

REPORT

Odor Control Study Yonkers Joint WWTP CONTRACT NUMBER 09-937

Department of
Environmental Facilities

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Appendix B Odor Sampling Plan
Appendix C Odor Sampling Map
Appendix D Odalog Data

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Executive Summary

Background

The Yonkers Joint WWTP has a permitted flow of 120 MGD on a 12-month rolling average basis. It has bar screens, aerated grit tanks, primary settling tanks, aeration tanks, final settling tanks, chlorine contact tanks, gravity thickeners, dissolved air floatation and gravity belt thickeners, primary and secondary digesters with centrifuge dewatering operations. The Plant has made several improvements over the years to address odors at the facility including the installation of scrubbers, modifying ventilation systems and covering the primary settling tanks and grit tanks. There are a total of 13 existing odor scrubber units and multiple small carbon canisters at the plant, as follows:

- Three for the primary settling tanks (two duty one stand-by);
- Three for primary thickener area (two duty one stand-by);
- Two, three stage scrubbers for H₂S and ammonia removal for dewatering (one duty one stand-by);
- Three for screen and grit area (including dewatering in the future);
- Two for CSO building; and
- Various locations with carbon canisters (six for the Secondary Digester overflow boxes and one for the secondary sludge transfer wet well).

These scrubber units were installed at varying times, with the oldest units (Primary Thickening Scrubbers) going into service in the mid 1990's.

Odors and their impact on residents located near the plant are an utmost concern to the Department. Although the Department has made excellent strides in addressing odors throughout the plant, there remain some areas of concern relative to the generation of odors. Additionally, with some of the odor control equipment having more than twenty years in service, ensuring this equipment is running optimally is critical to mitigating odors.

Study Approach

CDM Smith utilized a multi-phased approach to evaluate odor sources and the odor control systems at the facility and provide recommendations for improvements. The evaluation included:

- A plantwide odor sampling and analysis program;
- Development of modeling updates as an initial step in the evaluation of the odor control systems and identification of odor sources. Existing data from the plant including wind data and ventilation grab samples were incorporated into the model update, in addition to the odor sampling results;

- Smoke testing to evaluate the cover and duct systems on the Primary Settling and Grit Tanks and identify potential leaks that would result in other potential odor sources at the plant;
- Inspection of existing scrubbers and ducts to determine their condition;
- Development of standard operating procedures for taking tanks out of service;
- Evaluate air flow and ventilation in the sludge loading bay; and
- Development of near term (5 year) and long term (greater than 5 year) recommendations.

Findings

Sampling and Modeling

The results of the sampling and modeling found that the Primary Settling Tank Scrubbers A, B, & C and the Aeration Tanks were the most frequent sources of moderate strength odors at the plant. Specifically, these sources were predicted to impact the nearest receptors with a moderate odor level (40 to 50 odor units) approximately 100 times per year. It should be noted that the magnitude is based upon a 5-minute interval and the frequency is based upon an impact greater than 7 odor units/m³.

Smoke Testing

The results of the smoke testing found that much of the existing cover and ventilation systems are tight and in good working order. Some isolated locations were found to have some leakage including:

- Hatches
- Areas on the Grit Effluent Channel
- Areas on the Primary Influent Channel

Scrubber Inspection

The scrubber inspections found the units to generally be in good condition. Some deficiencies were identified, as follows:

- Primary Thickening Scrubbers 2, 3 & 4 – Exposed Fibers on the Exterior
- Primary Settling Scrubber B – Floor and lower two feet had Barcol Hardness measurements of below 20 (this is being scheduled to be repaired by the Plant)
- Primary Settling Scrubber C – Floor and lower one foot had Barcol Hardness measurements of below 17, discoloration and blistering Sludge Loading Bay Ventilation Testing (this has subsequently been repaired by the Plant)

Recommendations

The results of the study have found that the plant has an excellent odor control program including odor containment and treatment. Additionally, the Department is very proactive in monitoring odors, tracking complaints, and following up on those complaints. The sampling and modeling found that although the plant has extensive systems in place for odor control, there are some areas for further improvement. As such, CDM Smith recommends that a systematic phased approach be used to implement the various recommendations. Using a phased approach will allow the Department to implement certain improvements in the short term, then assess the effectiveness of those improvements through an updated round of sampling and modeling. If the resulting modeling finds that further improvements are required, then the long-term recommendations would be re-evaluated and implemented.

The near-term recommendations include:

- Recoat the exterior of Primary Thickener Scrubbers 2, 3, and 4 and replace the misting nozzles (page 2-12);
- Address existing cover leaks identified with smoke testing (page 3-3);
- Install registers on the sludge loading bay supply ducts (page 7-1);
- Install automated washdown stations and follow revised standard operating procedures for taking tanks out of service (page 5-3); and
- Retrofit the existing Primary Settling Tank Scrubbers A, B, and C with packed media (page 5-2);

Concerning the retrofit of the existing scrubbers, as noted below, it is recommended to replace Primary Settling Tank Scrubbers A, B, and C. Therefore, retrofitting the existing scrubbers is only recommended if the replacement of the existing scrubbers cannot be completed within the remaining ten-year life expectancy of the Primary Settling Tank Scrubbers A, B, and C.

The total probable construction cost to perform the near-term improvements is \$1,117,000. This includes the recoating of the Primary Thickener Scrubbers, washdown stations, and retrofitting all three Primary Settling Tank Scrubbers.

Once the near-term recommendations are completed and the model is updated, the following long-term items should be reevaluated;

- Replace the Primary Settling Tank Scrubbers A, B, and C (page 5-1); and
- Cover the Aeration Tanks and add odor control systems to treat ventilated air, (page 6-1).

The total probable construction cost to perform the long-term improvements is \$20,603,000.

Section 1

Sampling and Analysis

1.1 Introduction

To understand the performance of existing odor control equipment, as well as to establish an updated baseline odor model, CDM Smith performed an odor sampling program at the Yonkers Joint WWTP. Odors from wastewater treatment plants are created by a wide variety of chemical compounds or odorants, each odorant requires a specific analytical protocol to maximize the accuracy of the results. The sampling technique is based on the requirements for the analytical protocol. No detect (ND) indicates the sample concentration was below the minimum detection level (MDL) for the particular method. Grab samples include:

- Grab samples for Hydrogen Sulfide (H_2S) use hand held detectors that pull air into a device that has specific electrical or electrochemical components to measure H_2S . While this is a standard procedure for the measurement of H_2S , the measurement only depicts H_2S levels at a moment in time. The Jerome 631 handheld H_2S sensor has a detection limit of 3.0 parts per billion (ppb).
- Colorimetric tubes are used for grab samples for ammonia (NH_3). The hand pump draws a metered amount of air through a glass tube with media that is specific for NH_3 and the concentration range anticipated. As the air passes through the media the target contaminant reacts with the media in the tube and it changes color along the length of the calibrated glass. The concentration is read at the color interface. The detection limits for various analytes vary, for NH_3 the detection limit was 1.0 ppm
- Bag samples are collected when a laboratory analysis is required. A sample of the emission from the source is drawn into a laboratory prepared inert bag, and it is shipped to a laboratory for the specific analysis. Like the grab samples for H_2S , a bag sample depicts conditions only for the short time the sample is taken. Bag samples are collected for Organic Reduced Sulfur Compounds (ORSCs), Volatile Organic Compounds (VOCs) and Odor.
 - Organic Reduced Sulfur Compounds (ORSCs) are measured with a gas chromatographic separation method and a flame photometric detector (FPD) and mass spectrometer as a detector (GC/FPD/MS). ORSCs include methyl mercaptan, ethyl mercaptan, dimethyl sulfide, dimethyl disulfide to name a few since there are many reduced sulfur compounds that appear in wastewater odors. The analysis will also measure H_2S . All reduced sulfur compounds are odorous. Analytical method detection limits (MDL) for ORSCs is 3 ppb with the exception of methyl trisulfide, which the laboratory seeks out at lower levels because its odor threshold is 10 parts per trillion (ppt). **Table 1.1.1** shows the Organic Reduced Sulfur Compounds that were included in the analysis and some of the known detection thresholds.

Table 1.1.1 Organic Reduced Sulfur Compounds

Organic Reduced Sulfur Compounds and Odor Detection Levels			
Compound	Odor Detection Level (ppb)	Compound	Odor Detection Level (ppb)
COS	55	2-M-1-(Methylthio) Propane	
Methanethiol (MM)	0.01	Diisopropyl Disulfide	
Ethanethiol	0.01	2-(Methylthio) Butane	
Dimethyl Sulfide	1	Methyl Ethyl Disulfide	
Carbon Disulfide	10	Methyl Thiophene	
2-Propanethiol		Dimethyl Thiophene	
2-Methyl-2-Propanethiol		3-Ethyl Thiophene	
Thiophene		Methyl Propyl Disulfide	
Allyl Methyl Sulfide	0.1	Diethyl Disulfide	2
Diethyl Sulfide	0.03	2,2-Bis(ethylthio) Propane	
Methylthioacetate		Dimethyl Trisulfide	0.01
1-(Methyl Thio) Propane		Methyl Isopropyl Disulfide	
2-(Ethylthio) Propane		Methyl 2-Propenyl Disulfide	
Dimethyl Disulfide	2.2	M-1-M-1-(Mthio)E-Disulfide	

- VOCs are measured with a gas chromatographic separation method and a mass spectrometer as a detector. VOCs include a wide variety of chemical compounds including alcohols, benzene and other aromatic compounds, chlorinated compounds, nitrogen compounds (amines), and terpenes to name a few. **Table 1.1.2** shows the individual organic compounds that are included under each category. The analytical method detection limits (MDL) for VOCs in this analysis are 1.0 ppb. The odor thresholds for VOCs are included in “*Reference Guide To Odor Thresholds For Hazardous Air Pollutants Listed In The Clean Air Act Amendments Of 1990*” **Appendix A**.

Table 1.1.2 Volatile Organic Compounds

Volatile Organic Compounds (VOCs)			
Aromatics	Halogen Compounds	Oxygen & Nitrogen Compounds	Fatty Acids
Benzene	Chloroform	Ethanol	Acetic Acid
Toluene	Perchloroethylene	Acetone	Propanoic Acid
Ethyl Benzene	2-Propanone, 1,1,1-trichloro	Isopropyl Alcohol	N-Butyric Acid (Butanoic Acid)
O,P-Xylene	1,4-Dichlorobenzene	n-Propanol	Propyl 2-Methyl Butanoate
M-Xylene	Hydrocarbons	Methyl Butanone	Valeric Acid (Pentanoic Acid)
Styrene	Pentane	Methyl Ethyl Ketone	Hexanoic Acid
1-Ethyl 4-Methyl Benzene	Acetic Anhydride	Ethyl Acetate	Heptanoic Acid
1,3,5-Trimethyl benzene	Methyl Pentane	2-Methyl-1-Propanol	Octanoic Acid
1,2,3-Trimethyl benzene	Dimethyl Butane	1-Butanol	Nananoic Acid
1-Methyl-2-(1-MethylEthyl) Benzene	3,5,5-Trimethyl Cyclohexene	N-Propyl Acetate	Decanoic Acid
Decahydro-2-Methyl-Naphthalene	Trimethyl Octane	Pentyl Furan	N-Hexadecanoic Acid
Decahydro-1-Methyl-Naphthalene	N-Decane	Benzyl Alcohol	Dodecanoic Acid
Decahydro-2,3-Naphthalene	2,6-Dimethyloctane	Dextro-Camphor	Tetradecanoic Acid
Trans-Decahydro Naphthalene	2,6,10-TrimethylDodecane	1-Octadecyne	Pentadecanoic Acid
Naphthalene	2,7,10-TrimethylDodecane	Aldehydes	Terpenes & Fragrance Compounds
	Ethyl-methyl-octane	2-Methyl Butanal (2-M-Butraldehyde)	α-Pinene
	DimethylOctane	Hexanal (5-ppb)	Camphene
	2,4-Dimethyl-1-Decane	Furfural	β--Pinene
	Dodecane	Benzaldehyde	3-Carene
	Pentadecane	Octanal	β-Ocimene
		Nonanal	Limonene
		Decanal	Gamma-Terpiene

- Odor is measured through a laboratory analysis called olfactometry, the method is described in two standards: EN13725 and ASTM 691. The protocol requires that a set of human panelists sample the odor taken from the source through a series of decreasing dilutions. The dilution level where the panelists determine the sample to be perceptible is considered the strength of the odor, expressed as “dilutions to threshold” or D/T, also expressed as “odor units” (OUs). D/T is the detection threshold where the odor is detected, RT is the recognition threshold where the odor can be described and HD is the hedonic tone, a relative measure of offensiveness on a scale from -10 to +10 with -10 being the most offensive and zero being neutral. Odor samples are used for odor dispersion modeling.
- Logged samples are restricted to H₂S measurements. Rugged detectors are utilized to continually sample a harsh odor source, i.e. wet well or scrubber inlet or exhaust and log the results for up to ten days. Unlike bag samples this technique indicates trends in the strength of H₂S over a period and as such can act as a surrogate for trends in the overall odor from the source.

Sampling for chemical odorants and odors and the associated analytical protocols are shown in **Table 1.1.3** below.

Table 1.1.3 Sampling and Analysis Protocols

Odorant	Sample Protocol	Analytical Protocol
H ₂ S	Jerome 631	Grab Sample (1 min./sample)
H ₂ S	Odialog	Logged Data (1 sample/min.)
ORSCs	Grab Bag Sample	GC/MS/FPD
VOCs	Grab Bag Sample	GC/MS
Odor	Grab Bag Sample	Olefactometry (EN 13725)

Sampling the liquid stream can help provide support for the air data. Grab samples were taken with instruments and for liquid chemistry for:

- Oxidation Reduction Potential (ORP), which provides a relative measure of the septicity of the liquid. 0.0 millivolts is a neutral state, as the liquid becomes more septic the ORP becomes more negative as the ORP becomes more positive it has a more oxidative potential. Septic conditions indicate a stronger tendency to develop odors; ORP levels less than -50 mv indicate a strong odor potential.
- pH provides a measure of acidity in the liquid. pH 7 is neutral while a pH less than 7 is acidic and a pH greater than 7 is basic. At pH 7 total sulfide is equally distributed between the dissolved state and the vapor state. As the pH decreases the sulfide distribution shifts toward the vapor phase, similarly as the pH increases the distribution shifts toward the liquid phase. The shift is exponential such that at pH 5 virtually all the sulfide is in the volatile H₂S form.
- Dissolved Oxygen (DO) is a measure of the level of oxygen dissolved in the liquid, a DO of <0.5 mg/l indicates septic conditions and the potential to form odors.

- Dissolved sulfide (dS-) is a measurement of the amount of sulfide that is dissolved in the liquid solution. Since H₂S (in the gas phase) has a direct relationship to dissolved sulfide this measurement can provide an indication of odor and corrosion potential. Dissolved sulfide levels greater than 0.5 mg/l is considered an odor problem, however in some locations levels even less than that can pose a problem.

1.2 Yonkers Joint WWTP Sampling Program

Sampling was performed at the Yonkers Joint WWTP from September 5 – 7, 2017 and again from September 12 – 13, 2017 according to the plan included in **Appendix B** and the associated sampling map as **Appendix C**. Data for active exhaust points from scrubbers and fans are presented in the section below followed by open tanks and fugitive emissions sources.

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Section 2

Scrubber Sampling

As discussed in the previous section, sampling occurred at the Yonkers WWTP Plant according to the plan included in Appendix B and the associated sampling map as Appendix C from September 5 – 7, 2017 and again from September 12 – 13, 2017.

2.1 Zone 1, Chemical Scrubbers 2, 3, and 4

These scrubbers are hypochlorite mist scrubbers that treat exhaust from primary thickener building, sludge storage tanks, and the overflow boxes.

2.1.1 Odalog Data

Scrubbers 2, 3, and 4 were sampled at the inlet and outlet with an Odalog H₂S logging system for seven days; Scrubber 2 was off at the time. While Scrubber 2 was off, air was still passing through untreated, as such samples were collected. The Odalog system pulls a sample concurrently from the inlet and outlet of the scrubber measuring H₂S every minute on two separate detectors. The raw Odalog data for Scrubbers 2, 3, and 4 is shown in **Appendix D** as **Figure D-1** and **Figure D-2** for the inlet and outlet of Scrubber 3, respectively, **Figure D-3** and **Figure D-4** for Scrubber 4 inlet and outlet respectively. **Table 2.1.1.1** shows a summary of the data from the Odalogs and grab samples for both H₂S and NH₃.

Table 2.1.1.1 Scrubber 2, 3, and 4 Odalog, Grab Sample H₂S and NH₃ Data

Scrubber	Location	H ₂ S (ppb)		NH ₃	
		Odalogs		Grab	
		Average	Maximum		
2 (OFF)	Inlet	800	2000	ND	ND
	Outlet	ND	ND	ND	ND
3	Inlet	200	2700	6	ND
	Outlet	100	1700	ND	ND
4	Inlet	100	600	ND	ND
	Outlet	ND	200	ND	ND
2,3,4	Outlet	Not sampled		ND	ND

2.1.2 ORSC Data

The scrubbers were sampled at the inlet and outlet for ORSCs, shown in **Table 2.1.2.1** below; the common inlet was used to sample the inlet for the three scrubbers.

Table 2.1.2.1 Scrubbers 2, 3, and 4 Organic Reduced Sulfur Compound Data

Scrubber	Location	Organic Reduced Sulfur Compounds (ORSCs) (ppb)						
		Total	Carbonyl Sulfide	Methyl Mercaptan	Dimethyl Sulfide	Dimethyl Disulfide	Carbon Disulfide	Dimethyl Trisulfide
2 (OFF)	Inlet	22	11	ND	ND	ND	11	0.3
	Outlet	15	7.5	ND	ND	ND	7.5	0.1
3	Inlet	22	11	ND	ND	ND	11	0.3
	Outlet	15	7.4	ND	ND	ND	7.4	0.3
4	Inlet	22	11	ND	ND	ND	11	0.3
	Outlet	28	9.1	ND	6.7	ND	12	0.2
2,3,4	Outlet	31	5	ND	ND	16	7.7	1.7

2.1.3 VOC Data

Scrubbers 2, 3, and 4 and were sampled at the inlet and outlet for VOCs shown in **Table 2.1.3.1**; the common inlet was used to sample the inlet for the three scrubbers.

Table 2.1.3.1 Scrubbers 2, 3, and 4 Volatile Organic Compound Data

Scrubber	Location	Volatile Organic Compounds (ppb)							
		Total	Aromatics	Halogen	Hydrocarbons	Oxygen and Nitrogen	Aldehydes	Fatty Acids	Terpenes and Fragrance
2 (OFF)	Inlet	1715	97	12	16	664	684	234	7
	Outlet	647	100	12	22	123	9	233	18
3	Inlet	1715	97	12	16	664	17	234	7
	Outlet	712	85	9	38	132	9	290	10
4	Inlet	1715	97	12	16	664	684	234	7
	Outlet	801	84	9	33	76	8	501	8
2,3,4	Outlet	793	130	10	33	126	9	335	19

Odor data was collected at the inlet and outlet of Scrubbers 2, 3, and 4. Data is shown in **Table 2.1.3.2**; the common inlet was used to sample the inlet for the three scrubbers.

Table 2.1.3.2 Scrubbers 2, 3, and 4 Odor Data

Scrubber	Location	Odor (D/T)		Hedonic Tone
		Detection Threshold (D/T)	Recognition Threshold (D/T)	
2 (OFF)	Inlet	2200	1400	0.6
	Outlet	1800	1000	0.9
3	Inlet	2200	1400	0.6
	Outlet	4100	2300	-3.8
4	Inlet	2200	1400	0.6
	Outlet	780	520	-27
2,3,4 (Common Stack)	Outlet	2,000	1,400	-2.9

2.1.4 Scrubber 2, 3, and 4 Data Summary

The inspection of the facilities for these scrubbers indicated that they were carefully operated. The loading to these scrubbers is low in all categories, however overall performance is also low with odor showing a tendency to rise across the scrubber. Mist scrubbers are heavily dependent on proper mixing and the residence time within the tank. Therefore, the efficiency of the misting nozzle located at the top of the vessel, as well as the airflow through the vessels are paramount design considerations. The nozzle assembly should be evaluated every ten years and will probably require replacement by 15 years. The measured air flow exceeded the design rate as indicated in **Table 2.1.4.1** decreasing the residence time in the vessel from 10.7 seconds at the design rate to 7.1 seconds.

Table 2.1.4.1 Scrubbers 2, 3, and 4 Airflow Data

Scrubbers 2, 3, and 4 Airflow Data				
Location	Velocity (ft/min)	Duct Diameter (in)	Measured Flow (cfm)	Design Flow (cfm)
Scrubber 2	OFF	48	NA	19,000
Scrubber 3	2250	48	28,200	19,000
Scrubber 4	2275	54	28,500	19,000

Realistically less than 1000 OUs should be expected in the exhaust of a chemical scrubber and optimally about 500 OUs. Scrubber 3 indicates an increase in odor, which is not reflected in the analytical data. The H₂S trends for all scrubbers showed levels of less than 3 ppm and removal rates for scrubbers 3 and 4 at 37% and 67% respectively. Organic reduced sulfur compounds and volatile organic compounds were measured in the low ppb range with varied removal rates. The decreased residence time in itself would be sufficient to affect the poor H₂S and odor level in the exhaust, poor “misting” from the nozzle would exacerbate the problem. Excessive airflow creating the low residence time along with the condition of the mist nozzles should be evaluated.

The flow to scrubbers 3 and 4 added up to over 57,000 cfm, however the total flow from the primary building plus the sludge storage tanks and the contribution from the 54-in duct from the north added up to approximately 40,000, creating a discrepancy of 30%. The total airflow from the main 54-in diameter exhaust stack was measured at just over 60,000 cfm, the totals from Scrubber 3 and 4 plus the Severn Trent Scrubber 2 (described in the next section) added up to over 69,000 making a 15% discrepancy in the measurements. Some additional work is advised in investigating and balancing the flow to Scrubbers 2, 3, and 4.

2.2 Zone 1, Severn Trent Chemical Scrubbers 1 and 2

These scrubbers are three stage scrubbers. Stage one utilizes sulfuric acid (H₂SO₄) to remove NH₃, second stage uses sodium hydroxide (NaOH) to target H₂S, and the third stage uses hypochlorite (NaOCl) and bleach NaOH as a polishing stage. These scrubbers treat air from the truck loading bay adjacent to the dewatering building, centrate, and the cake pump room. The scrubbers are duty/stand-by and therefore only one scrubber was operating during sampling, Scrubber Train No.2 (ST2)

Odalog Data

The raw data is included in **Appendix D** as **Figure D-5** and **Figure D-6** for the inlet and outlet of Scrubber 2, respectively. H₂S and NH₃ grab samples data, as well as a summary of the logged (Odalogs) data for these scrubbers is shown in **Table 2.2.1**.

Table 2.2.1 Severn Trent Scrubber 1 and 2, Odalog and H₂S and NH₃ Grab Sample Data

Scrubber	Location	H ₂ S (ppb)		NH ₃ (ppb)	
		Odalogs		Grab	
		Average	Maximum		
Scrubber 1 (OFF)	Inlet	Not Sampled			
	Outlet	Not Sampled			
Scrubber 2	Inlet	200	8500	1	8000
	Outlet	ND	800	3	ND

2.2.1 ORSC Data

The Inlet and outlet of Scrubber 2 was sampled at the inlet and outlet for ORSCs, shown in **Table 2.2.1.1** below.

Table 2.2.1.1 Severn Trent Scrubber 1 and 2 Organic Reduced Sulfur Compound Data

Scrubber	Location	Organic Reduced Sulfur Compounds (ORSCs) (ppb)						
		Total	Carbonyl Sulfide	Methyl Mercaptan	Dimethyl Sulfide	Dimethyl Disulfide	Carbon Disulfide	Dimethyl Trisulfide
Scrubber 1 (OFF)	Inlet	Not Sampled						
	Outlet	Not Sampled						
Scrubber 2	Inlet	255	10	ND	215	ND	12	5.5
	Outlet	24	8.7	ND	ND	ND	15	0.2

2.2.2 VOC Data

Scrubber 2 was sampled at the inlet and outlet for VOCs shown in **Table 2.2.2.1**.

Table 2.2.2.1 Severn Trent Scrubber 1 and 2 Volatile Organic Compound Data

Scrubber	Location	Volatile Organic Compounds (VOCs) (ppb)							
		Total	Aromatics	Halogen	Hydrocarbons	Oxygen and Nitrogen	Aldehydes	Fatty Acids	Terpenes and Fragrance
Scrubber 1 (OFF)	Inlet	Not Sampled							
	Outlet	Not Sampled							
Scrubber 2	Inlet	776	100	8	16	118	8	319	74
	Outlet	743	117	2	7	423	15	172	13

2.2.3 Odor Data

Odor data was collected at the inlet and outlet of Scrubber 2; data is shown in **Table 2.2.3.1**.

Table 2.2.3.1 Severn Trent Scrubbers 1 and 2 Odor Data

Scrubber	Location	Odor (D/T)		Hedonic Tone
		Detection Threshold (D/T)	Recognition Threshold (D/T)	
Scrubber 1 (OFF)	Inlet	Not sampled		
	Outlet	Nor Sampled		
Scrubber 2	Inlet	15,000	7,900	-5
	Outlet	2,000	1,400	-2.9

2.2.4 Severn Trent Scrubbers 1 and 2 Summary

Like scrubbers 2, 3, and 4, analytically the loading was low, however dimethyl sulfide and trimethyl sulfide stand out. Dimethyl sulfide has a detection level of 1 ppb and dimethyl trisulfide has a detection limit at 0.01 ppb contributing to the high inlet odor level at 15,000 OUs. Maximum H₂S levels were sharp spikes that to be removed by over 90% the lower sustained levels some breakthrough not expected from a three stage scrubber Overall odor removal is 98.7% due to the more aggressive packed bed dual chemistry design as compared to mist scrubbers.

Although the scrubber appeared to be well operated, with proper chemistry and a measured air flow in reasonable proximity to the design flow as indicated in **Table 2.2.4.1**, these scrubbers should be able to achieve less than 500 OUs at the exhaust on a regular basis. Notwithstanding the best attention to chemistry and recirculation rates. There may be inefficiencies in the packing or the liquid distribution system, and the performance may be optimized with a thorough cleaning and perhaps media and/or nozzle replacement.

Table 2.2.4.1 Severn Trent Scrubbers Airflow Data

Severn Trent Scrubbers Airflow Data				
Location	Velocity (ft/min)	Duct Diameter (in)	Measured Flow (cfm)	Design Flow (cfm)
Scrubber 1 (OFF)	Not Sampled			
Scrubber 2	1800	36	12,800	15,000

2.3 Zone 2, Siemens LoPro Chemical Scrubbers 1, 2, and 3

These scrubbers are similar low profile multi stage design as the Severn Trent scrubbers, however these are dual stage scrubbers with stage one as sodium hydroxide (NaOH) that focuses on H₂S removal and sodium hypochlorite (NaOCl) and NaOH in the second polishing stage; the LoPro scrubbers treat air from the Screen and Grit Building. The three scrubbers are completely installed, however the installation of all the peripheral ductwork was still underway, therefore only Scrubber 3 was operating.

Odalog Data

The raw data is included in **Appendix D** as **Figure D-7** for the inlet of Scrubber 3. Odalog data, and grab samples for H₂S and NH₃ are summarized for LoPro Units 1, 2, and 3 in **Table 2.3.1**.

Table 2.3.1 LoPro Scrubber 3 Odalog Data Summary, H₂S and NH₃ Grab Samples

Scrubber	Location	H ₂ S (ppb)			NH ₃
		Odaglog		Grab	
LoPro 1 (OFF)	Inlet	Not Sampled			
	Outlet	Not Sampled			
LoPro 2 (OFF)	Inlet	Not Sampled			
	Outlet	Not Sampled			
LoPro 3	Inlet	ND	ND	6	ND
	Outlet	ND	ND	ND	ND

2.3.1 ORSC Data

Scrubber 3 was sampled at the inlet and outlet for ORSCs, shown in **Table 2.3.1.1** below. Scrubbers 1 and 2 were not running.

Table 2.3.1.1 Siemens LoPro 1, 2, and 3 Organic Reduced Sulfur Compound Data

Scrubber	Location	Organic Reduced Sulfur Compounds (ORSCs) (ppb)						
		Total	Carbonyl Sulfide	Methyl Mercaptan	Dimethyl Sulfide	Dimethyl Disulfide	Carbon Disulfide	Dimethyl Trisulfide
LoPro 1 (OFF)	Inlet	Not Sampled						
	Outlet	Not Sampled						
LoPro 2 (OFF)	Inlet	Not Sampled						
	Outlet	Not Sampled						
LoPro 3	Inlet	31	10	ND	ND	ND	20	0.3
	Outlet	12	5	ND	ND	ND	7	0.2

2.3.2 VOC Data

Scrubber 3 was sampled at the inlet and outlet for VOCs shown in **Table 2.3.2.1**.

Table 2.3.2.1 Siemens LoPro 1, 2, and 3 VOC Data

Scrubber	Location	VOCs (ppb)							
		Total	Aromatics	Halogen	Hydrocarbons	Oxygen and Nitrogen	Aldehydes	Fatty Acids	Terpenes and Fragrance
LoPro 1 (OFF)	Inlet	Not Sampled							
	Outlet	Not Sampled							
LoPro 2 (OFF)	Inlet	Not Sampled							
	Outlet	Not Sampled							
LoPro 3	Inlet	1,032	96	4	41	180	15	443	74
	Outlet	979	89	5	29	569	10	257	16

2.3.3 Odor Data

Odor data was collected at the inlet and outlet of Scrubber 3; Data is shown in **Table 2.3.3.1**.

Table 2.3.3.1 Siemens LoPro 1, 2, and 3 Odor Data

Scrubber	Location	Odor (D/T)		
		Detection Threshold (D/T)	Recognition Threshold (D/T)	Hedonic Tone
LoPro 1 (OFF)	Inlet	Not Sampled		
	Outlet	Not Sampled		
LoPro 2 (OFF)	Inlet	Not Sampled		
	Outlet	Not Sampled		
LoPro 3	Inlet	420	190	-3.6
	Outlet	140	100	-1.9

2.3.4 LoPro Scrubbers 1, 2, and 3 Data Summary

Scrubber 3 was the only scrubber in operation and is lightly loaded since all building areas are not yet connected. The remaining systems are being connected under the Phase III HVAC/Odor Control Project. All the inlet parameters were low as represented by the odor data. The data indicates a decrease in all parameters (ORSCs, VOCs, and odor) across the scrubber with odor less than 200 OUs in the exhaust. The data at these levels is inconsequential because the levels are so low and currently there is no reason to believe that they are malfunctioning. Testing should be performed when the installation is complete. The exhaust from this source is picked up by a dispersion fan and exhausted to the atmosphere. **Table 2.3.4.1** shows the airflow data for the LoPro scrubbers.

Table 2.3.4.1 LoPro 1, 2, and 3 Airflow Data

LoPro Airflow Data				
Location	Velocity (ft/min)	Duct Diameter (in)	Measured Flow (cfm)	Design Flow (cfm)
LoPro 1 (OFF)	Not Sampled			15,525
LoPro 2 (OFF)	Not Sampled			15,525
LoPro 3 ¹	625	54	10,000	15,525

1. Measured at the dispersion fan inlet duct

2.4 Zone 2 Dispersion Fan

The dispersion fan is located on the roof of the Dewatering Building and collects air from the Siemens chemical scrubbers 1, 2, and 3, the fan dilutes and disperses the exhaust vertically at high velocity. The effect is a “effective stack height” that mimics the effect of an actual exhaust stack. Only odor samples were collected from this source, data is shown in **Table 2.4.1**.

Table 2.4.1 Dispersion Fan Odor Concentrations

Scrubber	Location	Odor (D/T)		Hedonic Tone
		Detection Threshold (D/T)	Recognition Threshold (D/T)	
Dispersion Fan	Inlet ¹	140	100	-1.9
	Outlet	260	180	-2

1. Inlet value taken from LoPro 3 exhaust

2.4.1 Summary Dispersion Fan

The dispersion fan exhaust odor levels should realistically show a decrease from the chemical LoPro scrubber 3 exhaust levels. Odor measurement (olfactometry) is a subjective analysis using the human sensory system with a statistical analysis of the results rather than being completely analytical. As such it is not unusual to see unexpected odor numbers at such low levels with mixed gases. Performance testing once Phase III is complete will provide more significant data.

2.5 Zone 4, Scrubbers A, B, and C

Scrubbers A, B, and C ventilate and treat emissions from the primary settling tanks. These scrubbers operate as hypochlorite mist scrubbers like Scrubbers 2, 3, and 4. Only scrubbers A and B were functioning during the sampling.

2.5.1 Odalog Data

The raw logged H₂S data is included in **Appendix D** as **Figure D-8** is the inlet data for all three scrubbers, **Figure D-9** is the outlet data for Scrubber A, **Figure D-10** the outlet data for Scrubber B and **Figure D-11**, the outlet data for Scrubber C. **Table 2.5.1.1** shows summarized Odalog data as well as both H₂S and NH₃ grab sample data.

Table 2.5.1.1 Scrubber A, B, and C Odalog Summary, H₂S and NH₃ Grab Samples

Scrubber	Location	H ₂ S (ppm)		NH ₃	
		Oialog		Grab	
		Average	Maximum		
A	Inlet ¹	0.6	10.8	ND	ND
	Outlet	ND	3.1	ND	ND
B	Inlet ¹	0.6	10.8	ND	ND
	Outlet	ND	12.1	ND	ND
C OFF	Inlet ¹	0.6	10.8	ND	ND
	Outlet	ND	ND	ND	ND

1. Inlet data from a common inlet

2.5.2 ORSC Data

Scrubber A and B were sampled at the inlet and outlet for ORSC, Scrubber C was off. Data is shown in **Table 2.5.2.1** below.

Table 2.5.2.1 Scrubbers A, B, and C Organic Reduced Sulfur Compound Data

Scrubber	Location	Organic Reduced Sulfur Compounds (ORSCs) (ppb)						
		Total	Carbonyl Sulfide	Methyl Mercaptan	Dimethyl Sulfide	Dimethyl Disulfide	Carbon Disulfide	Dimethyl Trisulfide
Scrubber A	Inlet ¹	27	ND	ND	ND	ND	18	0.2
	Outlet	26	12	ND	ND	ND	14	0.3
Scrubber B	Inlet ¹	27	ND	ND	ND	ND	18	0.2
	Outlet	29	ND	ND	ND	ND	20	0.2
Scrubber C (OFF)	Inlet	Not Sampled						
	Outlet	Not Sampled						

1. Inlet data from common inlet

2.5.3 VOC Data

Scrubber A and B were sampled at the inlet and outlet for VOCs, Scrubber C was off. Data is shown in **Table 2.5.3.1**.

Table 2.5.3.1 Scrubbers A, B, and C Volatile Organic Compound Data

Scrubber	Location	Volatile Organic Compounds (VOCs) (ppb)							
		Total	Aromatics	Halogen	Hydrocarbons	Oxygen and Nitrogen	Aldehydes	Fatty Acids	Terpenes and Fragrance
Scrubber A	Inlet ¹	5,795	140	3,177	40	998	16	412	12
	Outlet	1,255	106	39	29	397	15	256	11
Scrubber B	Inlet ¹	5795	140	3,177	40	998	16	412	12
	Outlet	10,368	113	75,90	10	1,190	13	251	8
Scrubber C OFF	Inlet	Not Sampled							
	Outlet	Not sampled							

1. Inlet Data from a common inlet

2.5.4 Odor Data

Odor data was collected at the inlet and outlet of Scrubbers A, and B, Scrubber C was off; data is shown in **Table 2.5.4.1**.

Table 2.5.4.1 Scrubbers A, B, and C Odor Data

Scrubber	Location	Odor (D/T)		Hedonic Tone
		Detection Threshold (D/T)	Recognition Threshold (D/T)	
Scrubber A	Inlet ¹	3,300	1,900	-1.4
	Outlet	1,900	1,300	0.1
Scrubber B	Inlet ¹	3,300	1,900	-1.4
	Outlet	11,000	6,000	-0.3
Scrubber C (OFF)	Inlet	Not Sampled		
	Outlet	Not Sampled		

1. Inlet data from a common inlet

2.5.5 Summary Scrubbers A, B, and C

Loading to these units included H₂S levels with a maximum on a single day at over 10 ppm then diminishing amounts, H₂S levels increased across Scrubber B. The VOC levels stand out, in particular the high levels of halogenated compounds such as perchloroethylene and chloroform at the inlet and the unusual high levels of both perchloroethylene and chloroform in the Scrubber B, **Table 2.5.5.1**. The airflow information as well as design flows can be seen in **Table 2.5.5.2**.

Table 2.5.5.1 Scrubber B Data

Scrubber B			Odor Threshold (ppb)
Analyte	Inlet	Outlet	
Chloroform	98	2,764	600 – 1,400,000
Perchloroethylene	3,076	4,825	2,000 – 71,000

Table 2.5.5.1 Scrubbers A, B, and C Airflow

Scrubbers A, B, and C Airflow Data				
Location	Velocity (ft/min)	Duct Diameter (in)	Measured Flow (cfm)	Design Flow (cfm)
Scrubber A	575	36	4062	11,500
Scrubber B	1075	36	7595	11,500
Scrubber C (OFF)	Not Sampled			11,500

The difference in performance and the difference in the exhaust levels of all parameters between Scrubber A and Scrubber B is outstanding. The difference in the airflow to Scrubber B is almost twice the flow of Scrubber A.

Mist scrubbers are heavily dependent proper mixing and the residence time within the tank. Therefore, the efficiency of the misting nozzle located at the top of the vessel as well as the airflow through the vessels are paramount design considerations. The nozzle assembly should be evaluated every ten years and will probably require replacement by 15 years. Further the airflow from the primary tanks through to the scrubbers should be balanced to provide the correct residence time. Scrubber renovation with the correct residence time will not cure the problem of

the high levels of chlorinated solvents present in both the inlet and exhaust as these scrubbers are not capable of removing such solvents.

Notwithstanding, regular liquid measurements monitoring for VOCs is recommended at the influent diversion chambers to determine if there is the potential for an industrial discharge or vapor intrusion in to the sewer. Chloroform and Perchloroethylene are only slightly soluble in water and are very volatile and would not necessarily be found in routine liquid samples.

2.6 Existing Scrubber Inspections

Inspections of all the existing scrubbers onsite was conducted by Detect Tank Services. The inspection consisted of investigating the condition of the exterior, interior, anchors, supports, ladders, accessways and connected piping via visual observations and Barcol Hardness Testing. A report for each scrubber is provided with recommendations for rehabilitation if necessary. A summary of the inspection results is provided below in **Table 2.6.1**. The full reports for each tank is provided in **Appendix E**.

Table 2.6.1 Scrubber Inspection Summary Table

Scrubber	Findings	Recommendation
CSO Scrubber 1	No Deficiencies	None
CSO Scrubber 2	No Deficiencies	None
Screen & Grit Scrubber 1	No Deficiencies	None
Screen & Grit Scrubber 2	No Deficiencies	None
Screen & Grit Scrubber 3	No Deficiencies	None
Severn Trent Scrubber 1	No Deficiencies	None
Severn Trent Scrubber 2	No Deficiencies	None
Primary Thickener Scrubber 2	Exposed Fibers on Exterior	Recoat Exterior
Primary Thickener Scrubber 3	Exposed Fibers on Exterior	Recoat Exterior
Primary Thickener Scrubber 4	Exposed Fibers on Exterior	Recoat Exterior
Primary Settling Scrubber A	No Deficiencies	None
Primary Settling Scrubber B	Floor and lower two feet had Barcol Hardness measurements of below 20	Floor and lower two feet recommended to be repaired – Repairs scheduled for Spring 2019 due to weather constraints
Primary Settling Scrubber C	Floor and lower one foot had Barcol Hardness measurements of below 17, discoloration and blistering	Floor and lower one foot recommended to be repaired – Completed

Table 2.6.2 Opinion of Probable Construction Cost for Primary Thickener Scrubber Recoat

Description	Opinion of Probable Construction
Fiberglass Recoat of Three 12'X30' Scrubbers	\$150,000
Contractor Overhead and Profit (15%)	\$22,500
Subtotal Material and Labor	\$172,500
Contingency (25%)	\$43,125
Soft Costs – Engineering, Construction Admin. (20%)	\$34,500
Total	\$250,125

Section 3

Fugitive Emission Sources

Other emission sources are fugitive emissions from tanks and open channels. H₂S was logged at the South Influent Structure and the North Influent Structure, although the device at the North Influent Structure malfunctioned and there is no data from that location. The data logged for the South Influent Structure is shown in **Table 3.1**, the raw data is included in **Appendix D, Figure D-12**. Liquid data for both the North and South Influent Structures in **Table 3.2** and the inlet and effluent of the primary tanks in **Table 3.3**.

Table 3.1 South Influent Structure Odialog Summary

Location	H ₂ S (ppb) Odialog	
	Average	Maximum
South Influent Structure	ND	2,000

Table 3.2 Liquid Data for the North and South Influent Structures

Location	Temperature (degC)	pH	Dissolved Oxygen (mg/L)	Dissolved Sulfide (mg/L)	Oxidation Reduction Potential (mv)
Southern Control Structure	21.9	7.3	1.3	0.1	-34.7
Northern Control Structure	21.8	7.3	0.11	0.4	-219

Table 3.3 Liquid Data from the Primary Tanks

Location	Temperature (degC)	pH	DO (mg/L)	DS ⁻ (mg/L)	ORP (mv)
Primary Influent Channel	21.9	7.2	1.7	0.1	-7.8
Primary Effluent Channel	21.9	7.3	1.3	ND	3.5

3.1 North and South Influent Structures Summary

Neither the H₂S data nor the liquid data reflect the potential for high hydrogen sulfide levels from the South Influent Structure, however the sulfide levels at the Northern Control Structure indicate a much higher potential for sulfide development. Septicity decreases across the primary tanks, which is unusual since the primary tanks require extended residence time to settle primary sludge. Often septicity increases dramatically depending on the level of sludge maintained in the tanks.

3.2 Overflow Box and Centrifuge Room

Odialog data summary is shown for the overflow box and the Centrifuge room in **Table 3.2.1**, the raw data is included in **Appendix D Figure D-12** and **Figure D-13** for the Overflow and the Centrifuge room respectively.

Table 3.2.1 Miscellaneous Odor Data

Location	H ₂ S (ppm)		NH ₃	
	Odialog		Grab	
	Average	Maximum		
Overflow Tank	0.2	3.6	ND	ND
Centrifuge Room	ND	0.4	ND	ND

3.3 Overflow Box and Centrifuge Room Summary

Strictly speaking these spaces do not contribute to offsite odors. The Odialog for the Overflow Box was placed over the top of the box away from the inlet of the exhaust duct such that emission from the tank are collected. No H₂S was measured in the adjoining space with the hand-held meter. Low levels of H₂S were logged (< 1.0 ppm) in the Centrifuge Room but no H₂S was measured with the hand-held meter.

3.4 Fugitive Emissions

Odor data was collected from emission sources such as the aeration tanks and pressurized vents and building spaces such as the DAF building that could exhaust to the outside. These sources are not treated however are significant in the dispersion analysis in addition to the scrubber exhausts. The odor data from these sources is included in **Table 3.4.1**. In addition to these sources the Sludge storage tanks, located in Zone 1 at the southern end of the plant were inspected and it was found that the tanks were under -0.5 in. wc pressure with air entering the tanks at the mushroom intake vents.

Table 3.4.1. Miscellaneous Fugitive Emissions Odor Data

Location	Odor (D/T)		Hedonic Tone
	Dilutions to Threshold (D/T)	Recognition Threshold (D/T)	
Aeration Tanks	2,200	1,500	-1.1
Aeration Effluent Channel	1,800	1,200	-1.5
Aeration Influent Vent	2,800	1,900	0.5
Dissolved Air Flotation (Bay)	2,100	1,300	0.6

3.4.1 Summary Fugitive Emissions

The odor levels from these sources are not excessive however the large open area of the Aeration Tanks makes it a significant contributor to odor emissions, to a lesser extent the Aeration Tank Effluent Channel and an open Dissolved Air Flotation Bay door. The Aeration Influent Vent is a mushroom type vent located on the East side of the Aeration Tanks that is pressurized and releases air from the influent channel, representing a small contribution to the overall odor. Note that the hedonic tone in each case is not extremely low as would be expected with secondary wastewater processes.

3.5 Flares

The flares were not measured directly as there is no standard for sampling and measuring odor from flares, further, analysis of flare exhaust has proven that the results are unpredictable. Based on consultation with the odor laboratory (St. Croix Sensory) the emissions were assessed a value of 10,000 OUs. With this value the plots showed no offsite effects as shown in **Figure 4.4.24** and **Figure 4.4.34** for the Isopleth Plot and the Frequency Plot respectively for the N flares and **Figure 4.4.21** and **Figure 4.4.36** for the Isopleth Plot and the Frequency Plot respectively for the S flare.

3.6 Smoke Testing

Smoke visualization testing of the tank covers, pressure relief vents and other potential odor sources was performed at the Plant to confirm the integrity of the odor control and ventilation systems and identify any leakage as well as proper airflow.

Testing was conducted utilizing smoke candles. The candles were lit and lowered below the tank covers at the hatch locations using the rope and bucket method. The hatches were closed, and any leaks were observed. The results of the testing are presented below in **Table 3.6.1**.

Table 3.6.1. Smoke Testing Results

Location	Observation
Influent Channels	Some Leakage
North Influent Structure	Some Leakage
South Influent Structure	Some Leakage
Primary Tanks	No Leakage

3.6.1 South Control Structure

This structure receives raw wastewater and conveys it to the Screening Building; there is no ventilation. Ventilation of the source with improved gaskets would correct the leakage problem. **Figure 3.6.1.1** indicates leakage from the cover.

Figure 3.6.1.1 South Influent Diversion Structure



3.6.2 North Control Structure

The Northern Diversion Structure is also not ventilated and has similar leakage. Ventilation of the source with improved gaskets would correct this problem. **Figure 3.6.2.1** shows leakage at the covers.

Figure 3.6.2.1 Northern Influent Diversion Structure

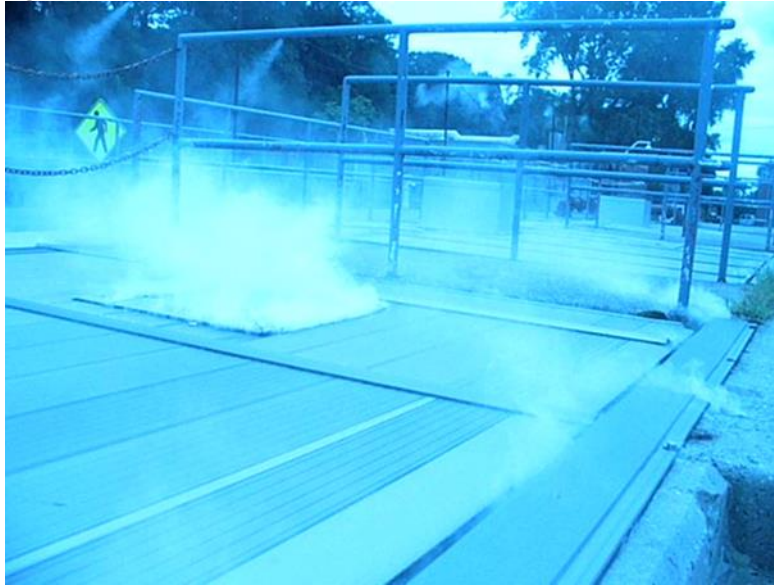


3.6.3 Grit Tanks

The grit tanks had transient leaks from the hatches where the smoke candle was placed but quickly disappeared, indicating that ventilation was adequate, however improved gasketing is recommended.

3.6.4 Grit Effluent Channels

Leakage was found at the Grit Effluent Channels leading to the Primary Influent Channels, shown in **Figure 3.6.4.1**. There is no ventilation duct in this section, the leakage is due to poor ventilation as well as inadequate gasketing of the hatch.

Figure 3.6.4.1 Grit Effluent Channel

3.6.5 Primary Influent Channels

The Primary Influent Channels showed continuous leakage at the hatches and the equipment covers. This source is ventilated however the pick-up points are located at the primary tanks and air may not be captured from the influent channels due to constraints in transition to the Primary Tanks themselves. Primary Clarifier Number 1 was under renovation at the time of sampling and that section of influent Channel was not tested. **Figures 3.6.5.1 and 3.6.5.2** show leakage from the Primary Influent Channels' hatches and equipment covers at Primary Tank 2.

Figure 3.6.5.1 Primary Tank Number 2 Influent Channel

Figure 3.6.5.2 Primary Tank Number 2 Influent Channel



Figure 3.6.5.3 shows minimal leakage at the Influent Channels to Primary Tank 3.

Figure 3.6.5.3 Primary Tank 3 Influent Channel



Figures 3.6.5.4 and 3.6.5.5 show smoke testing at the Influent Channels for Primary Clarifier Number 4.

Figure 3.6.5.4 Primary Tanks Number 4 Influent Channel**Figure 3.6.5.5 Primary Tanks Number 4 Influent Channel**

3.6.6 Primary Clarifiers and Effluent Channels

The Primary Clarifiers and Effluent Channels showed no leakage indicating good ventilation of the headspace.

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Section 4

Odor Dispersion Model

4.1 Introduction

Atmospheric dispersion modeling is not mandatory for the development of an odor abatement plan, but it is an extremely useful tool. Its greatest value comes from the ability it provides to assess the relative off-site impacts of proposed control measures. It can be used to provide a quantitative answer to the question – to what degree does the facility impact the surrounding community? Specifically, off-site peak odor concentrations (defined in odor units, OU) are predicted by the dispersion model and then presented as a series of concentric contours, or isopleths, which are typically shown on an aerial photograph.

Contours of odor impact frequency can also be generated from the model predictions. Frequency is an effective decision-making criterion and relatively easy to communicate to the public. The model calculates off-site impacts for each hour of five representative years over hundreds of points on a receptor grid. It therefore accounts for every type of meteorological condition in the region. The model can also be queried about specific meteorological conditions of interest.

Dispersion modeling was performed on the facility using the data gathered from the odor survey. The basis for model development, as well as modeling results and findings, are presented in the following sections.

4.2 Modeling Approach

The modeling approach used in this analysis was selected based on regulatory guidance, professional experience, and site requirements. While this analysis was not performed for any regulatory requirement, the approach and data used generally meet air quality modeling guidelines established by the U.S. Environmental Protection Agency (EPA) and outlined in Appendix W to 40 Code of Federal Regulations (CFR) Part 51 (Guideline on Air Quality Models). The New York State Department of Environmental Conservation (NYSDEC) does not have specific guidance for odor modeling, but it provides general modeling guidance for AERMOD.¹ The general adoption of regulatory guidelines for odor dispersion modeling efforts that are not driven by regulatory requirements is an accepted modeling practice.

Key components of the modeling effort, including model selection and model inputs, are described below.

4.2.1 Model Selection

The most recent version of the EPA AERMOD refined dispersion model (Version 16216r) was selected to predict odor impacts from the facility. The graphical user interface AERMOD View, created by Lakes Environmental, was used to facilitate model setup and post-processing of data.

¹ NYSDEC. 2006. Policy DAR-10: NYSDEC Guidelines on Dispersion Modeling Procedures for Air Quality Impact Analysis. Available online at: <http://www.dec.ny.gov/chemical/8923.html> [Accessed on November 14, 2017].

AERMOD was selected for this analysis because it:

- Is the required EPA model for all refined regulatory analyses for receptors within 50 kilometers of a source;
- Is a refined model for facilities with multiple sources, source types, and building-induced downwash;
- Uses actual representative hourly meteorological data;
- Incorporates direction-specific building parameters that can be used to predict impacts within the wake region of nearby structures;
- Allows the modeling of multiple sources together to predict cumulative downwind impacts;
- Provides for variable emission rates;
- Provides options to adjust the one-hour impact to a peak impact less than one-hour; and,
- Allows the use of large receptor grids, as well as discrete receptor locations.

4.2.2 Modeling Protocol

The AERMOD input file was setup to produce concentration output for one-hour averaging periods. This is the smallest averaging period that can be calculated accurately with a one-hour meteorological observation interval. Because odor is an “instantaneous” phenomenon, an averaging time of five minutes is typically calculated. For this model, the one-hour average concentrations predicted by AERMOD were converted to five-minute peak concentrations using the “one-fifth power law.” The ratio of concentrations for the different time intervals is equal to the inverse ratio of the averaging periods raised to the one-fifth power:

$$C_p = C_m(t_m/t_p)^{0.2}$$

where: C_m = the modeled concentration,

C_p = the predicted concentration,

t_m = 60 minutes, and

t_p = 5 minutes.

All one-hour concentrations were multiplied by 1.64 to determine the predicted concentrations at a five-minute interval.

Regulatory default options adopted for the model include:

- *Use stack-tip downwash (except for building downwash).* Stack-tip downwash is an adjustment of the actual stack release height for conditions when the gas exit velocity is less than 1.5 times the wind speed. For these conditions, the effective release height is

reduced a bit, based on the diameter of the stack and the wind and gas exit velocity. This option applies to point sources only.

- *Incorporate the effects of elevated terrain.* Elevated terrain options were selected to be consistent with regulatory default options and to account for any slight changes in terrain between receptor and source base elevations.
- *Use the missing data and calms processing routines.* The model treats missing meteorological data in the same way as the calms processing routine, i.e., it sets the concentration values to zero for that hour, and calculates the short-term averages according to EPA's calms policy, as set forth in the Guidelines. Because we are only interested in one-hour averages, concentrations predicted with calm or missing data would not affect model results.

AERMOD can assign sources to a rural or urban category to allow specified urban sources to use the effects of increased surface heating under stable atmospheric conditions. As specified in USEPA modeling guidance, the land-use characteristics within a 3-kilometer radius of the project site define the classification of the region. Sites in which at least 50% of the surrounding area is heavily developed are Urban. Single family houses do not count as heavily developed and the EPA has an extensive list of specifics for this classification. The Yonkers site is less than 50% heavily developed due to the being such a large portion of the surrounding 3km. For this area, roughly 30% is developed, well below the Urban setting threshold. Largely due to the forested area on the far side of the Hudson River and the river itself, the rural dispersion classification was selected for the purposes of this model.

Odor Source Parameters

Data for all odor sources sampled at the facility were included in the modeling analysis. **Figure 4.2.1** shows the sources overlaid on an aerial photo. **Table through 4.2.3** summarize the existing source characteristics modeled across each modeling scenario. The sampling data presented in the tables reflect a single sampling event. While the ideal sampling program would include more than one event, most sampling programs conducted for purposes like this study are limited to single sample events.

- **Baseline:** This scenario represents the conditions resulting from the current operation of the Westchester County Wastewater Treatment Plant. Sources include the main stacks 2, 3, 4 common exhaust; a flare; the dispersion flare exhaust port; the screenings bay door; the A, B, C stacks common exhaust; the DAF bay door; the secondary influent vent; the secondary effluent tanks; the secondary aeration tanks; and an N-Flares (north) unit.
- **Scenario 1:** This scenario represents the conditions resulting from an alternative operating scenario of the plant. The scenario contains all sources in the baseline except the N-Flares unit.
- **Scenario 2:** This scenario represents the conditions resulting from an alternative operating scenario of the plant. The scenario contains all sources in the baseline except the DAF bay door.

- **Scenario 3:** This scenario represents the conditions resulting from an alternative operating scenario of the plant. The scenario contains all sources in the baseline except the screenings bay door.
- **Scenario 4:** This scenario represents the conditions resulting from an alternative operating scenario of the plant. The scenario contains all sources in the baseline except that emissions of odor from the A, B, C stacks common exhaust port has been controlled.

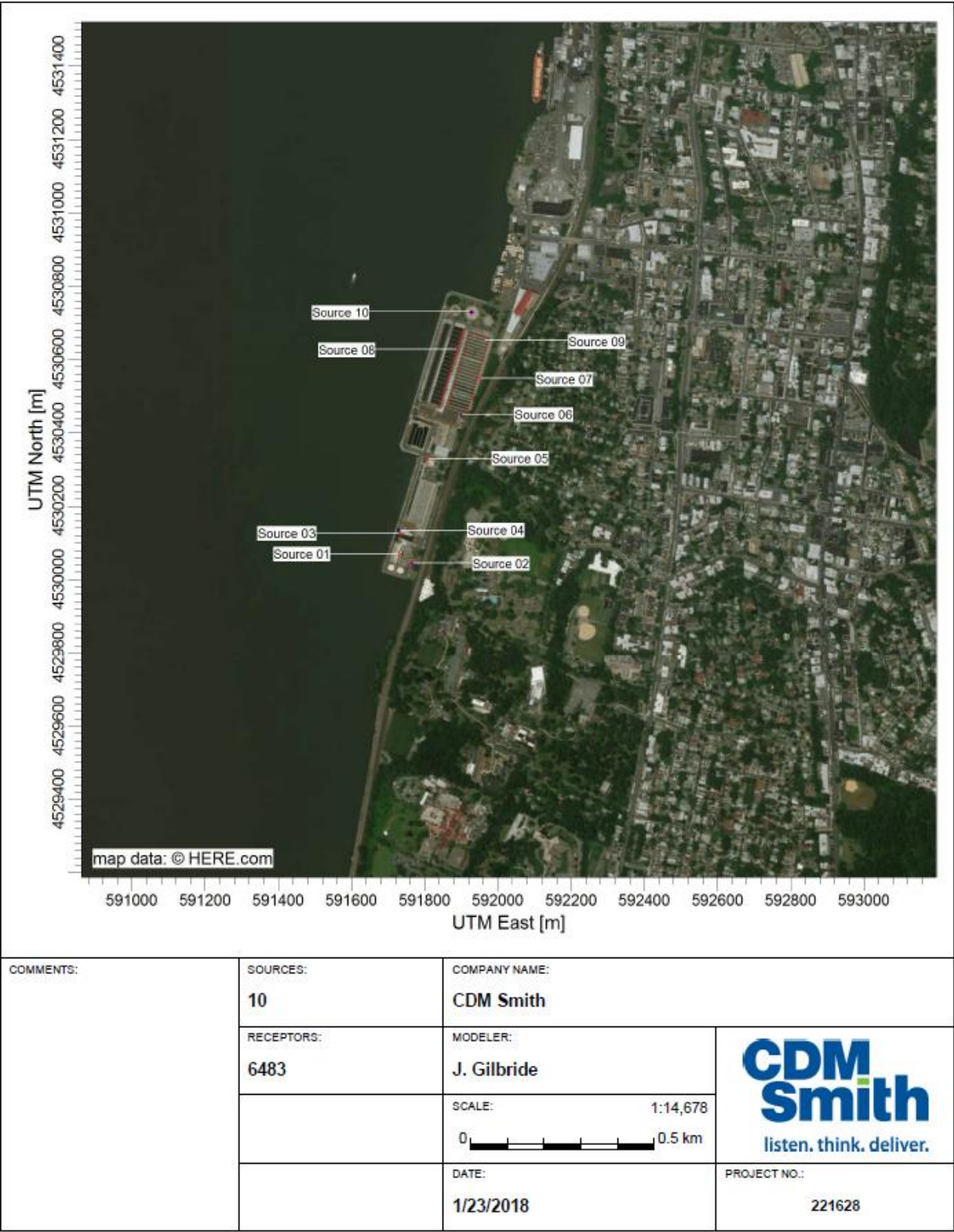
As indicated in **Table 4.2.1-4.2.3**, sources were either modeled as point, volume, or area sources. These different source types can be further described as follows:

- *Area sources* – These sources generally include tanks and other horizontal surfaces. Area source dimensions were estimated from georeferenced digital aerial photographs and from site drawings. Heights were estimated from field observations, site drawings, or Google Earth Pro.
- *Volume sources* – These sources generally include building openings, such as doors and other vertical surfaces. Volume source dimensions were obtained from site drawings or were estimated from field observations or measurements taken by CDM Smith staff in the field.
- *Point sources* – Point sources include stacks like odor control discharge stacks. Release heights and stack diameters were obtained from site drawings. Airflows were obtained from stack specifications or measurements taken by CDM Smith staff in the field.

Point sources require a stack or release height, an internal diameter, a gas exit velocity, and a gas temperature. The exit velocity is often calculated from a fan or blower capacity and the internal diameter. The model can assign the ambient temperature for non-buoyant gases.

Source emission rates were estimated from sampled odor concentrations and airflow rates. The basis for airflow rates used in the model varied according to source as follows:

Figure 4.2.1 Sources Overlaid on Aerial Photo



- *Quiescent surfaces* – Emission rates for un-aerated tanks such as the uncovered aeration basins were based upon the flux chamber rate used during sampling.
- *Aerated and ventilated areas* - For sources with mechanical aeration or ventilation, airflow rates were determined based upon specified equipment airflows (i.e., aeration rates or odor control equipment treatment volumes).

AERMOD can calculate aggregate impacts from all sources, as well as from individual sources or combinations thereof. For this modeling effort, like sources were combined according to use (e.g., aeration basin).

Table 4.2.1 Point Source Parameters and Emission Rates

Source ID	Emission Source	Release Height (ft)	Diameter (ft) ^[a]	Exit Temperature	Air Flow (cfm)	Odor Strength (OU)	Emission Rate (OU/s)
MS234	Main Stack 2,3,4	41.27	4.5	ambient	63,585	1,400	39,722
FLARES2	Flare	44.06	2	ambient	200	10,000	949
DISFAN	Dispersion Fan Exhaust	40.00	4.4	ambient	46,000	260	5,644
CEABC ^[b]	A, B, C Common Exhaust	41.30	3	ambient	31,400	6,450	95,622
CEABCR ^[c]	Controlled A, B, C Common Exhaust	41.30	3	ambient	31,400	600	8,895
INFVENT	Secondary Influent Vent	1.52	2.1	ambient	500	2,800	661
NFLARES	N-Flares	27.90	2.0	ambient	615	10,000	2,906

Notes:

^[a] Diameter calculated from the projected air flow rate and exit velocity for each source.

^[b] CEABC represents the uncontrolled exhaust of the A, B, C stacks common exhaust port. It is modeled in the Baseline scenario, as well as Scenarios 1 through 3.

^[c] CEABCR represents the controlled exhaust of the A, B, C stacks common exhaust port. It is modeled in Scenario 4 only.

Key: cfm = cubic feet per minute; ft = feet; OU = odor units; OU/s = odor units per second

Table 4.2.2 Volume Source Parameters and Emission Rates

Source ID	Emission Source	Release Height (ft)	Width (ft)	Length (ft)	Air Flow (cfm)	Odor Strength (OU)	Emission Rate (OU/s)
SCRBAY	Screenings Bay Door	5.68	12	10	1200	1,200	680
DAFBAY	DAF Bay Door	1.48	15	14	2100	2,100	2,082

Notes:

[a] NYSDEC has not established specific guidance for the modeling of vertical odor sources as volumes; therefore, established AERMOD modeling guidance for modeling vertical odor sources as volumes by the San Joaquin Valley Air Pollution Control District was used.²

Key: cfm = cubic feet per minute; ft = feet; OU = odor units; OU/s = odor units per second

Table 4.2.3 Area Source Parameters and Emission Rates

Source ID	Emission Source	Release Height (ft)	Width (ft)	Length (ft)	Total Area (ft ²)	Air Flow (m ³ /s/m ²)	Odor Strength (OU)	Emission Rate (OU/s/m ²)
EFFLU	Effluent	7.61	16	721	11,536	6.47E-04	1,800 [a]	1.16
AERTNKS	Aeration Tanks	2.31	680	176	119,680	1.42E-03	2,200	3.13

Notes:

[a] Odor strength was measured by means of a flux chamber a rate of 5 L/min and an opening of 0.129 square meters.

Key: cfm = cubic feet per minute; L/min = liters per minute; ft = feet; OU = odor units; OU/s = odor units per second

4.2.3 Receptor Grid

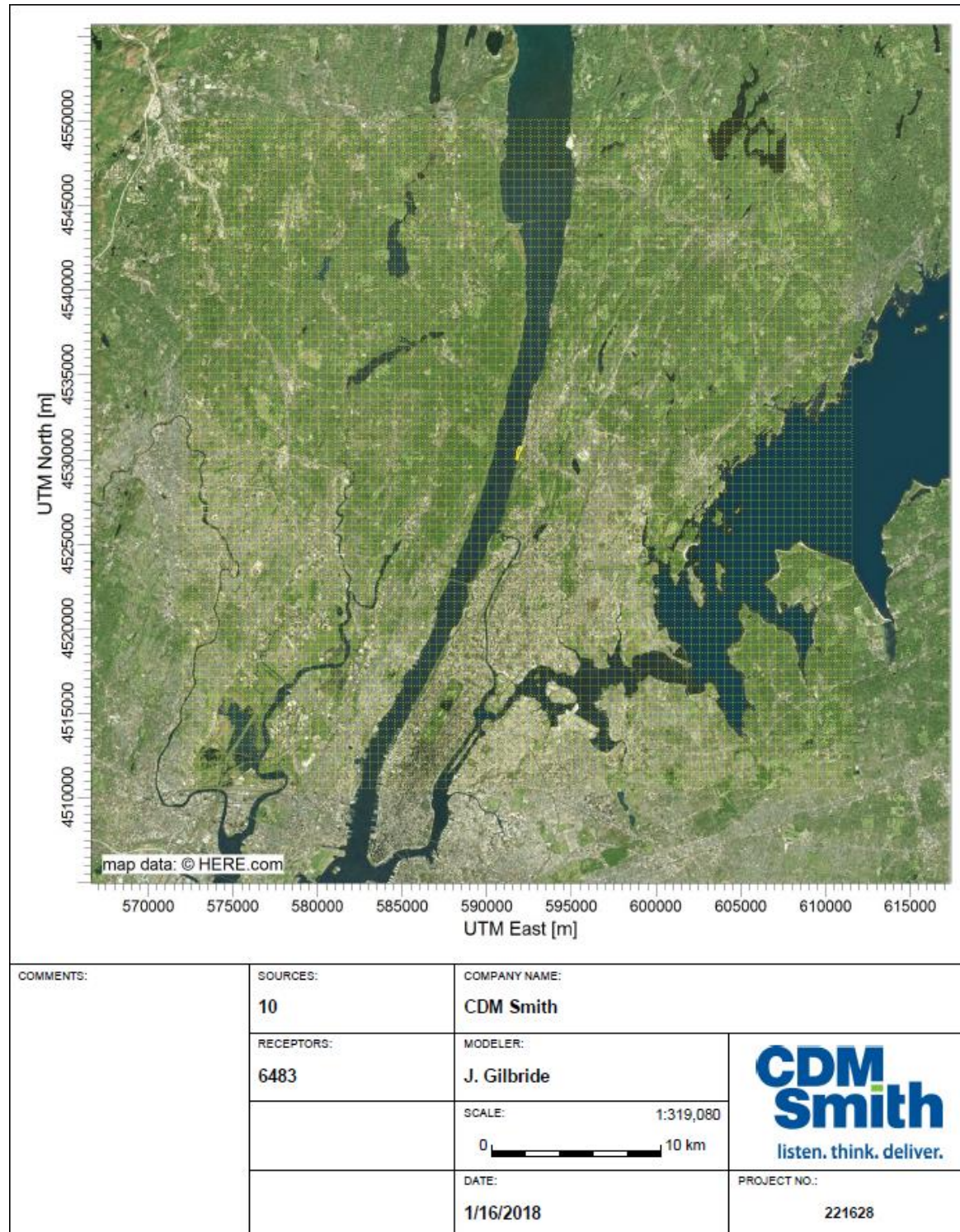
A critical step in model development is the establishment of a receptor grid for the study area. Based upon model inputs, the model calculates both the number and strength of odor exceedances at each receptor node.

Receptors were located every 500 meters, extending 20 kilometers to the east and west, and 20 kilometers from the north and south from the facility center. Additionally, receptors were placed every 25 meters along the facility property line. The resulting receptor grid contained 6,483 receptors, excluding receptors that would lie within the facility. Terrain elevations were obtained and assigned to receptors using the Lakes AERMOD View terrain processor (AERMAP utility).

Figure 4.2.2 presents the receptor grid.

² SJVAPCD. 2017. Modeling Guidance. Available online at: http://www.valleyair.org/busind/pto/Tox_Resources/Modeling%20Guidance.pdf [Accessed on January 8, 2018].

Figure 4.2.2 Receptor Grid



4.2.4 Meteorological Data

Five years (2012 to 2016) of actual hourly data were created with the EPA's AERMET version 16126 meteorological preprocessor. Hourly surface data were obtained from the Teterboro Airport (Weather Bureau Army Navy [WBAN] Number 94741), the closest meteorological station to the facility with representative conditions.³ Upper air sounding data in Forecast Systems Laboratory (FSL) format were obtained from New York City, New York (WBAN Number 94703).⁴ The AERMINUTE utility was used to process 1-minute Automated Surface Observing System (ASOS) wind data and Integrated Hourly Data (ISHD) from the surface station to generate the hourly averages of wind speed and wind direction. Consistent with EPA guidance, an ASOS threshold wind speed of 0.5 meters per second (m/s) was used.⁵ U.S. Geological Survey (USGS) land cover data were processed with the AERSURFACE utility to produce surface characteristic values.

The hourly surface dataset shows that there are 1,081 calm hours and 111 missing hours (99.75 percent completeness). The average surface wind speed is 3.42 meters per second (7.65 miles per hour) and occurs most frequently out of the north west. **Figure 4.2.3** presents a wind rose of the surface data.

4.2.5 Output Options

AERMOD can predict concentrations for one-hour, three-hour, eight-hour, 24-hour, period, and annual averaging times. As described earlier, one-hour average concentrations were converted to five-minute average concentrations to simulate instantaneous odor concentrations. This analysis assumes that exceedances of 7 OU for five-minute averaging time concentrations constitute a “nuisance” condition (7 OU is an accepted value below which odors are not generally noticeable).

Nuisance is defined by three specific measures: spatial extent, magnitude, and frequency. The spatial extent is used to determine which areas are impacted most. The area of impact is shown graphically with isopleth maps. The second measure, magnitude, denotes the strength of a problem. The third measure, frequency, is used to describe the persistence of a problem. All three measured criteria are essential to evaluate the level of the nuisance.

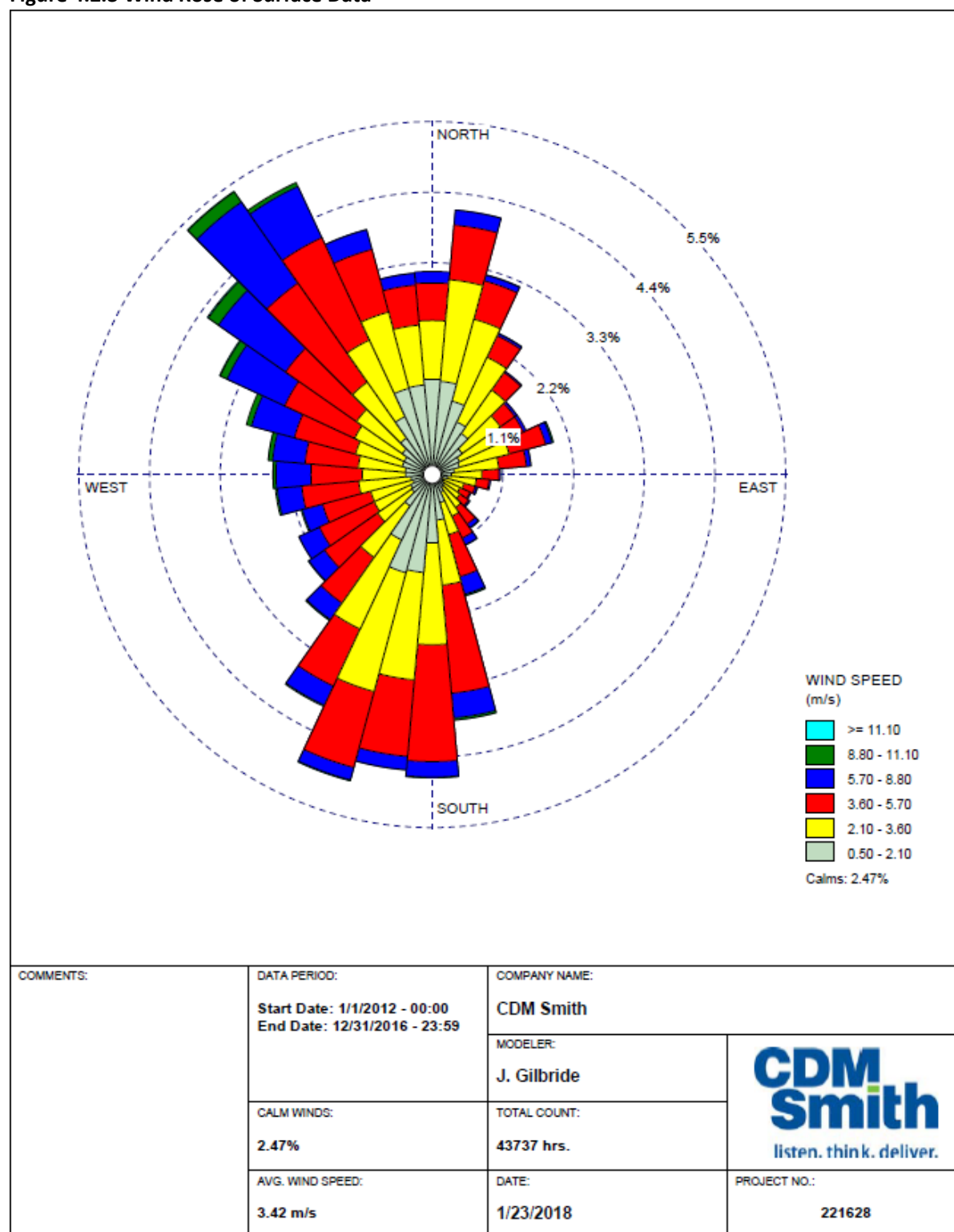
To quantify frequency, the number of exceedances at each receptor point is counted. Each receptor has the potential of up to 43,848 “hits,” or exceedances of the 7 OU five-minute odor nuisance threshold, as there are 8,760 hours in a year, except for leap years.

³ National Centers for Environmental Information. 2017. Land-Based Station Data. FTP Access: Integrated Surface Hourly Data Base (3505). Available online at: <https://www.ncdc.noaa.gov/data-access/land-based-station-data> [Accessed on October 24, 2017].

⁴ National Oceanic and Atmospheric Administration. 2017. NOAA/ESRL Radiosonde Database. Available online at: <https://ruc.noaa.gov/raobs/> [Accessed on October 24, 2017].

⁵ EPA. 2013. “Use of ASOS meteorological data in AERMOD dispersion modeling.” March 8. Available online at: https://www3.epa.gov/scram001/guidance/clarification/20130308_Met_Data_Clarification.pdf [Accessed on October 24, 2017].

Figure 4.2.3 Wind Rose of Surface Data



The main output file presents maximum concentrations at each receptor. AERMOD will produce a file containing the highest predicted concentration at each receptor for the five years of meteorology data (PLOTFILE option). The model is also capable of producing data files containing receptor and hour information for those concentrations which exceed a predetermined threshold (MAXIFILE option). These outputs were analyzed to interpret results and conclusions of the dispersion modeling analysis.

4.3 Modeling Results

As noted above, odor nuisance impacts are not only quantified by the absolute maximum concentration, but also by the frequency of their occurrence. The maximum five-minute odor impact represents the most noticeable or worst odor. The spatial extent represents the number of receptors where the 7 OU odor threshold is exceeded at least once. The frequency value (in units of receptor-hours) represents the total number of occurrences in the modeled year where the 7 OU odor threshold was exceeded at all modeled receptors. The total number of receptor-hours modeled is 284,266,584 (6,483 total receptors and 43,848 modeled hours).

Four modeling scenarios were modeled to evaluate differences in odor emissions and mitigation effectiveness. These scenarios evaluated: 1) halted operation of the N-Flares unit; 2) closed DAF bay door; 3) closed screenings bay door; and 4) Improvement of the A, B, C stacks common exhaust.

4.3.1 Predicted Odor Impacts

Table 4.3.1 presents the results of the dispersion modeling using a 7 OU odor impact threshold for each scenario. The baseline, scenario 3, and scenario 4 has the highest peak odor magnitudes at 606 OU/m³. The next highest peak odor magnitude was for scenario 1 at 605 OU/m³. Scenario 2 has the lowest odor magnitude at 596 OU/m³. The odor magnitude is the level that is found closest to the source generally within the plant boundary. The highest spatial event was modeled under the baseline with 1,017 receptors exceeding the 7 OU threshold at least once. Scenarios 3, 2, and 1 has the next highest spatial events at 1,016, 1,003, and 1,000 receptors respectively. Scenario 4 has the lowest spatial event at 334 receptors impacted. This parameter includes all receptors as indicated in **Figure 4.2.2**, including those within the plant boundary. The highest frequency of impacts was modeled under the baseline with 489,004 exceedances of the 7 OU/m³ thresholds. Scenarios 3, 1, and 2 has the next highest frequencies at 481,426, 481,259, and 471,452 exceedances respectively. Scenario 4 has the lowest frequency of impacts at 340,112 exceedances. These values include all receptors within and surrounding the plant boundary as indicated in **Figure 4.2.2**.

Table 4.3.1 Odor Modeling Results with 7 OU as the 5-Minute Odor Threshold

Source Description	Magnitude	Spatial Extent		Frequency	
	Max 5-Minute Odor Impact ⁽¹⁾ (OU/m ³)	Number of Receptors > 7 OU/m ³	Percentage of Receptors ⁽²⁾ (%)	Number of Impacts > 7 OU/m ³	Percentage of Possible Occurrences ⁽³⁾ (%)
<i>Baseline</i>					
Sources 01-10 (Total Plant)	606	1,017	15.7%	489,004	0.2%
<i>Scenario 1</i>					
Sources 01-09 (No N-Flares)	605	1,000	15.4%	481,259	0.2%
<i>Scenario 2</i>					
Sources 01-05 and 07-10 (No DAF Bay Door)	596	1,003	15.5%	471,452	0.2%
<i>Scenario 3</i>					
Sources 01-03 and 05-10 (No Screenings Bay)	606	1,016	15.7%	481,426	0.2%
<i>Scenario 4</i>					
Sources 01-10 (Source 5 Controlled)	606	334	5.2%	340,112	0.1%
<i>Individual Sources</i>					
Source 9, Aeration Tanks	589	204	3.1%	244,442	0.1%
Source 5, A, B, C Common Exhaust	155	227	3.5%	136,982	<0.1%
Source 1, Main Stack 2,3,4	47	102	1.6%	33,948	<0.1%
Source 6, DAF Bay Door	35	23	0.4%	12,505	<0.1%
Source 7, Secondary	35	10	0.2%	4,914	<0.1%

Source Description	Magnitude	Spatial Extent		Frequency	
	Max 5-Minute Odor Impact ⁽¹⁾ (OU/m ³)	Number of Receptors > 7 OU/m ³	Percentage of Receptors ⁽²⁾ (%)	Number of Impacts > 7 OU/m ³	Percentage of Possible Occurrences ⁽³⁾ (%)
Influent Vent					
Source 8, Effluent	19	54	0.8%	2,370	<0.1%
Source 4, Screenings Bay	15	3	<0.1%	2,644	<0.1%
Source 5, Controlled A, B, C Common Exhaust	9	2	<0.1%	8	<0.1%
Source 10, N Flares	8	4	0.1%	8	<0.1%
Source 3, Dispersion Fan Exhaust	8	2	<0.1%	3	<0.1%
Source 2, Flare	2	0	0.0%	0	0.0%

Notes:

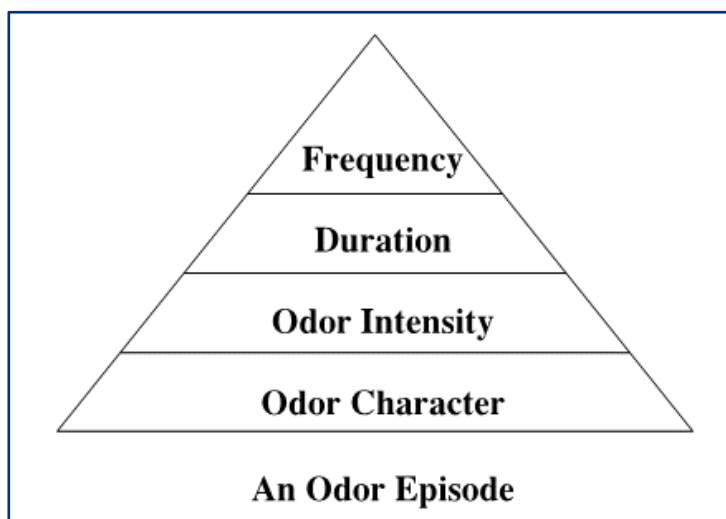
- (1) The maximum individual impact may not occur at the same receptor during the same 5-minute period as the total plant impact.
- (2) The maximum number of possible receptors is 6,483.
- (3) The maximum number of possible occurrences is 284,266,584 (6,483 receptors x 43,848 hours of meteorological data)

Isopleths maps, **Figures 4.4.5 through 4.4.35**, presented at the end of this section, illustrate the magnitude (strength), frequency, and geographic extent of odor impacts from modeled odor sources at the facility.

4.4 Odor Dispersion Model Summary

Odors that become a nuisance are the result of the effect of different ingredients, including the character of the odor, the intensity of the odor, the duration of the odor, and the frequency of the episodes. The accumulation of the various ingredients shown in **Figure 4.4.4** will result in a complaint. Odor Character is the “smells like” term that is used, also called descriptors; less familiar odors or odors perceived to come from wastewater processes will tend to be considered more offensive. Hedonic Tone indicated in the preceding tables is a relative measurement of unpleasantness determined by the panelists without knowledge of the source; Hedonic Tone differs from Character. The Duration of the odor is the length of time the odor is perceived a short duration odor may be easily ignored while a long duration odor could become a quality of life issue. The odor Intensity is the strength of the odor, and combined with the character of the odor can be offensive. A short duration of a fecal odor is offensive however even a long duration from a bakery could be considered inoffensive. Frequency may drive most odor complaints; occasional odor excursions may be explained by accidental discharges however frequent odor events are likely to be perceived as a problem that requires some remedy and will elicit a complaint to be certain it is understood that the odor is persistent.

Figure 4.4.4. Odor Pyramid



There are few odor standards throughout the United States, **Table 4.4.1** shows the known laws. For the odor limits there may also be additional requirements regarding duration, frequency etc. depending on the state. Notwithstanding an odor level of less than 7 OUs is generally considered a target.

Table 4.4.1 Representative State Odor Laws

State	Odor Level (OUs)	Reference
Colorado	Residential: 7 Commercial: 15	Department of Public Health and Environment <u>Regulation No. 2 (2013)</u> Odor Emission
Connecticut	7	Department of Environmental Protection <u>Section 22a-174-23 (2006)</u> Control of Odors
Illinois	Residential: 8 Commercial: 24	Environmental Protection Agency <u>Chapter I, Part 245</u> Odors
Delaware	Value not Stipulated	Natural Resources & Environmental Control <u>Title 7, 1119</u> Control of Odorous Air Contaminants
Kentucky	7	Environmental Protection Agency <u>Title 401, Chapter 53:010</u> Ambient Air Quality Standards
Nevada	8	Department of Conservation and Natural Resources <u>NAC Chapter 445B.22087</u> Air Controls - Odor
North Dakota	7	Department of Health - Div. of Air Quality <u>Chapter 33-15-16</u> Restriction of Odorous Air Contaminants
West Virginia	Not Stipulated	Department of Environmental Protection <u>Chapter 2, Section 11</u> Ambient Standards for Odors

The location of the plant near the residential area to the east is problematic as the prevailing winds are from the southwest and northwest as indicated in the wind rose in **Figure 4.2.3**. The baseline Isopleth plot that shows lines of odor concentration, **Figure 4.4.5**, indicates odor concentrations at 10 OUs or less to the east. The associated Baseline frequency map, **Figure 4.4.6**, indicates excursions above 7 OUs of up to 500 times over 5 years. The odor complaint map shown in **Figure 4.4.37** reflects the effect of the emissions effect.

Scenarios 2, 3, and 4 were developed to determine whether any normal range of activity could be contributing to the offsite effects. Since the model is “built” alternate scenarios can be modeled in the future. A further discussion of the offsite effects directly to the east for each scenario:

- **Scenario 1:** Isopleth and frequency map, **Figure 4.4.7** and **Figure 4.4.8** respectively, show the baseline model with the flares off and show no change to the offsite effects. The data shows a strong odor effect to the east with odor levels as high as 50 OUs and potential for 500 occurrences of odor levels greater than 7 OUs over 5 years.
- **Scenario 2:** Isopleth and frequency map, **Figure 4.4.9** and **Figure 4.4.10** respectively, show the baseline model with the DAF Building Bay doors closed; minor effect is shown. Note that Scenario 2 is closer to what should be considered actual baseline because the DAF is exhausted to odor control and under a negative pressure and in addition the DAF Bay doors are closed unless a delivery is required.
- **Scenario 3:** Isopleth and frequency map, **Figure 4.4.11** and **Figure 4.4.12** respectively, show the baseline model with the Screening Building Bay doors closed; minor effect is shown. Similar to Scenario 2 the Screenings Bay is exhausted to odor control and under a negative pressure and in addition the Screening Bay doors are closed unless the dumpster is to be removed.
- **Scenario 4:** Isopleth and frequency map, **Figure 4.4.13** and **Figure 4.4.14** respectively, show the baseline model with the exhaust from scrubbers A, B, and C optimized. Greater effect is shown however not sufficient to bring the offsite odors below 7 OUs; 40 OUs are indicated to the east. More significantly the frequency of excursions greater than 7 OUs are reduced from 400 occurrences in 5 years to 40.

An inspection of the source data from the modeled sources for their offsite effect to the east indicate that the aeration tanks with the influent channel vent are the strongest emission sources, Scrubbers A, B, and C operating at their current treatment rate are next followed by the common exhaust for Scrubbers 2, 3, and 4 and the Severn Trent scrubber. The offsite concentrations from Scrubbers 2, 3, and 4 would provide odor levels at 10 OUs to the east and therefore with some improvement would not pose a problem. **Figure 4.4.15** and **Figure 4.4.26** for the isopleth plot and the frequency plot, respectively indicate that the aeration tanks will remain a problem notwithstanding the correction of scrubbers' performance throughout the plant with levels as high as 50 OUs and frequency of exceeding 7 OUs over 500 times per year.

A summary of the identified odor sources under the baseline conditions are provided in **Table 4.4.2**.

Table 4.4.2 Summary of Identified Odor Sources

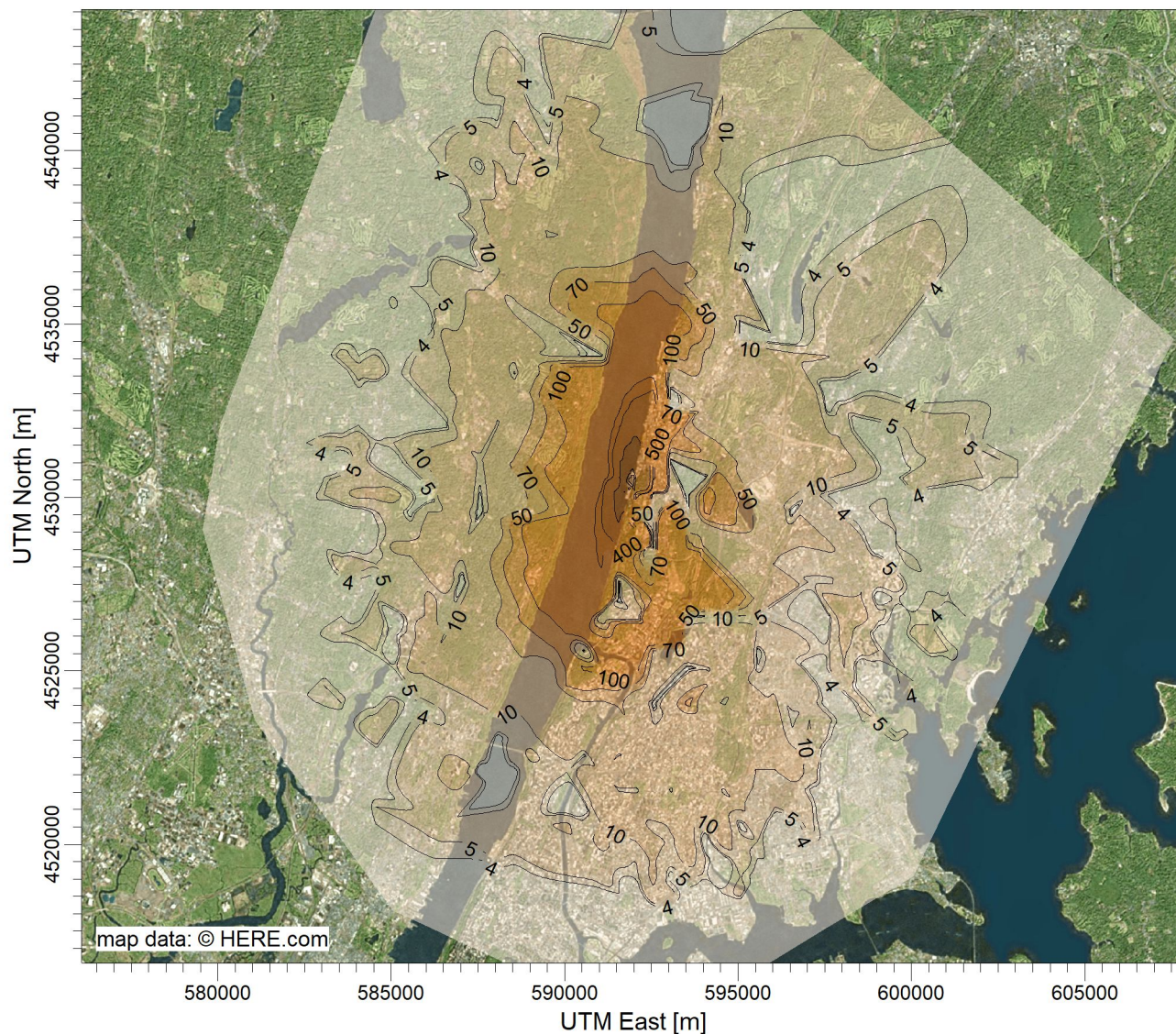
Source	Frequency	Magnitude
Primary Settling Tank Scrubbers A, B & C	High (100 times/year)	Moderate (40 Odor Units)
Aeration Tanks	High (100 times/year)	Moderate (50 Odor Units)
Scrubber 2, 3 and 4 w/ Severn Trent Scrubber 2	Moderate (20 times/year)	Low (20 Odor Units)
Flares	None	None
Screen and Grit Scrubbers	None	None

Note: Magnitude is based on a 5-minute interval and the frequency is based on occurrences greater than 7 odor units/m³.

PROJECT TITLE:

Figure 4.4.6

Frequency of Impacts, Baseline Scenario



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 18795 [COUNT] at (591938.82, 4530460.96)

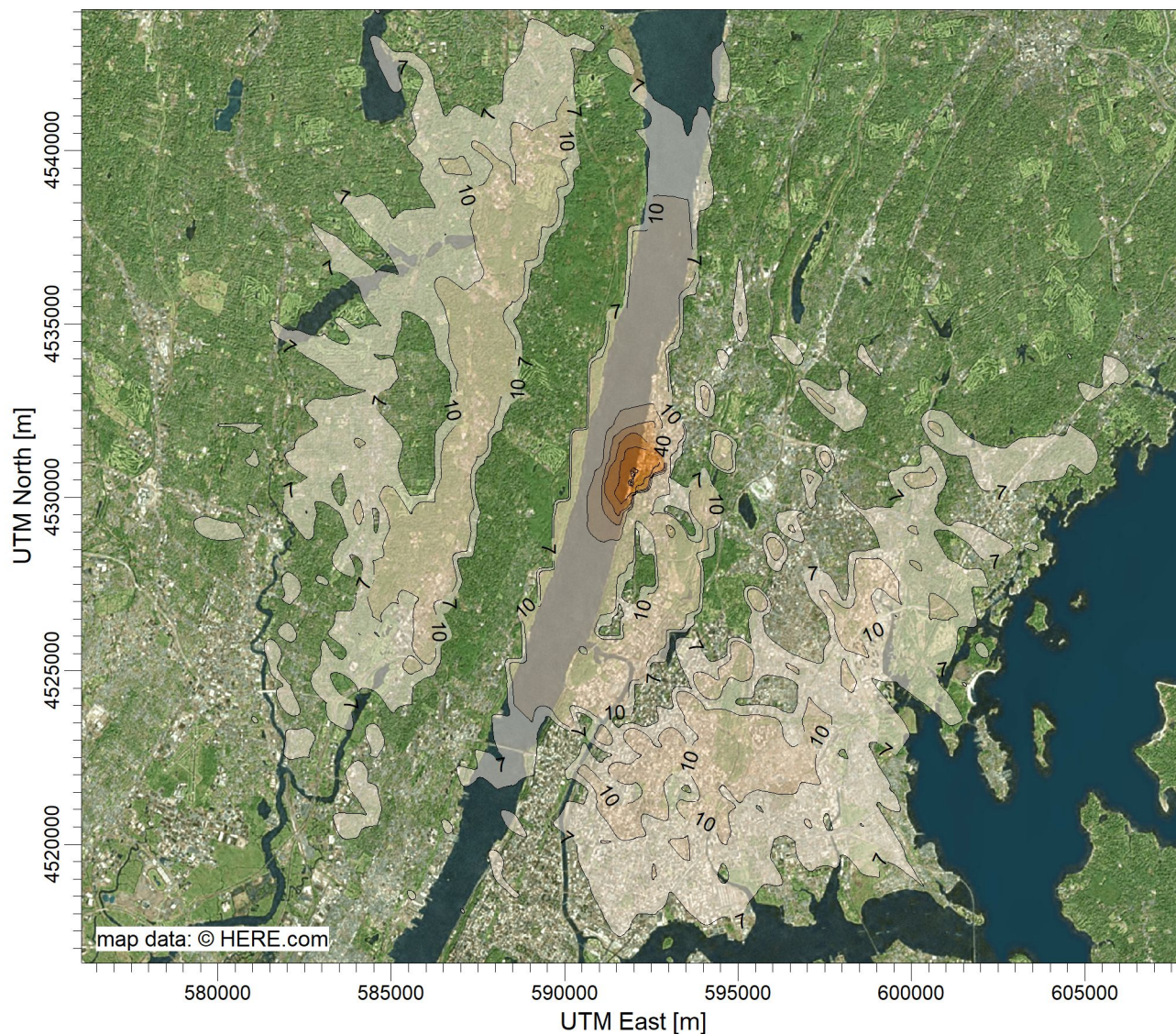


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:200,000
	Concentration	0 5 km	
	MAX:	DATE:	PROJECT NO.:
	18795 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.7

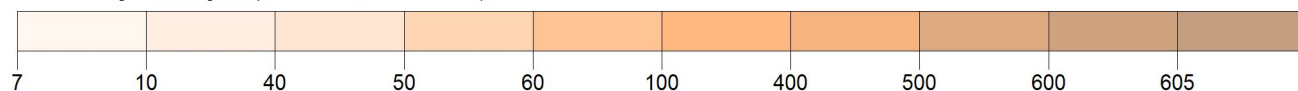
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Scenario 1 North Flares Off



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: SCNR01

OU/M**3

Max: 605 [OU/M**3] at (591929.39, 4530438.74)



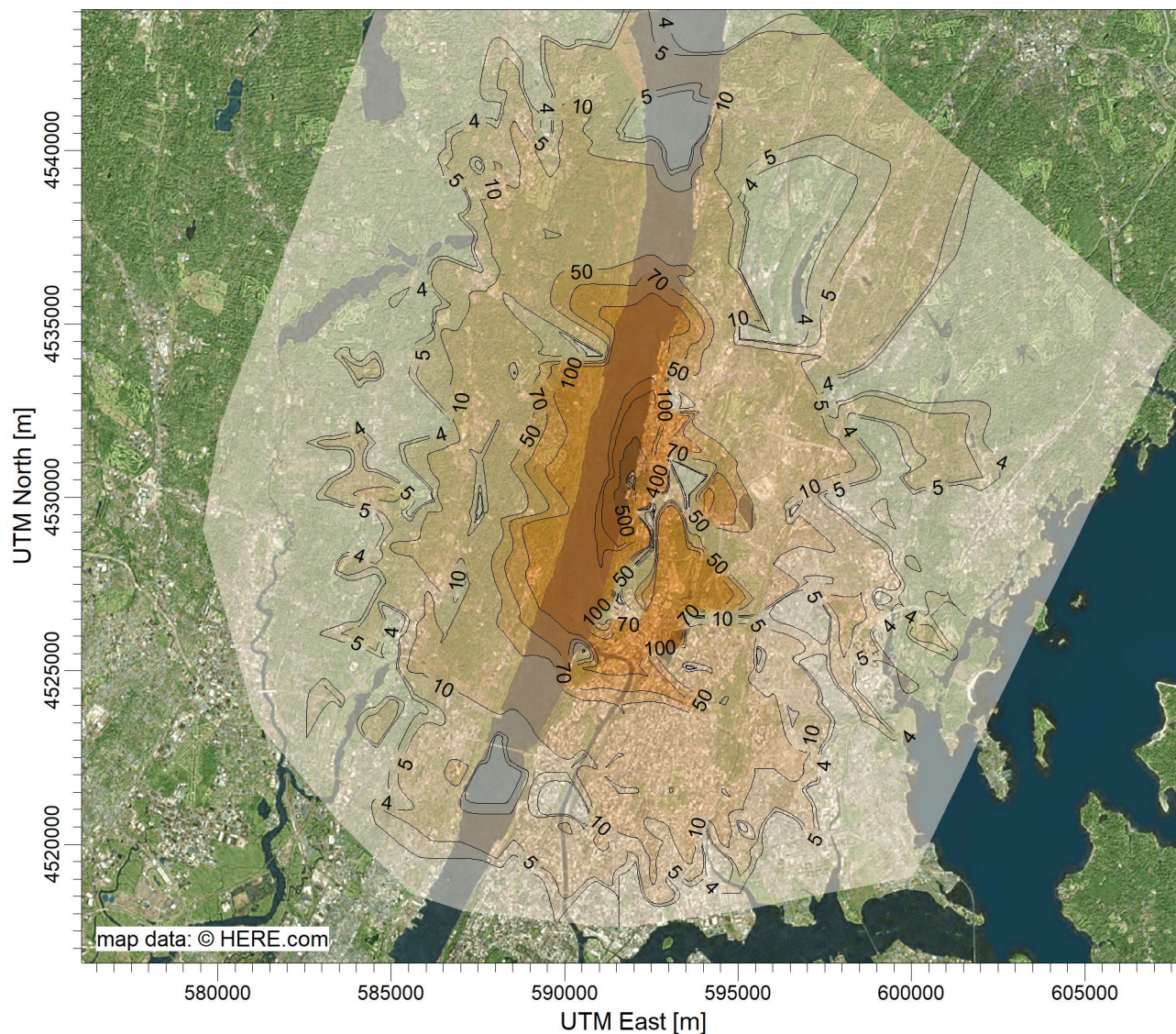
COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:200,000 0 5 km	
	MAX: 605 OU/M**3	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.8

Frequency of Impacts, Scenario 1

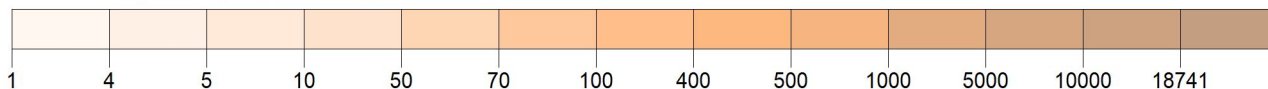
North Flares Off



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 18741 [COUNT] at (591938.82, 4530460.96)



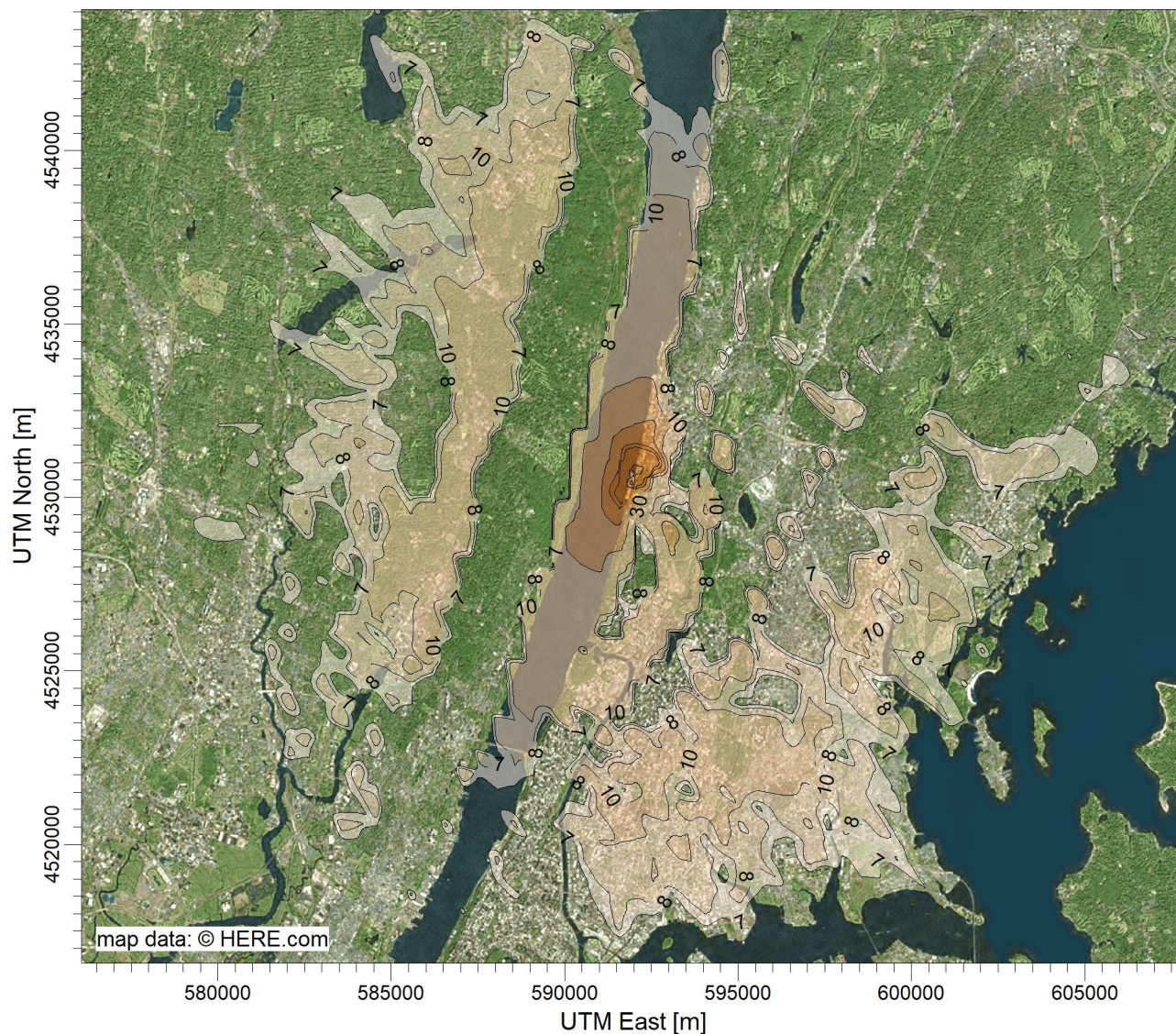
COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:200,000
	Concentration	0 5 km	
	MAX:	DATE:	PROJECT NO.:
	18741 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.9

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Scenario 2

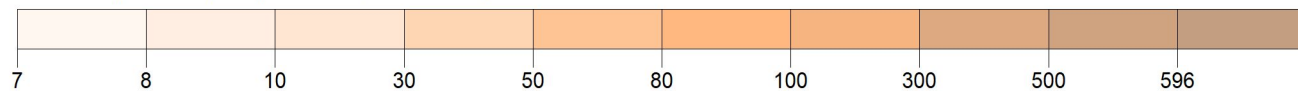
DAF Bay Door Closed



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: SCNR02

OU/M**3

Max: 596 [OU/M**3] at (591919.95, 4530416.51)



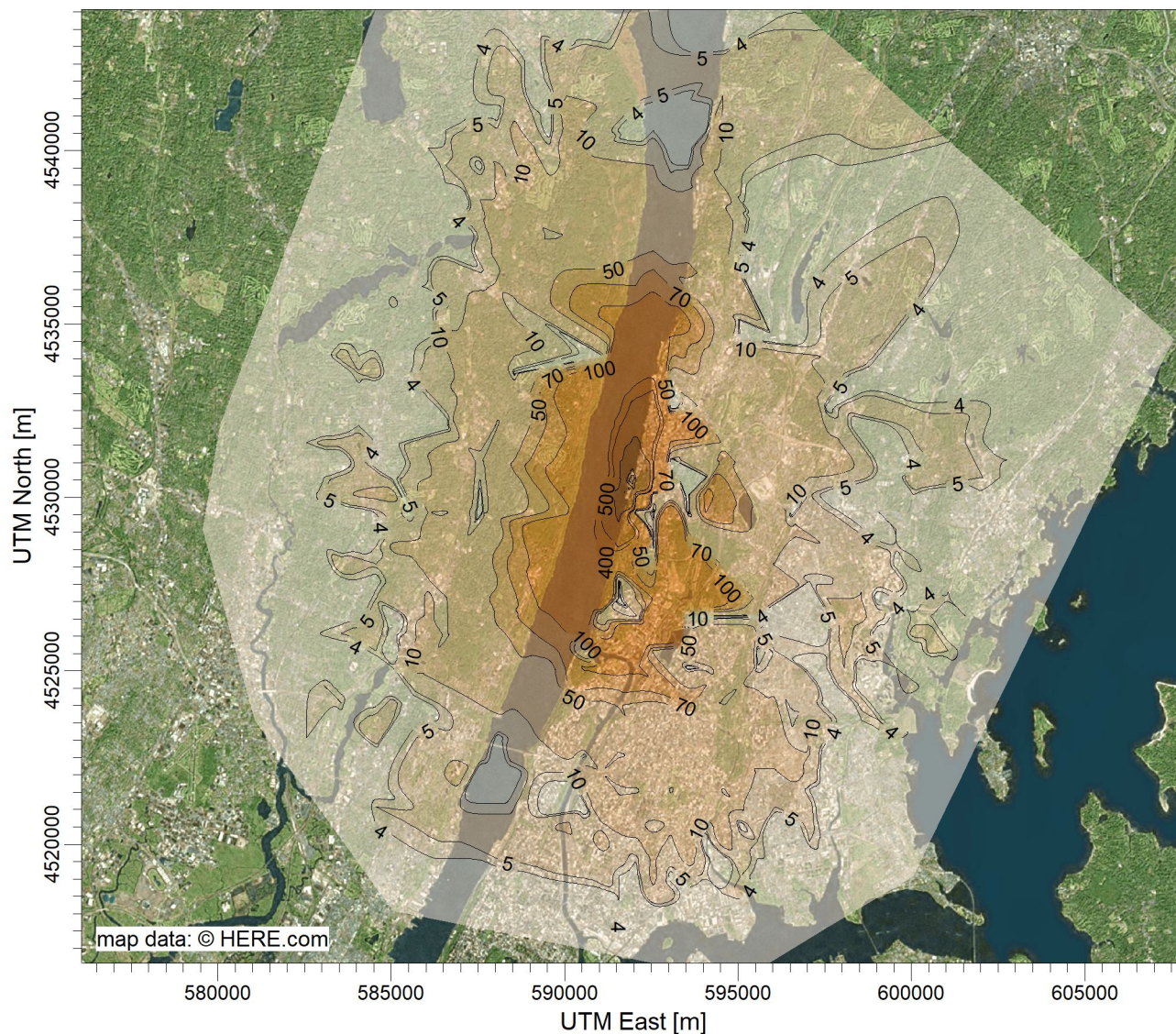
COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:200,000 0 5 km	
	MAX: 596 OU/M**3	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.10

Frequency of Impacts, Scenario 2

DAF Bay Doors closed



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 17020 [COUNT] at (591950.13, 4530481.87)



COMMENTS:

SOURCES:

COMPANY NAME:

11

RECEPTORS:

MODELER:

6483

OUTPUT TYPE:

SCALE:

1:200,000

Concentration

0 5 km

MAX:

DATE:

PROJECT NO.:

17020 COUNT

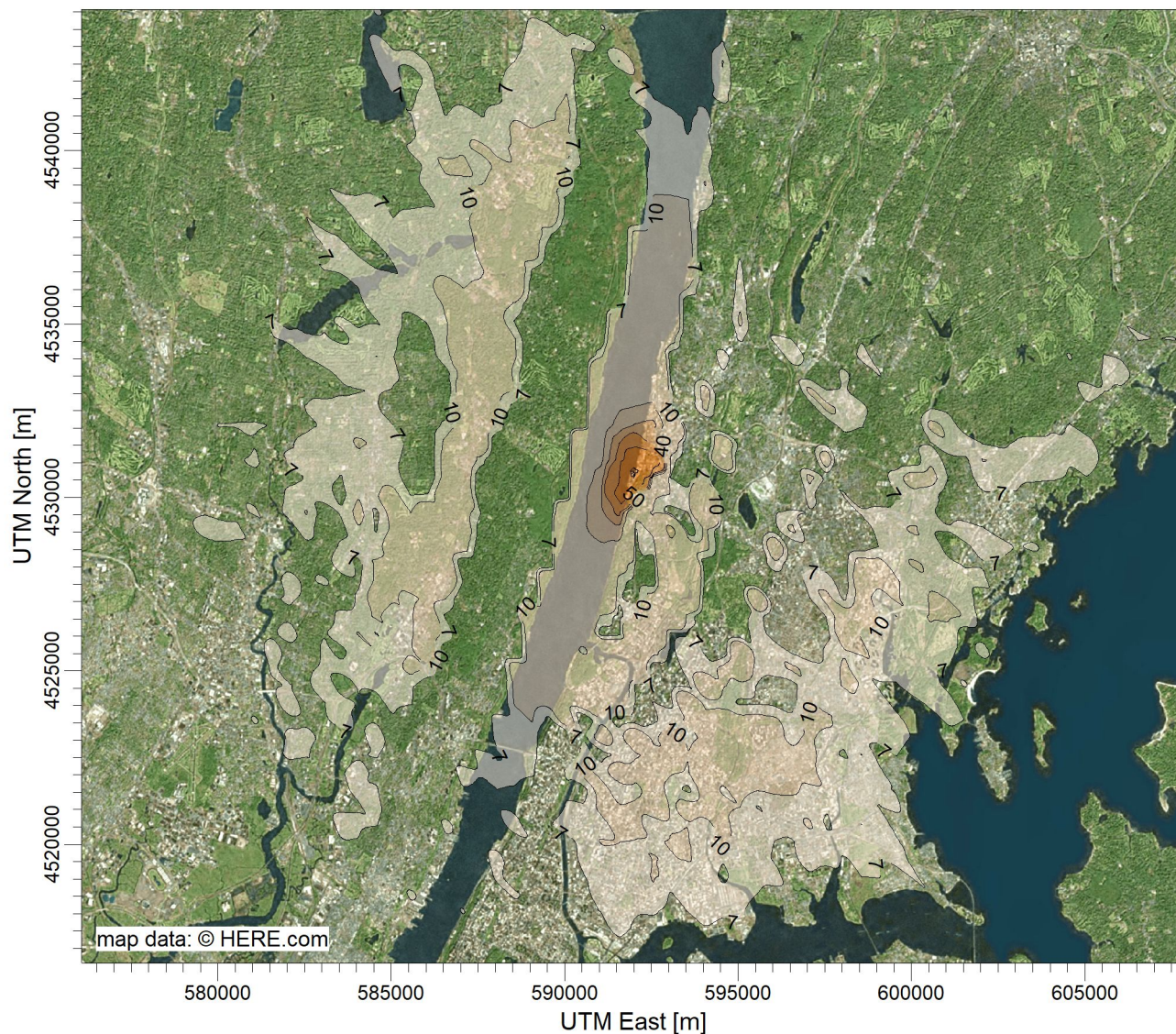
3/9/2018

221628

PROJECT TITLE:

Figure 4.4.11

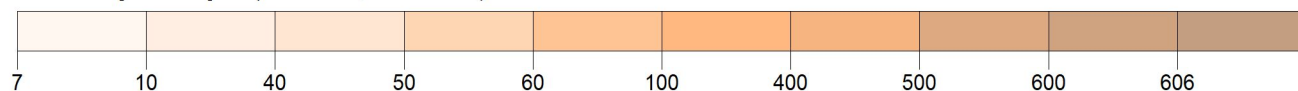
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Scenario 3 Screenings Bay Door Closed



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: SCNR03

OU/M**3

Max: 606 [OU/M**3] at (591929.39, 4530438.74)



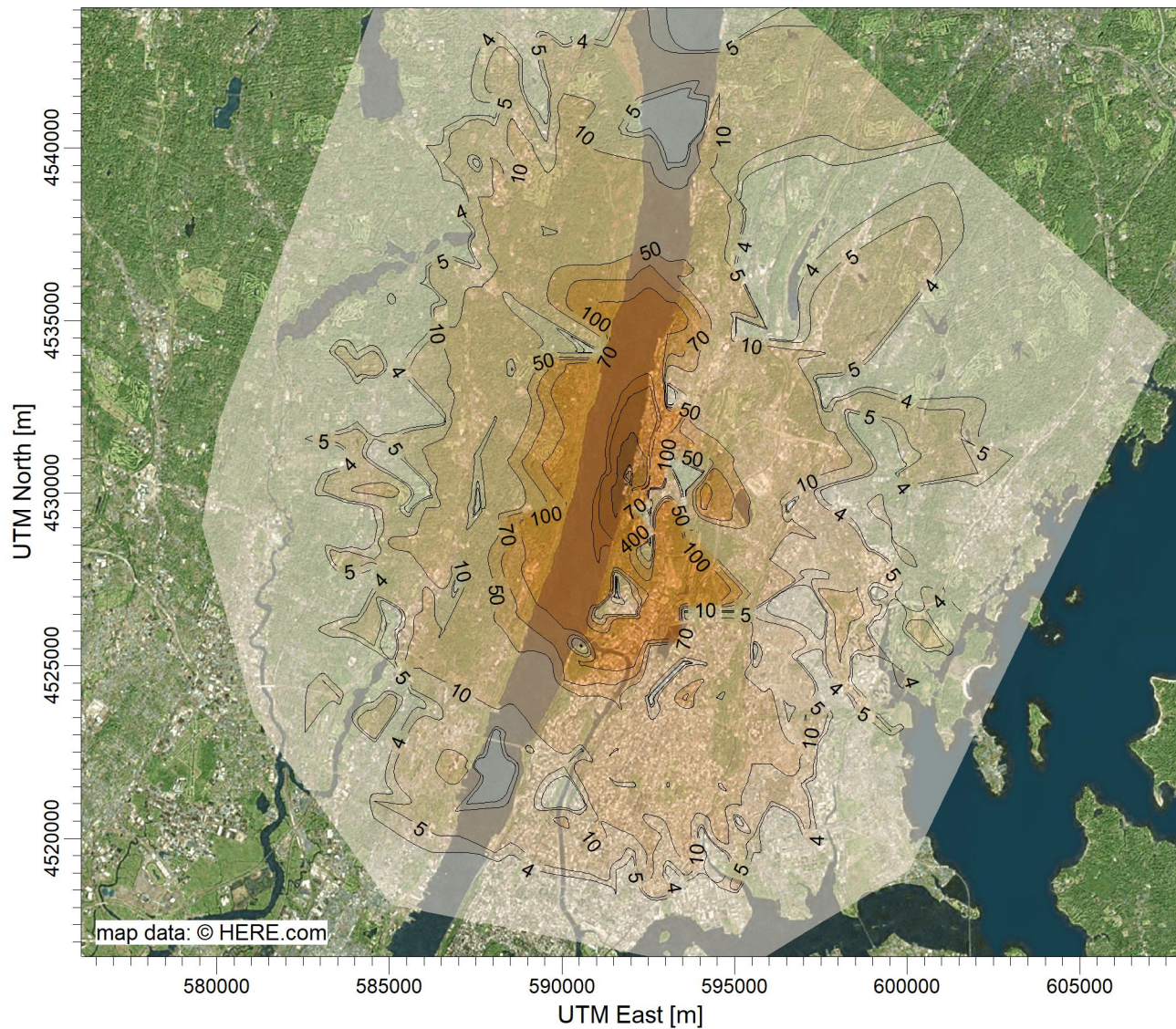
COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:200,000 0 5 km	
	MAX: 606 OU/M**3	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.12

Frequency of Impacts, Scenario 3

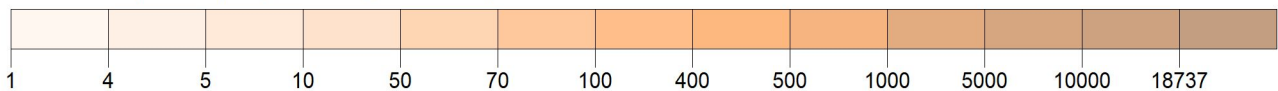
Screenings Bay Door Closed



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 18737 [COUNT] at (591938.82, 4530460.96)



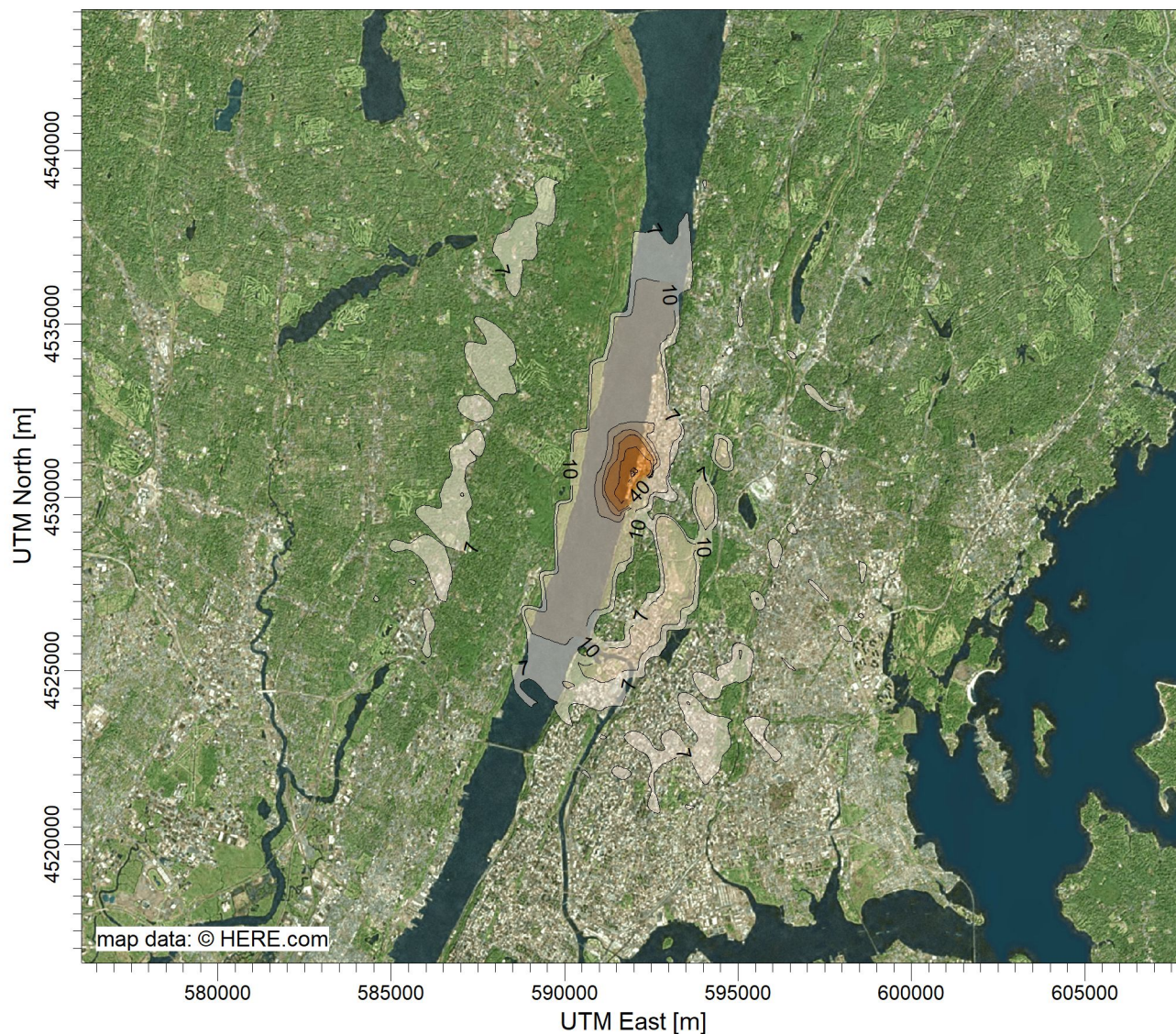
COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:200,000 0 5 km	
	MAX: 18737 COUNT	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.13

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Scenario 4

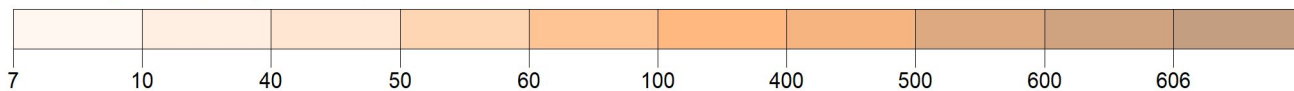
Scrubbers A, B, C controlled



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: SCNR04

OU/M**3

Max: 606 [OU/M**3] at (591929.39, 4530438.74)



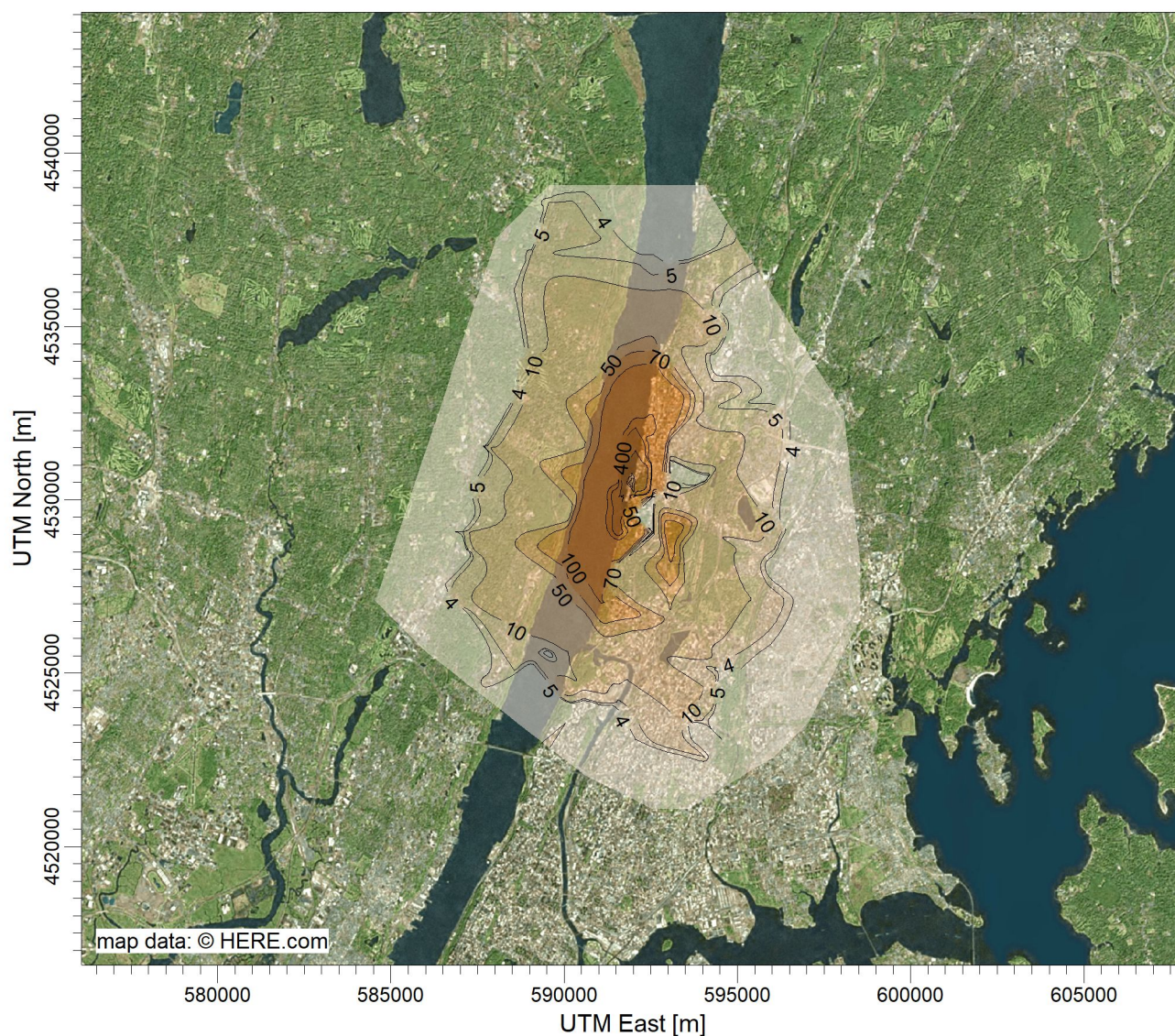
COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:200,000 0 5 km	
	MAX: 606 OU/M**3	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.14

Frequency of Impacts, Scenario 4

Scrubbers A, B, and C Controlled



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 16476 [COUNT] at (591938.82, 4530460.96)

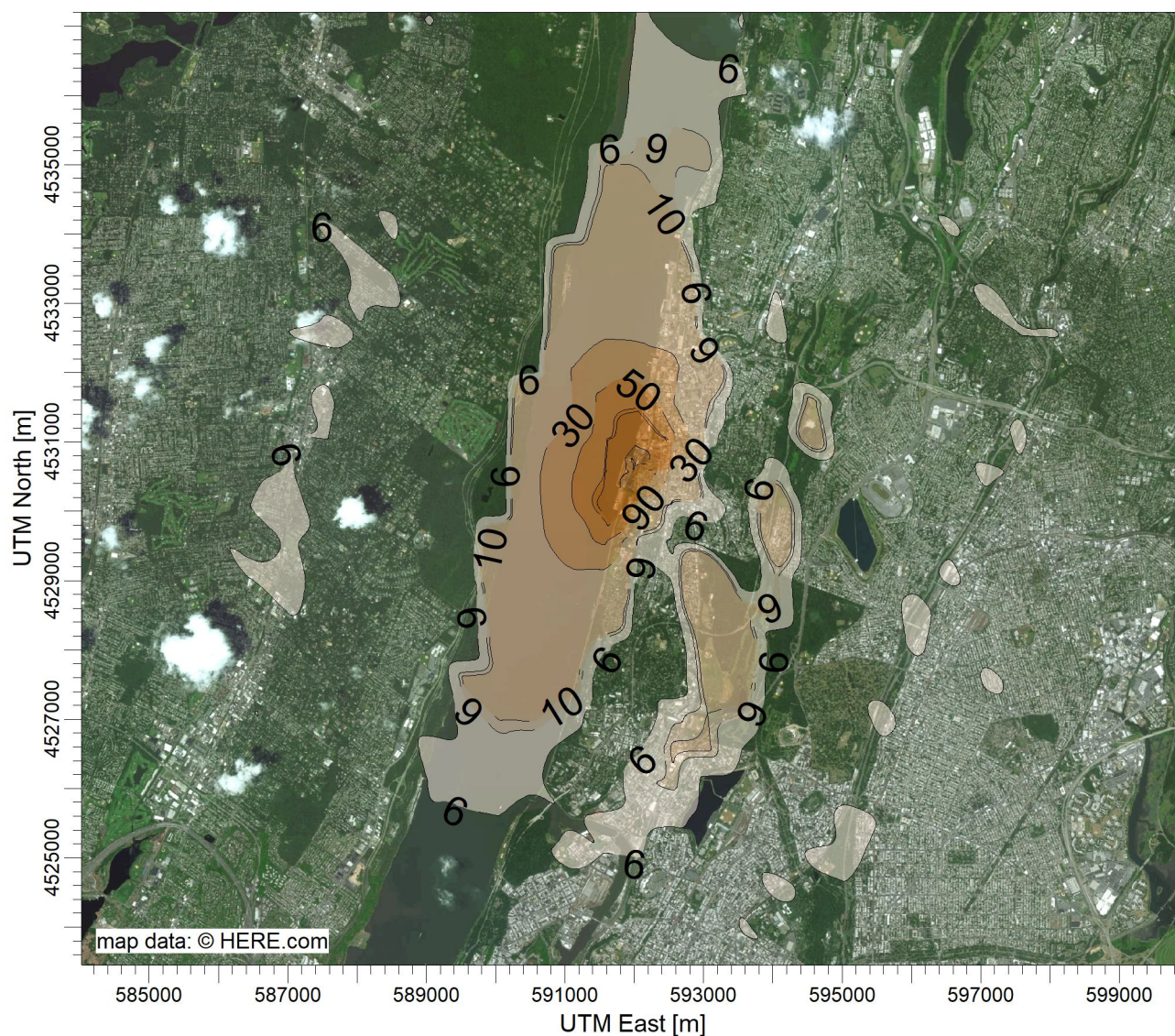


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:200,000
	Concentration	0 5 km	
	MAX:	DATE:	PROJECT NO.:
	16476 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.15

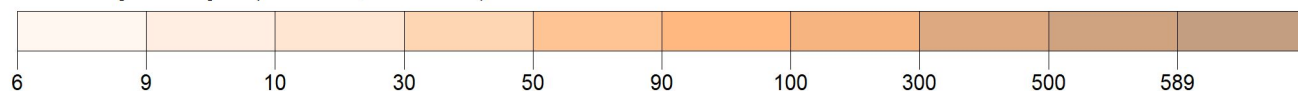
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Aeration Tanks



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: AERTNKS

OU/M**3

Max: 589 [OU/M**3] at (591919.95, 4530416.51)

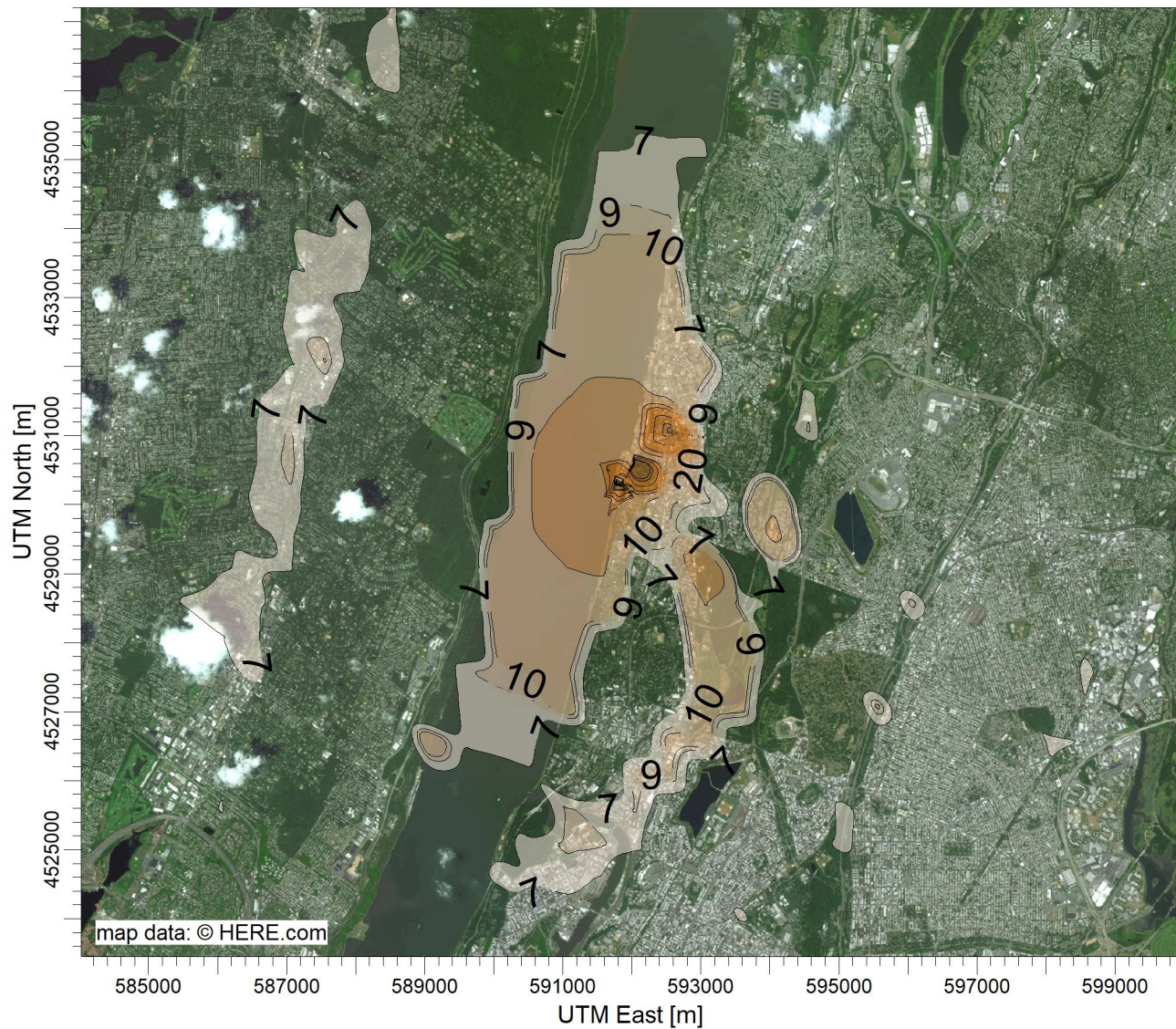


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:100,000
	Concentration	0 4 km	
	MAX:	DATE:	PROJECT NO.:
	589 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.16

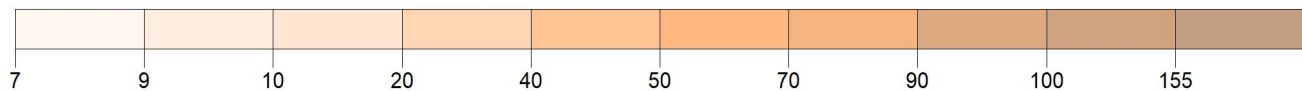
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Scrubber A, B, C Common Exhaust



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: CEABC

OU/M**3

Max: 155 [OU/M**3] at (592058.63, 4530579.58)

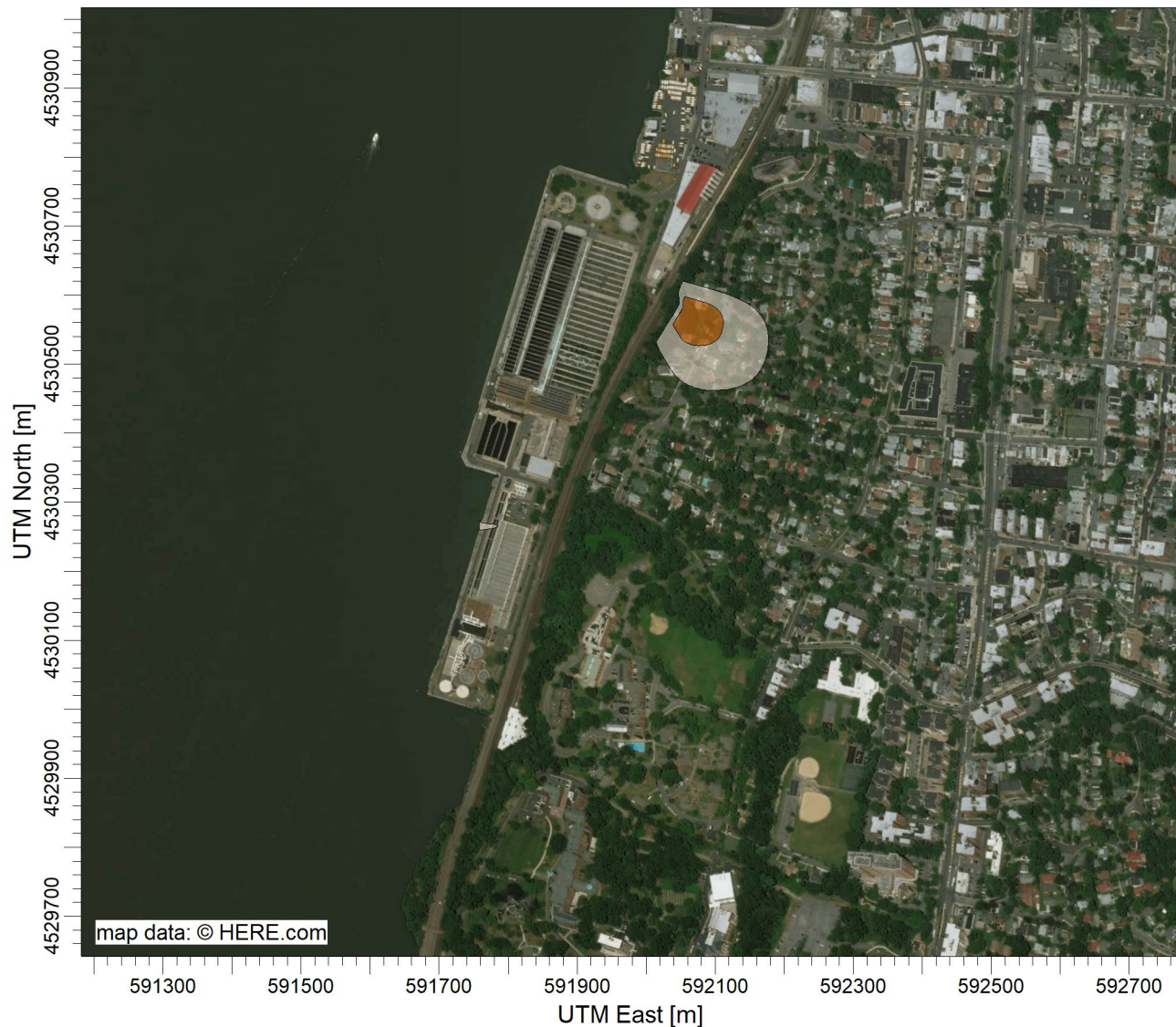


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:100,000
	Concentration	0 4 km	
	MAX:	DATE:	PROJECT NO.:
	155 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.17

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Scrubbers A, B, and C Controlled



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: CEABCR

OU/M**3

Max: 8.81 [OU/M**3] at (592058.63, 4530579.58)

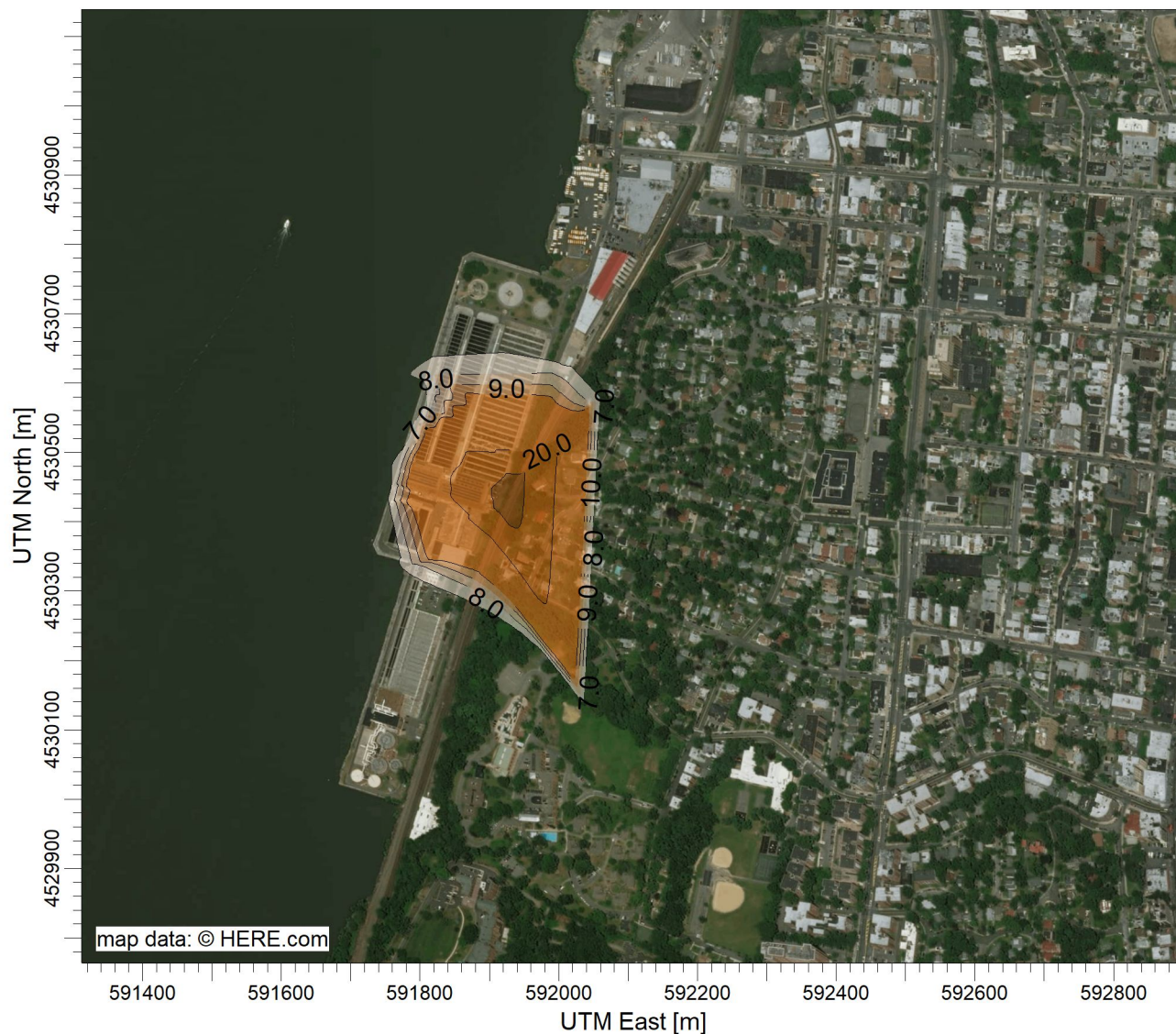


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0 0.3 km	
	MAX:	DATE:	PROJECT NO.:
	8.81 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.18

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: DAF Bay Door Open




PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: DAFBAY

OU/M**3

Max: 34.6 [OU/M**3] at (591929.39, 4530438.74)



COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	34.6 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.19

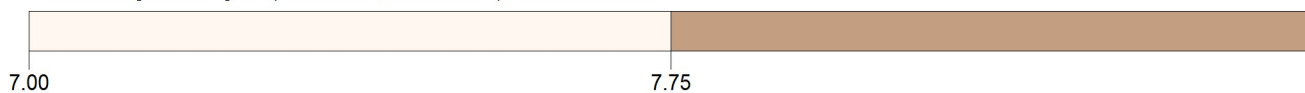
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Dispersion fan




PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: DISFAN

OU/M**3

Max: 7.75 [OU/M**3] at (591696.07, 4530065.23)



COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	7.75 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.20

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Secondary Effluent Channel



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: EFFLU

OU/M**3

Max: 18.9 [OU/M**3] at (591921.19, 4530772.82)

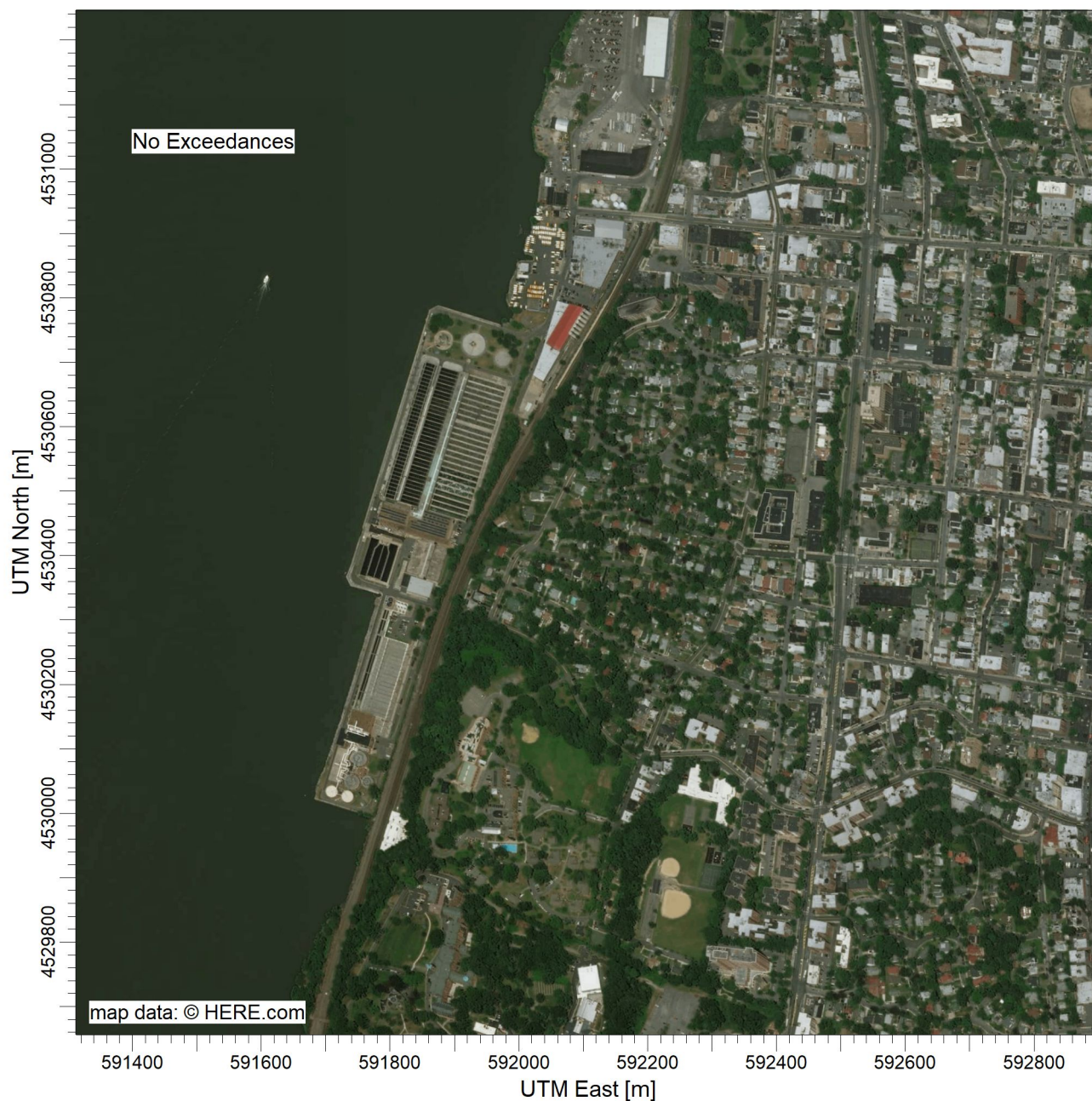


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0 0.3 km	
	MAX:	DATE:	PROJECT NO.:
	18.9 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.21

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: South Flare



COMMENTS:

SOURCES:

11

COMPANY NAME:

RECEPTORS:

6483

MODELER:

OUTPUT TYPE:

Concentration

SCALE: 1:10,000

0 0.3 km

MAX:

2.24 OU/M3**

DATE:

3/9/2018

PROJECT NO.:

221628

PROJECT TITLE:

Figure 4.4.22

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Aeration Influent Channel Vent




PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: INFVENT

OU/M**3

Max: 34.7 [OU/M**3] at (591972.75, 4530523.69)

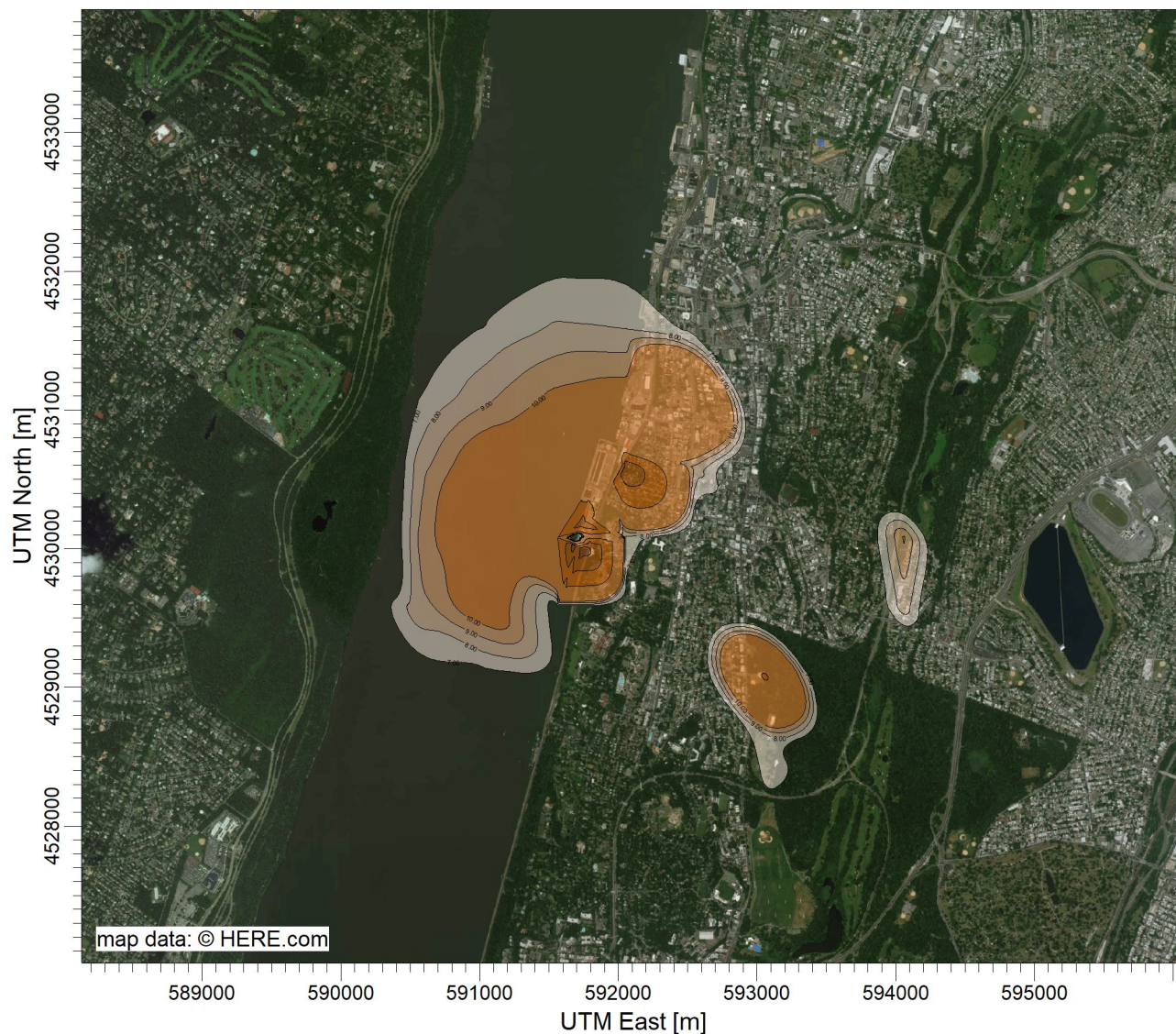


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	34.7 OU/M**3	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.23

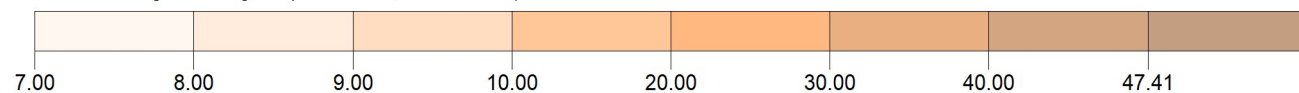
Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Scrubber 2, 3, and 4 Stack




PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: MS234

OU/M**3

Max: 47.41 [OU/M**3] at (591751.23, 4529997.24)



COMMENTS:	SOURCES: 11	COMPANY NAME:	
	RECEPTORS: 6483	MODELER:	
	OUTPUT TYPE: Concentration	SCALE: 1:50,000 0  2 km	
	MAX: 47.41 OU/M**3	DATE: 3/9/2018	PROJECT NO.: 221628

PROJECT TITLE:

Figure 4.4.24

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: North Flares



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: NFLARES

OU/M**3

Max: 8.26 [OU/M**3] at (591944.47, 4530766.01)



COMMENTS:

SOURCES:

COMPANY NAME:

11

RECEPTORS:

MODELER:

6483

OUTPUT TYPE:

SCALE: 1:10,000

Concentration

0 0.3 km

MAX:

DATE:

PROJECT NO.:

8.26 OU/M3**

3/9/2018

221628

PROJECT TITLE:

Figure 4.4.25

Magnitude Isopleths, Odor Units (D/T), 5-min averaging, Source: Screenings Bay




PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: SCRBY

OU/M**3

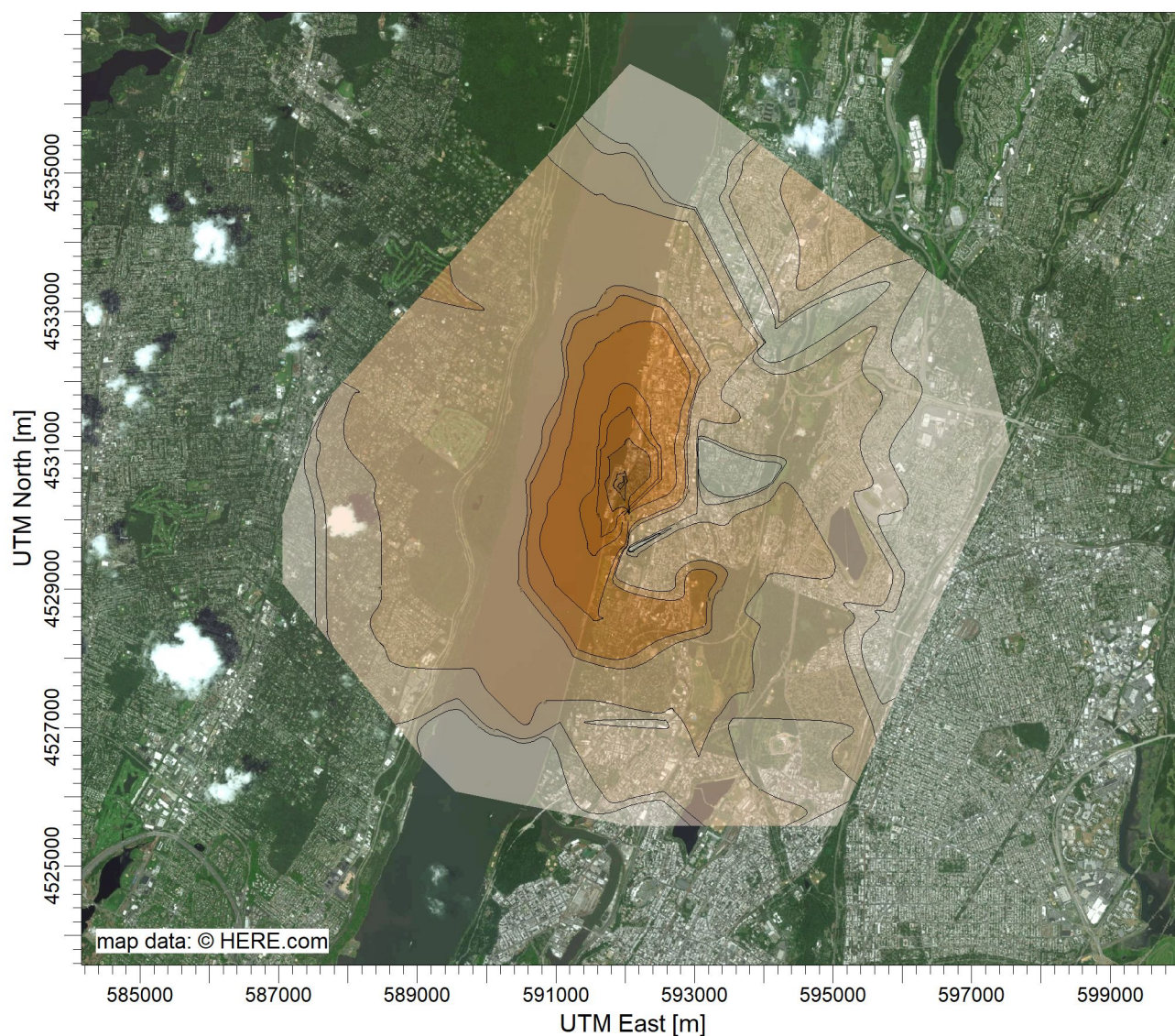
Max: 15.2 [OU/M**3] at (591724.75, 4530155.98)



COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	15.2 OU/M**3	3/9/2018	221628

PROJECT TITLE:

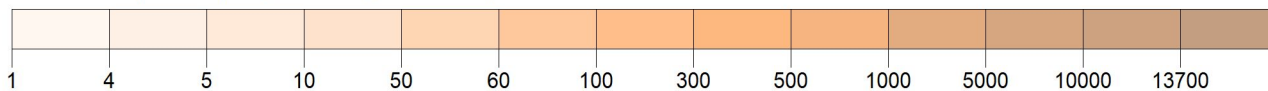
Figure 4.4.26
Frequency of Impacts, Source: Aeration Tanks



EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 13679 [COUNT] at (591950.13, 4530481.87)

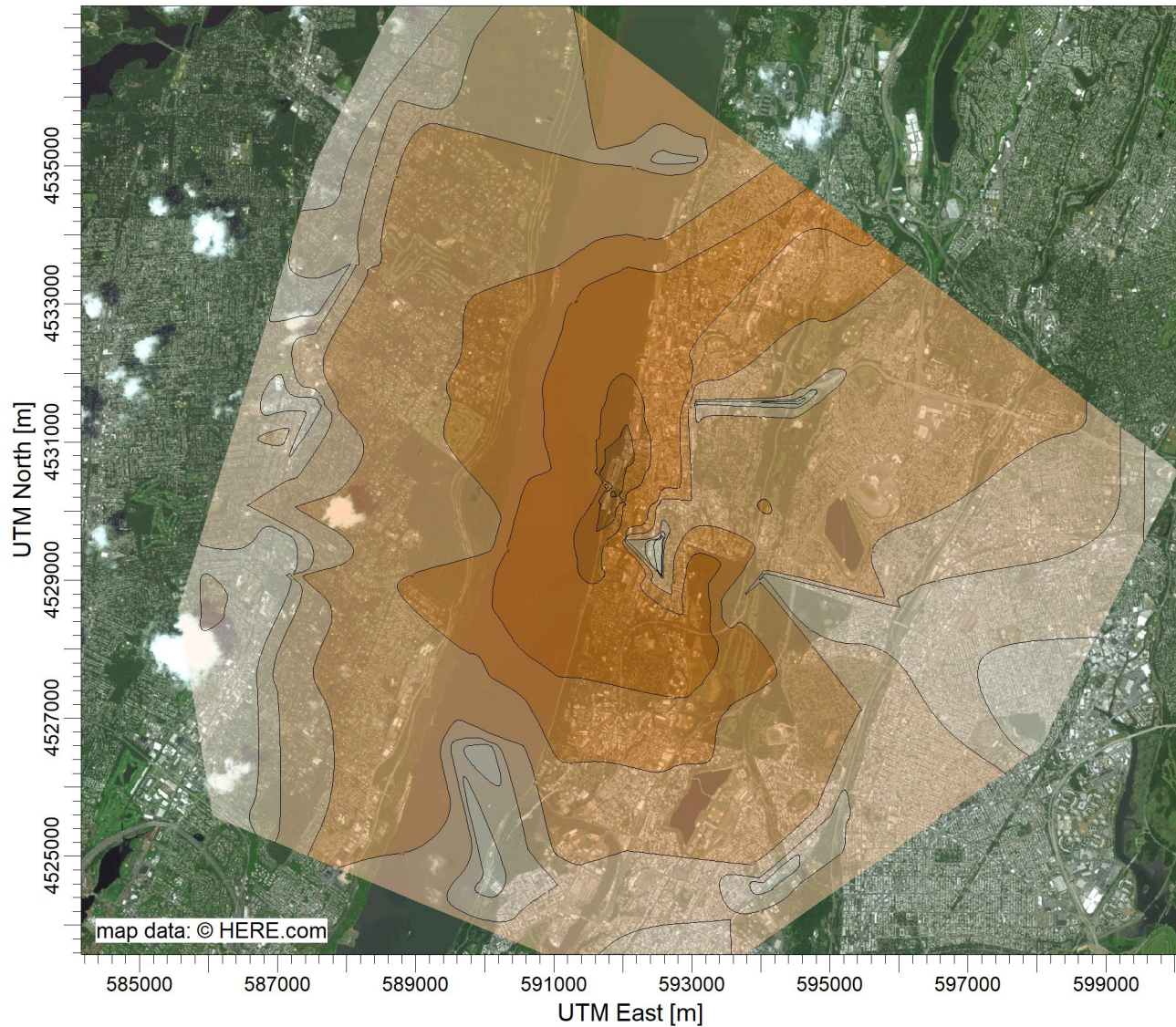


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:100,000
	Concentration	0 4 km	
	MAX:	DATE:	PROJECT NO.:
	13679 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.27

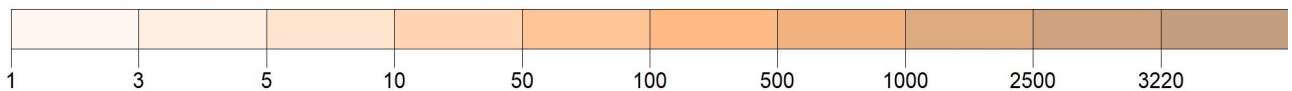
Frequency of Impacts, Source: Scrubbers A, B, and C Common Exhaust




EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 3219 [COUNT] at (591860.66, 4530260.03)

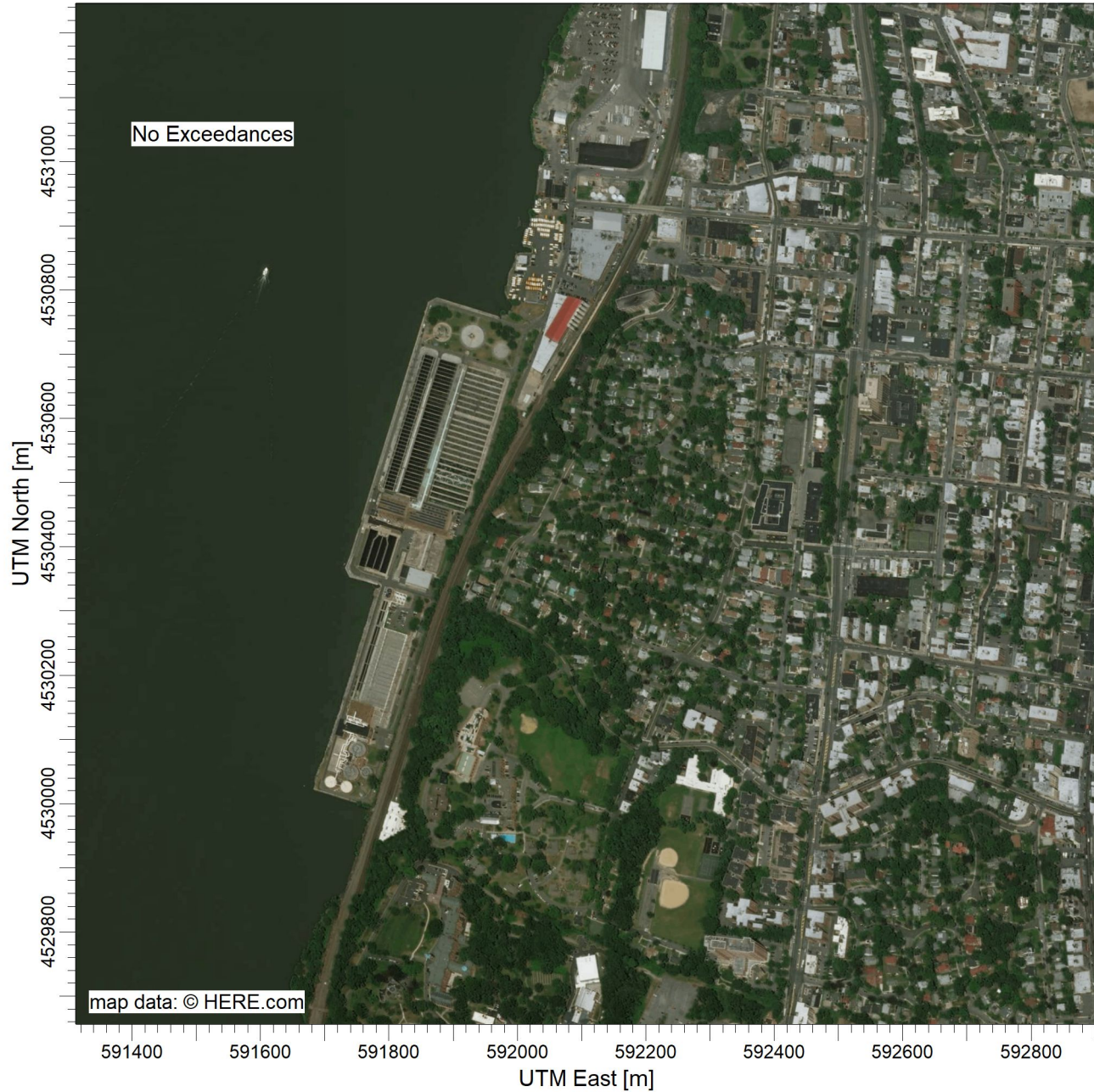


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:100,000
	Concentration	0  4 km	
	MAX:	DATE:	PROJECT NO.:
	3219 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.28

Frequency of Impacts, Source: Scrubbers A, B, and C Exhaust Controlled



COMMENTS:

SOURCES:

11

COMPANY NAME:

RECEPTORS:

6483

MODELER:

OUTPUT TYPE:

Concentration

SCALE: 1:10,000

0 0.3 km

MAX:

7.00 COUNT

DATE:

3/9/2018

PROJECT NO.:

221628

PROJECT TITLE:

Figure 4.4.29

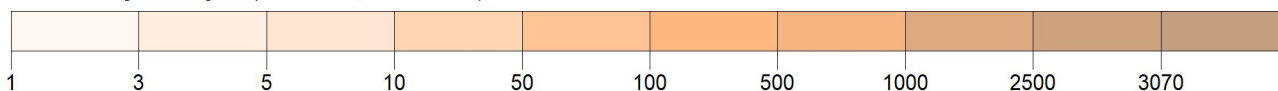
Frequency of Impacts, Source: DAF Bay Door




EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 3070 [COUNT] at (591919.95, 4530416.51)

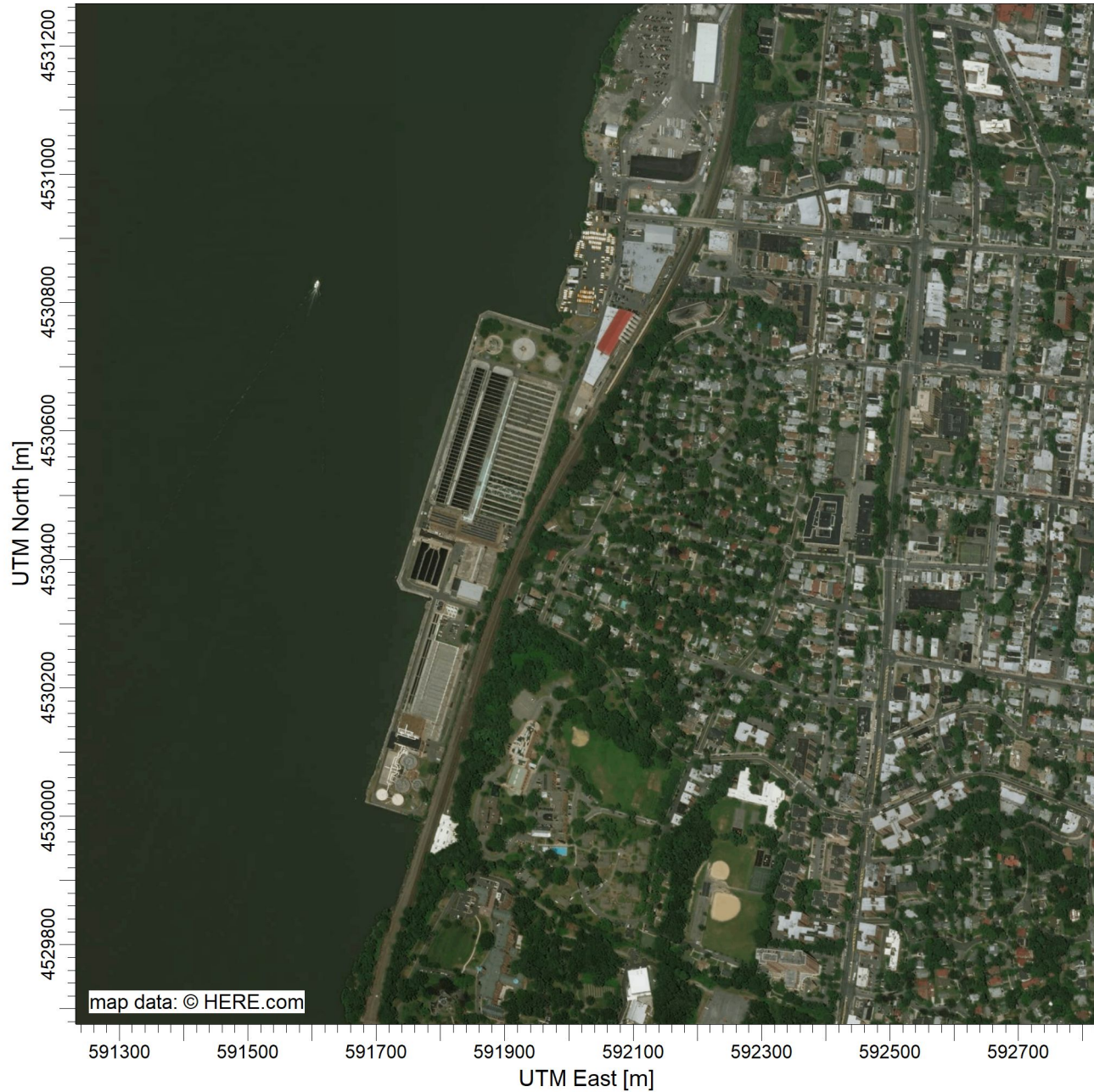


COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	3070 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.30

Frequency of Impacts, Source: Dispersion fan



COMMENTS:

SOURCES:

11

COMPANY NAME:

RECEPTORS:

6483

MODELER:

OUTPUT TYPE:

Concentration

SCALE: 1:10,000

0 0.3 km

MAX:

2.00 COUNT

DATE:

3/9/2018

PROJECT NO.:

221628

PROJECT TITLE:

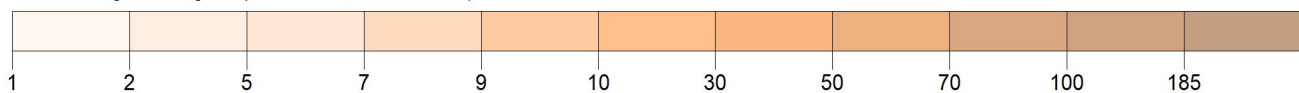
Figure 4.4.31
Frequency of Impacts, Source: Secondary Effluent Channels




EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 185 [COUNT] at (591921.19, 4530772.82)



COMMENTS:	SOURCES:	COMPANY NAME:	
	11		
	RECEPTORS:	MODELER:	
	6483		
	OUTPUT TYPE:	SCALE:	1:10,000
	Concentration	0  0.3 km	
	MAX:	DATE:	PROJECT NO.:
	185 COUNT	3/9/2018	221628

PROJECT TITLE:

Figure 4.4.32

Frequency of Impacts, Source: Aeration Tanks influent Channel Vent




EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

Max: 1402 [COUNT] at (591972.75, 4530523.69)

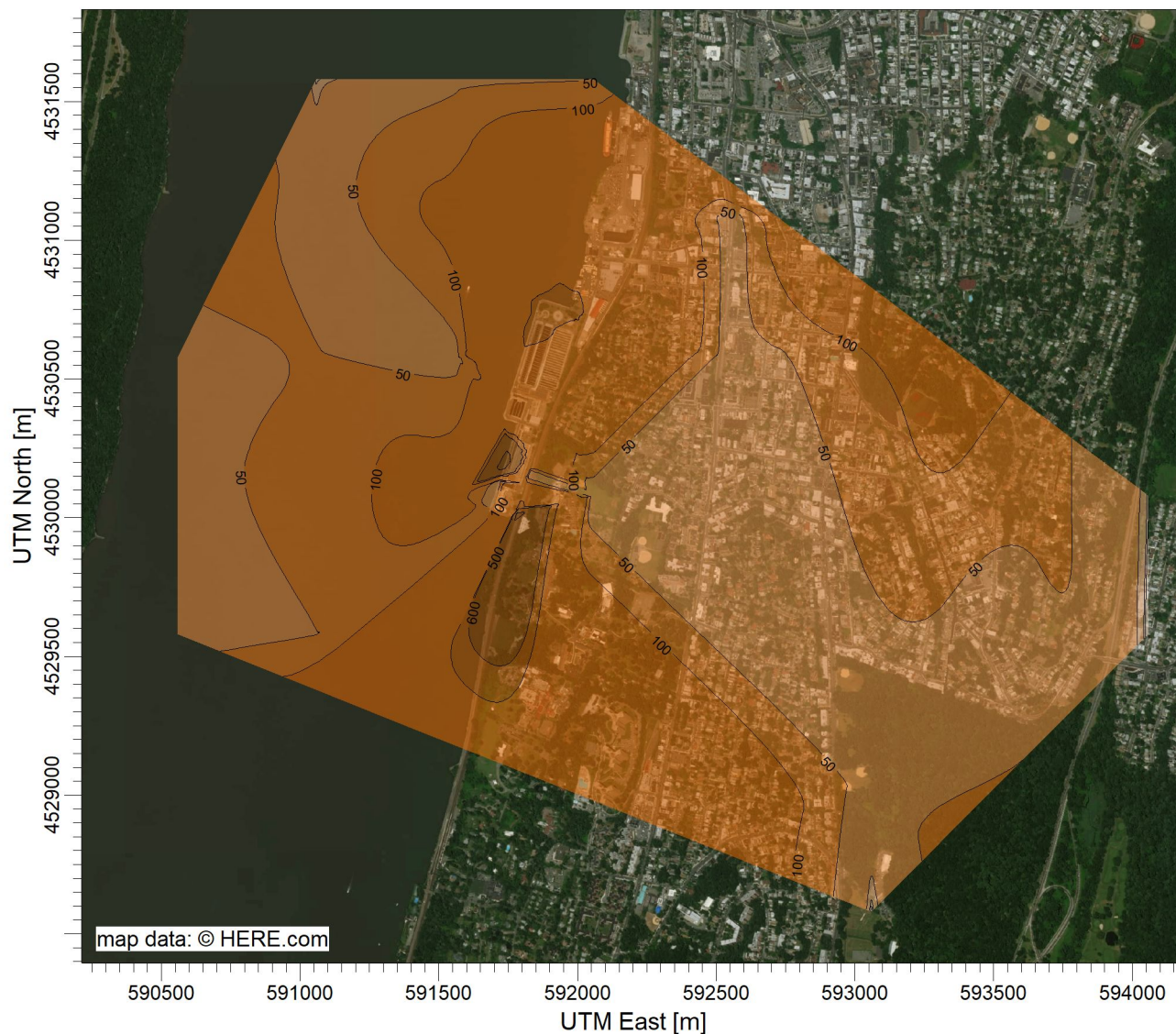


COMMENTS:	SOURCES:	COMPANY NAME:	
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PROJECT TITLE:

Figure 4.4.33

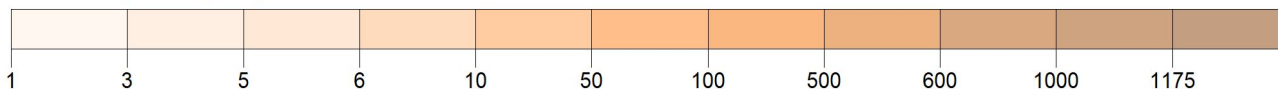
Frequency of Impacts, Source: Scrubbers 2, 3, and 4 Exhaust Stack




EXCEEDANCE FILE FOR 1-HR VALUES \geq A THRESHOLD OF 7.000

COUNT

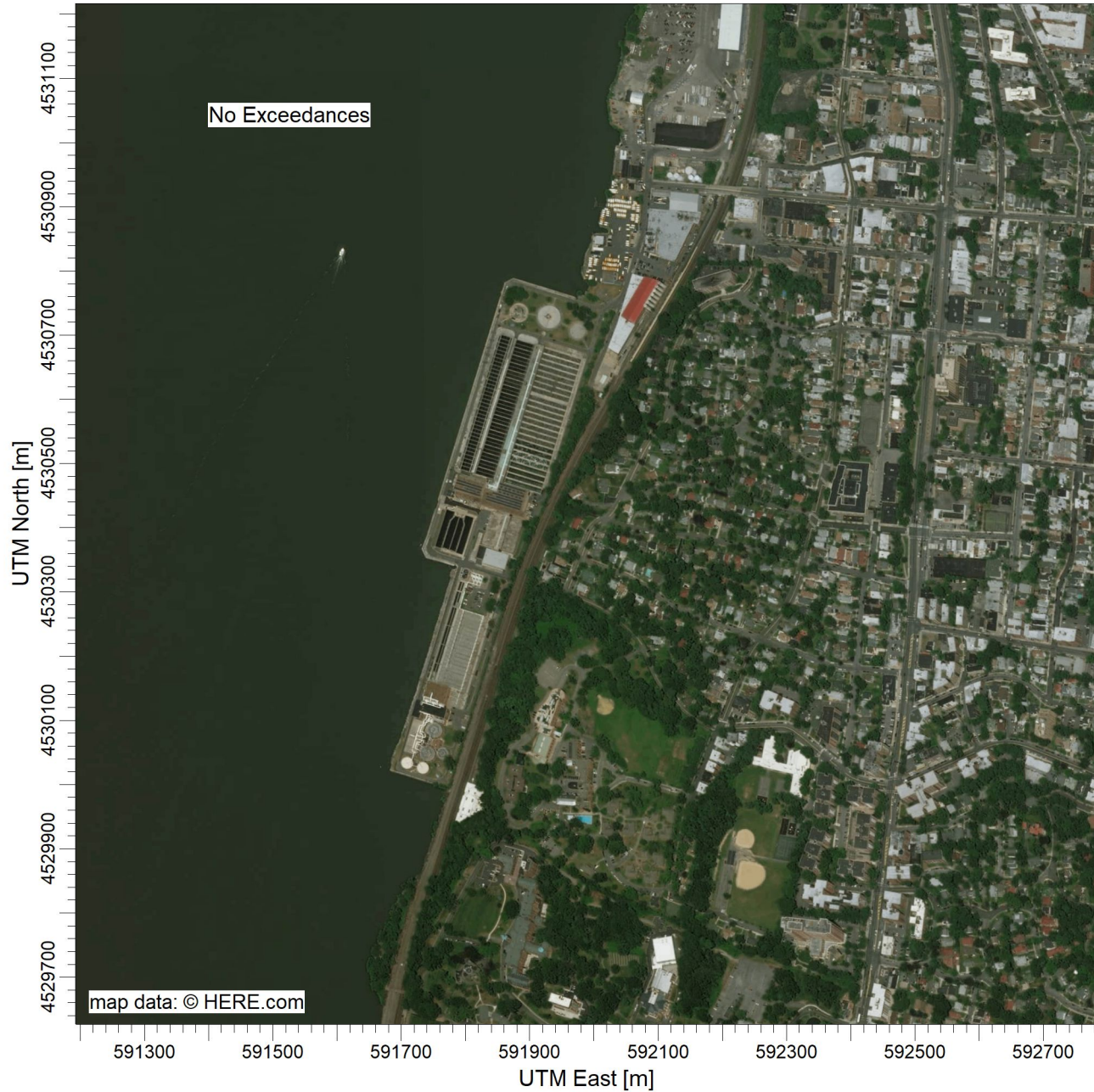
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PROJECT TITLE:

Figure 4.4.34
Frequency of Impacts, Source: North Flares



COMMENTS:

SOURCES:

11

COMPANY NAME:

RECEPTORS:

6483

MODELER:

OUTPUT TYPE:

Concentration

SCALE: 1:10,000

0 0.3 km

MAX:

3.00 COUNT

DATE:

3/9/2018

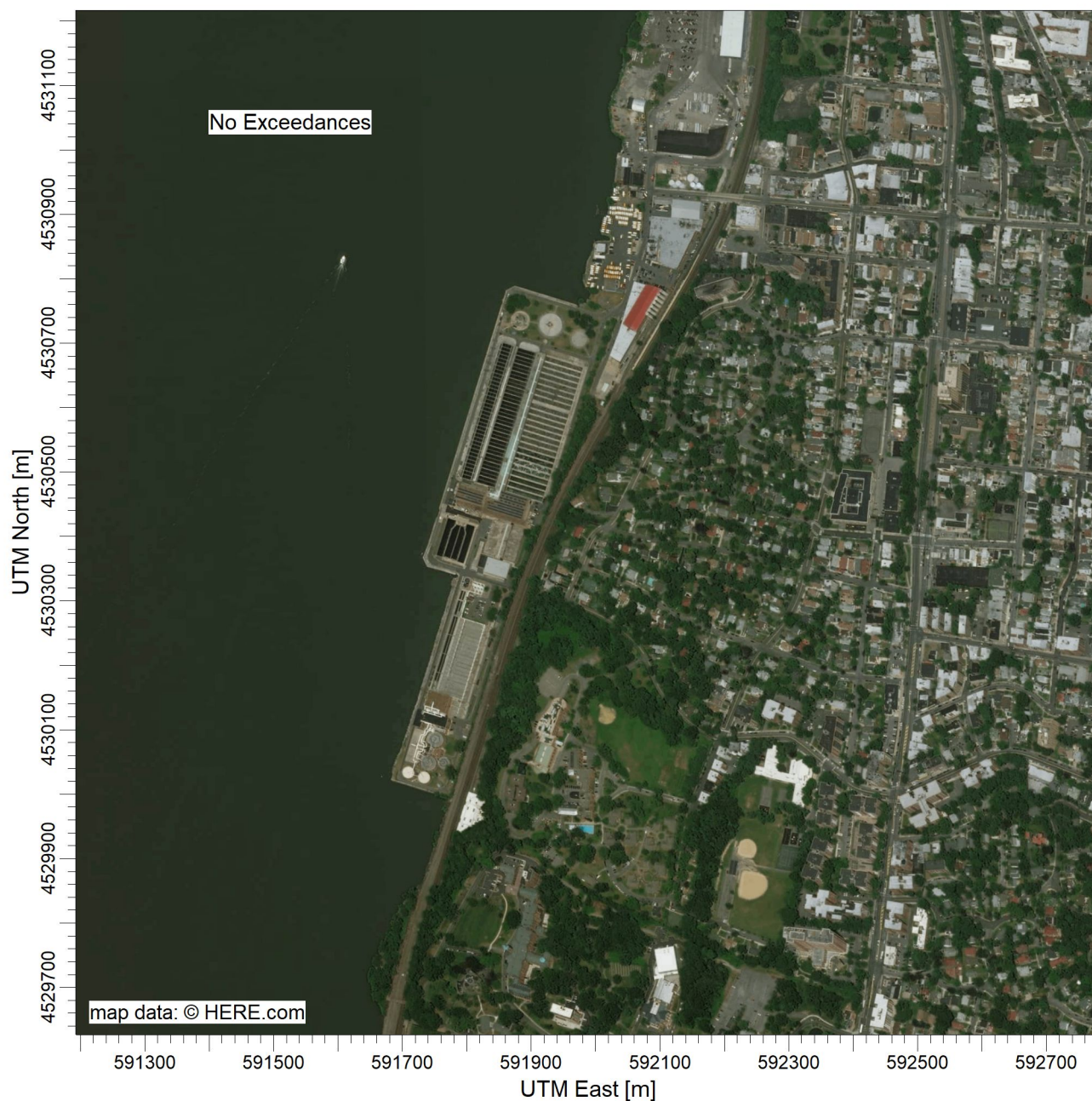
PROJECT NO.:

221628

PROJECT TITLE:

Figure 4.4.35

Frequency of Impacts, Source: Screenings Bay Door



COMMENTS:

SOURCES:

11

COMPANY NAME:

RECEPTORS:

6483

MODELER:

OUTPUT TYPE:

Concentration

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MAX:

1473 COUNT

DATE:

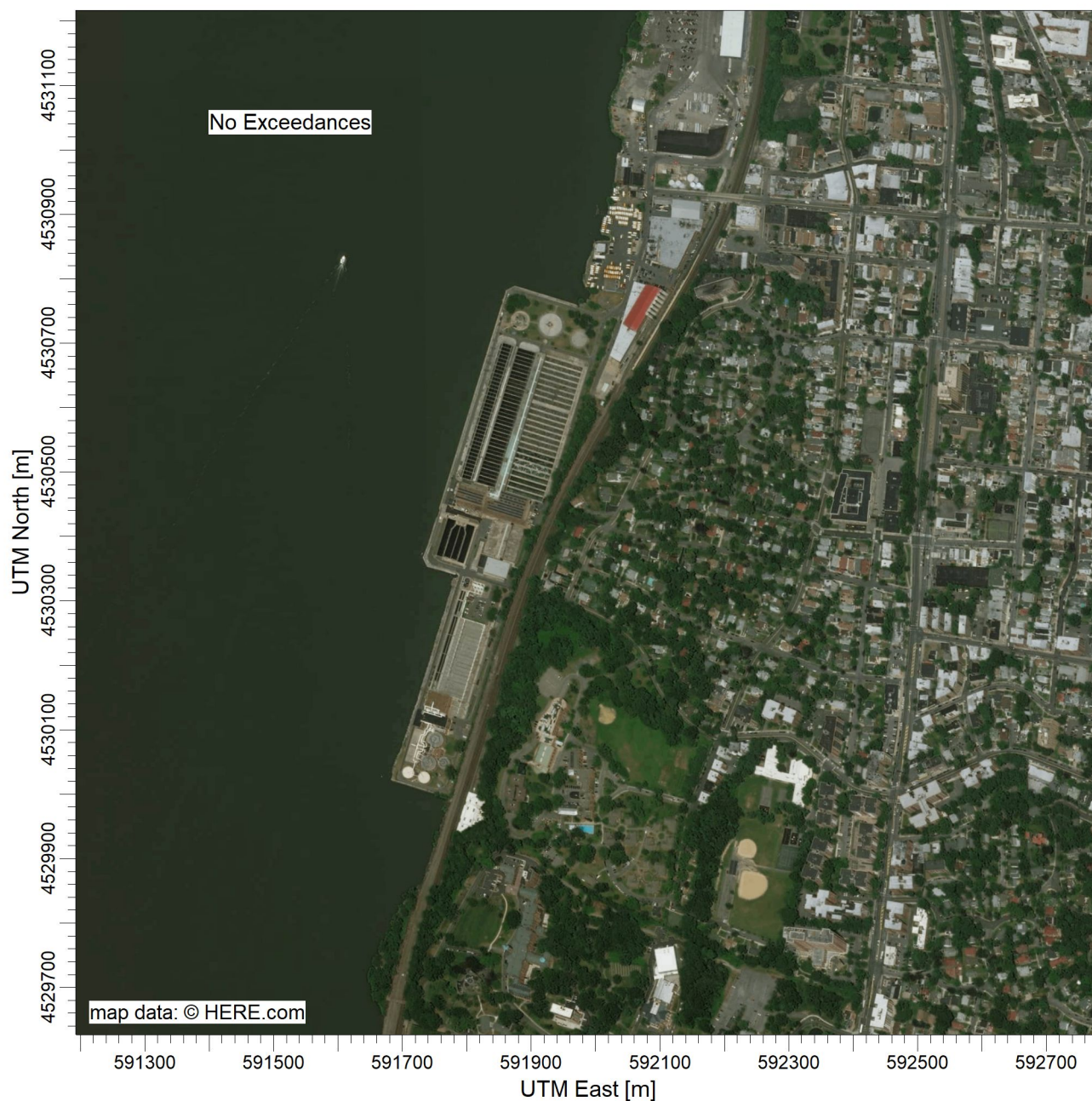
3/9/2018


PROJECT NO.:

221628

PROJECT TITLE:

Figure 4.4.36
Frequency of Impacts, Source: South Flares



COMMENTS:	SOURCES:	COMPANY NAME:	
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	MAX:	DATE:	PROJECT NO.:
	1.000 COUNT	3/9/2018	221628

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Section 5

Grit Tanks and Primary Settling Tanks Maintenance Improvements

When tanks are taken out of service, and residual material such as grit, sludge and scum can release odors into the atmosphere. Typically, when tanks are being drained the tank covers are opened to allow the plant staff to manually spray down the interior of the tanks as well as to provide additional ventilation. In reviewing this procedure, two options were identified for mitigating these odors. The first option is to install an automatic wash down system, which would assist with the removal of and conveyance of residual material while keeping the covers closed, allowing for odors to remain contained while the tanks are being taken down. The second option is to increase the airflow rates in the tanks being taken out of service and conveying that air to scrubbers to avoid fugitive odors.

5.1 Grit Tank Servicing

The three scrubbers currently servicing this area are Siemens LO/PRO Scrubbers 1, 2 and 3 sized for 15,525 CFM each and service the Screen and Grit areas. As the air flow from this area is well below the total design flow of the system, the existing scrubbers are anticipated to be adequate to treat any additional odors associated with the Grit Tanks being taken out of service. When airflow and odor data was collected during the sampling program, only one scrubber was in operation.

When a grit tank is taken out of service, an additional scrubber should be taken out of standby mode and placed into operation. This will allow for increased airflow in the grit tank that is being drained and cleaned, while the covers remain closed. To facilitate the ventilation, dampers will need to be added or adjusted so that airflow is increased in the tank being taken out of service. When the tank has been fully drained an automatic washdown cycle can be initiated. Once the washdown is complete, the covers can be opened for inspection. When the tank covers are opened, the additional scrubber if in standby mode, should be turned on to pull any odorous air in the tank through the odor control units instead of being allowed to escape through the open covers. Any additional washdown of the tank can then be performed by plant staff, through the openings. When the tank is ready to be placed back into service the covers would be closed and ventilation would be returned to normal operation.

5.2 Primary Settling Tank Servicing

The three scrubbers servicing the Primary Tanks are sized for 11,500 CFM each. Based on the results of the odor control sampling, it is recommended that these scrubbers be retrofitted with packed media or replaced as they are nearing the end of their useful life. The retrofit of the existing scrubbers with packed media should be considered a near term option since it can be implemented in a short timeframe and is a less costly option to achieve more efficient odor removal. It is recommended that one of the existing scrubbers would be retrofitted, reevaluated

for efficiency, and then a determination on whether the other two scrubbers should be retrofit or replaced.

5.2.1 Primary Scrubber Packed Media Retrofit

Scrubbers A, B, & C are designed as mist scrubbers and have no internal packing material. The odor removal mechanism for mist scrubbers is based on misting the chemical reactants with compressed air into the empty vessel where they contact the odorous air molecules; this process is inherently inefficient. Packed tower scrubber design relies on the odorous molecules in the air making contact on a liquid film of the chemical reactants located on plastic packing material. The movement of odorous sulfur compounds into the liquid film is enhanced by the high pH of the solution.

The mist scrubber and packed tower scrubber have different design criteria to size the vessel. Mist tower designs are primarily a function of residence time, packed tower vessel diameters are based on velocity (400 – 500 ft/min), the height of the vessel is based on the height of the packing base, which is a function of the inlet H₂S levels and performance requirements (percent removal).

Renovation of a mist tower scrubber to a packed tower design can be achieved with modifications. Table 5.2.1 shows the basic conversion calculations for primary tank mist scrubbers (A, B, & C), and shows that a single mist tower vessel could accommodate the entire total of 23,000 cfm that scrubbers A, B, & C treat, operating as two duty and one stand-by. This further supports the recommendation to only retrofit one scrubber initially. The height of the existing towers would accommodate a sump, ten feet of packing, and an irrigation nozzle assembly, enough to treat the design H₂S load.

Table 5.2.1. Chemical Scrubber Calculations

Scrubber	Diameter (ft)	Mist Tower Design Airflow (cfm)	Packed Tower Airflow at 400 ft/min (cfm)
A	12	11,500	45,216
B	12	11,500	45,216
C	12	11,500	45,216

Considerations for modification are:

- Storage Tank capacity may have to be increased.
- Chemical pump capacity may have to be increased.
- Vessel Structure:
 - The vessel will require an analysis by a structural engineer that specializes in fiberglass design to confirm the ability of the existing tower to accommodate renovation with the additional loads on the sidewall from the addition of packing material.
 - Supports for internal grating and will be required inside the vessel.
 - Additional nozzles (flanged pipe fittings) will be required to be installed on the vessel to accommodate recirculation piping, make-up water piping, drainage piping, chemical addition piping, pH and ORP probes.

- Manways will be required in the sidewall of the tank to facilitate the addition and removal of packing media.
- Recirculation Pumps. Duty/Stand-by recirculation pumps that recirculate the chemical solution from the vessel sump to the irrigation nozzles located in the top of the tower are required.

Table 5.2.2 Opinion of Probable Construction Cost

Description	Opinion of Probable Construction
Packing Media, supports, piping, pumps, manways for one scrubber	\$100,000
Contractor Overhead and Profit (15%)	\$15,000
Subtotal Material and Labor	\$115,000
Contingency (25%)	\$28,750
Soft Costs – Engineering, Construction Admin. (20%)	\$23,000
Total	\$166,750

5.2.2 Primary Scrubber Replacement

If the retrofit of one of the existing scrubbers does not yield the desired results, more efficient, single or dual stage scrubbers are recommended for this replacement. These new scrubbers would be sized to not only treat the airflow from normal operation, but also have the ability to increase capacity when a tank is being taken out of service. Similar to the Grit Tanks, automatic washdown stations would be installed to allow the tanks being taken out of service to be washed down without the covers being opened. While washdown occurs, ventilation in tanks being taken out of service would be increased to treat the any odorous air. This would be accomplished by installing new dampers to pull additional air from the out-of-service tank(s). When the tank has been fully drained, an automatic washdown cycle can be initiated. Following the washdown, the covers would be opened for inspection. When the tank cover(s) are opened, the additional scrubber capacity would be utilized to pull any odorous air in the tank through the odor control units instead of being allowed to escape through the open covers. The tank would then be washed down further by the Plant, through the openings. When the tank is ready to be placed back into service, the covers would be closed, and ventilation would be returned to normal operation.

Table 5.2.3 Opinion of Probable Construction Cost

Description	Opinion of Probable Construction
Odor Control Scrubbers Fabrication and Installation	\$1,612,500
Contractor Overhead and Profit (15%)	\$241,875
Subtotal Material and Labor	\$1,854,375
Contingency (25%)	\$463,593
Soft Costs – Engineering, Construction Admin. (20%)	\$370,875
Total	\$2,688,843

5.3 Washdown System Components

The automatic washdown systems consist of spray nozzles which oscillate through predetermined positions. The nozzle movement is propelled with pressurized water, avoiding the

need for motorized systems. These nozzles would be installed at strategic locations along the length of the tanks and piped to a central automatic washdown skid. The skid would consist of a control panel, pumps, and zone control valves. Zones could be configured to spray different sections of the tank as it drains or zoned strictly by tank. One limitation of this system is that the plant water being utilized must have a low turbidity for the nozzles to operate properly without the risk of clogs that would prevent oscillation. The nozzles can be fitted with magnetic gearboxes to reduce the frequency of seal replacements. See **Figure 5.3.1** for the washdown system drive and **Figure 5.3.2** for the nozzle. Costs for the automated washdown nozzles are approximately \$20,000 each and the pump skid and controls are approximately \$100,000. The estimated cost for installing washdown systems for the grit tanks are below.

Table 5.3.1 Opinion of Probable Construction Cost

Description	Opinion of Probable Construction
Automatic Washdown Stations (six)	\$120,000
Control Skid, Pumps and Piping	\$100,000
Contractor Overhead and Profit (15%)	\$33,000
Subtotal Material and Labor	\$253,000
Contingency (25%)	\$63,250
Soft Costs – Engineering, Construction Admin. (20%)	\$50,600
Total	\$366,850

Figure 5.3.1 Washdown System Drive

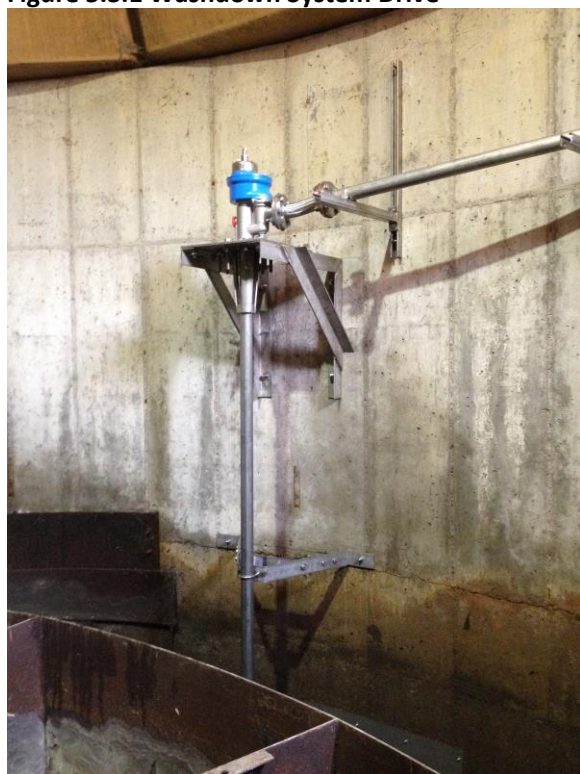
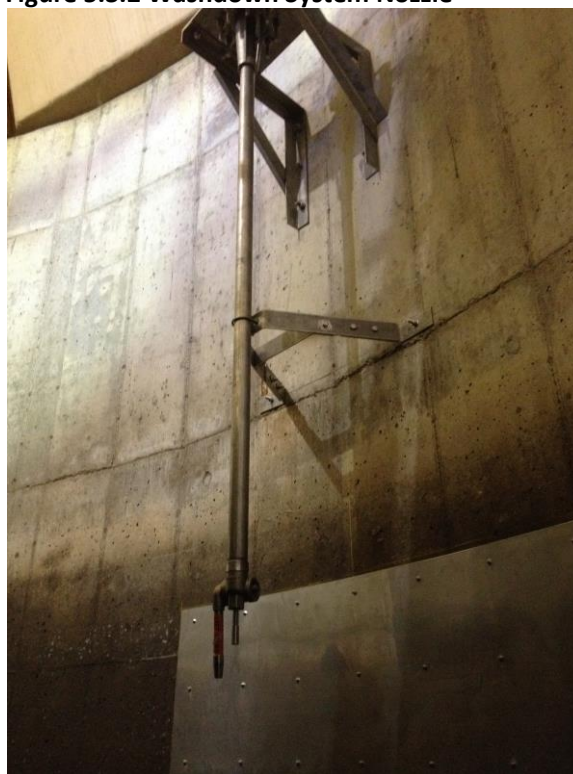


Figure 5.3.2 Washdown System Nozzle



Section 6

Aeration Tank Cover and Odor Control

Since the modeling results found that the aeration tanks are one of the largest odor sources at the facility, the installation of covers for the Aeration Tanks as well as new odor control scrubber units were investigated as a potential mitigation measure. This proposed solution would reduce the amount of odors leaving the site from the Aeration Tanks and provide a single monitoring location for odors generated by these tanks.

6.1 Aeration Tank Covers

The proposed aeration tank covers would be similar to the configuration of the existing Primary Tank covers. To cover the 24 basins (23-foot wide by 200-foot long) approximately 111,600 square feet of open area needs to be covered. The same anodized aluminum cover design would be utilized as the Primary Tank covers. **Figure 6.1** Yonkers WWTP Site Plan provides the location of the Aeration Tanks and **Figure 6.2** provides the current configuration of the Aeration Tanks. Details of the original construction of the Aeration Tanks is provided in **Figures 6.3** Aeration and Final Tanks Plan at El 9.00, **Figure 6.4** Aeration and Final Tanks Sectional Plan, **Figure 6.5** Aeration and Final Tanks Partial Sectional Plan Area 1, and **Figure 6.6** Partial Sectional Plan Area 4. **Figure 6.7** below illustrates a similar cover design at another facility.

Figure 6.7 Aluminum Tank Covers

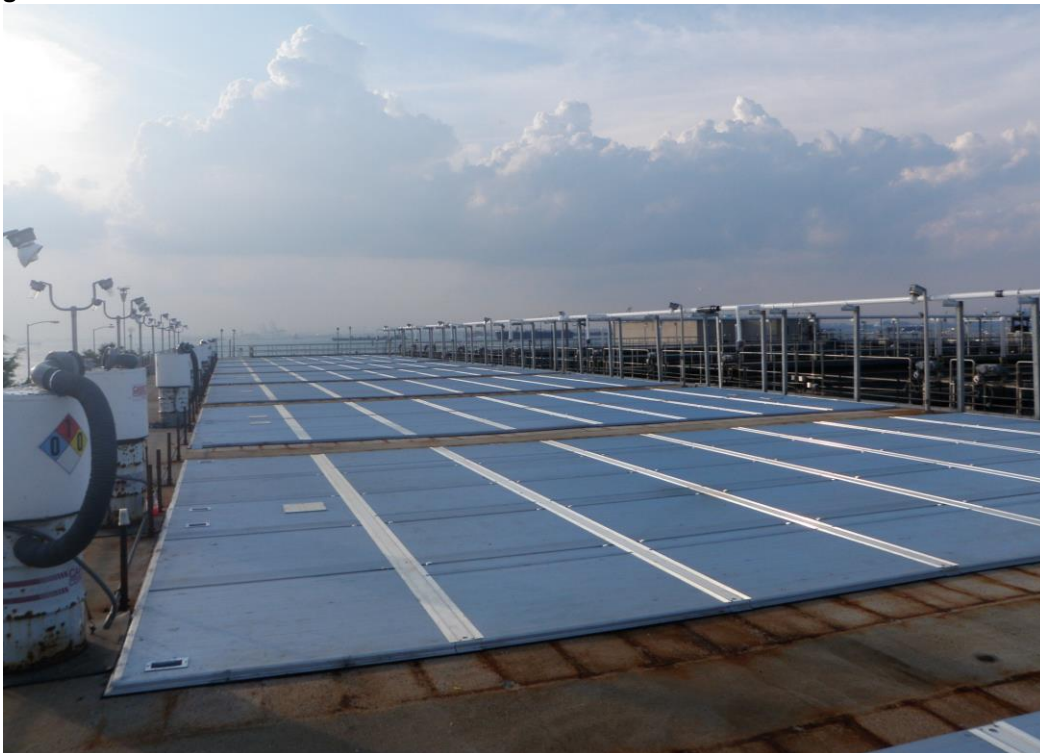


Figure 6.1 Yonkers WWTP Site Plan

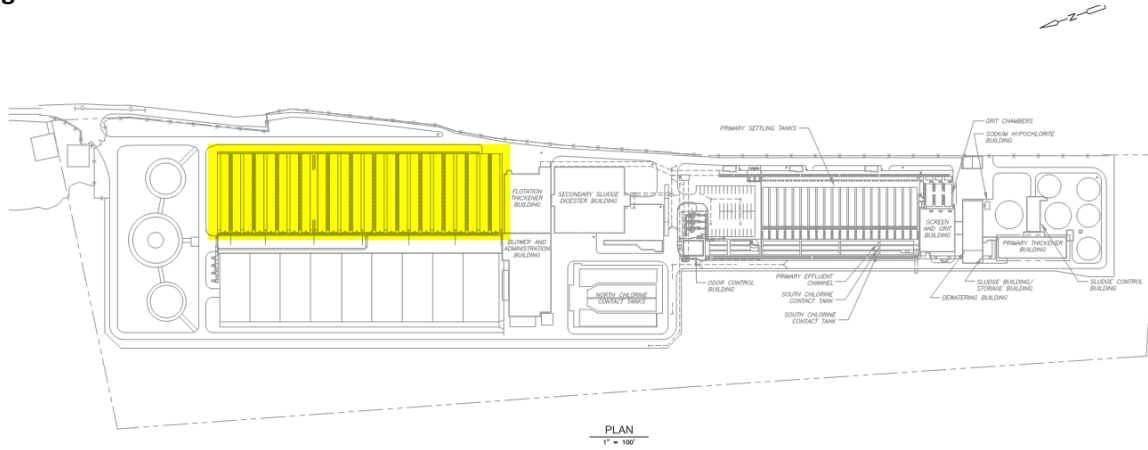
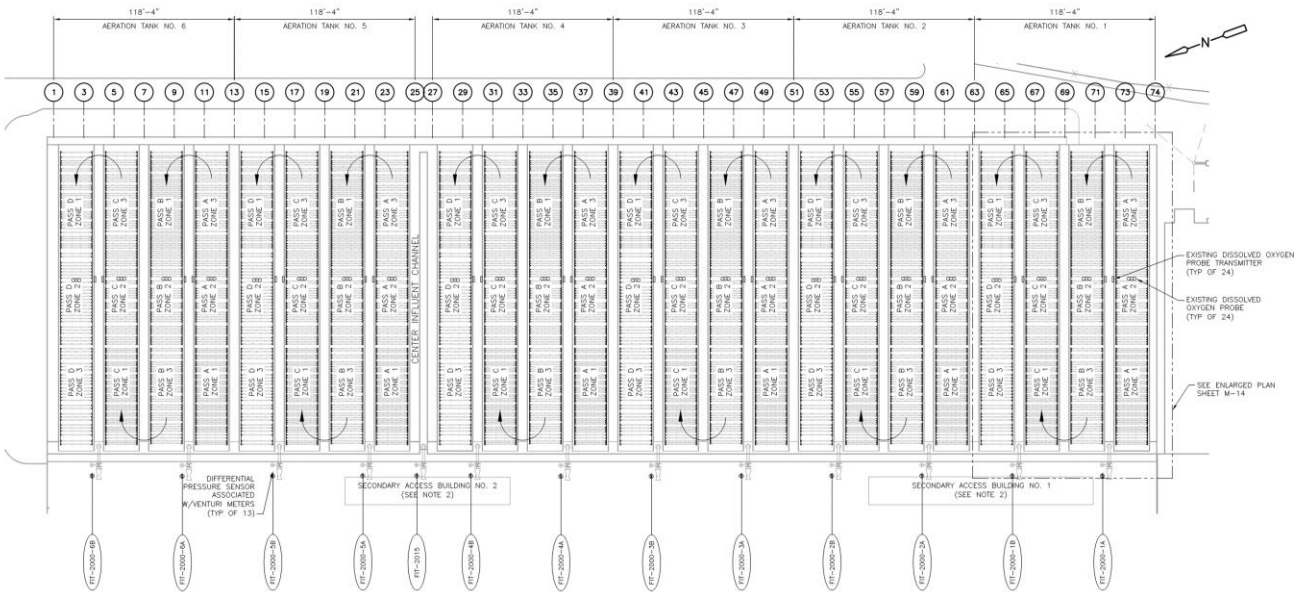


Figure 6.2 Yonkers Aeration Tank Plan



Figures 6.3 Aeration and Final Tanks Plan at EL 9.00

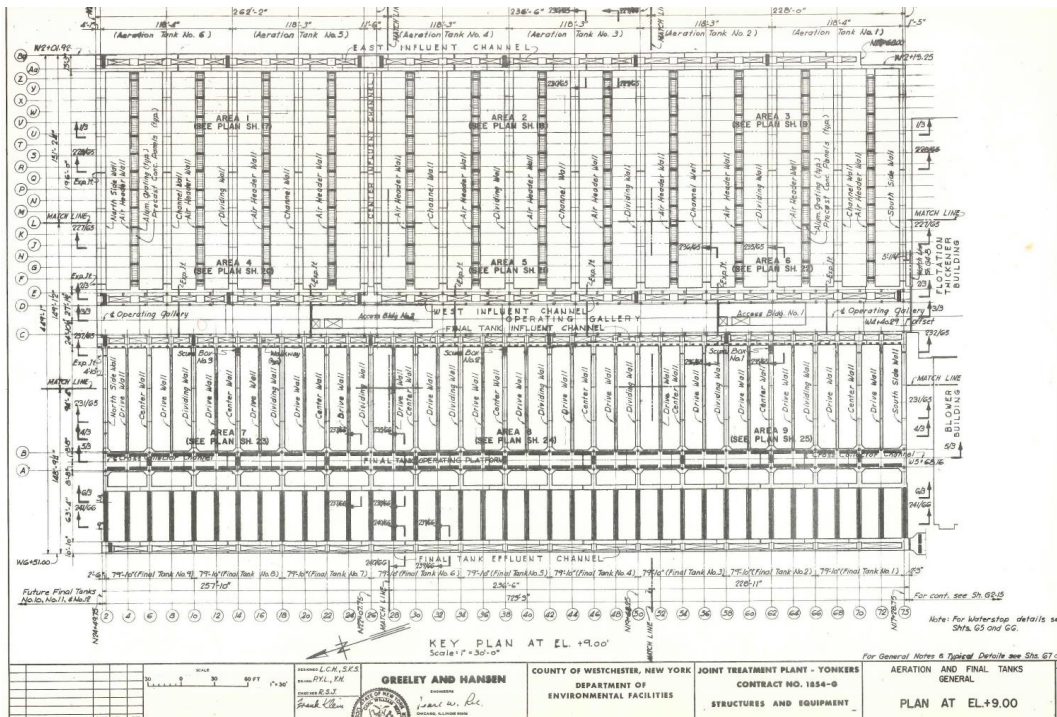


Figure 6.4 Aeration and Final Tanks Sectional Plan

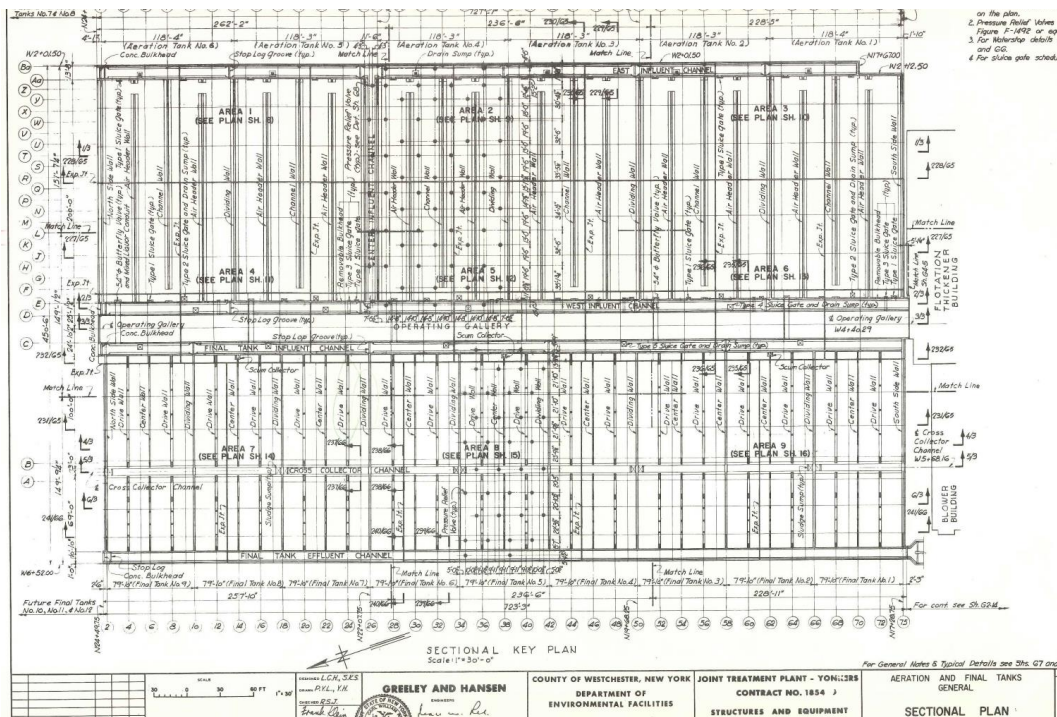


Figure 6.5 Aeration and Final Tanks Partial Sectional Plan Area 1

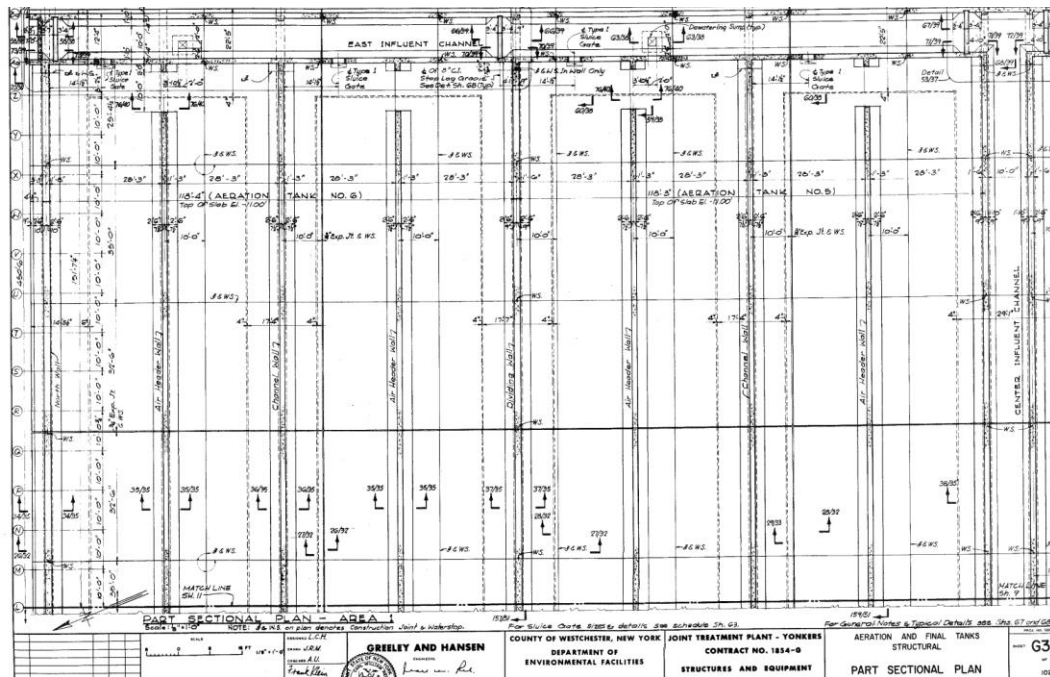
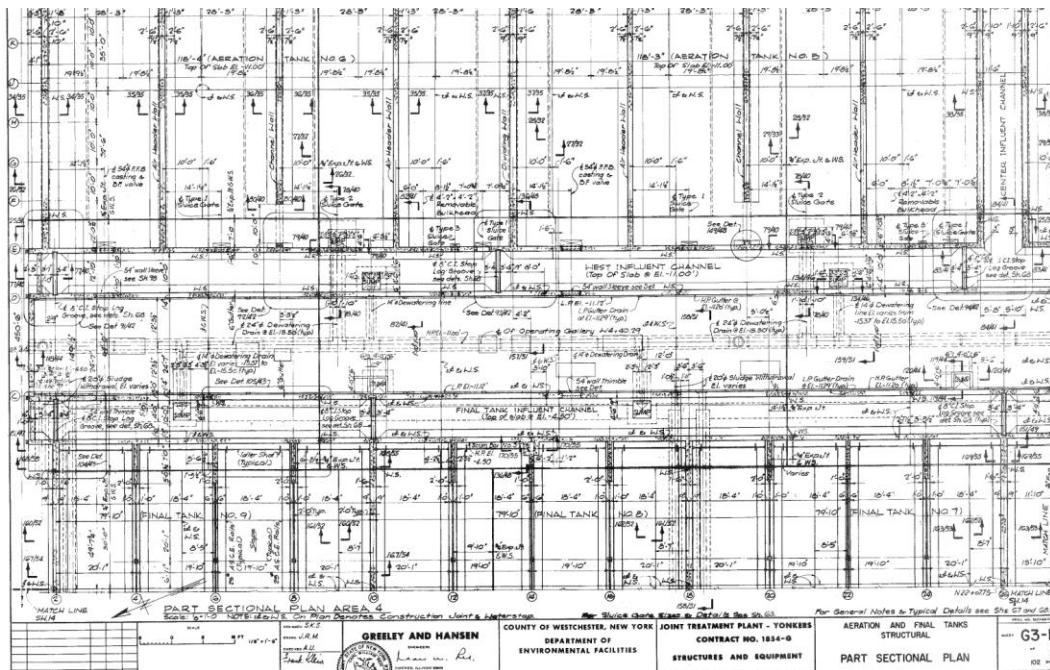


Figure 6.6 Partial Sectional Plan Area 4

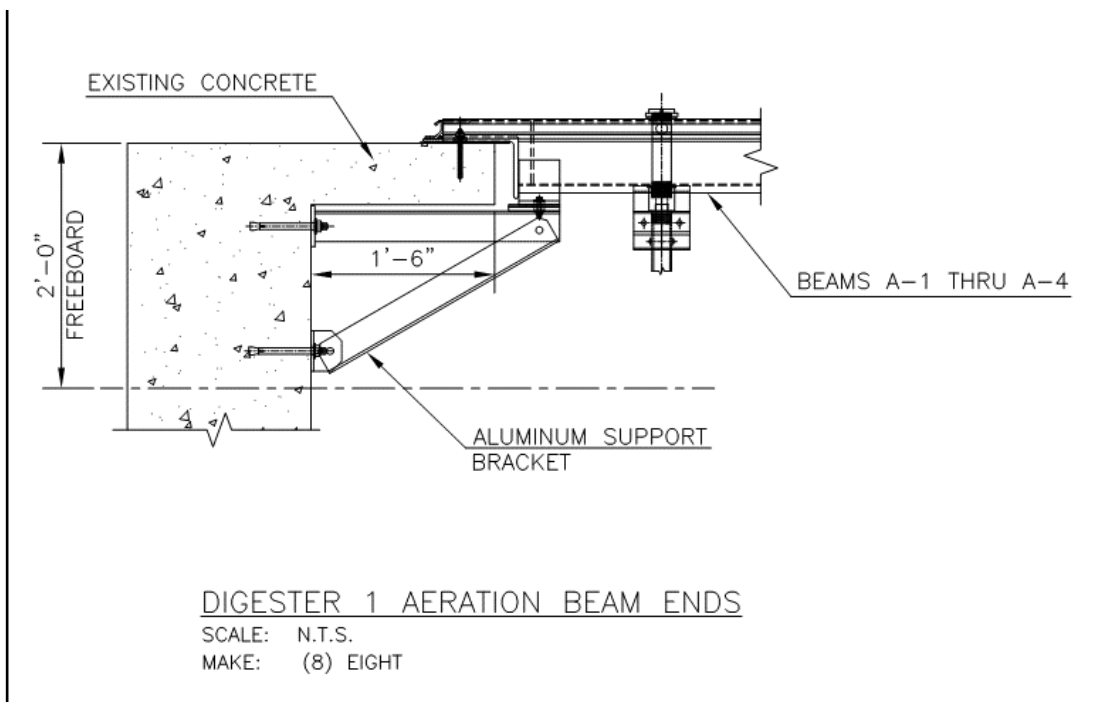


The same manufacturer of the existing anodized aluminum covers for the Primary Tanks, Hallsten, was contacted for information on new covers for the Aeration Tanks. The proposed covers would be anodized aluminum supported by mounting brackets attached to the load bearing portion of the T-wall separating the basins, see **Figure 6.7** Aluminum Tank Covers and **Figure 6.8** Cover Mounting Brackets. A detail for the mounting brackets can be seen in **Figure 6.9**

Figure 6.8 Cover Mounting Brackets



Figure 6.9 Cover Mounting Bracket Detail



6.2 Aeration Tank Odor Control

With the Aeration Tanks being covered, new odor control units would be required to treat any odorous air leaving the headspace above the water surface through ventilation. The size of the new odor control units would be based on the aeration rate plus 15%. Existing aeration rates range from 40,000 CFM to 50,000 CFM. The new odor control system would be sized for 46,000 CFM to 57,500 CFM. The same existing LO/PRO units which are working effectively at the Plant were selected to treat the odors from the potential new covers over the Aeration Tanks. The largest units are the LP-6500 sized for 19,000 CFM each. To treat the high end of the flow range three units would be installed, with one additional as standby, for a total of four.

6.3 Opinion of Probable Cost

Cost estimates for the covers are estimated using a base price for the material as \$65 per square foot from the manufacturer. Installed price is \$77 per square foot, with 111,600 square feet of tank area. The budget price for the odor control units is \$268,750 each, or \$1,075,000 and installation is estimated to double that cost. The opinion of probable construction cost is provided in **Table 6.3.1**.

Table 6.3.1 Opinion of Probable Construction Cost

Description	Opinion of Probable Construction
Odor Control Scrubbers Fabrication and Installation	\$2,150,000
Cover Fabrication and Installation	\$8,593,200
Contractor Overhead and Profit (15%)	\$1,611,480
Subtotal Material and Labor	\$12,354,680
Contingency (25%)	\$3,088,670
Soft Costs – Engineering, Construction Admin. (20%)	\$2,470,936
Total	\$17,914,286

Section 7

Sludge Loading Bay Ventilation

To confirm the ventilation in the Sludge Loading Bay, Mechanical Testing Group (MTI) was contracted to perform testing and balancing in this building. This testing was conducted on March 25, 2019. A summary of the results is presented below in tabular form. As indicated in the table, the measured flows were found to be higher than the design flows. To determine the air changes, the volume of the Sludge Loading Bay is calculated and compared to the design and actual airflows. The air changes were calculated at 14 ACH.

Table 7.1 Sludge Loading Bay Ventilation Results

Fan	Design Flow	Measured Flow
Supply Fan 1	4,350 CFM	6,009 CFM
Supply Fan 2	4,800 CFM	4,435 CGM
Exhaust Fan 1	15,275 CFM	20,746 CFM

Table 7.2 Sludge Loading Bay Air Changes

Dimension	Value
Length	88 Feet
Width	30 Feet
Height	32.25 Feet
Volume	85,140 Cubic Feet
Measured Flow	1,244,760 CFH
Air Changes	14 ACH

Although the ventilations rates are adequate in the space, some improvements to the circulation patterns in the room are suggested. It is noted that the ducting for Supply Fan 1 does not have registers. Without them, the flow cannot be evenly distributed throughout the room. This is demonstrated by the air flows ranging from 529 CFM to 1554 CFM at different locations where the supply air exits the ducting. The design intent of this ducting was to supply 870 CFM per register. Therefore, registers should be added to the supply fan ducting. Additionally, to ensure supply air reaches the east side of the first floor, registers should be aimed near the lower portion of the east wall. Adding the registers will improve the distribution of supply air into the room and directing them as described will improve circulation for a minimal cost. These registers are anticipated to cost less than \$1,000 each, therefore they can be purchased and installed by the facility or be included as part of an existing capital project.

Appendix A

Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990

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Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990



— AIR RISK INFORMATION SUPPORT CENTER —

**REFERENCE GUIDE TO ODOR THRESHOLDS
FOR HAZARDOUS AIR POLLUTANTS LISTED IN THE
CLEAN AIR ACT AMENDMENTS OF 1990**

Prepared for

Air Risk Information Support Center (Air RISC)
U.S. Environmental Protection Agency

Sponsored by:

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PREFACE

Many State and local agencies are developing or implementing programs to control emissions of toxic air pollutants. To successfully carry out these programs, in many cases, agency personnel must be familiar with a wide range of issues related to health, exposure, and risk assessment for toxic air pollutants. However, locating appropriate sources of information on these topics is not always an easy task. This reference guide to odor thresholds has been prepared by the U.S. Environmental Protection Agency's (EPA's) Air Risk Information Support Center (Air RISC) as a resource tool for State and local air pollution control agencies and EPA Regional Offices to identify information regarding odor thresholds for hazardous air pollutants.

Air RISC is operated by EPA's Office of Air Quality Planning and Standards (OAQPS) and Office of Health and Environmental Assessment (OHEA). The key goal of Air RISC is to provide technical assistance to State and local air pollution control agencies and EPA Regional Offices, in obtaining, reviewing, and interpreting health, exposure, and risk assessment information for air pollutants. Through Air RISC, State, local, and EPA Regional Office personnel can request expert guidance and information on health, exposure, and risk assessment issues and methodologies related to air pollutants.

In response to a large number of requests concerning the identification and interpretation of odor thresholds for a variety of chemicals, Air RISC initiated the project that resulted in this document. This document consists of three sections. Section 1 is an introductory discussion of basic concepts related to olfactory function and the measurement of odor thresholds. Section 1 also describes the criteria that are used to evaluate and determine the acceptability of published odor threshold values. Section 2 contains the tabulated results of a literature search and critical review of published odor threshold values for the chemicals listed as hazardous air pollutants in the Clean Air Act Amendments of 1990 at the time of passage. Each odor threshold value is evaluated according to the criteria discussed in Section 1 and a geometric mean of the acceptable values is provided as the best estimate of the odor threshold. Section 3 lists the references used in preparation of this report.

1. INTRODUCTION

The growing public concern about chemicals in the environment has resulted in legislation such as the 1986 Superfund Amendments and Reauthorization Act, Title III, and 1990 Clean Air Act Amendment, Title III, air toxic provisions. Historically, local environmental protection agencies report that odor complaints make up a large number of the citizen complaints received. In general, the public does not understand the relationship between odor and risk and believes "If it smells, it must be bad." Local agency staff answering these complaints sometimes have to assess the potential health risk from exposure to chemicals by relying on odor threshold values reported in the literature; unfortunately, these reported odor threshold values vary considerably from one literature source to another. It is not uncommon for reported odor threshold values of some chemical compounds to range over three or four orders of magnitude. Major sources of variability include the type of data source; differences in experimental methodology; and the characteristics of human olfactory response, which demonstrate a great deal of interindividual variability.

A recent report from the American Industrial Hygiene Association reviewed and critiqued odor threshold data ("Odor Thresholds for Chemicals with Established Occupational Health Standards", American Industrial Hygiene Association, 1989). The project identified and compiled experimental odor threshold references in the literature, and evaluated methodologies used in published reports against a set of objective criteria. Using these methods to eliminate questionable data, an attempt was made to estimate a better odor threshold value for certain compounds if the information was available. The geometric mean of the acceptable data was taken and is considered to be a reasonable estimate of the actual odor threshold (American Industrial Hygiene Association, 1989).

This approach is now being used to focus upon the hazardous air pollutants listed in the 1990 Clean Air Act Amendment for EPA's Air Risk Information Support Center. One of the major goals is to provide state and local agencies with data tables and an explanatory narrative so that community odor perception can be properly evaluated and interpreted in terms of chemical exposure and risk.

A related issue is how to assess health risks when odors are detected. This could be done by systematically comparing odor thresholds to guidelines or standards for ambient or occupational exposure depending upon the population of concern. The purpose would be to determine whether, or in which cases, the detection of odor is a suitable indicator of health risk. Factors that affect this analysis are variability in the odor threshold data and in the human olfaction mechanism and the choice of health-based ambient criteria and background information pertinent to the particular case in which odors are detected.

This document contains a general background discussion of odor threshold measurement, interpretation and use in risk assessment. Section 1.1 presents background material on odor perception and odor properties. In Section 1.2, a brief review of odor threshold methodology is given. Section 1.2 also describes the criteria used to evaluate the odor threshold sources. Section 1.3 will discuss the use of odor thresholds as a tool in assessing risk. Section 1.4 describes the literature search and review procedure. Summaries of available odor threshold data are presented in tabular form in Section 2. Section 3 contains the references cited in the summaries and sources used during the research for this report.

1.1 THE CONCEPT OF ODOR THRESHOLD

A brief review of the sensory properties of odor and some of the attributes of human olfactory response is presented to facilitate understanding of odor threshold values.

1.1.1 Dimensions of Odor

The sensory perception of odorants has four major dimensions: detectability, intensity, character, and hedonic tone. Odorant *detectability* (or threshold) refers to the theoretical minimum concentration of odorant stimulus necessary for detection in some specified percentage of the population. This is usually defined as the mean, 50% of the population; however, it is sometimes defined as 100% (including the most insensitive) or 10% (the most sensitive). Threshold values are not fixed physiological facts or physical constants but are a statistical point representing the best estimate value from a group of individual responses. As such, it may be an interpolated concentration value and not necessarily one that was actually

presented. Two types of thresholds are evaluated: the *detection* threshold and the *recognition* threshold. The detection threshold is the lowest concentration of odorant that will elicit an olfactory response without reference to odor quality in a specified percentage of a given population. In test procedures it is the minimum concentration of stimulus detected by a specific percentage of the panel members. Additionally, Russian literature defines detection thresholds as absolute thresholds (i.e., the lowest concentration that will produce any measurable physiological change [e.g., as an electroencephalogram response] in the most sensitive human subject).

The detection threshold is identified by an awareness of the presence of an added substance. The recognition threshold is defined as the minimum concentration that is recognized as having a characteristic odor quality by a specific percentage (usually 50%) of the population.

Odor *intensity* refers to the perceived strength of the odor sensation. Intensity increases as a function of concentration. The relationship between perceived strength (intensity) and concentration can often be expressed as a power function, as follows (Stevens' Law):

$$S = k I^n$$

where S = perceived intensity of sensation, k = y-intercept, I = physical intensity of stimulus (odorant concentration), and n = exponent of psychophysical function, typically less than 1.0.

In logarithmic coordinates, Stevens' Law becomes $\log S = n \log I + \log K$, which is a linear function with slope equal to n . An intensity function for a standard odorant, 1-butanol, is shown in logarithmic coordinates in Figure 1-1. The slope of the function varies with type of odorant typically over a range from about 0.2 to 0.7. The slope of the function for butanol shown in Figure 1-1 equals 0.66. This is an important consideration in the control of odors. A discussion of odor intensity and how such curves are derived can be found in Dravnieks (1972).

In air pollution control, we are often concerned with the "dose-response" or psychophysical function, which is reflected by the slope. The slope also describes the degree of dilution necessary to decrease the intensity. A low slope value would indicate an odor

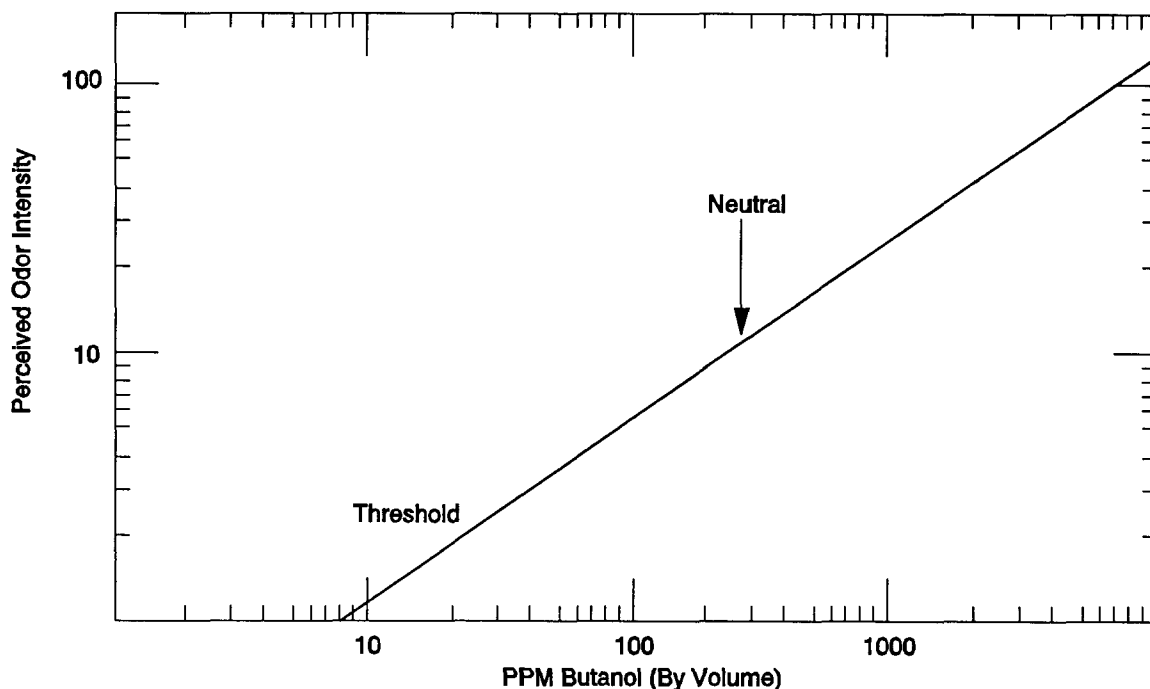


Figure 1-1. An intensity function for 1-butanol.

that requires greater relative dilution for the odor to dissipate; a high slope value indicates an odor that can more quickly be reduced by dilution. Examples of compounds with low slope values include hydrogen sulfide, butyl acetate, and the amines; those with high slope values are ammonia and the aldehydes. In general, substances with low thresholds yield low slopes and those with high thresholds show high slopes. The relative slopes of hydrogen sulfide and ammonia are depicted schematically in Figure 1-2. Similar curves for other compounds can be found in Dravnieks (1972). The difference in the degree to which these two chemicals affect the olfactory system is apparent from this illustration. For a 1:1 mixture of ammonia and hydrogen sulfide, ammonia is often perceived as the odor character of the mixture at higher concentration levels. However, when diluted, or if the observer walks away from the source, the hydrogen sulfide odor becomes the dominating odor character. This phenomenon is commonly encountered at wastewater treatment plants.

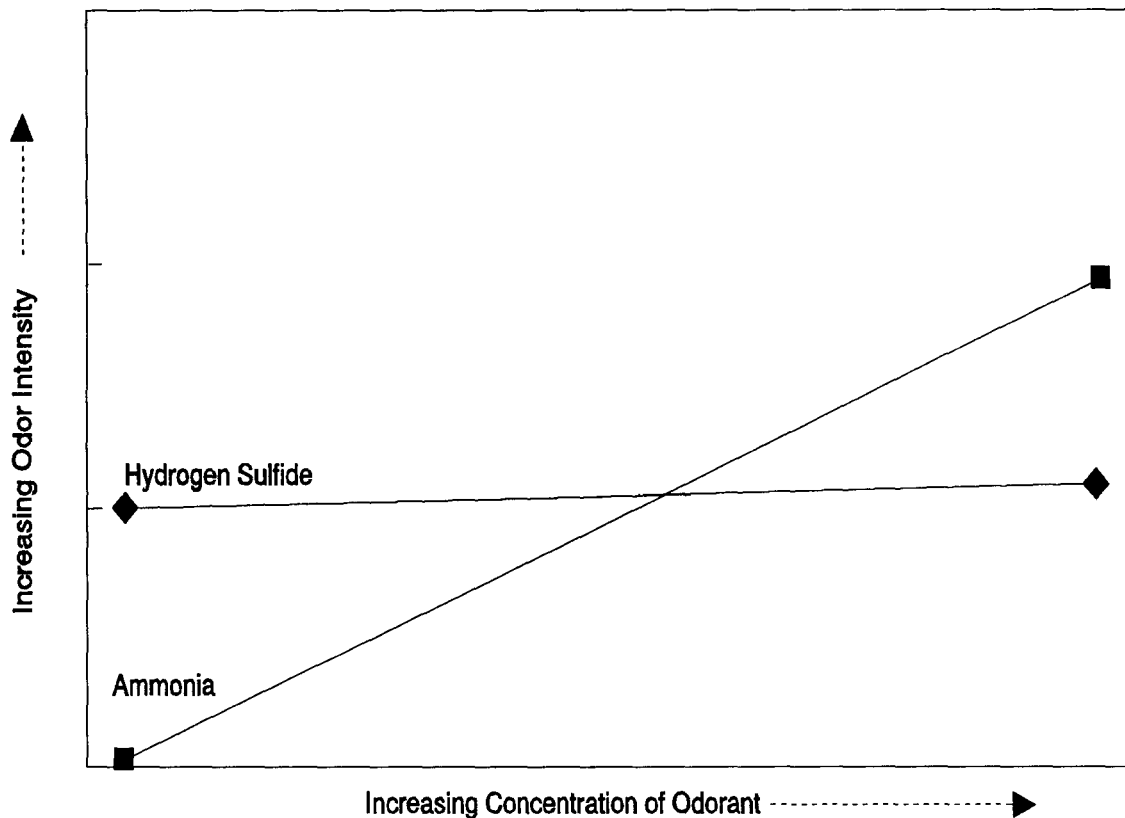


Figure 1-2. Relative slopes of psychophysical functions for ammonia and hydrogen sulfide. The schematic diagram depicts the steep odor intensity/concentration slope for ammonia as compared to the shallow slope for hydrogen sulfide. The difference in slopes means that at high concentrations of both odorants, the predominant odor will be that of ammonia, while at lower concentrations hydrogen sulfide will be detected.

The third dimension of odor is the *character*, in other words, what the substance smells like. An American Society for Testing and Materials (ASTM) publication (Dravnieks, 1985) presents character profiles for 180 chemicals using 146 descriptors, rated on a scale of 0 to 5. The descriptors include such terms as fishy, hay, nutty, creosote, turpentine, rancid, sewer, and ammonia.

The fourth dimension of odor is *hedonic tone*. Hedonic tone represents a judgment of the relative pleasantness or unpleasantness of the odor. Perception of hedonic tone outside the laboratory is influenced by such factors as subjective experience, frequency of occurrence, odor character, odor intensity, and duration.

1.1.2 Introduction to Olfactory Function

Human odor perception has a few functional aspects of particular relevance: sensitivity, specificity, and somewhat independent processing of olfactory input by the cortex and more primitive brain structures. The close coupling of molecular odorant recognition events to neural signaling enables the nose to detect a few parts per trillion of some odorants (Reed, 1990). The molecular nature of recognition permits the nose to distinguish between very similar molecules.

The initial events of odor recognition occur in a mucous layer covering the olfactory neuroepithelium, which overlays the convoluted cartilage in the back of the nasal cavity. Each of the millions of olfactory neurons in the middle layer of this epithelium extends a small ciliated dendritic knob to the surface epithelial layer and into the overlaying mucus. As in the immune system, receptors on different cells have different specificities. The binding of a single odorant molecule to a receptor on this dendritic tip may be adequate to trigger a neural signal to the brain. On each tip dozens of cilia increase the surface area available for recognition events and may stir the local mucus, aiding in the rapid detection of small concentrations of odorants. Individual receptors desensitize with use, temporarily losing their ability to transduce signals.

The peripheral olfactory neurons project to the olfactory bulb from which signals are relayed to the olfactory cortex and more primitive brain structures such as the hippocampus and amygdala. This last structure affects whole brain-body emotive states. For further information on the olfactory system physiology, see Dodd and Castellucci (1991).

Human response to odorant perception follows certain characteristic patterns common among sensory systems. For example, olfactory acuity in the population conforms to a normal distribution. Most people, assumed to be about 96% of the population, have a "normal" sense of smell as depicted in Figure 1-3. Two percent of the population are predictably hypersensitive and two percent insensitive. The insensitive range includes people who are anosmic (unable to smell) and hyposmic (partial smell loss). The sensitive range includes people who are hyperosmic (very sensitive) and people who are sensitized to a particular odor through repeated exposure. Individual threshold concentrations may be normally distributed around the mean value (e.g., Figure 1-3) or log-normally distributed. In some instances, the threshold distribution is bimodal, with a small antinode that represents

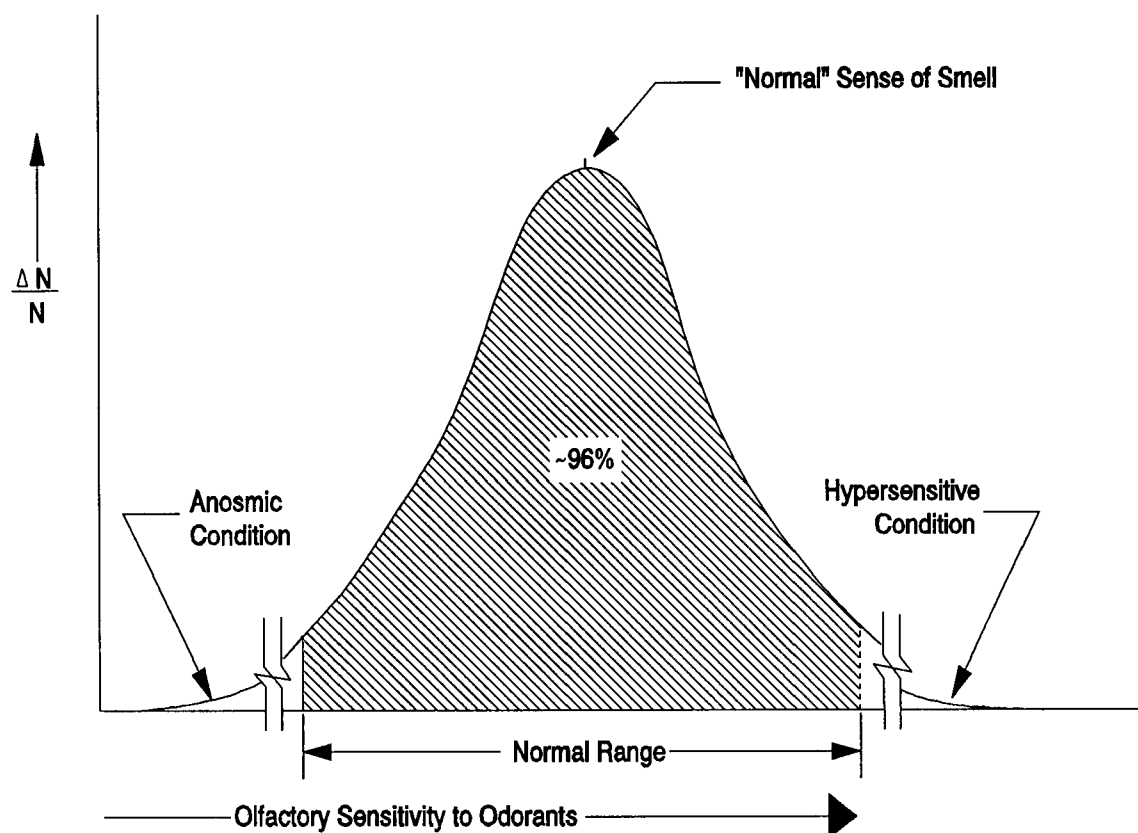


Figure 1-3. Illustration of the normal range concept showing a potential population distribution of olfactory sensitivities to odorants.

people with a specific insensitivity, commonly called specific anosmia. For example, the odor threshold for hydrogen cyanide is bimodally distributed since there are at least two distinct groupings with markedly different abilities to detect hydrogen cyanide (Agency for Toxic Substances and Disease Registry, 1988).

Another property of olfactory functioning includes adaptation to an odor, also known as olfactory fatigue. These terms describe a temporary desensitization after smelling an odor. After smelling a strong odor, a weaker near-threshold odor may not be detectable. For this reason, odor threshold measurement studies must be carefully designed.

As mentioned in the previous section, mixtures of compounds such as ammonia and hydrogen sulfide may have varying odor character depending on their relative concentrations. All odorants have the ability to mask the odor of other compounds, in mixtures of appropriate

proportions. Some mixtures of odorants may be perceived as qualitatively different from the individual components (Foster, 1963; Mitchell and McBride, 1971). The perceived intensity of a mixture of two odors can be represented using a vector model. Two odors can be thought of as the vectors A and B. The length of the vectors can represent the relative intensities of the odors. The angle between the two vectors typically has a value of about 110 degrees. The vector model illustrates the nature of mixtures of odors. The intensities are not simply additive. Two odors in concentrations that give similar intensities, when added together can result in an odor with intensity that is approximately the same, but with a slightly different character or quality than the two odors as perceived individually (Berglund, 1974).

A sensory property of odor that can cause confusion in organoleptic (i.e., sensory as opposed to analytical) odor identification is that odor character may change with concentration. For example, butyl acetate has a sweet odor at low concentrations, but takes on its characteristic banana oil odor at higher intensities. Carbonyl sulfide has a "fireworks" or "burnt" character at concentrations below 1 part per million (ppm) and "rotten egg" character at higher levels. This, along with individual variability, accounts for discrepancies in odor character reports. The odor character descriptors in this paper are based on a combination of reports in the literature and experience in odor investigation.

The ability to discriminate between different odor intensities is very sensitive. It has generally been found that concentrations higher or lower by 25 to 33% are perceived as different. In a carefully controlled study by Cain (1977), the average perceptible difference between concentrations was 11%, ranging from 5 to 16% for different compounds.

As noted above, there are two basic types of odor thresholds: the detection threshold and the recognition threshold. Detection is defined as the concentration at which the average panel member notices an odor, but cannot necessarily identify it. The recognition threshold is the lowest concentration at which the average panelist can identify a definite character of the odor. The difference in concentration between detection and recognition thresholds can vary from approximately twofold to tenfold. For example, Hellman and Small (1974) found the detection and recognition thresholds of acetophenone to be 0.3 ppm and 0.6 ppm, which is a twofold concentration difference. While for acrylic acid, the thresholds were found to be 0.092 ppm and 1 ppm, an 11-fold concentration difference.

The order of presentation of odorants in experimental determination of odor threshold is very important so as not to induce olfactory fatigue. The olfactometer commonly used in recent odor threshold experiments is a device that dilutes samples of odorant with odor-free air and presents the diluted samples to panelists in ascending order of concentration in two- or threefold concentration steps. Panelists choose which of the three nozzles in a cup differs from the other two. In this forced-choice procedure, panelists must pick a port whether they detect a difference or not (i.e., panelists are asked to guess even if they discern no difference). Odorous exhaust air from the olfactometer is removed through an exhaust line outside the building to avoid odor build-up within the room. A thorough discussion of olfactometers and odor threshold measurement is given in Dravnieks (1980).

1.2 EVALUATION OF ODOR THRESHOLD INFORMATION

Odor threshold determination has interested researchers for a century. Over this period, hundreds of threshold measurements along with nearly as many measurement techniques have been reported in the literature. Odor thresholds are often determined in a laboratory setting using various methods to dilute odorants that are presented to a panel of subjects. In order to consistently evaluate experiments of odor thresholds, which vary widely in design and reporting detail, a set of standard criteria was established.

1.2.1 Criteria Used To Evaluate Odor Threshold Information

The method of presentation of the odorant is dependent upon what chemical odor threshold is to be measured. In this report, only gas-air mixtures have been considered. A delivery system that reduces the intake of unmeasured ambient air is most desirable.

A known concentration of odorant is delivered to the panel and responses are measured. Usually a verbal response is taken by a monitor. Responses can include whether or not an odor is detected, the strength of the odor, and odor quality (e.g., pleasant vs. unpleasant, fishy, aromatic, etc.).

Once the responses of the panel are recorded, statistical methods can be used to determine the odor threshold for either detection or recognition. Some of the important variables of odor threshold measurement are discussed below.

A set of criteria considered essential to any modern threshold determination procedure was developed (see below). The sources with published odor thresholds (listed in Section 2) were evaluated in terms of their conformity to these criteria. The criteria are summarized below.

Sources that did not account for these criteria in their experimental design were not accepted. For example, a random presentation series was accepted when concentration levels were evaluated by different subjects (Gundlach and Kenway, 1939) but not when presented to the same subjects. An exception would be when a random presentation to the same subjects was used, but the interval between trials was long enough to permit reversal of olfactory adaptation.

1.2.1.1 Panel Size of at Least Six per Group

In order to approximate the distribution of olfactory sensitivity in the population, it is preferable to use a large number of subjects or, since this is often impossible, a smaller group selected to represent the general population. Accordingly, to replicate the distribution curve shown in Figure 1-3, it is preferable to use a larger panel with fewer trials rather than a small panel (e.g., 2 or 4 subjects) with many trials. Additionally, panels of fewer than six subjects reduce precision for a reliable mean value. Repeatability for individuals' threshold results are poor ($\pm 18\%$); therefore, results should not be based on the repeated observations of less than six panelists. However, there is a point beyond which more panelists become superfluous. One study found that a pooled group of ten with one trial produced the same thresholds as a group of thirty-six with five trial presentations (Punter, 1983). Odor threshold determinations using fewer than six panelists or with the number of panelists not reported were not accepted.

1.2.1.2 Panelist Selection Based on Odor Sensitivity

Prospective panelists should be evaluated for olfactory sensitivity to the chemical compounds in question. This will insure that the panel will not include judges with general or specific anosmia. An early version of an ASTM threshold procedure (ASTM 1391-57 Syringe Dilution Method) recommended testing with only two all-purpose odorants, vanillin and methyl salicylate. Subsequent studies showed that these compounds did not rate panelists

properly. Panelists should be evaluated with a compound selected to represent the particular chemicals under investigation, rather than with two standard compounds.

Physiological and personal factors to be considered when selecting a panel include smoking, drug dependency, pregnancy, sex, and age. Smokers should be excluded from the panel even though the effect of smoking on olfactory acuity is unclear. Studies have reported results ranging from definite to no effect from smoking (see Cometto-Muniz and Cain, 1982, for discussion).

Drug dependency and pregnancy are known to reduce and elevate odor perception, respectively (Amerine et al., 1965). Anosmia due to drug dependency would be discovered during screening. Similarly, prospective panelists being treated with high levels of medication would be screened and omitted from the panel. Pregnant women should be excluded as a precautionary measure.

As with smoking, results of investigations of changes in olfactory acuity due to age and sex are in disagreement. The common conception has been that women are more sensitive than men and that sensory acuity decreases with age. However, this may be too simplistic an explanation. Recently, the approach has been to separate odor sensitivity from odor identification ability (e.g., see Doty et al., 1984, for changes with age; Cain, 1982, for differences between sexes).

Odor threshold determinations were not accepted if there was no screening of panelists reported.

1.2.1.3 Panel Calibration

Panel odor sensitivity should be measured over time to monitor gross individual discrepancies and maintain panel consistency. Individual variability is $\pm 18\%$ while person-to-person variability can differ by four orders of magnitude. A daily rating of an n-butanol wheel olfactometer would provide a quick and accurate measure of individual and group variability.

1.2.1.4 Consideration of Vapor Modality (Air or Water)

Vapor modality (i.e., whether the odor measured is in the form of a gas-air mixture or vapor over an aqueous or other solution) is determined by the test purpose and in turn

determines the presentation method. The majority of reported thresholds are gas-air measurements. Therefore, some criteria for the apparatus will pertain directly to gas-air instead of vapor over an aqueous solution. Only gas-air mixtures were accepted in this report.

1.2.1.5 Diluent in Accord with Compound

The diluent, whether liquid or gaseous, should be consistent with the chemical compounds tested and not influence odor perception. For example, diluent air may be filtered through activated carbon or be unfiltered room air. Liquid diluents include water, diethyl phthalate, benzyl benzoate, and mineral oil. The selected diluent is determined by the test purpose and practical considerations of the compound. Additionally, the relative humidity of diluent air (or other inert gas) should be controlled at approximately 50%.

1.2.1.6 Presentation Mode That Minimizes Additional Dilution (Ambient) Air Intake

Vapors are inhaled from openings of varying size. Some of these allow ambient air to be inspired along with the sample, thereby increasing the dilution factor by an unknown amount. Common delivery systems are (1) nose ports held under the nostrils, (2) vents into which the whole head is inserted, (3) flasks into which the nose is inserted, (4) syringes that impinge vapor into the nose, and (5) whole rooms into which the odorant is injected. In general, an opening that allows insertion of the nose or the whole head is desirable as it reduces the intake of ambient air. Delivery systems that did not control the mixing of the odorant with ambient air were not accepted.

1.2.1.7 Analytic Measurement of Odorant Concentration

The concentration of odorant as it reaches the panelist should be measured accurately. The capability to measure concentration of some odorants has occurred only recently. Therefore, a major problem with early threshold studies and a drawback of some modern studies is the absence of such analytic devices.

1.2.1.8 Calibration of Flow Rate and Face Velocity (for Olfactometers)

Important system calibrations include flow rate and face velocity. Flow rates on individual olfactometers vary from 0.5 L/min to more than 9 L/min. This disparity in the flow rate has been found to cause a fourfold difference in threshold values. Odorant flow rate should be at approximately 3 L/min, although researchers differ in their opinion of a "best" flow rate. Flow rate then becomes an important consideration in the critique. The face velocity refers to the rate at which the odor is flowed at the panelist and should be maintained at a flow barely perceptible by the panelist.

1.2.1.9 Consideration of Threshold Type (Detection or Recognition)

Thresholds may be either of two types, detection or recognition. The detection threshold is defined as the lowest concentration at which a specified percentage of the panel (usually 50%) detects a stimulus as being different from odor-free blanks. The recognition threshold is the lowest odorant concentration at which a specified percentage of the panel (again, usually 50% or the median) can ascribe a definite character to the odor. In general, recognition thresholds are approximately two to ten times higher than detection thresholds (Hellman and Small, 1974). The type of threshold measured is dependent on the test purpose. For example, detection thresholds are of greater interest in basic research, while recognition thresholds are of greater value to the food industry. Recognition and detection thresholds are differentiated in this report.

1.2.1.10 Presentation Series That Reduces Olfactory Fatigue

Concentration presentation order is an important factor in the presentation method, as olfactory adaptation occurs rapidly. After three minutes of exposure to an odorant, perceived intensity is reduced about 75% (Bartoshuk and Cain, 1977). A common method to control for this is to present concentrations in ascending order (from weaker to stronger concentrations, or greater to lesser dilution) or to allow for long periods between presentations. Descending and random presentation series do not control for adaptation unless specific steps are taken to eliminate it. Recognizing the need to control for adaptation in random or descending patterns of presentation, researchers apply various methods such as presenting one concentration per day (Dixon and Ikels, 1977) or using different subjects at

each concentration step (Gundlach and Kenway, 1939). Odor threshold determinations were accepted only if the methods used controlled adequately for adaptation.

1.2.1.11 Repeated Trials

Individual test-retest reliability for threshold values is generally low (Punter, 1983) but is dependent on the number of trials (Cain and Gent, 1991). Determinations should be repeated for reliability. Additionally, computing the mean across panelists' scores will reduce individual variability.

1.2.1.12 Forced-Choice Procedure

A forced-choice procedure minimizes anticipation effects for thresholds by eliminating false positive responses. Panelists choose between the stimuli and one or two blanks.

Use of forced-choice procedures was not stringently applied as a criterion. An earlier method, presenting a stimuli and blank as a paired comparison, was also included in this category. Both methods reduce anticipation effects.

1.2.1.13 Concentration Step Increasing by a Factor of Two or Three

In determining odor threshold values, the odorant should be presented successively at concentration intervals no more than three times the preceding one. Interval size is determined by the range of sensitivity of the sample of panelists and by the number of concentrations that can be analyzed in a given experiment. Smaller step size may result in failure to identify the threshold for all panelists. Larger step size might result in a less precise calculation of the average threshold because of the extrapolation over a greater range. A 3-fold interval is selected as a maximum necessary to result in a useful dose-response.

1.2.2 Critique of Odor Threshold Measurement Techniques

Threshold compilations such as Van Gemert and Nettenbreijer (1977), Verschueren (1977), and Fazzalari (1978) contain threshold values from sources published in the early 1900s and before. In some cases, reported threshold values vary by a factor of a million or more for one compound. The reported values for n-butyl alcohol range from 1.8×10^{-4} to 1.45×10^{-7} g/L (Amoore and Hautala, 1983).

The fact that threshold values and the methodology involved may vary widely has often been recognized. Factors affecting threshold measurement (Punter, 1983) include stimuli flow rate, olfactometric systems, age and type of panelist, instruction and threshold procedure, and panelists' experimental experience.

Other important factors contributing to threshold value variability are the purity of the chemical compound, the type of threshold (detection or recognition) determined, and the stimulus itself (water vapor or gas vapor). These last two factors make the practice of pooling thresholds questionable at best. Considering the sources of variability, it is understandable that published threshold values differ.

References were reviewed for their overall adherence to experimental procedures that address the response characteristics of the human olfactory system. The results of the literature search and review are presented in tabular form in Section 2. The following are included in Table 2-1.

- CAS RN (Chemical Abstracts Service registry number)
- Chemical name and some of its synonyms
- Chemical formula
- Molecular weight
- First author, date
- Odor threshold
- Type of threshold
- Geometric mean of critically acceptable odor threshold value
- Type of odor threshold represented by geometric mean
- Odor character

1.3 ODOR THRESHOLDS IN RELATION TO RISK ASSESSMENT

The detection of chemical odors may trigger odor complaints that are associated with safety concerns due to chemical exposure. The key questions regarding odor detection, safety, and risk assessment are:

1. If a chemical odor is present, does that indicate a health risk?
2. If chemical odors are absent, does that signify an absence of health risk?
3. Does olfaction provide an adequate margin of safety by allowing detection of toxic chemicals that prompts avoidance of exposure?

Knowledge of odor threshold values, together with a variety of background information, toxicity data, and analytical data are necessary to answer these questions in specific situations.

1.3.1 Relationship Between Odor Threshold Values and Health-Based Ambient Criteria

The relationship between odor threshold values and health-based exposure criteria (e.g., inhalation reference concentrations [RfCs] for noncancer endpoints, inhalation risk-specific concentrations for cancer risk, acceptable ambient concentrations [AACs], occupational exposure limits [OELs]) is an essential determinant of the usefulness of odor as an indicator in a site evaluation. If the odor threshold value is lower than the ambient criteria, then absence of odor may signify that the ambient concentration is below that which could produce adverse health effects. In this case, detection of odor is not a sufficient indicator of whether a health threat is posed because the ability of the sensory apparatus to quantify odor and thus chemical exposure is very limited. Accurate methods of chemical quantification need to be used to determine whether ambient concentrations are sufficient to pose a risk.

The converse of the above, cases in which the odor threshold value is greater than health-based ambient criteria, present the opposite type of problem. In this case, odor is useful as an indicator of potential harm since the detection of odor indicates chemical concentrations in the potentially toxic range. However, a lack of odor does not necessarily indicate absence of risk, since toxic effects can occur at chemical concentrations that are below that perceptible by the nose. Here again, analytical chemistry is needed to ensure that toxic levels of ambient contaminants are not present.

Chemical mixtures can present odors that may or may not reflect the hazard potential of the chemical constituents. For example, a highly odorous but relatively nontoxic chemical may be present along with a nonodorous but highly toxic chemical. In this case, the odorous chemical serves as a warning that the toxic chemical is present. However, there may be instances in which the two chemicals become dissociated (aging of the mixture, in different manufacturing or disposal processes, etc.); and judgments about the presence or absence of the toxic component would be incorrect if they were based upon detection of the odorous component. Therefore, assumptions about the relationship between odor and risk can only be made for the specific circumstances in which chemical mixtures are found.

An exemplary study of complex mixtures and odor at an industrial site was that performed for tar-contaminated soils at manufactured gas plants (Roberson et al., 1989). For analysis of odors from complex mixtures, the odorous sample must be fractionated and fractions characterized in terms of odor and chemical identity. In this case, the sample was analyzed by gas chromatography with mass spectrometry (GC/MS) in such a way so that the GC effluent was split delivering a portion to the MS and a portion to the odor scientist. This enabled the odor associated with each component to be separately evaluated. Several different types of soil contamination were evaluated in this way to describe the prevalent odors and chemical constituents associated with different soil samples. Odor threshold values were then compared to health-based ambient criteria to determine if odor detection would be a suitable marker for elevated risks. The ambient criteria were threshold limit values (TLVs) for workers and 1/100th the TLV for a residential exposure limit. In their samples, odorous components (thiophene, hydrogen sulfide, naphthalene) were detected in conjunction with relatively nonodorous components (cycloalkanes, benzene), thus providing an applicable signal for toxicant exposure. The authors concluded from this study that health risks were unlikely where no odor is present, but analytical data are needed if odors can be detected. Their conclusion, however, did not carefully consider the relative concentrations of odorous vs. nonodorous/toxic components, in relation to differences between odor threshold values for the odorous compounds and exposure limits for the most toxic compounds. Both the relative quantities and the odor threshold-to-exposure limit ratios of all chemicals in the mixture must be assessed before firm conclusions can be drawn. However, the study reported a fairly good correlation between the perceived odor intensity and the measured levels of naphthalene, total

polycyclic aromatic hydrocarbons, and total volatile organic compounds. Thus, in this case, where odors were detected they were useful indices of exposure to toxic components.

These types of relationships between odor thresholds and health-based ambient criteria are the basis for using odor as an indicator of toxicity and risk. However, as outlined below, several additional factors must be taken into account when attempting to relate odor to risk.

1.3.1.1 Background Exposure

Continued exposure to odorous chemicals generally causes a decreased ability to smell these chemicals. Therefore, if the background concentration in the vicinity of a source is sufficient to cause a detectable odor, the odor threshold value for individuals in the affected environment may be higher than that reported in the literature. If reported odor threshold concentrations are lower than the ambient criteria, the desensitizing influence of background exposure may narrow or eliminate the safety margin between the odor threshold concentration and the ambient criteria. In this case, a previously unexposed person may be warned by olfactory indicators from an episode of excessive chemical release, while a chronically exposed person might not as readily detect the release and thus be at greater risk. Therefore, to evaluate whether detection of a chemical via the sense of smell is a reasonable indicator of risk, the ambient concentrations that the receptor is acclimated to must be known, together with the chemical's ability to desensitize olfaction.

1.3.1.2 Variability in the Odor Threshold Data

As discussed in previous sections, the odor threshold literature for a particular chemical can provide a wide range of threshold values. Often the disparity stems, in part, from interindividual differences in olfaction, and in part, from methodological differences. A wide range of odor thresholds presents a large degree of uncertainty regarding the threshold for a particular individual. This diminishes the usefulness of the odor threshold for assessing whether a margin of safety exists between it and the ambient criteria value. Further, the variability decreases the usefulness of odor detection as an indicator of toxicant exposure.

Another related factor that governs the usefulness of the threshold data for risk assessment is the type of threshold reported. While detection thresholds may be more commonly reported, they are not as useful as recognition thresholds because simply detecting

an olfaction stimulus may not be a sufficient warning of chemical exposure. Further, in situations where numerous chemicals are present, a specific and characteristic odor may be required to clearly indicate that a release above background has occurred. Therefore, the utility of and margin of safety afforded by the threshold can be overestimated if the threshold is for detection rather than recognition. However, in cases where individuals anticipate a chemical exposure, odor detection may be a suitable signal to trigger a more extensive investigation.

1.3.1.3 Choice of Health-Based Ambient Criteria

The ambient criteria used for comparison with odor threshold values can greatly affect the interpretation of odor threshold value usefulness as an indicator of risk. Use of OELs such as TLVs (American Conference of Governmental Industrial Hygienists, 1986), permissible exposure limits (PELs), recommended exposure limits (RELs), or short-term exposure limits (STELs) may be appropriate for the workplace.

However, these OELs are not considered to be protective of the general population, which may receive continuous ambient exposure, and which may include more sensitive individuals (e.g., young children, pregnant woman, the elderly). This has been addressed by numerous states and localities in the form of AACs, which are potentially useful health-based ambient criteria, especially because they have been developed for a large number of chemicals.

Other types of health-based criteria are the inhalation RfC and the inhalation unit risk. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (U.S. Environmental Protection Agency, 1990). The RfCs are developed by EPA, and values are verified by the RfD/RfC Work Group, which affords a degree of oversight and standardization. The RfCs are based upon available toxicity data (subchronic and chronic animal studies and epidemiological studies) and are derived by dividing the highest concentration level at which no adverse effects were seen (the NOAEL) by uncertainty factors to approximate, as necessary, interspecies extrapolations, intraspecies variability, data base deficiencies, extrapolation from subchronic to chronic effects, and extrapolation from a lowest observable

adverse effect level (LOAEL) to a NOAEL. Uncertainty factors are applied to the exposure concentration after calculation of the human equivalent concentration as described in U.S. Environmental Protection Agency, (1990). The RfCs are based upon the most sensitive toxicity endpoint, as determined by available data. If several reliable studies are available, the RfC is based upon the study demonstrating effects at the lowest concentration. The RfC values are available from EPA in online format (Integrated Risk Information System [IRIS], U.S. Environmental Protection Agency, 1991).

The inhalation unit risk is the cancer risk level associated with a specific ambient concentration. The U.S. EPA has derived these values and has normalized them to an ambient concentration of $1 \mu\text{g}/\text{m}^3$ (i.e., the risk per μg chemical/ m^3 air) assuming exposure for a lifetime. To convert these values for use as health-based ambient criteria, the concentration associated with a specific level of risk (e.g., 1×10^{-6}) can be calculated by dividing the target risk level by the unit risk factor. For example, the unit risk factor for acrylonitrile is 6.8×10^{-5} per mg/m^3 (U.S. Environmental Protection Agency, 1991) and the ambient concentration associated with a 1×10^{-6} risk is $0.015 \text{ mg}/\text{m}^3$, which conceivably could be used as the health-based ambient criteria protective against cancer risk. The inhalation unit risk factors available on IRIS have undergone a review and verification process in the Carcinogen Risk Assessment Verification Endeavor Work Group, which ensures that appropriate test data and standardized methods were used to derive the values.

The RfC values and inhalation unit risk factors are currently in preparation for the 189 listed chemicals. Many of the listed chemicals will not have verified inhalation RfC values or unit risk factors, in large part due to the general lack of chronic toxicity studies conducted by the inhalation route of exposure. Thus, the evaluation of the usefulness of odor threshold values for risk assessment suffers from the relative lack of inhalation toxicology data. However, detailed analysis of the toxicology data base development for RfC and unit risk estimates is proceeding in EPA, as is the development of methods for risk assessment of acute exposure. New inhalation studies, method development, or dose route extrapolation will make possible the derivation of new ambient criteria for use in assessing the relationship between odor and risk.

1.3.2 Theoretical Considerations: Is There a Link Between Odor and Toxicity?

Detection of chemical odors may raise health concerns due to the awareness of exposure to chemicals. However, while odor itself is a signal of some type of exposure, it does not necessarily indicate a potential health risk unless the detected chemical is identified, and its toxicity is understood. Without this information, odor detection is not useful in risk assessment. This is because the mechanisms that appear to be involved with odor detection have very little to do with the mechanisms involved in chemical-induced toxicity and carcinogenesis.

The mechanisms involved in toxic phenomena are likely to be quite specific and distinct from those involved in olfaction. Although the toxic mechanisms for many agents require further study, a unifying hypothesis for cytotoxicants and carcinogens is that highly reactive species result from chemical entry into a cell (Coles, 1984; Vaca et al., 1988; Recknagel and Glende, 1973). These species may be the parent molecule, metabolites, or endogeneous molecules (e.g., superoxide, lipid peroxides), which become disproportionately numerous due to xenobiotic influences on normal cellular functioning. These reactive species are typically electrophiles or oxidants, which can then irreversibly bind to or denature tissue macromolecules (DNA, protein) such that normal structure and function is lost. While many exceptions to this mechanistic framework likely exist, key aspects of this hypothesis are relevant for a wide variety of potent toxicants and carcinogens.

The major distinctions between toxicant and odorant mechanisms are site of action (nasal olfactory epithelium for odorants; various organs for toxicants), type of receptor (odor receptor for odorants; DNA, miscellaneous protein receptors, or oxidant systems for toxicants), and the chemical requirements for efficacy. The key point is that odorants need not be strong toxicants and toxicants need not be odorous, so that there is no rationale for making assumptions about risk based solely upon odor perception. However, detection of odor in combination with information regarding chemical identity and toxic potency can be useful information, especially in those cases where the odor threshold concentration is known and can be compared to health-based ambient criteria. Since odor threshold concentration values are often imprecise and since they may not be relevant for a particular individual, it is advisable to obtain quantitative analytical data in cases where unknown or suspicious odors

are detected, or where potentially harmful chemical releases are suspected, even if no odors are detected.

1.3.3 Conclusions

Odor thresholds can be useful as a screening level, semi-quantitative approach for hazard identification in cases where:

1. The chemical identity of the odor is known or can reasonably be presumed;
2. Acute and chronic toxicity data are available and these data have been converted to appropriate health-based ambient criteria; and
3. The odor threshold data is not highly uncertain (i.e., reliable measurements of odor threshold fall within an order of magnitude range).

In these cases, Table 1-1 applies. If the odor threshold is above the threshold for toxic effects or safety concerns and an odor is detected, then cessation of exposure is prudent until further testing can be done. Conversely, if the odor threshold is clearly below the toxicity threshold and no odors are detected, then there is no immediate cause for concern. In cases where the odor threshold is similar to or greater than the ambient criteria, the absence of odor is not informative. Further, when the odor threshold is less than or similar to the ambient criteria and odor is detected, the hazard potential cannot be evaluated without analytical data. Although the detection of odor does not necessarily indicate risk in these cases, it does indicate a chemical exposure that should be analyzed and quantified.

**TABLE 1-1. RELATIONSHIP BETWEEN ODOR THRESHOLD VALUES
AND AMBIENT CRITERIA**

	Odor Threshold Below Ambient Criteria	Odor Threshold \approx Ambient Criteria	Odor Threshold Above Ambient Criteria
No odor	Low level of concern	Analytical data required	Analytical data required
Odor detected	Analytical data required	Analytical data required	High level of concern

1.4 LITERATURE SEARCH AND REVIEW

1.4.1 Critiqued Odor Threshold Values

The literature search consisted of a review of odor threshold compilations that were prepared by Van Gemert (1982), Van Gemert and Nettenbreijer (1977), Stahl (1973), Fazzalari (1978), and the American Industrial Hygiene Association (1989). The original references were then located if possible and reviewed based on the criteria discussed in Section 1.2.1. Those references that were accepted are listed in Table 2-1 and coded with an "A" next to the author's name.

The critiqued references and the odor threshold values are presented in Table 2-1. Threshold methodologies are evaluated according to each of the thirteen criteria discussed in Section 1.2.1. The geometric mean value, based on all accepted values, or recommended best estimate for the odor threshold for each of the compounds is given in Table 2-1. This is a common practice in sensory evaluation, as it accounts for the wide range of response over several orders of magnitude. The means were rounded off to two significant digits. Where values were given as a range, the geometric mean of the two points was taken for the threshold.

In some cases, the mean value for detection is higher than the mean value for recognition. This is a result of pooling of several data sets for the geometric mean.

Odor character descriptors in Table 2-1 are based on reports in the literature and experience in odor investigation. The intensity level at which the character is determined is seldom given in the sources reviewed. Since odor character can change with intensity, it should be remembered that the character reported may differ from source to source. The purpose here is to include an observation on the odorant character to accompany the threshold value.

2. ODOR THRESHOLD DATA FOR INDIVIDUAL CHEMICALS AND CHEMICAL CATEGORIES

Table 2-1 summarizes all published odor thresholds for the 189 hazardous air pollutants found to have reported odor thresholds. Chemicals are listed alphabetically. There are two sets of entries for each chemical: Phase I Unreviewed Sources and Phase II Critiqued Sources. Under the former are presented odor threshold values from sources that either were rejected or were not reviewed. Under the latter are presented odor threshold values from primary experimental sources that were critiqued. The table provides the following information.

- CAS number
- Chemical name and synonyms
- Chemical formula
- Molecular weight
- Last name of the first author listed for the source
- Source code:
 - A Accepted value based on critique
 - B Rejected value based on criteria
 - B1 Rejected value—water threshold
 - B2 Rejected value—minimum perceptible value
 - B3 Rejected value—water threshold/air conversion
 - B4 Rejected value—intensity
 - B5 Rejected value—insufficient methodology
 - C1 Rejected source based on review—secondary source
 - C2 Rejected source—incidental reference
 - C3 Rejected source—passive exposure/workplace
 - C4 Rejected source—passive exposure/experiment
 - D1 Omitted source—unpublished data
 - D2 Omitted source—personal communication
 - D3 Omitted source—anonymous reference
 - D4 Omitted source—omitted in Gemert
 - D5 Omitted source—pre-1900 reference
 - E1 Source located but not reviewed
 - E2 Source not located

- Odor threshold values in milligrams per cubic meter (mg/m^3) and parts per million (ppm)
- Type of threshold: d = detection, r = recognition, ng = not given
- Geometric mean odor threshold
- Type of geometric mean threshold: d = detection, r = recognition
- Odor characteristic

TABLE 2-1. REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
75070	Acetaldehyde Ethanal	C ₂ H ₄ O	44.05	Unreviewed Sources					0.067	d	Pungent/fruity
				Zwaardemaker (1914)	E2	0.7	0.39	d			
				Backman (1917)	E1	0.062-0.075	0.034-0.042	r			
				Takhirov (1974)	E1	0.49	0.27	ng			
				Anonymous (1980)	D3	0.0027	0.0015	d			
				Anonymous (1980)	D3	0.027	0.015	r			
				Critiqued Sources							
				Pliska and Janicek (1965)	B	1,800	1,000	ng			
				Katz and Talbert (1930)	A	0.12	0.067	d			
				Gofmekler (1967)	B2	0.012	0.0067	d			
				Leonardos et al. (1969)	B	0.38	0.21	r			
				Hartung et al. (1971)	B5	0.005	0.0028	ng			
60355	Acetamide Acetic Acid Amide Ethanamide	CH ₃ CONH ₂	59.07	Unreviewed Sources					None		Mousy
				Backman (1917)	E1	140-160	58-66	r			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
75058	Acetonitrile Methyl Cyanide Ethanenitrile	C ₂ H ₃ N	41.05	Unreviewed Sources					1,611	d	Etherish, aromatic
				No C-E Codes	-	-	-	-			
				Critiqued Sources							
				Pozzani et al. (1959)	A	<67	<40	ng			
				Dravnieks (1974)	A	1,950	1,161	d			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
98862	Acetophenone Acetylbenzene Methyl Phenyl Ketone	C ₆ H ₅ COCH ₃	120.2	Unreviewed Sources					0.3	d	Sweet/almond, pleasant
				Gavaudan and Poussel (1966)	E1	0.23	0.047	ng	0.6	r	
				Critiqued Sources							
				Imasheva (1963)	B2	0.01	0.002	ng			
				Tkach (1965)	B2	0.01	0.002	ng			
				Korneev (1965)	B2	0.01	0.002	ng			
				Hellman and Small (1974)	A	1.5	0.3	d			
				Hellman and Small (1974)	A	2.9	0.6	r			
53963	2-Acetylaminofluorene 2-Acetamidofluorene	C ₁₅ H ₁₃ NO	223.3	No sources found							
107028	Acrolein 2-Propenal Acrylaldehyde	C ₃ H ₄ O	56.06	Unreviewed Sources					1.8	d	Pungent, choking
				Buchberg et al. (1961)	E2	0.2-0.7	0.087-0.31	ng			
				Knuth (1973)	D2	0.14	0.061	ng			
				Anonymous (1980)	D3	0.069	0.03	d			
				Anonymous (1980)	D3	0.32	0.14	r			
				Critiqued Sources							
				Katz and Talbert (1930)	A	4.1	1.8	ng			
				Plotnikova (1957)	B2	0.8	0.35	ng			
				Leonardos et al. (1969)	B	0.48	0.21	r			
				Sinkuvene (1970)	B2	0.07	0.031	ng			
				Cormack et al. (1974)	B	0.23	0.1	ng			
79061	Acrylamide Acrylic Amide Ethylenecarboxamide	CH ₂ CHCONH ₂	71.08	No sources found							Odorless

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
79107	Acrylic Acid	C ₃ H ₄ O ₂	72.06	Unreviewed Sources					0.092	d	Rancid/plastic/sweet/acrid
	Glacial Acrylic Acid			No C-E Codes	-	-	-	-	1.0	r	
	2-Propenoic Acid			Critiqued Sources							
	Propenoic Acid			Hellman and Small							
	Vinyl Formic Acid			(1974)	A	0.27	0.092	d			
	Acroleic Acid			Hellman and Small							
	Propenoic Acid			(1974)	A	3	1	r			
	Ethylene Carboxylic Acid										
107131	Acrylonitrile	C ₃ H ₃ N	53.06	Unreviewed Sources					1.6	d	Onion/garlic, mild
	Vinyl Cyanide			No C-E Codes	-	-	-	-			
	2-Propenenitrile			Critiqued Sources							
				Stalker (1963)	A	3.4	1.6	d			
				Leonardos et al. (1969)	B	47	22	r			
107051	Allyl Chloride	C ₃ H ₅ Cl	76.53	Unreviewed Sources					None		Pungent, unpleasant
	3-Chloro-1-propene			Shell Chemical Corporation (1958)	C1	9.3-18.6	3.0-5.9	ng			
	3-Chloropropene			Torkelson et al. (1959)	C4	3-9	1-3	ng			
				Critiqued Sources							
				Leonardos et al. (1969)	B	1.5	0.48	r			
92671	4-Aminobiphenyl	C ₁₂ H ₁₁ N	169.2	Unreviewed Sources					None		
	p-Aminobiphenyl			Backman (1917)	E1	0.15-0.17	0.022-0.025	r			
	Diphenylamine			Critiqued Sources							
				No A or B Codes	-	-	-	-			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
62533	Aniline	C ₆ H ₅ NH ₂	93.12	Unreviewed Sources					10	ng	Pungent/oily, characteristic
				Tempelaar (1913)	E2	0.97	0.25	d			
				Huijer (1917)	E2	0.046	0.012	d			
				Backman (1917)	E1	5.0-5.8	1.3-1.5	r			
				Geier (1936)	E2	1.2-1.5	0.32-0.39	d			
				Geier (1936)	E2	2.0-2.5	0.53-0.66	r			
				Critiqued Sources							
				Jacobson et al. (1958)	A	38	10	ng			
				Tkachev (1963)	B2	0.37	0.097	ng			
				Leonardos et al. (1969)	B	3.8	1	r			
90040	o-Anisidine	C ₇ H ₉ NO	123.2	No Sources Found							
1332214	Asbestos	Magnesium and/or Iron Silicate Fibers		No Sources Found							Odorless

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
71432	Benzene	C ₆ H ₆	78.11	Unreviewed Sources					61	d	Aromatic/ sweet/solvent
				Backman (1917)	E1	6.6-6.9	2.1-2.2	r	97	r	
				Backman (1918)	E2	5.3	1.7	ng			
				Grijns (1919)	E2	420	131	ng			
				Schley (1934)	E2	8.8	2.8	d			
				Schley (1934)	E2	12	3.8	r			
				Deadman and Prigg (1959)	E2	9	2.8	d			
				Koster (1971)	E2	37	12	d			
				Naus (1962)	C1	6	1.9	d			
				Critiqued Sources							
				Jones (1954)	B	480-510	150-160	r			
				Jones (1955)	B	180	56	d			
				Novikov (1957)	B2	4.9	1.5	ng			
				Gusev (1965)	B2	2.8-4.0	0.88-1.3	ng			
				May (1966)	A	180	56	d			
				May (1966)	A	310	97	r			
				Elfimova (1966)	B5	2.5	0.78	ng			
				Leonardos et al. (1969)	B	15	4.7	r			
				Alibaev (1970)	B2	2.9	0.91	ng			
				Dravnieks and O'Donnell (1971)	B5	38	12	ng			
				Laffort and Dravnieks (1973)	B	14.5	4.5	ng			
				Dravnieks (1974)	A	380	119	d			
				Punter (1980)	A	108	34	d			
92875	Benzidine 4,4'-Bianiline p,p'-Bianiline 4,4'-Biphenyldiamine	C ₁₂ H ₁₂ N ₂	184.2	No Sources Found							
98077	Benzotrichloride Benzenyl Chloride Benzotrichloride Benzenyl Trichloride Benzylidene Chloride	C ₆ H ₅ CCl ₃	195.5	No Sources Found							Penetrating

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
100447	Benzyl Chloride alpha-Chlorotoluene	C ₇ H ₇ Cl	126.58	Unreviewed Sources No C-E Codes Critiqued Sources Katz and Talbert (1930) Leonardos et al. (1969)	- A B	- 0.21 0.24	- 0.041 0.046	- r	0.041	ng	Pungent
92524	Biphenyl Phenylbenzene	C ₁₂ H ₁₀	154.21	Unreviewed Sources No C-E Codes Critiqued Sources Solomin (1961)	- B2	- 0.06	- 0.0095	-	None		Pleasant/ butter-like
117817	Bis(2-ethylhexyl) Phthalate (DEHP) Bis(2-ethylhexyl)phthalate Phthalic Acid, bis(2-ethylhexyl)ester	C ₂₄ H ₃₈ O ₄	390.6	No Sources Found							
542881	Bis(chloromethyl)ether Chloromethyl Ether Dichlorodimethyl Ether	(CH ₂ Cl)O(CH ₂ Cl)	115	No Sources Found							
75252	Bromoform Tribromomethane	CHBr ₃	252.75	Unreviewed Sources Passy (1893) Backman (1917) Grijns (1919) Roc��n (1920) Critiqued Sources No A or B Codes	D5 E1 E2 E2 - -	2-5 2.2-2.5 150 30 - -	0.19-0.48 0.21-0.24 15 2.9 - -	d r ng r - -	None		Chloroform/ sweet/ suffocating

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
106990	1,3-Butadiene Butadiene Divinyl Biethylene Erythrene	C ₄ H ₆	54.09	Unreviewed Sources Deadman and Prigg (1959) Jeltes (1975) Critiqued Sources Mullins (1955) Ripp (1968) Laffort and Dravnieks (1973) Hellman and Small (1974) Hellman and Small (1974)	E2 E2 B5 B2 B A A	2.1 0.22 169 4 5.8 1 2.4	0.95 0.099 76 1.8 2.6 0.45 1.1	d ng r ng ng d r	0.45 1.1	d r	Aromatic/ rubber, mild
156627	Calcium Cyanamide Calcium Carbamide	CaCN ₂	80.1	No Sources Found							
105602	Caprolactam 6-Aminohexanoic Acid 6-Aminohexanoic Acid Lactam	C ₆ H ₁₁ ON	113.2	Unreviewed Sources No C-E Codes Critiqued Sources Krichevskaya (1968)	- - B2	- - 0.3	- - 0.065	- - ng	None		
133062	Captan	C ₉ H ₈ O ₂ SNCl ₃	300.6	No Sources Found							Slightly pungent
63252	Carbaryl	C ₁₂ H ₁₁ NO ₂	201.2	No Sources Found							
75150	Carbon Disulfide	CS ₂	76.13	Unreviewed Sources Deadman and Prigg (1959) Frantikova (1962) Critiqued Sources Hildenskiold (1959) Baikov (1963) Leonardos et al. (1969)	E2 E2 B2 B2 B	0.07 1.3 0.05 0.08-0.5 0.65	0.022 0.42 0.016 0.026-0.16 0.21	d ng ng ng r	None		Vegetable sulfide/ medicinal

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
56235	Carbon Tetrachloride Tetrachloromethane Perchloromethane Benzoinform	CCl ₄	153.82	Unreviewed Sources					255*	d	Sweet/dry/ cleaner, distinctive
				Lehmann and Schmidt-Kehl (1936)	E1	900	143	ng	250	r	
				Davis (1934)	C1	500	79	ng			
				Critiqued Sources							
				Allison and Katz (1919)	B5	4,533	720	ng			
				May (1966)	A	1,260	200	d			
				May (1966)	A	1,600	250	r			
				Leonardos et al. (1969)	B	135-630	21-100	r			
				Belkov (1969)	B5	11.5-58	1.8-9.0	ng			
				Nikiforov (1970)	B5	10.58	1.68	ng			
463581	Carbonyl Sulfide Carbon Oxsulfide Carbonyl Oxsulfide	COS	60.07	Unreviewed Sources					0.1	ng	sulfide
				No C-E Codes	-	-	-	-			
				Critiqued Sources							
				Polgar et al. (1975)	A	0.25	0.1	ng			
120809	Catechol 1,2-Benzenediol 2-Hydroxyphenol	C ₆ H ₆ O ₂	110.1	No Sources Found							
133904	Chloramben	C ₇ H ₅ NO ₂ Cl ₂	206	No Sources Found							
57749	Chlordane 1,2,3,4,5,6,7, 8,8-octachloro- 2,3,3a,4,7,7a-hexahydro-4,7- methano-1H-indene	C ₁₀ H ₆ Cl ₈	409.8	No Sources Found							Odorless

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
7782505	Chlorine	Cl	35.45	Unreviewed Sources					0.16	d	Suffocating/ sharp/bleach
				Fieldner et al. (1921)	C1	10	6.9	ng			
				Smolczyk and Cobler (1930)	E2	1.43-14.3	0.99-9.9	ng			
				Styazhkin (1963)	E2	0.7	0.48	ng			
				Rupp and Henschler (1967)	C4	0.06-0.15	0.041-0.1	d			
				Rupp and Henschler (1967)	C4	0.3	0.2	r			
				Kramer (1976)	D2	3.2-7.8	0.21-5.38	ng			
				Critiqued Sources							
				Takhiroff (1957)	B2	0.8	0.55	ng			
				Leonardos et al. (1969)	B	0.6	0.41	r			
				Dixon and Ikels (1977)	A	0.23	0.16	d			
79118	Chloroacetic Acid	C ₂ H ₃ ClO ₂	94.5	Unreviewed Sources					None	ng	Penetrating odor similar to vinegar
				Backman (1917)	E1	0.6	0.19	r			
				Critiqued Sources							
				Smith and Hochstettler (1969)	B	0.05	0.02	r			
532274	2-Chloroacetophenone Phenyl Chloromethyl Ketone Phenacyl Chloride	C ₈ H ₇ ClO	154.6	Unreviewed Sources					0.07	ng	Pungent/floral
				No C-E Codes	-	-	-	-			
				Critiqued Sources							
				Katz and Talbert (1930)	A	0.1-0.7	0.02-0.11	ng			
108907	Chlorobenzene Monochlorobenzene	C ₆ H ₅ Cl	112.56	Unreviewed Sources					1.3	d	Almond-like/ shoe polish
				Backman (1917)	E1	7.5-8.1	1.6-1.8	r			
				Critiqued Sources							
				Mateson (1955)	B5	21.6	4.7	ng			
				Tarkhova (1965)	B2	0.4	0.087	ng			
				Leonardos et al. (1969)	B	0.97	0.21	r			
				Smith and Hochstettler (1969)	B	3	0.65	r			
				Punter (1980)	A	5.9	1.3	d			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
510156	Chlorobenzilate	C ₁₆ H ₁₄ Cl ₂ O ₃	325.2	No Sources Found							
67663	Chloroform Trichloromethane	CHCl ₃	119.4	Unreviewed Sources					192	d	Sweet/ suffocating characteristic
				Passy (1893)	D5	30	6.1	d			
				Tempelaar (1913)	E2	3,000	614	d			
				Backman (1917)	E1	14.1-15.1	2.9-3.1	r			
				Grijns (1919)	E2	2,350	481	ng			
				Rocén (1920)	E2	730	150	d			
				Rocén (1920)	E2	2,500	512	r			
				Mitsumoto (1926)	E1	353.8-589	72.5-121	r			
				Schley (1934)	E2	42	8.6	d			
				Schley (1934)	E2	56	11	r			
				Morimura (1934)	E1	480-622	98-127	r			
				Lehmann and							
				Schmidt-Kehl (1936)	E1	1,000-1,500	205-307	ng			
				Janicek et al. (1960)	E1	3,700	758	ng			
				Naus (1962)	C1	3	0.6	d			
				Critiqued Sources							
				Allison and Katz (1919)	B5	3,300	676	ng			
				Scherberger et al. (1958)	B	6,900	1,413	r			
				Dravnieks (1974)	A	1,350	276	d			
				Punter (1980)	A	650	133	d			
107302	Chloromethyl Methyl Ether			No Sources Found							
126998	Chloroprene 2-Chloro-1,3-butadiene	C ₄ H ₅ Cl	88.54	Unreviewed Sources					None		Rubber
				Nystrom (1948)	C1	500-1,000	138.1-276.1	r			
				Critiqued Sources							
				Mnatsakanyan (1962)	B	0.4-2.0	0.11-0.55	ng			
1319773	Cresols (isomers and mixtures) Cresylic Acid See o-Cresol See m-Cresol See p-Cresol										

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
95487	o-Cresol o-Cresylic Acid 2-Methylphenol	C ₇ H ₈ O	108.1	Unreviewed Sources					None		Phenolic, tarry
				Backman (1917)	E1	0.004	0.0009	r			
				Stuiver (1958)	E2	0.0004	0.00009	d			
				Kendall et al. (1968)	E2	0.0028	0.00063	r			
				Anonymous (1980)	D3	0.0017	0.00038	d			
				Anonymous (1980)	D3	0.027	0.0061	r			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
108934	m-Cresol 3-Methylphenol	C ₇ H ₈ O	108.1	Unreviewed Sources					0.004	d	Phenolic
				Backman (1917)	E1	0.0007-0.0009	0.00016-0.00020	r			
				Stuiver (1958)	E2	0.0004	0.00009	d			
				Anonymous (1980)	D3	0.00057	0.00013	d			
				Anonymous (1980)	D3	0.011	0.0025	r			
				Critiqued Sources							
				Nader (1958)	A	0.00022-.035	0.000050-0.0079	ng			
106445	p-Cresol p-Hydroxytoluene 4-Methylphenol	C ₇ H ₈ O	108.1	Unreviewed Sources					None		Phenolic
				Backman (1917)	E1	0.03-0.04	0.0068-0.0090	r			
				Baldus (1936)	E2	0.0125	0.0028	d			
				Baldus (1936)	E2	0.015	0.0034	r			
				Stuiver (1958)	E2	0.00005	0.000011	d			
				Punter (1975, 1979)	D1,D2	0.024	0.0054	d			
				Anonymous (1980)	D3	0.00018	0.000041	d			
				Anonymous (1980)	D3	0.0084	0.0019	r			
				Critiqued Sources							
				Leonardos et al. (1969)	B	0.0044	0.00099	r			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
98828	Cumene Isopropylbenzene	C ₉ H ₁₂	120.2	Unreviewed Sources					0.032	d	Sharp
				Koster (1971)	E2	0.25	0.051	d	0.047	r	
				Anonymous (1980)	D3	0.074	0.015	d			
				Anonymous (1980)	D3	0.54	0.11	r			
				Critiqued Sources							
				Solomin (1964)	B2	0.06	0.012	ng			
				Elfimova (1966)	B5	0.025	0.0051	ng			
				Turk (1973)	B	4.8-6.4	0.98-1.3	r			
				Hellman and Small (1974)	A	0.04	0.008	d			
				Hellman and Small (1974)	A	0.23	0.047	r			
				Punter (1980)	A	.65	0.132	d			
94757	2,4-D, Salts and Esters 2,4-Dichlorophenoxyacetic Acid	C ₈ H ₆ Cl ₂ O ₃	221	No Sources Found							
72559	DDE Dichlorodiphenyldichloroethylene	(ClC ₆ H ₄) ₂ :CCl ₂		No Sources Found							
334883	Diazomethane	CH ₂ N ₂	42.04	No Sources Found							
132649	Dibenzofuran Diphenylene Oxide	C ₁₂ H ₈ O	168.2	No Sources Found							
96128	1,2-Dibromo-3-chloropropane	C ₃ H ₅ Br ₂ Cl	236.3	Unreviewed Sources					None		
				Torkelson and Rowe (1981)	C1	0.1-0.3	0.01-0.03	ng			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
84742	Dibutylphthalate	C ₆ H ₄ (COOC ₄ H ₉) ₂	278.3	No Sources Found							Slightly ester
106467	p-Dichlorobenzene 1,4-Dichlorobenzene	C ₆ H ₄ Cl ₂	147	Unreviewed Sources					0.12	d	Camphor/ mothballs, penetrating
				Hollingsworth et al. (1956)	C3	<90	<15	ng			
				Critiqued Sources							
				Punter (1980)	A	0.73	0.121	d			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
91941	3,3'-Dichlorobenzidine	C ₁₂ H ₁₀ Cl ₂ N ₂	253.1	No Sources Found							
111444	Dichloroethyl Ether Bis(2-chloroethyl) Ether	C ₄ H ₈ Cl ₂ O	143	No Sources Found							Sweet, like chloroform
542756	1,3-Dichloropropene 1,3-Dichloropropylene 3-Chloroallyl Chloride 3-Chloropropenyl Chloride	C ₃ H ₄ Cl ₂	111	No Sources Found							
62737	Dichlorvos 2,2 Dichloroethenyl Dimethyl Phosphate 2,2 Dichlorovinyl Dimethyl Phosphate Phosphoric Acid, 2,2-Dichloroethenyl Dimethyl Ester Phosphoric Acid, 2,2-Dichlorovinyl Dimethyl Ester	C ₄ H ₇ O ₄ PCl ₂	221	No Sources Found							
111422	Diethanolamine 3-Azapentane-1,5-Diol 2,2 Dihydroxydiethylamine	C ₄ H ₁₁ NO ₂	105.1	Unreviewed Sources England et al. (1978) Critiqued Sources No A or B Codes	E2 - -	1.2 - -	0.28 - -	r - -	None		
64675	Diethyl Sulfate Diethyl Sulphate Ethyl Sulfate Sulfuric Acid, Diethyl Esters	C ₄ H ₁₀ SO ₄	154.2	No Sources Found							Faint, ethereal, irritating after-effect
121697	Dimethylaniline N,N-Dimethylaniline N,N-Diethyl Aniline	C ₈ H ₁₁ N	121.2	Unreviewed Sources Backman (1917) Geier (1936) Geier (1936) Deadman and Prigg (1959) Critiqued Sources No A or B Codes	E1 E2 E2 E2 - -	0.8-1.0 0.005-0.1 0.05-0.25 0.012 - -	0.16-0.20 0.0010- 0.020 0.010-0.050 0.0024 -	r d r d - -	None		Oily

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Odor Thresholds			Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
					Code	mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
119904	3,3-Dimethoxybenzidine Dianisidine	C ₁₄ H ₁₆ N ₂ O ₂	244.3	No Sources Found							
60117	Dimethyl aminoazobenzene Benzenamine, N,N-dimethyl-4-(phenylazo) p-(Dimethylamino) Azobenzene 4-(N,N-Dimethylamino)azobenzene	C ₁₄ H ₁₅ N ₃	225.3	No Sources Found							
119937	3,3'-Dimethyl Benzidine Dimethyl Carbamoyl Chloride Carbamic Chloride, Dimethyl Dimethylcarbaminc Acid Chloride Dimethylcarbamidoyl Chloride Dimethylcarbamy Chloride Dimethylchloroformamide Ortho-Tolidine	C ₁₄ H ₁₆ N ₂	212.3	No Sources Found							
68122	Dimethyl Formamide N,N-Dimethyl Formamide DMF	C ₃ H ₇ ON	73.09	Unreviewed Sources No C-E Codes Critiqued Sources Odoshashvili (1962) Leonardos et al. (1969)	- - B2 B	- - 0.14 300	- - 0.047 100	- - ng r	None		Fishy
57147	1,1-Dimethylhydrazine N,N-Dimethylhydrazine unsym-Dimethylhydrazine	C ₂ H ₈ N ₂	60.1	Unreviewed Sources Rumsey and Cesta (1970) Critiqued Sources Jacobson et al. (1955)	C3 A	<0.75 15-35	<0.31 6.1-14	ng ng	10		Fishy/ammonia
131113	Dimethyl Phthalate	C ₁₀ H ₁₀ O ₄	194.2	No Sources Found							
77781	Dimethyl Sulfate Sulfuric Acid, Dimethyl Ester	C ₂ H ₆ O ₄	102.1	No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
534521	4,6-Dinitro-o-cresol, and Salts 4,6-Dinitro-2-methylphenol	C ₇ H ₆ N ₂ O ₅	198.1	Unreviewed Sources Kurtschatowa and Dawidkova (1970) Critiqued Sources No A or B Codes	E2	0.004-0.021	0.0005-0.0026	ng	None		
51285	2,4-Dinitrophenol	C ₆ H ₄ N ₂ O ₅	184.1	No Sources Found							Sweet, musty
121142	2,4-Dinitrotoluene	C ₇ H ₆ N ₂ O ₄	182.1	No Sources Found							
123911	Dioxane 1,4-Diethylene Dioxide 1,4-Dioxane Diethylene Oxide Dioxyethylene Ether 1,4-Diethyleneoxide	C ₄ H ₈ O ₂	88.1	Unreviewed Sources Koster (1971) Wirth and Klimmer (1937) Critiqued Sources May (1966) May (1966) Hellman and Small (1973, 1974) Hellman and Small (1973, 1974) Dravnieks (1974)	E2 C1 A A A A A	45-9,400 10 620 1,000 2.9 6.5 270	12-2,609 2.8 172 278 0.8 1.8 75	d d d r d r d	22* 22	d r	Sweet/mild, alcohol/ ethereal
122667	1,2-Diphenylhydrazine	C ₁₂ H ₁₂ N ₂	184.2	No Sources Found							
106898	Epichlorohydrin 1-Chloro-2,3-epoxypropane Glycidyl Chloride 3-Chloropropene-1,2-oxide	C ₃ H ₅ ClO	92.53	Unreviewed Sources Shell Chemical Corporation (1959) Critiqued Sources Fomin (1966)	C1 B2	38-46 0.3	10-12 0.08	ng ng	None		Chloroform, pungent, garlic, sweet
106887	1,2-Epoxybutane 1,2-Butylene Oxide	C ₄ H ₈ O	72.12	No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
140885	Ethyl Acrylate Ethyl 2-Propenoate	C ₅ H ₈ O ₂	100.1	Unreviewed Sources Anonymous (1980) Anonymous (1980) Critiqued Sources Leonardos et al. (1969) Hellman and Small (1973, 1974) Hellman and Small (1973, 1974)	D3 D3 B A A	0.00082 0.0053 0.0019 0.001 0.0015	0.0002 0.0013 0.00046 0.00024 0.00037	d r r d r	0.00024 0.00037	d r	Sweet/ester/ plastic
100414	Ethyl Benzene Phenylethane	C ₈ H ₁₀	106.2	Unreviewed Sources Koster (1971) Critiqued Sources Ivanov (1964)	E2 B2	0.4 2.0-2.6	0.092 0.46-0.60	d ng	None		Oily/solvent, aromatic
51796	Ethyl Carbamate Urethane	C ₃ H ₇ NO ₂	89.1	No Sources Found							Odorless
75003	Ethyl Chloride Chloroethane	C ₂ H ₅ Cl	64.52	No Sources Found							Etherial, pungent
106934	Ethylene Dibromide Dibromoethane	BrCH ₂ CH ₂ Br	187.9	No Sources Found							Sweet

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
107062	Ethylene Dichloride 1,2-Dichloroethane Ethylene Chloride	C ₂ H ₄ Cl ₂	98.96	Unreviewed Sources					26	d	Chloroform
				McCawley (1942)	E2	1,200-4,000	297-988	ng	87	r	
				Irish (1963)	C1	200	49	ng			
				Critiqued Sources							
				Jones (1955)	B	1,500	371	d			
				Borisova (1957)	B2	1.75-23.2	4.3-5.7	ng			
				Scherberger et al. (1958)	B	820	203	r			
				May (1966)	A	450	111	d			
				May (1966)	A	750	185	r			
				Dravnieks and O'Donnell (1971)	B5	190	47	ng			
				Hellman and Small (1974)	A	25	6	d			
				Hellman and Small (1974)	A	165	41	r			
107211	Ethylene Glycol	C ₂ H ₆ O ₂	62.07	No Sources Found							Odorless
151564	Ethylenimine Dimethylenimine Aziridine	C ₂ H ₅ N	43.07	Unreviewed Sources					None		Ammonia
				Carpenter et al. (1948)	C4	3.6	2	ng			
				Critiqued Sources							
				Berzins (1968)	B5	1.25-3.5	0.71-2.0	ng			
75218	Ethylene Oxide Oxirane 1,2-Epoxyethane	C ₂ H ₄ O	44.05	Unreviewed Sources					257	d	Sweet/olefinic
				No C-E Codes	-	-	-	-	493	r	
				Critiqued Sources							
				Jacobson et al. (1956)	A	1,260	690	ng			
				Yuldashev (1965)	B2	1.5	0.82	ng			
				Hellman and Small (1974)	A	470	257	d			
				Hellman and Small (1974)	A	900	493	r			
96457	Ethylene Thiourea	C ₃ H ₆ N ₂ S	102.1	No Sources Found							Faint ammonia
75343	1,1-Dichloroethane	C ₂ H ₄ Cl ₂	98.97	No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
50000	Formaldehyde Methanal	CH ₂ O	30.03	Unreviewed Sources					None		Pungent/strong
				Backman (1917)	E1	0.033-0.036	0.027-0.029	r			
				Buchberg et al. (1961)	E2	1.1-2.2	0.90-1.8	ng			
				Takhirov (1974)	E1	0.065	0.053	ng			
				Makeicheva (1978)	E1	0.077	0.063	ng			
				Anonymous (1980)	D3	0.49	0.4	d			
				Anonymous (1980)	D3	2.3	1.9	r			
				Critiqued Sources							
				Melekhina (1958)	B2	0.07	0.057	ng			
				Pliska and Janicek (1965)	B	12,000	9,770	ng			
				Sgibnev (1968)	B2	0.3-0.4	0.24-0.33	ng			
				Leonardos et al. (1969)	B	1.2	0.98	r			
				Fel'dman and Bonasheuskaya (1971)	B2	0.073	0.059	ng			
76448	Heptachlor	C ₁₀ H ₇ Cl ₇	375.3	No Sources Found							
118741	Hexachlorobenzene	C ₆ Cl ₆	284.8	No Sources Found							
87683	Hexachlorobutadiene	C ₄ Cl ₆	260.8	No Sources Found							Mild
77474	Hexachlorocyclopentadiene Perchlorocyclopentadiene	C ₅ Cl ₆	272.8	Unreviewed Sources					None		Harsh, pungent
				Treon et al. (1955)	C2	1.7	0.15	ng			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
67721	Hexachloroethane	C ₂ Cl ₆	236.7	No Sources Found							Camphor-like
822060	Hexamethylene-1,6-diisocyanate	C ₈ H ₁₂ N ₂ O ₂	168.2	No Sources Found							
680319	Hexamethylphosphoramide Hempa	C ₆ H ₁₈ N ₃ PO	179.2	No Sources Found							Mild, ammonia

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
110543	Hexane n-Hexane	C ₆ H ₁₄	86.17	Unreviewed Sources Patty and Yant (1929) Critiqued Sources Laffort and Dravnieks (1973)	C4 B	875 230	248 65	ng ng	None		Faint gasoline
302012	Hydrazine	N ₂ H ₄	32.05	Unreviewed Sources No C-E Codes Critiqued Sources Jacobson et al. (1955) Jacobson et al. (1958)	- A A	- 3.9-5.2 5.2	- 3.0-4.0 4	- ng ng	3.7	d	Ammonia
7647010	Hydrogen Chloride Hydrochloric Acid	HCl	36.47	Unreviewed Sources Schley (1934) Heyroth (1963) Styazhkin (1963) Takhirov (1974) Critiqued Sources Melekhina (1968) Leonardos et al. (1969)	E2 C1 E2 E1 B2 B	4.5 1.5-7.5 0.2 0.38 0.39 15	3.02 1.01-5.03 0.134 0.255 0.262 10.06	ng d ng ng d r	None		Sharp/ suffocating, irritating
7664393	Hydrogen Fluoride Hydrofluoric Acid	HF	20.01	Unreviewed Sources No C-E Codes Critiqued Sources Sadilova (1968)	- B2	- 0.03	- 0.04	- ng	None		
123319	Hydroquinone	C ₆ H ₆ O ₂	110.1	No Sources Found							
78591	Isophorone 3,5,5-Trimethyl-2-cyclohexenone	C ₉ H ₁₄ O	138.2	Unreviewed Sources No C-E Codes Critiqued Sources Hellman and Small (1974) Hellman and Small (1974)	- A A	- 1.1 3	- 0.19 0.53	- d r	0.19 0.53	d r	Sharp

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
58899	Lindane (all isomers)	C ₆ H ₆ Cl ₆	290.8	No Sources Found							
108316	Maleic Anhydride 2,5-Furandione	C ₄ H ₂ O ₃	98.06	Unreviewed Sources					None		Acrid, faint
				No C-E Codes	-	-	-	-			
				Critiqued Sources							
				Grigor'eva (1964)	B2	1.0-1.3	0.25-0.32	ng			
67561	Methyl Alcohol Methanol	CH ₄ O	32.04	Unreviewed Sources					160	d	Sour/sweet
				Passy (1892)	D5	1,000	764	d			
				Zwaardemaker (1914)	E2	600	458	d	690	r	
				Backman (1917)	E1	900-1,000	687-763	r			
				Grijns (1919)	E2	2,150	1,641	ng			
				Jung (1936)	E2	23.4-54.6	17.9-41.7	d			
				Jung (1936)	E2	54.6-62.4	41.7-47.7	r			
				Gavaudan et al. (1948)	E2	150	114	ng			
				Janicek et al. (1960)	E1	4,000	3,053	ng			
				Anonymous (1980)	D3	74	56	d			
				Anonymous (1980)	D3	260	198	r			
				Critiqued Sources							
				Mullins (1955)	B5	19,300	14,729	r			
				Scherberger et al. (1958)	B	1,950	1,490	r			
				Chao-Chen-Tzi (1959)	B2	4.3	3.3	ng			
				Pliska and Janicek (1965)	B	260,000	198,416	ng			
				May (1966)	A	7,800	5,950	d			
				May (1966)	A	11,700	8,930	r			
				Ubaidullaev (1966)	B2	4.5	3.4	ng			
				Leonardos et al. (1969)	B	130	99	r			
				Hellman and Small (1974)	A	5.5	1.2	d			
				Hellman and Small (1974)	A	69	53	r			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
72435	Methoxychlor	C ₁₆ H ₁₅ Cl ₃ O ₂	345.7	No Sources Found							Slightly fruity
74839	Methyl Bromide Bromomethane	CH ₃ Br	94.94	No Sources Found							Relatively odorless, sweet, chloroform
74873	Methyl Chloride Chloromethane	CH ₃ Cl	50.49	Unreviewed Sources No C-E Codes Critiqued Sources Leonardos et al. (1969)	- - B	- - >21	- - >10	- - r	None		Sweet/etherish
71556	Methyl Chloroform 1,1,1-Trichloroethane	C ₂ H ₃ Cl ₃	133.4	Unreviewed Sources Kendall et al. (1968) Critiqued Sources Scherberger et al. (1958) May (1966) May (1966)	E2 B A A	88 1,650 2,100 3,900	16 302 385 715	r r d r	385 715	d r	Sweet/etherish
78933	Methyl Ethyl Ketone 2-Butanone MEK	C ₄ H ₈ O	72.1	Unreviewed Sources Backman (1917) Anonymous (1980) Anonymous (1980) Critiqued Sources May (1966) May (1966) Leonardos et al. (1969) Mukhitov and Azimbekov (1972) Dravnieks (1974) Hellman and Small (1974) Hellman and Small (1974) Hartung et al. (1971)	E1 D3 D3 A A B B5 A A A B5	63-70 8.4 29 80 163 29 0.75 250 5.8 16 7	21-24 2.8 9.8 27 55 9.8 0.25 85 2 5.4 2.4	r d r d r r ng d d r ng	17* 17	d r	Sweet/sharp, acetone

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
60344	Methyl Hydrazine	CH ₆ N ₂	46.07	Unreviewed Sources No C-E Codes Critiqued Sources Jacobson et al. (1955)	- A	- 1.9-5.7	- 1.0-3.0	- ng	1.73		Like ammonia
74884	Methyl Iodide Iodomethane	CH ₃ I	141.9	No Sources Found							
108101	Methyl Isobutyl Ketone Hexone MIBK 4-Methyl-2-pentanone	C ₆ H ₁₂ O	100.2	Unreviewed Sources Backman (1917) Anonymous (1980) Anonymous (1980) Critiqued Sources May (1966) May (1966) Stone et al. (1967) Steinmetz et al. (1969) Leonardos et al. (1969) Hellman and Small (1974) Hellman and Small (1974)	E1 D3 D3 A A B B B A A	0.6-0.8 0.7 2.8 32 64 0.97-9.7 1.21 1.9 0.4 1.1	0.15-2.0 0.17 0.68 7.8 16 0.24-2.4 0.3 0.46 0.1 0.27	r d r d r d d r d r	0.88 2.1	d r	Sweet/sharp, pleasant
624839	Methyl Isocyanate Isocyanic Acid-Methyl Ester MIC	C ₂ H ₃ NO	57.05	Unreviewed Sources Kimmerle and Eben (1964) Critiqued Sources No A or B Codes	C4 -	5 -	2.1 -	ng -	None		

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric	Geometric	Odor
						mg/m ³	ppm		Mean Air Odor Threshold (ppm)	Mean Air Odor Type of Threshold	
80626	Methyl Methacrylate Methyl 2-methyl-2-propenoate	C ₅ H ₈ O ₂	100.1	Unreviewed Sources					0.049	d	Plastic/sharp
				Holland (1974)	D2	0.057	0.014	ng	0.34	r	
				Anonymous (1980)	D3	0.62	0.15	d			
				Anonymous (1980)	D3	1.9	0.46	r			
				Critiqued Sources							
				Filatova (1962)	B2	0.2	0.049	ng			
				Leonardos et al. (1969)	B	0.85	0.21	r			
				Hellman and Small (1973, 1974)	A	0.2	0.049	d			
				Hellman and Small (1973, 1974)	A	1.4	0.34	r			
1634044	Methyl Tert Butyl Ether	(CH ₃) ₃ COCH ₃	88.15	No Sources Found							
101144	4,4-Methylene bis(2-Chloroaniline)	C ₁₃ H ₁₄ Cl ₂ N ₂	269.2	No Sources Found							
75092	Methylene Chloride Dichloromethane	CH ₂ Cl ₂	84.94	Unreviewed Sources					144	d	Sweet/ ethereal, penetrating
				Lehmann and Schmidt-Kehl (1936)	E1	1,100	317	ng	227	r	
				Basmadshijewa et al. (1970)	E2	4.1-33.2	1.2-9.6	d			
				Critiqued Sources							
				Scherberger et al. (1958)	B	1,530	440	r			
				May (1966)	A	500	144	d			
				May (1966)	A	790	227	r			
				Leonardos et al. (1969)	B	730	210	r			
				101688	Methylene Bisphenyl Isocyanate Diphenylmethane 4,4-Diisocyanate Methylene Diphenyl Diisocyanate MDI	C ₁₅ H ₁₀ O ₂ N ₂	250	Unreviewed Sources			
Woolrich (1982)	C1	4	0.39					ng			
Critiqued Sources											
				No A or B Codes	-	-	-	-			
101779	4,4-Methylenedianiline para,para'-Diaminodiphenylmethane	C ₁₃ H ₁₄ N ₂	196.3	No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
91203	Naphthalene	C ₁₀ H ₈	128.2	Unreviewed Sources					0.038	d	Tar/cresote/ mothballs
				Backman (1917)	E1	0.05-0.055	0.0095-	r			
				Mitsumoto (1926)	E1	4.0-4.4	0.0105	r			
				Morimura (1934)	E1	3.37-5.34	0.76-0.84	r			
				Robbins (1951)	C3	<1.6	0.64-1.02	ng			
				Critiqued Sources			0.31				
98953	Nitrobenzene	C ₆ H ₅ NO ₂	123.1	Punter (1980)	A	0.2	0.038	d	1.9	ng	Almonds/shoe polish
				Unreviewed Sources							
				Hermanides (1909)	E2	0.0412	0.0082	r			
				Zwaardemaker (1914)	E2	0.041	0.0082	d			
				Backman (1917)	E1	0.34-7.0	0.068-0.14	r			
				Henning (1924)	C1	0.0065	0.0013	d			
				Van Anrooji (1931)	E2	0.019	0.0038	d			
				Janicek et al. (1960)	E1	19	3.78	ng			
				Gavaudan and Poussel (1966)	E1	0.15	0.03	ng			
				Critiqued Sources							
				Allison and Katz (1919)	B5	146	29	ng			
				Katz and Talbert (1930)	A	9.6	1.9	ng			
				Andreeshcheva (1964)	B2	0.0182	0.0036	ng			
				Leonardos et al. (1969)	B	0.024	0.0048	r			
				Randebrock (1971)	B5	0.002	0.0004	ng			
92933	4-Nitrophenyl	C ₁₂ H ₉ NO ₂	199.2	No Sources Found					None		
100027	4-Nitrophenol	C ₆ H ₅ NO ₃	139.1	Unreviewed Sources							
				Stuiver (1958)	E2	2.3	0.4	d			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Threshold Type of Threshold	Odor Characteristic
79469	2-Nitropropane beta-Nitropropane Dimethylnitromethane Isonitropropane Nitroisopropane	C ₃ H ₇ NO ₂	89.09	Unreviewed Sources Treon and Dutra (1952) Hine et al. (1978) Critiqued Sources No A or B Codes	C1 C1 -	297-1,050 580 -	82-288 159 -	ng r -	None		Sweet, slight
684935	N-Nitroso-N-methylurea	H ₂ NCON(NO) CH ₃	103.1	No Sources Found							
62759	N-Nitrosodimethyl Amine N-Methyl-N-Nitrosomethanamine Dimethyl Nitrosamine DMN DMNA	C ₂ H ₆ N ₂ O	74.08	Unreviewed Sources No C-E Codes Critiqued Sources Prusakov et al. (1976)	- B2	- 0.024-0.04	- 0.0079-0.013	- ng	None		
59892	N-Nitrosomorpholine			No Sources Found							
56382	Parathion Ethyl Parathion	C ₁₀ H ₁₄ O ₅ PSN	291.3	No Sources Found							Faint
82688	Pentachloronitrobenzene Quintobenzene	C ₆ Cl ₅ NO ₂	295.3	No Sources Found							Very weak/musty
87865	Pentachlorophenol	C ₆ HCl ₅ O	266.3	No Sources Found							
127184	Perchloroethylene Tetrachloroethylene	C ₂ Cl ₄	165.8	Unreviewed Sources Carpenter (1937) Anonymous (1980) Anonymous (1980) Torkelson and Rowe (1981) Critiqued Sources May (1966) May (1966) Leonardos et al. (1969)	C4 D3 D3 C1 A A B	<340 12 55 340 320 480 32	<50 2 8 50 47 71 5	ng d r ng d r r	47 71	d r	Etherish

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
108952	Phenol Carbolic Acid; Phenic Acid; Phenyl Hydroxide; Hydroxybenzene; Oxybenzene	C ₆ H ₅ OH	94.11	Unreviewed Sources					0.060	d	Medicinal/ acid/creosote
				Grijns (1906)	E2	2.2-6.8	0.57-1.8	ng			
				Zwaardemaker (1914)	E2	4	1	d			
				Backman (1917)	E1	0.13-0.26	0.034-0.068	r			
				Henning (1924)	C1	1.2	0.31	d			
				Takhirov (1974)	E1	0.022	0.0057	ng			
				Punter (1975, 1979)	D1,D2	0.8	0.21	d			
				Makeicheva (1978)	E1	0.027	0.007	ng			
				Anonymous (1980)	D3	0.046	0.012	d			
				Anonymous (1980)	D3	0.22	0.057	r			
				Critiqued Sources							
				Mukhitov (1962)	B2	0.022	0.0057	ng			
				Itskovich and Vinogradova (1962)	B5	3	0.78	ng			
				Pogosyan (1965)	B2	0.022	0.0057	ng			
				Korneev (1965)	B2	0.0172	0.0045	ng			
				Makhinya (1966)	B2	0.022	0.0057	ng			
				Basmadzhieva and Argirova (1968)	B2	0.021	0.0055	ng			
				Leonardos et al. (1969)	B	0.18	0.047	r			
				Punter (1980)	A	0.23	0.06	d			
106503	p-Phenylenediamine	C ₆ H ₈ N ₂	108.2	No Sources Found							
75445	Phosgene Carbonyl Chloride	Cl ₂ CO	98.92	Unreviewed Sources					None		Haylike
				Fieldner et al. (1921)	C1	23	5.7	ng			
				Schley (1934)	E2	0.5	0.12	d			
				Schley (1934)	E2	0.5-1.0	0.12-0.25	r			
				Patty (1963a)	C1	2	0.49	ng			
				Suchier (1930)	C2	4	1	ng			
				Critiqued Sources							
				Leonardos et al. (1969)	B	4	1	r			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
7803512	Phosphine	PH ₃	34	Unreviewed Sources					1.0	ng	Garlic
				Valentin (1848)	D5	1.4	1	ng			
				Valentin (1850)	D5	0.13	0.094	ng			
				Singh et al. (1967)	C2	7	5	d			
				Berck (1968)	C2	<2	<1.4	r			
				Critiqued Sources							
				Leonardos et al. (1969)	B	0.03	0.022	r			
				Fluck (1976)	A	0.014-2.8	0.010-2.014	ng			
7723140	Phosphorus	P	30.97	No Sources Found							Practically odorless
85449	Phthalic Anhydride 1,3-Isobenzofurandione PAN	C ₈ H ₆ O ₄	166.1	Unreviewed Sources					None		Choking
				No C-E Codes	-	-	-	-			
				Critiqued Sources							
				Slavgorodskiy (1968)	B2	0.32	0.053	ng			
1336363	Polychlorinated Byphenyls Aroclors			No Sources Found							
1120714	1,3-Propane Sultone			No Sources Found							
57578	beta-Propiolactone	C ₃ H ₄ O ₂	72.07	No Sources Found							Pungent

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
123386	Propionaldehyde 2-Propynal	C ₃ H ₆ O	58.08	Unreviewed Sources					0.04	d	Pungent, suffocating, unpleasant
				Backman (1917)	E1	0.02	0.008	r	0.08	r	
				Knuth (1973)	D2	0.026	0.011	ng			
				Bedborough and Trout (1979)	E2	0.014	0.0058	d			
				Anonymous (1980)	D3	0.0036	0.0015	d			
				Anonymous (1980)	D3	0.036	0.015	r			
				Critiqued Sources							
				Hartung et al. (1971)	B5	1.7	0.72	ng			
				Pliska and Janicek (1965)	B	0.022	0.0093	ng			
				Teranishi et al. (1974)	B3	0.02	0.008	ng			
				Hellman and Small (1974)	A	0.2	0.08	r			
				Hellman and Small (1974)	A	0.1	0.04	d			
114261	Propoxur (Baygon) Orthoisopropoxyphenyl-N-methylcarbamate	C ₁₁ H ₁₅ NO ₃	209.2	No Sources Found							Odorless
78875	Propylene Dichloride 1,2-Dichloropropane	C ₃ H ₆ Cl ₂	113	Unreviewed Sources					0.26	d	Sweet/ chloroform
				No C-E Codes	-	-	-	-	0.52	r	
				Critiqued Sources							
				Hellman and Small (1974)	A	1.2	0.26	d			
75569	Propylene Oxide Methyloxidrane Propene Oxide 1,2-Epoxypropane	C ₃ H ₆ O	58.08	Hellman and Small (1974)	A	2.4	0.52	r			Sweet/ethereal
				Unreviewed Sources					45*	d	
				No C-E Codes	-	-	-	-	35	r	
				Critiqued Sources							
				Jacobson et al. (1956)	A	473	199	ng			
75569	Propylene Oxide Methyloxidrane Propene Oxide 1,2-Epoxypropane	C ₃ H ₆ O	58.08	Hellman and Small (1974)	A	24	10	d			Sweet/ethereal
				Hellman and Small (1974)	A	84	35	r			
				Hellman and Small (1974)	A	84	35	r			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
75558	1,2-Propyleinimine (2-Methyl Aziridine)	C ₃ H ₇ N	57.1	No Sources Found							Strong, ammonia-like
91225	Quinoline	C ₉ H ₇ N	129.2	Unreviewed Sources					5.3	d	Unpleasant/peculiar
				Geier (1936)	E2	0.03	0.0057	d			
				Geier (1936)	E2	0.05-0.1	0.009-0.189	r			
				Critiqued Sources							
				Gundlach and Kenway (1939)	A	28	5.3	d			
106514	Quinone 1,4-Benzoquinone	C ₆ H ₄ O ₂	108.1	Unreviewed Sources					None		Irritating
				Backman (1917)	E1	0.047-0.05	0.0106-0.0113	r			
				Oglesby et al. (1947)	C3	0.44	0.1	ng			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
100425	Styrene, Monomer Phenyl Ethylene Polystyrene Vinyl Benzene Cinnamene	(C ₈ H ₈) _n	104.1	Unreviewed Sources					0.15*	d	Sharp/sweet/aromatic, unpleasant
				Wolf et al. (1956)	E2	43-258	10-61	ng	0.15	r	
				Deadman and Prigg (1959)	E2	0.11	0.026	d			
				Anonymous (1980)	D3	0.14	0.033	d			
				Anonymous (1980)	D3	0.73	0.17	r			
				Critiqued Sources							
				Li-Shen (1961)	B2	0.02	0.0047	ng			
				Stalker (1963)	A	0.073	0.017	d			
				Muehlen (1968)	B	4.3	1	r			
				Leonardos et al. (1969)	B	0.2-0.4	0.047-0.094	r			
				Smith and Hochstettler (1969)	B	0.2	0.047	r			
				Hellman and Small (1973, 1974)	A	0.22-0.64	0.052-0.15	d			
				Hellman and Small (1973, 1974)	A	0.64	0.15	r			
				Dravnieks (1974)	A	8	1.9	d			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
96093	Styrene Oxide 1-Phenyl-1,2-Epoxyethane	C ₈ H ₈ O	120.2	Unreviewed Sources					0.061	d	Sweet/pleasant
				No C-E Codes	-	-	-	-	0.4	r	
				Critiqued Sources							
				Hellman and Small (1974)	A	0.3	0.061	d			
				Hellman and Small (1974)	A	2	0.4	r			
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin Dioxin			No Sources Found							
79345	1,1,2,2-Tetrachloroethane Acetylene Tetrachloride sym-Tetrachlorethane	C ₂ H ₂ Cl ₄	167.9	Unreviewed Sources					7.3	d	Solvent
				Lehmann and Schmidt-Kehl (1936)	E1	20	2.9	ng			
				Critiqued Sources							
				Dravnieks (1974)	A	50	7.3	d			
7550450	Titanium Tetrachloride	TiCl ₄	189.7	No Sources Found							
											Acrid, choking

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
108883	Toluene Toluol; Methylbenzene; Phenylmethane	C ₇ H ₈	92.13	Unreviewed Sources					2.8	d	Sour/burnt, benzene-like
				Backman (1917)	E1	3.5-3.6	0.93-0.96	r	7.6	r	
				Backman (1918)	E2	2	0.53	ng			
				Grijns (1919)	E2	170	45	ng			
				Schley (1934)	E2	6	1.6	d			
				Schley (1934)	E2	16	4.2	r			
				Deadman and Prigg (1959)	E2	5.5	1.5	d			
				Koster (1971)	E2	13.7	3.6	d			
				Naus (1962)	C1	2	0.53	d			
				Winneke and Kastka (1975)	E2	46-84	12-22	ng			
				Anonymous (1980)	D3	3.5	0.93	d			
				Anonymous (1980)	D3	18	4.8	r			
				Critiqued Sources							
				Nader (1958)	A	0.08-1.9	0.021-0.50	ng			
				Stalker (1963)	A	1	0.27	d			
				Gusev (1965)	B2	1.5-3.2	0.40-0.85	ng			
				May (1966)	A	140	37	d			
				May (1966)	A	260	69	r			
				Leonardos et al. (1969)	B	8.1-17.8	2.1-4.7	r			
				Dravnieks and O'Donnell (1971)	B5	45	12	ng			
				Hellman and Small (1973, 1974)	A	0.6	0.16	d			
				Hellman and Small (1973, 1974)	A	7	1.9	r			
				Dravnieks (1974)	A	60	16	d			
				Punter (1980)	A	25.4	6.7	d			
95807	2,4-Toluene Diamine	C ₇ H ₁₀ N ₂	122.2	No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
584849	2,4-Toluene Diisocyanate Tolylene Diisocyanate 2,4-Diisocyanato-1-methylbenzene	C ₉ H ₆ N ₂ O ₂	174.2	Unreviewed Sources					None		Sharp/pungent
				Zapp (1957)	C1	2.8	0.4	ng			
				Henschler et al. (1962)	C3	0.14-0.35	0.020-0.050	ng			
				Chizhikov (1963)	E1	0.2	0.03	ng			
				Critiqued Sources							
				Leonardos et al. (1969)	B	15	2.11	r			
95534	o-Toluidine 2-Methylbenzenamine; 1-Amino-2-methylbenzene; 2-Methylaniline; 2-Aminotoluene	C ₇ H ₉ N	107.2	Unreviewed Sources					None		
				Huijter (1917)	E2	29	6.6	d			
				Backman (1917)	E1	4.0-5.4	0.91-1.23	r			
				Stuiver (1958)	E2	0.11	0.025	d			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
8001352	Toxaphene Chlorinated Camphene	C ₁₀ H ₁₀ Cl ₈	413.8	No Sources Found							Mild, chlorine, camphor
120821	1,2,4-Trichlorobenzene	C ₆ H ₃ Cl ₃	181.5	Unreviewed Sources					None		Aromatic
				Rowe (1975)	D2	22	2.96	ng			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
79005	1,1,2-Trichloroethane	C ₂ H ₃ Cl ₃	133.4	No Sources Found							Chloroform-like, sweet

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
79016	Trichloroethylene 1,1,2-Trichloroethylene; TCE; Trichloroethene	C ₂ HCl ₃	131.4	Unreviewed Sources Lehmann and Schmidt-Kehl (1936) Weitbrecht (1957) Frantikova (1962) Naus (1962) Torkelson and Rowe (1981) Critiqued Sources Scherberger et al. (1958) May (1966) May (1966) Malyarova (1967) Leonardos et al. (1969)	E1 C1 E2 C1 C1 C1 B A A B5 B	900 110 69 3 538	167 20 13 0.56 100	ng ng ng d ng	82 108	d r	Ether/solvent, chloroform
95954	2,4,5-Trichlorophenol	C ₆ H ₃ Cl ₃ O	197.5	No Sources Found							Strong disinfectant
88062	2,4,6-Trichlorophenol	C ₆ H ₃ Cl ₃ O	197.5	Unreviewed Sources Backman (1917) Kendall et al. (1968) Critiqued Sources Punter (1980)	E1 E2 A	0.0010-0.0016 0.021 0.00016	0.0001-0.0002 0.0026 0.00002	r r d	0.00002	d	Strong disinfectant
121448	Triethylamine	C ₆ H ₁₅ N	101.2	Unreviewed Sources No C-E Codes Critiqued Sources Tkachev (1970) Hellman and Small (1974) Hellman and Small (1974) Laing et al. (1978) Homans et al. (1978)	- - B5 A A A A A	- - 0.33 <0.4 1.1 11.9 2.7	- - 0.08 <0.10 0.27 2.9 0.65	- - ng d r r ng	<0.10 0.88	d r	Fishy/ammopia

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
1582098	Trifluralin	C ₁₃ H ₁₆ N ₃ O ₄ F ₃	335.3	No Sources Found							
540841	2,2,4-Trimethylpentane Isooctane	C ₈ H ₁₈	114.2	No Sources Found							
108054	Vinyl Acetate	C ₄ H ₆ O ₂	86.09	Unreviewed Sources Deese and Joyner (1969)	C4	<1.4	<0.40	r	0.11 0.4	d r	Sour/sharp
				Critiqued Sources Gofmekler (1960)	B2	1	0.28	ng			
				Hellman and Small (1973, 1974)	A	0.4	0.11	d			
				Hellman and Small (1973, 1974)	A	1.4	0.4	r			
593602	Vinyl Bromide	C ₂ H ₃ Br	107	No Sources Found							
75014	Vinyl Chloride Chloroethylene Chloroethene	C ₂ H ₃ Cl	62.5	Unreviewed Sources No C-E Codes	-	-	-	-	None		Sweet/ethereal
				Critiqued Sources Hori et al. (1972)	B	26-52	10-20	ng			
75354	Vinylidene Chloride 1,1-Dichloroethylene	C ₂ H ₂ Cl ₂	96.94	Unreviewed Sources Janicek et al. (1960)	E1	5,500	1,390	ng	None		
				Irish (1963)	C1	2,000-4,000	504-1,009	ng			
				Dalla Valle and Dudley (1939)	E2	4.3	1.08	d			
				Critiqued Sources No A or B Codes	-	-	-	-			
1330207	Xylene (Dimethylbenzene) See o-Xylene See m-Xylene See p-Xylene	C ₈ H ₁₀	106.2								Sweet

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
						mg/m ³	ppm				
95476	o-Xylene 1,2-Dimethylbenzene	C ₈ H ₁₀	106.2	Unreviewed Sources					5.4	d	
				Backman (1917)	E1	1.0-1.2	0.23-0.28	r			
				Backman (1918)	E2	0.8	0.18	ng			
				Stuiver (1958)	E2	2.1	0.48	d			
				Koster (1971)	E2	11	2.5	d			
				Naus (1962)	C1	1	0.23	d			
				Anonymous (1980)	D3	0.77	0.18	d			
				Anonymous (1980)	D3	3.1	0.71	r			
				Critiqued Sources							
				Punter (1980)	A	23.6	5.4	d			
108383	m-Xylene 1,3-Dimethylbenzene	C ₈ H ₁₀	106.2	Unreviewed Sources					0.73	d	
				Backman (1917)	E1	1.1-1.3	0.25-0.30	r			
				Stuiver (1958)	E2	0.35	0.081	d			
				Koster (1971)	E2	0.7-86	0.16-20	d			
				Anonymous (1980)	D3	0.52	0.12	d			
				Anonymous (1980)	D3	2.4	0.55	r			
				Critiqued Sources							
				Gusev (1965)	B2	0.6-1.9	0.14-0.44	ng			
				Dravnieks and O'Donnell (1971)	B5	1.3	0.3	ng			
				Punter (1980)	A	1.5-4.9	0.35-1.1	d			
106423	p-Xylene 1,4-Dimethylbenzene	C ₈ H ₁₀	106.2	Unreviewed Sources					2.1	d	
				Backman (1917)	E1	1.4-1.5	0.32-0.35	r			
				Stuiver (1958)	E2	0.6	0.14	d			
				Koster (1971)	E2	8	1.8	d			
				Knuth (1973)	D2	0.8	0.18	ng			
				Anonymous (1980)	D3	0.52	0.12	d			
				Anonymous (1980)	D3	2.2	0.51	r			
				Critiqued Sources							
				Leonardos et al. (1969)	B	2	0.46	r			
				Punter (1980)	A	9.1	2.1	d			
0	Antimony Compounds			No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
0	Arsenic Compounds (inorganic including arsine)										
	Arsine Arsenic Hydride	AsH ₃	77.95	Unreviewed Sources Patty (1963b) Critiqued Sources No A or B Codes	C1 - -	<3.2 - -	<1 - -	ng - -	None		
	Diphenylcyanarsine			Unreviewed Sources Flury (1921) Critiqued Sources No A or B Codes	C4 - -	<0.005 - -		ng - -	None		
	Ethylchloroarsine	C ₂ H ₅ AsCl ₂	174.9	Unreviewed Sources Flury (1921) Critiqued Sources No A or B Codes	C4 - -	0.17-0.85 - -	0.024-0.12 - -	ng - -	None		Fruity
0	Beryllium Compounds			No Sources Found							
0	Cadmium Compounds			No Sources Found							
0	Chromium Compounds			No Sources Found							
0	Cobalt Compounds			No Sources Found							
0	Coke Oven Emissions See Polycyclic Organic Matter See Benzene See Toluene			No Sources Found							

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Threshold Type of Threshold	Odor Characteristic
0	Cyanide Compounds										
	Methyl Isocyanide Methylcarbamine			Unreviewed Sources Pozlomek et al. (1971)	C1	0.0006-0.006		r	None		
				Critiqued Sources Stone and Pryor (1967)	B	0.0069-0.0127		d			
				Stone and Pryor (1967)	B	0.069		r			
	Hydrogen Cyanide	HCN	27	Unreviewed Sources Fieldner et al. (1921)	E2	1	0.091	d	None		Faint, bitter almonds
	See Acetonitrile Methyl Cyanide See Acrylonitrile Vinyl Cyanide										
0	Glycol Ethers										
110805	2-Ethoxyethanol Ethylene Glycol Monoethyl Ether Monoethyl Ether of Ethylene Glycol Cellosolve	C ₈ H ₁₆ O ₃	160.2	Unreviewed Sources No C-E Codes	-	-	-	-	2.7 5.1	d r	Sweet/ musty, rose-like
				Critiqued Sources May (1966)	A	90	24	d			
				May (1966)	A	180	49	r			
				Hellman and Small (1973, 1974)	A	1.1	0.3	d			
				Hellman and Small (1973, 1974)	A	2	0.54	r			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Threshold Type of Threshold	Odor Characteristic
0	Glycol Ethers (cont'd)										
	2-Ethoxyethyl Acetate	C ₈ H ₁₆ O ₃	160.2	Rejected/Unreviewed Sources					0.06	d	Sweet/ester/ fruity
	Ethyl Glycol Acetate								0.13	r	
	Ethylene Glycol Monoethyl Ether Acetate			No C-E Codes	-	-	-	-			
	Cellosolve Acetate			Critiqued Sources							
				Hellman and Small (1973, 1974)	A	0.3	0.06	d			
				Hellman and Small (1973, 1974)	A	0.7	0.13	r			
0	Lead Compounds			No Sources Found							
0	Manganese Compounds			No Sources Found							
0	Mercury Compounds			No Sources Found							
0	Fine Mineral Fibers			No Sources Found							
0	Nickel Compounds										
	Nickel Carbonyl	Ni(CO) ₄	170.7	Unreviewed Sources					None		Sooty
	Nickel Tetracarbonyl			Armit (1907)	E2	3.5	0.5	ng			
				Kincaid et al. (1956)	C1	7-21	1.0-3.0	ng			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
0	Polycyclic Organic Matter										
	Acenaphthene	C ₁₂ H ₁₀	154.2	Unreviewed Sources					None		
	Naphthyleneethylene			Lillard and Powers (1975)	E2	3.1	0.5	d			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			
	1-Aminonaphthalene	C ₁₀ H ₉ N	143.2	Unreviewed Sources					None		
				Backman (1917)	E1	0.014-0.29	0.024-0.5	r			
				Critiqued Sources							
				No A or B Codes	-	-	-	-			

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds mg/m ³ ppm		Type of Threshold	Geometric Mean Air Odor Threshold (ppm)	Geometric Mean Air Odor Type of Threshold	Odor Characteristic
0	Polycyclic Organic Matter (cont'd)										
	1-Hydroxynaphthalene 1-Naphthol alpha-Naphthol	C ₁₀ H ₈ O	144.2	Unreviewed Sources Backman (1917) Critiqued Sources No A or B Codes	E1 - -	0.0030-0.0052 - -	0.00051- 0.00088 -	r - -	None		
	2-Hydroxynaphthalene 2-Naphthol beta-Naphthol	C ₁₀ H ₈ O	144.2	Unreviewed Sources Backman (1917) Critiqued Sources No A or B Codes	E1 - -	0.23-0.30 - -	0.040-0.051 - -	r - -	None		Faint, phenolic
	Indene Indonaphthene	C ₉ H ₈	117.2	Unreviewed Sources Deadman and Prigg (1959) Critiqued Sources No A or B Codes	E2 - -	0.02 - -	0.004 - -	d - -	None		
	Indole 1-Benzo[b]pynole	C ₈ NH ₇	117.2	Unreviewed Sources Punter (1975, 1979) Templaar (1913) Critiqued Sources No A or B Codes	D1,D2 E2 - -	0.0071 0.0006 - -	0.015 0.00013 - -	d d - -	None		Strong/ unpleasant, weak/pleasant
	3-Methylindole Skatole	C ₉ H ₉ N	131.2	Unreviewed Sources Hermanides (1909) Zwaardemaker (1914) Van Anrooji (1931) Critiqued Sources Katz and Talbert (1930)	E2 E2 E2 A	0.00035 0.0004 0.00078 0.1	0.000065 0.000075 0.00015 0.019	r d d ng	0.019		Fecal
	Phenanthrene	C ₁₄ H ₁₀	178.2	Unreviewed Sources Backman (1917) Critiqued Sources No A or B Codes	E1 - -	0.055-0.06 - -	0.0075-0.0082 - -	r - -	None		

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
0	Polycyclic Organic Matter (cont'd)										
110861	Pyridine Azabenzene Azine	C ₅ H ₅ N	79.1	Unreviewed Sources					1.85*	d	Nauseating
				Tausch (1974)	E2	198.5	61.4	d	0.74	r	
				Zwaardemaker (1914)	E2	0.04	0.012	d			
				Sales (1958)	E2	0.42	0.13	ng			
				Geier (1936)	E2	0.095	0.03	r			
				Geier (1936)	E2	0.09	0.028	d			
				Van Anrooji (1931)	E2	0.078	0.024	d			
				Hermanides (1909)	E2	0.16	0.049	r			
				Koelega (1974)	E2	25,391	7,849	d			
				Hangartner (1981)	E2	0.08-2.9	0.025-0.90	ng			
				Dalla Valle and Dudley (1939)	E2	3.7	1.14	d			
				Washburn (1926)	E2	0.00041	0.00013	ng			
				Washburn (1926)	E2	1.58	0.49	ng			
				Tausch (1974)	E2	31,482	9,730	d			
				Moncrieff (1951)	E2	0.97	0.3	d			
				Amerine et al. (1965)	E1	0.74	0.23	d			
				Janicek et al. (1960)	E1	4.6	1.42	ng			
				Backman (1917)	E1	0.02	0.006	r			
				Sutton (1963)	C1	<3.2	<1.0	ng			
				Critiqued Sources							
				Laffort and Dravnieks (1973)	B	0.74	0.23	ng			
				Allison and Katz (1919)	B5	32	9.9	ng			
				Kristesashvili (1965)	B2	0.21	0.06	ng			
				Leonardos et al. (1969)	B	0.067	0.021	r			
				Jones (1955c)	B	40	12	d			
				Katz and Talbert (1930)	A	0.074	0.023	ng			
				Dravnieks (1974)	A	6	1.85	d			
				Laing et al. (1978)	A	2.4	0.74	r			
	See Quinoline										
	See 2-Acetylaminofluorene										

TABLE 2-1 (cont'd). REPORTED ODOR THRESHOLDS FROM ALL SOURCES

CAS #	Compound Name Synonyms	Formula	M.W.	Source	Code	Odor Thresholds		Type of Threshold	Geometric Mean	Geometric Mean	Odor Characteristic
						mg/m ³	ppm		Air Odor Threshold (ppm)	Air Odor Type of Threshold	
0	Radionuclides			No Sources Found							
0	Selenium Compounds Hydrogen Selenide	H ₂ Se	80.98	Unreviewed Sources Dudley and Miller (1941) Critiqued Sources No A or B Codes	C1 - -	<1.0 - -	0.3 - -	ng - -	None		Garlic

*The mean detection threshold may be greater than or equal to the recognition threshold as a result of pooling several data sets.

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Appendix B

Odor Sampling Plan

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Odor Sampling for Yonkers

Preliminary Sampling Locations and Methods

Site Plan Key	Location	Notes	Vapor-Phase Sampling								Liquid-Phase Sampling				
			H2S (Interscan/Jerome)	OdaLog	Methyl Mercaptan	Ammonia	H2S	TRS	Odor ⁽¹⁾	Velocity ⁽²⁾	Temperature (deg C)	pH	DO (mg/L)	Sulfide (ppm)	ORP
ZONE 1															
	Primary Thickener Building	Atmospheric readings throughout the building, velocity at any openings	Min 3 readings			1	1								
	Primary Sludge Thickener No. 1	Atmospheric readings, further samples as necessary	Min 3 readings												
	Primary Sludge Thickener No. 2	Atmospheric readings, further samples as necessary	Min 3 readings												
	Primary Sludge Thickener No. 3	Atmospheric readings, further samples as necessary	Min 3 readings												
	Primary Sludge Digester No. 1	Atmospheric readings, further samples as necessary	Min 3 readings												
	Primary Sludge Digester No. 2	Atmospheric readings, further samples as necessary	Min 3 readings												
	Primary Sludge Digester No. 3	Atmospheric readings, further samples as necessary	Min 3 readings												
	Sludge Storage Tank No. 1	Atmospheric readings, further samples as necessary; confirm location of Bio-Kat inject, see if can sample before and after	Min 3 readings												
	Sludge Storage Tank No. 2	Atmospheric readings, further samples as necessary; confirm location of Bio-Kat inject, see if can sample before and after	Min 3 readings												
	Dewatering Building	Atmospheric readings throughout the building, velocity at any openings	Min 3 readings			1	1								
	Sludge Loading Area	Atmospheric readings throughout the area, velocity at any openings, get sampling when loading	Min 3 readings												
	Primary Sludge Thickener Building Chemical Mist Scrubber No. 1 (2) influent	One scrubber used for Odor, TRS; maybe a composite, will determine onsite	Min 3 readings			1	1	1	1						
	Primary Sludge Thickener Building Chemical Mist Scrubber No. 1 (2) effluent	One scrubber used for Odor, TRS; maybe a composite, will determine onsite	Min 3 readings			1	1	1	1						
	Primary Sludge Thickener Building Chemical Mist Scrubber No. 2 (3) influent		Min 3 readings												
	Primary Sludge Thickener Building Chemical Mist Scrubber No. 2 (3) effluent		Min 3 readings					1	1						

Odor Sampling for Yonkers

Preliminary Sampling Locations and Methods

[illegible]

Odor Sampling for Yonkers

Preliminary Sampling Locations and Methods

[illegible]

Odor Sampling for Yonkers

Preliminary Sampling Locations and Methods

[illegible]

Odor Sampling for Yonkers

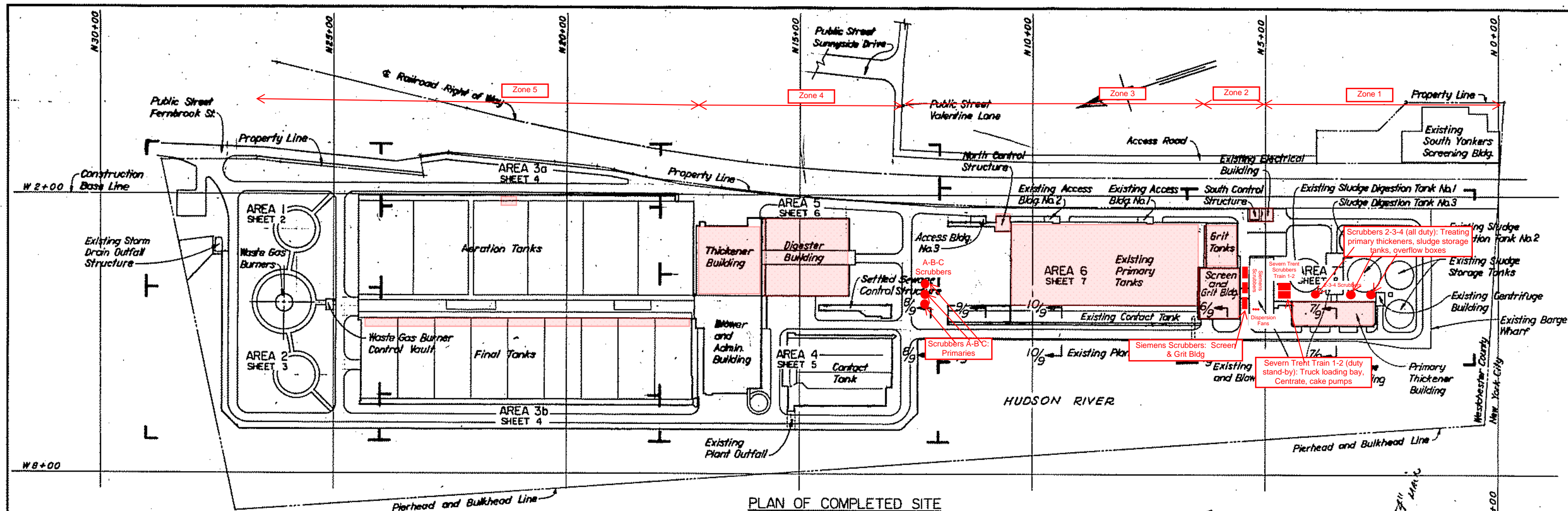
Preliminary Sampling Locations and Methods

Site Plan Key	Location	Notes	Vapor-Phase Sampling								Liquid-Phase Sampling				
			H2S (Interscan/Jerome)	OdaLog	Methyl Mercaptan	Ammonia	H2S	TRS	Odor ⁽¹⁾	Velocity ⁽²⁾	Temperature (deg C)	pH	DO (mg/L)	Sulfide (ppm)	ORP
	Aeration Tanks Influent Channel Vent		Min 3 readings						1						
	Aeration Tank No. 1	One tank used for Odor, TRS; maybe a composite, will determine onsite	Min 3 readings					1	1						
	Aeration Tank No. 2		Min 3 readings												
	Aeration Tank No. 3		Min 3 readings												
	Aeration Tanks		Min 3 readings												
	Final Settling Tanks Influent Channel		Min 3 readings						1						
	Final Settling Tanks Influent Channel		Min 3 readings												
	Waste Gas Burner	Not sure how this will work							1						
ZONE 6															
	South Yonkers Screen House	Atmospheric readings throughout the building	Min 3 readings												
Totals				4	0	15	17	13	16	0	5	5	5	5	5

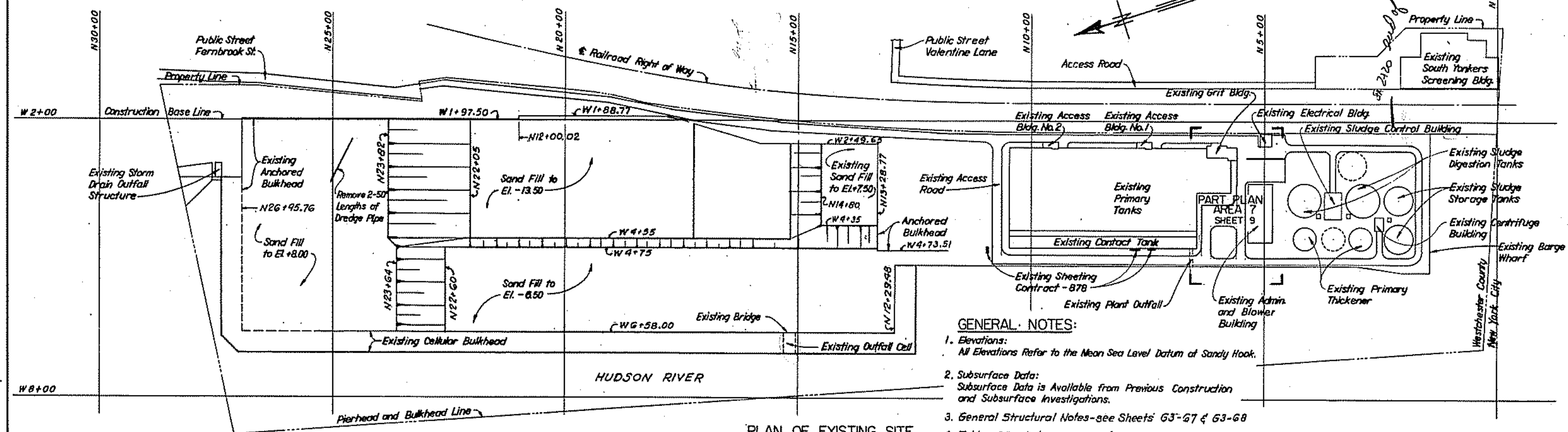
Appendix C

Odor Sampling Map

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PLAN OF COMPLETED SITE



PLAN OF EXISTING SITE

GENERAL NOTES:

1. Elevations:
All Elevations Refer to the Mean Sea Level Datum at Sandy Hook.
2. Subsurface Data:
Subsurface Data is Available from Previous Construction and Subsurface Investigations.
3. General Structural Notes-see Sheets G3-G7 & G3-G8
4. Table of Symbols - see Sheet G6-43

NO. LOCATION DATE BY CDD REVISIONS				SCALE 1" = 100' 0 100 200 FEET		DESIGNED TJS, DND DRAW LCC, JK CHECKED TJS		GRIELEY AND HANSEN ENGINEERS 100 N. 10th St. CHICAGO, ILLINOIS 60602		COUNTY OF WESTCHESTER, NEW YORK DEPARTMENT OF ENVIRONMENTAL FACILITIES WILLIAM E. BORNHARD, COMMISSIONER		JOINT TREATMENT PLANT - YONKERS CONTRACT NO. 1654-G STRUCTURES AND EQUIPMENT FOR SECONDARY SEWAGE TREATMENT		GENERAL SITE PLAN		PROJ. NO. 627-69-110 SHEET G1-1 OF 10 SHEETS DATE AUGUST, 1972 DWG. 1 OF 367	
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Appendix D

Odalog Data

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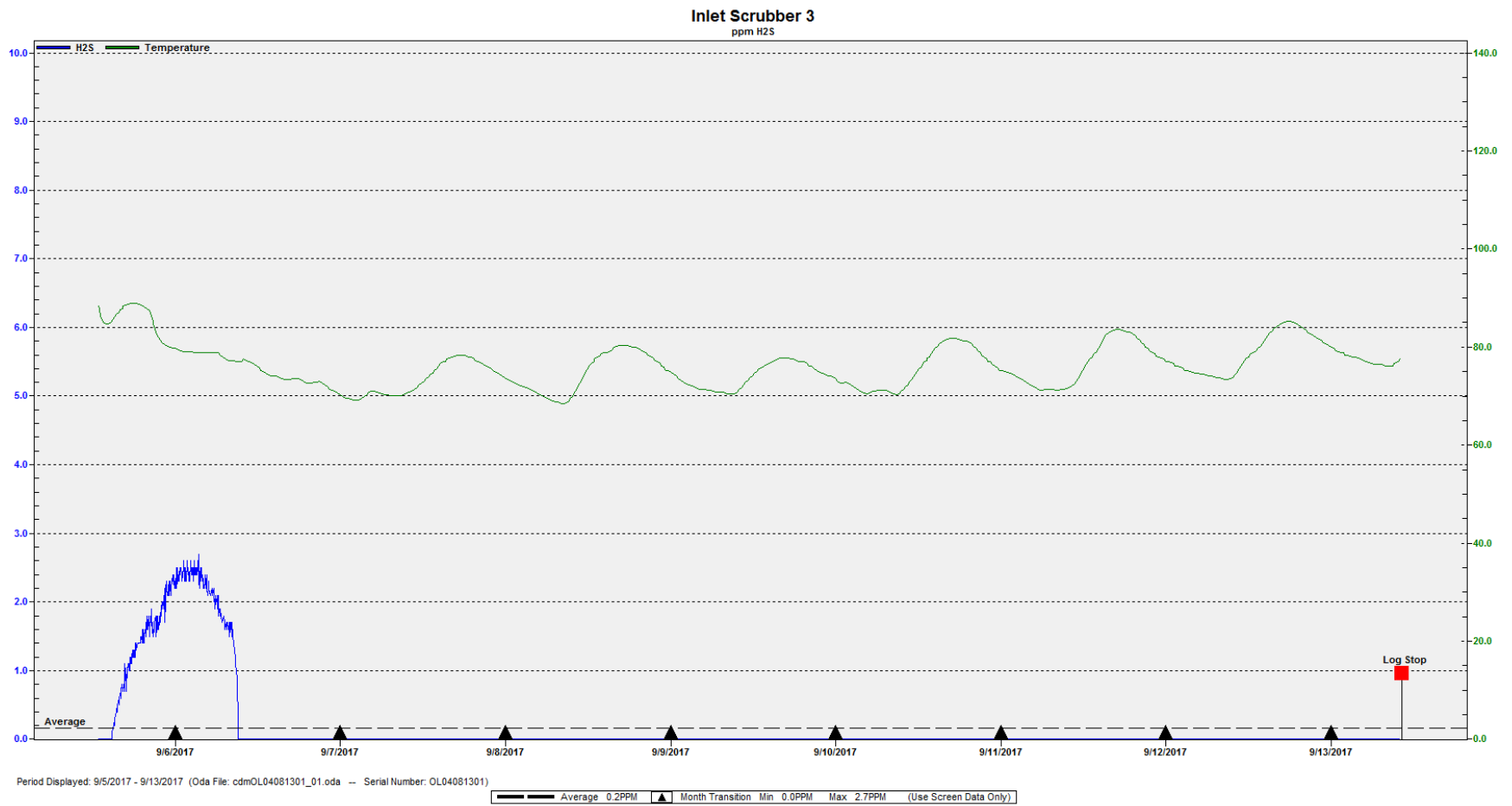


Figure 1. Inlet to Scrubber 3

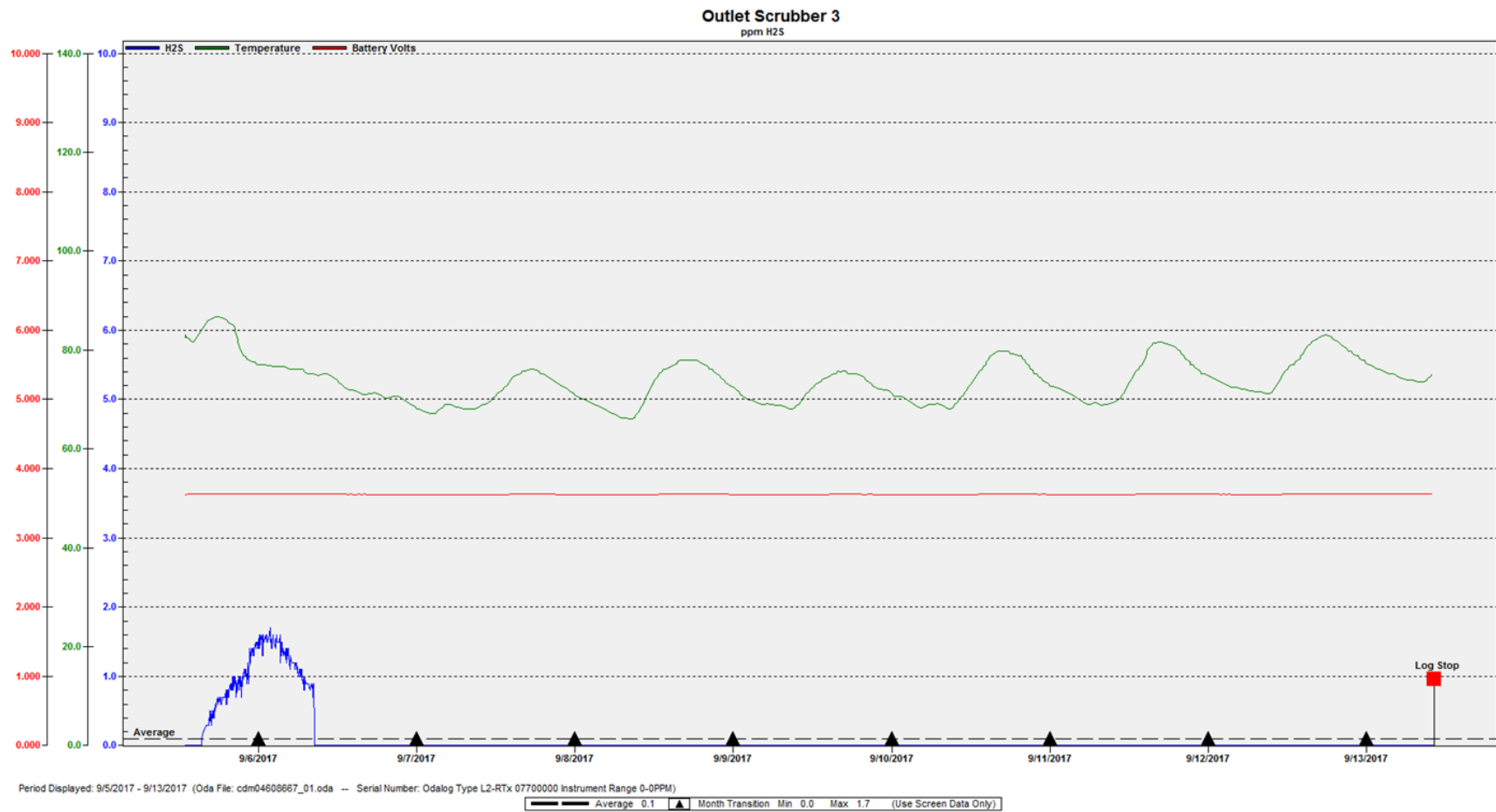


Figure 2. Outlet of Scrubber 3

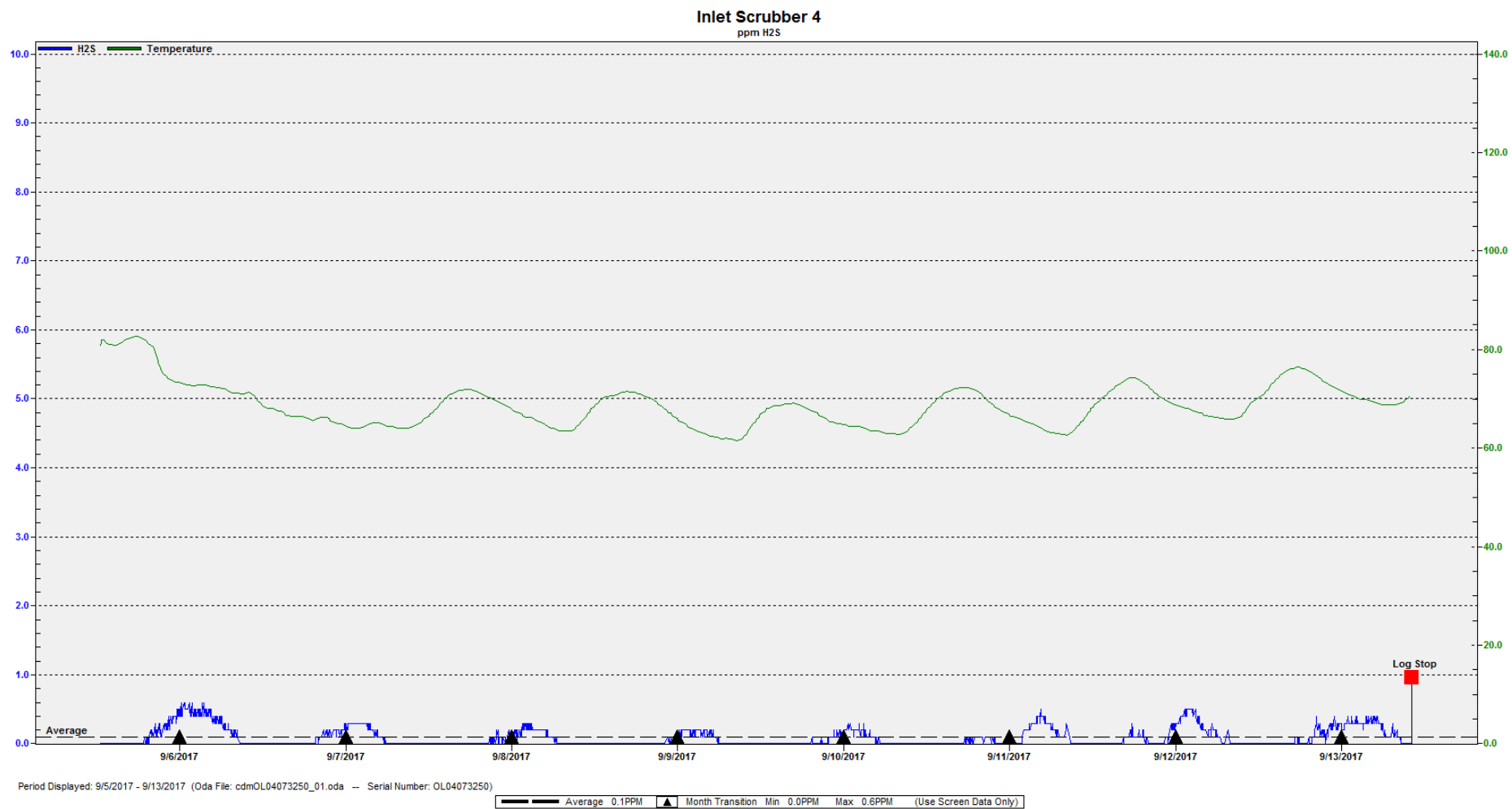


Figure 3. Inlet to Scrubber 4

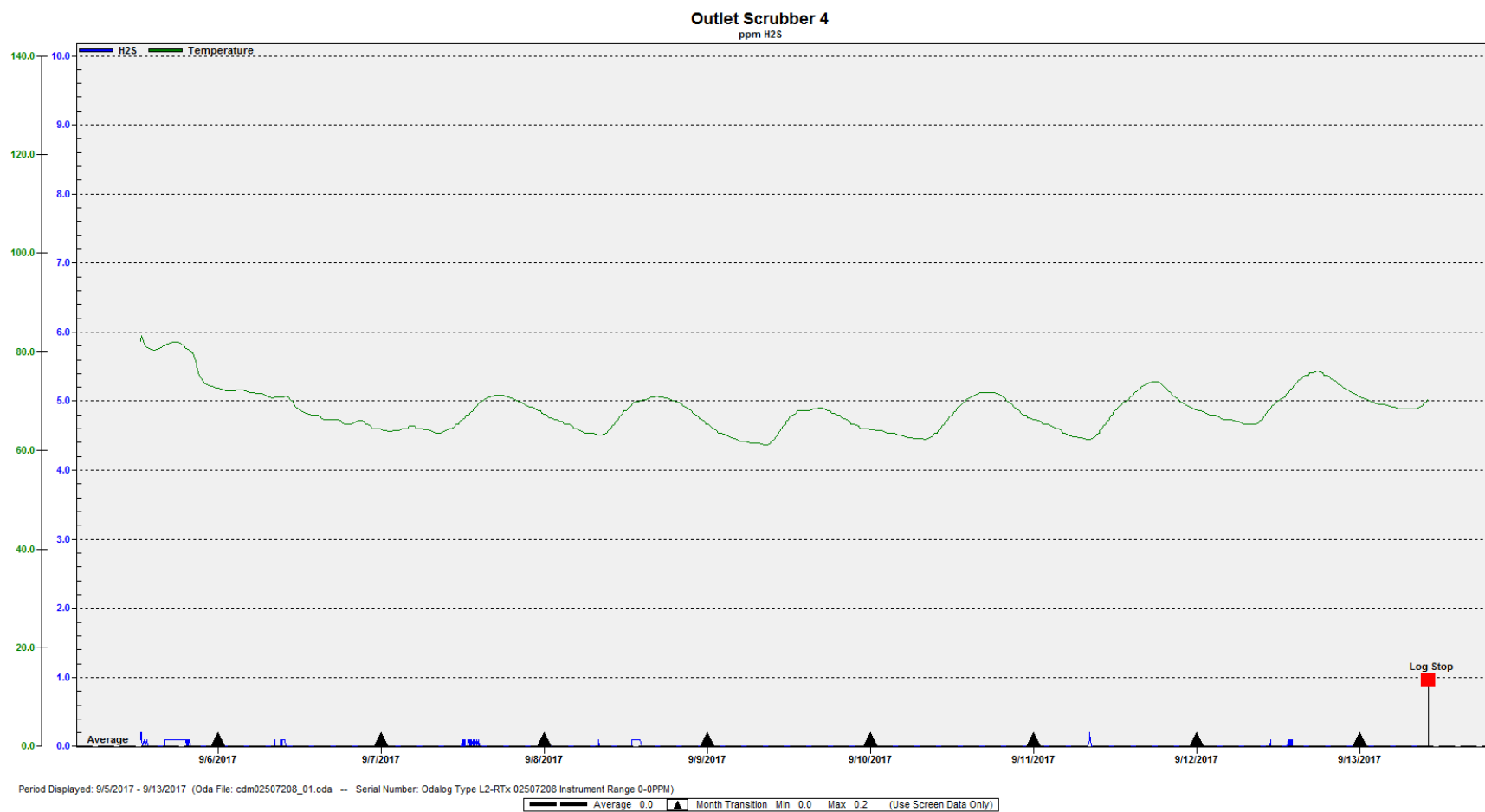


Figure 4. Outlet of Scrubber 4

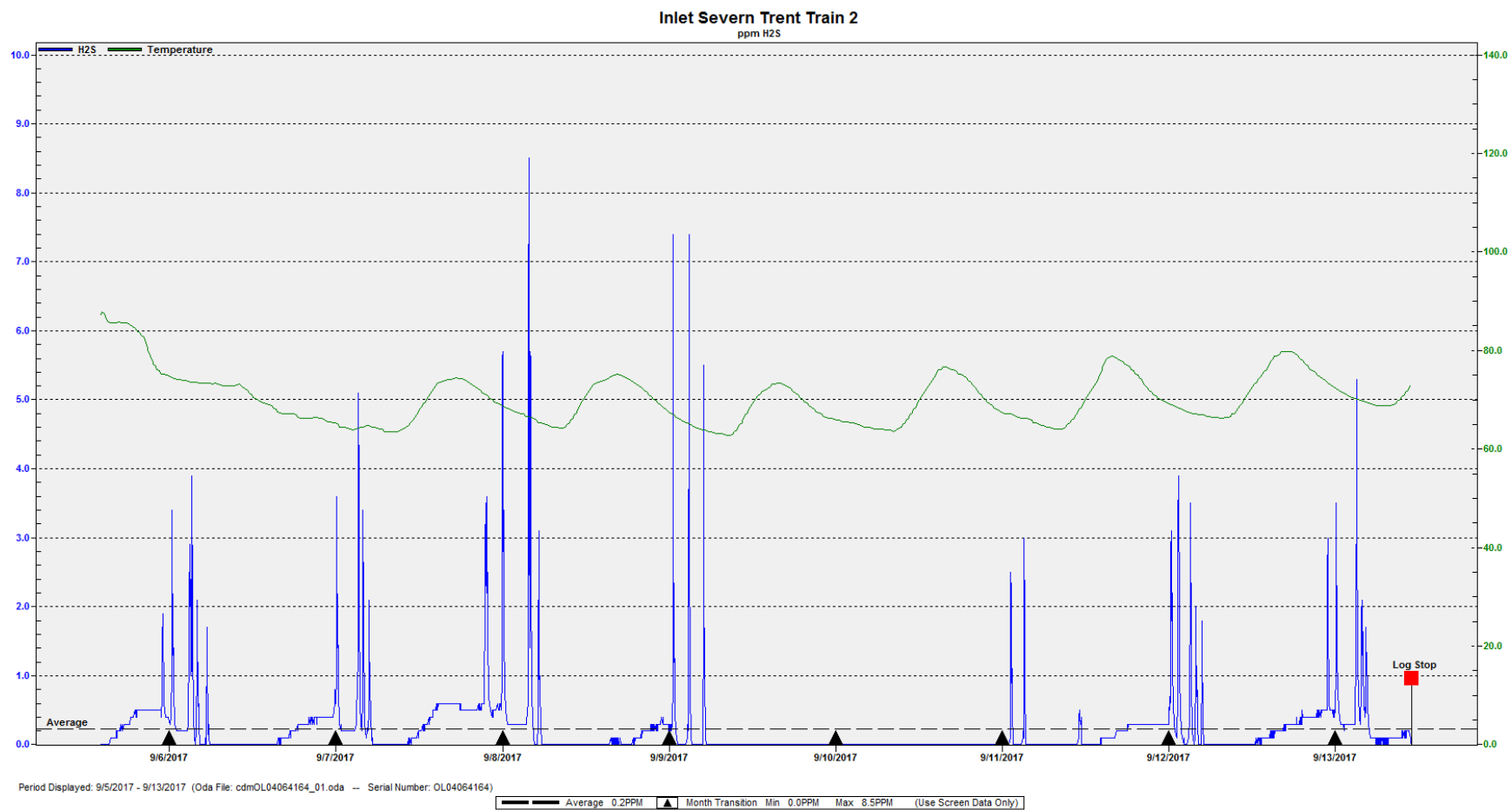


Figure 5. Severn Trent Scrubber 2 Inlet Odialog Data

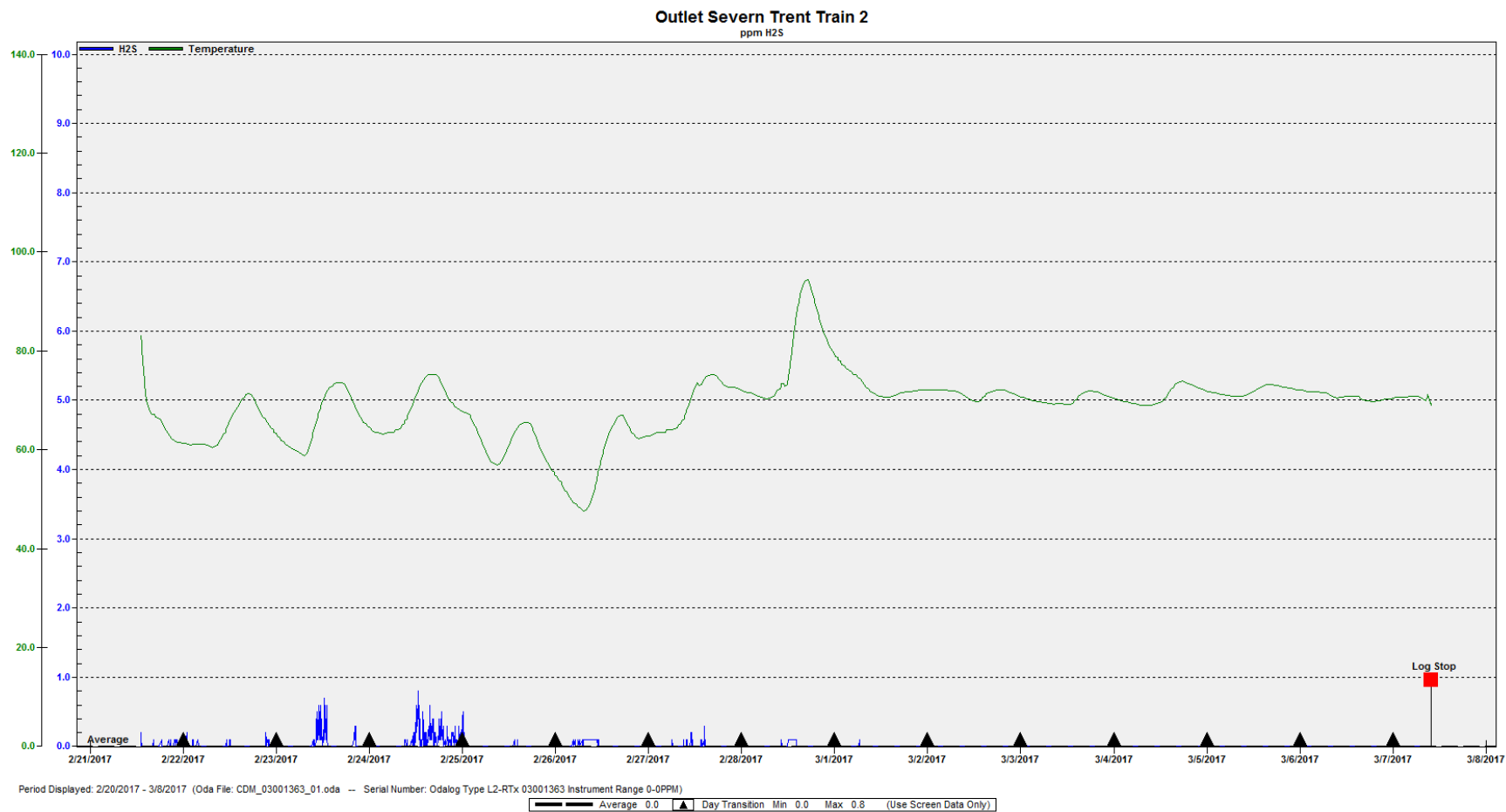


Figure 6. Severn Trent Scrubber 2 Outlet OdaLog Data

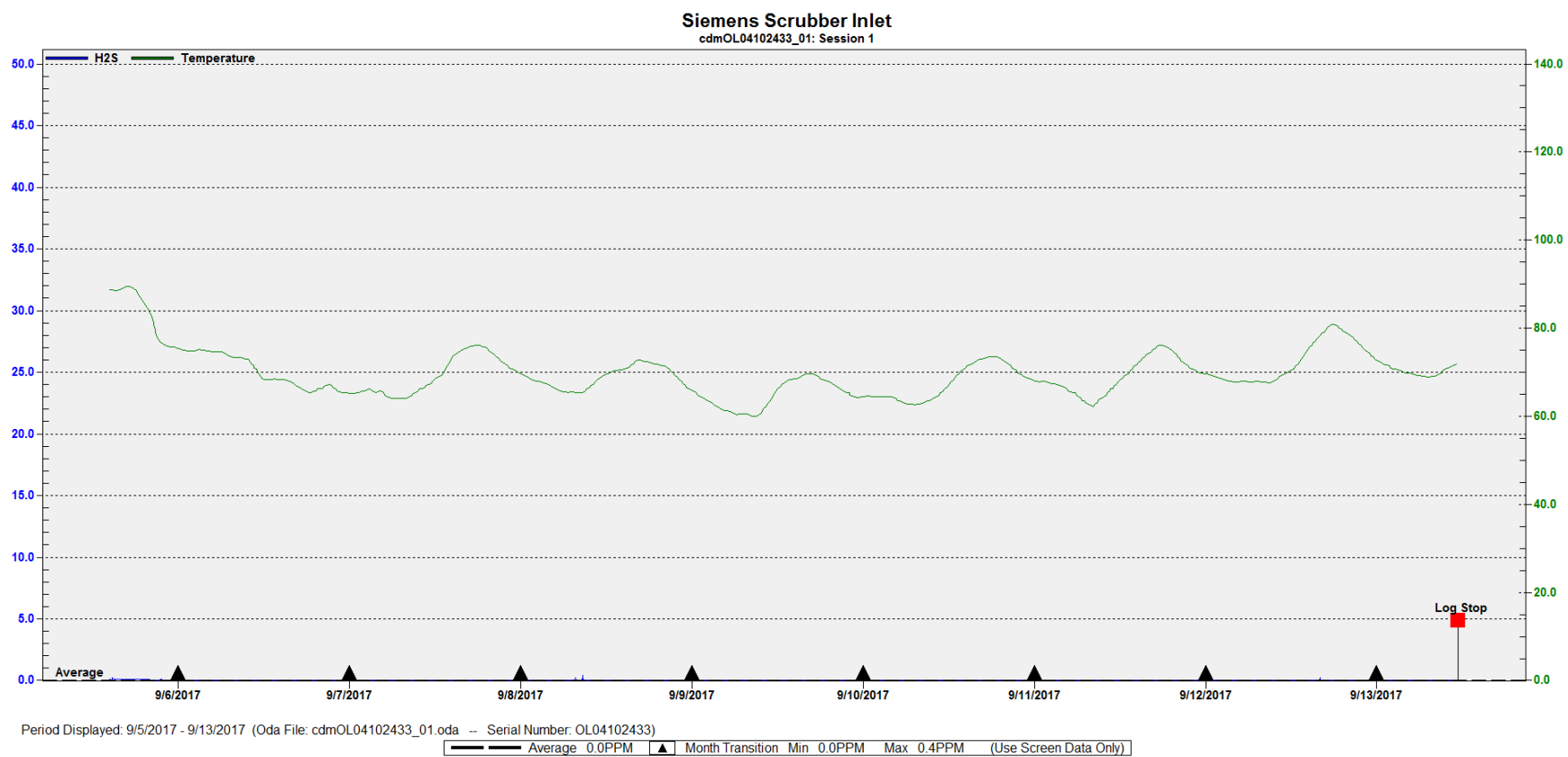


Figure 7. Siemens Scrubber 3 Odialog Inlet

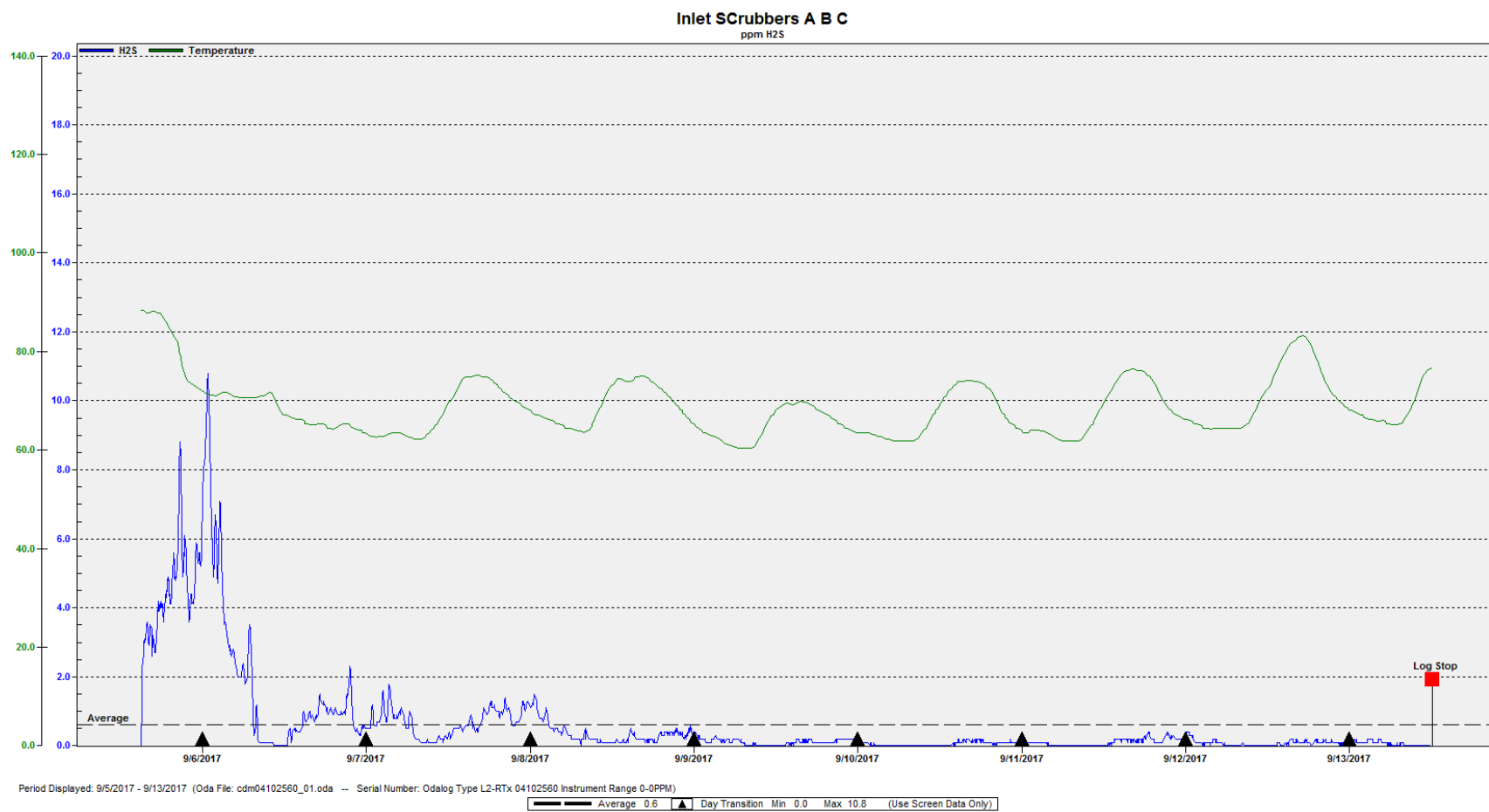


Figure 8. Scrubber A, B, and C Odialog Inlet

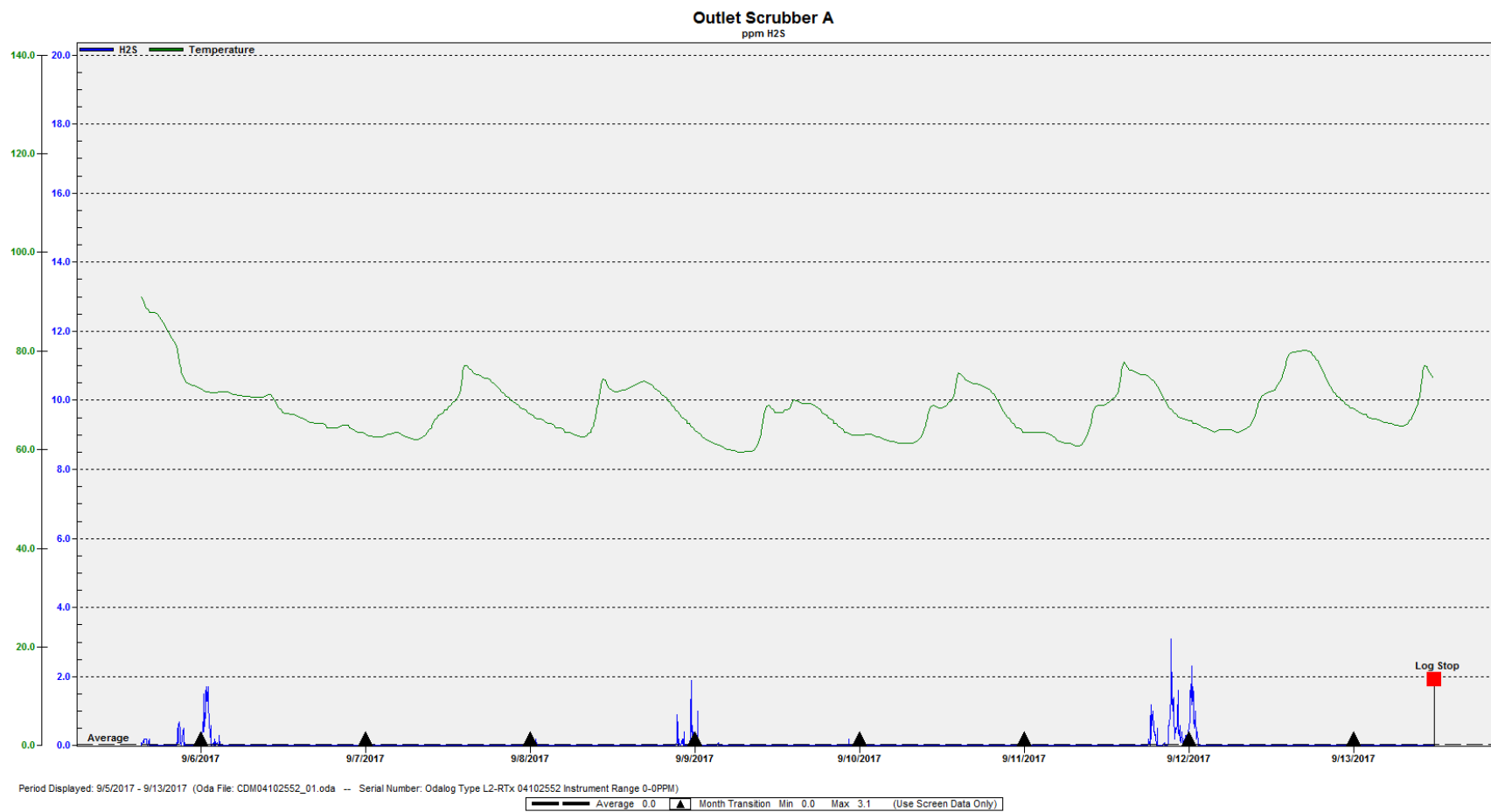


Figure 9. Scrubber A OdaLog Outlet

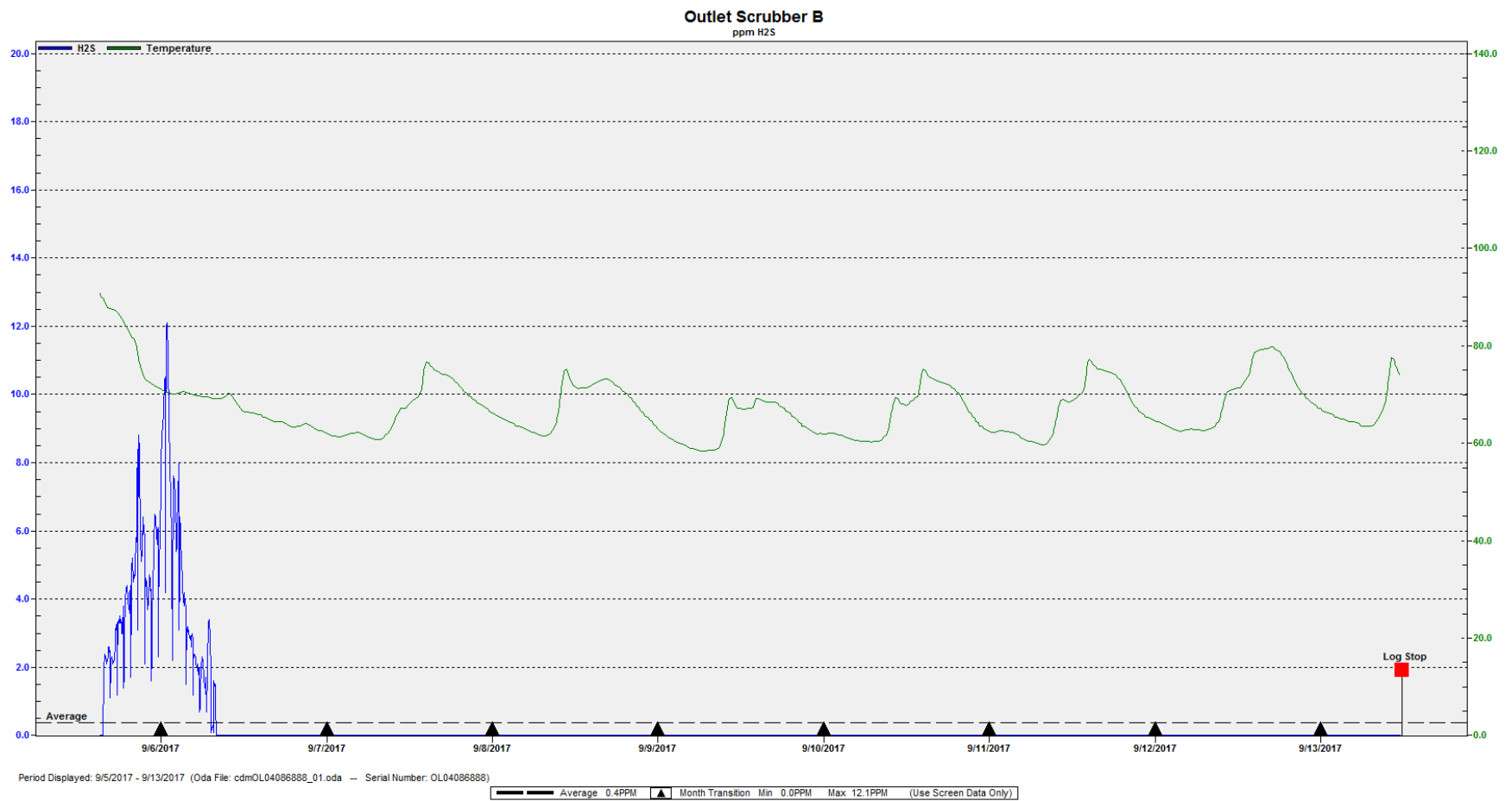


Figure 10. Scrubber B Odialog Outlet

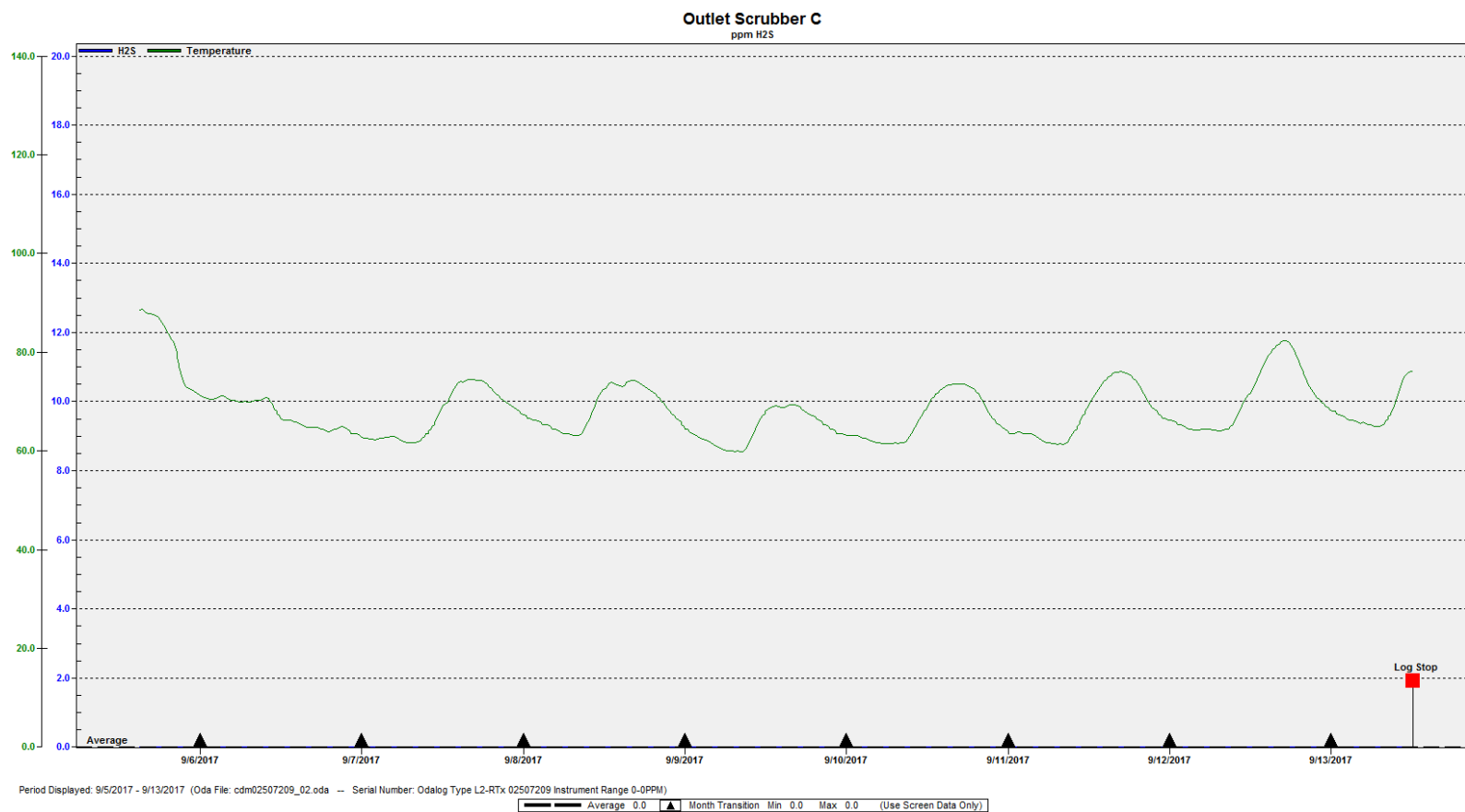


Figure 11. Scrubber C (not operating) Odialog Data

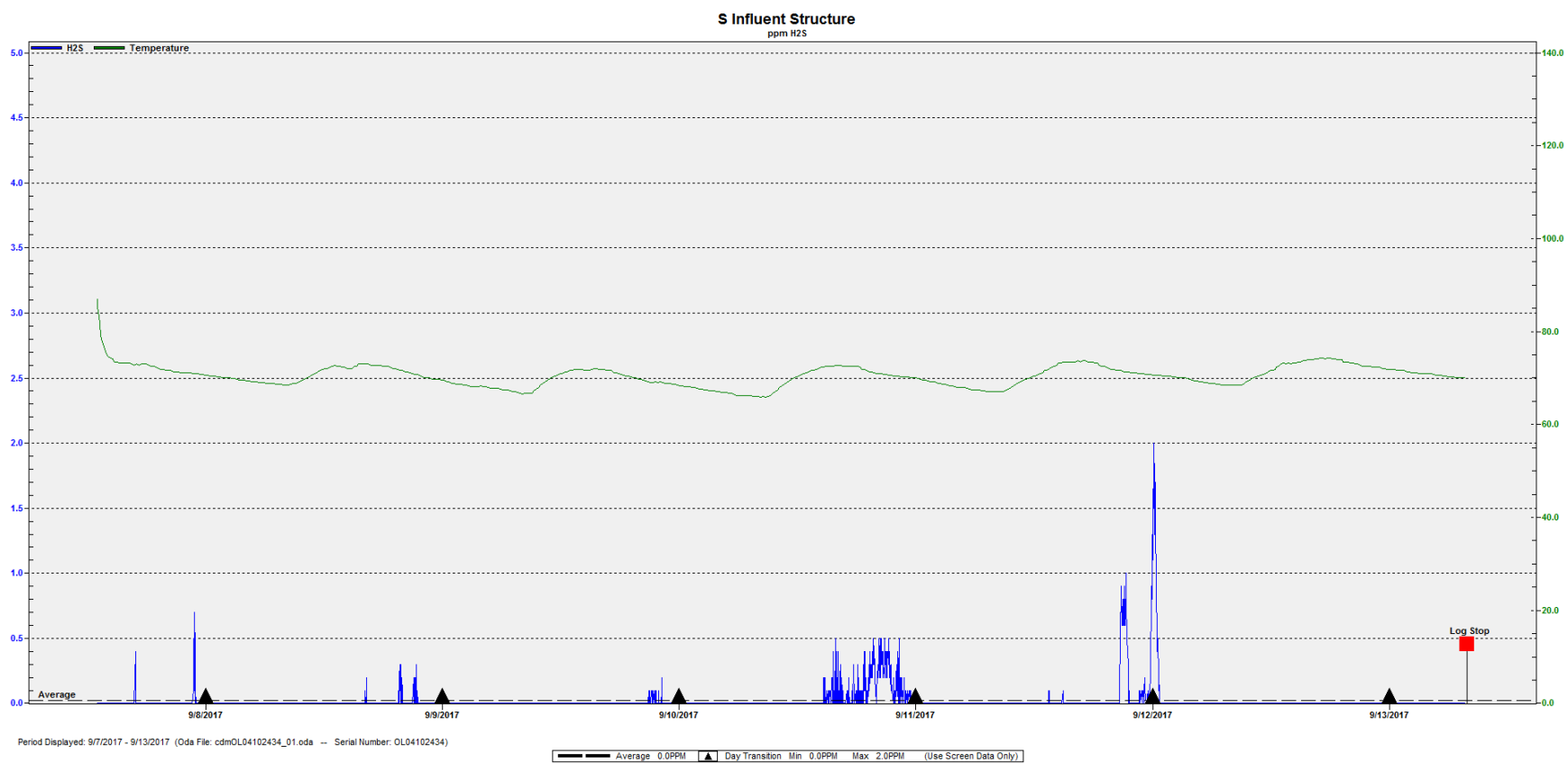


Figure 12. South Influent Structure Odialog Data

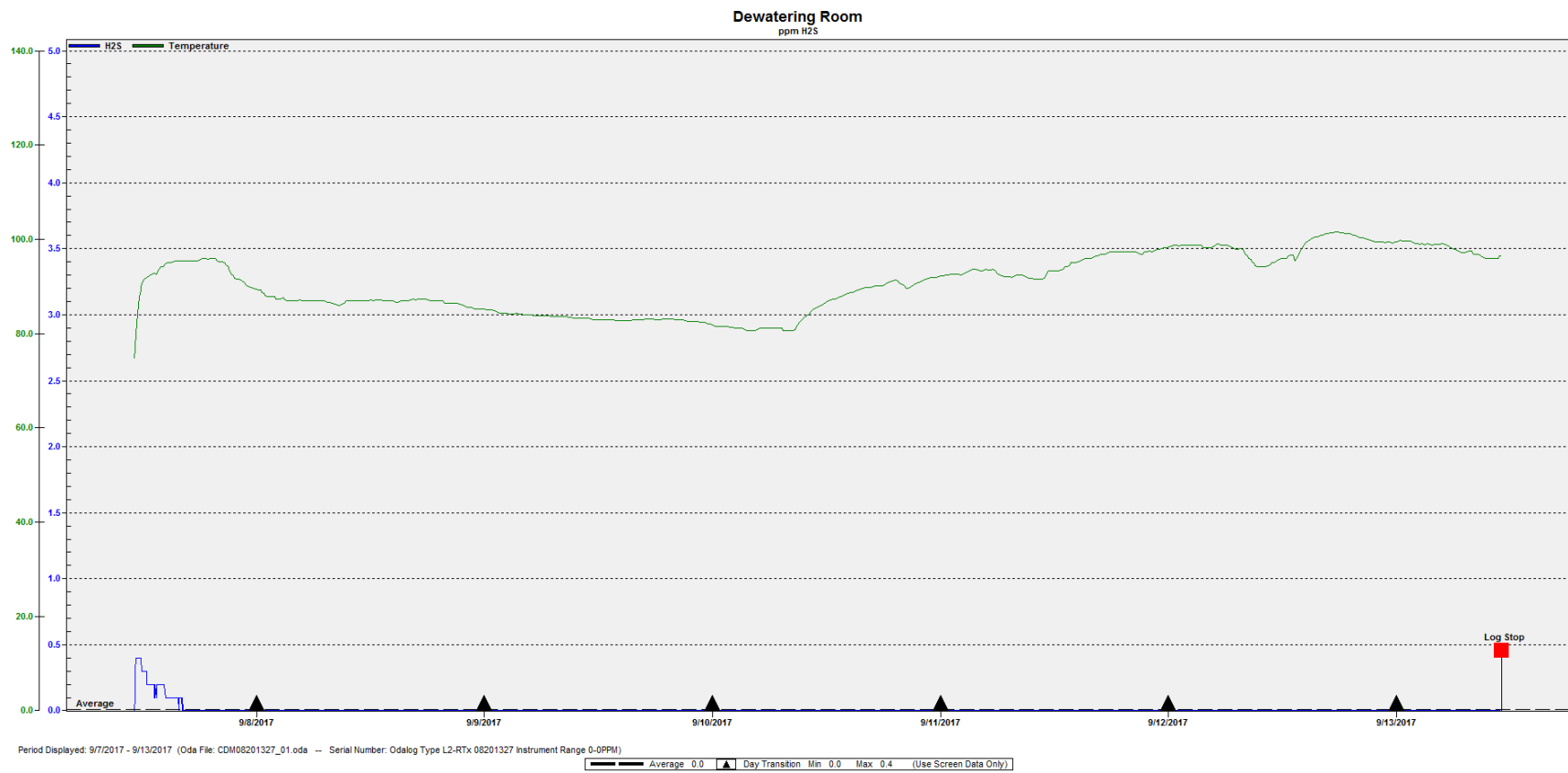


Figure 13. Dewatering Building Interior Odialog data