Air Dispersion Modeling

Annapolis Water Reclamation Facility

Modeling Results and Analysis

December 10, 2024

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1 INTRODUCTION

The Annapolis Water Reclamation Facility (WRF) is a wastewater treatment plant, jointly owned by the City of Annapolis and Anne Arundel County. The County is responsible for the operation and maintenance of the facility. The facility employs an advanced activated sludge process with nitrification/de-nitrification for Enhanced Nutrient Removal (ENR) level treatment. The treated effluent is discharged into the Chesapeake Bay. The aerial view of the WRF and its surrounding neighborhoods is shown in Figure 1-1.

Figure 1-1: Aerial View of the Annapolis Water Reclamation Facility

Recent projects at the WRF have upgraded various portions of the treatment plant. However, the odor control facilities have not been evaluated. The County desired to complete a comprehensive odor control evaluation at the plant to identify sources of odor and potential capital improvements.

The overall goal of the project is to conduct a comprehensive odor evaluation including monitoring, data collection, data analysis, and air dispersion modeling to identify sources of odors and potential capital improvements needed to address them.

This Technical Memo (TM) presents the odor dispersion modeling results for the Annapolis WRF. This work was informed by odor sampling and monitoring presented in separate TMs. The modeling results are based on hydrogen sulfide (H_2S) measurements, which are an indicator of odor. The primary goal of the odor modeling is to analyze the magnitude of odor impacts, determine where the odor disperses in the surrounding areas, and evaluate impacts of odor control systems in mitigating odors in the community. The odor modeling is a tool for evaluating upgrades to the facility – it should not be used as an absolute indicator of future predicted offsite odors. The modeling helps the County and Engineers focus on critical odor emitting units, including establishing odor control recommendations for those units. Odor control technology evaluations are provided in a separate TM.

2 MODELING METHODOLOGY

Dispersion modeling is commonly conducted for regulatory air quality assessments, adhering to established guidelines and methodologies. Although this analysis isn't mandated by regulations, it aligns closely with the principles outlined by the United States Environmental Protection Agency (US EPA) in Appendix W to Code of Federal Regulations (CFR) Title 40, Part 51 (Guideline on Air Quality Models). Following these requirements is standard practice for dispersion modeling evaluations.

2.1 Model Selection

The regulatory dispersion model chosen for this analysis is AERMOD, co-developed by the American Meteorological Society (AMS) and US EPA. The version utilized is the most recent one available, version 23132, dated 2023. AERMOD is a preferred model listed in the Guideline on Air Quality Models, functioning by computing near-field impacts of emissions within a 50-kilometer range based on real-time meteorological data from a representative source on an hourly basis.

2.2 Model Options

AERMOD allows for several custom modeling features to be selected as part of the overall model setup. A few regulatory standard options were selected for this analysis:

- Building downwash (wake effects from nearby structures) was incorporated using the Building Profile Input Program (BPIP) as a pre-processor to AERMOD.
- Rural dispersion characteristics were defined based on aerial imagery of the area surrounding the WRF, regulatory criteria for urban/rural designations and the absence of an urban-heat-island effect in the area.
- Elevated terrain for facility sources and modeled receptors was incorporated.

2.3 Receptor Grid

Receptors (or calculation result points) were placed throughout the area surrounding the WRF at ground level to allow for isopleths of odor impacts to be developed. The receptors are aligned in a multi-tiered Cartesian grid with two tiers of spacing starting at the WRF property boundary:

- Tier 1: 25-meter receptor density, extending 1000 meters outward from center.
- Tier 2: 100-meter receptor density, extending from 1000–2,500 meters from center.

Additional receptors are placed 10 m apart along the border of the property. In total, 8,876 receptors were evaluated in this analysis. Figure 2-1 shows the receptor grid used in the modeling.

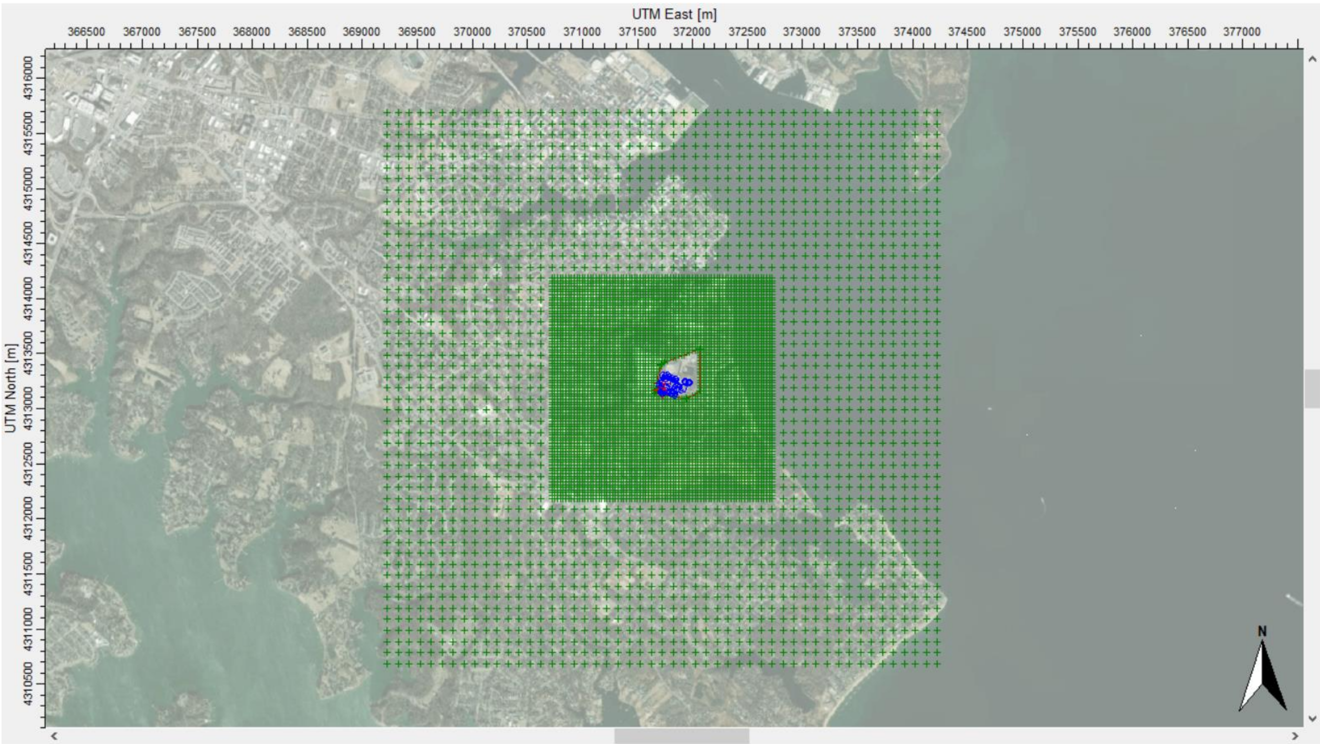

Figure 2-1: Receptor Grid in AERMOD

2.4 Meteorological Data

AERMOD utilizes meteorological data from both surface observations and upper air weather balloon sounding data to characterize atmospheric conditions and dispersion patterns on an hourly basis. Raw meteorological data are sourced directly from the National Oceanic and Atmospheric Administration (NOAA) archives for representative observation sites and then formatted for input into AERMOD using the AERMET preprocessor program (a companion software program for AERMOD) as described below. The most recent 3 years of available data (2019–2021) were used in this analysis.

Surface Observations.

Surface data were obtained from the United States Naval Academy (KNAK), which is 2.3 miles (3.7 km) to the northwest of the WRF. Aerial imagery of the surface and upper air observation sites in relation to the WRF is shown below in Figure 2-2. The Naval Academy site is the closest surface observation station to the WRF and has similar land water characteristics and, therefore, was judged representative of the meteorological conditions at the WRF.

Upper Air Data.

There are a limited number of locations from which weather balloon data are available. The nearest site for upper air sounding data is based out of the Washington Dulles International Airport (KIAD), which is 52 miles (84 km) away. Despite being further away at 89 miles (143 km) from the site, the Wallops Flight Facility Airport (KWAL) was chosen for the upper air data since it better represents the marine environment near the WRF than KIAD, which is further inland. Figure 2-2 shows the location of each of the sites with respect to the WRF. Data are gathered via weather balloon launches of radiosonde equipment twice daily to obtain temperature, pressure, wind, and humidity measurements throughout the vertical profile of the atmosphere.

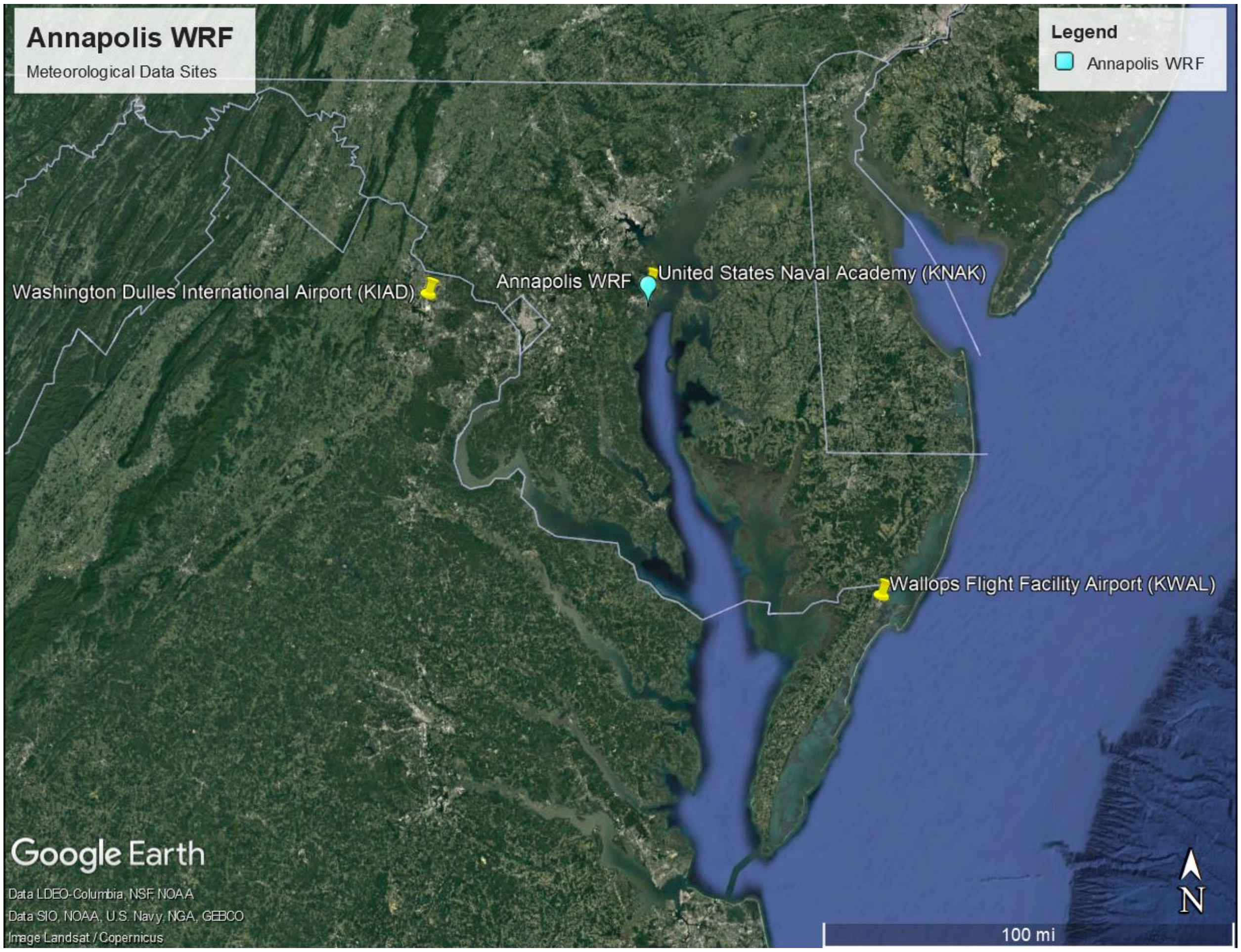

Figure 2-2: Meteorological Observation Sites
Source: Google Earth Imagery, September 2024.

2.4.1 AERMET Processing

To translate weather observations into a format that is suitable for AERMOD to interpret, data must be processed with the AERMET preprocessing program. AERMET also incorporates surface roughness characteristics via AERSURFACE, which establishes certain parameters for the observation site such as albedo, Bowen ratio, and surface roughness lengths to assist with developing hourly atmospheric dispersion profiles. AERMET requires these parameters as input data from AERSURFACE to accurately capture dispersion factors such as the potential for surface heating and atmospheric stability.

The current version of AERSURFACE (version 20060) was executed using 12 equal-sized compass sectors for each month of the year. The input surface land cover data file was from the National Land Cover Database (NLCD).

Surface moisture was calculated using the climatological precipitation data set from the National Climatic Data Center for the Anne Arundel County, MD, as this is the nearest long-term climate data location. Data were sorted from dry to wet and each of the years being processed was compared to the data set based on the annual precipitation. If the year being processed fell within the lowest 9 years it was classified as dry, if the year fell in the middle 12 years it was classified as average, and if the year fell in the top 9 years it was classified as wet. Figure 2-3 illustrates the annual precipitation for the area, relative to the 30-year average.

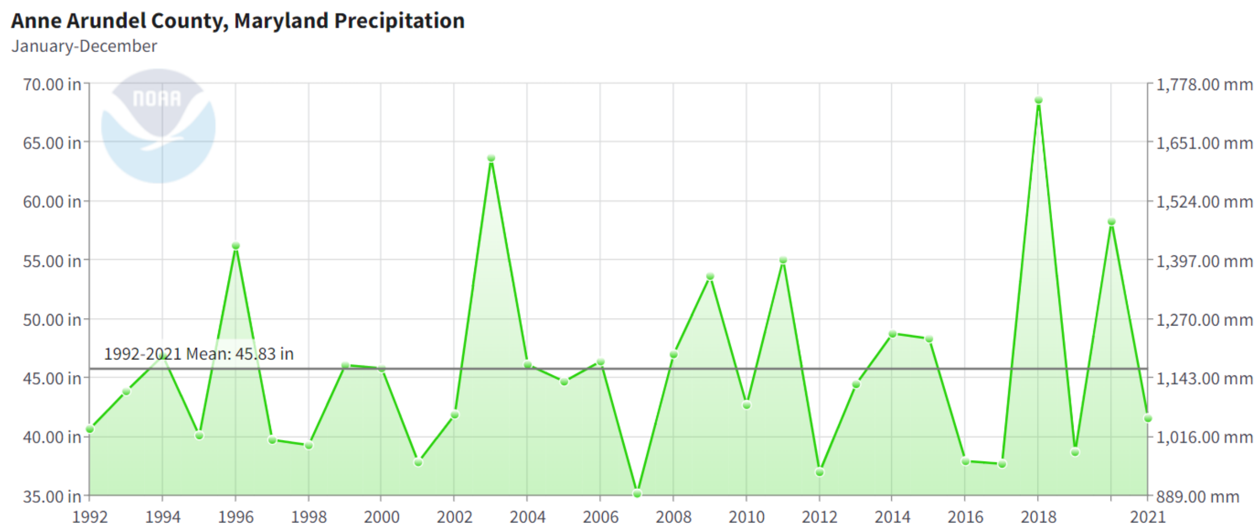

Figure 2-3: Annual Precipitation Relative to 30-Year Mean, Anne Arundel County, MD
Source: NOAA National Centers for Environmental Information (NCEI)

The year determined to be wet was 2020; 2021 was average; 2019 was dry. Other AERSURFACE inputs were as follows:

- Surface station location (38.99 N, 76.49 W)
- Upper air station location (37.93 N, 75.48 W)
- Default seasons of winter (12, 1, 2), spring (3, 4, 5), summer (6, 7, 8), and autumn (9, 10, 11)
- No continuous snow cover
- Not arid

Meteorological data were processed using the current AERMET (version 23132) software using a 0.5-meter per second (m/s) threshold wind speed to address missing and calm conditions. The profile base elevation of 2 meters was used, which is the elevation of the surface meteorological data weather station.

After the meteorological data is processed, it is loaded into the AERMOD model which is then used to simulate observed weather conditions over the length of the model run and the resultant concentrations. Meteorological data is crucial since weather conditions such as wind direction and pressure systems can aid or restrain poor air quality. As seen in Figure 2-4, the predominant wind directions from the KNAK data set are from the northwest and from the southwest. On average, odor would primarily be blown in those two directions.

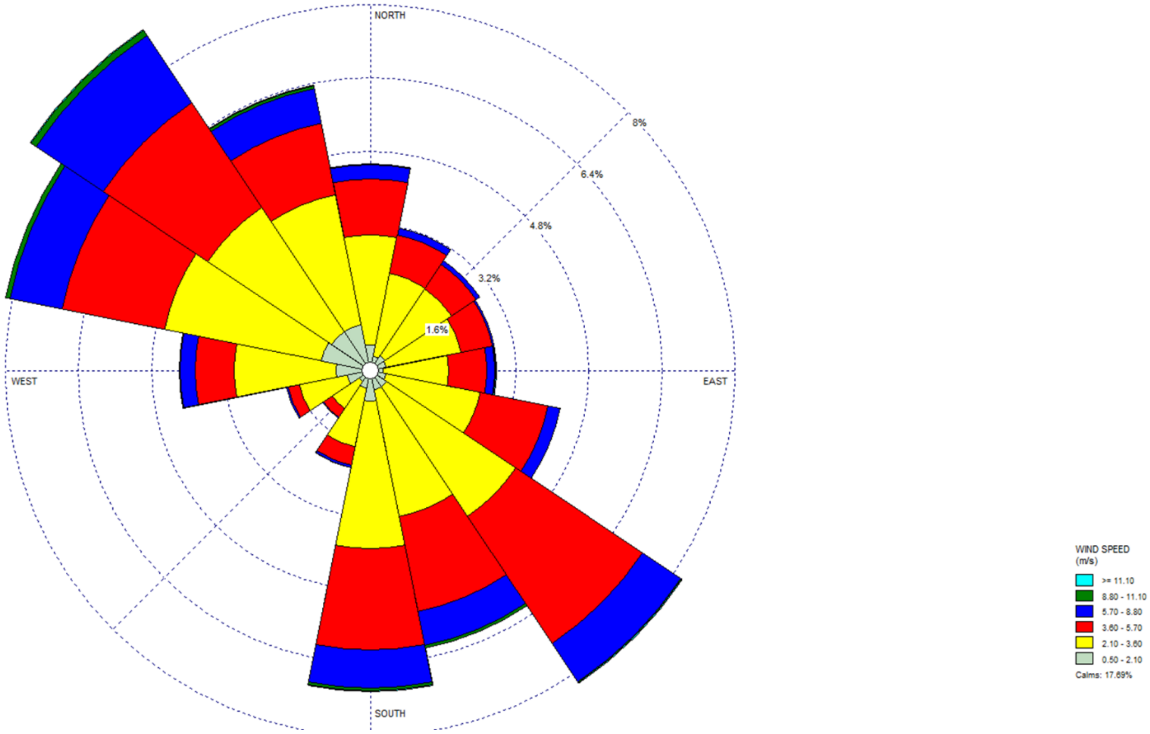

Figure 2-4: Wind Rose for Surface Observations at United States Naval Academy (KNAK) for 2019 - 2021

Source: Image created by Lakes WRPLOT View (version 12.0.0), data from National Oceanic and Atmospheric Administration (NOAA).

2.5 Sources

AERMOD allows for several types of releases of emissions, which in turn affect the dispersion of the odors across the surrounding area. For this project, the only type of emissions included in the model were point sources. A point source in AERMOD is represented by an isolated, vertically oriented emission point like a stack or vent, with specified physical parameters and emission rates. Figure 2-5 shows the AERMOD source layout at the WRF.

Figure 2-5: AERMOD Source Layout for WRF

For each identified odor source, emission rates were developed based on measured concentrations of H_2S and the exhaust flow rate of each point source. Exhaust flow rate was based on design conditions. Once calculated, the modeled H_2S concentrations are used as a representation of odor impacts. Table 2-1 provides details of the modeled source parameters for the three point sources at the WRF.

Table 2-1: Modeled Emission Source Parameters

Emission Source	Model ID	Release height (ft)	Exit Diameter (ft)	Exit Temp (°F)	Exit Velocity (cfm)
Solids	SOLIDS	29.5	3	Ambient	28,500
Influent Pump Station	INF_PS	15.0	1.25	Ambient	2,400
Headworks	HEADWKS	26.75	3.4	Ambient	23,000

2.5.1 Emission Rates

Each of the sources was evaluated at different emissions rates to evaluate H_2S concentrations at low, medium, and high cases determined based on H_2S sampling performed on each source. The resulting exhaust concentrations and corresponding emission rates are presented in Table 2-2 and Table 2-3. The high emission rates were based on preliminary odor monitoring of the sources completed in the winter/spring of 2024. The mid emission rates reflect a poorly operating odor control system, whereas the low emission rates represent an effective odor control system.

Note, the existing backwash tank was not included in the air dispersion modeling as emission rates cannot be determined at this time. The County is proceeding with designing odor control improvements to the backwash tank, including covers and automatic flushing systems.

Table 2-2: Exhaust H_2S Concentrations in Parts Per Million (ppm) for Each Emission Source

Emission Source	Model ID	Exhaust H_2S Concentration (ppm)		
		Low	Mid	High
Solids	SOLIDS	0.1	N/A	1
Influent Pump Station	INF_PS	0.1	2	10
Headworks	HEADWKS	0.1	5	20

Table 2-3: Modeled H_2S Emission Rates (g/s) for Each Emission Source

Emission Source	Model ID	H_2S Emission Rate (g/s)		
		Low	Mid	High
Solids Building	SOLIDS	0.00191	N/A	0.0191
Influent Pump Station	INF_PS	0.00016	0.00321	0.016
Headworks	HEADWKS	0.00154	0.0769	0.308

3 MODELING RESULTS

The H_2S concentrations modeled by AERMOD were in the units of µg/m^3, which were then converted to parts per billion (ppb) using the Ideal Gas Law.

3.1 Results for Individual Sources

Individual runs were completed based on the individual source low, mid, and high cases of the emission rates, which shows the influence of each source as the emission rate increases or decreases. Maximum hourly odor emissions were calculated by AERMOD for each hour of the 3-year meteorological data period. Figure 3-1 through Figure 3-8 represent the highest hourly H_2S concentration for each source over the entire 3-year period.

Figure 3-1: Individual Sources – Solids Low Concentration Case Maximum Modeled H_2S Impacts (ppb)

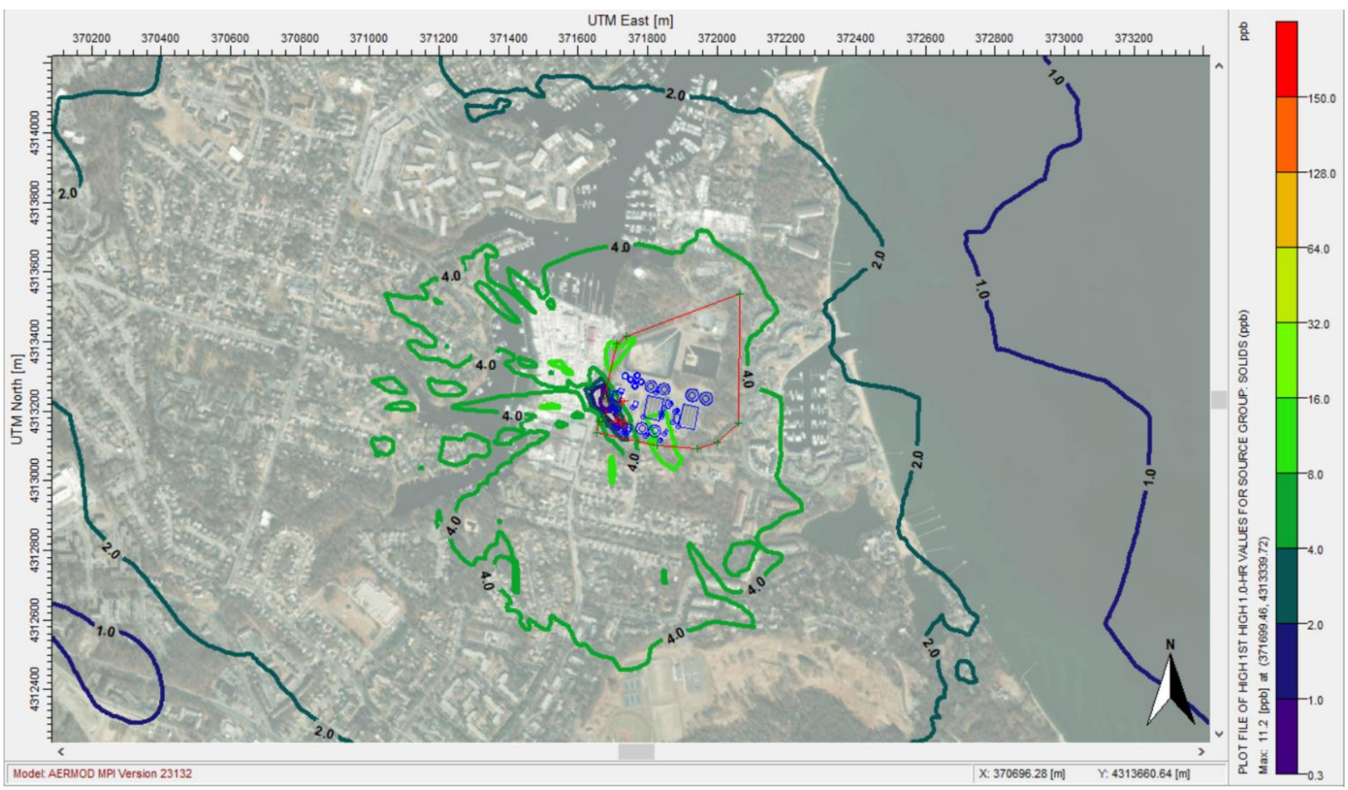

Figure 3-2: Individual Sources – Solids High Concentration Case Maximum Modeled H_2S Impacts (ppb)

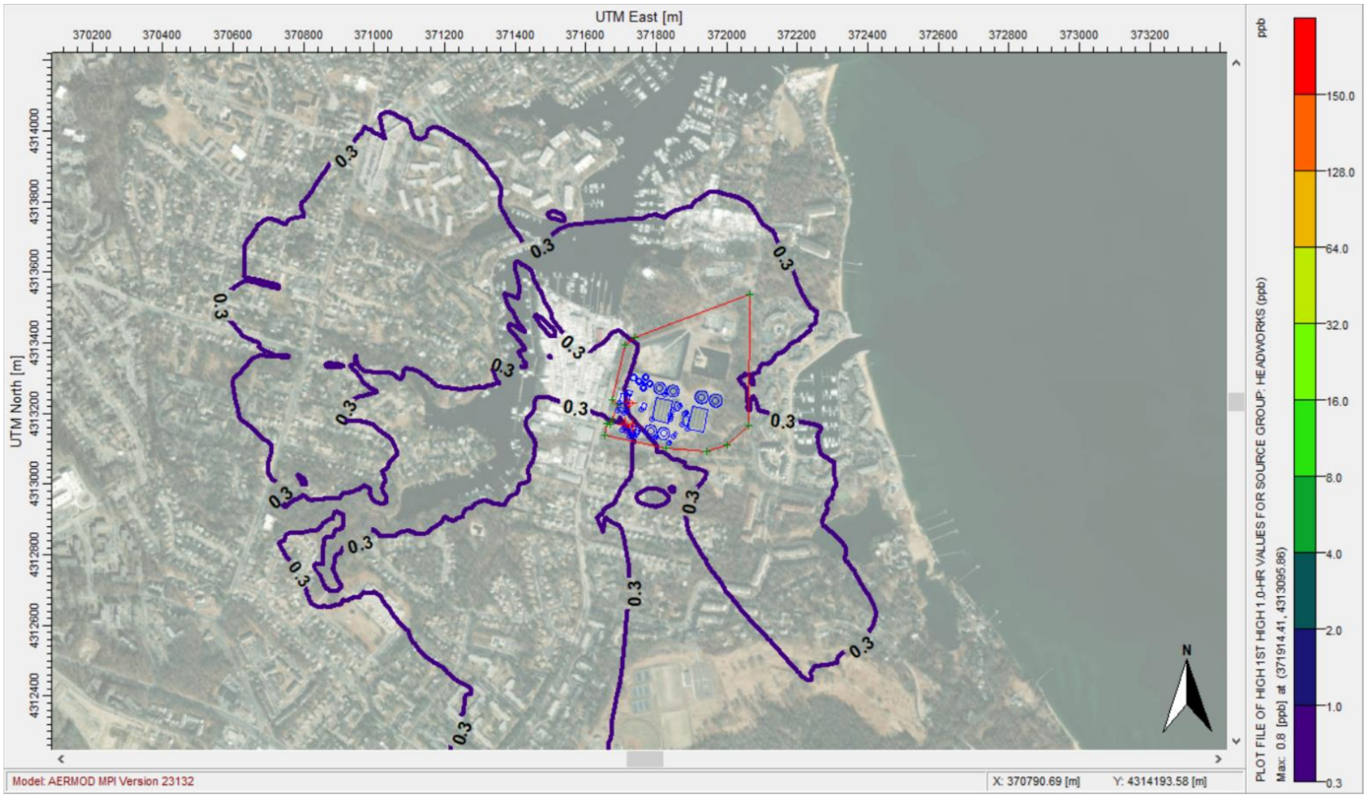

Figure 3-3: Individual Sources – Headworks Low Concentration Case Maximum Modeled H_2S Impacts (ppb)

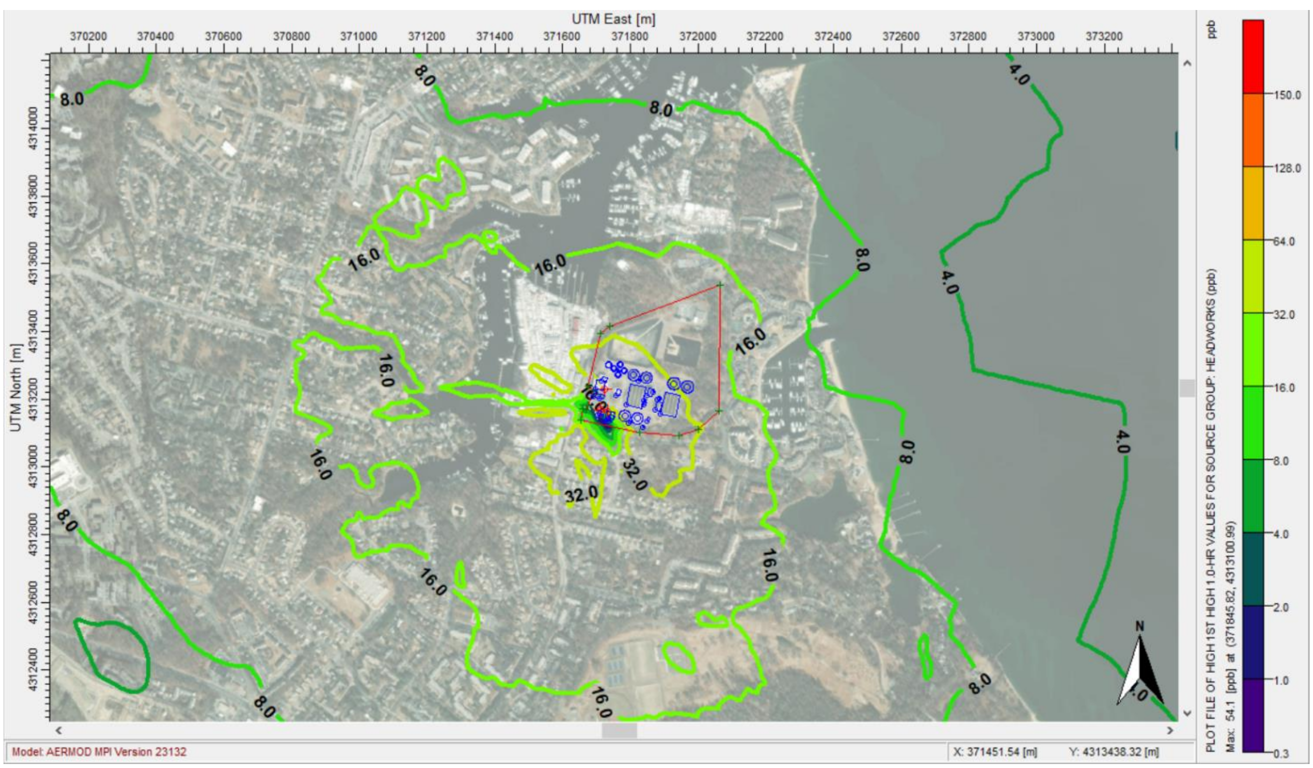

Figure 3-4: Individual Sources – Headworks Mid Concentration Case Maximum Modeled H_2S Impacts (ppb)

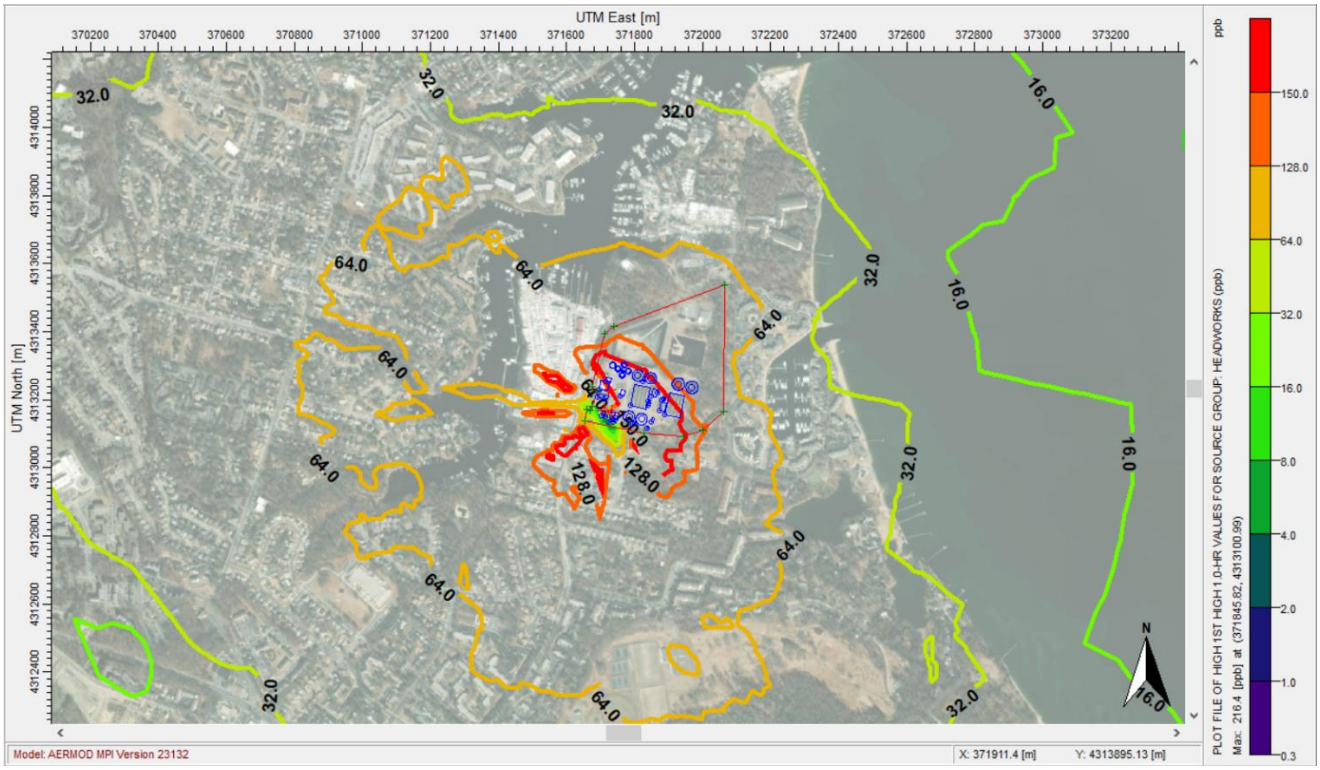

Figure 3-5: Individual Sources – Headworks High Concentration Case Maximum Modeled H_2S Impacts (ppb)

Figure 3-6: Individual Sources – Influent Pump Station Low Concentration Case Maximum Modeled H_2S Impacts (ppb)

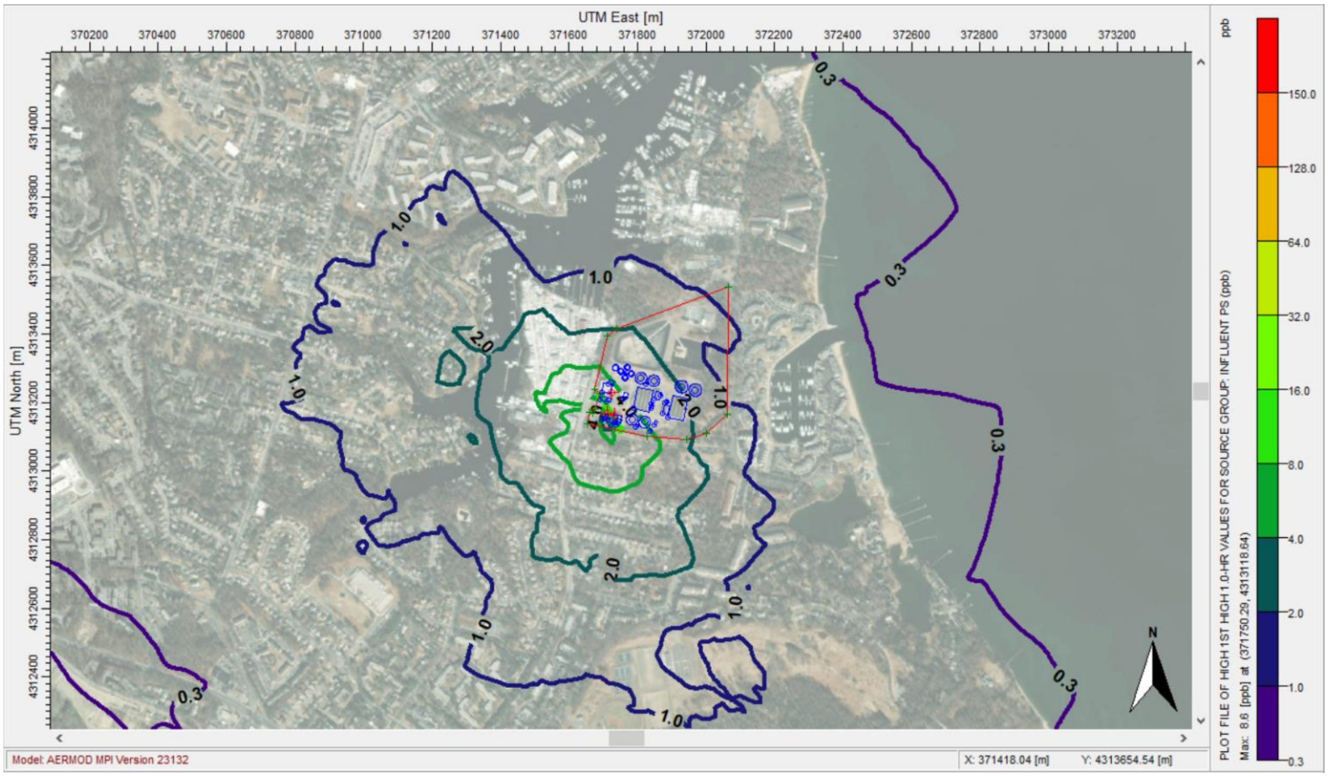

Figure 3-7: Individual Sources – Influent Pump Station Mid Concentration Case Maximum Modeled H_2S Impacts (ppb)

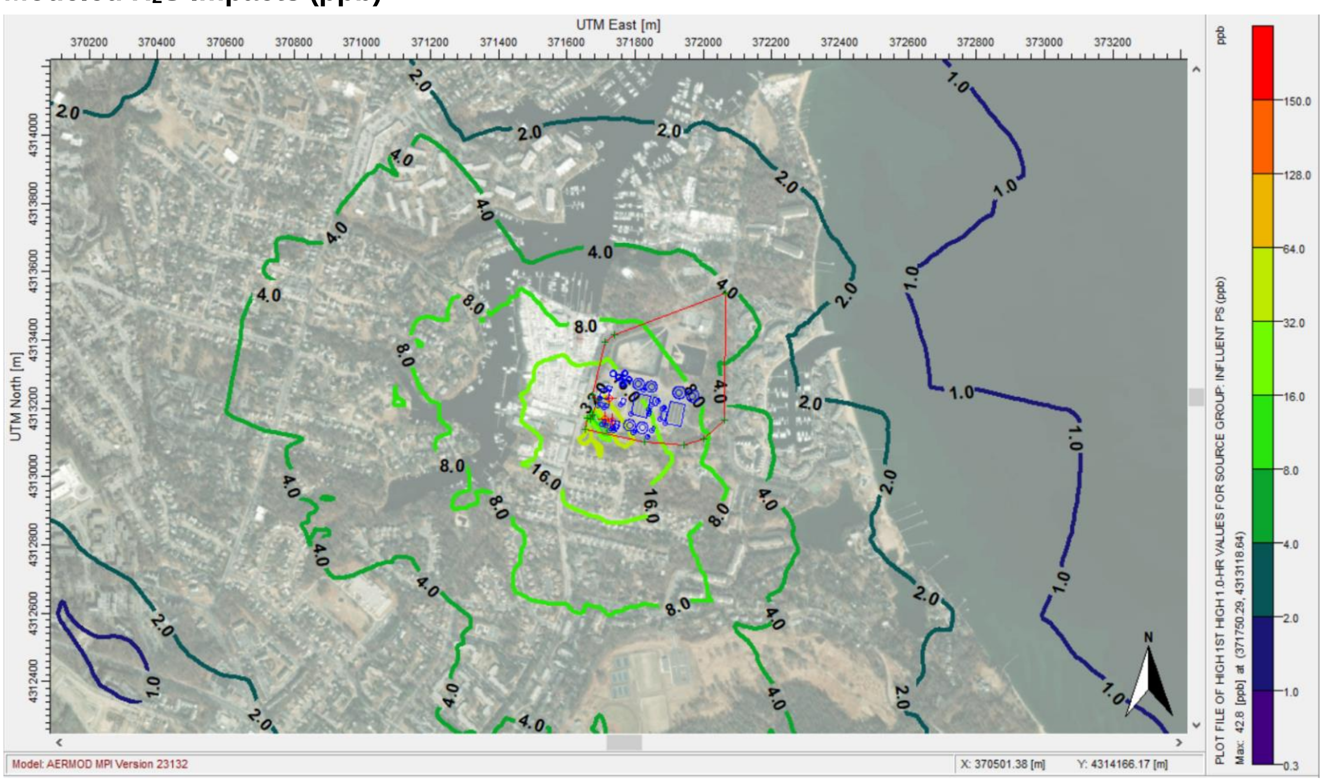

Figure 3-8: Individual Sources – Influent Pump Station High Concentration Case Maximum Modeled H_2S Impacts (ppb)

Table 3-1 summarizes the results of all the separate, individual runs for the low, mid, and high emission rates. As expected, the headworks at the high emissions rate is the potential major contributor to offside odors.

Table 3-1: Modeled H_2S Concentration (ppb) for Individual Emission Sources Between Low, Mid, and High Cases

Emission Source	Model ID	Modeled H_2S Concentration (ppb)		
		Low	Mid	High
Solids Building	SOLIDS	0.5	N/A	11
Influent Pump Station	INF_PS	0.3	9	43
Headworks	HEADWKS	0.8	54	216

3.2 Results for All Sources

Four different scenarios based on the different measured exhaust H_2S concentrations and emission rates from each source were modeled. The different scenarios are as follows:

- **Scenario 1:** Solids – 0.1 ppm, Headworks – 20 ppm, Influent Pump Station: 0.1 ppm. This scenario is reflective of existing conditions with a functional influent pump station odor control system, but a non-functioning headworks odor control system.
- **Scenario 2:** Solids – 0.1 ppm, Headworks – 5 ppm, Influent Pump Station: 0.1 ppm. This scenario is reflective of a functional influent pump station odor control system and a poorly functioning headworks odor control system.
- **Scenario 3:** Solids – 0.1 ppm, Headworks – 0.1 ppm, Influent Pump Station: 0.1 ppm. This scenario is reflective of a functional odor control systems for all facilities.
- **Scenario 4:** Solids – 1 ppm, Headworks – 5 ppm, Influent Pump Station – 2 ppm. This scenario is reflective of a poorly functioning odor control systems for all facilities.

Hourly H_2S concentrations were calculated by AERMOD for each hour of the 3-year meteorological data period. Figure 3-9 through Figure 3-12 represent the highest hourly H_2S concentration for each of the four modeled scenarios over the entire 3-year period.

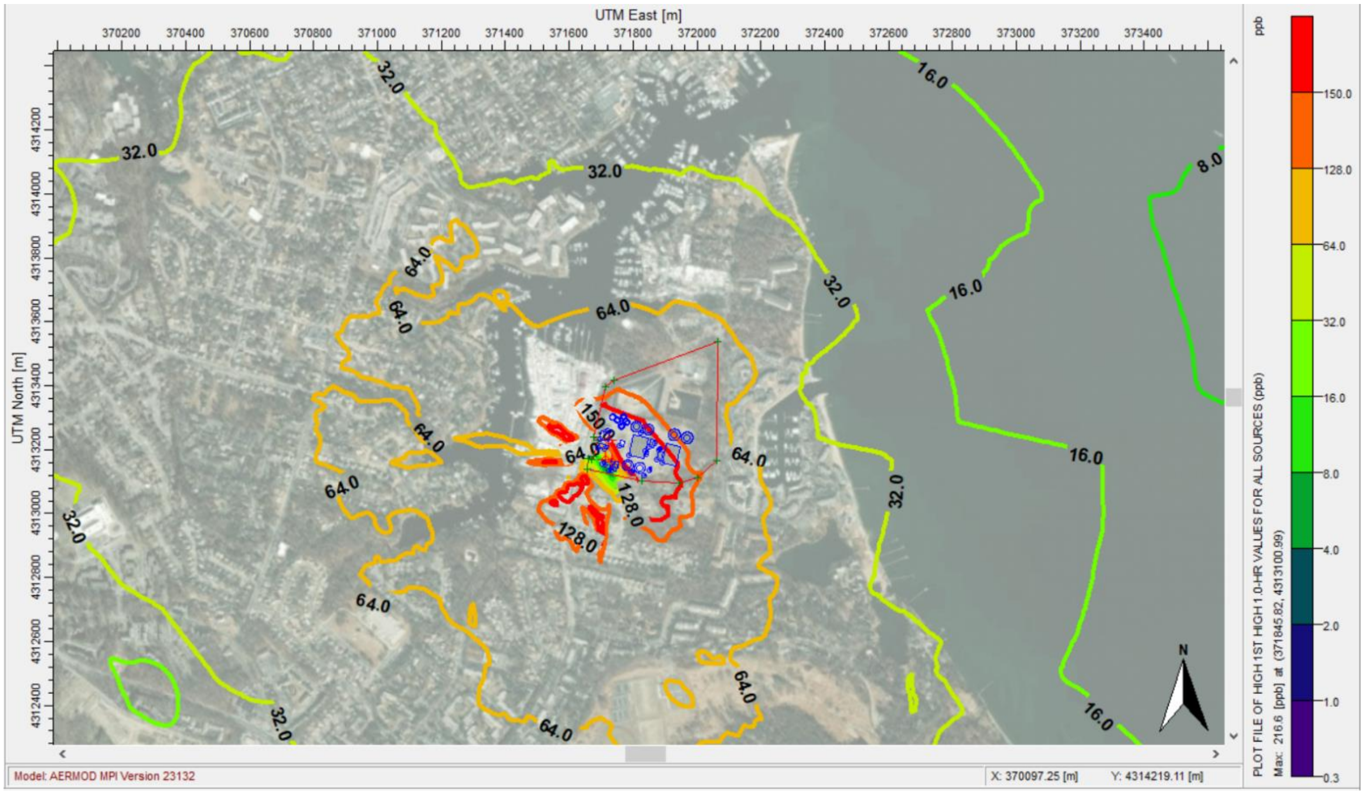

Figure 3-9: All Sources – Scenario 1 Maximum Modeled H_2S Impacts (ppb)

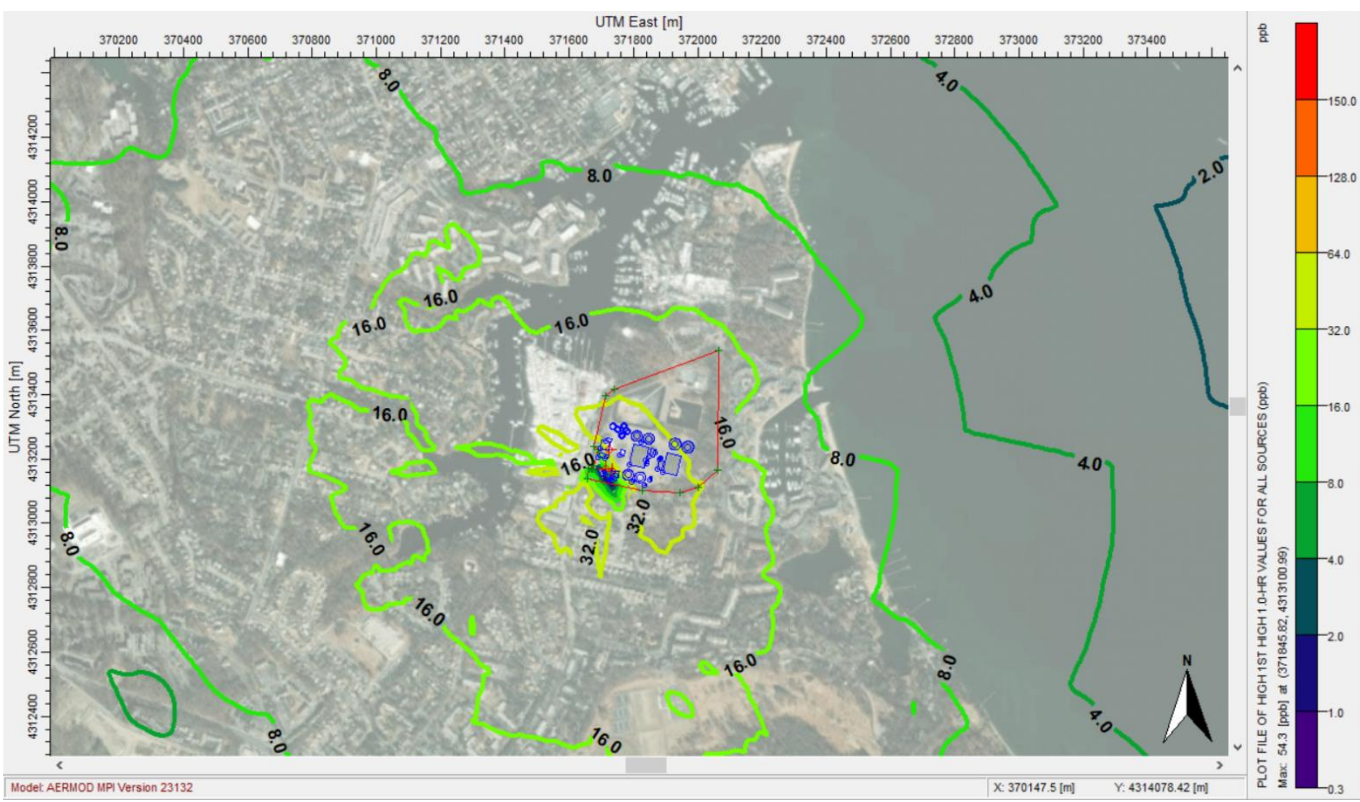

Figure 3-10: All Sources – Scenario 2 Maximum Modeled H_2S Impacts (ppb).

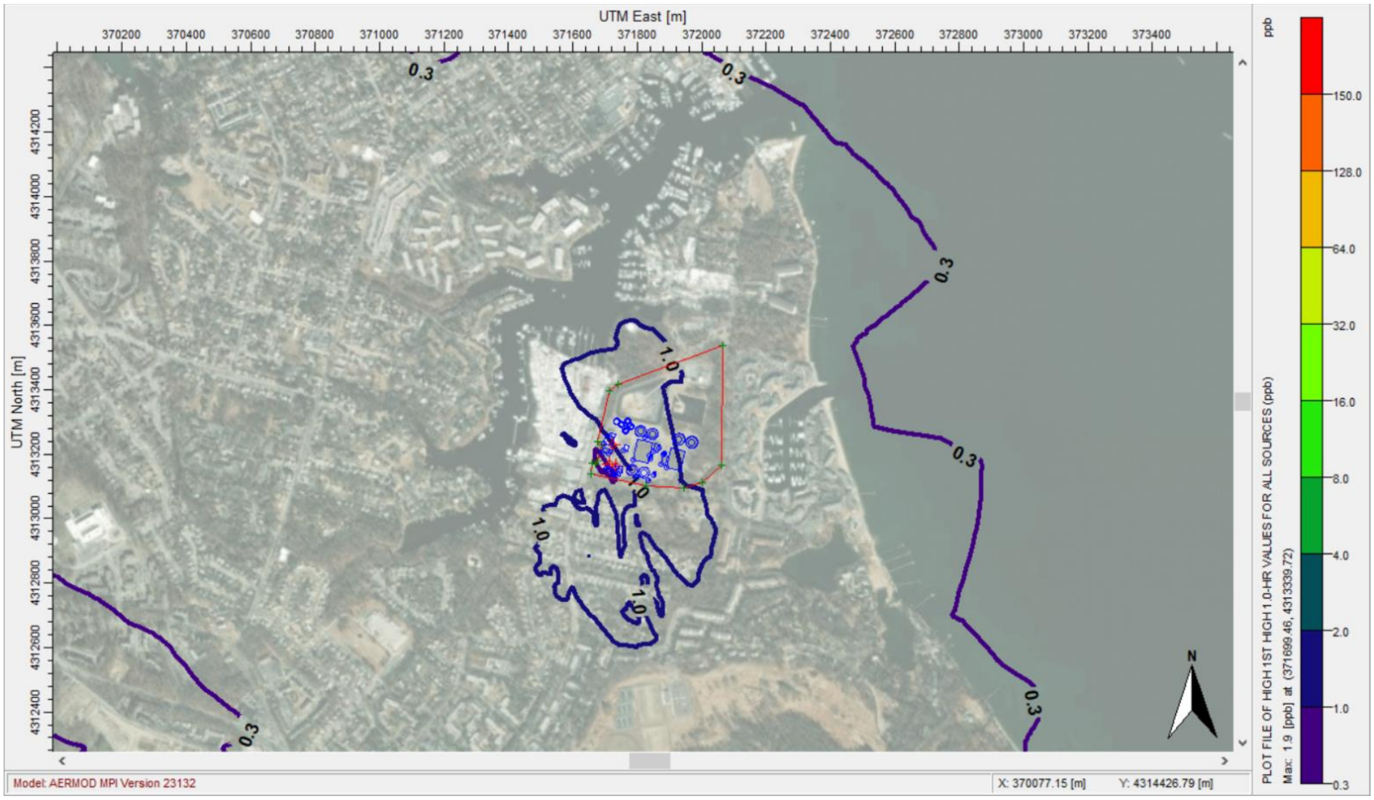

Figure 3-11: All Sources – Scenario 3 Maximum Modeled H_2S Impacts (ppb)

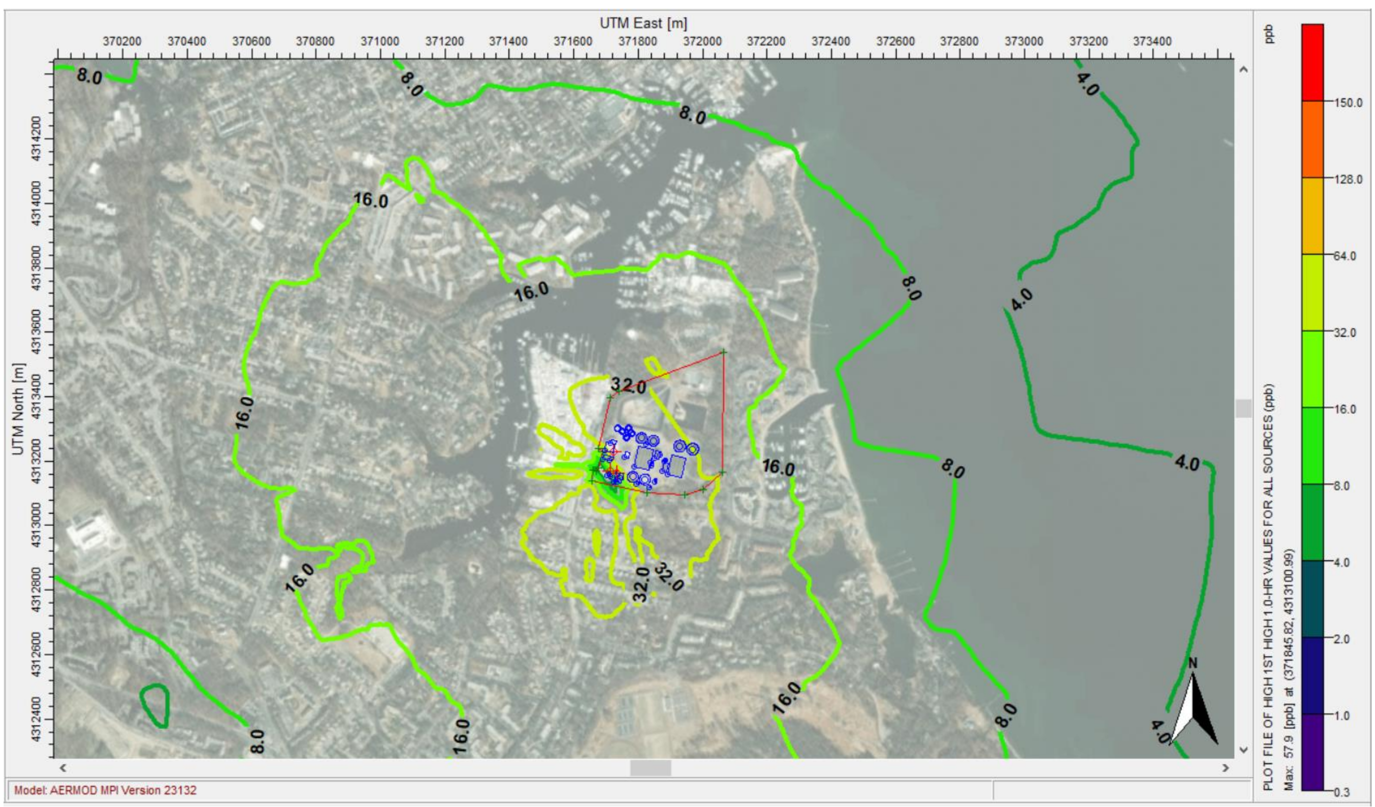

Figure 3-12: All Sources – Scenario 4 Maximum Modeled H_2S Impacts (ppb)

Table 3-2 displays the modeled maximum 1-hour H_2S concentration for each scenario. The run with the highest max 1-hour H_2S concentration was in Scenario 1, as the headworks has the highest emission rate out of all the rest of the scenarios. Over all the models, the highest H_2S concentrations were mainly along the western edge and south/southeastern edge of the facility boundary. Scenario 3 was the lowest out of all the four scenarios; which is positive as this is representative of properly functioning odor control systems at all facilities.

Table 3-2: Maximum Modeled Hourly H_2S Concentration (ppb)

Scenario	Concentration (ppb)
Scenario 1	217
Scenario 2	54
Scenario 3	2
Scenario 4	58

3.3 Odor Exceedances

A feature of AERMOD is the ability to calculate the number of exceedances of a specified threshold value over the length of the model run. A threshold of 10 ppb (0.01 ppm) was chosen since it is in the lower range of reported detection odor threshold for H_2S (0.0005-0.3 ppm)[1]. Since this model was run over a 3-year meteorological data period, the total number of hours is 26,280 hours. While these figures represent an hourly average, it's worth noting that odor perception can occur at smaller time intervals. Thus, it is essential to recognize that the odor intensity may be higher on a sub-hourly scale, which results in a degree of subjectivity tied to the exceedance count results.

Table 3-3 shows the number of maximum exceedances with the percent of total hours that the modeled hourly H_2S concentration surpassed 10 ppb over the 3-year run. Scenario 3 does not have any exceedances since the max 1-hour H_2S concentration was below 10 ppb throughout the length of the model run.

Table 3-3: Maximum Exceedance Count and Percent of Total Hours

Scenario	Exceedance	Hours
Scenario 1	2,258	9%
Scenario 2	1,180	4%
Scenario 3	NA	NA
Scenario 4	1,305	5%

The number of exceedances of 10 ppb on an hourly basis were then found for each of the four scenarios and are shown in Figure 3-13 through Figure 3-15. Again, Scenario 3 is not present due to no hourly concentrations exceeding 10 ppb over the length of the model run. Table 3-4 is a key for the isopleths shown in each of the figures. Since each isopleth is a boundary for the respective

[1] https://www.atsdr.cdc.gov/ToxProfiles/tp114-c4.pdf

exceedance count, Table 3-4 interprets each exceedance count that each isopleth represents with the corresponding percentage of hours over the 3-year period.

The following considerations are important when interpreting this plot:

- The hours listed are not necessarily consecutive and can be spread across the entire 3-year data set.
- The hours listed could be at any time of day, including overnight periods with limited human exposure.
- The number of hours here should be compared against the total number of hours evaluated (26,280 hours) for relative magnitude.

Table 3-4: Equivalent Percentages of Exceedance Count Hours to Isopleths

Isopleth Color	Exceedance	Total
Red	2,000	8%
Orange	1,500	6%
Yellow	1,000	4%
Green	500	2%
Blue	100	0.4%
Violet	10	0.04%

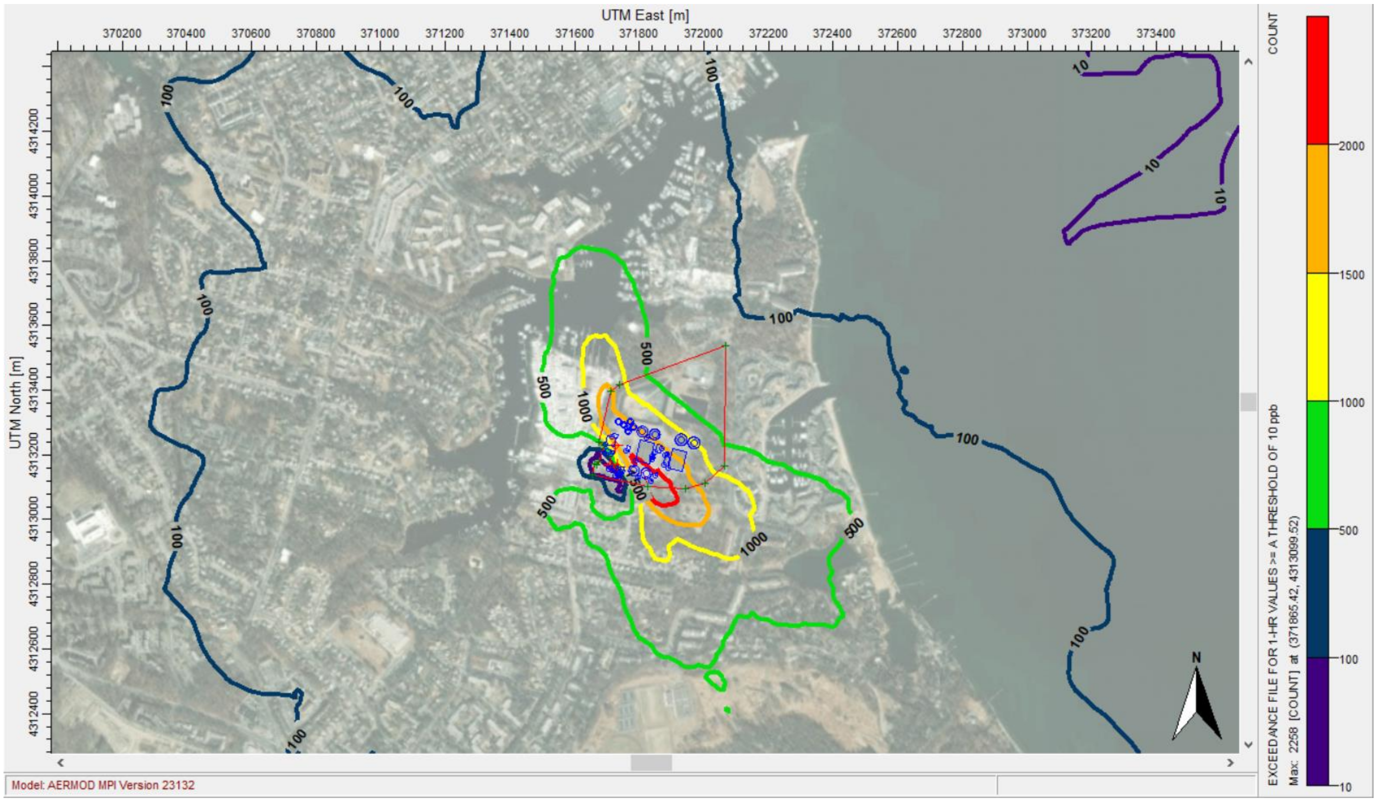

Figure 3-13: All Sources – Scenario 1 Hourly Exceedance Count

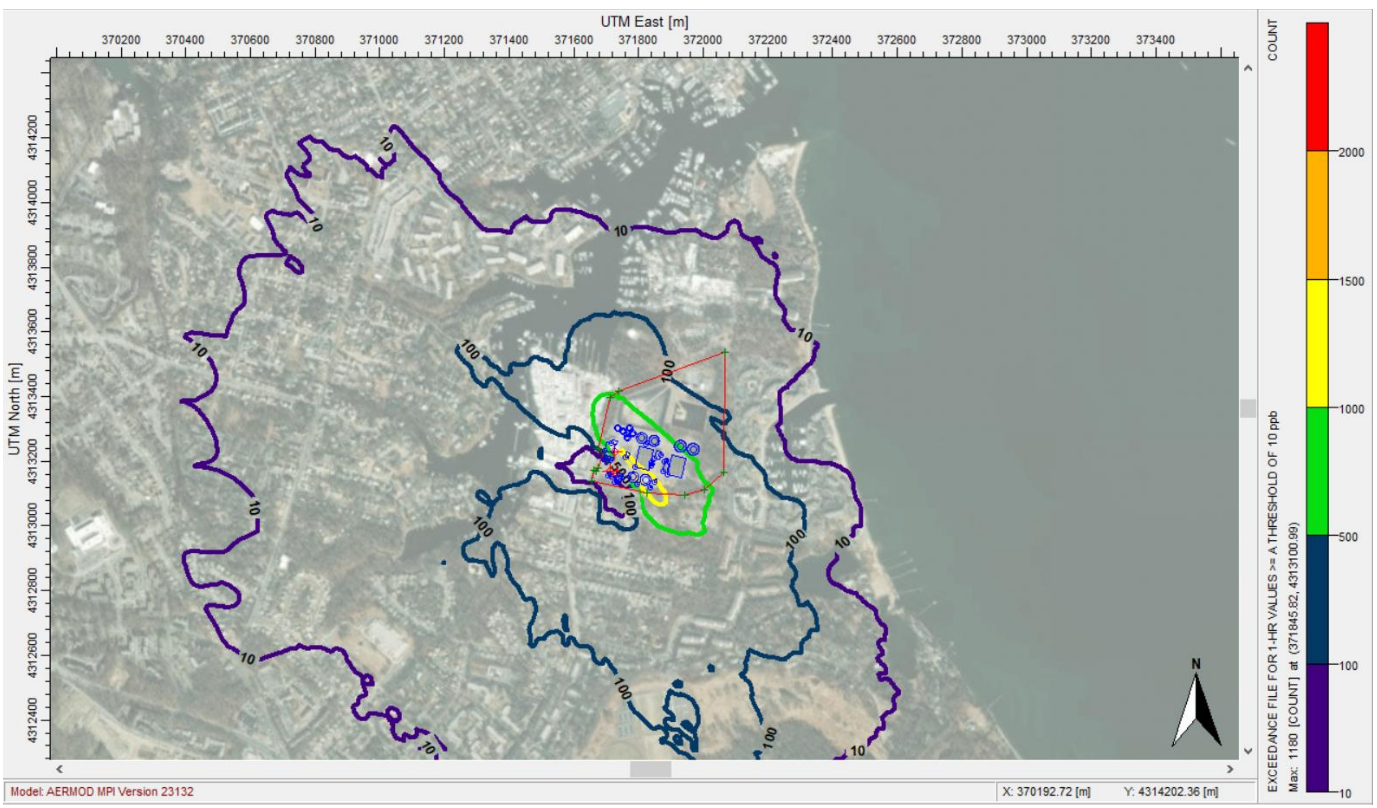

Figure 3-14: All Sources – Scenario 2 Hourly Exceedance Count

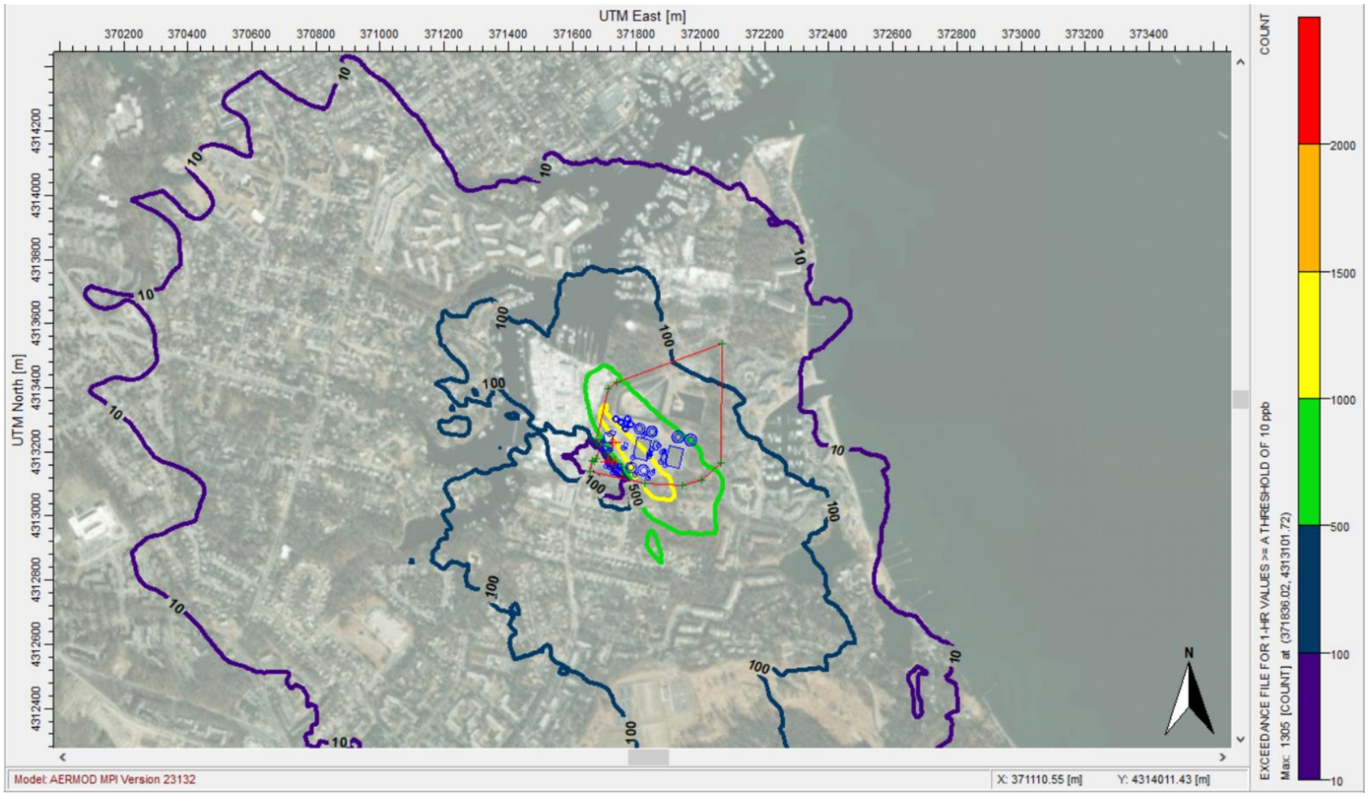

Figure 3-15: All Sources – Scenario 4 Hourly Exceedance Count

4 CONCLUSION

Two conclusions can be drawn from the modeling results:

- The headworks (screen and grit building) is likely a contributor to offsite odors
- Offsite odors can likely be significantly reduced with installation and operation of functional odor control systems at the headworks and influent pump station.

Evaluation of odor control technologies and systems for the individual sources will be documented in a separate TM.