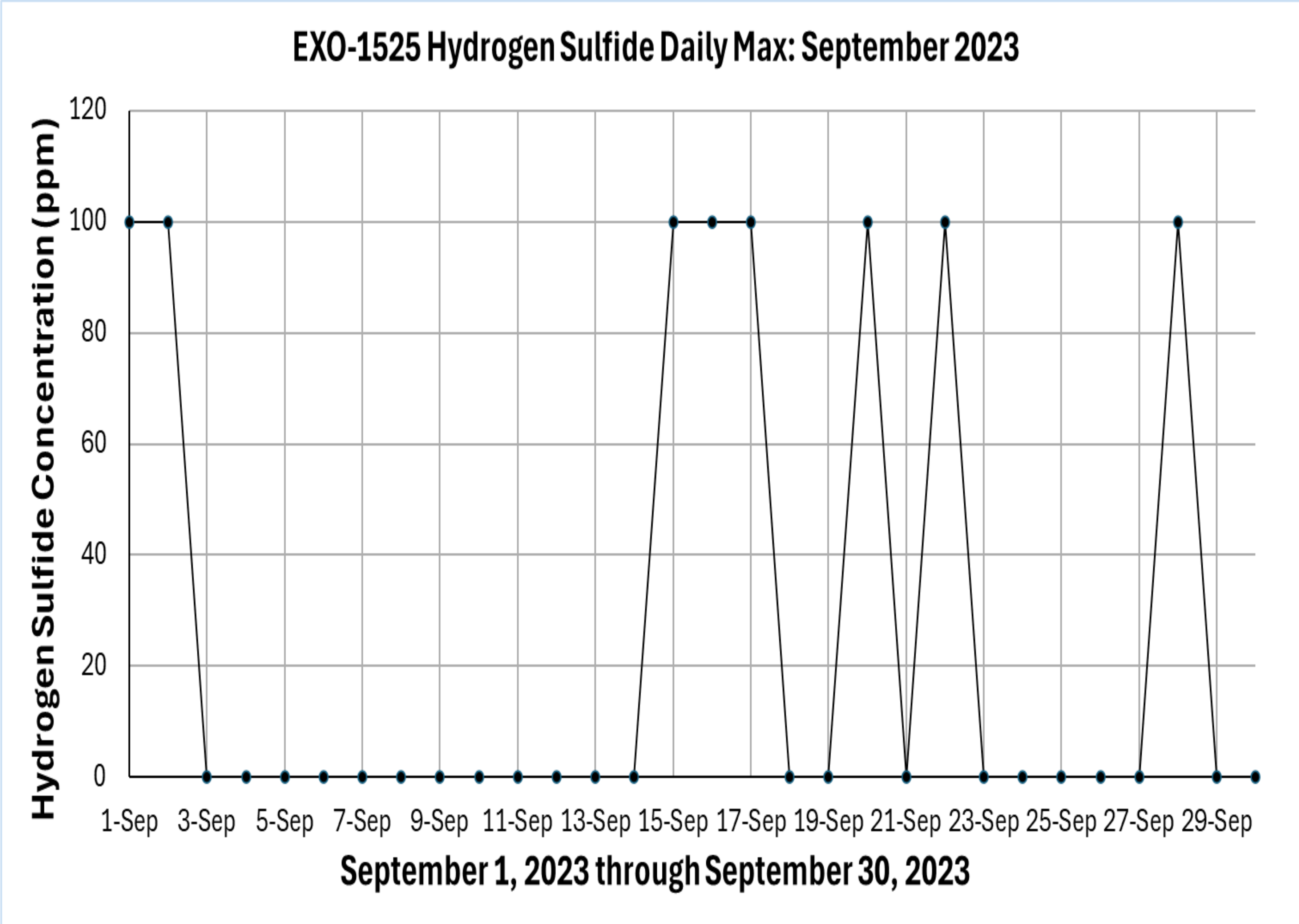

EXO-1525 Hydrogen Sulfide Daily Max: April 2023
Hydrogen Sulfide Concentration (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Apr
3-Apr
5-Apr
7-Apr
9-Apr
11-Apr
13-Apr
15-Apr
17-Apr
19-Apr
21-Apr
23-Apr
25-Apr
27-Apr
29-Apr
April 1, 2023 through April 30, 2023

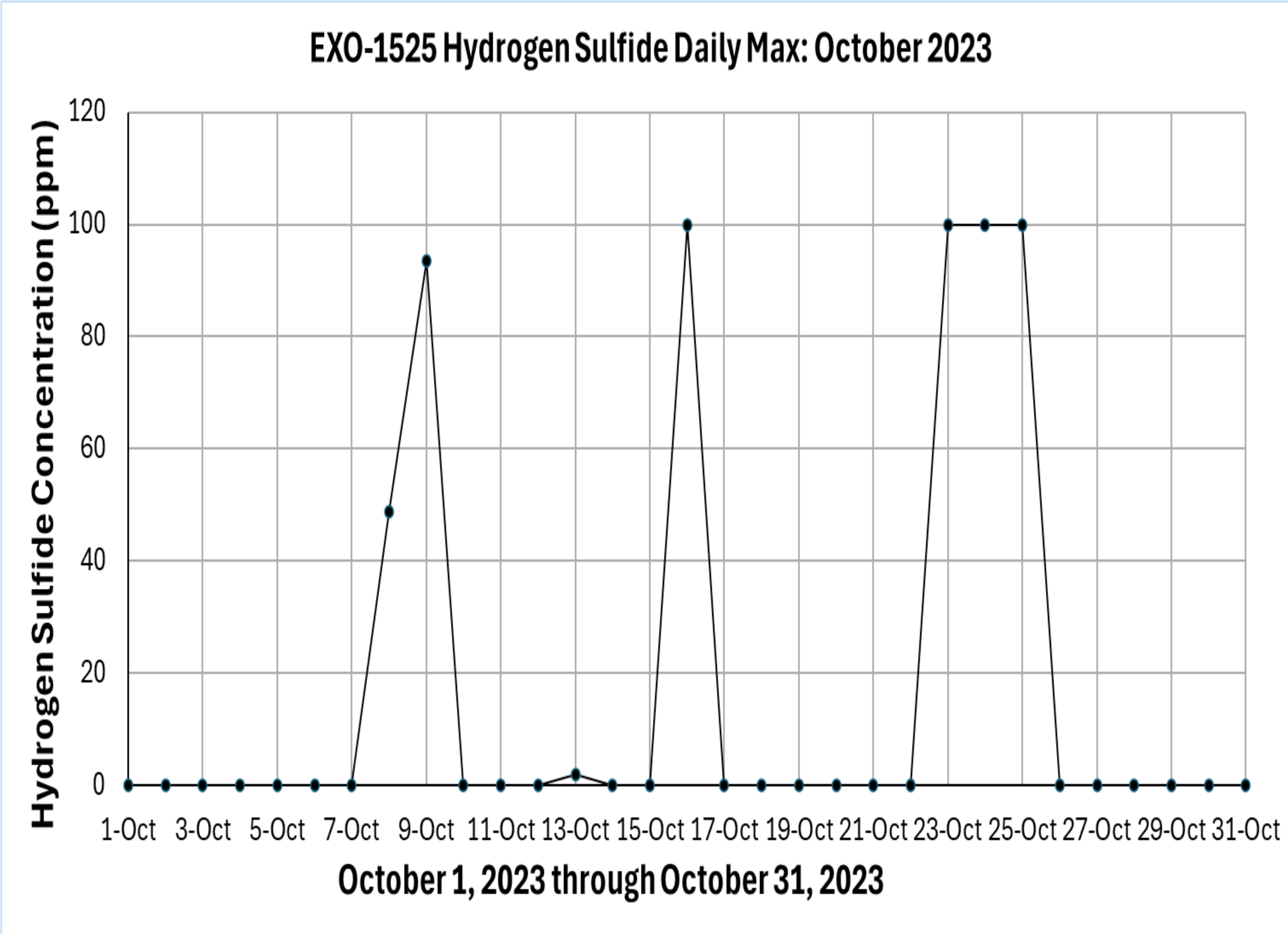

EXO-1525 Hydrogen Sulfide Daily Max: May 2023
Hydrogen Sulfide Concentration (ppm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
May 1, 2023 through May 31, 2023

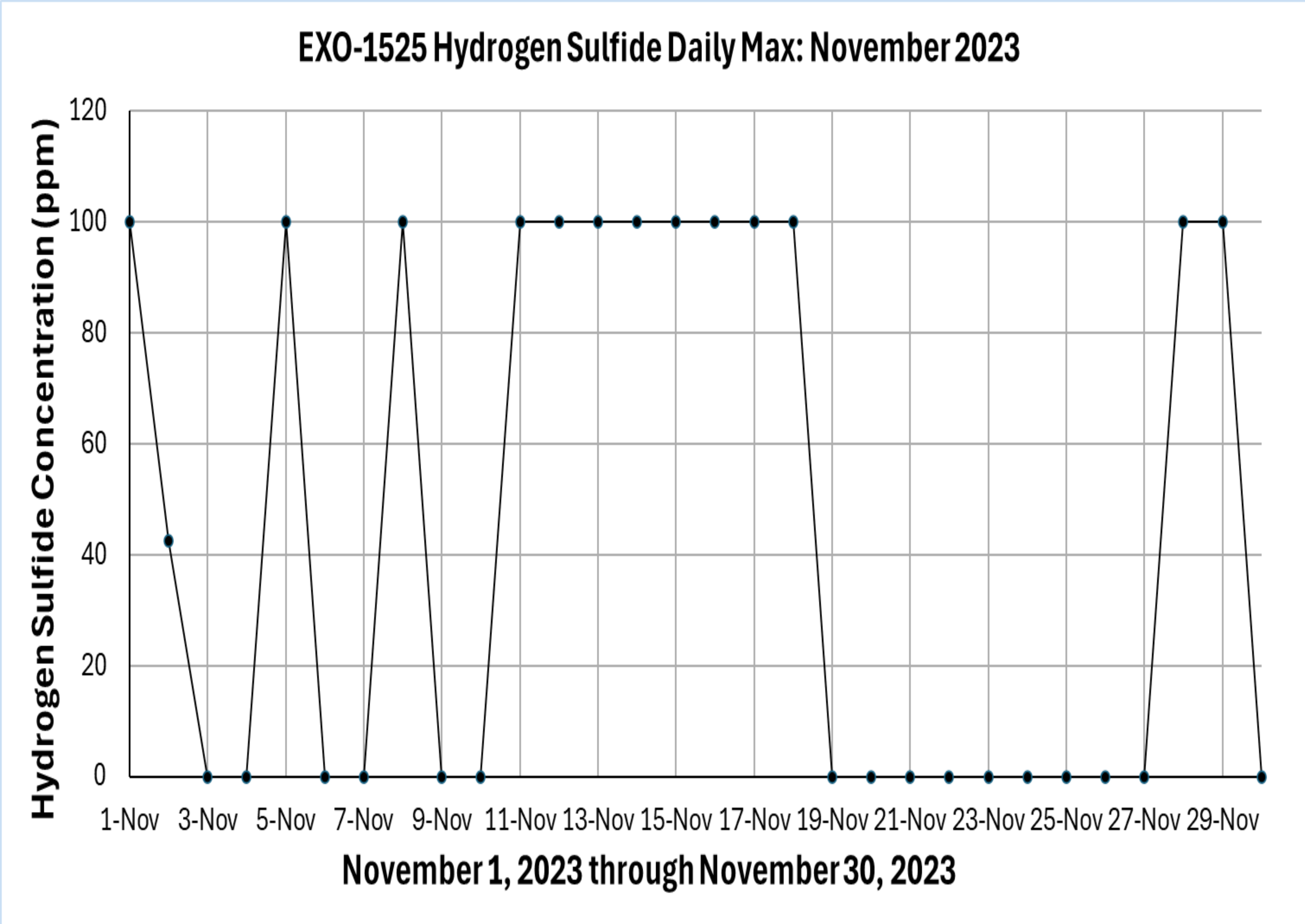

EXO-1525 Hydrogen Sulfide Daily Max: June 2023
Hydrogen Sulfide Concentration (ppm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1-Jun
3-Jun
5-Jun
7-Jun
9-Jun
11-Jun
13-Jun
15-Jun
17-Jun
19-Jun
21-Jun
23-Jun
25-Jun
27-Jun
29-Jun
June 1, 2023 through June 30, 2023

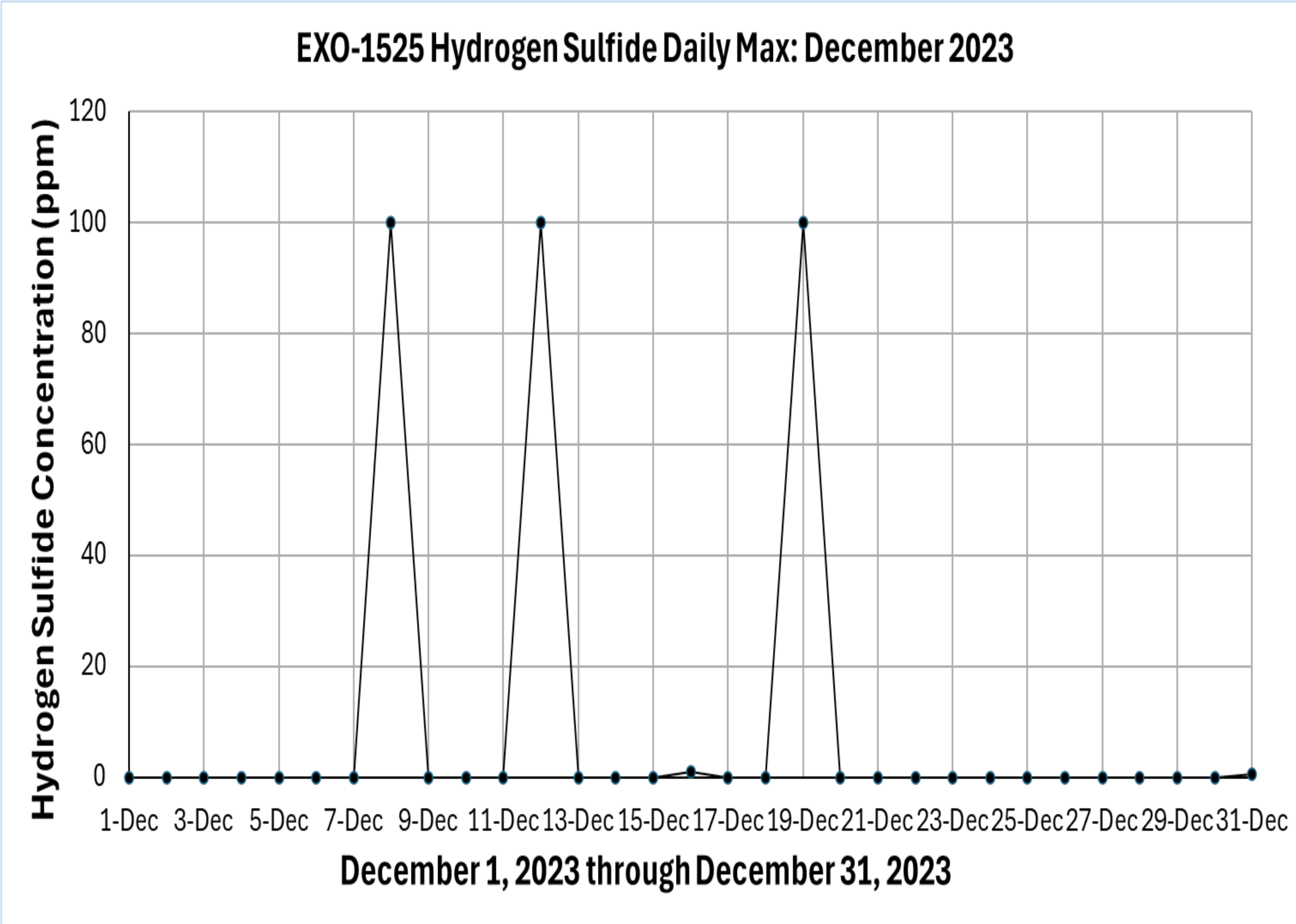

EXO-1525 Hydrogen Sulfide Daily Max: July 2023
Hydrogen Sulfide Concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1-Jul
3-Jul
5-Jul
7-Jul
9-Jul
11-Jul
13-Jul
15-Jul
17-Jul
19-Jul
21-Jul
23-Jul
25-Jul
27-Jul
29-Jul
31-Jul
July 1, 2023 through July 31, 2023

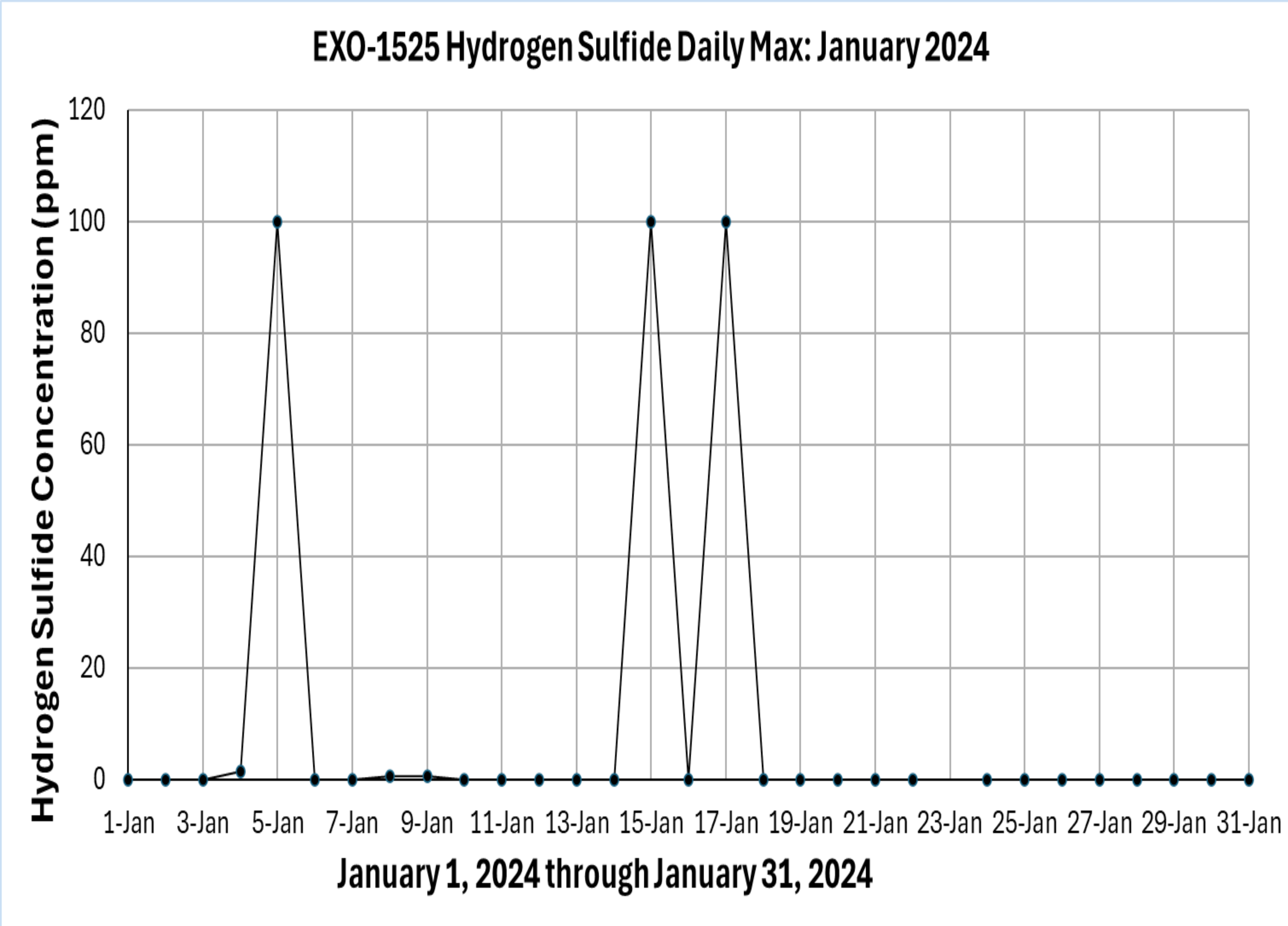

EXO-1525 Hydrogen Sulfide Daily Max: August 2023
Hydrogen Sulfide Concentration (ppm)
0
20
40
60
80
100
120
1-Aug
3-Aug
5-Aug
7-Aug
9-Aug
11-Aug
13-Aug
15-Aug
17-Aug
19-Aug
21-Aug
23-Aug
25-Aug
27-Aug
29-Aug
31-Aug
August 1, 2023 through August 31, 2023


EXO-1525 Hydrogen Sulfide Daily Max: September 2023
Hydrogen Sulfide Concentration (ppm)
120
100
80
60
40
20
0
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
September 1, 2023 through September 30, 2023

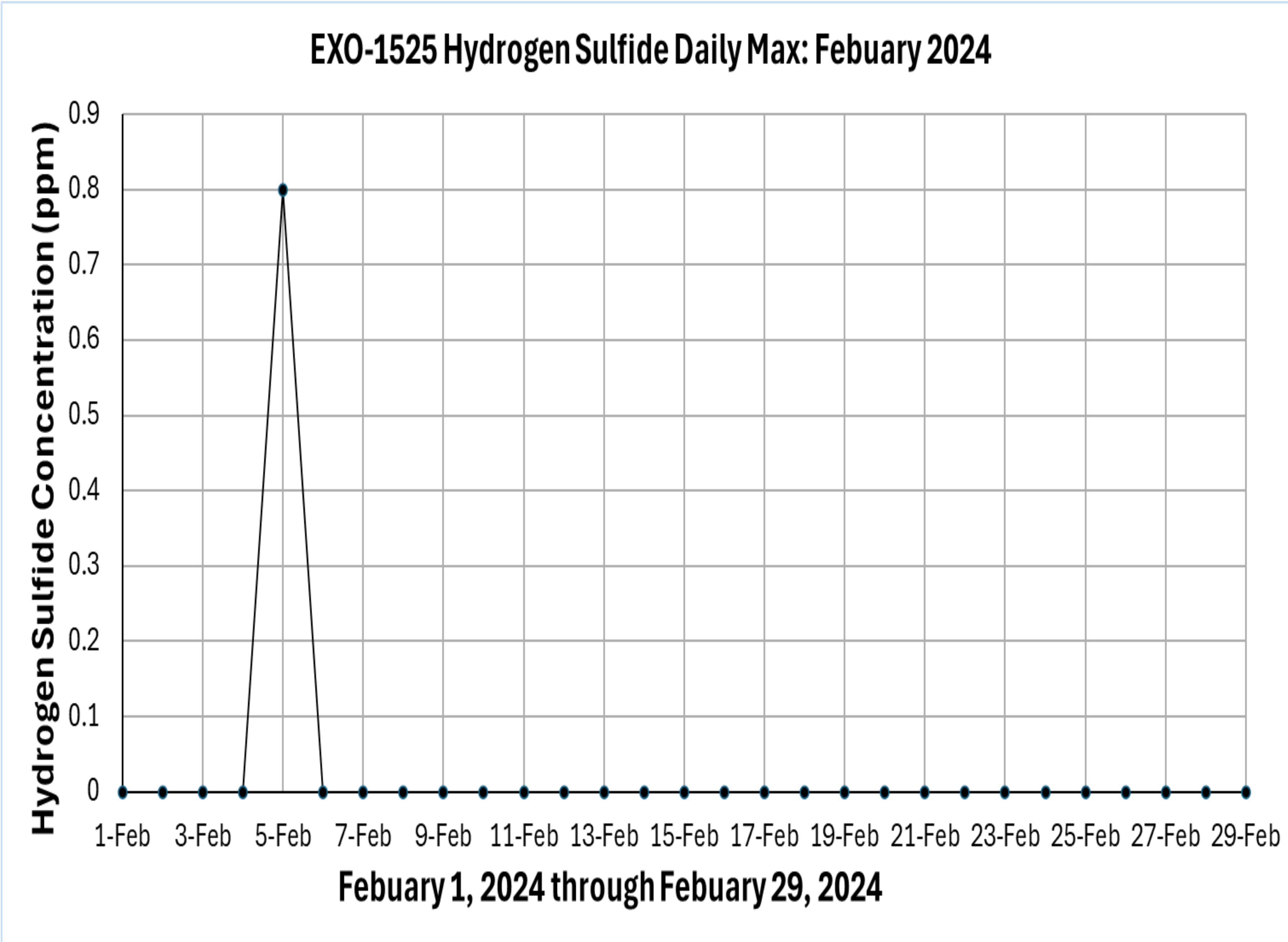

EXO-1525 Hydrogen Sulfide Daily Max: October 2023
Hydrogen Sulfide Concentration (ppm)
0
20
40
60
80
100
120
1-Oct 3-Oct 5-Oct 7-Oct 9-Oct 11-Oct 13-Oct 15-Oct 17-Oct 19-Oct 21-Oct 23-Oct 25-Oct 27-Oct 29-Oct 31-Oct
October 1, 2023 through October 31, 2023


EXO-1525 Hydrogen Sulfide Daily Max: November 2023
Hydrogen Sulfide Concentration (ppm)
120
100
80
60
40
20
0
1-Nov
3-Nov
5-Nov
7-Nov
9-Nov
11-Nov
13-Nov
15-Nov
17-Nov
19-Nov
21-Nov
23-Nov
25-Nov
27-Nov
29-Nov
November 1, 2023 through November 30, 2023


EXO-1525 Hydrogen Sulfide Daily Max: December 2023
Hydrogen Sulfide Concentration (ppm)
0
20
40
60
80
100
120
1-Dec
3-Dec
5-Dec
7-Dec
9-Dec
11-Dec
13-Dec
15-Dec
17-Dec
19-Dec
21-Dec
23-Dec
25-Dec
27-Dec
29-Dec
31-Dec
December 1, 2023 through December 31, 2023

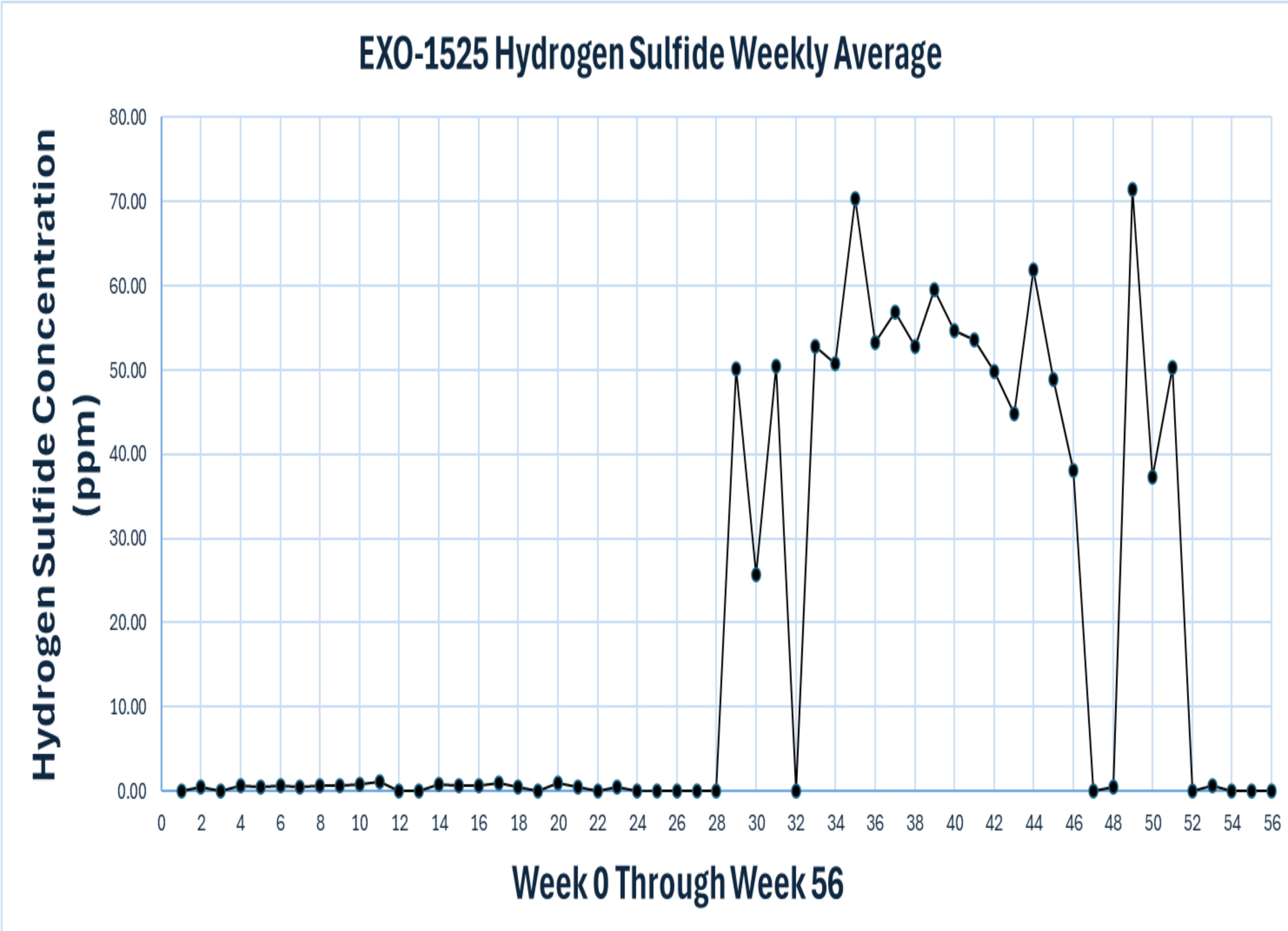


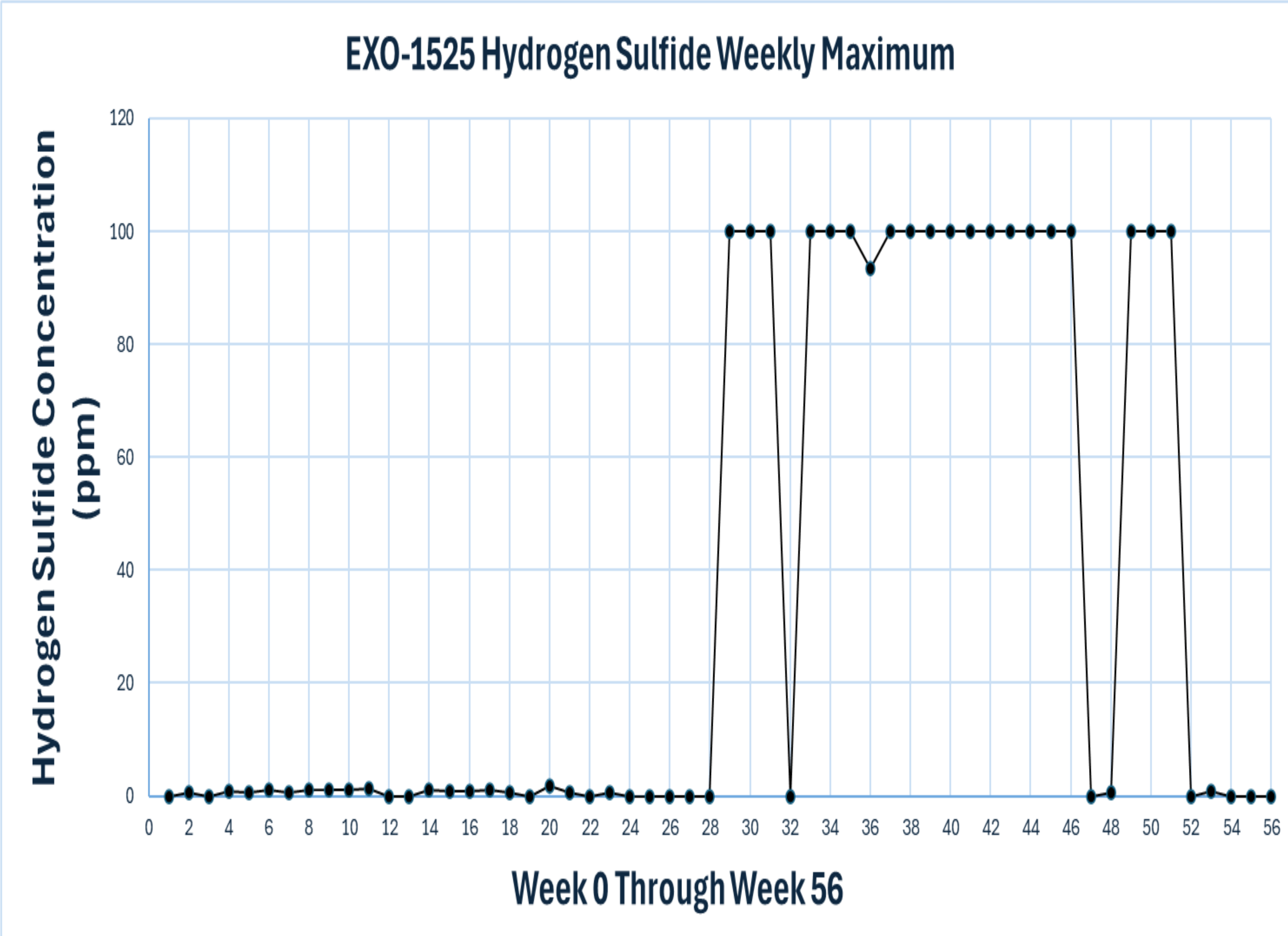
EXO-1525 Hydrogen Sulfide Daily Max: January 2024
Hydrogen Sulfide Concentration (ppm)
0
20
40
60
80
100
120
1-Jan
3-Jan
5-Jan
7-Jan
9-Jan
11-Jan
13-Jan
15-Jan
17-Jan
19-Jan
21-Jan
23-Jan
25-Jan
27-Jan
29-Jan
31-Jan
January 1, 2024 through January 31, 2024

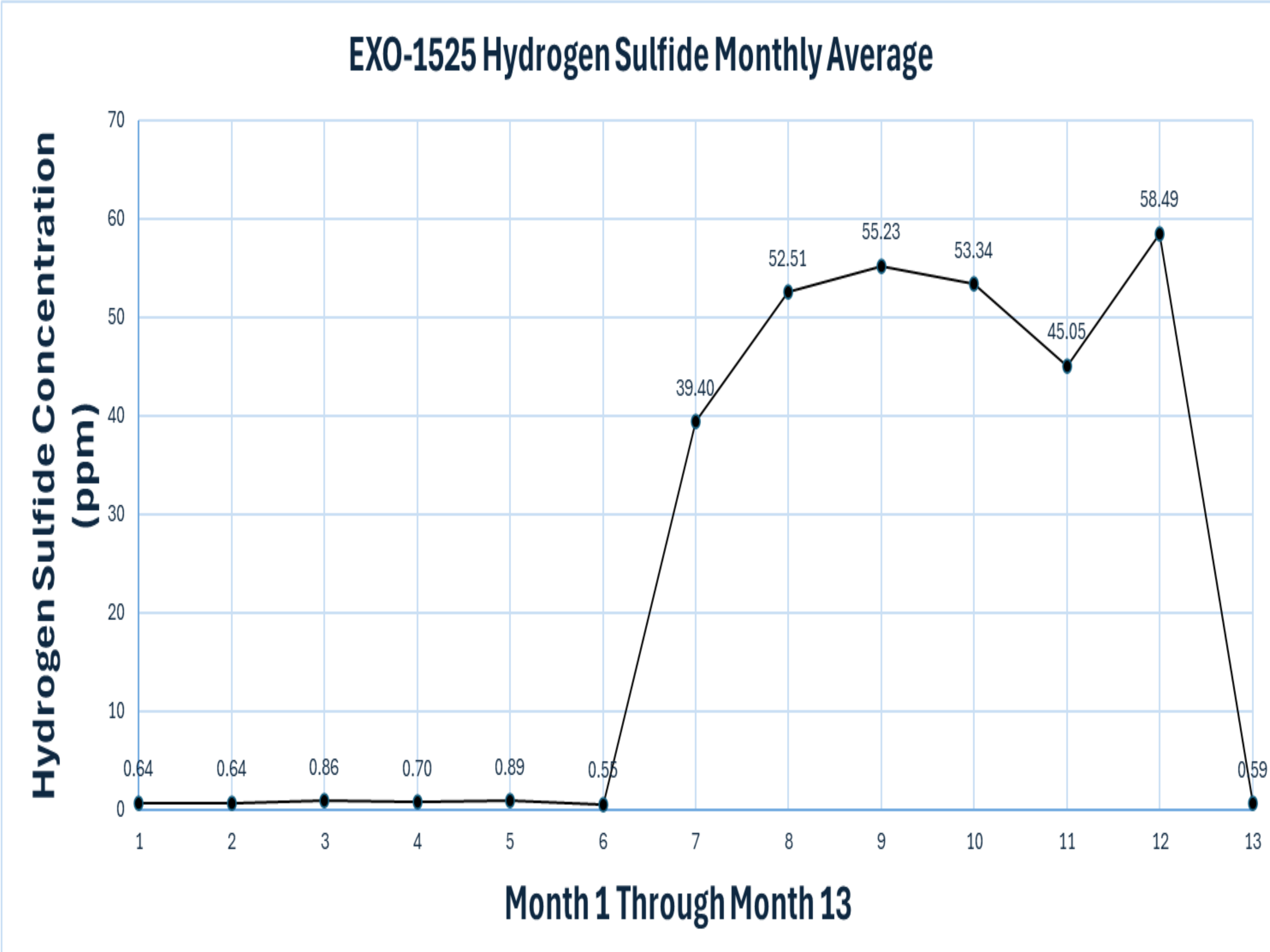

EXO-1525 Hydrogen Sulfide Daily Max: Febuary 2024
Hydrogen Sulfide Concentration (ppm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
21-Feb
23-Feb
25-Feb
27-Feb
29-Feb
Febuary 1, 2024 through Febuary 29, 2024

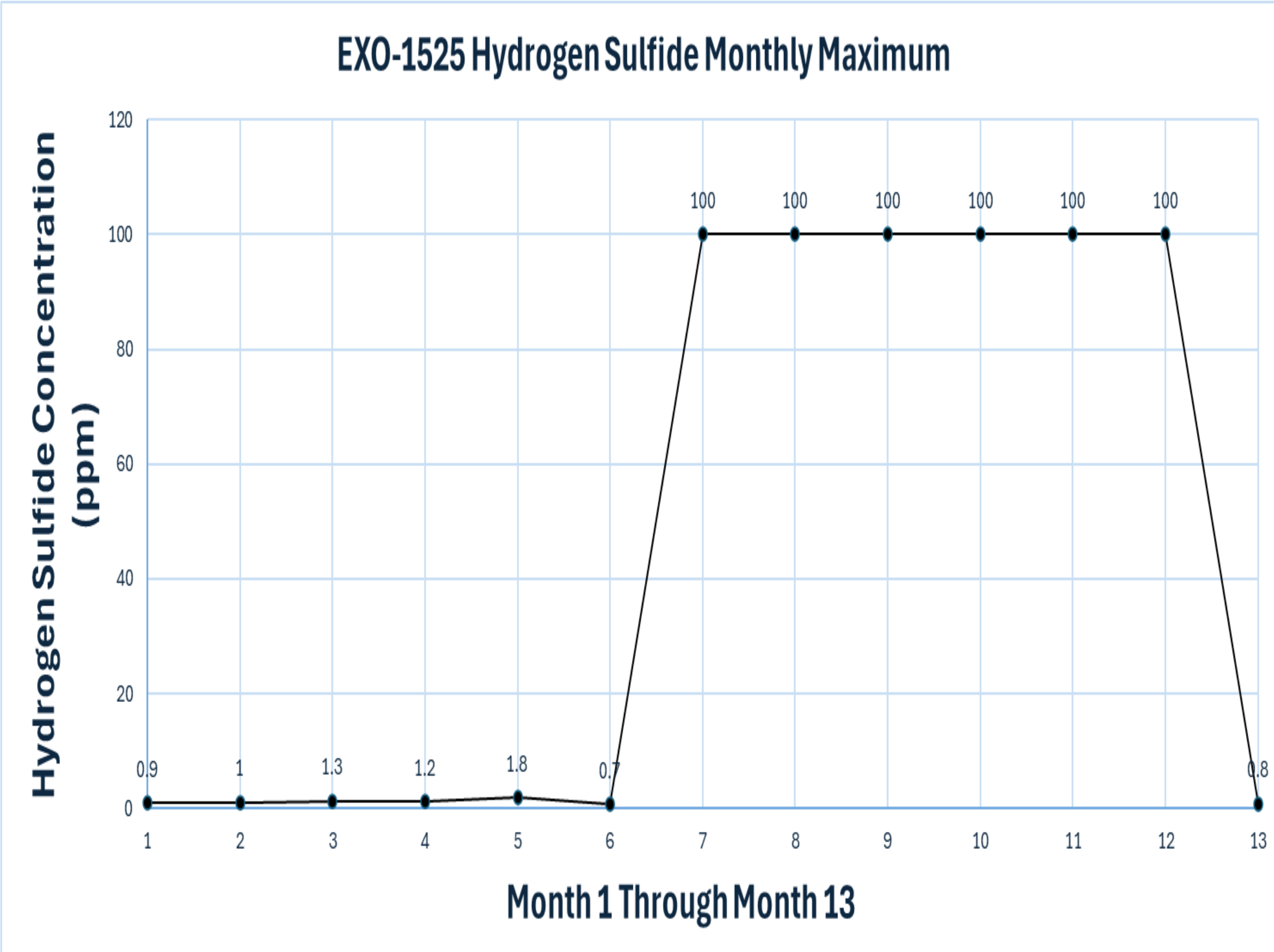
APPENDIX B: Location A

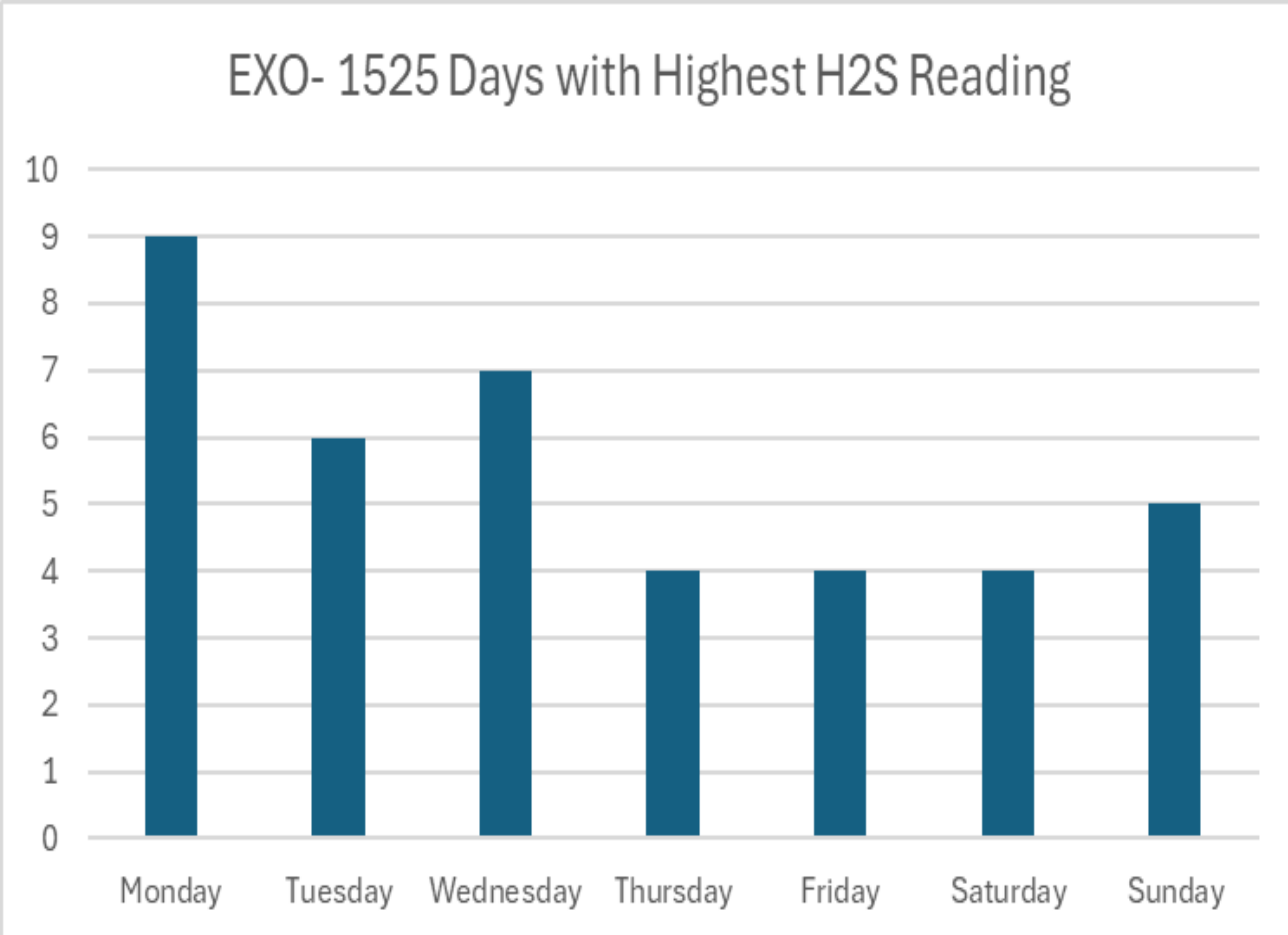
EXO-1525 Weekly Information Graphs


EXO-1525 Hydrogen Sulfide Weekly Average
Hydrogen Sulfide Concentration (ppm)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
Week 0 Through Week 56


EXO-1525 Hydrogen Sulfide Weekly Maximum
Hydrogen Sulfide Concentration (ppm)
120
100
80
60
40
20
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
Week 0 Through Week 56

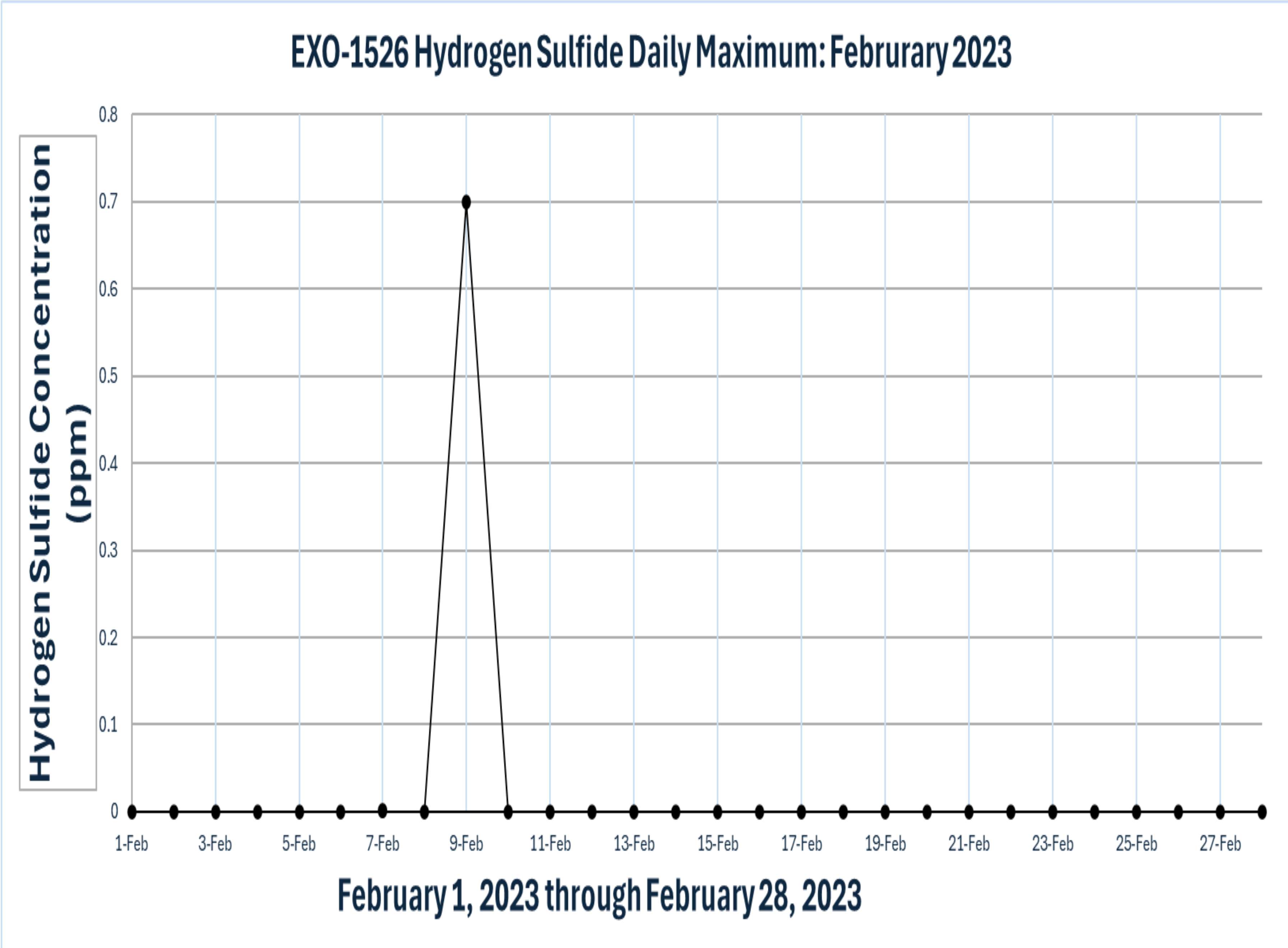

EXO-1525 Hydrogen Sulfide Monthly Average
Hydrogen Sulfide Concentration (ppm)
Month 1 Through Month 13
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
11
12
13
0.64
0.64
0.86
0.70
0.89
0.55
39.40
52.51
55.23
53.34
45.05
58.49
0.59


EXO-1525 Hydrogen Sulfide Monthly Maximum
Hydrogen Sulfide Concentration (ppm)
0
20
40
60
80
100
120
0.9
1
1.3
1.2
1.8
0.7
100
100
100
100
100
100
0.8
1
2
3
4
5
6
7
8
9
10
11
12
13
Month 1 Through Month 13

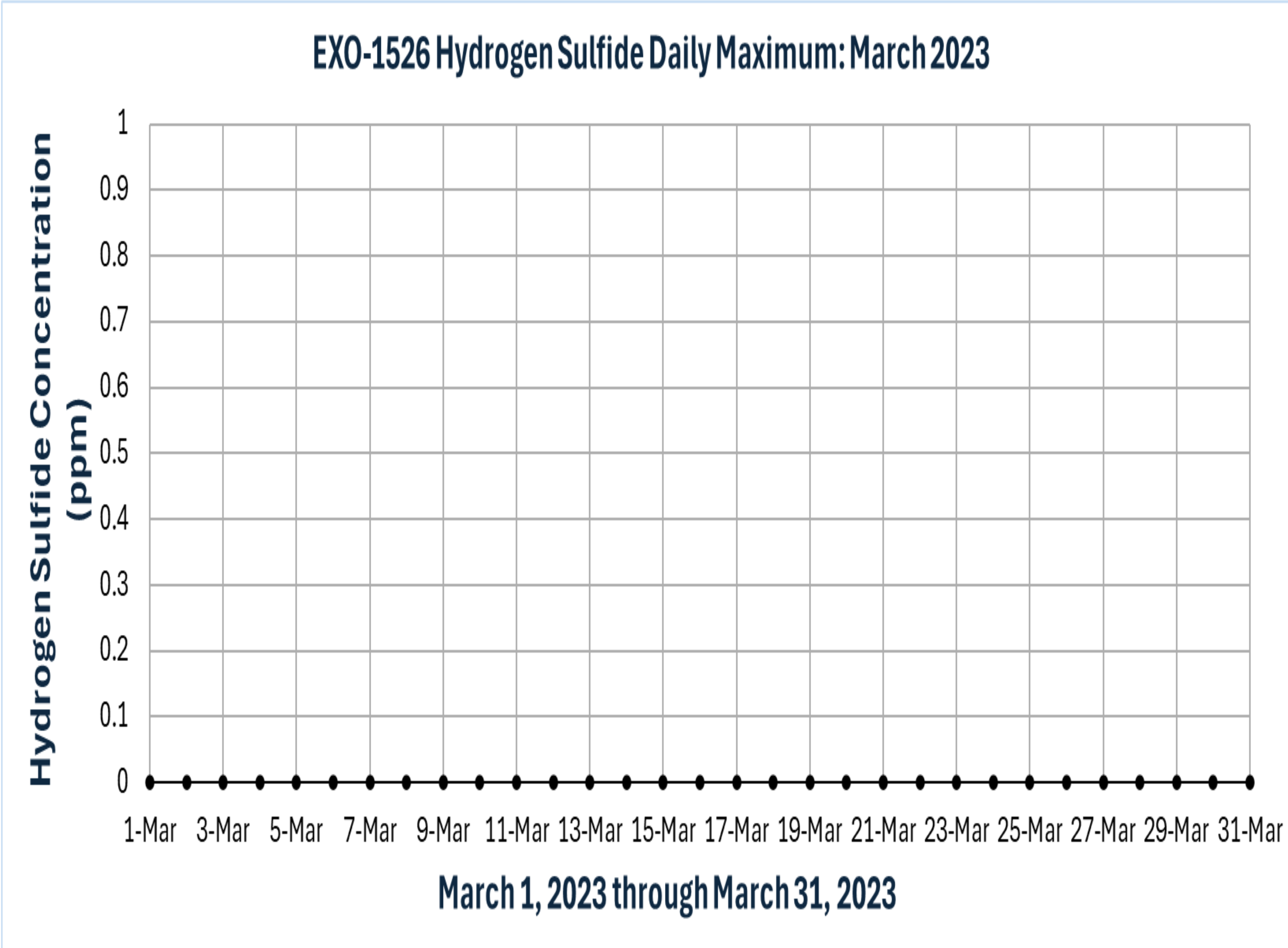

EXO- 1525 Days with Highest H2S Reading
10
9
8
7
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday

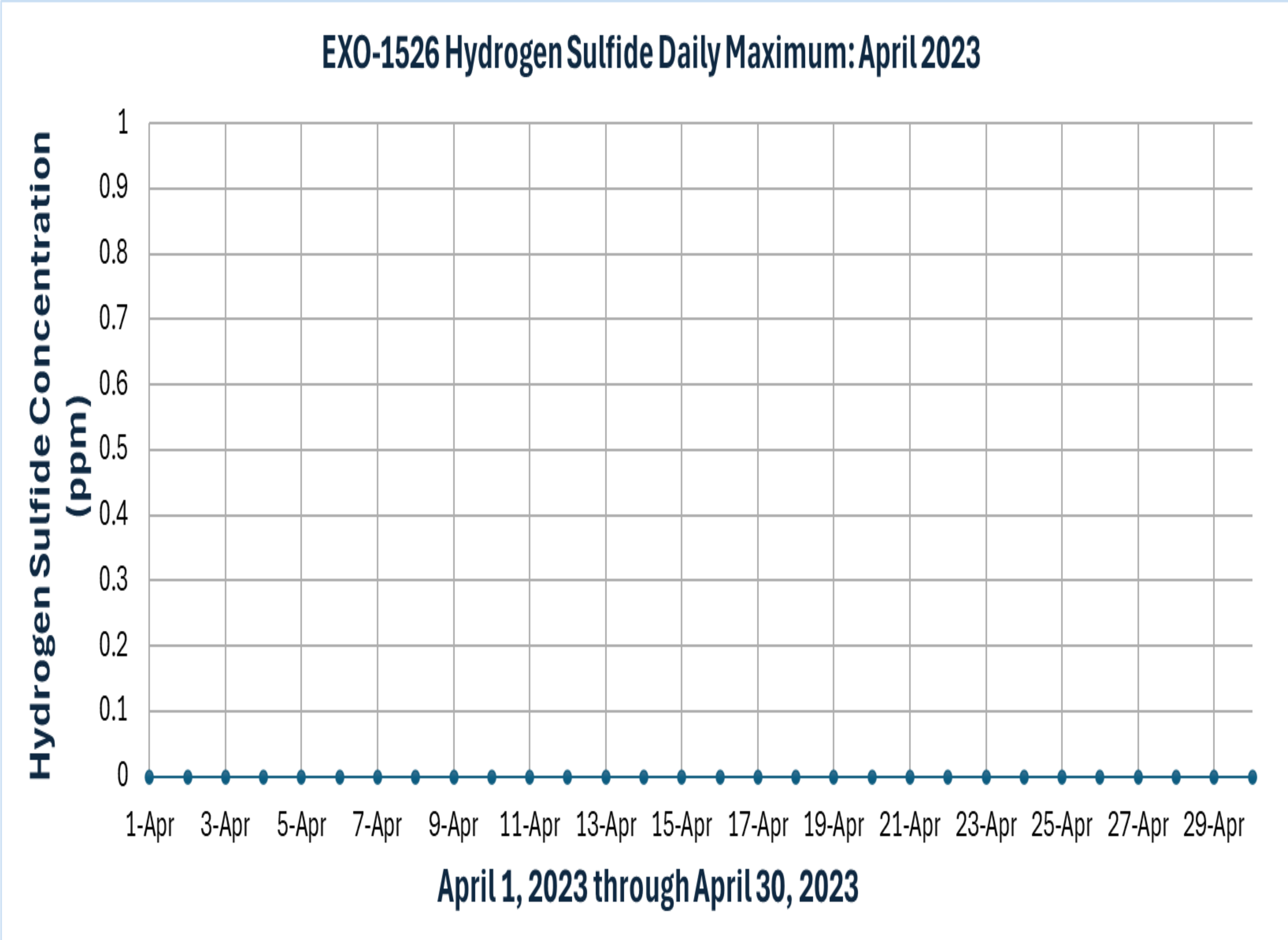
APPENDIX C: Location B

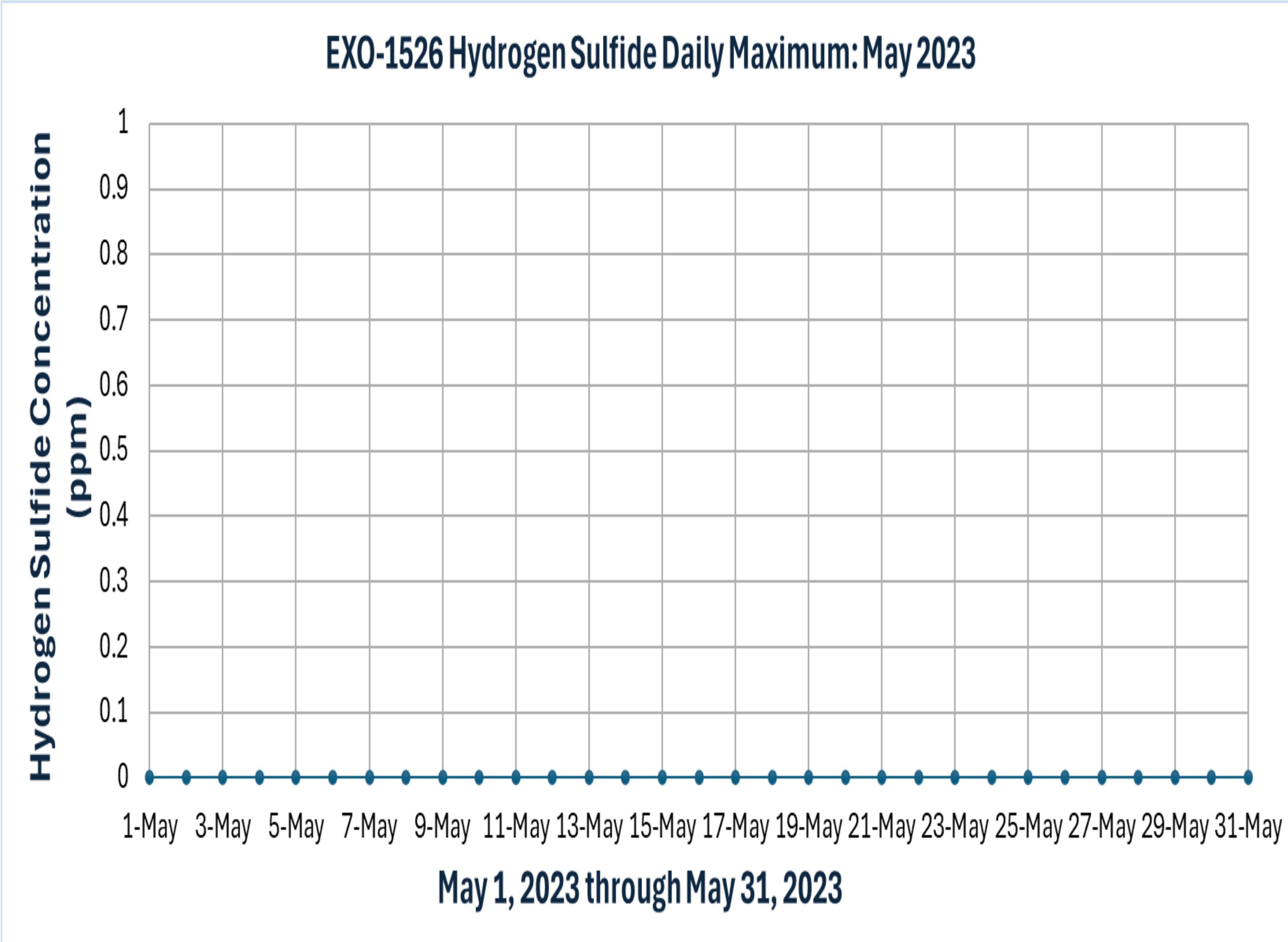
EXO-1526 Daily Maximum Graphs

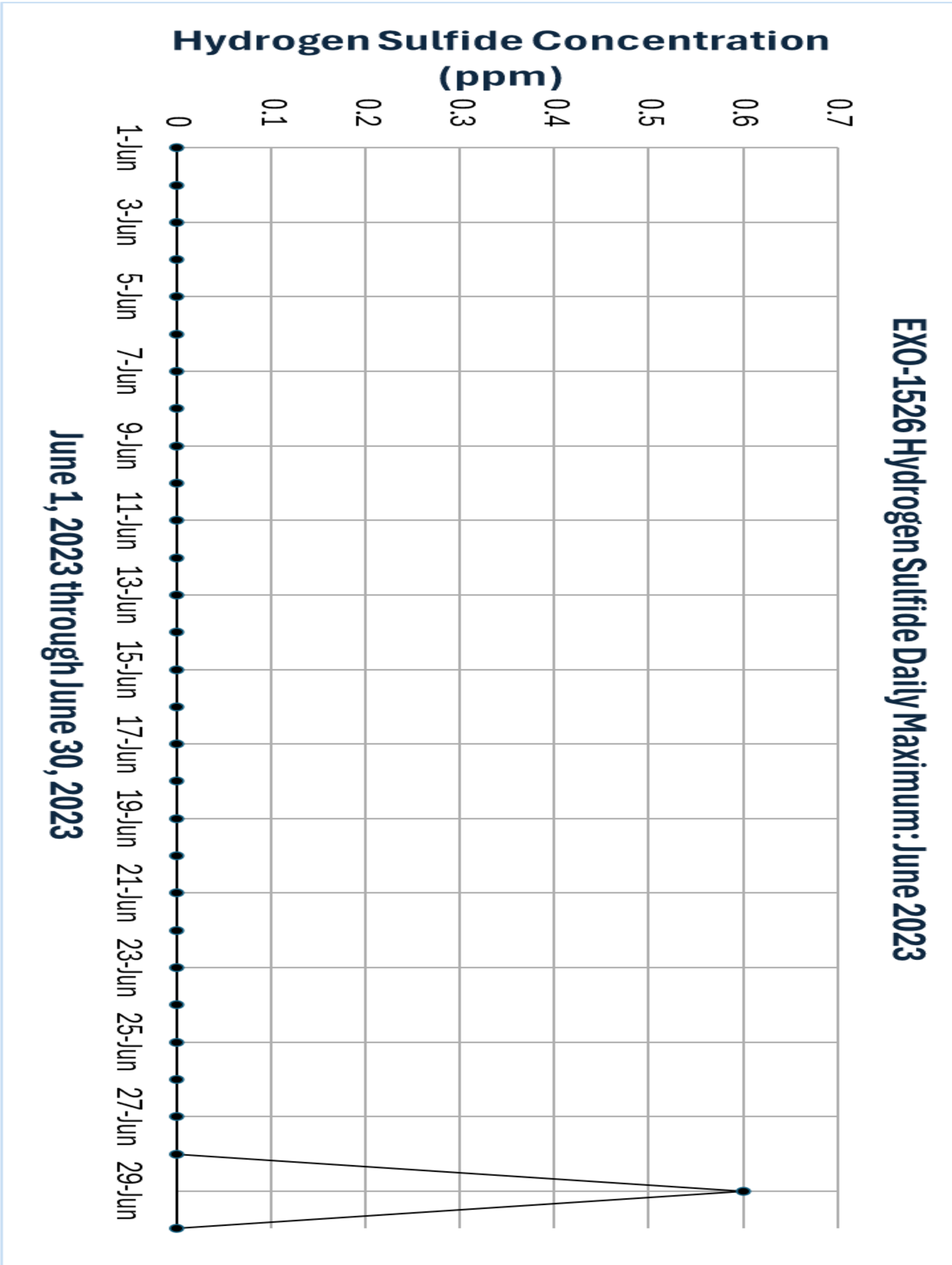


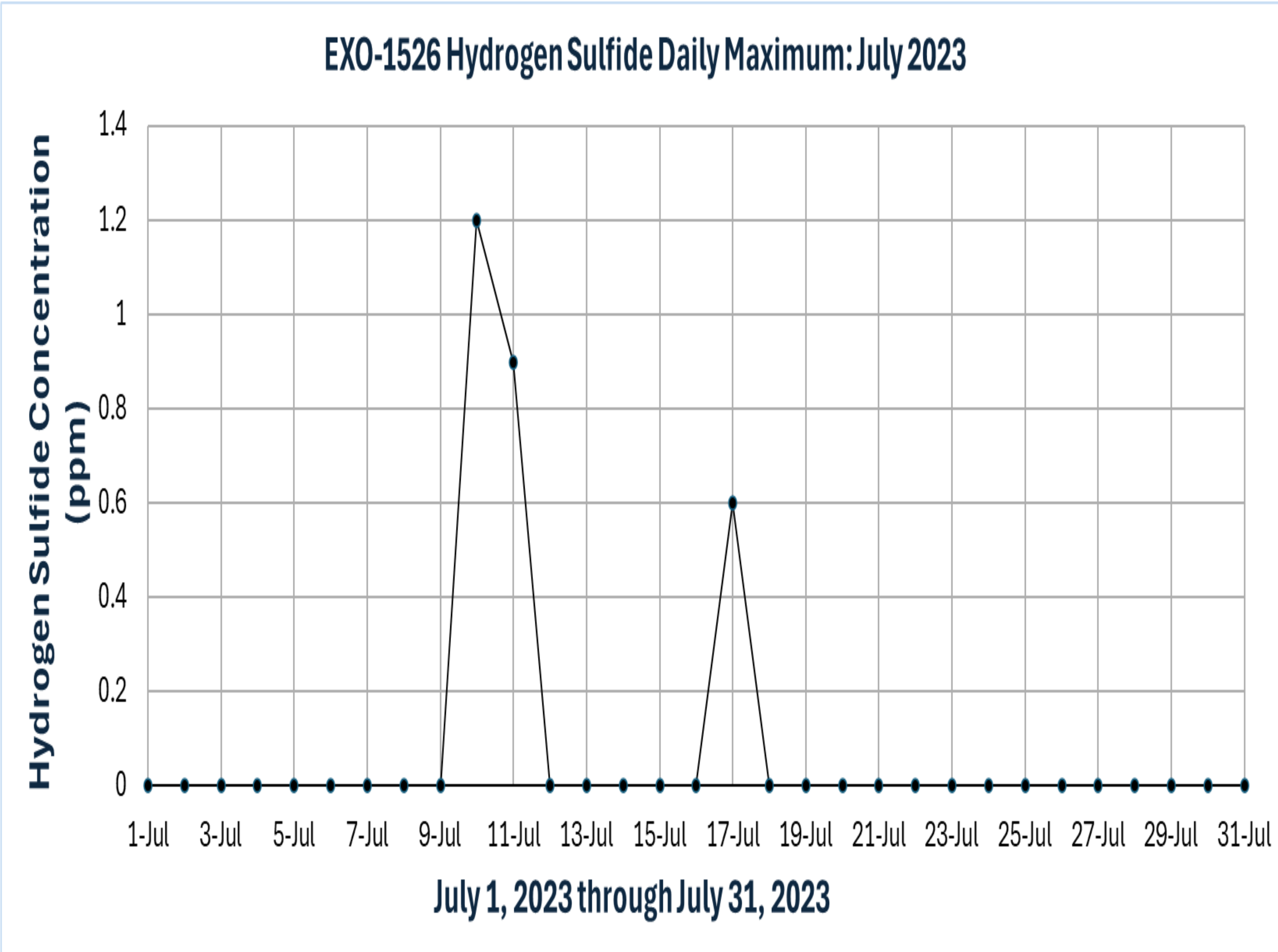
EXO-1526 Hydrogen Sulfide Daily Maximum: Februrary 2023
Hydrogen Sulfide Concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
21-Feb
23-Feb
25-Feb
27-Feb
February 1, 2023 through February 28, 2023

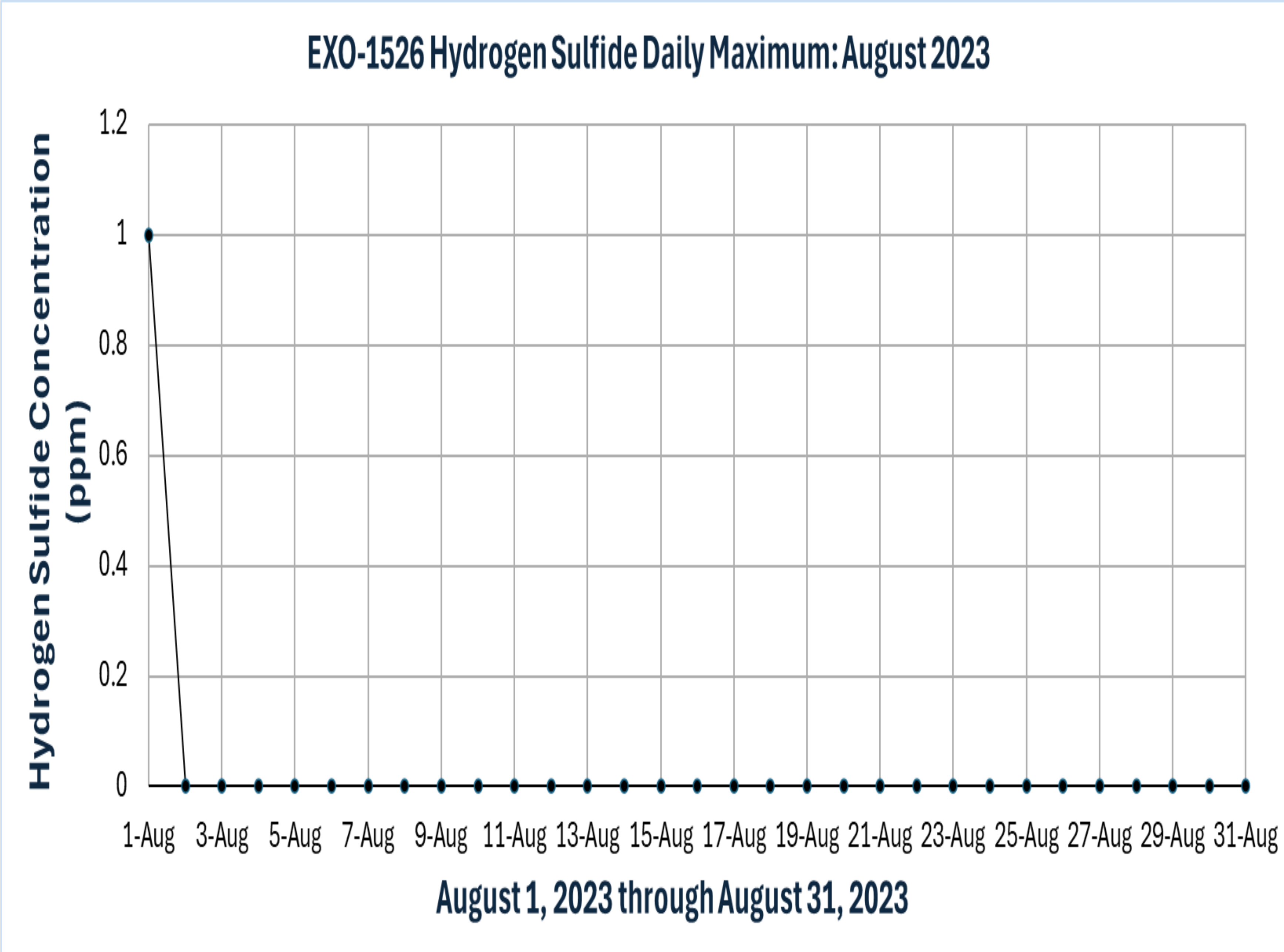

EXO-1526 Hydrogen Sulfide Daily Maximum: March 2023
Hydrogen Sulfide Concentration (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1-Mar
3-Mar
5-Mar
7-Mar
9-Mar
11-Mar
13-Mar
15-Mar
17-Mar
19-Mar
21-Mar
23-Mar
25-Mar
27-Mar
29-Mar
31-Mar
March 1, 2023 through March 31, 2023

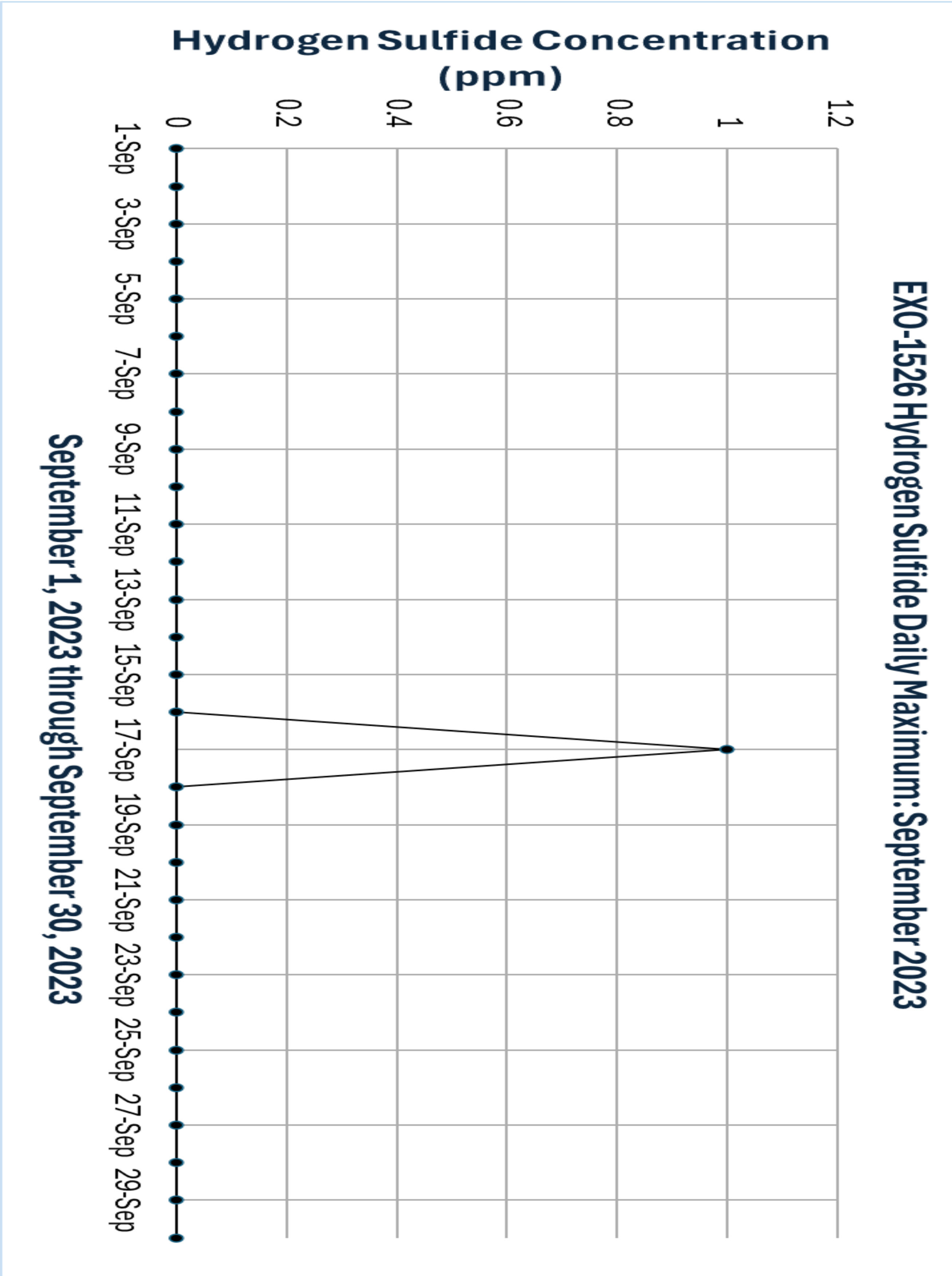

EXO-1526 Hydrogen Sulfide Daily Maximum: April 2023
Hydrogen Sulfide Concentration (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1-Apr
3-Apr
5-Apr
7-Apr
9-Apr
11-Apr
13-Apr
15-Apr
17-Apr
19-Apr
21-Apr
23-Apr
25-Apr
27-Apr
29-Apr
April 1, 2023 through April 30, 2023


EXO-1526 Hydrogen Sulfide Daily Maximum: May 2023
Hydrogen Sulfide Concentration (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1-May 3-May 5-May 7-May 9-May 11-May 13-May 15-May 17-May 19-May 21-May 23-May 25-May 27-May 29-May 31-May
May 1, 2023 through May 31, 2023

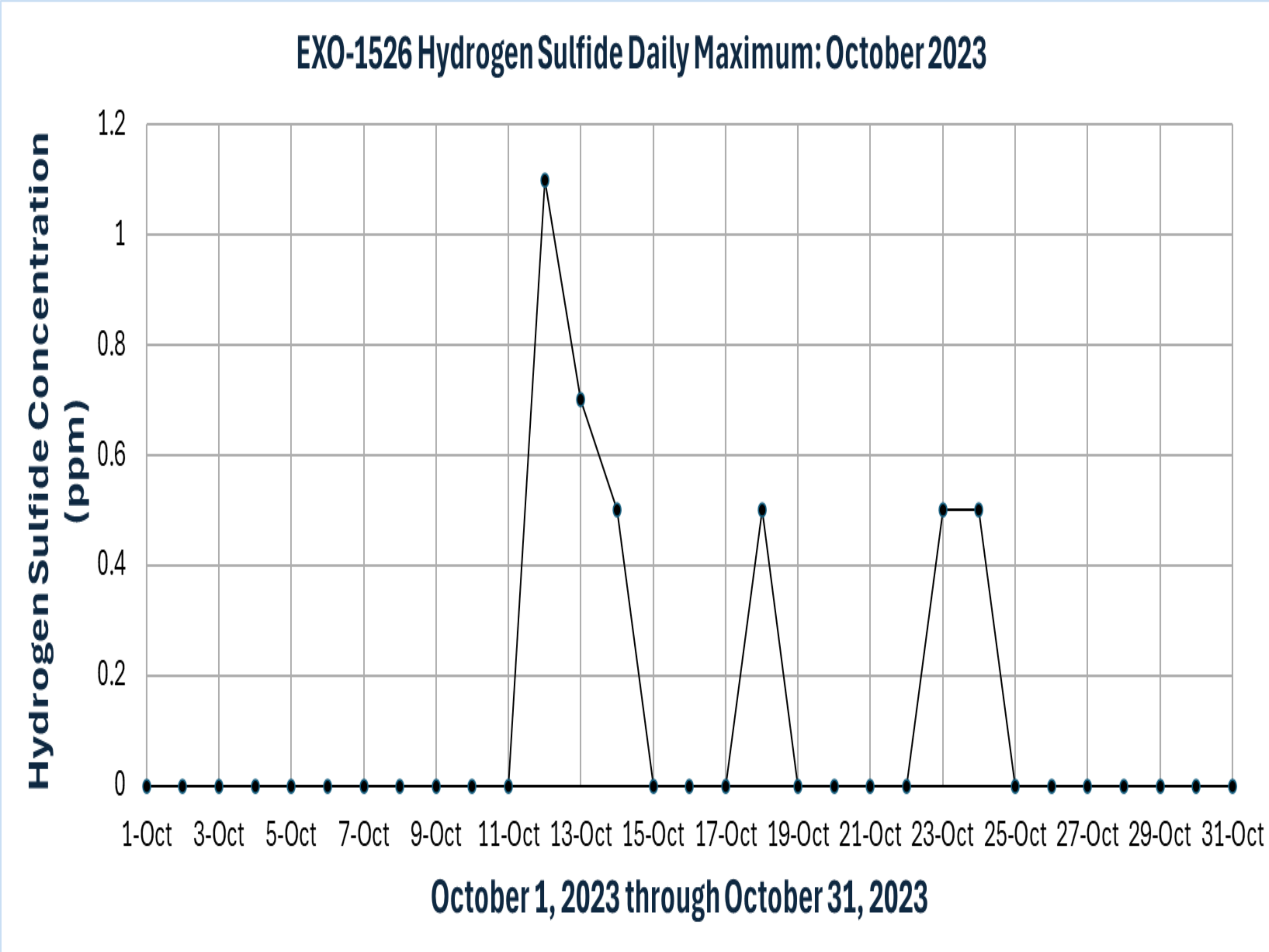

EXO-1526 Hydrogen Sulfide Daily Maximum: June 2023
Hydrogen Sulfide Concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1-Jun
3-Jun
5-Jun
7-Jun
9-Jun
11-Jun
13-Jun
15-Jun
17-Jun
19-Jun
21-Jun
23-Jun
25-Jun
27-Jun
29-Jun
June 1, 2023 through June 30, 2023

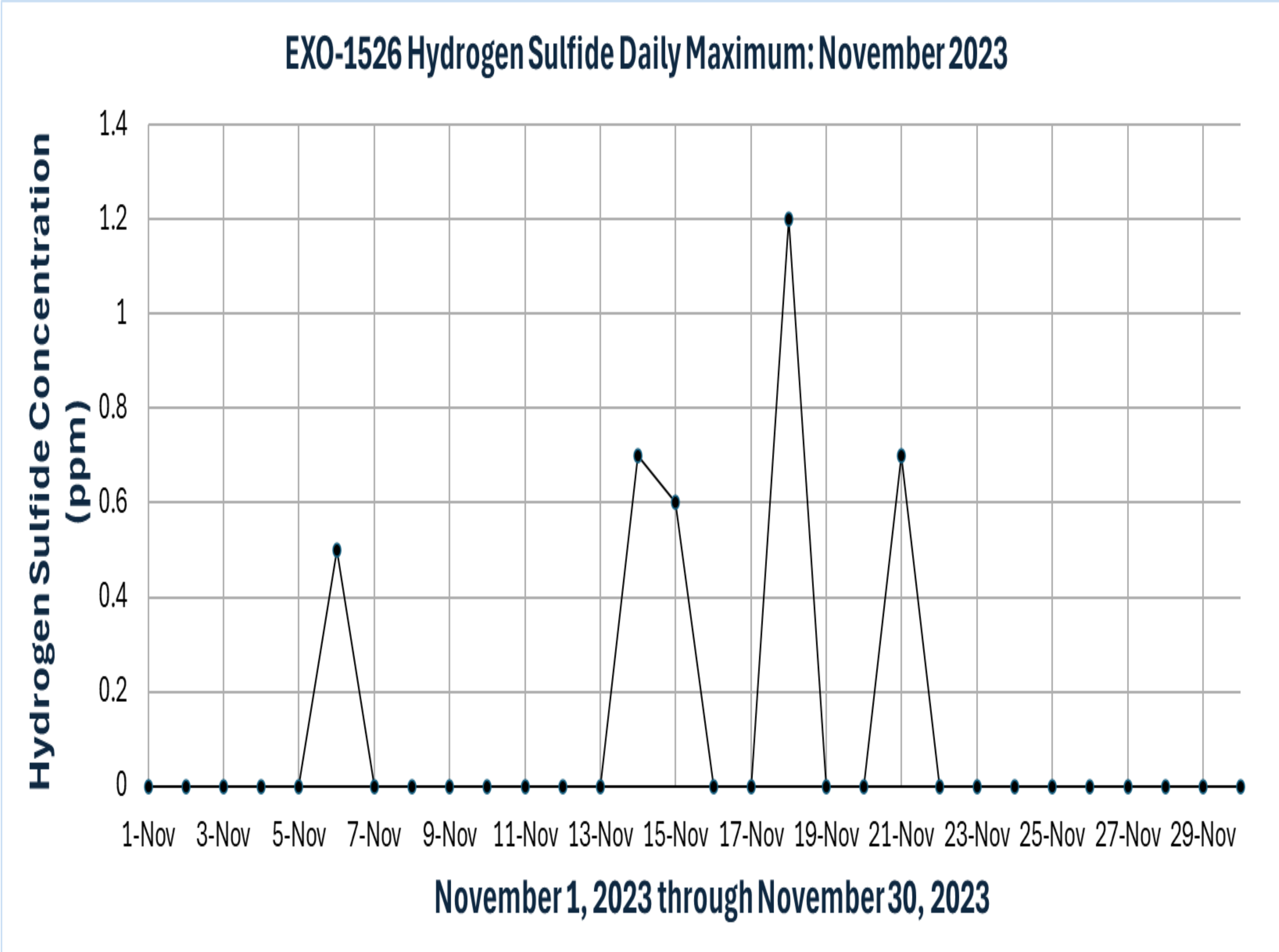

EXO-1526 Hydrogen Sulfide Daily Maximum: July 2023
Hydrogen Sulfide Concentration (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Jul
3-Jul
5-Jul
7-Jul
9-Jul
11-Jul
13-Jul
15-Jul
17-Jul
19-Jul
21-Jul
23-Jul
25-Jul
27-Jul
29-Jul
31-Jul
July 1, 2023 through July 31, 2023


EXO-1526 Hydrogen Sulfide Daily Maximum: August 2023
Hydrogen Sulfide Concentration (ppm)
1.2
1
0.8
0.6
0.4
0.2
0
1-Aug 3-Aug 5-Aug 7-Aug 9-Aug 11-Aug 13-Aug 15-Aug 17-Aug 19-Aug 21-Aug 23-Aug 25-Aug 27-Aug 29-Aug 31-Aug
August 1, 2023 through August 31, 2023

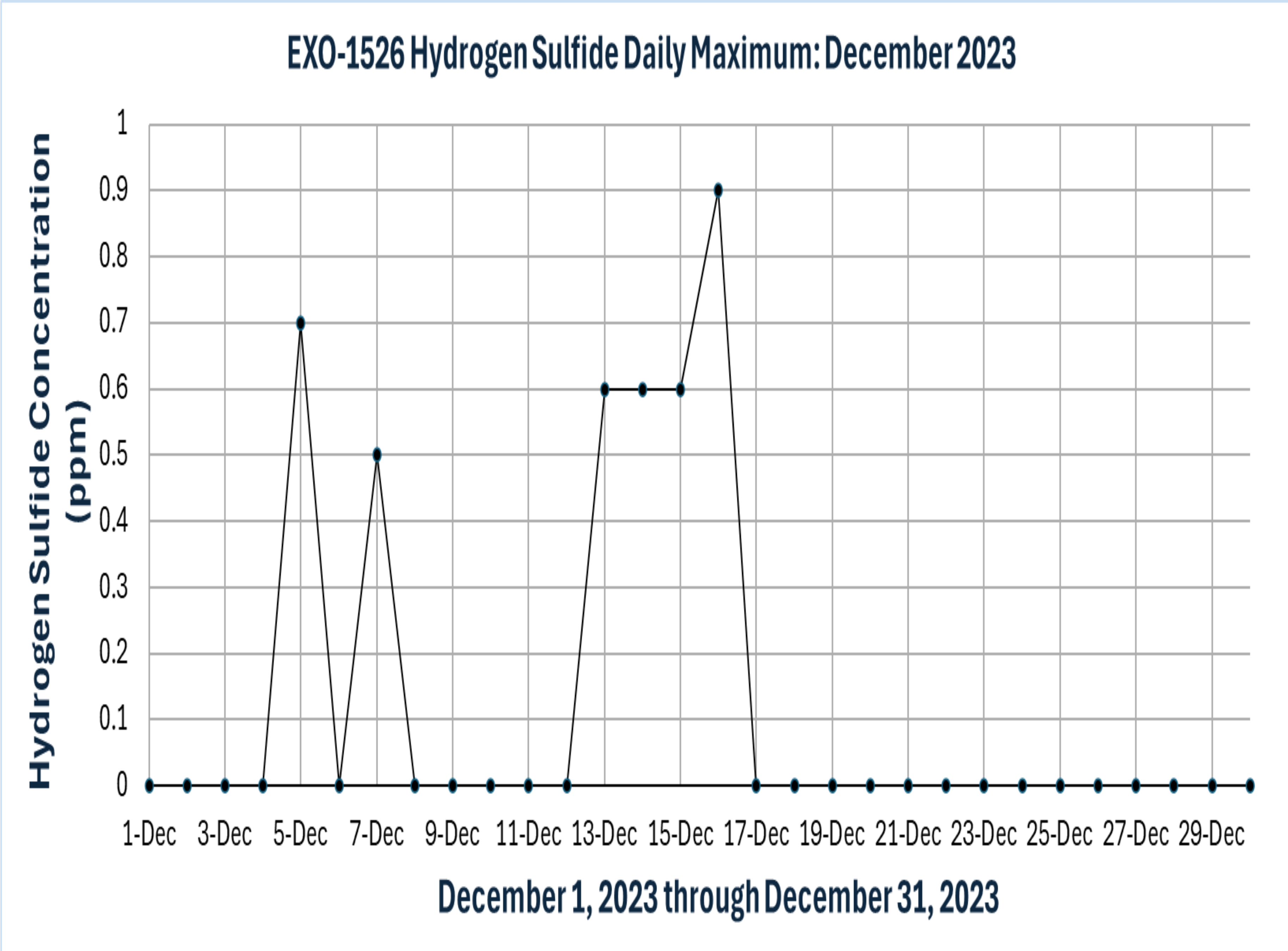


EXO-1526 Hydrogen Sulfide Daily Maximum: September 2023
Hydrogen Sulfide Concentration (ppm)
0
0.2
0.4
0.6
0.8
1
1.2
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
September 1, 2023 through September 30, 2023

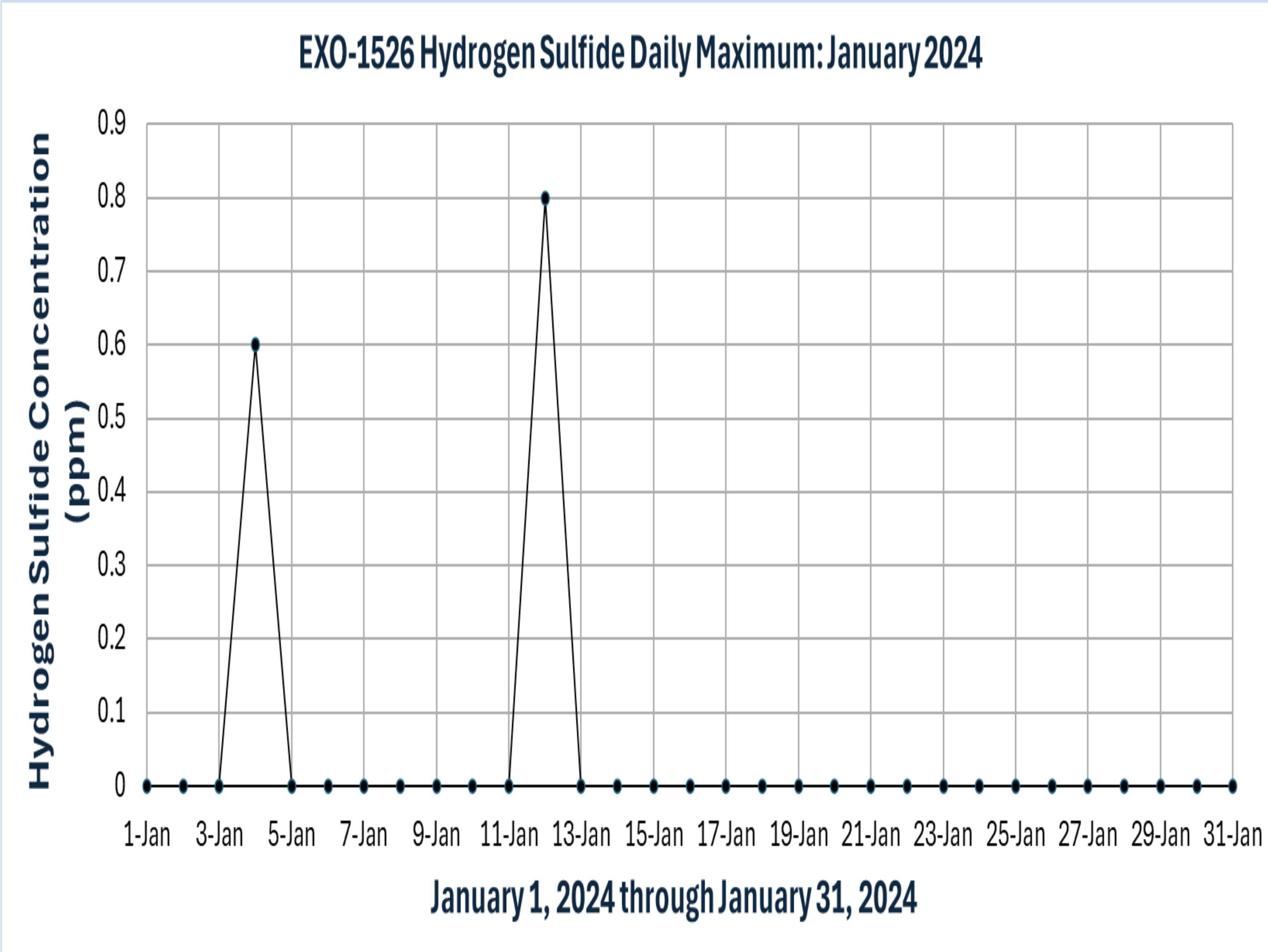

EXO-1526 Hydrogen Sulfide Daily Maximum: October 2023
Hydrogen Sulfide Concentration (ppm)
0
0.2
0.4
0.6
0.8
1
1.2
1-Oct
3-Oct
5-Oct
7-Oct
9-Oct
11-Oct
13-Oct
15-Oct
17-Oct
19-Oct
21-Oct
23-Oct
25-Oct
27-Oct
29-Oct
31-Oct
October 1, 2023 through October 31, 2023

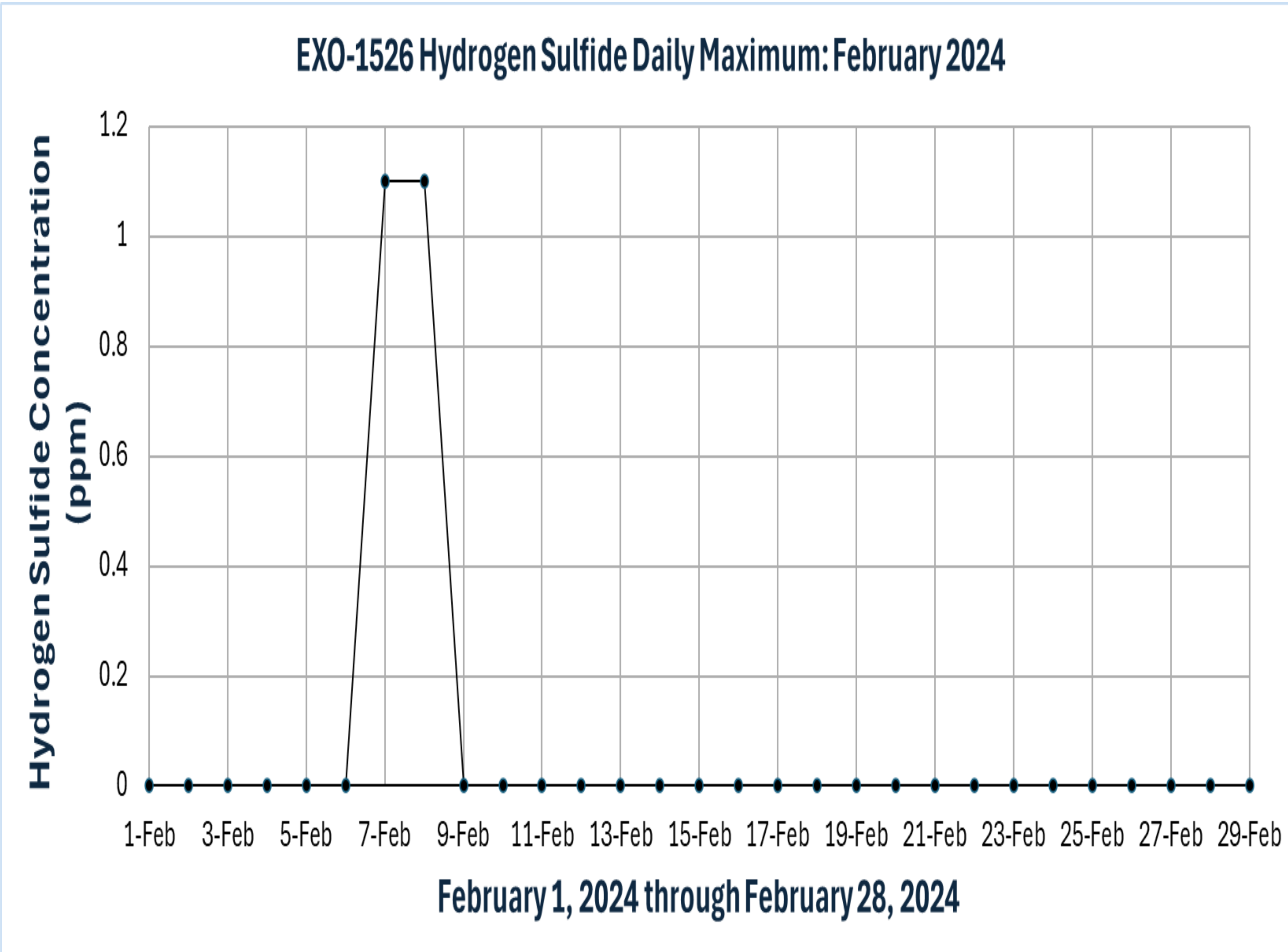


EXO-1526 Hydrogen Sulfide Daily Maximum: November 2023
Hydrogen Sulfide Concentration (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Nov
3-Nov
5-Nov
7-Nov
9-Nov
11-Nov
13-Nov
15-Nov
17-Nov
19-Nov
21-Nov
23-Nov
25-Nov
27-Nov
29-Nov
November 1, 2023 through November 30, 2023

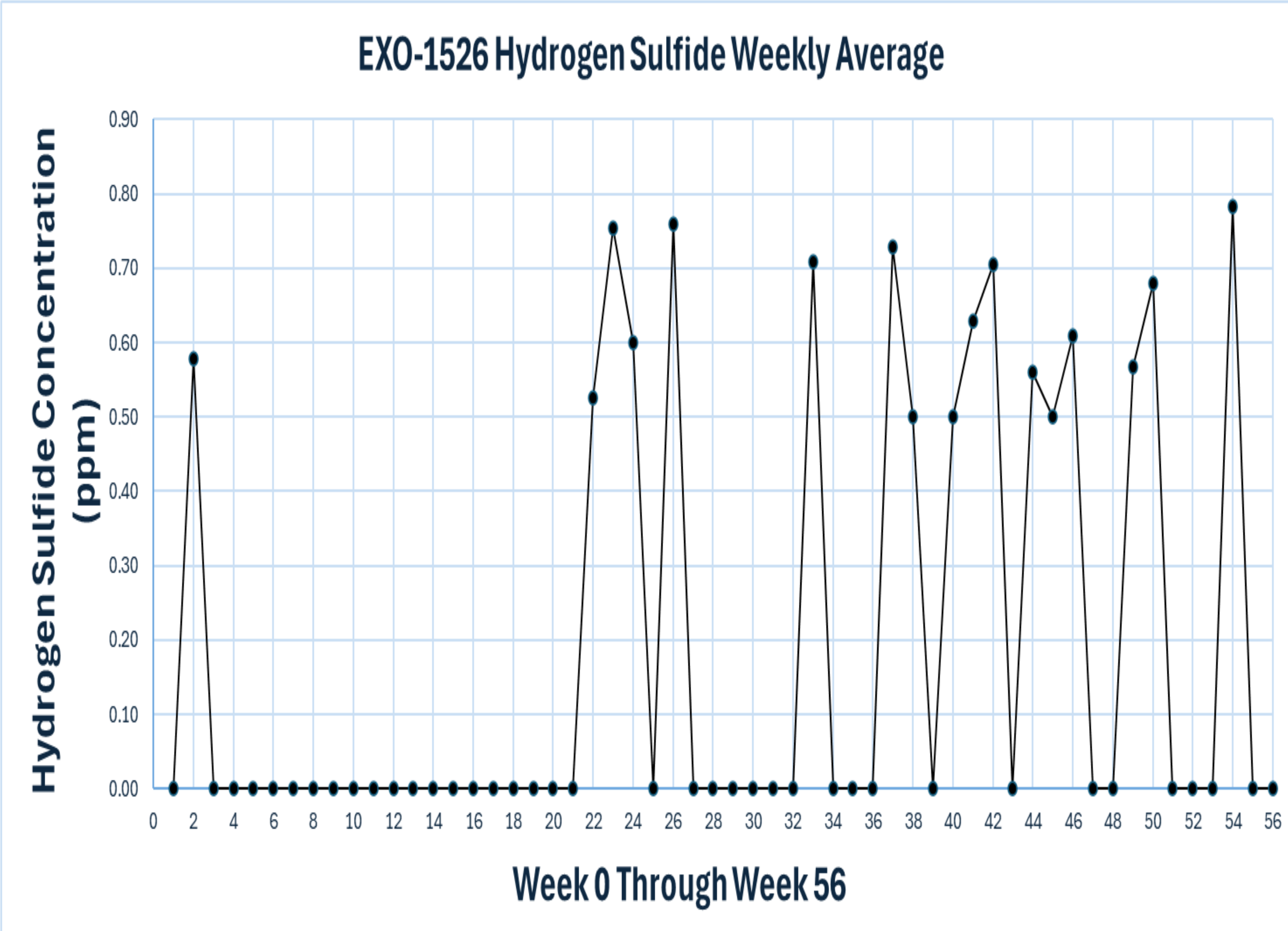


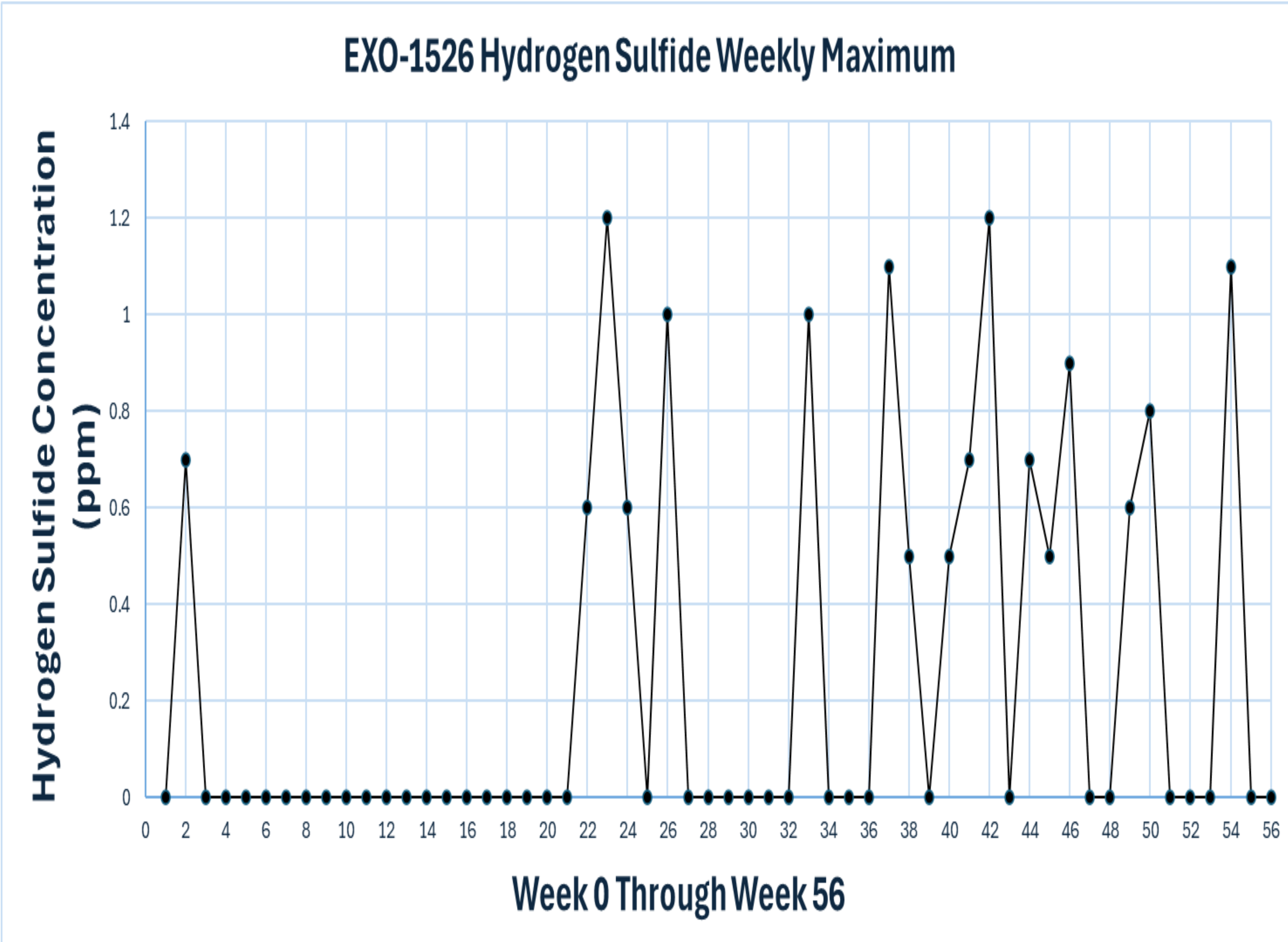
EXO-1526 Hydrogen Sulfide Daily Maximum: December 2023
Hydrogen Sulfide Concentration (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1-Dec
3-Dec
5-Dec
7-Dec
9-Dec
11-Dec
13-Dec
15-Dec
17-Dec
19-Dec
21-Dec
23-Dec
25-Dec
27-Dec
29-Dec
December 1, 2023 through December 31, 2023

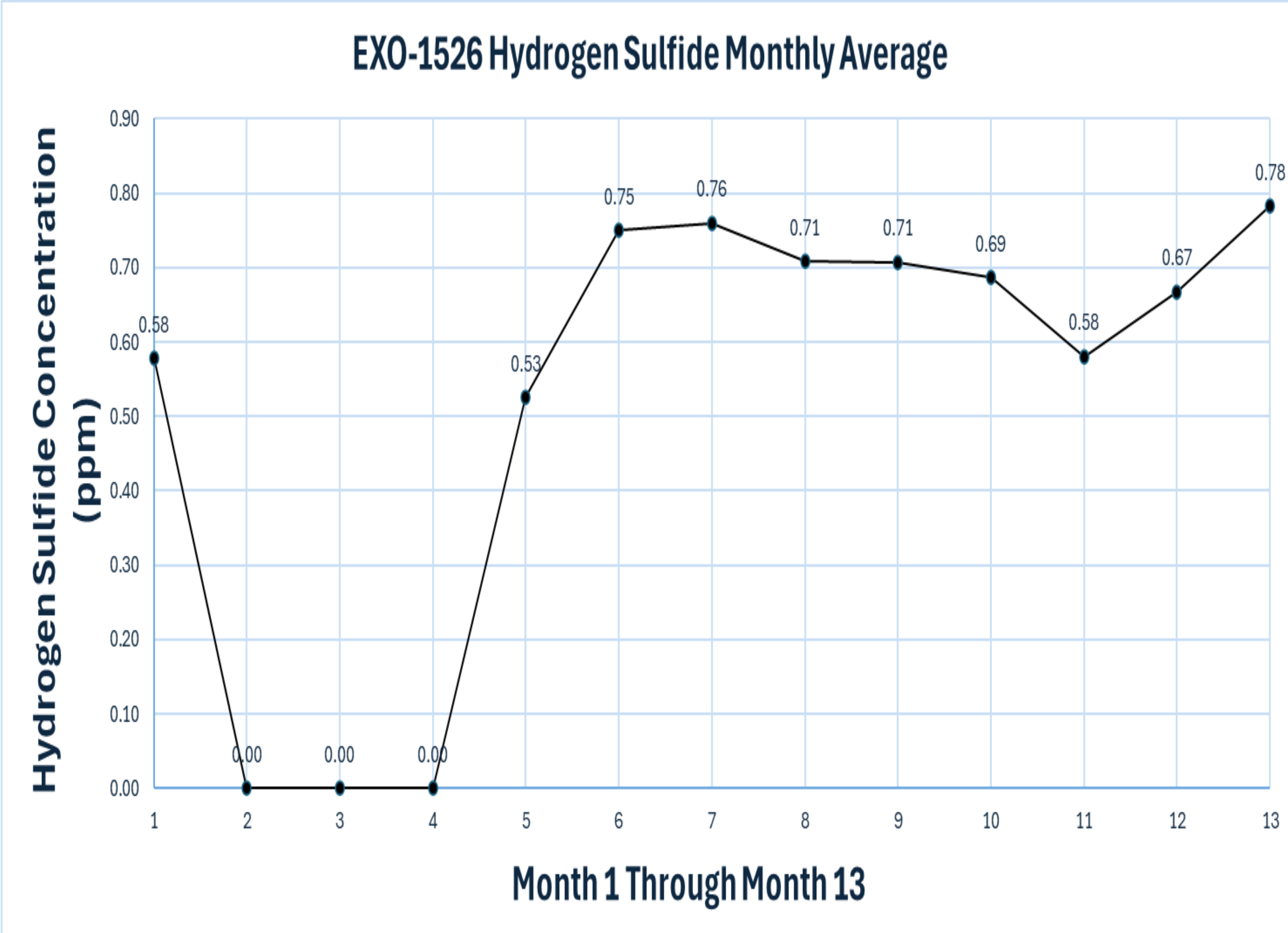

EXO-1526 Hydrogen Sulfide Daily Maximum: January 2024
Hydrogen Sulfide Concentration (ppm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1-Jan
3-Jan
5-Jan
7-Jan
9-Jan
11-Jan
13-Jan
15-Jan
17-Jan
19-Jan
21-Jan
23-Jan
25-Jan
27-Jan
29-Jan
31-Jan
January 1, 2024 through January 31, 2024

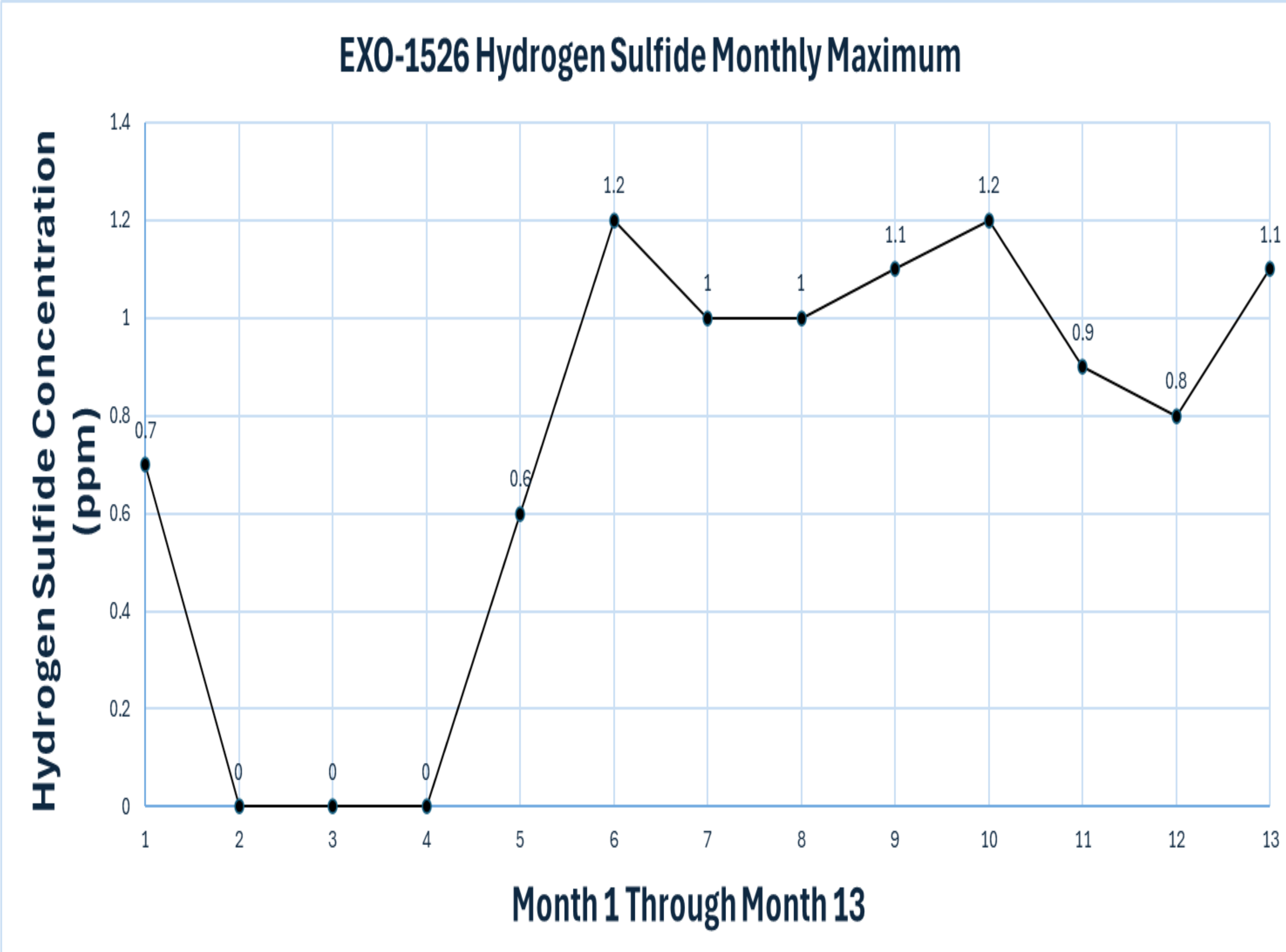

EXO-1526 Hydrogen Sulfide Daily Maximum: February 2024
Hydrogen Sulfide Concentration (ppm)
1.2
1
0.8
0.6
0.4
0.2
0
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
21-Feb
23-Feb
25-Feb
27-Feb
29-Feb
February 1, 2024 through February 28, 2024

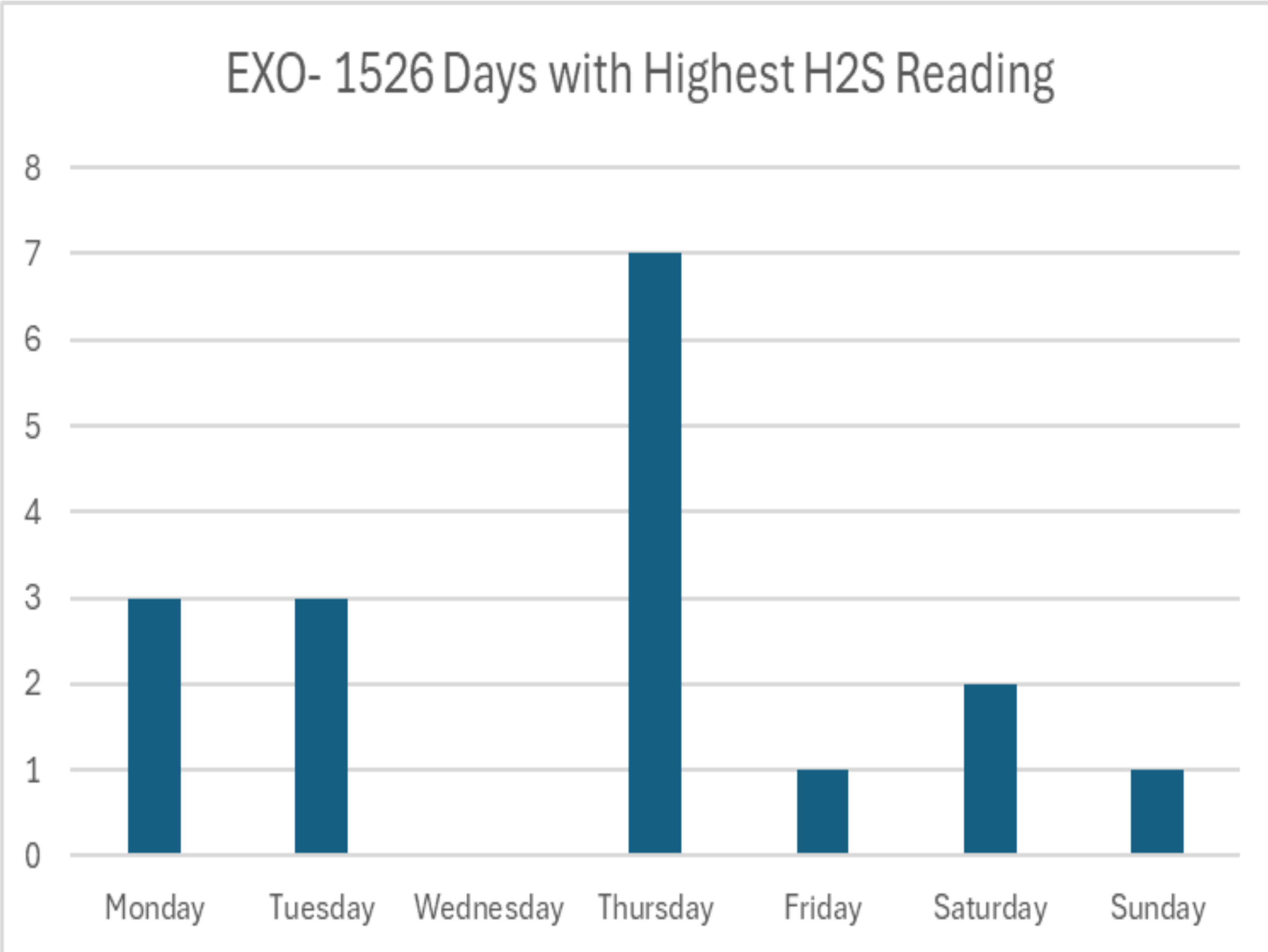
APPENDIX D: Location B
EXO-1526 Weekly Information Graphs


EXO-1526 Hydrogen Sulfide Weekly Average
Hydrogen Sulfide Concentration (ppm)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
Week 0 Through Week 56

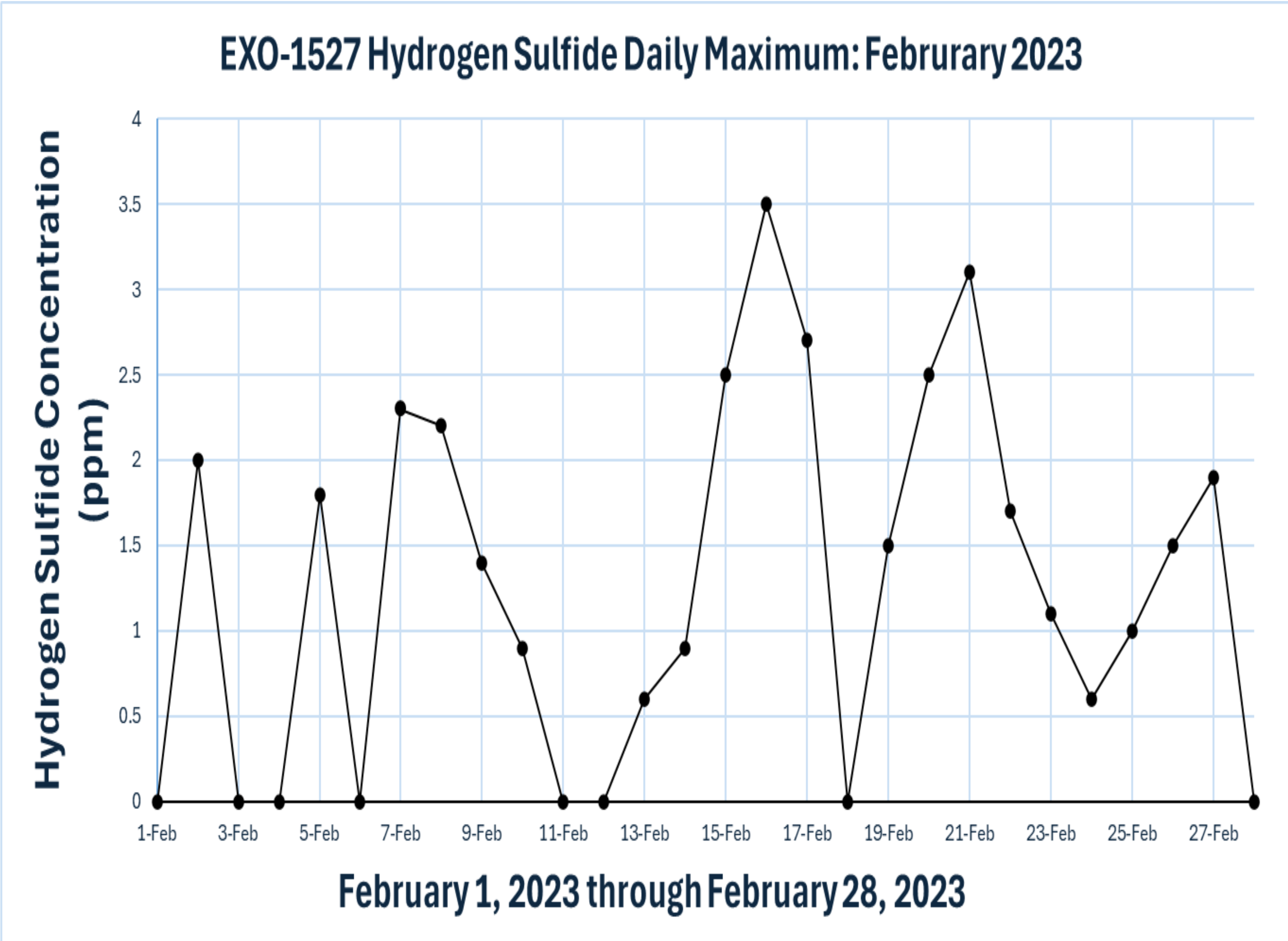

EXO-1526 Hydrogen Sulfide Weekly Maximum
Hydrogen Sulfide Concentration (ppm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
Week 0 Through Week 56

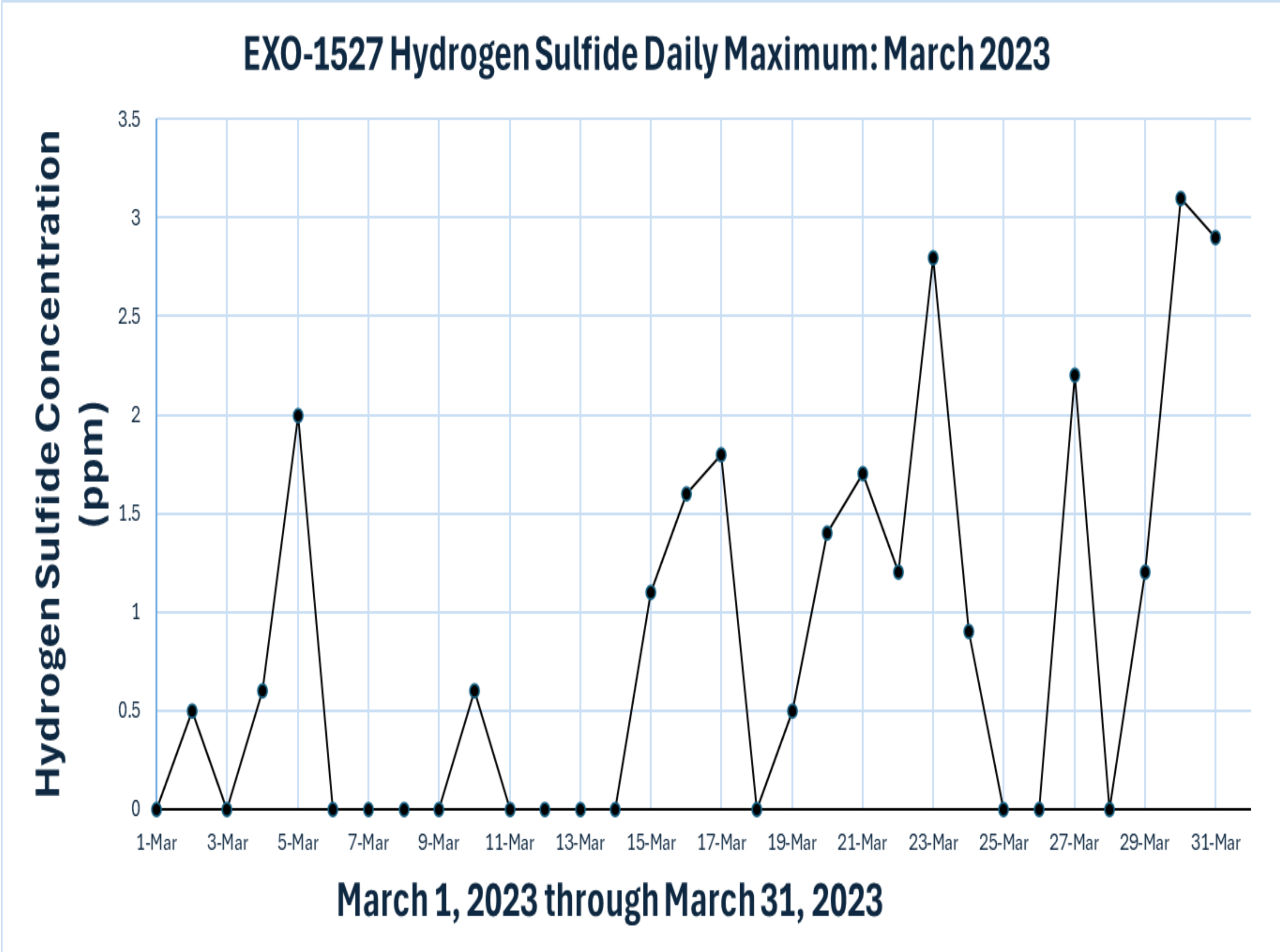

EXO-1526 Hydrogen Sulfide Monthly Average
Hydrogen Sulfide Concentration (ppm)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.58
0.00
0.00
0.00
0.53
0.75
0.76
0.71
0.71
0.69
0.58
0.67
0.78
1
2
3
4
5
6
7
8
9
10
11
12
13
Month 1 Through Month 13

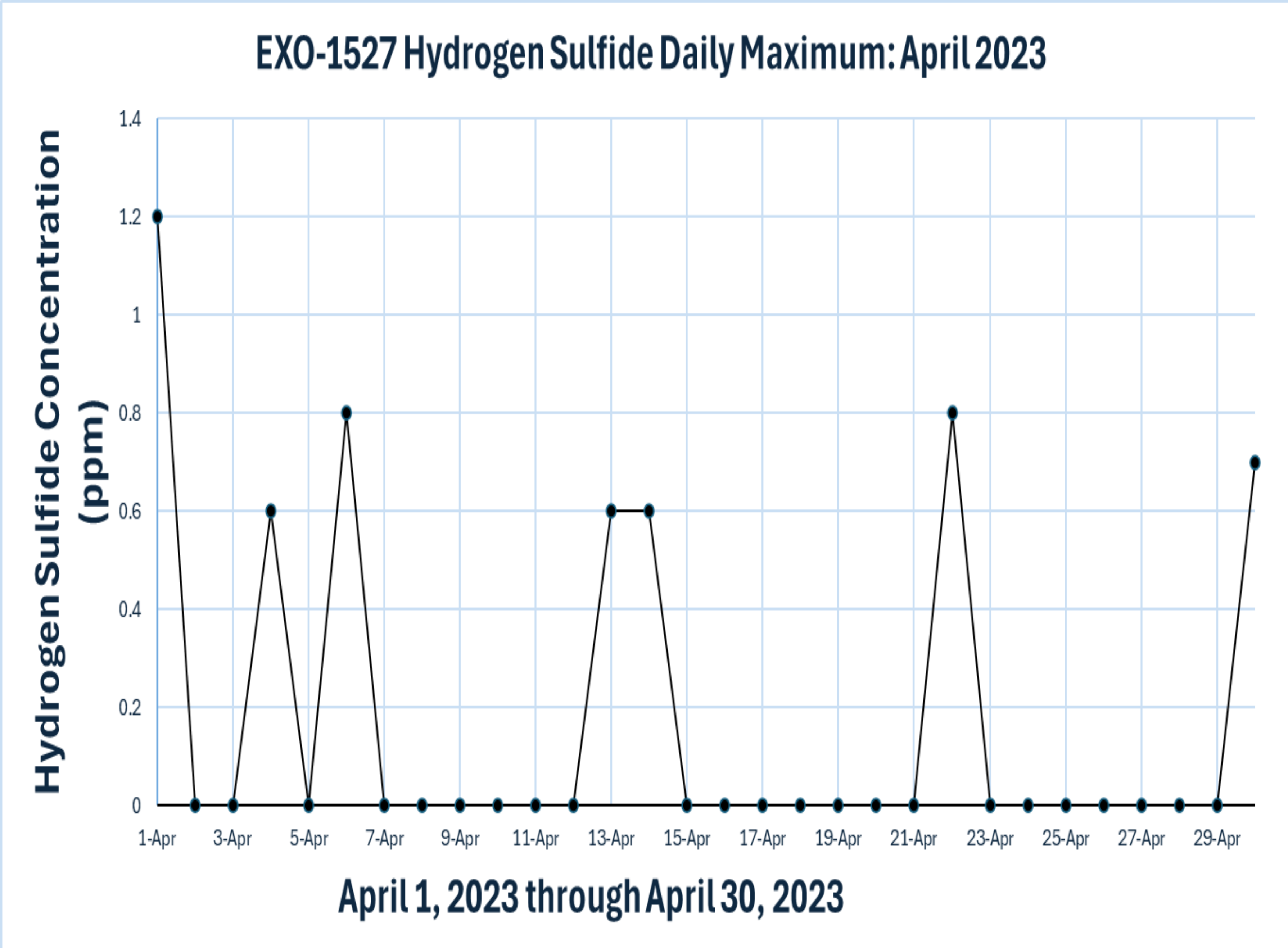

EXO-1526 Hydrogen Sulfide Monthly Maximum
Hydrogen Sulfide Concentration (ppm)
Month 1 Through Month 13
0.7
0
0
0
0.6
1.2
1
1
1.1
1.2
0.9
0.8
1.1

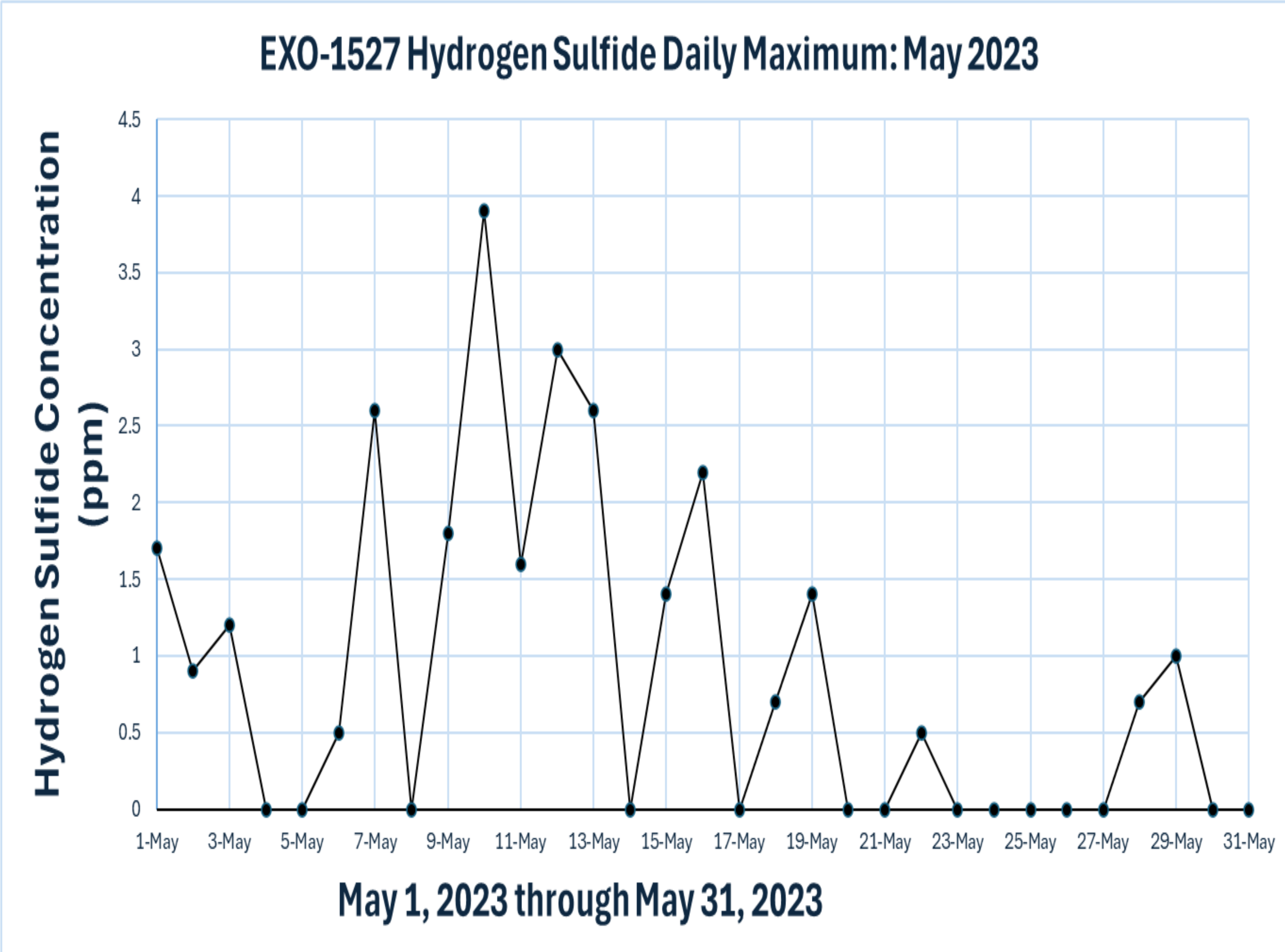

EXO- 1526 Days with Highest H2S Reading
8
7
6
5
4
3
2
1
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday

APPENDIX E: Location C
EXO-1527 Daily Maximum Graphs

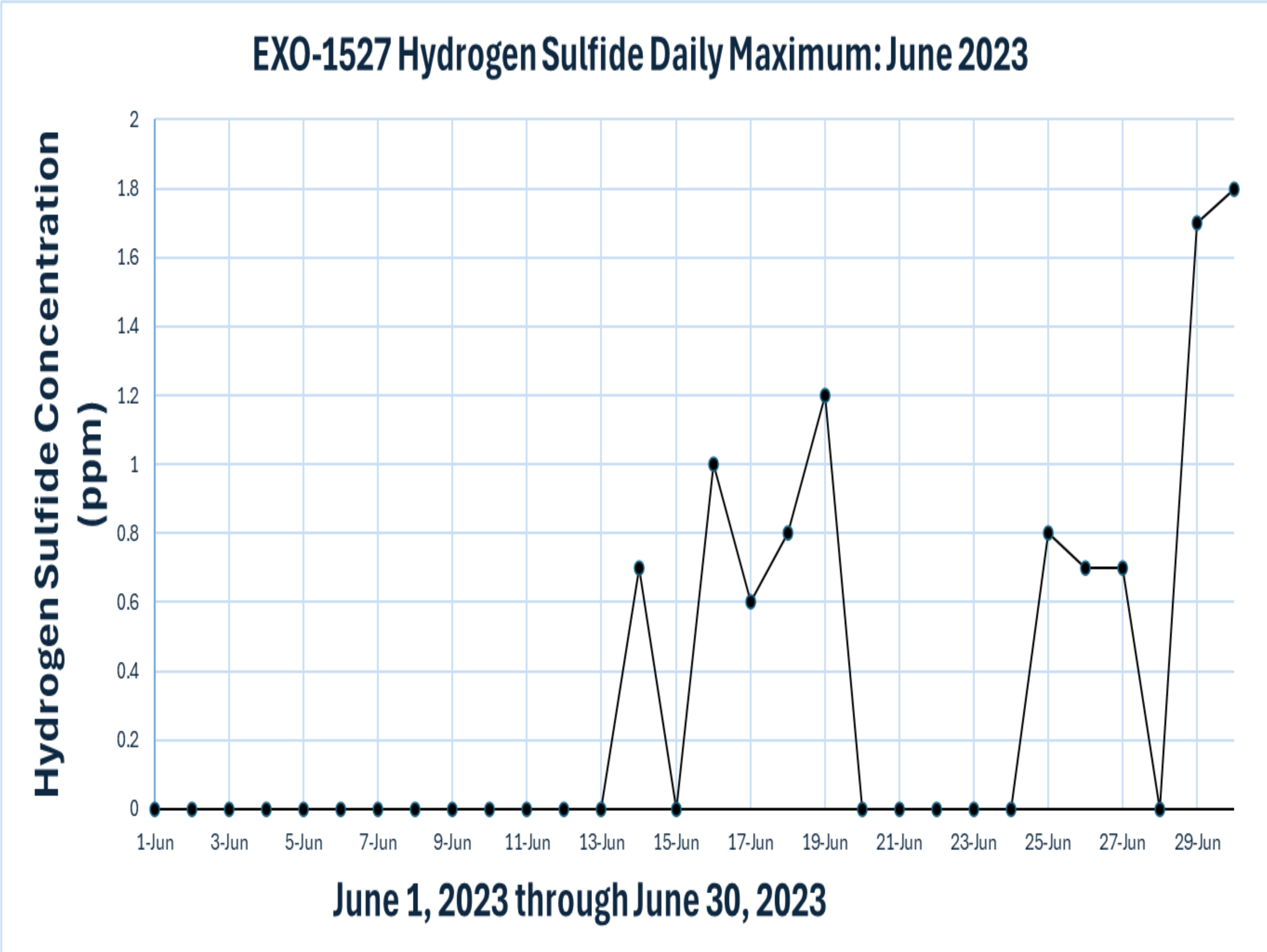

EXO-1527 Hydrogen Sulfide Daily Maximum: Februrary 2023
Hydrogen Sulfide Concentration (ppm)
4
3.5
3
2.5
2
1.5
1
0.5
0
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
21-Feb
23-Feb
25-Feb
27-Feb
February 1, 2023 through February 28, 2023

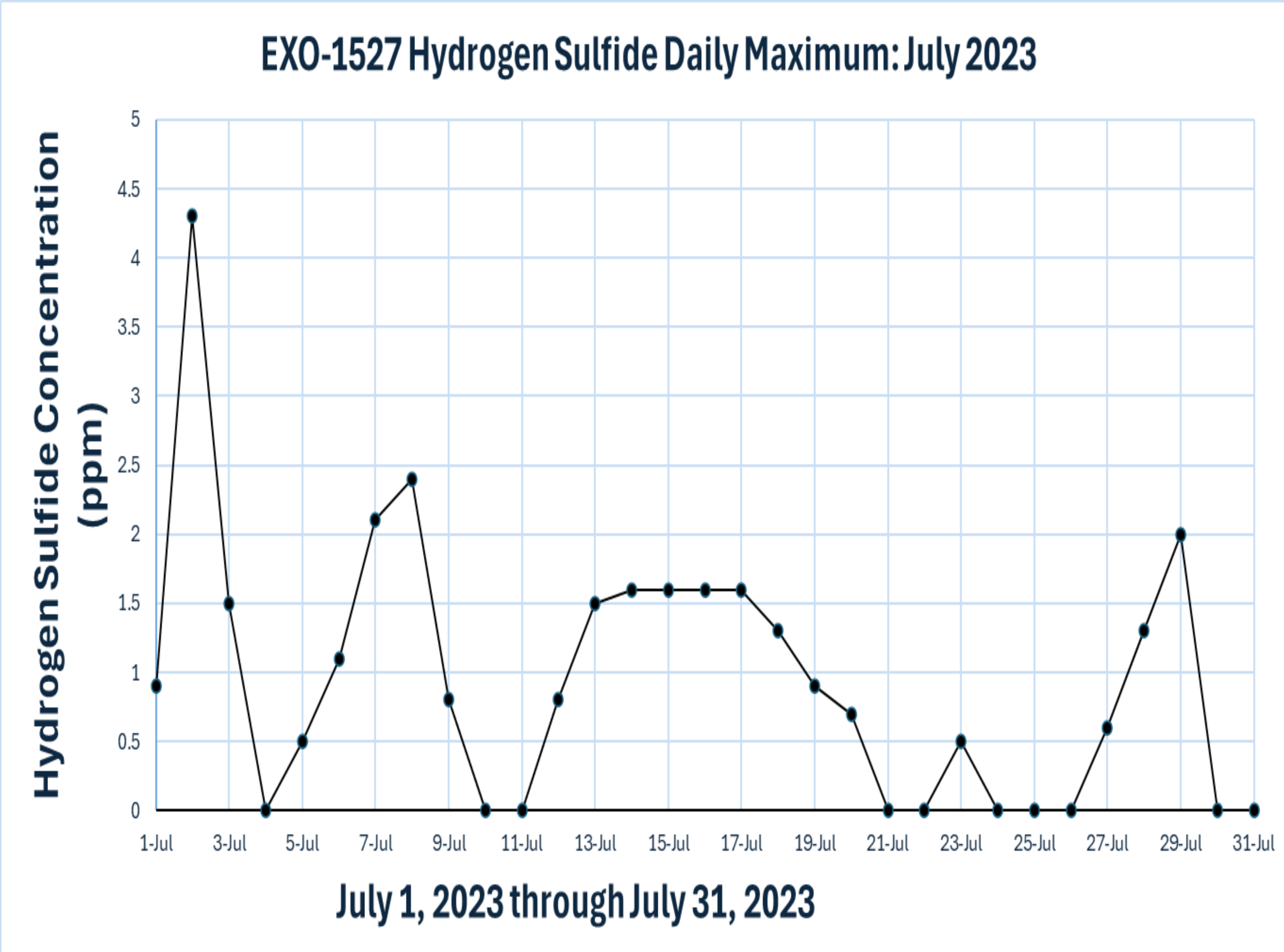

EXO-1527 Hydrogen Sulfide Daily Maximum: March 2023
Hydrogen Sulfide Concentration (ppm)
0
0.5
1
1.5
2
2.5
3
3.5
1-Mar
3-Mar
5-Mar
7-Mar
9-Mar
11-Mar
13-Mar
15-Mar
17-Mar
19-Mar
21-Mar
23-Mar
25-Mar
27-Mar
29-Mar
31-Mar
March 1, 2023 through March 31, 2023

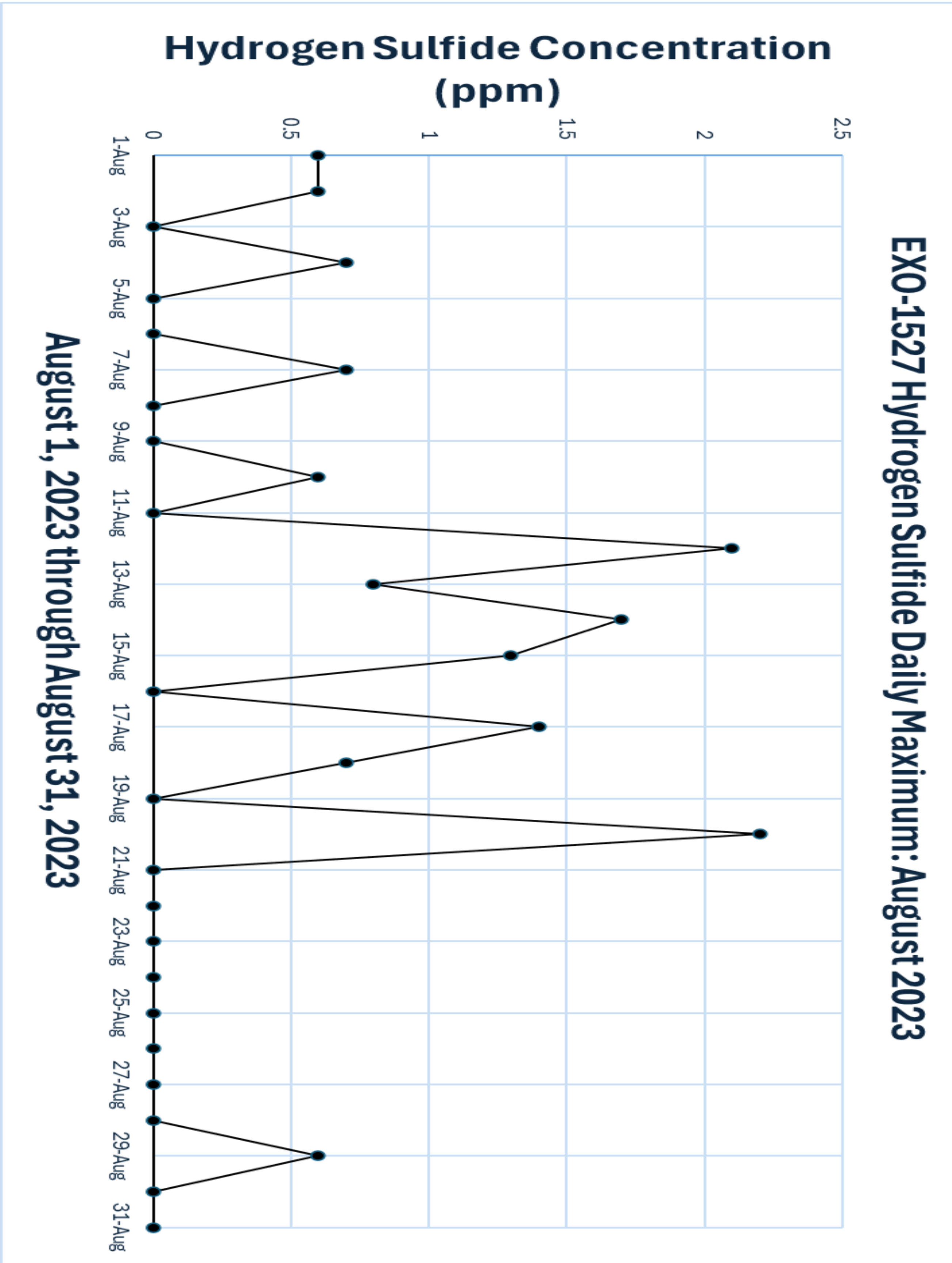

EXO-1527 Hydrogen Sulfide Daily Maximum: April 2023
Hydrogen Sulfide Concentration (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Apr
3-Apr
5-Apr
7-Apr
9-Apr
11-Apr
13-Apr
15-Apr
17-Apr
19-Apr
21-Apr
23-Apr
25-Apr
27-Apr
29-Apr
April 1, 2023 through April 30, 2023

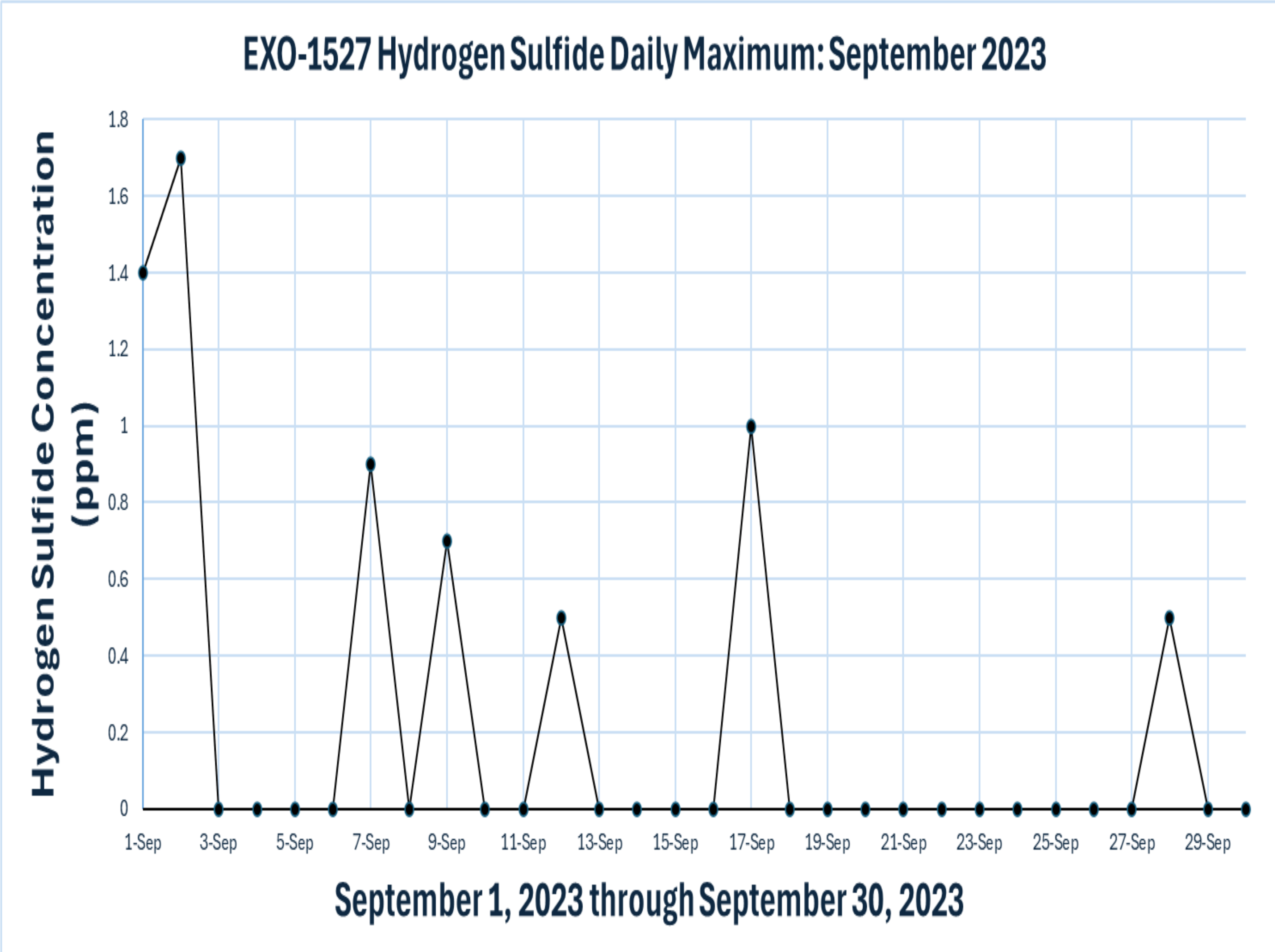


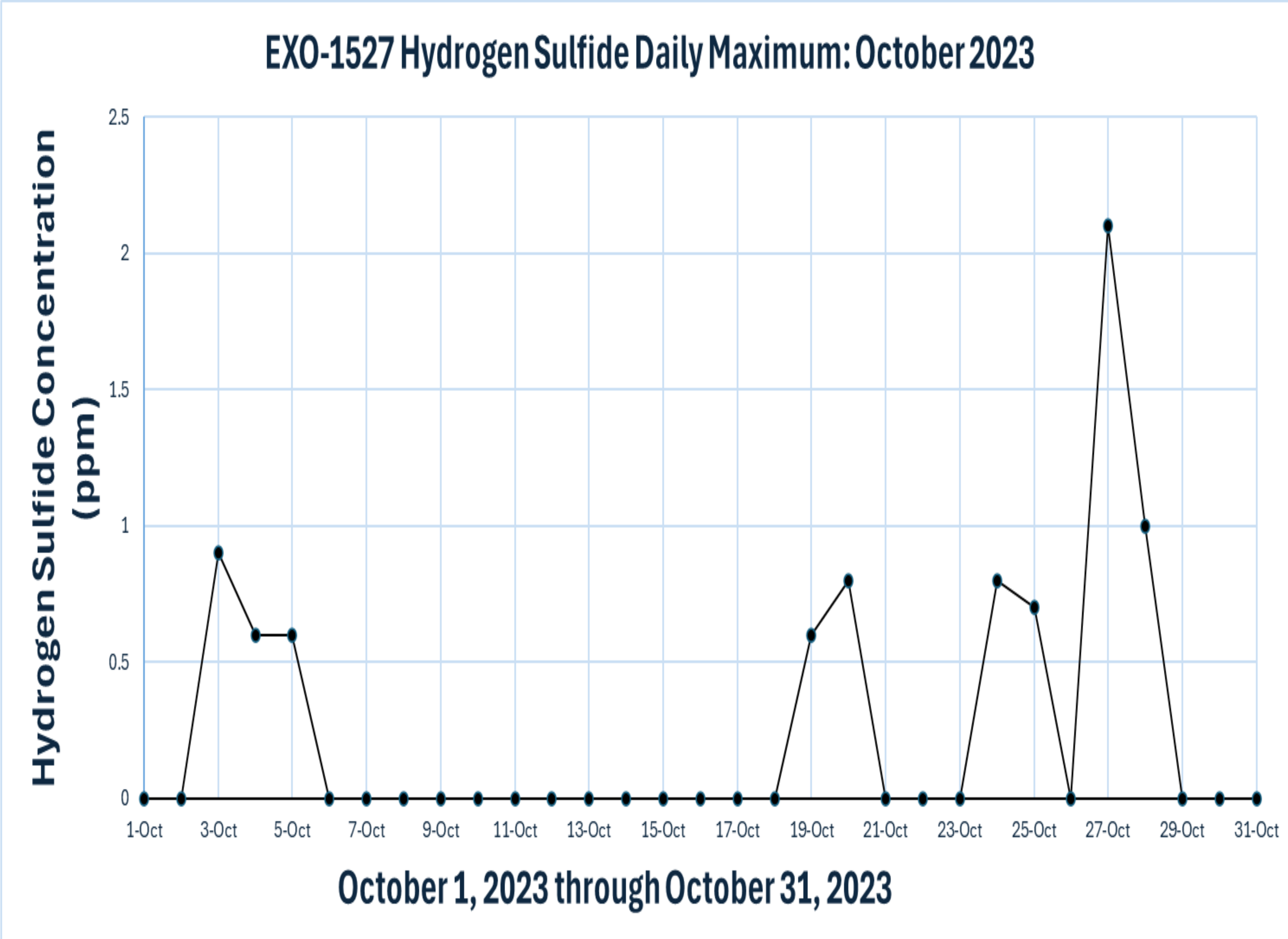
EXO-1527 Hydrogen Sulfide Daily Maximum: May 2023
Hydrogen Sulfide Concentration (ppm)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
May 1, 2023 through May 31, 2023

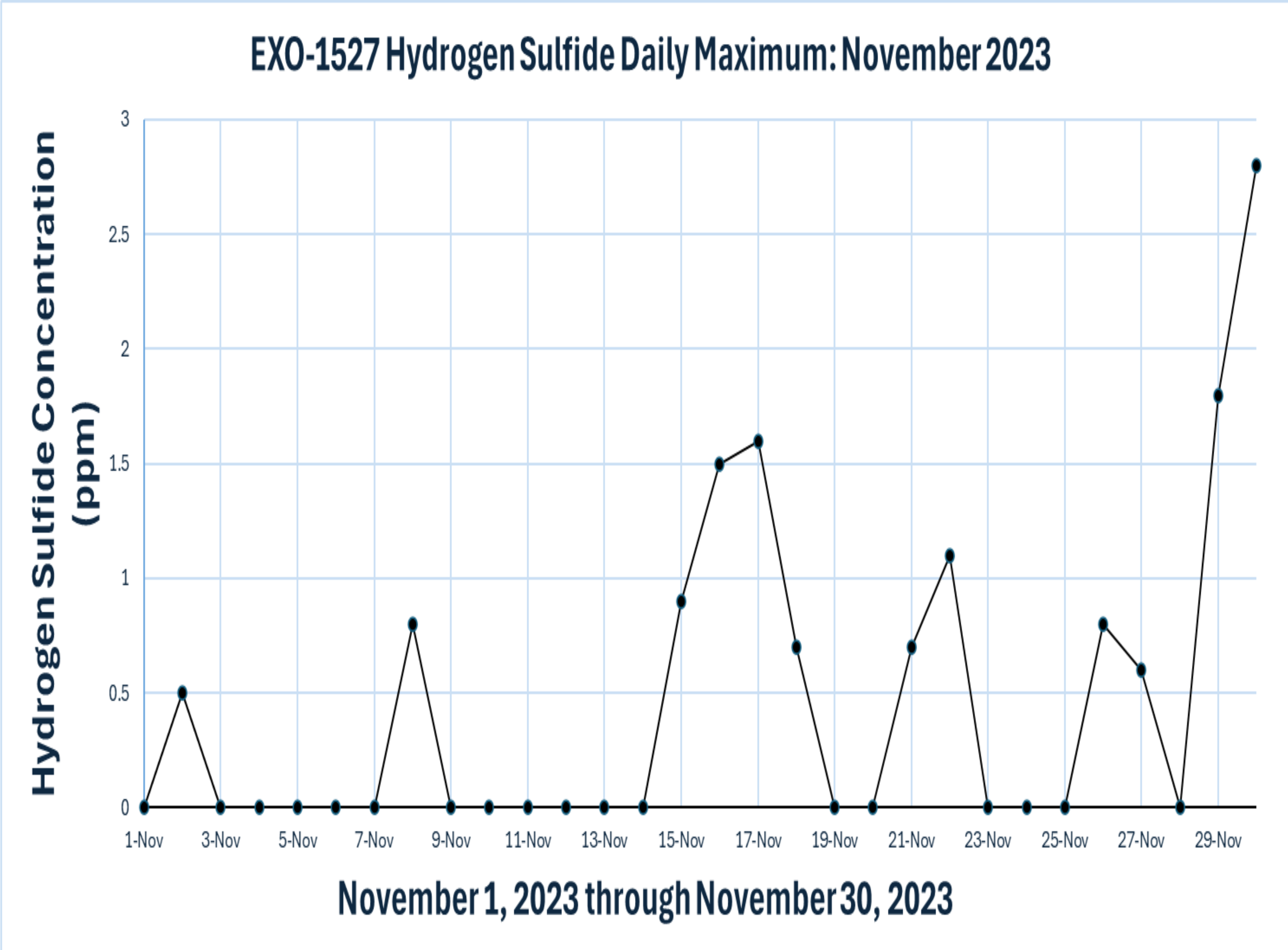

EXO-1527 Hydrogen Sulfide Daily Maximum: June 2023
Hydrogen Sulfide Concentration (ppm)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Jun
3-Jun
5-Jun
7-Jun
9-Jun
11-Jun
13-Jun
15-Jun
17-Jun
19-Jun
21-Jun
23-Jun
25-Jun
27-Jun
29-Jun
June 1, 2023 through June 30, 2023

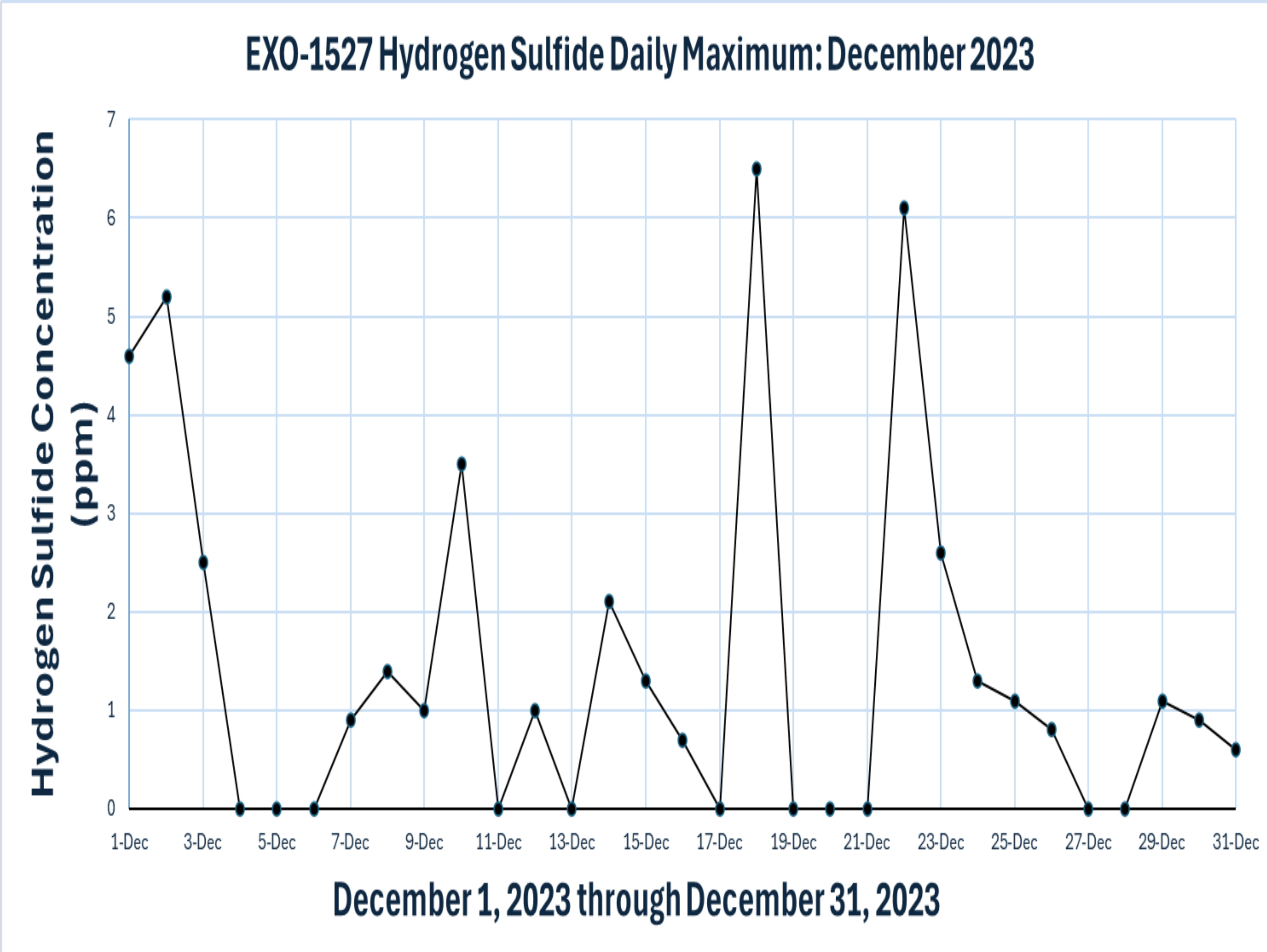

EXO-1527 Hydrogen Sulfide Daily Maximum: July 2023
Hydrogen Sulfide Concentration (ppm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1-Jul
3-Jul
5-Jul
7-Jul
9-Jul
11-Jul
13-Jul
15-Jul
17-Jul
19-Jul
21-Jul
23-Jul
25-Jul
27-Jul
29-Jul
31-Jul
July 1, 2023 through July 31, 2023

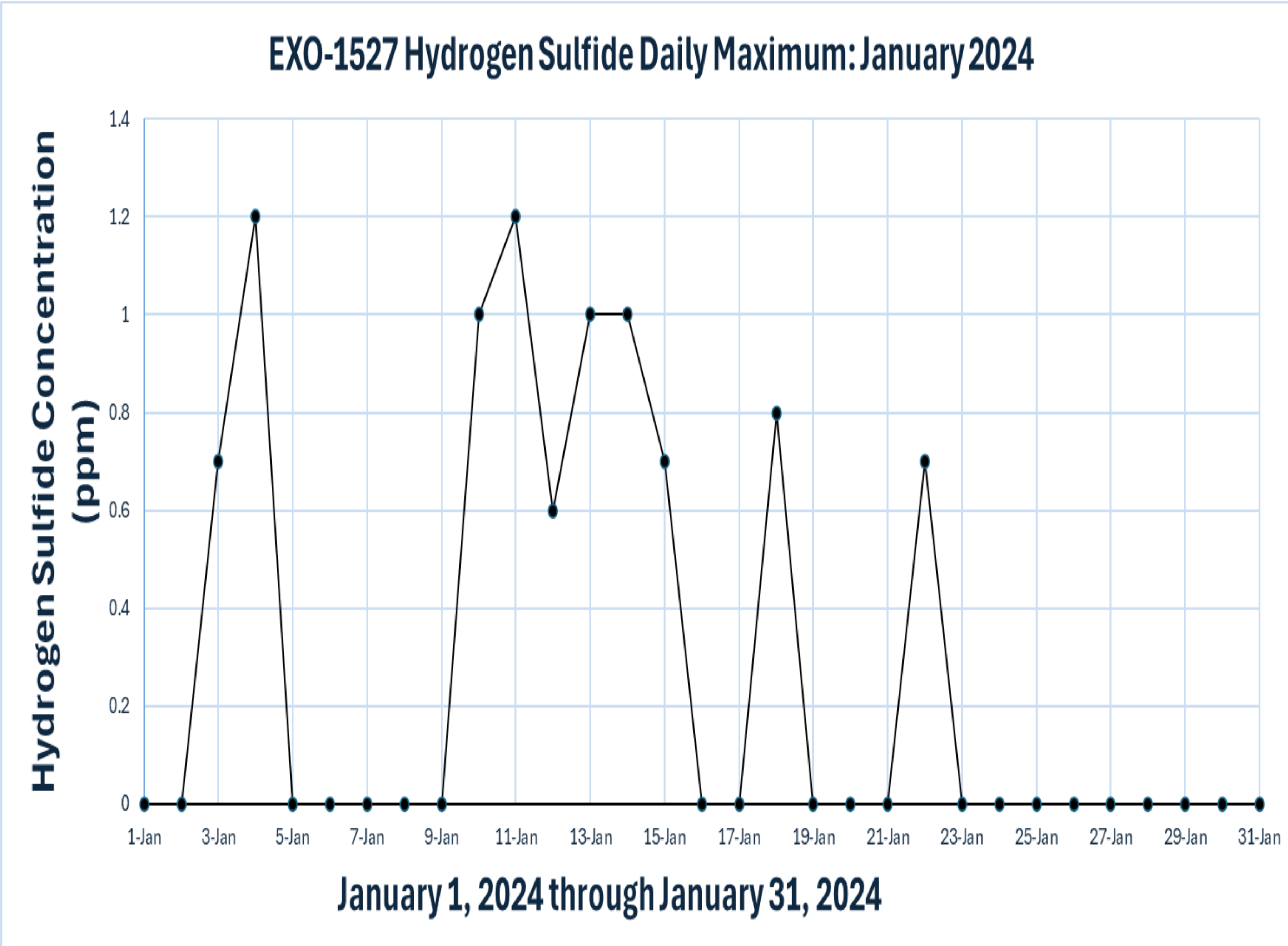

EXO-1527 Hydrogen Sulfide Daily Maximum: August 2023
Hydrogen Sulfide Concentration (ppm)
0
0.5
1
1.5
2
2.5
1-Aug
3-Aug
5-Aug
7-Aug
9-Aug
11-Aug
13-Aug
15-Aug
17-Aug
19-Aug
21-Aug
23-Aug
25-Aug
27-Aug
29-Aug
31-Aug
August 1, 2023 through August 31, 2023

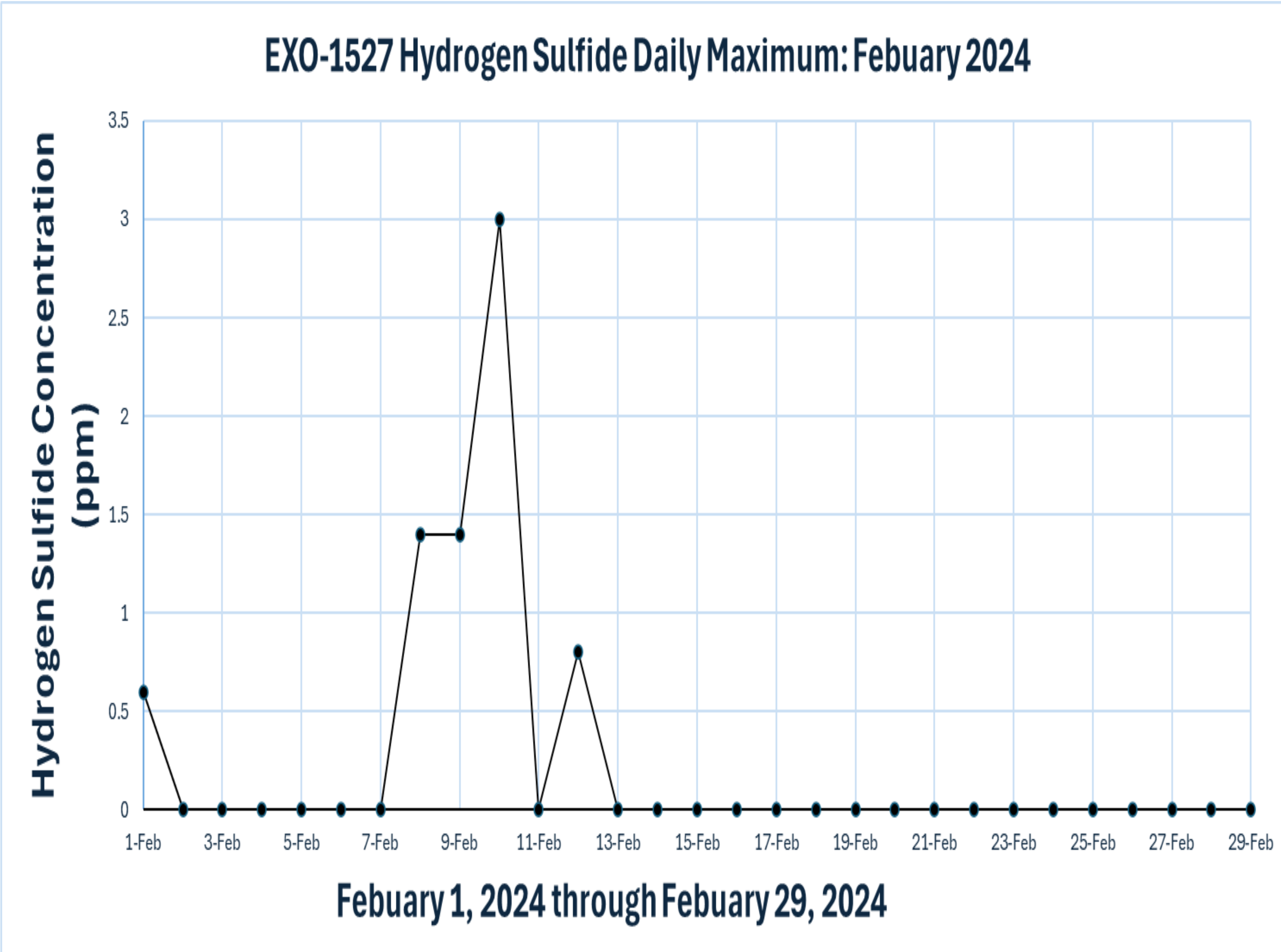

EXO-1527 Hydrogen Sulfide Daily Maximum: September 2023
Hydrogen Sulfide Concentration (ppm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
September 1, 2023 through September 30, 2023


EXO-1527 Hydrogen Sulfide Daily Maximum: October 2023
Hydrogen Sulfide Concentration (ppm)
2.5
2
1.5
1
0.5
0
1-Oct
3-Oct
5-Oct
7-Oct
9-Oct
11-Oct
13-Oct
15-Oct
17-Oct
19-Oct
21-Oct
23-Oct
25-Oct
27-Oct
29-Oct
31-Oct
October 1, 2023 through October 31, 2023


EXO-1527 Hydrogen Sulfide Daily Maximum: November 2023
Hydrogen Sulfide Concentration (ppm)
3
2.5
2
1.5
1
0.5
0
1-Nov
3-Nov
5-Nov
7-Nov
9-Nov
11-Nov
13-Nov
15-Nov
17-Nov
19-Nov
21-Nov
23-Nov
25-Nov
27-Nov
29-Nov
November 1, 2023 through November 30, 2023

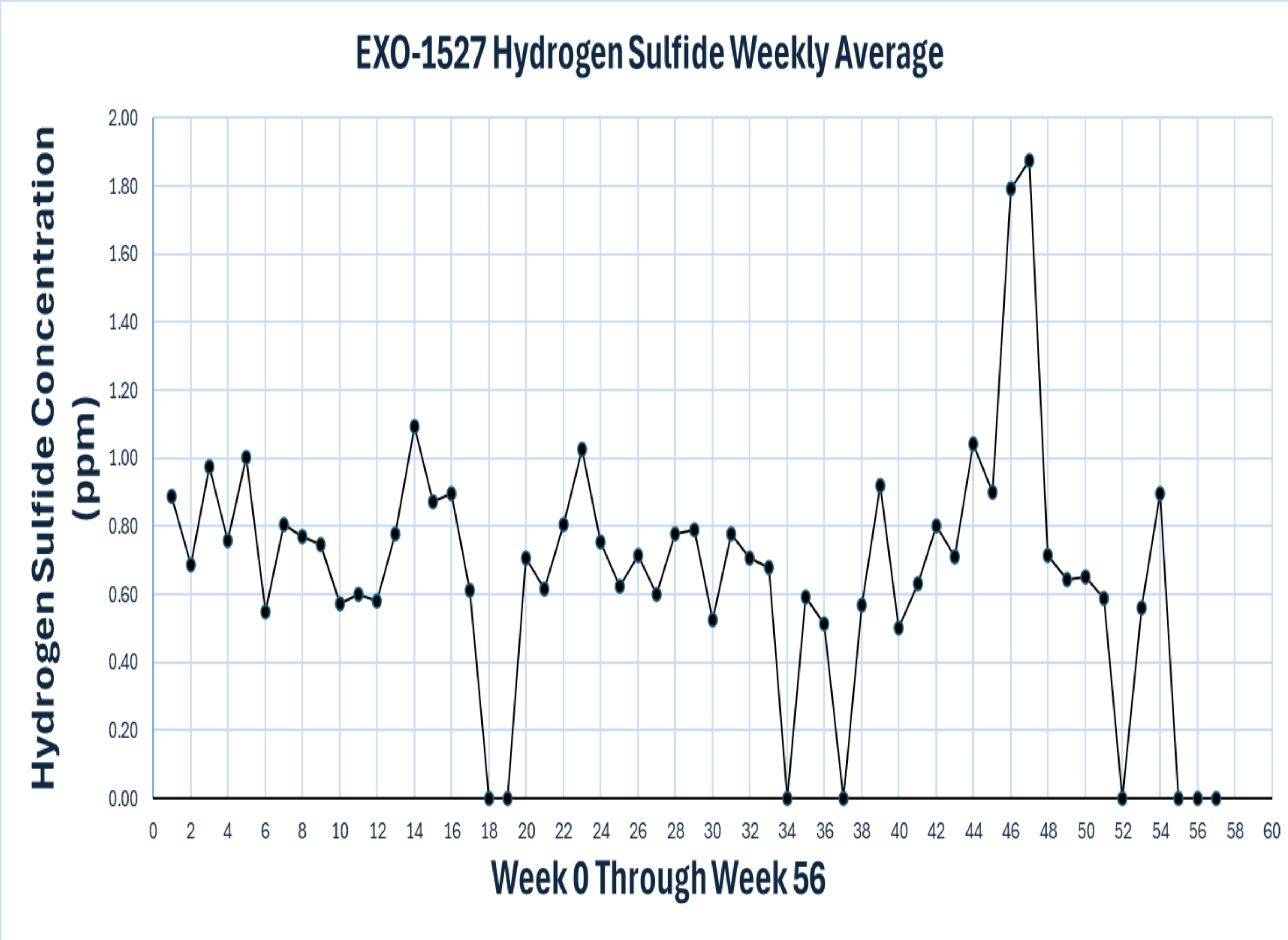

EXO-1527 Hydrogen Sulfide Daily Maximum: December 2023
Hydrogen Sulfide Concentration (ppm)
0
1
2
3
4
5
6
7
1-Dec
3-Dec
5-Dec
7-Dec
9-Dec
11-Dec
13-Dec
15-Dec
17-Dec
19-Dec
21-Dec
23-Dec
25-Dec
27-Dec
29-Dec
31-Dec
December 1, 2023 through December 31, 2023

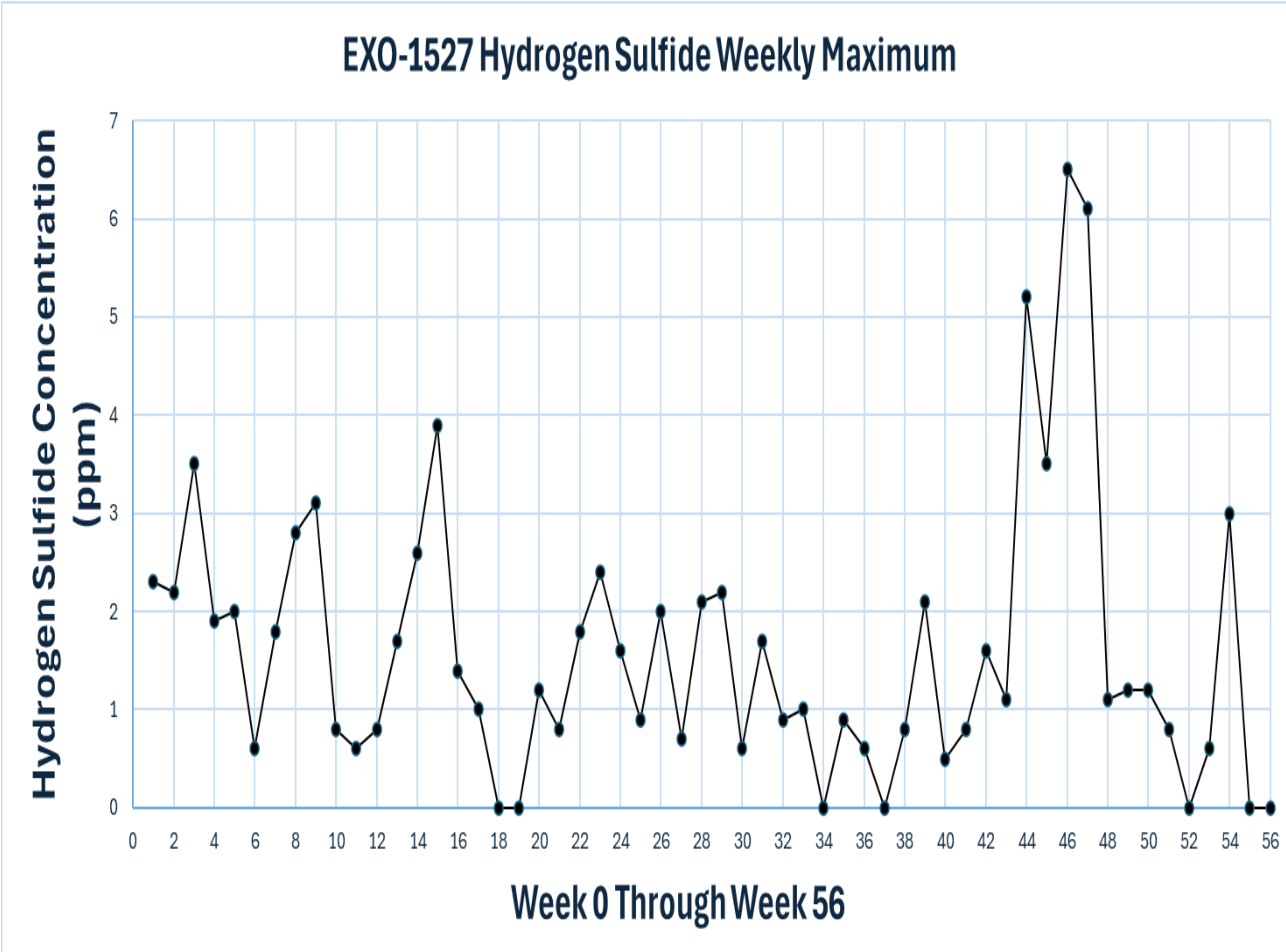

EXO-1527 Hydrogen Sulfide Daily Maximum: January 2024
Hydrogen Sulfide Concentration (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1-Jan
3-Jan
5-Jan
7-Jan
9-Jan
11-Jan
13-Jan
15-Jan
17-Jan
19-Jan
21-Jan
23-Jan
25-Jan
27-Jan
29-Jan
31-Jan
January 1, 2024 through January 31, 2024

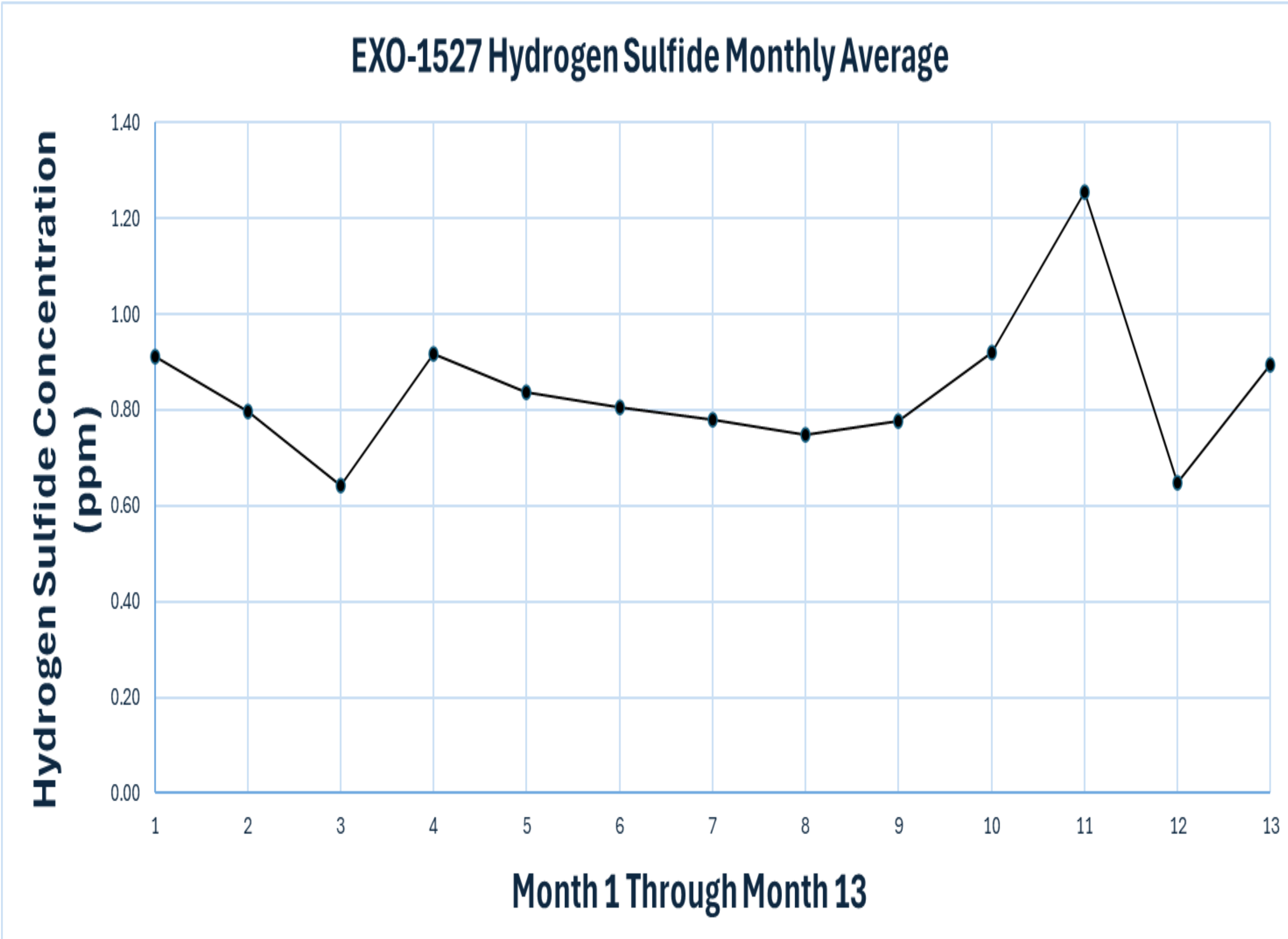

EXO-1527 Hydrogen Sulfide Daily Maximum: Febuary 2024
Hydrogen Sulfide Concentration (ppm)
3.5
3
2.5
2
1.5
1
0.5
0
1-Feb
3-Feb
5-Feb
7-Feb
9-Feb
11-Feb
13-Feb
15-Feb
17-Feb
19-Feb
21-Feb
23-Feb
25-Feb
27-Feb
29-Feb
Febuary 1, 2024 through Febuary 29, 2024

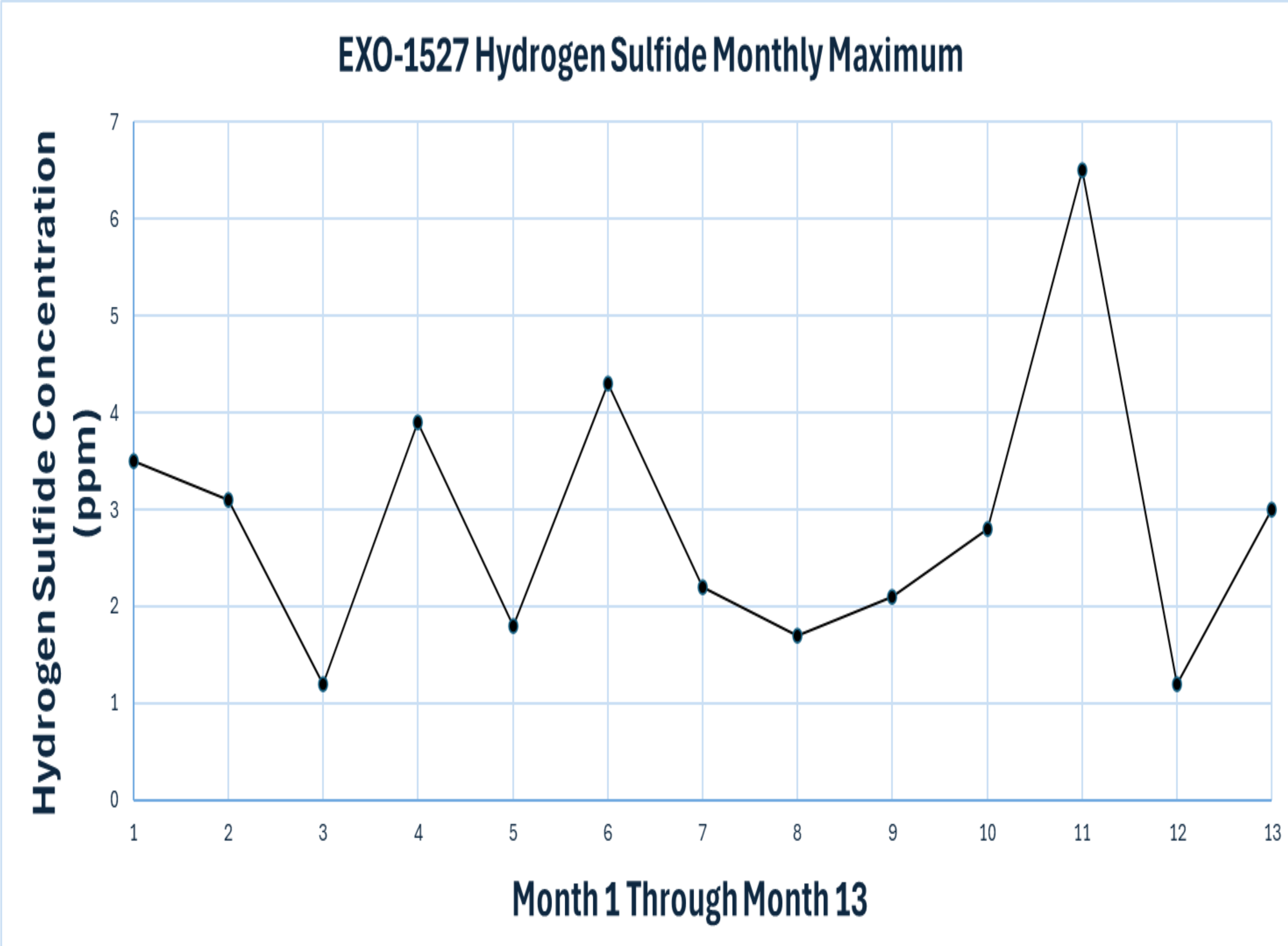
APPENDIX F: Location C

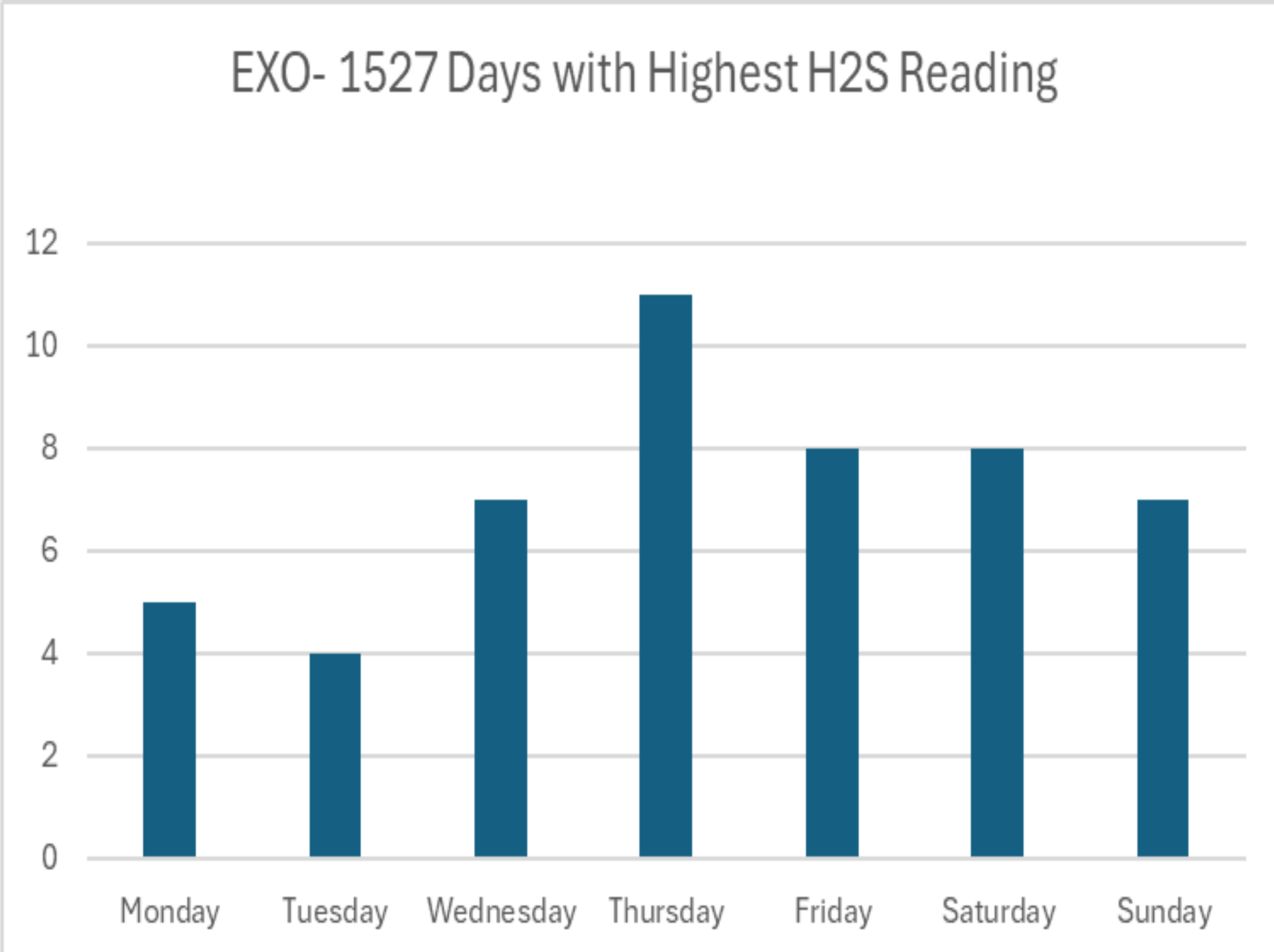
EXO-1527 Weekly Information Graphs

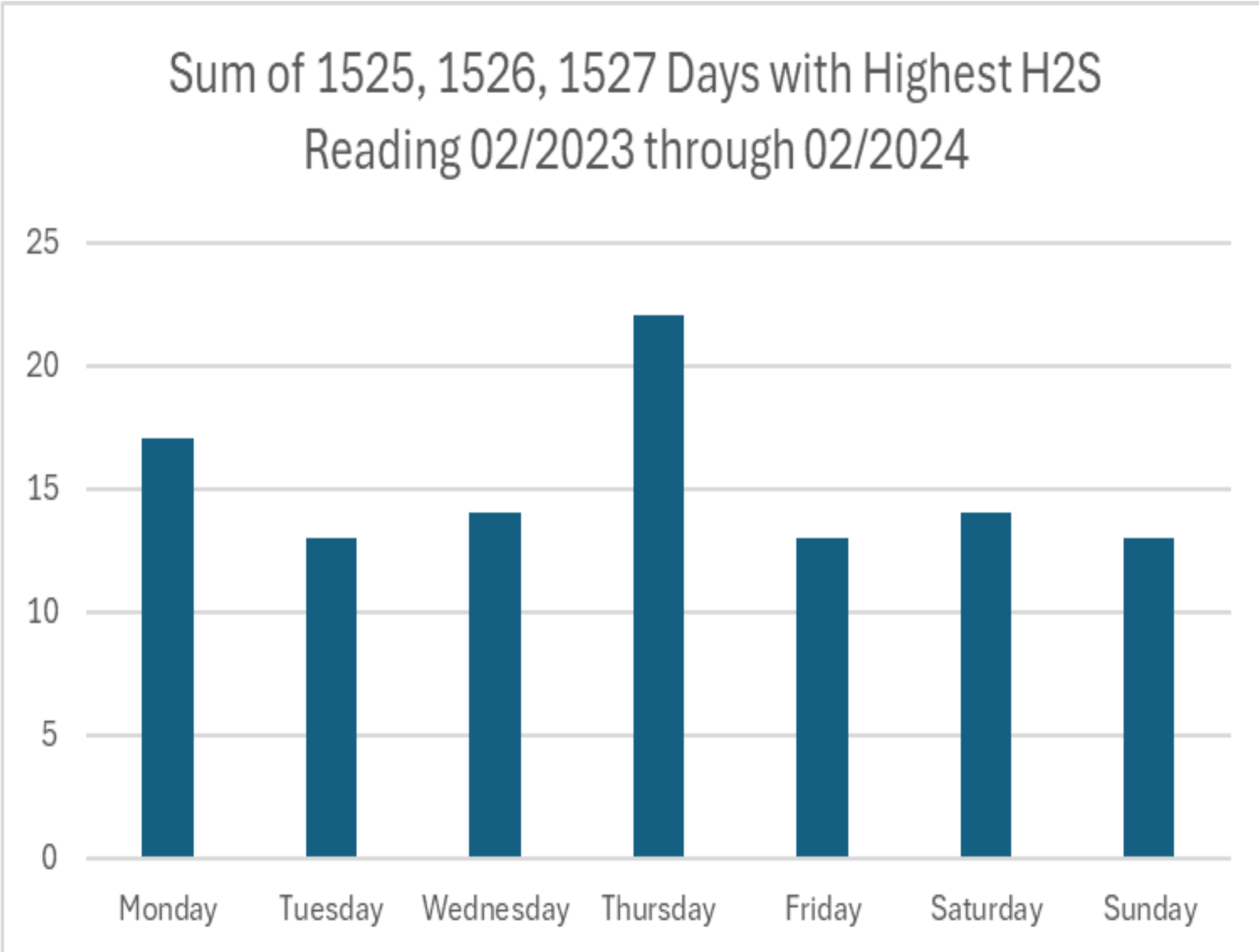

EXO-1527 Hydrogen Sulfide Weekly Average
Hydrogen Sulfide Concentration (ppm)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Week 0 Through Week 56


EXO-1527 Hydrogen Sulfide Weekly Maximum
Hydrogen Sulfide Concentration (ppm)
0
1
2
3
4
5
6
7
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
Week 0 Through Week 56


EXO-1527 Hydrogen Sulfide Monthly Average
Hydrogen Sulfide Concentration (ppm)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
Month 1 Through Month 13


EXO-1527 Hydrogen Sulfide Monthly Maximum
Hydrogen Sulfide Concentration (ppm)
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
9
10
11
12
13
Month 1 Through Month 13


EXO- 1527 Days with Highest H2S Reading
12
10
8
6
4
2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday


Sum of 1525, 1526, 1527 Days with Highest H2S
Reading 02/2023 through 02/2024
25
20
15
10
5
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday