Health Consultation

Exposure Investigation

Outdoor Air Exposures from the Port Townsend Paper Corporation

PORT TOWNSEND PAPER CORPORATION

PORT TOWNSEND, JEFFERSON
COUNTY, WASHINGTON

EPA FACILITY ID: WAD009270919

JUNE 24, 2024

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry (ATSDR)
Office of Community Health and Hazard Assessment
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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About ATSDR

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency of the U.S. Department of Health and Human Services (HHS). ATSDR works with other agencies and tribal, state, and local governments to study possible health risks in communities where people could come in contact with dangerous chemicals. For more information about ATSDR, visit the ATSDR website.

HEALTH CONSULTATION

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Prepared By:
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List of Abbreviations and Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AQG	Air Quality Guideline
AQI	Air Quality Index
ASB	aerated stabilization basin
ATSDR	Agency for Toxic Substances and Disease Registry
CREG	Cancer Risk Evaluation Guideline
CV	comparison value
DQO	data quality objective
E-BAM	environmental beta attenuation monitor (Met One)
ECY	Washington Department of Ecology
EF	exposure factor
EI	exposure investigation
EPA	(U.S.) Environmental Protection Agency
EPC	exposure point concentration
HEM-4	Human Exposure Model 4
HI	Hazard Index
HQ	Hazard Quotient
IQR	interquartile range
IUR	Inhalation Unit Risk
$\mu g/m^3$	micrograms per cubic meter
LOAEL	lowest observed adverse effect level
MEDOR	$_{TRS}$MEDOR® ppb method for measuring total sulfur
mmHg	millimeter of mercury
MRL	Minimum Risk Level
NAAQS	National Ambient Air Quality Standards
NOAEL	no observable adverse effect level
PM	particulate matter
$PM_{2.5}$	particulate matter with aerodynamic diameter less than or equal to 2.5 microns
PM_{10}	particulate matter with aerodynamic diameter less than or equal to 10 microns
ppb	parts per billion
ppm	parts per million
PTPC	Port Townsend Paper Corporation

RfC	Reference Concentration
SL	screening level
SPM	single point monitor
Thermo	Thermo Scientific ™ 43I Analyzer
TLV®–STEL	Threshold Limit Value- Short Term Exposure Limit
UCL	upper confidence limit (95% upper confidence limit of the mean)
WDH	Washington Department of Health
WHO	World Health Organization
WTN	Washington Tracking Network

1. Summary

The Agency for Toxic Substances and Disease Registry (ATSDR) conducted an exposure investigation (EI) to measure people's exposure to contaminants in outdoor air near Port Townsend Paper Corporation (PTPC) in Port Townsend, WA. This EI was requested by the Washington Department of Health (WDH) after ATSDR assisted WDH with air dispersion modeling of PTPC emissions [ATSDR 2016a, 2016b, 2017a]. The air dispersion modeling predicted elevated levels of some contaminants in areas surrounding PTPC. In addition, community members living near PTPC have complained about strong sulfur-like odors near PTPC. ATSDR collected air samples near PTPC for 10 weeks in the fall of 2018.

ATSDR designed this EI to determine if the communities near PTPC have been exposed to harmful contaminants in air from the facility and review data on the general air quality in the area. As part of the EI process, ATSDR compared the measured concentrations to health-based screening levels (SLs), which are intended to protect the general public from negative health effects from acute (less than 14 days), intermediate (14 days to less than 1 year), or chronic exposures (greater than 1 year). A concentration above the SL does not necessarily mean that an adverse effect will occur, but it is an indication that the specific contaminant should be further investigated and compared to the health effects documented in scientific literature.

The program included a total of eight fixed sampling sites, with locations including six residential areas, one public school facility, and one business. Monitors were all within 3 miles of PTPC. Contaminants of interest near PTPC included several sulfur compounds (hydrogen sulfide, sulfur dioxide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide), particulate matter ($PM_{2.5}$ and PM_{10}, particles smaller than 2.5 or 10 microns, respectively), and aldehydes (acetaldehyde, formaldehyde, and propionaldehyde).

ATSDR measured concentrations of the above contaminants and averaged the durations of the measurements to match the duration of exposure from the study that was used to derive the SL. Maximum 24-hour (and shorter) averaged concentrations were used as estimates of acute exposure. The 95% upper confidence level of the mean (UCL) calculated at each site and used as an estimate of intermediate and chronic exposures.

To address community concerns of strong sulfur-like odors near PTPC, ATSDR incorporated a sampling method that measured a range of sulfur compounds in addition to other standard methods to measure hydrogen sulfide and sulfur dioxide. The measured concentrations of each sulfur compound were compared to SLs and the odor thresholds (the level of each compound that individuals can smell in air). ATSDR also reviewed thousands of odor complaints made to Washington Department of Ecology (ECY) and PTPC from 2016 through 2021.

The measured concentrations at PTPC to were also compared to modeled estimates from the Environmental Protection Agency's (EPA) Human Exposure Model – 4 (HEM-4) [EPA 2020]. This model incorporated the latest reported emissions and building downwash parameters from PTPC and the wind and weather data collected during the EI. Emissions data were available for aldehydes, PM, sulfur dioxide, and total reduced sulfur compounds. ATSDR also separated data from before, during, and after a 1-week shutdown of PTPC to better determine the effect of PTPC operations on the community.

Based on the air sampling, modeling, and odor complaints, ATSDR made the following conclusions:

Conclusion 1: Breathing sulfur compounds (sulfur dioxide, hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methyl mercaptan) in air near PTPC can potentially cause adverse acute respiratory effects. While exposure to the concentrations of the individual sulfur contaminants is not likely to cause adverse effects, exposure to the mixture of contaminants may cause occasional acute respiratory effects. Sulfur compounds are associated with the environmental odors described in complaints from community members.

Basis for Conclusion: Of the sulfur compounds measured, dimethyl sulfide, dimethyl disulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide were measured at levels that can cause offensive odors. All but methyl mercaptan and dimethyl sulfide exceeded acute health-based SLs. The concentrations of the sulfur compounds were positively correlated, meaning when one compound was found to be high, the others were likely to be high as well. When higher concentrations of each of the contaminants occur at the same time, there is an increased potential for adverse health effects. While the individual compounds had different rates of detection ranging from 4-18%, together they can contribute to acute respiratory symptoms and odor-related health effects.

ATSDR also analyzed local health data for evidence of an increase in in acute respiratory effects. Data were available for asthma hospitalizations from 2010 to 2020 in the state of Washington, Jefferson County, and the zip code 98368; all of which contain the city of Port Townsend and PTPC. The asthma hospitalizations for the zip code 98368 were not statistically different from that of Jefferson County or the state of Washington.

Conclusion 2: Higher concentrations of some contaminants and more reports of odors occurred when PTPC was in operation compared to when it was shut down.

Basis for Conclusion: Measured concentrations of aldehydes, sulfur dioxide, hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide were significantly higher during operation than during shutdown of PTPC. More odor complaints were made during the time immediately before the shutdown and after the facility restarted compared to during the shutdown.

Conclusion 3: Sulfur dioxide concentrations near PTPC rarely reached levels that can cause acute respiratory effects. Chronic exposure to sulfur dioxide is not expected to harm people's health.

Basis for Conclusion: In the present EI, sulfur dioxide was measured at one site using two separate methods. In the first method, it was measured alone (Thermo) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). Sulfur dioxide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the Thermo instrument.

The concentration of sulfur dioxide measured by both instruments was compared to EPA's Air Quality Index (AQI), which categorizes air quality based on the concentration of a contaminant. For the MEDOR, almost all 1-hour averaged samples (99.2%) and all 24-hour averaged samples were designated as *good* by the AQI. Similarly, all 10-minute averaged concentrations were designated as *good* by the AQI as measured by the Thermo instrument. There are no cautionary statements from the EPA on days when sulfur dioxide concentrations are in the *good* category.

Conclusion 4: Breathing hydrogen sulfide near PTPC is not expected to harm people's health. Hydrogen sulfide in outdoor air can cause environmental odors.

Basis for Conclusion: In the present EI, hydrogen sulfide was measured using two separate methods. In the first method, it was measured alone using a single point monitor (SPM) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). Hydrogen sulfide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the SPM instrument. A UCL could only be calculated using SPM data.

The highest hydrogen sulfide concentration measured was using the SPM was nearly thirty times lower than any effect level documented in literature. The highest hydrogen sulfide concentration measured was using the MEDOR was roughly 4 times lower than any effect level documented in literature. The UCLs at half of the sites just exceeded the chronic SL but were nearly 500 times lower than levels documented to cause adverse health effects.

ATSDR notes that when hydrogen sulfide exceeds its odor threshold (0.5 ppb) [ATSDR 2016c], people may experience odor-related health symptoms such as headaches, nausea, and stress or annoyance.

Conclusion 5: Breathing particulate matter (PM_{10} or $PM_{2.5}$) near PTPC is not expected to harm people's health, although on some days there is a potential for respiratory symptoms in unusually sensitive individuals with advanced heart or lung disease.

Basis for Conclusion: The AQI and the World Health Organization's (WHO) air quality guidelines (AQG) were used to evaluate exposures to $PM_{2.5}$ and PM_{10} at PTPC.

For $PM_{2.5}$, 9.3% of the 24-hour samples exceeded the WHO 24-hour AQG. Using EPA's AQI, 20% of the $PM_{2.5}$ 24-hour concentrations were categorized as *moderate* by the AQI. The other 80% of days were categorized as *good* by the AQI.

For PM_{10}, only one (0.4%) PM_{10} 24-hour sample exceeded the WHO 24-hour AQG and was categorized as *moderate* by the AQI, with all others designated as *good.*

When PM concentrations reach the *moderate* category, they have the potential to cause respiratory symptoms in unusually sensitive individuals and exacerbation of cardiopulmonary disease. On days with *moderate* air quality, unusually sensitive people should consider reducing prolonged or heavy exertion. Sensitive individuals include children, the elderly (≥65 years), and people with preexisting heart or lung disease. There are no cautionary statements from the EPA on days when PM concentrations are in the *good* category.

The UCLs of $PM_{2.5}$ and PM_{10} 24-hour concentrations exceeded the WHO annual AQGs. Prolonged exposures to PM above the AQGs may slightly increase the likelihood of harm for individuals with pre-existing health conditions, such as cardiopulmonary disease.

Conclusion 6: Breathing aldehydes near PTPC is not expected to harm people's health.

Basis for Conclusion: Three types of aldehydes were measured at one site: acetaldehyde, formaldehyde, and propionaldehyde. None of the 24-hour concentrations exceeded any of their respective noncancer SLs. The average combined exposure for measured aldehydes over a lifetime would result in an additional cancer risk of 11 cases per 1,000,000 individuals (1.1×10^{-5}). PTPC operations result in a low additional cancer risk. This cancer risk is dominated by formaldehyde.

Recommendations

- ECY should continue to monitor odor complaints.
- ECY and PTPC should make additional efforts to reduce environmental odors coming from PTPC that impact areas outside facility boundaries.
- ECY and PTPC may consider implementing a community-based outdoor air monitoring program to inform policy makers and community members of exposures in the area.
- Individuals sensitive to environmental odors should consider reducing their exposure. When environmental odors are strong, individuals can reduce exposure by limiting outdoor activities or leaving the area for a few hours if needed.
- Community members should report odors from the Port Townsend Paper Mill to Washington Department of Ecology's Environmental Engineer, Emily Toffol, via email (emily.toffol@ecy.wa.gov) or phone (360-790-8363). When reporting odors, please provide the following information: date, time, location, odor description, and any health impacts experienced.
- Learn more on Washington Department of Ecology's webpage for PTPC at https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Industrial-facilities-permits/Port-Townsend-Paper.

This health consultation report explains these conclusions. An easy-to-read summary is also available at: https://wwwn.cdc.gov/TSP/PHA/PHAListing.aspx?StateIndicator=WA. If you have questions or comments, call ATSDR's regional office director, Rhonda Kaetzel, at 404- 718-7804 or our toll-free number at 1-800-CDC-INFO ask for information on the Port Townsend Paper Corporation site..

2. Background

2.1 Statement of Issue and Purpose

PTPC (Figure 1) produces unbleached kraft pulp, lightweight linerboard, corrugating medium, and unbleached converting grades. Construction on the mill began in 1927, and operation started in 1928. The mill has operated continuously since it was built [PTPC 2015]. PTPC is located along the coast where there are significant elevation changes (approximately 150 meters) that can affect the dispersion of contaminants in air. There are several sources of air releases from the PTPC including stack emissions, fugitive emissions, and emissions to air from open units [such as the aerated stabilization basin (ASB)]. Emission sources can generally be split into two categories: area sources and point sources. Area sources include fugitive dust emissions from the chip piles, emissions from the ASB and clarifier, as well as some other emissions sources (e.g., storage tanks) where emissions occur from an area instead of a defined point. Point sources include the kraft recovery furnace, smelt tank, lime kiln, washer vents, boilers, and other sources where emissions are released from a defined stack.

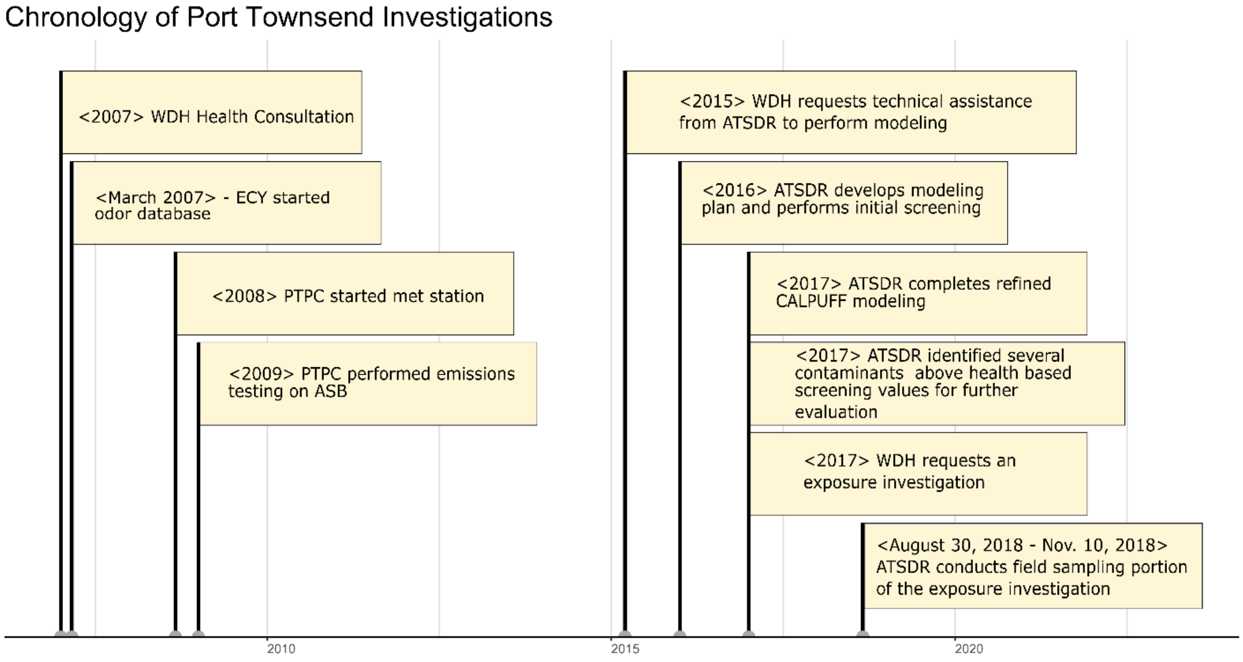
Figure 1: Photo of Port Townsend Paper Corporation, 2015 (Photo taken by ATSDR staff)

2.2 Site Description and Timeline of Previous Public Health Activities

ATSDR and WDH have been involved with assessing the air around PTPC since 2007 (Figure 2). Citizens in Port Townsend and Jefferson County, Washington contacted WDH in 2007 because of health concerns related to past, current, and future air emissions from PTPC. In response to community health concerns, WDH conducted a health consultation based on health outcome data for the area [ATSDR 2008]. Air monitoring data were not available to determine exposure to specific contaminants. Because of the data gaps, the health consultation report from WDH included the following recommendations:

- develop an expanded emission inventory,
- obtain meteorological (met) data near the source,
- track community odor complaints,
- conduct air dispersion or risk modeling to estimate levels of contaminants in outdoor air at locations in the community.

Figure 2: Timeline of Events Leading to ATSDR Exposure Investigation



*WDH- Washington Department of Health; ECY- Washington Department of Ecology; ATSDR- The Agency for Toxicology and Disease Registry; PTPC- Port Townsend Paper Corporation; ASB- Aerated Stabilization Basin

ECY, who issues and oversees the PTPC air operating permit, negotiated an Agreed Order that directed the mill to expand its emissions inventory, obtain meteorological data, and track community odor complaints. PTPC subsequently developed a more detailed emissions inventory and installed a meteorological station on mill property. Both PTPC and ECY have been tracking community odor complaints for several years. Several residents and community groups regularly make complaints about odors in and around Port Townsend. Odor complaints typically describe the odor as “rotten cabbage” or reference a general sulfur smell [ECY 2021].

In March 2015, WDH requested assistance from ATSDR to conduct air dispersion modeling for the PTPC facility. ATSDR used available emissions inventory and meteorological data to conduct air dispersion modeling for emissions from PTPC. ATSDR prepared three technical assist documents for WDH to communicate the modeling plan [ATSDR 2016a], preliminary modeling results [ATSDR 2016b], and final modeling results [ATSDR 2017]. The preliminary modeling was used to screen an initial list of more than 50 air contaminants. The preliminary model predicted that nine contaminants (acetaldehyde, formaldehyde, propionaldehyde, chromium (VI), sulfur dioxide, nitrogen oxides, reduced sulfur compounds, PM_{10}, and $PM_{2.5}$) could potentially exceed health-based screening levels (SLs) for outdoor air [ATSDR 2016b].

In February of 2017, WADOH requested that ATSDR conduct an environmental exposure investigation in Port Townsend to better determine if community members were exposed to the harmful contaminants from PTPC identified from the preliminary sampling. ATSDR accepted this request and collected environmental air samples in the fall of 2018. ATSDR selected sampling locations and contaminants based on complaints of odors from Port Townsend community members and predicted air concentrations estimated through air dispersion modeling [ATSDR 2017a]. Measured contaminants included reduced sulfur compounds [hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide], particulate matter ($PM_{2.5}$ and PM_{10}, particulate matter with aerodynamic diameter less than or equal to 2.5 or 10 microns, respectively), sulfur dioxide, and aldehydes (acetaldehyde, formaldehyde, and propionaldehyde). Although chromium (VI) compounds and nitrogen oxides were identified using the preliminary modeling, they were not selected for inclusion in the EI because, based on the model's predictions, these contaminants rarely exceeded screening values and the elevated concentrations were short in duration.

See Appendix A for a summary of ATSDR's public health assessment process.

3. Community Description and Concerns

3.1. Community Demographics

Approximately 2,463 persons lived within 1 mile of PTPC in 2020 (Figure 3). U.S. Census data show that the population increased by 1% from 2010 to 2020. In 2020, approximately 37% of the population within 1 mile of PTPC was older than 65 (a 56% increase from 2010), and 5% were children 6 and under (a 7% decrease from 2010) [US Census 2020]. The communities bordering PTPC range from the 70-98th percentile for individuals over 65. Children and older adults are the most susceptible populations to the adverse effects from the contaminants measured during this EI. Most of the nearby population is located to the north and west of the facility with a small cluster of residential houses to the south of the facility (referred to as "Glen Cove").

Figure 3: Site Map and Demographics Data

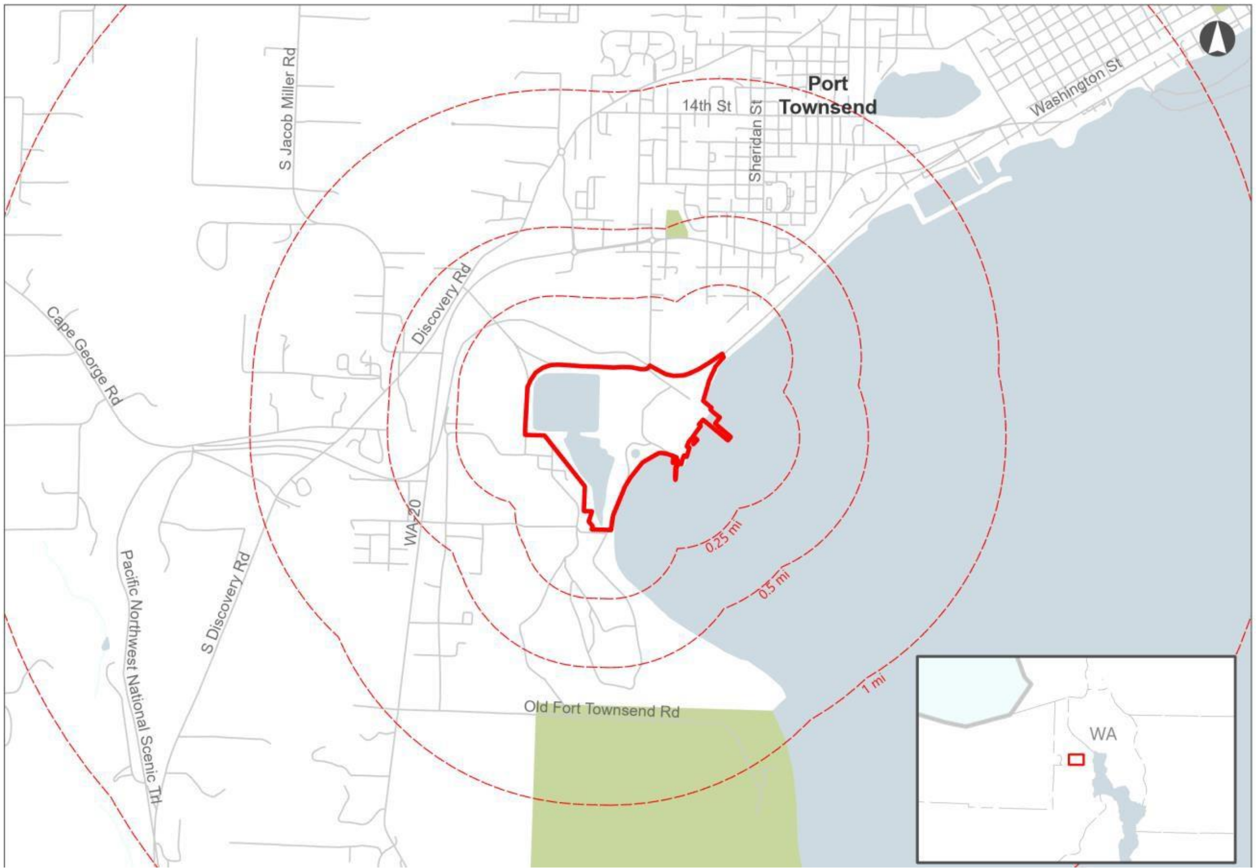
Port Townsend Paper Mill

Port Townsend, Jefferson County, WA

INTRODUCTORY MAP SERIES

SITE & DEMOGRAPHIC SNAPSHOT

EPA FACILITY ID WAD009270919



Demographic Statistics[4,5]

Within 1 Miles buffer of site boundary

Measure	2010	2020	Change	Measure	2010	2020	Change
Total Population	2,426	2,463	+1%	Two or More Races	90	216	+140%
White Alone	2,212	2,126	-3%	Hispanic or Latino[6]	104	118	+13%
Black Alone	15	9	-40%	Children Aged 6 and Younger	139	128	-7%
Am. Indian & AK Native Alone	33	29	-12%	Adults Aged 65 and Older	578	903	+56%
Asian Alone	38	34	-10%	Females Aged 15 to 44	376	328	-12%
Native Hawaiian & Other Pacific Islander Alone	17	1	-94%	Housing Units	1,376	1,341	-2%
Some Other Race Alone	24	46	+91%	Housing Units Pre-1950	95	212	+123%

Data Sources: [1]ATSDR GRASP Hazardous Waste Site Boundary Database, [2]ATSDR GRASP, [3]TomTom 2021Q3, [4]US Census 2020 Demographic and Housing Characteristics. **Notes:** [5]Calculated using area-proportion spatial analysis method, [6]Individuals identifying origin as Hispanic or Latino may be of any race. **Coordinate System:** NAD 1983 StatePlane Washington North FIPS 4601

ATSDR Agency for Toxic Substances and Disease Registry

GRASP Geospatial Research, Analysis, and Services Program

3.2 Community Concerns

Citizens in Port Townsend and Jefferson County, Washington contacted WDH in 2007 because of health concerns related to past, current, and future air emissions from PTPC. Both PTPC and ECY have been tracking community odor complaints since 2007. Several residents and community groups regularly make complaints about odors in and around Port Townsend. The community complaints come from within 5 miles of PTPC and include smells of rotten egg and/or "pungent acid" odors that irritate eyes, throat, and nose and cause headaches [ATSDR 2008]. Some residents have reported that these odors trigger asthma-like reactions and vomiting.

In the 2008 health consultation, ATSDR stated the following [ATSDR 2008]:

> WDH has received numerous health complaints since May 2007, from the Port Townsend AirWatchers and local citizens. WDH received community complaints by regular mail, electronic mail, and summaries from the Port Townsend Paper Corporation. WDH received a list of 285 complaints recorded by the mill from 1/19/2004 to 7/10/2007, ten written letters and ten electronic mail messages.

Between 2016 and 2021, nearly two-thousand odor complaints were recorded by ECY and PTPC. Residents have also stated that odors coming from PTPC have impacted their quality of life in terms of time spent outdoors and related recreational activities.

4. Methods and Sampling Data

4.1 Exposure Investigation Design and Site Selection

EIs are designed to evaluate community exposures to specific contaminants, and samples are collected in times and locations where individuals are likely to have the highest exposures. ATSDR selected sampling locations and contaminants based on the proximity to the facility, complaints of odors from Port Townsend community members, and air concentrations estimated through air dispersion modeling [ATSDR 2016b, 2017]. See Appendix B for figures showing the modeling results in relation to the site locations. Additional constraints were also considered, such as availability of electrical power and sampling equipment, the ability to secure equipment at the site location, and the ability to identify willing participants.

The following contaminants were measured near PTPC: several reduced sulfur compounds (including hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide), $PM_{2.5}$, PM_{10}, sulfur dioxide, and aldehydes (acetaldehyde, formaldehyde, and propionaldehyde).

As part of the EI process, ATSDR compared the measured concentrations of contaminants to SLs, which are intended to protect the general public from adverse health effects from acute, intermediate, or chronic exposures [ATSDR 2022a]. A concentration above the SL does not necessarily mean that an adverse effect will occur, but it is an indication that the specific contaminant should be further investigated and compared to the health effects documented in scientific literature. If ATSDR derived SLs are not available, appropriate SLs from other authoritative/reliable sources may be used to screen the data. See Appendix C for a detailed description of all SLs used in this assessment.

The program included a total of eight fixed sampling sites, including six residential areas, one public school facility, and one business. Sampling systems were placed at the eight locations (Sites 1 through 8), and as a quality control measure, collocated systems were established at two sites (i.e., Site 3 for PM_{10} and Site 4 for hydrogen sulfide). Collocated measurements are collected simultaneously using two identical independent collection systems at the same location at the same time. Analysis of collocated measurements provides information on the potential for variability (or precision) expected between different collection systems. The sampling locations, and the pollutants measured at each, are shown in Table 1. Sampling locations were all within 3 miles of PTPC (Figure 4).

In the planning of this EI, data quality objectives (DQOs) were developed to determine the amount and quality of data needed for this EI. There were both operational (sampling time, duration, location, frequency) and technical (sampling accuracy and precision) DQOs. These DQOs help ATSDR determine if the data collected are of sufficient quality to achieve the EI project's specific goals and objectives. The Port Townsend EI met all of its specified operational DQOs and met some, but not all of its technical DQOs. See Appendix D for more information on the DQOs for the Port Townsend EI.

Table 1: ATSDR Exposure Investigation Site Location Descriptions*

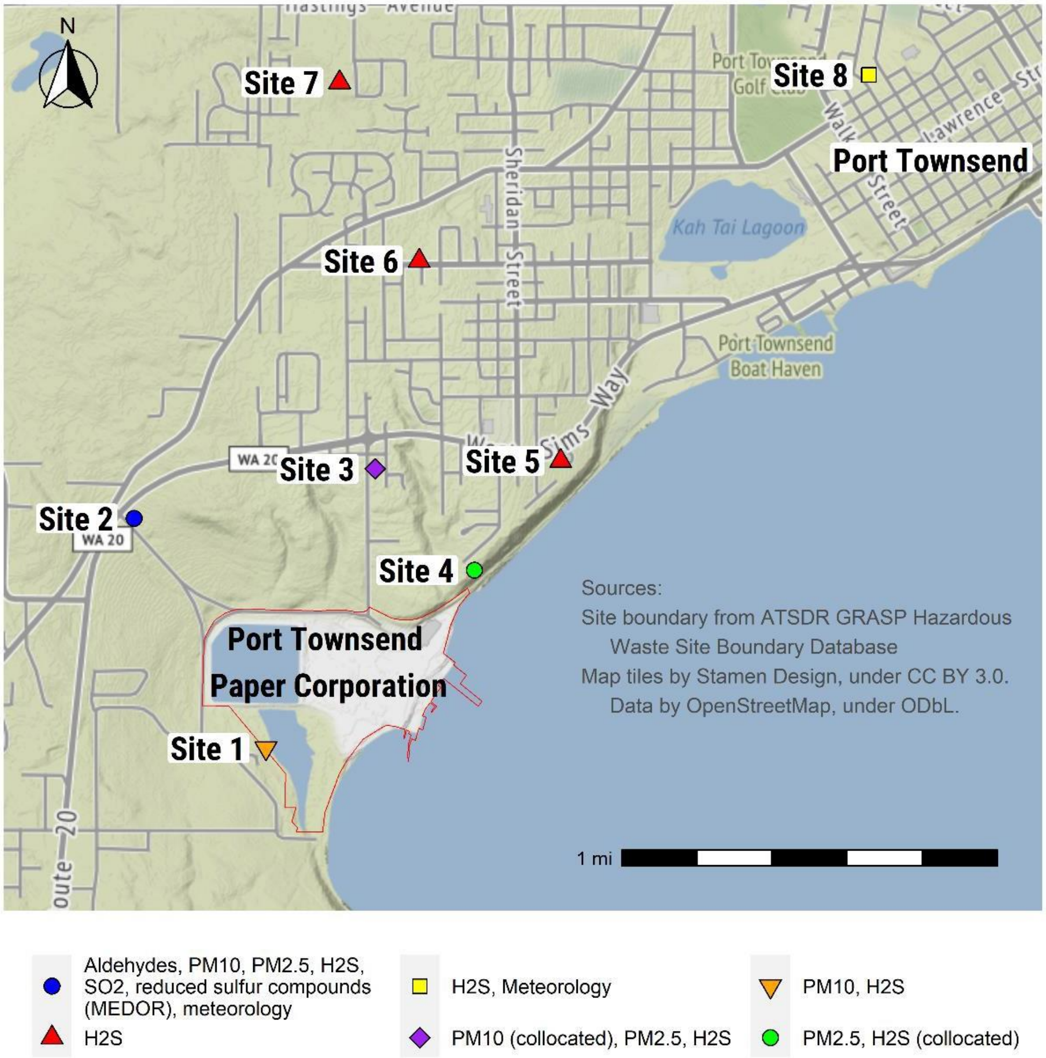
Site Identification	Site Description	Pollutant Measurement Type
Site 1	Private residence on Stevens Avenue	Hydrogen sulfide, PM_{10}
Site 2	Private business on Sims Way	Aldehydes, hydrogen sulfide†, $PM_{2.5}$, PM_{10}, reduced sulfur compounds†, sulfur dioxide†, meteorology
Site 3-Primary	Private residence on Thomas Street‡	Hydrogen sulfide, $PM_{2.5}$, PM_{10} (primary)
Site 3-Collocated	Private residence on Thomas Street	PM_{10} (collocated)
Site 4-Primary	Private residence on Vista Boulevard	Hydrogen sulfide (primary), $PM_{2.5}$
Site 4-Collocated	Private residence on Vista Boulevard	Hydrogen sulfide (collocated)
Site 5	Private residence on Wilson Street	Hydrogen sulfide
Site 6	Private residence on 14th Street	Hydrogen sulfide
Site 7	Private residence on Thomas Street‡	Hydrogen sulfide
Site 8	Public school facility on Blaine Street	Hydrogen sulfide, meteorology

*SPM- single point monitor; PM_{10}- particulate matter 10 micrometers or smaller; $PM_{2.5}$- particulate matter 2.5 micrometers or smaller

†Hydrogen sulfide and sulfur dioxide were measure using two separate methods at Site 2. In the first method they were measured alone (using single point monitor or Thermo Scientific ™ 43I Analyzer respectively) and, in the second, they were measured along with other sulfur containing compounds (MEDOR).

‡There were two sampling locations on Thomas Street situated several blocks apart from each other.

Figure 4: ATSDR Exposure Investigation Monitor Locations



Sources:
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL.

*PM10- particulate matter 10 micrometers or smaller; PM2.5$_5$- particulate matter 2.5 micrometers or smaller; H2S- hydrogen sulfide; SO2- sulfur dioxide.

4.2 Data Collection

The EI was conducted over a 10-week period from August 30, 2018, to November 10, 2018. Additional details on sample collection and analysis are provided in Appendix D. In addition to sampling, the Human Exposure Model – 4 (HEM-4) [EPA 2020] was used to predict chemical concentrations using concurrent meteorology (measured at Site 2),and emissions and building downwash parameters from ATSDR [2016b]. All contaminants were measured continuously, except for aldehydes, which were sampled over a 24-hour period on alternate days.

Although the EI duration in the protocol was 8 weeks, ATSDR decided to extend the investigation period to 10 weeks to accommodate a 1-week shutdown of PTPC operations and the week following the shutdown when PTPC operations resumed. ATSDR data were aggregated by plant operating status.

4.3 Laboratory and Data Analysis

All contaminants, except the aldehydes, were measured automatically at the site. Aldehyde samples were collected at Site 2 and shipped to Eastern Research Group (ERG) laboratories for analysis. Specific methods of sample analysis are provided in Appendix D.

5.1 Exposure Pathway Analysis

Community members can be exposed to contaminants produced by PTPC via inhalation of outdoor air. Several epidemiological studies have been conducted on workers in the paper pulp industry and populations located near pulp mills. Exposure in these studies was due to inhalation of a mixture of sulfur compounds, including dimethyl sulfide, hydrogen sulfide, methyl mercaptan, dimethyl disulfide, and sulfur dioxide [EPA 2005]. ATSDR measured these contaminants, as well as particulate matter ($PM_{2.5}$ and PM_{10}) and aldehydes (acetaldehyde, formaldehyde, and propionaldehyde) in air near PTPC during this EI. Contaminants were measured in residential areas where community members could be exposed via inhalation with sampling locations that included private residences, one local business, and a school.

5.2 Outdoor Air Evaluation

5.2.1 Screening Analysis

To determine the potential for effects from chemical exposure, ATSDR uses SLs to screen out contaminants that are measured at concentrations that are generally safe (below the SL). SLs can be set for acute exposures– less than 2 weeks of exposure, intermediate exposures – less than 1 year of exposure, or chronic exposures – more than one year of exposure.

In the initial screening, the maximum measured concentration for each contaminant was compared to the lowest SL. All contaminants measured except propionaldehyde exceeded at least one SL and required additional evaluation. ATSDR calculated 24-hour averages from the data at each site. For hydrogen sulfide and sulfur dioxide, even shorter durations were assessed for comparison to effects observed in literature. The highest 24-hour (and shorter) averaged concentrations were used as estimates of acute exposure. The measured concentrations for each contaminant were averaged to match the duration of exposure from the study that was used to derive the acute SL. The 95% upper confidence limit of the mean (UCL) was calculated at each site and used as an estimate of intermediate and chronic exposures. Polar plots, which show the wind speed and direction associated with the measured concentrations, were also developed for each monitor [Carslaw and Ropkins 2012]. See Appendix D for all result tables and figures.

Table 2 below shows the method detection limit, outdoor air SLs, the averaging time (exposure duration) used for comparison to effects levels, and the reference for the SL associated with each of the measured contaminants. See Appendix C for a detailed description of all SLs used in this assessment.

Table 2: Screening Levels Used in Exposure Investigation*

Pollutant Measured (Sample Duration)	Reporting Limit	Screening Level, Source (averaging time for comparison)	Screening Level Reference(s)
Hydrogen sulfide[†] (SPM- measured continuously in 1-min increments) (MEDOR- measured continuously in 20-min increments)	1 ppb	70 ppb, acute ATSDR MRL (30 minutes), 20 ppb, intermediate ATSDR MRL (1 day), 1.4 ppb, EPA reference concentration (EI 10-wk average)[‡]	[ATSDR 2016c, 2022; EPA 2003]
Particulate matter under 10 microns (PM$_{10}$) (measured in 1-hour increments)	< 1 µg/m^3 [§]	45 µg/m^3, WHO air quality guideline (1 day), 15 µg/m^3, WHO air quality guideline (EI 10-wk average)[‡]	[ATSDR 2020; WHO 2021]
Particulate matter under 2.5 microns (PM$_{2.5}$) (measured in 1-hour increments)	< 1 µg/m^3 [§]	15 µg/m^3, WHO AQG (1 day) 5 µg/m^3, WHO AQG (EI 10-wk average)[‡]	[ATSDR 2020; WHO 2021]
Sulfur dioxide[†] (Thermo- measured continuously in 1-minute increments) (MEDOR- measured continuously in 20-min increments)	<1 ppb[§] (Thermo) <1ppb[§] (MEDOR)	10 ppb, acute ATSDR MRL (10 minutes)	[ATSDR 1998, 2022]
Acetaldehyde (24-hour samples measured every other day)	0.042 µg/m^3	9 µg/m^3, EPA reference concentration (EI 10-wk average)[‡] 0.45 µg/m^3, ATSDR CREG (EI 10-wk average)[‡]	[ATSDR 2022b; EPA 1991]
Formaldehyde (24-hour samples measured every other day)	0.062 µg/m^3	49 µg/m^3, acute ATSDR MRL (1 day), 37 µg/m^3, intermediate ATSDR MRL (EI 10-wk average)[‡] 9.8 µg/m^3, chronic ATSDR MRL (EI 10-wk average)[‡] 0.077 µg/m^3, CREG (EI 10-wk average)[‡]	[ATSDR 1999, 2022]

Pollutant Measured (Sample Duration)	Reporting Limit	Screening Level, Source (averaging time for comparison)	Screening Level Reference(s)

Propionaldehyde (24-hour samples measured every other day)	0.014 $\mu g/m^3$	8 $\mu g/m^3$, EPA reference concentration (EI 10-wk average)[‡]	[EPA 2008a; ATSDR 2022b]
Dimethyl disulfide (DMDS) (MEDOR- measured along with other sulfur compounds, continuously in 20-min increments)	<1 ppb[§]	500 ppb, ACGIH TLV®–STEL (20 minutes)[¶]	[ACGIH 2021]
Dimethyl sulfide (DMS) (MEDOR- measured along with other sulfur compounds, continuously in 20-min increments)	<1 ppb[§]	10,000 ppb, ACGIH TLV®–STEL (20 minutes)[¶]	[ACGIH 2021]
Methyl mercaptan (MEDOR- measured along with other sulfur compounds, continuously in 20-min increments)	<1 ppb[§]	500 ppb, ACGIH TLV®–STEL (20 minutes)[¶]	[ACGIH 2021]

*ATSDR- Agency for Toxic Substances and Disease Registry; MRL- minimal risk level; EPA- U.S. Environmental Protection Agency; CREG- cancer risk evaluation guide; ACGIH- American Conference of Governmental Industrial Hygienists; TLV®–STEL — Threshold Limit Value – Short Term Exposure Limit; SPM- single point monitor; Thermo- Thermo Scientific ™ 43I Analyzer; MEDOR- TRSMEDOR® ppb method for measuring total sulfur; µg/m3 = micrograms per cubic meter; ppb = parts per billion

†Hydrogen sulfide and sulfur dioxide were measure using two separate methods. In the first method they were measured alone (using single point monitor or Thermo Scientific ™ 43I Analyzer, respectively) and, in the second, they were measured along with other sulfur containing compounds (MEDOR).

‡The average of data collected during the 10-week EI

§This is the lowest reported value during the EI, which can be lower than the linear method detection limit.

¶ACGIH TLVs are occupational standards that were used in the absence of other SLs but are not necessarily protective of community exposures.

5.2.2 Evaluation of Breathing Air

Evaluation of Potential Hazards and Cancer Risks

Noncancer Health Assessment of Individual Contaminants

Contaminants that exceeded SLs were then further evaluated by deriving exposure point concentrations (EPCs) that were compared to effect levels documented in literature. EPCs are duration-adjusted concentrations that reflect acute, intermediate, or chronic exposure durations associated with adverse health effects.

Noncancer Health Assessment of the Mixture of Contaminants

The agency’s noncancer *quantitative* approach evaluates the contaminants in the mixture by assuming they have an additive toxic effect. ATSDR also considers the possibility of other joint interactions (greater than or less than additive effects), as appropriate via reviews of its chemical-specific interaction profiles and the Health Effects chapter in each contaminant’s ATSDR toxicological profile.

To conduct the noncancer chemical mixtures analyses, ATSDR calculates hazard quotients (HQs) for each contaminant and a hazard index (HI) for exposure to the mixture of contaminants. HQs and HIs were calculated for acute, intermediate, and chronic exposures where applicable. The HQ is equal to the duration-specific EPC divided by the corresponding SL. The HI is the sum of the individual contaminant HQs for each exposure duration. ATSDR considers that HI values less than 1 indicate no hazard from the combined exposure of the contaminant mixture. HIs equal to and greater than 1 indicate the agency should evaluate target-organ exposures. To calculate the overall HI, the agency sums the individual HQs for each exposure duration.

Cancer Risk Assessment

For substances that have carcinogenic effects, ATSDR screens for cancer risk using ATSDR's cancer risk evaluation guide (CREG). The CREG is based on U.S. environmental Protection Agency (EPA) inhalation unit risk factor (IUR) and represents an exposure level estimated to result in 1 in 1 million lifetime cancer risk (1×10^{-6}).

ATSDR calculates the cancer risk for a population with an average life expectancy of 78 years by multiplying the chronic EPC by the IUR and adjusting the duration of exposure using the appropriate exposure factor EF. The cancer risk calculation is as follows:

Cancer risk = IUR x EPC [micrograms per cubic meter ($\mu g/m^3$)] x EF

ATSDR assumes an exposure of 33 years, which is the 95th percentile for the length of time a person resides in a specific property [ATSDR 2016d]. The corresponding EF is 33/78.

Use of EPA's Air Quality Index

EPA's Air Quality Index (AQI) online tool, "AIRNow AQI Calculator" was used to estimate the potential for health effects from short-term exposure to PM_{10}, $PM_{2.5}$, and sulfur dioxide measured in Port Townsend [EPA 2018]. Other contaminants measured at Port Townsend are not included in the AQI. This tool offers guidance to the potential health effects associated with short-term exposure to specific concentrations of PM and sulfur dioxide. The AQI categorizes air concentrations into six categories: *good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy,* and *hazardous*. For specific AQI categories and health statements see Appendix C, Table C1.

ATSDR used the *moderate* category as a screening tool to determine if concentrations measured in Port Townsend had the potential to cause adverse health effects. Exposures in the *moderate* AQI category may require unusually sensitive individuals to reduce prolonged or heavy exertion; the health of other individuals should not be affected.

People with heart or lung disease, older adults, children, and people of lower socioeconomic status are most at risk for health effects from $PM_{2.5}$ and PM_{10}. People with asthma, children, and older adults are the groups most at risk for health effects from sulfur dioxide [EPA 2018]. See Appendix C, Table C1, for the concentration range of each AQI category, the associated public health statements, and relevant SLs and measured concentrations.

Environmental Odors

ATSDR also assessed the potential for environmental odors near PTPC. ECY and WDH have received thousands of complaints made by community members about odors coming from PTPC operations. ATSDR qualitatively reviewed these complaints and compared differences in the number of complaints during operation and shutdown of PTPC. ATSDR also compared measured concentrations to the odor threshold of the contaminants measured in and around PTPC to determine the frequency of environmental odors in the area.

Comparison of Measured Concentrations from Sampling Methods and Modeled Estimates

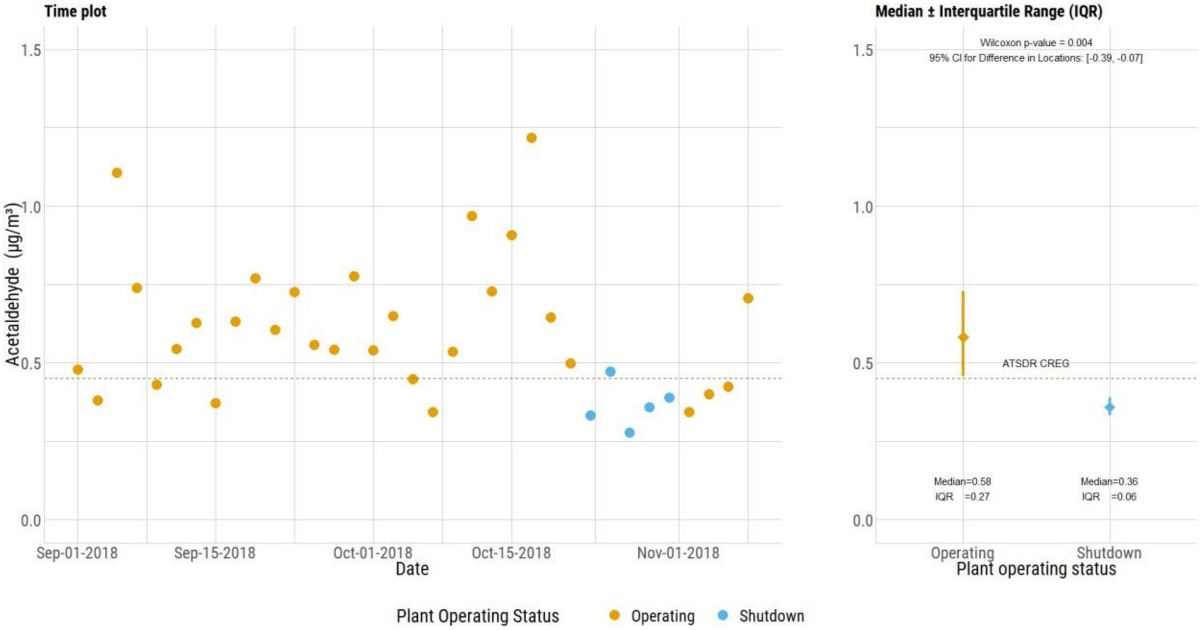
In this EI, two additional methods were applied to determine their application in future EIs and similar exposure investigations. The first was the measurement of sulfur containing compounds, which consists of a range of sulfides measured continuously. This type of sampling has not been regularly implemented in ATSDR EIs, and the results were compared to that of hydrogen sulfide and sulfur dioxide measured by standardized EPA methods.

The second is the use of the EPA's HEM-4 model to predict exposure concentrations. This model used emissions parameters from PTPC and the meteorology data measured during the EI to predict concentrations of aldehydes (acetaldehyde, formaldehyde, and propionaldehyde), PM, and several sulfur compounds. The accuracy of the model to the measured concentrations was assessed to support its future use in exposure assessments. The modeled estimates were not used to assess exposure or make health-based recommendations.

5.2.3 Data Analysis

The following figures and tables visualize the data from all locations where contaminants were measured during the EI. When possible, the data from each contaminant were averaged to match the duration of the studies used as the basis for the derivation of the SL and compared to specific concentrations relevant to public health. The timeplots, boxplots, and tables below were used to present each type of data, as appropriate. The timeplots show the variation in individual samples and the frequency that SLs were exceeded. The boxplots and tables show EPCs compared to SLs and AQI categories when available. Specific numerical values and other statistics surrounding contaminants measured at each site are contained in Appendix D.

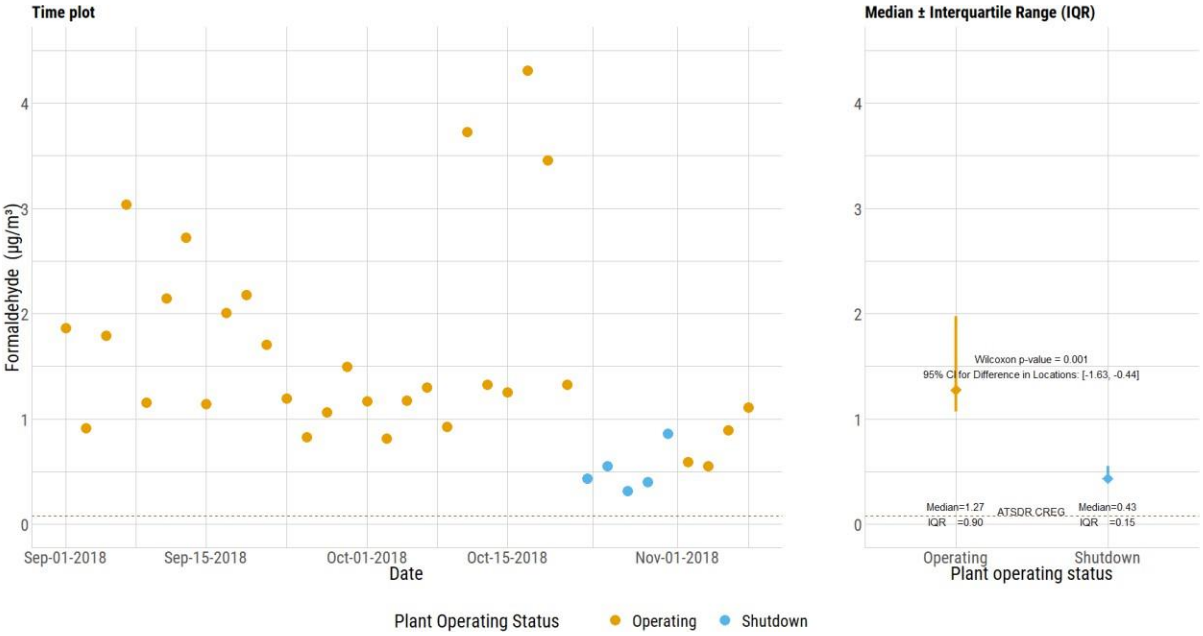
Figure 5: Acetaldehyde 24-hour Samples and Comparison of PTPC Operation and Shutdown*†



*µg/m^3- micrograms per cubic meter; ATSDR- Agency for Toxic Substances and Disease Registry; CREG- cancer risk evaluation guide; 95% CI- 95% confidence interval

†The dotted line represents the ATSDR cancer risk evaluation guide CREG (0.45 µg/m^3); ATSDR chronic minimum risk level (MRL) (9 µg/m^3) not shown. Due to the small number of samples taken during shutdown ATSDR opted to present these data as a scatter plot with the bars to the right showing the median and IQR. Acetaldehyde concentrations were significantly higher when PTPC was in operation.

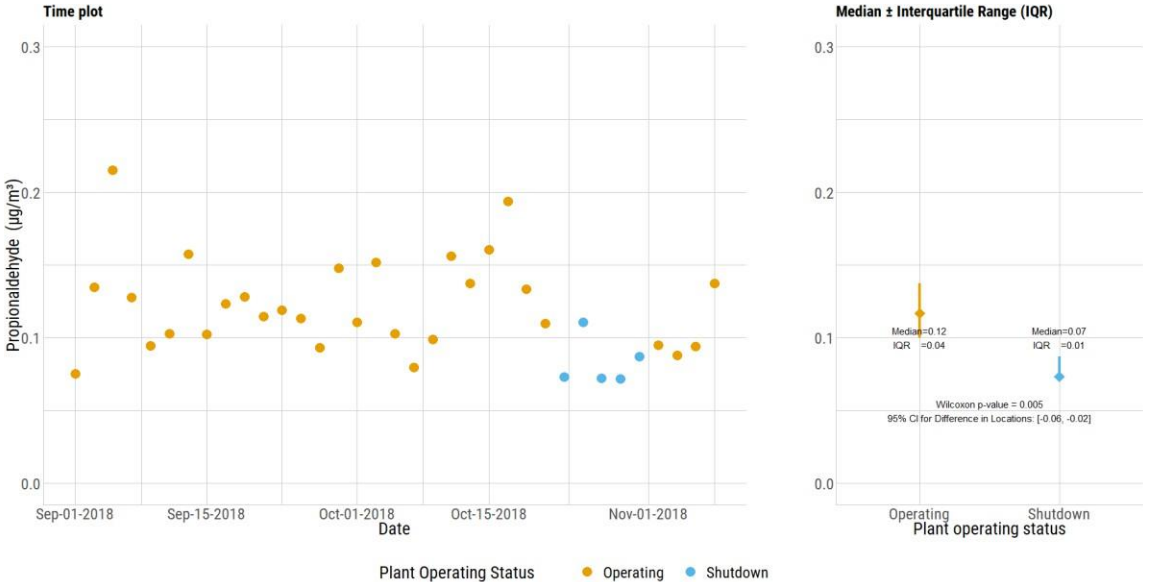
Figure 6: Formaldehyde 24-Hour Samples and Comparison of PTPC Operation and Shutdown*†



*µg/m^3- micrograms per cubic meter; ATSDR- Agency for Toxic Substances and Disease Registry; CREG- cancer risk evaluation guide; 95% CI- 95% confidence interval

†Dotted line represents the ATSDR CREG (0.077 ug/m^3). ATSDR chronic MRL 9.8 ug/m^3 not shown. This figure shows formaldehyde concentrations regularly exceed ATSDR's cancer risk evaluation guide (CREG), and the highest concentrations were measured while PTPC was in operation. Formaldehyde concentrations were significantly higher when PTPC was in operation.

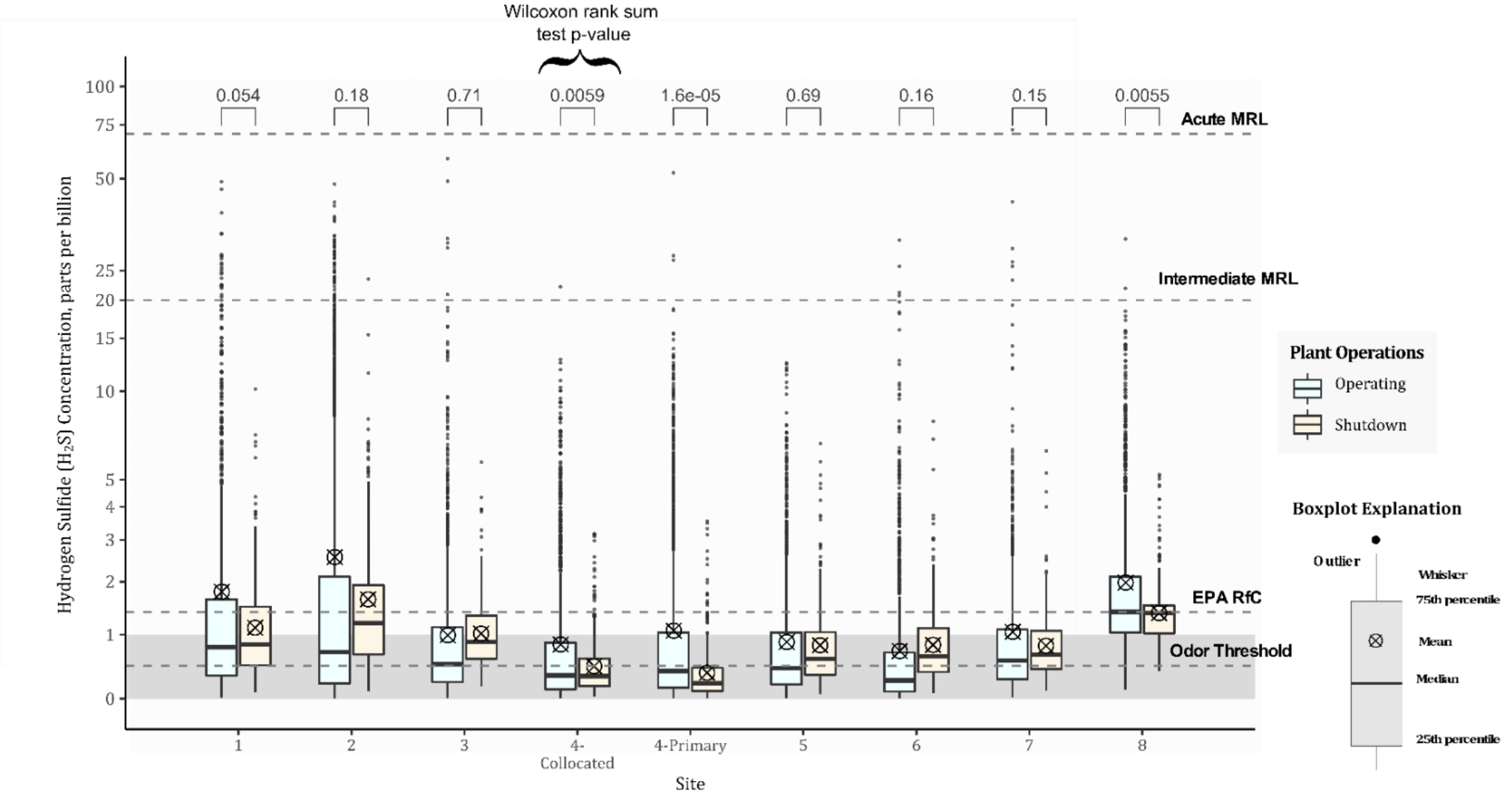
Figure 7: Propionaldehyde 24-Hour Samples and Comparison of Port Townsend Paper Corporation (PTPC) Operation and Shutdown*†



*µg/m³- micrograms per cubic meter; ATSDR- Agency for Toxic Substances and Disease Registry; 95% CI- 95% confidence interval

†This figure shows propionaldehyde concentrations were all below the chronic SL (EPA RfC of 8 µg/m³ not shown), and the highest concentrations were measured while PTPC was in operation. Propionaldehyde concentrations were significantly higher when PTPC was in operation.

Figure 8: Boxplot of Hydrogen Sulfide Single Point Monitor Results (30 min averages)*†‡§¶



*ATSDR- Agency for Toxic Substances and Disease Registry; EPA- U.S. Environmental Protection Agency; RfC-EPA reference concentration; MRL- minimal risk level

†EPA RfC (1.4ppb); odor threshold (0.5 ppb); ATSDR intermediate MRL (20 ppb); ATSDR acute MRL (70ppb); On top of the x axis are p-values for the Wilcoxon Rank-Sum test, which compares the levels during PTPC operation and shutdown.

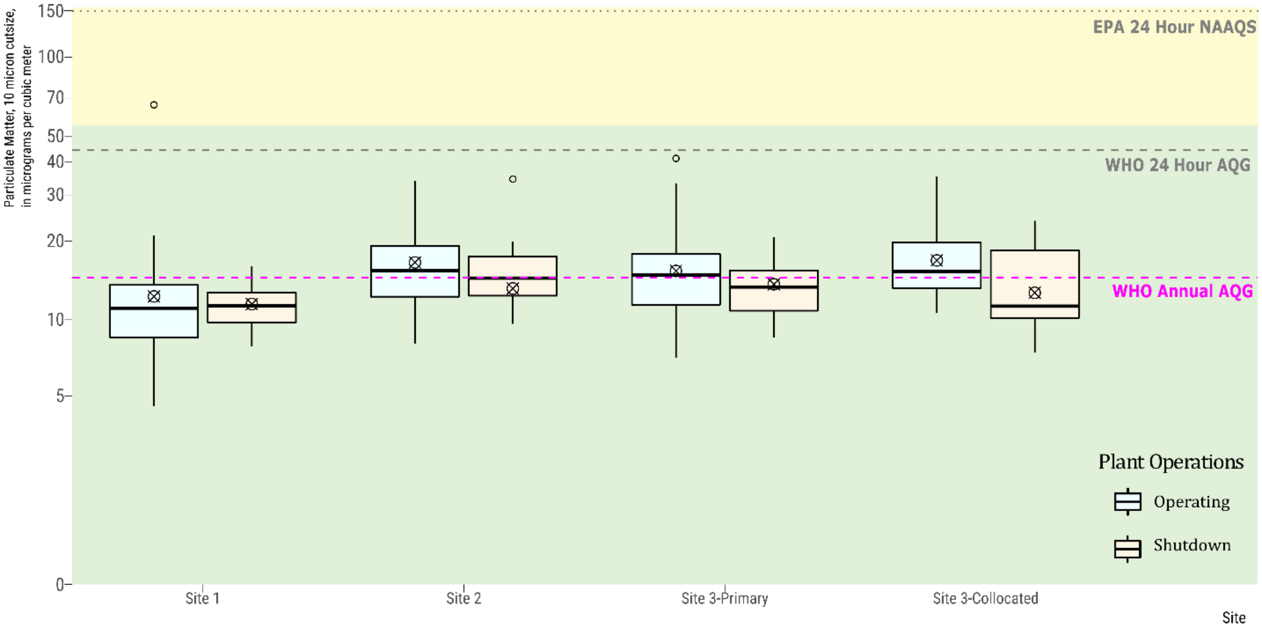
‡The grey area represents values below 1ppm and were imputed using robust regression order statistics. Comparisons are using Wilcoxon rank sum test on values after thinning to match effective sample size to account for autocorrelation.

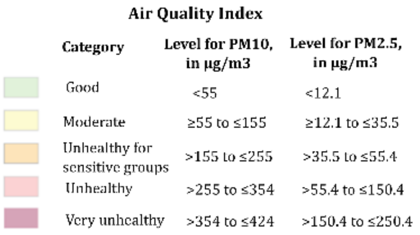
§Boxplot Notes- The whiskers extend to the largest or lowest value within 1.5 times the interquartile range, which is defined as the difference between the 75th and 25th percentile.

¶EPA RfC (1.4ppb); odor threshold (0.5 ppb); ATSDR intermediate MRL (20 ppb); ATSDR acute MRL (70ppb). On top of the x axis are p-values for the Wilcoxon Rank-Sum test, which compares the levels during PTPC operation and shutdown.

**This figure shows that hydrogen sulfide was regularly measured above the odor threshold and the chronic SL (EPA RfC). Fewer samples exceeded the ATSDR intermediate MRL, and only one sample reached the acute MRL. While the highest concentrations of hydrogen sulfide at each site were measured while PTPC was in operation, the increase was most significant at sites 4 and 8.

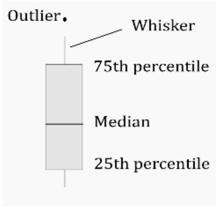
Figure 9: Boxplot of PM$_{10}$ 24-Hour Averages and Comparison of Port Townsend Paper Corporation (PTPC) Operation and Shutdown*†‡





Air Quality Index

	Category	Level for PM10, in µg/m3	Level for PM2.5, in µg/m3
🟩	Good	<55	<12.1
🟨	Moderate	≥55 to ≤155	≥12.1 to ≤35.5
🟧	Unhealthy for sensitive groups	>155 to ≤255	>35.5 to ≤55.4
🟥	Unhealthy	>255 to ≤354	>55.4 to ≤150.4
🟪	Very unhealthy	>354 to ≤424	>150.4 to ≤250.4



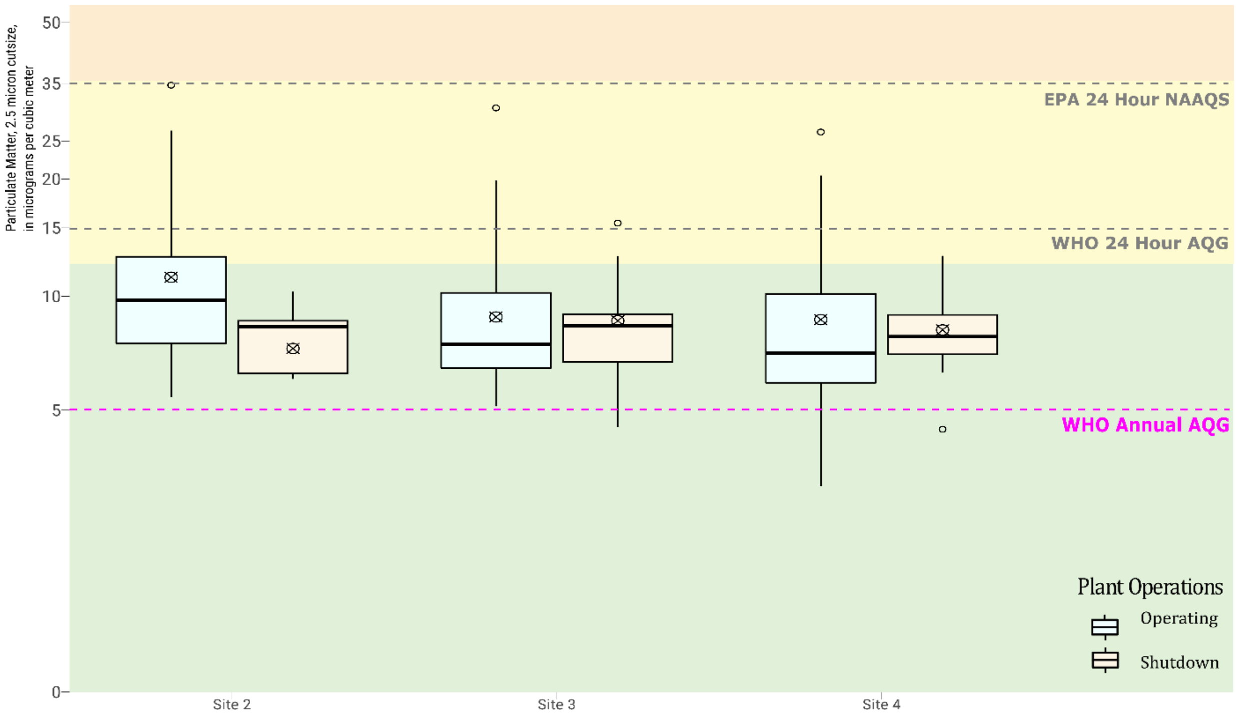
*PTPC- Port Townsend Paper Corporation; PM10- particulate matter 10 microns or smaller; PM2.5- particulate matter 2.5 micrometers smaller; EPA- U.S. Environmental Protection Agency; NAAQS- National Ambient Air Quality Standards; WHO- World Health Organization; AQG- air quality guideline

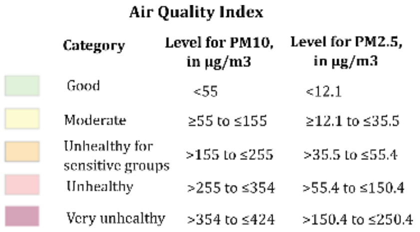
†WHO 24-hour air quality guideline (45 $\mu g/m^3$); WHO annual air quality guideline (15 $\mu g/m^3$); EPA 24-hour National Ambient Air Quality Standard (150 $\mu g/m^3$)

‡Boxplot Notes- The whiskers extend to the largest or lowest value within 1.5 times the interquartile range, which is defined as the difference between the 75th and 25th percentile.

§This figure shows nearly all days measured were designated as *good* air quality by the EPA AQI.

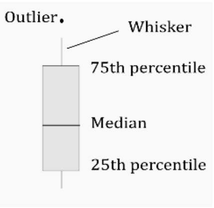
Figure 10: Boxplot of $PM_{2.5}$ 24-Hour Averages and Comparison of Port Townsend Paper Corporation (PTPC) Operation and Shutdown*†‡





Air Quality Index

	Category	Level for PM10, in µg/m3	Level for PM2.5, in µg/m3
🟩	Good	<55	<12.1
🟨	Moderate	≥55 to ≤155	≥12.1 to ≤35.5
🟧	Unhealthy for sensitive groups	>155 to ≤255	>35.5 to ≤55.4
🟥	Unhealthy	>255 to ≤354	>55.4 to ≤150.4
🟪	Very unhealthy	>354 to ≤424	>150.4 to ≤250.4



*PTPC- Port Townsend Paper Corporation; PM_{10}- particulate matter 10 microns or smaller; $PM_{2.5}$- particulate matter 2.5 micrometers or smaller; EPA- U.S. Environmental Protection Agency; NAAQS- National Ambient Air Quality Standards; WHO- World Health Organization; AQG- air quality guideline

†WHO 24-hour air quality guideline (15 µg/m^3); WHO annual air quality guideline (5 µg/m^3); EPA 24-hour National Ambient Air Quality Standard (35 µg/m^3); EPA Annual National Ambient Air Quality Standards (12 µg/m^3) not shown; micrograms per cubic meter (µg/m^3).

‡Boxplot Notes- The whiskers extend to the largest or lowest value within 1.5 times the interquartile range, which is defined as the difference between the 75th and 25th percentile.

§This figure shows most $PM_{2.5}$ 24-hour concentrations were below the WHO 24-hour AQG, and averages at all sites exceeded the WHO annual AQG. Although several days were designated as *moderate* air quality by the EPA AQI, most days sampled were designated as *good* air quality.

Table 3: Percent and Number of Days That Particulate Matter (PM_{10} and $PM_{2.5}$) Fall Into Each Category of the EPA Air Quality Index*†

Pollutant (Sample Size)	*Good* Percent (Number of Days)	*Moderate* Percent (Number of Days)	*Unhealthy for Sensitive Groups* Percent (Number of Days)
$PM_{2.5}$ (216)	79.63 (172)	20.37 (44)	0 (0)
PM_{10} (245)	99.59 (244)	0.41 (1)	0 (0)

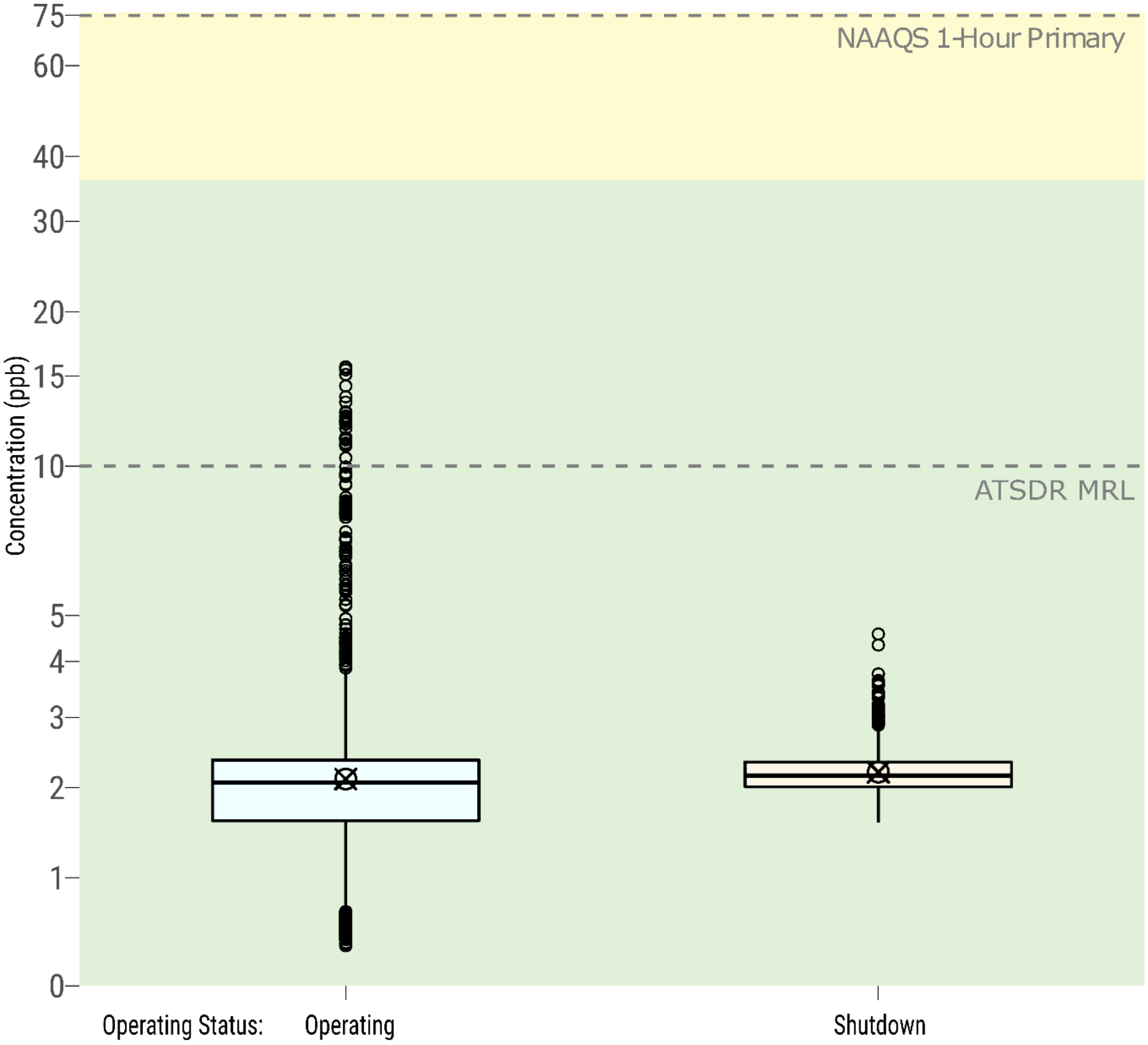
*PM10- particulate matter 10 microns or smaller; $PM_{2.5}$- particulate matter 2.5 micrometers or smaller; EPA- U.S. Environmental Protection Agency

†Particulate matter (PM) concentration ranges for EPA AQI Categories are as follows in micrograms per cubic meter ($\mu g/m^3$):

$PM_{2.5}$- *Good* (less than 12.1 $\mu g/m^3$); *Moderate* (12.1 to 35.5 $\mu g/m^3$); *Unhealthy for Sensitive Groups* (greater than 35.5 to 55.4 $\mu g/m^3$)

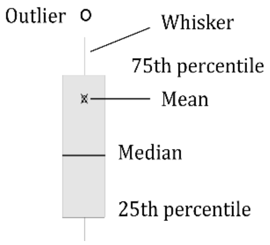
PM_{10}- *Good* (less than 55 $\mu g/m^3$); *Moderate* (55 to 155 $\mu g/m^3$); *Unhealthy for Sensitive Groups* (greater than 155 to 255 $\mu g/m^3$)

Figure 11: Boxplot of Sulfur Dioxide (SO_2) Thermo 10-minute Averages in parts per billion (ppb) and Comparison of PTPC Operation and Shutdown*†



Air Quality Index

	Category	Level for SO2, in ppb
🟩	Good	<36
🟨	Moderate	≥36 to ≤75
🟧	Unhealthy for sensitive groups	>75 to ≤185
🟥	Unhealthy	>185 to ≤304
🟪	Very unhealthy	>304 to ≤604



*NAAQS- National Ambient Air Quality Standards; ATSDR- Agency for Toxic Substances and Disease Registry; MRL- Minimal Risk Level; ppb- parts per billion

†EPA 1-hour primary national ambient air quality standard (NAAQS) (75 ppb); ATSDR acute MRL (10 ppb); part per billion (ppb).

‡Boxplot Notes- The whiskers extend to the largest or lowest value within 1.5 times the interquartile range, which is defined as the difference between the 75th and 25th percentile.

§This figure shows most sulfur dioxide concentrations were below the ATSDR acute MRL and, based on the sulfur dioxide concentrations measured with the Thermo instrument, all were designated as good by the EPA AQI.

Table 4: Percent and number of days that sulfur dioxide measurements fell into each category of the EPA Air Quality Index*†

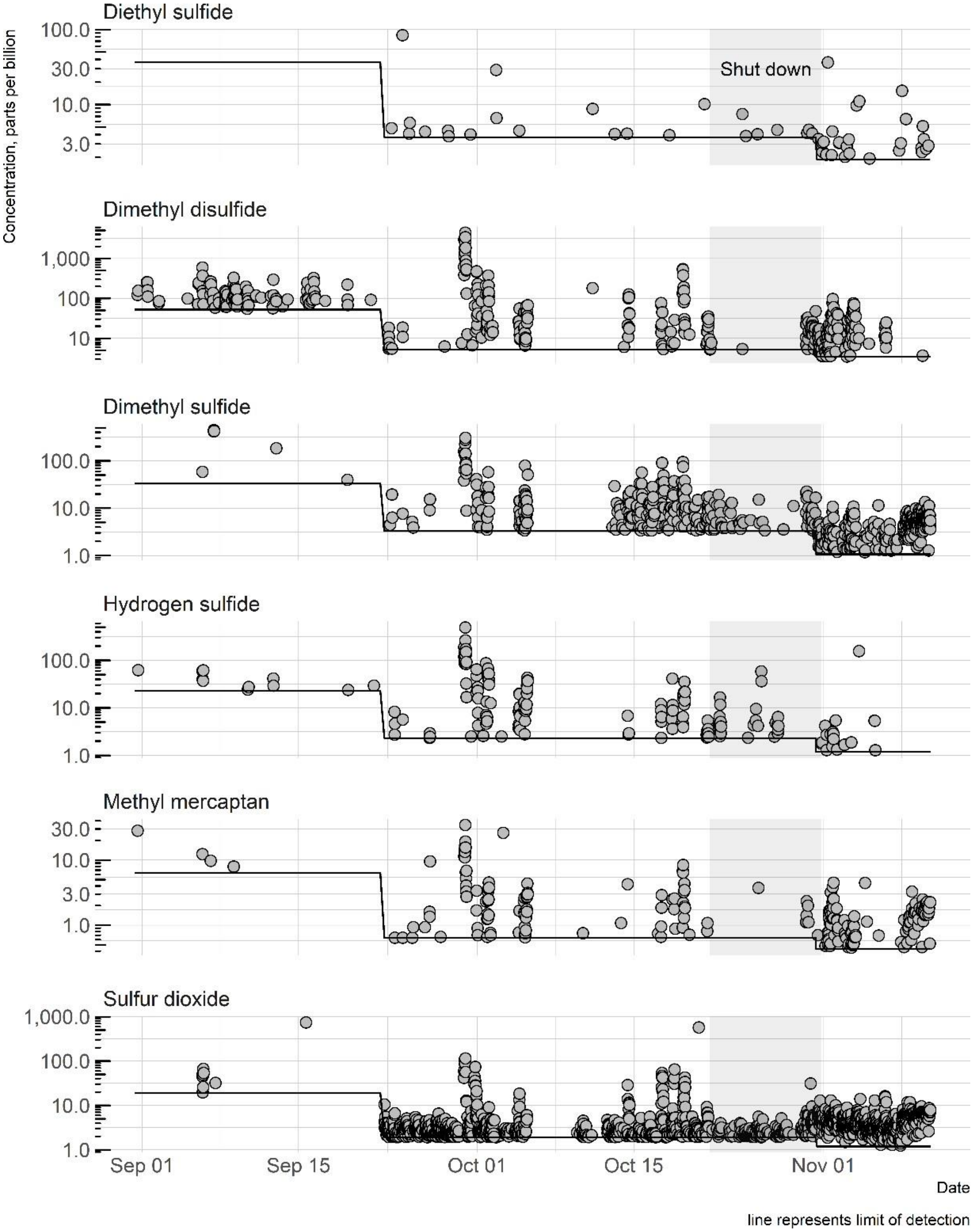
Sampling Method/Duration (Sample Size)	*Good* Percent (Number of Averages)	*Moderate* Percent (Number of Averages)	*Unhealthy for Sensitive Groups* Percent (Number of Averages)	*Unhealthy* Percent (Number of Averages)
1-hour Thermo (819)	100 (819)	0 (0)	0 (0)	0 (0)
24-hour Thermo (245)‡	100 (32)	0 (0)	0 (0)	0 (0)
MEDOR 1-hour (1563)	99.2 (1551)	0.6 (9)	0.1 (1)	0.1 (2)
MEDOR 24-hour (70)	100 (70)	0 (0)	0 (0)	0 (0)

*EPA- U.S. Environmental Protection Agency; AQI- Air Quality Index

†The ranges for EPA AQI Categories for sulfur dioxide are as follows: *Good* (less than 35 ppb); *Moderate* (36 to 75 ppb); *Unhealthy for Sensitive Groups* (76 to 185 ppb); *Unhealthy* (186 to 304 ppb)

‡For concentrations higher than 304 ppb, the AQI suggests using the 24-hour average. Two 20- minute averaged samples exceeded 304 ppb, and the highest 20-min sample was 739 ppb. See Appendix C Table C1. For specific recommendations for each category.

Figure 12: Timeplot of MEDOR Sulfur Compounds 20 min Samples*



*Solid lines represent the detection limit; shaded area is plant shutdown. Higher concentrations of sulfur compounds were measured in the weeks up to and following the shutdown than were measured during the shutdown. The concentrations of the sulfur compounds are positively correlated to each other.

Table 5: Acute and chronic hazard quotients (HQs) and overall hazard index (HI) for all contaminants measured at Port Townsend during the exposure investigation (EI)* †

Contaminant	Units	% Detection	Maximum (Acute EPC)	Acute SL	Acute HQ‡	UCL (Chronic EPC)†	Chronic SL	Chronic HQ‡	Odor Threshold [source]
Acetaldehyde	µg/m^3	100	1.2	N/A	N/A	0.68	9	0.08	380 [EPA 1992a]
Formaldehyde	µg/m^3	100	4.3	49	0.09	1.9	9.8	0.20	1200 [EPA 1992b]
Hydrogen Sulfide§¶**	ppb	(20 – 79) (SPM) 3.8 (MEDOR)	490 (MEDOR)	70	7.0	2.1 (SPM)	1.4	1.5	0.5 [Leonardos et al. 1962]
Dimethyl disulfide¶**	ppb	9.5	4390	500	8.8	N/A	10	N/A	7 [Florida 2014]
Dimethyl sulfide¶**	ppb	14	444	10,000	0.04	N/A	500	N/A	1 [Leonardos et al. 1962]
Methyl Mercaptan¶**	ppb	5.7	34.5	500	0.07	N/A	2	N/A	2.1 [Leonardos et al. 1962]
Propionaldehyde	µg/m^3	100	0.22	N/A	N/A	0.13	8	0.02	1000 [EPA 1992c]
Sulfur Dioxide¶	ppb	97 (Thermo) 36 (MEDOR)	739 (MEDOR)	10 ppb	74	2.1 (Thermo) 3.6 (MEDOR)	N/A	N/A	470 [Leonardos et al. 1962]
Hazard Index (HI)††	N/A	N/A	N/A	N/A	90	N/A	N/A	1.8	N/A

* N/A- not applicable; ppb- parts per billion; µg/m^3- micrograms per cubic meter; EPC- exposure point concentration; SL- screening level; HG- hazard quotient; SPM- single point monitor; UCL- 95% upper confidence limit of the mean

†PM was screened using the World Health Organization air quality guideline which is not appropriate for HQ calculations.

‡HQs were calculated with the highest acute and chronic EPC calculated across all sites. Individual HQ = EPC/ SL

§Hydrogen sulfide is the only contaminant that has an intermediate SL. The UCL of hydrogen sulfide was below the intermediate SL;

¶Hydrogen sulfide and sulfur dioxide were measure using two separate methods. In the first method they were measured alone (using single point monitor or Thermo Scientific ™ 43I Analyzer respectively) and, in the second, they were measured along with other sulfur containing compounds (MEDOR). Dimethyl disulfide, dimethyl sulfide, and methyl mercaptan were only measured with the MEDOR instrument. Due to the low detection using the MEDOR instrument, a UCL could only be calculated for sulfur dioxide.

**For hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methyl mercaptan, the limit of quantitation (LOQ) was higher than the odor threshold, and individuals may smell odors more often than the percent detection.

††HI = Individual $HQ_{\text{Contaminant 1}}$ + Individual $HQ_{\text{Contaminant 2}}$ + … Individual $HQ_{\text{Contaminant n}}$; The HI is the sum of the individual contaminant HQs for each exposure duration. ATSDR considers that overall HI values less than 1 indicate no hazard from the combined exposure of the contaminant mixture. HIs equal to and greater than 1 indicate the agency should evaluate target-organ exposures. To calculate the overall HI, the agency sums the individual HQs for each exposure duration.

Table 6. Cancer risk of acetaldehyde and formaldehyde*†

Contaminant	Units	UCL (Chronic EPC) µg/m^3	CREG µg/m^3	Inhalation Unit Risk (µg/m^3)$^{-1}$	Cancer Risk‡§ unitless
Acetaldehyde	µg/m^3	0.68	0.45	2.2×10^{-6}	6.3×10^{-7}
Formaldehyde	µg/m^3	1.9	0.077	1.3×10^{-5}	1.0×10^{-5}

[*] µg/m^3- micrograms per cubic meter; EPC exposure point concentration; IUR- inhalation unit risk

[†] Both contaminants exceeded the cancer risk evaluation guideline (CREG), but the total estimated risk (1.1×10^{-5}) was low.

[‡] Cancer risk = IUR x UCL (µg/m^3) x EF

[§] ATSDR assumes an exposure factor (EF) of 33 years, which is the 95th percentile for the length of time a person resides in a specific property over a lifetime (78 years). The corresponding EF is 33/78.

5.2.4 Health Evaluations

Aldehydes

Three types of aldehydes were measured: acetaldehyde, formaldehyde, and propionaldehyde. Of the three, formaldehyde has been the focus of most of the literature documenting exposure to aldehydes, followed by acetaldehyde and propionaldehyde. All are acute respiratory irritants with varying chronic effects. In previous modeling efforts by ATSDR, based on emissions reported by PTPC, aldehydes were predicted to exceed screening values [ATSDR 2008].

Formaldehyde is a colorless gas with a distinct pungent odor. It is produced in the environment by the incomplete combustion of organic material and is a constituent of motor vehicle exhaust, cigarette smoke, wood smoke, and emissions from power plants and incinerators. In the air, the secondary formation of formaldehyde can occur as the result of oxidation of volatile organic compounds and from reactions between ozone and alkenes (especially terpenes). Formaldehyde concentrations in outdoor air vary depending on location, traffic, season of the year, weather, and other conditions. In outdoor air, formaldehyde concentrations in unpolluted areas are typically less than 6 µg/m^3 although concentrations of 60 µg/m^3 or more have been reported in areas with heavy air pollution [ATSDR 1999].

Formaldehyde is used mainly to produce resins used in particleboard products and as an intermediate in the synthesis of other chemicals. Exposure to formaldehyde may occur by breathing contaminated indoor air, tobacco smoke, or outdoor urban air. Acute (short-term) and chronic (long-term) inhalation exposure to formaldehyde in humans can result in respiratory symptoms, and eye, nose, and throat irritation. Limited human studies have reported an association between formaldehyde exposure and lung and nasopharyngeal cancer. Animal inhalation studies have reported an increased incidence of nasal squamous cell cancer. National Toxicology Program (NTP) classifies formaldehyde as a known human carcinogen; EPA considers formaldehyde a probable human carcinogen; and the and the International Agency for Research on Cancer (IARC) classifies formaldehyde as carcinogenic to humans [ATSDR 2022b].

Acetaldehyde is mainly used as an intermediate in the synthesis of other chemicals. It is ubiquitous in the environment and may be formed in the body from the breakdown of ethanol [EPA 1992b]. Acute (short-term) exposure to acetaldehyde results in effects including irritation of the eyes, skin, and respiratory tract. Symptoms of chronic (long-term) intoxication of acetaldehyde resemble those of alcoholism. NTP classifies acetaldehyde as reasonably anticipated to be a carcinogen; EPA considers formaldehyde a probable human carcinogen; and the IARC classifies formaldehyde as possibly carcinogenic to humans [ATSDR 2022b].

Propionaldehyde is used in the manufacture of plastics, in the synthesis of rubber chemicals, and as a disinfectant and preservative. Limited information is available on the health effects of propionaldehyde. Animal studies have reported that exposure to high levels of propionaldehyde, via inhalation, results in anesthesia and liver damage, and intraperitoneal exposure results in increased blood pressure. Neither NTP, EPA, nor IARC have classified propionaldehyde for carcinogenicity.

Noncancer Health Effects- None of the 24-hour concentrations of any of these contaminants exceeded their respective noncancer SLs (See Figures 5-7). Thus, ATSDR does not expect noncancer effects from exposure to aldehydes near PTPC.

Cancer Risk- Of the aldehydes measured, acetaldehyde and formaldehyde both exceeded the ATSDR CREG, which is protective of cancer effects over a lifetime of exposure (78 years) (See Table 6). Propionaldehyde does not have a cancer SL. Acetaldehyde and formaldehyde have similar carcinogenic effects in animal studies, and their cancer risks are summed together. The cancer risk associated with each contaminant is described below for a 33-year exposure, which is the 95th percentile for the length of time a person resides in a specific property over a lifetime [ATSDR 2016].

Acetaldehyde

In all, 23 of 35 acetaldehyde 24-hour samples (66%) exceeded the CREG (0.45 µg/m^3). The UCL of the 24-hour concentrations while PTPC was in operation (0.68 µg/m^3) results in an additional cancer risk of 6.3 x 10^{-7} or less than 1 additional case per 1,000,000 individuals.

Formaldehyde

All 30 formaldehyde 24-hour samples (100%) exceeded the CREG (0.077 µg/m^3). The UCL of the 24-hour concentrations while PTPC was in operation (1.9 µg/m^3) results in an additional cancer risk of 1.0 x 10^{-5} or roughly 10 additional cases per 1,000,000 individuals.

The combined estimated additional cancer risk due to exposure of acetaldehyde and formaldehyde is roughly 11 additional cases per 1,000,000 individuals. This risk is low and would be reduced with less than 33 years of continuous exposure at the site.

Data Trends and HEM-4 Comparison

During the EI, the PTPC shut down for one week, and ATSDR was able to compare the measured concentrations while the facility was in operation to that when the facility was shut down. The concentrations of all aldehydes were significantly higher when PTPC is in operation, which shows PTPC is a source for some of the aldehydes measured in air. See Figures 5-7.

The HEM-4 model predicted means for all the measured aldehydes were lower than the measured mean. This difference was largest for formaldehyde, the only chemical where the measured mean was more than ten times higher than that predicted by the HEM-4 model. This is evidence that, for formaldehyde, there is a possibility that either the emission estimates in the HEM-4 model are not accurate, or there are other contributing sources not accounted for in the model.

Hydrogen Sulfide

Hydrogen sulfide is a gas released from both natural and anthropogenic sources and known for its rotten egg odor. Some industrial sources include sewage treatment facilities, manure-handling operations, pulp and paper mills such as PTPC, petroleum refineries, and food processing plants [ATSDR 2006]. Steel mills and cement manufacturing facilities can have operations (e.g., wastewater treatment) known to release hydrogen sulfide. Outdoor air concentrations of hydrogen sulfide from natural sources are estimated in the range of 0.11–0.33 ppb, while concentrations in urban areas are often greater than 1 ppb [ATSDR 2006]. These outdoor concentrations have no documented health effects. Reduced sulfur compounds were predicted to exceed SLs in previous models based on self-reported emissions from PTPC.

Noncancer Health Effects- Exposure to hydrogen sulfide can have a range of respiratory and neurological effects. ATSDR has an acute minimal risk level (MRL) of 70 ppb and an intermediate MRL of 20 ppb (See Table 2 and Figure 5). The EPA reference concentration (RfC) for hydrogen sulfide is 1.4 ppb. Hydrogen sulfide has not been shown to cause cancer in humans and is not currently classified as a carcinogen [ATSDR 2006]. The EPA, in its most recent cancer assessment, determined that available data are inadequate to assess the carcinogenic potential of hydrogen sulfide [EPA 2003]. Neither NTP nor IARC have classified carcinogenicity of hydrogen sulfide.

In the present EI, hydrogen sulfide was measured using two separate methods. In the first method it was measured alone (SPM) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). See Appendix D for specific details on the sampling methods used for hydrogen sulfide. Hydrogen sulfide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the SPM instrument. The maximum from the MEDOR measurements was used to assess acute exposures. The 95% UCL from the SPM measurements was used to assess intermediate and chronic exposures. Due to hydrogen sulfide rarely being detected when measured using the MEDOR instrument, a 95% UCL could not be calculated using this method.

Acute Exposures

When measured by SPM, only one of the 24,854 thirty-minute samples collected across 8 sites (maximum 72.3 ppb) exceeded the acute SL (70 ppb) (See Figure 8). With the MEDOR, the maximum hydrogen sulfide 20-min concentration was 490 ppb (See Figure 12). The acute SL was exceeded using both methods (HQ is greater than 1; see Table 5). ATSDR assessed acute exposure based on the highest measured concentration but notes that hydrogen sulfide was rarely detected, and the majority of samples were below the acute SL. ATSDR's acute SL for hydrogen sulfide is based on health effects (i.e., headache and changes in respiratory tests suggesting bronchial obstruction) reported in some persons with asthma exposed to 2,000 ppb for 30 minutes [Jappinen et al. 1990]. The highest concentration measured is roughly 4 times lower than any effect level documented in literature.

Intermediate Exposures

The UCLs of the 30-min averaged samples over the duration of the EI for each site were all below the ATSDR intermediate MRL (20 ppb) (See Figure 5). The highest UCL was 3 ppb at Site 2 during plant operation.

Chronic Exposures

When measured by SPM, the UCLs at 3 of the 8 sites (Sites 1, 2, and 8) were above the chronic EPA RfC (HQ is greater than 1; See Table 5). The highest UCL (3 ppb) was measured at Site 2. The EPA RfC is based on a subchronic study that found no adverse effects in rats exposed to 10,000 ppb. EPA calculated a human equivalent lowest observable effect level of 1400 ppb from the data. The highest UCL measured near PTPC was nearly 500 times lower than the lowest effect level used to derive the chronic SL. Thus, ATSDR does not expect noncancer effects from exposure to hydrogen sulfide near PTPC.

ATSDR notes that when hydrogen sulfide exceeds its odor threshold (0.5 ppb) [ATSDR 2016c], people may experience odor-related health symptoms such as headaches, nausea, and stress or annoyance. See Appendix E for a more detailed discussion of odor-related effects.

Data Trends and HEM-4 Comparison

Across all sites, higher concentrations of hydrogen sulfide were measured during operation of PTPC, but only sites 1, 4, and 8 were significantly different. Sites 1, 2, and 8 had the highest measured concentrations of hydrogen sulfide. Of these, Sites 1 and 2 border PTPC and have polar plots that show higher concentrations when the wind is from the direction of PTPC (See Appendix D). Sites 1 and 2 were also predicted to have the higher concentrations of sulfur compounds in modeling conducted prior to the EI and in the HEM-4 model based on emissions during the EI (Appendix B and D respectively). The higher concentrations measured during the operation of PTPC suggests PTPC is a source for some of the hydrogen sulfide measured in air at these sites.

Particulate Matter (PM)

PM is a term used in air quality that refers to particles suspended in air. PM comes from industrial, manmade, and natural sources. PM_{10} is primarily produced by mechanical processes such as construction activities, road dust resuspension and wind. $PM_{2.5}$ originates primarily from combustion sources—like wood smoke, motor vehicle exhaust, and emissions from power plants—and certain industrial processes [EPA 2009]. The size of particles is directly linked to their potential for causing health problems [EPA 2006]. PM_{10} can pass through the throat and nose to enter the lungs. $PM_{2.5}$ can penetrate deeper into the lungs and lead to higher toxicity [EPA 2006]. PM_{10} and $PM_{2.5}$ were predicted to exceed SLs in previous modeling based on self-reported emissions from PTPC. Since the SLs for PM are based on several studies documenting a variety of respiratory and cardiovascular effects, ATSDR uses the AQI (not the HQs seen in Table 5) to evaluate health effects of PM.

Noncancer Health Effects- Exposure to PM_{10} and $PM_{2.5}$ can have both short-and long-term effects on cardiopulmonary function, morbidity, and mortality. People with heart or lung disease, older adults, children, and people of lower socioeconomic status are most susceptible to adverse health effects from PM [EPA 2018]. Numerous scientific studies have linked particle pollution exposure to the following [EPA 2019; WHO 2013]:

- increased likelihood of illness and death due to respiratory and/or cardiovascular disease
- cardiovascular effects (ischemic heart disease, cerebrovascular disease, and heart failure systemic inflammation, alteration of biomarkers for cardiovascular disease)
- respiratory effects (including aggravated asthma, decreased lung function, and symptoms such as coughing) and infections
- diabetes

- impaired neurological development in children and “brain aging” and neurological disorders in adults

ATSDR screened PM concentrations using the World Health Organization’s (WHO’s) air quality guidelines (AQGs) for PM_{10} and $PM_{2.5}$ [WHO 2021; ATSDR 2020](See Table 2):

PM_{10}: The WHO annual average AQG is 15 µg/m^3 and the 24-hour AQG is 45 µg/m^3.

$PM_{2.5}$: The WHO annual average AQG is 5 µg/m^3 and the 24-hour AQG is 15 µg/m^3.

Although WHO acknowledges that $PM_{2.5}$ is a better indicator of long-term health effects than PM_{10}, they maintained an annual PM_{10} AQG of 15 µg/m^3 to protect against the harmful effects of coarse particle ($PM_{2.5}$-PM_{10}) exposures [WHO 2021]. WHO considers the quantitative evidence insufficient to derive a PM_{10} guideline from chronic studies. There are no cancer risk guidelines for PM.

Acute Exposures

During the EI, some of the 24-hour concentrations of both $PM_{2.5}$ and PM_{10} exceeded the WHO AQGs (See Figures 9 and 10). Of the 216 $PM_{2.5}$ measurements collected during the EI, 20 (9.3%) of the 24 -hour samples exceeded the WHO 24-hour AQG (15 ug/m^3) (See Figure 9). The highest $PM_{2.5}$ 24-hour concentration measured was 34.7 µg/m^3, and forty-four of 216 days (20%) were categorized as *moderate* by the AQI. The other 80% of days were categorized as *good* by the AQI (See Table 3).

Of the 245 PM_{10} measurements collected during the EI, only one (0.4%) PM_{10} 24-hour sample exceeded the WHO 24-hour AQG (45 µg/m^3) (See Figure 10). For PM_{10}, only the highest day measured at Site 1 (66.1 µg/m^3) day was categorized as *moderate* by the AQI, and all others were designated as *good* (See Table 3).

EPA describes days when chemical concentrations reach the *moderate* category as having the potential to cause respiratory symptoms in unusually sensitive individuals and possible aggravation of heart or lung disease in people with cardiopulmonary disease and older adults. EPA cautions that on days with *moderate* air quality, unusually sensitive people should consider reducing prolonged or heavy exertion. Sensitive individuals include people with heart or lung disease, older adults, children, and people of lower socioeconomic status. See Appendix C for EPA statements for each category of the AQI.

Chronic Exposures

Generally, there is evidence for an association between long-term exposure to $PM_{2.5}$ and mortality (i.e., all-cause and cardiovascular) with mean concentrations of 10–32 µg/m^3 [EPA 2012]. Studies provide evidence for respiratory symptoms and incident asthma, as well as respiratory hospitalizations, from chronic exposures to $PM_{2.5}$ concentrations ranging from 9.7–27 µg/m^3 [EPA 2012].

$PM_{2.5}$ was measured at Sites 2-4, and the annual AQG (5 µg/m^3) was exceeded at each site (See Figure 10). The 95 UCL of the mean concentration of $PM_{2.5}$ ranged from 9.57–12.8 µg/m^3, and reached levels associated with an increased potential for adverse health effects in sensitive individuals.

PM_{10} was measured at sites 1-3, and the annual AQG (15 µg/m^3) was exceeded at Sites 2 and 3 (See Figure 9). The 95 UCLs of PM_{10} concentrations ranged from 13–19.8 µg/m^3 and reached levels associated with an increased potential for adverse health effects in sensitive individuals. Thus, ATSDR concludes that exposure to the average concentrations of PM_{10} and $PM_{2.5}$ near PTPC are not expected to be associated with adverse health effects for the general public but cannot exclude the possibility of respiratory and cardiopulmonary symptoms in sensitive groups.

Data Trends and HEM-4 Comparison

During the EI, the PTPC shut down for 1 week, and ATSDR was able to compare the measured concentrations while the facility was in operation to those when the facility was shut down. Slightly higher concentrations of PM where measured while PTPC was in operation, but overall, they were not statistically different from that when the facility was shut down, which shows that the operation of the PTPC was not a major contributor to the PM concentrations in air.

The HEM-4 model predicted means for PM at all sites were lower than the measured means. The measured mean was roughly ten times higher than the HEM-4 model at each site. This is evidence that there may be contributing sources of PM that were not included in the HEM-4 model.

Sulfur Dioxide

Sulfur dioxide is a gas formed when fuels containing sulfur (e.g., coal) are burned, when metal is smelted, and when other industrial processes occur. An EPA review of 1-hour sulfur dioxide samples from air monitors both inside and outside consolidated metropolitan statistical areas (CMSAs) found an average concentration of 4 ppb for both datasets. The highest values found were 714 ppb inside CMSAs and 636 ppb outside CMSAs [EPA 2008c]. ATSDR notes that outdoor air data are mentioned to put background concentrations into perspective for the reader—not to imply the acceptability of the levels from a public health perspective. Neither NTP, EPA, nor IARC have classified sulfur dioxide as a carcinogen. Sulfur dioxide was predicted to exceed SLs in previous modeling based on self-reported emissions from PTPC.

Noncancer Health Effects- ATSDR has an acute MRL for sulfur dioxide (10 ppb) based on a study that observed respiratory effects in humans exposed to 100 ppb for as little as 10 minutes. When possible, sulfur dioxide concentrations measured in Port Townsend were averaged at 10-minute intervals to capture higher levels of shorter duration that are comparable to the basis of the MRL. There is no chronic or intermediate SL for sulfur dioxide, and only acute effects are discussed.

In the present EI, sulfur dioxide was measured at one site using two separate methods. In the first method, it was measured alone (Thermo) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). See Appendix D for specific details on the sampling methods used for sulfur dioxide. Sulfur dioxide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the Thermo instrument. The maximum from the MEDOR measurements was used to assess acute exposures. Sulfur dioxide does not have any SLs for intermediate or chronic exposures.

EPA's air quality index (AQI) online tool, "AIRNow AQI Calculator" was used to estimate the potential for health effects from short-term exposure to sulfur dioxide. The AQI estimates effects from 1-hour and 24-hour exposures. ATSDR calculated one-hour average concentrations by averaging sequential 10- or 20-minute samples collected over an hour. The UCL of the 1-hour data was assessed with the 24-hour AQI. The AQI categorizes air concentrations into six categories: *good*, *moderate, unhealthy for sensitive groups, unhealthy, very unhealthy*, and *hazardous*. For specific AQI categories and health statements see Appendix C, Table C1.

Acute Exposures

The maximum sulfur dioxide 10-minute concentration was 15.6 ppb when measured with the Thermo instrument, but when measured by MEDOR, the maximum 20-min concentration was 739 ppb (See Table 5). The acute SL was exceeded using both methods of sampling (HQ is greater than 1; See Table 5). The odor threshold of sulfur dioxide is 470 ppb [Leonardos et al. 1962].

Although a 20-minute sample duration is not appropriate for comparison with the 1-hour AQI, several studies have shown that the highest concentration of sulfur dioxide measured (739 ppb) can cause respiratory effects (increased airway resistance) in humans in as little as 10 minutes [ATSDR 1998].

From the MEDOR data, ATSDR averaged the 20-min sulfur dioxide concentrations to 1 hour and 24 hours for direct comparison to the AQI. 1551 of 1563 (99.2%) 1-hour averaged samples were designated as *good* by the AQI. 9 of the 1-hour averages were designated as *moderate*, 1 as *unhealthy for sensitive groups*, and 2 as *unhealthy* (for the general population). All 24-hour averaged concentrations were designated as *good* by the AQI.

On days designated as *good* by the AQI, air quality is satisfactory, and air pollution poses little or no risk. On *moderate* days, air quality is acceptable. However, there may be a risk of adverse health effects for some people, particularly those who are unusually sensitive to air pollution. The *unhealthy* category suggests some members of the general public may experience health effects and members of sensitive groups (children, people with asthma, or other lung diseases) may experience more serious health effects. At unhealthy levels, sensitive individuals should limit outdoor exertion.

When measured with the Thermo instrument, 28 of 4148 10-minute samples (0.7%) exceeded the ATSDR acute MRL (10 ppb). The maximum 10-minute average concentration of sulfur dioxide (15.6 ppb) was more than 6 times lower than that which caused health effects in literature. All of the 1-hour concentrations averaged from the Thermo data were designated as *good* by the EPA AQI calculator.

Based on the concentration measured during the EI, ATSDR concludes that sulfur dioxide may infrequently reach levels that can cause acute respiratory effects.

Data Trends and HEM-4 Comparison

The mean sulfur dioxide concentration while in operation and shutdown were 2.11 and 2.2, respectively, when measured using the Thermo instrument but were 3.56 and 1.80 ppb, respectively, when measured with the MEDOR. Concentrations of sulfur dioxide during operation and shutdown were similar when measured using Thermo but were significantly different when measured with the MEDOR.

Reduced Sulfur Compounds

Reduced sulfur compounds were predicted to exceed SLs in previous modeling based on self-reported emissions from PTPC. Based on a review of odor complaints and previous modeling of PTPC emissions, ATSDR collected outdoor air measurements for several sulfur containing compounds with a strong unpleasant odor of rotting cabbage [ATSDR 1992; EPA 2005]. Sulfur containing compounds were measured with the MEDOR instrument, which measures a range of sulfides simultaneously and continuously. This type of sampling has not been regularly implemented in ATSDR EIs, and the results were compared to the separate measurement of hydrogen sulfide and sulfur dioxide by standardized EPA methods (SPM and Thermo, respectively). Hydrogen sulfide and sulfur dioxide concentrations measured by both methods have been separately described above.

Natural sources of sulfur containing compounds include vegetation, animal waste, microbial degradation, crude oils containing sulfur, and the "sour" natural gas of West Texas [ATSDR 1992; EPA 2005]. Industrial sources include wood pulp, oil shale, petroleum processing plants, and sewage treatment plants [ATSDR, 1992]. The following sulfur compounds were measured at Site 2: 2-butyl mercaptan, diethyl sulfide, dimethyl disulfide, dimethyl sulfide, ethyl mercaptan, ethyl methyl sulfide, hydrogen sulfide, isobutyl mercaptan, isopropyl mercaptan, methyl mercaptan, n-butyl mercaptan, n-propyl mercaptan, sulfur dioxide, tert-butylthiol, and tetrahydrothiophene. Hydrogen sulfide and sulfur dioxide are discussed individually above in their chemical specific sections.

Of the sulfur compounds measured, dimethyl disulfide, dimethyl sulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide had SLs. Of these contaminants hydrogen sulfide and sulfur dioxide effects have been extensively documented in literature, but much less is understood of the other contaminants. ATSDR screened dimethyl disulfide, dimethyl sulfide, and methyl mercaptan with the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) Short Term Exposure Limits (STELs) for each contaminant ACGIH TLV®–STELs are occupational standards that were used in the absence of other SLs but are not necessarily protective of community exposures. The ACGIH TLV®–STELs for these chemicals are based on the contaminants' strong odor and not on the occurrence of adverse health effects in literature.

Dimethyl disulfide, hydrogen sulfide, and sulfur dioxide were measured above their SLs (The HQs were greater than 1; See Table 5). From the time plot of the sulfur compounds (Figure 12), the contaminant concentrations are positively correlated to one another. None of the sulfur compounds measured have been associated with increased risk of cancer. Most of the sulfur compounds were rarely detected and a UCL could not be calculated. ATSDR used the maximum concentration of each of the sulfur compounds to assess acute exposures.

Acute Exposures

Several epidemiological studies were conducted on workers in the paper pulp industry and populations located near pulp mills. Exposure was to a mixture of sulfur compounds, including dimethyl sulfide, hydrogen sulfide, methyl mercaptan, dimethyl disulfide, and sulfur dioxide. Effects attributed to exposure to the mixture of sulfur compounds were headaches in workers, altered heme synthesis and iron metabolism in workers, and eye and respiratory symptoms in residents of communities located near the paper pulp mills [EPA 2005]. Specific concentrations of exposure in these studies were not well defined, but studies have shown that methyl mercaptan is more toxic than dimethyl disulfide followed by dimethyl sulfide.

Dimethyl disulfide (DMDS) is a ubiquitous natural product, common in the global sulfur cycle, and is detected as a metabolite in numerous biological processes including the oxidation of methyl mercaptan. DMDS is not only malodorous but can also be toxic. It exerts a complex mode of action through mitochondria dysfunction and activation of potassium channels and greatly inhibits the cytochrome oxidase [Fritsch, 2005]. The ACGIH TLV®–STEL for DMDS is 500 ppb. During operation, the maximum concentration of DMDS measured was 4390 ppb; it was detected in 358 samples (9.5%), and 17 of those exceeded the SL. During the shutdown, it was detected in 56 samples (8.6%); the maximum concentration measured (48 ppb) was below the SL. DMDS has an odor threshold of approximately 7 ppb [Florida 2014].

In comparative studies examining lethality in animals, methyl mercaptan was shown to be 10-100 times more toxic than DMDS [EPA 2005]. Methyl mercaptan concentrations were compared to the ACGIH TLV®–STEL of 500 ppb. During operation, the maximum concentration measured was 34.5 ppb; it was detected in 212 samples (5.7%). During the shutdown, the maximum concentration measured was 3.7 ppb; it was detected in 8 samples (1.2%). The odor threshold of methyl mercaptan is 2.1 ppb [Leonardos et al. 1962].

Dimethyl sulfide concentrations were compared the ACGIH TLV®–STEL of 10,000 ppb. During operation, the maximum concentration measured was 444 ppb; it was detected in 505 samples (13.6%. During the shutdown, the maximum concentration measured was 22.4 ppb; it was detected in 75 samples (11.5%). The odor threshold of dimethyl sulfide is 1 ppb [Leonardos et al. 1962].

The measurement of sulfur compounds using the MEDOR is a novel method used in ATSDR EIs. ATSDR considers measurement of the sulfur compounds in the present EI as complementary to the individual measurement of hydrogen sulfide and sulfur dioxide. Measurement of the range of sulfur compounds shows the presence of reduced sulfur compounds in Port Townsend air that would not be captured with sampling for hydrogen sulfide and/or sulfur dioxide alone. Together these sulfur compounds can have a combined adverse effect that is greater than that of the individual contaminants. In addition, these compounds are positively correlated and can simultaneously reach concentrations that result in acute respiratory effects.

Data Trends and HEM-4 Comparison

During the EI, the PTPC shut down for 1 week, and ATSDR was able to compare the measured concentrations while the facility was in operation to that when the facility was shut down. Maximum concentrations of dimethyl disulfide, dimethyl sulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide were roughly 10-100 times higher when PTPC was in operation than during the shutdown. This is evidence that shows that the operation of the facility was a major contributor to the concentration of the sulfur compounds in air. Sites 1 and 2, which border PTPC, were predicted to have higher sulfur 1-hour acute exposures in modeling conducted prior to the EI and in the HEM-4 model based on emissions during the EI (Appendix B and D respectively).

Health Effects from Exposure to Mixtures of Contaminants

To consider the effect of exposures to chemical mixtures, ATSDR reviewed the health effects of the individual chemicals to determine if the combination of the measured contaminants could cause any additional adverse effect. The agency's noncancer *quantitative* approach, called the hazard index (HI) approach (described in Section 3.3), evaluated the chemicals in the mixture by assuming they had an additive toxic effect.

Due to the strong odors in the community and some compounds exceeding SLs, HIs were calculated for both acute and chronic effects. The acute and chronic HQs of the individual contaminants and the resulting HIs are in Tables 5. Hydrogen sulfide, sulfur dioxide, and dimethyl disulfide exceeded acute SLs (all had HQs greater than 1) with an acute HI of 90. Only hydrogen sulfide exceeded its chronic SL resulting in a chronic HI of 1.8 (See Table 5).

Acute Exposures

In the acute mixtures assessment, the HI is dominated by sulfur dioxide with an HQ of 74 (see Table 5). The concentrations of sulfur compounds were positively correlated; thus, it is likely that higher concentrations of each of the contaminants could occur at the same time resulting in an increased potential for adverse health effects. These contaminants were detected in approximately 4-18% of samples, and together can contribute to acute respiratory symptoms and odor-related health effects.

Chronic Exposures

Chronic HQs are only determined for contaminants with enough samples above the detection limit to statistically calculate a UCL. A UCL could not be calculated for most of the sulfur compounds measured by the MEDOR. Of these contaminants only hydrogen sulfide had a HQ greater than 1. The HI of the mixture (1.8) was dominated by hydrogen sulfide, which had a chronic HQ of 1.5 (See Table 5). Exposure to the mixture of these contaminants will not result in a significant increase in the likelihood of chronic respiratory effects. See the hydrogen sulfide chronic exposure section above.

Data Trends

The MEDOR method in this assessment was less sensitive than SPM and Thermo methods for hydrogen sulfide and sulfur dioxide respectively but captures more extreme values. MEDOR data supports the complaints of environmental odors from the community and shows that the odors are not only related to hydrogen sulfide, but also to other sulfur containing contaminants in air.

Although PM concentrations are not correlated to sulfur compounds, elevated levels of PM could also exacerbate acute and chronic respiratory symptoms on days with higher concentrations of hydrogen sulfide and other sulfur compounds.

Environmental Odors

Odor complaints have been recorded by ECY and PTPC in the Port Townsend area since 2007. ATSDR reviewed nearly two-thousand odor complaints associated with PTPC made by community members between 2016 and 2021 [WDH 2021]. During the year of the EI, 2018, 680 complaints were recorded (13 per week average). PTPC shut down the last week in October for maintenance. The shutdown partially covered 2 weeks (Monday-Sunday). The two weeks before the PTPC shutdown there were 28 complaints, in the two weeks affected by the shutdown there was 1 complaint, and the two weeks following the shutdown there were 16 complaints. The reduced number of complaints in the weeks affected by the PTPC shutdown suggests that the odors in the community are related to the operations at PTPC.

From the present data, dimethyl disulfide, dimethyl sulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide were all measured above their odor threshold but were not detected consistently in every sample (See Table 4). These sulfur containing compounds can all cause pungent odors like hydrogen sulfide (rotten egg, decaying garbage etc.), but to varying degrees. There are also other chemicals not measured that can cause similar odors.

From the SPM monitors, hydrogen sulfide was measured above its odor threshold in at least 36% of samples at one site. Since the odor threshold is below the detection limit of the sampling method, the true number of samples above the odor threshold is unknown. These odors can be caused by other chemicals in the air including those mentioned above.

People can smell some sulfur compounds well before they reach a concentration that might cause a toxic effect. Thus, the perception of offensive odor does not necessarily mean there is a toxic threat to people’s health. However, offensive odors can quickly become a nuisance and may be the direct cause of some health symptoms even in concentrations below levels of toxicity [Schiffman and Williams 2005]. See Appendix E on Environmental Odors.

5.3 Evaluation of Health Outcome Data

As part of the public health evaluation process, ATSDR reviewed available, relevant health outcome data for indications of increased illness in the Port Townsend area. ATSDR specifically tried to identify potential health issues in and around Port Townsend that could be related to the measured contaminants in air.

ATSDR analyzed health outcome data from the Washington State Department of Health's Washington Tracking Network (WTN). The WTN is a public website, developed by the Washington State Department of Health, where users can find data and information about environmental health hazards, population characteristics, and health outcomes. Health statistics on asthma hospitalizations from (2000-2018) were available from the WTN for the state of Washington, Jefferson County, and the zip code 98368, all of which contain the city of Port Townsend. All data from the WTN are adjusted for age but not for race or socioeconomic status.

Although these data from the WTN supports an overall understanding of the health status in the community, they cannot provide any information on the cause of the health outcomes. Asthma hospitalization is the only health outcome in the WTN that has been associated with some of the measured contaminants and environmental odors. Asthma can be associated with various other factors that can occur over a person's lifetime, and ATSDR cannot determine if the specific concentrations measured were the cause any specific health outcome. The asthma hospitalizations for the zip code 98368 were not statistically different from that of Jefferson County or the state of Washington.

5.4 Summary of Limitations and Uncertainty

- The EI was conducted over a 10-week period and may not be representative of long-term exposure. ATSDR attempted to sample during the worst conditions (based on previous data from modeling), and the ten weeks of data were used as a protective estimate of community exposures throughout the year. ATSDR does note that this sampling strategy may result in elevated annual estimates of contaminant concentrations.
- During this EI, air samples were collected at fixed, stationary locations; however, people move around, and do not remain in one place all day long. Therefore, the data collected at the fixed locations are not directly equivalent to actual exposures that occurred.
- The MEDOR measurement of sulfur compounds, which consists of a range of sulfides measured continuously, has not been regularly implemented in ATSDR EIs. The results were less reliable for hydrogen sulfide and sulfur dioxide than when measured alone. Both contaminants were detected less frequently but had higher maximum concentrations when measured with the MEDOR instrument than when measured alone. The maximum from the MEDOR measurements was used to assess acute exposures, which could overestimate the potential for adverse effects.

6. Conclusions

Conclusion 1: Breathing sulfur compounds (sulfur dioxide, hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methyl mercaptan) in air near PTPC can potentially cause adverse acute respiratory effects. While exposure to the concentrations of the individual sulfur contaminants is not

likely to cause adverse effects, exposure to the mixture of contaminants may cause occasional acute respiratory effects. Sulfur compounds are associated with the environmental odors described in complaints from community members.

Basis for Conclusion: Of the sulfur compounds measured, dimethyl sulfide, dimethyl disulfide, hydrogen sulfide, methyl mercaptan, and sulfur dioxide were measured at levels that can cause offensive odors. All but methyl mercaptan and dimethyl sulfide exceeded acute health-based SLs. The concentrations of the sulfur compounds were positively correlated, meaning when one compound was found to be high, the others were likely to be high as well. When higher concentrations of each of the contaminants occur at the same time, there is an increased potential for adverse health effects. While the individual compounds had different rates of detection ranging from 4-18%, together they can contribute to acute respiratory symptoms and odor-related health effects.

ATSDR also analyzed local health data for evidence of an increase in in acute respiratory effects. Data were available for asthma hospitalizations from 2010 to 2020 in the state of Washington, Jefferson County, and the zip code 98368; all of which contain the city of Port Townsend and PTPC. The asthma hospitalizations for the zip code 98368 were not statistically different from that of Jefferson County or the state of Washington.

Conclusion 2: Higher concentrations of some contaminants and more reports of odors occurred when PTPC was in operation compared to when it was shut down.

Basis for Conclusion: Measured concentrations of aldehydes, sulfur dioxide, hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide were significantly higher during operation than during shutdown of PTPC. More odor complaints were made during the time immediately before the shutdown and after the facility restarted compared to during the shutdown.

Conclusion 3: Sulfur dioxide concentrations near PTPC rarely reached levels that can cause acute respiratory effects. Chronic exposure to sulfur dioxide is not expected to harm people's health.

Basis for Conclusion: In the present EI, sulfur dioxide was measured at one site using two separate methods. In the first method, it was measured alone (Thermo) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). Sulfur dioxide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the Thermo instrument.

The concentration of sulfur dioxide measured by both instruments was compared to EPA's Air Quality Index (AQI), which categorizes air quality based on the concentration of a contaminant. For the MEDOR, almost all 1-hour averaged samples (99.2%) and all 24-hour averaged samples were designated as *good* by the AQI. Similarly, all 10-minute averaged concentrations were designated as *good* by the AQI as measured by the Thermo instrument. There are no cautionary statements from the EPA on days when sulfur dioxide concentrations are in the *good* category.

Conclusion 4: Breathing hydrogen sulfide near PTPC is not expected to harm people's health. Hydrogen sulfide in outdoor air can cause environmental odors.

Basis for Conclusion: In the present EI, hydrogen sulfide was measured using two separate methods. In the first method, it was measured alone using a single point monitor (SPM) and, in the second, it was measured along with other sulfur containing compounds (MEDOR). Hydrogen sulfide was detected less frequently but had higher maximum concentrations with the MEDOR compared to the SPM instrument. A UCL could only be calculated using SPM data.

The highest hydrogen sulfide concentration measured was using the SPM was nearly thirty times lower than any effect level documented in literature. The highest hydrogen sulfide concentration measured was using the MEDOR was roughly 4 times lower than any effect level documented in literature. The UCLs at half of the sites just exceeded the chronic SL but were nearly 500 times lower than levels documented to cause adverse health effects.

ATSDR notes that when hydrogen sulfide exceeds its odor threshold (0.5 ppb) [ATSDR 2016c], people may experience odor-related health symptoms such as headaches, nausea, and stress or annoyance.

Conclusion 5: Breathing particulate matter (PM_{10} or $PM_{2.5}$) near PTPC is not expected to harm people's health, although on some days there is a potential for respiratory symptoms in unusually sensitive individuals with advanced heart or lung disease.

Basis for Conclusion: The AQI and the World Health Organization's (WHO) air quality guidelines (AQG) were used to evaluate exposures to $PM_{2.5}$ and PM_{10} at PTPC.

For $PM_{2.5}$, 9.3% of the 24-hour samples exceeded the WHO 24-hour AQG. Using EPA's AQI, 20% of the $PM_{2.5}$ 24-hour concentrations were categorized as *moderate* by the AQI. The other 80% of days were categorized as *good* by the AQI.

For PM_{10}, only one (0.4%) PM_{10} 24-hour sample exceeded the WHO 24-hour AQG and was categorized as *moderate* by the AQI, with all others designated as *good.*

When PM concentrations reach the *moderate* category, they have the potential to cause respiratory symptoms in unusually sensitive individuals and exacerbation of cardiopulmonary disease. On days with *moderate* air quality, unusually sensitive people should consider reducing prolonged or heavy exertion. Sensitive individuals include children, the elderly (≥65 years), and people with preexisting heart or lung disease. There are no cautionary statements from the EPA on days when PM concentrations are in the *good* category.

The UCLs of $PM_{2.5}$ and PM_{10} 24-hour concentrations exceeded the WHO annual AQGs. Prolonged exposures to PM above the AQGs may slightly increase the likelihood of harm for individuals with pre-existing health conditions, such as cardiopulmonary disease.

Conclusion 6: Breathing aldehydes near PTPC is not expected to harm people's health.

Basis for Conclusion: Three types of aldehydes were measured at one site: acetaldehyde, formaldehyde, and propionaldehyde. None of the 24-hour concentrations exceeded any of their respective noncancer SLs. The average combined exposure for measured aldehydes over a lifetime would result in an additional cancer risk of 11 cases per 1,000,000 individuals (1.1×10^{-5}). PTPC operations result in a low additional cancer risk. This cancer risk is dominated by formaldehyde.

7. Recommendations and Public Health Action Plan

Recommendations

- ECY should continue to monitor odor complaints.

- ECY and PTPC should make additional efforts to reduce environmental odors coming from PTPC that impact areas outside facility boundaries.
- ECY and PTPC may consider implementing a community-based outdoor air monitoring program to inform policy makers and community members of exposures in the area.
- Individuals sensitive to environmental odors should consider reducing their exposure. When environmental odors are strong, individuals can reduce exposure by limiting outdoor activities or leaving the area for a few hours if needed.
- Community members should report odors from the Port Townsend Paper Mill to Washington Department of Ecology's Environmental Engineer, Emily Toffol, via email (emily.toffol@ecy.wa.gov) or phone (360-790-8363). When reporting odors, please provide the following information: date, time, location, odor description, and any health impacts experienced.
- Learn more on Washington Department of Ecology's webpage for PTPC at https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Industrial-facilities-permits/Port-Townsend-Paper

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Appendix A: Brief Summary of ATSDR's Public Health Assessment (PHA) Process

The Agency for Toxic Substances and Disease Registry (ATSDR) follows the public health assessment (PHA) process to evaluate whether people living near a hazardous waste site are being exposed to toxic substances, whether that exposure is harmful, and what must be done to stop or reduce exposure.

The PHA process is a step-by-step approach during which ATSDR does the following:

- establishes communication mechanisms, including engaging communities at the beginning of site activities and involves them throughout the process to respond to their health concerns;
- collects many different kinds of site information;
- obtains, compiles, and evaluates the usability and quality of environmental and biological sampling data (and sometimes modeling data) to examine environmental contamination at a site;
- conducts four main, sequential scientific evaluations;
    - Exposure pathways evaluation- ATSDR identifies past, present, and future site-specific exposure situations, and categorize them as completed, potential, or eliminated;
    - Screening analysis- ATSDR compares the available sampling data to media-specific environmental screening levels (ATSDR comparison values and non-ATSDR screening levels). This identifies potential contaminants of concern that require further evaluation for completed and potential exposure pathways;
    - Exposure Point Concentrations (EPCs) and exposure calculations- When contaminants are flagged as requiring further evaluation in completed and potential exposure pathways, ATSDR calculates EPCs based on site-specific scenarios. The estimated EPCs are used in exposure calculations to determine if any of the site-specific exposure scenarios require an in-depth toxicological effects analysis;
    - In-depth toxicological effects evaluation- If necessary, based on the three previous scientific evaluations, ATSDR looks more closely at contaminant-specific information in the context of site exposures. This evaluation can also help determine if there is a potential for non-cancer or cancer health effects.
- summarizes findings and next steps, while acknowledging uncertainties and limitations.
- provides recommendations to site-related entities, partner agencies, and communities to prevent and minimize harmful exposures.

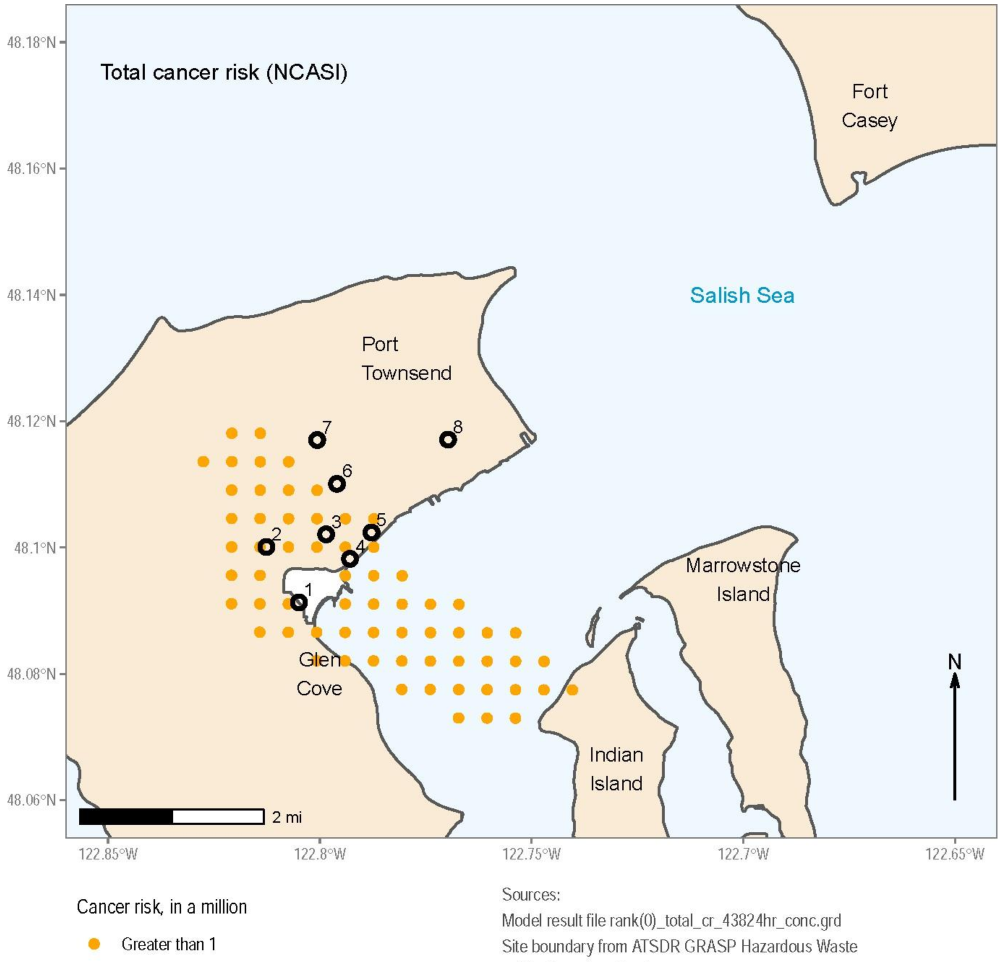
The sequence of steps can differ based on site-specific factors. For instance, health assessors might define an exposure unit before or after the screening analysis.

Readers can refer to ATSDR's Public Health Assessment Guidance Manual for all information related to the step-wise PHA process.

Appendix B. ATSDR 2017 Model Results in Relation to Exposure Investigation Monitor Sites

This appendix contains the modeling results from ATSDR's 2017 technical assistance document, which was used to predict the total cancer risk, and air concentrations of particulate matter, sulfur dioxide, and total reduced sulfur around PTPC (See figures B1-B5). These estimates were modeled using emission rate distribution and were used to determine site locations for sampling. The model incorporated meteorological data collected at PTPC (Figure B6). Total cancer risk was a sum of 3 compounds – formaldehyde, acetaldehyde, and hexavalent chromium.

Figure B1. CALPUFF Model Predicted Cancer Risk*†



Sources:
Model result file rank(0)_total_cr_43824hr_conc.grd
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Basemap from © OpenStreetMap contributors and https://osmdata.openstreetmap.de/

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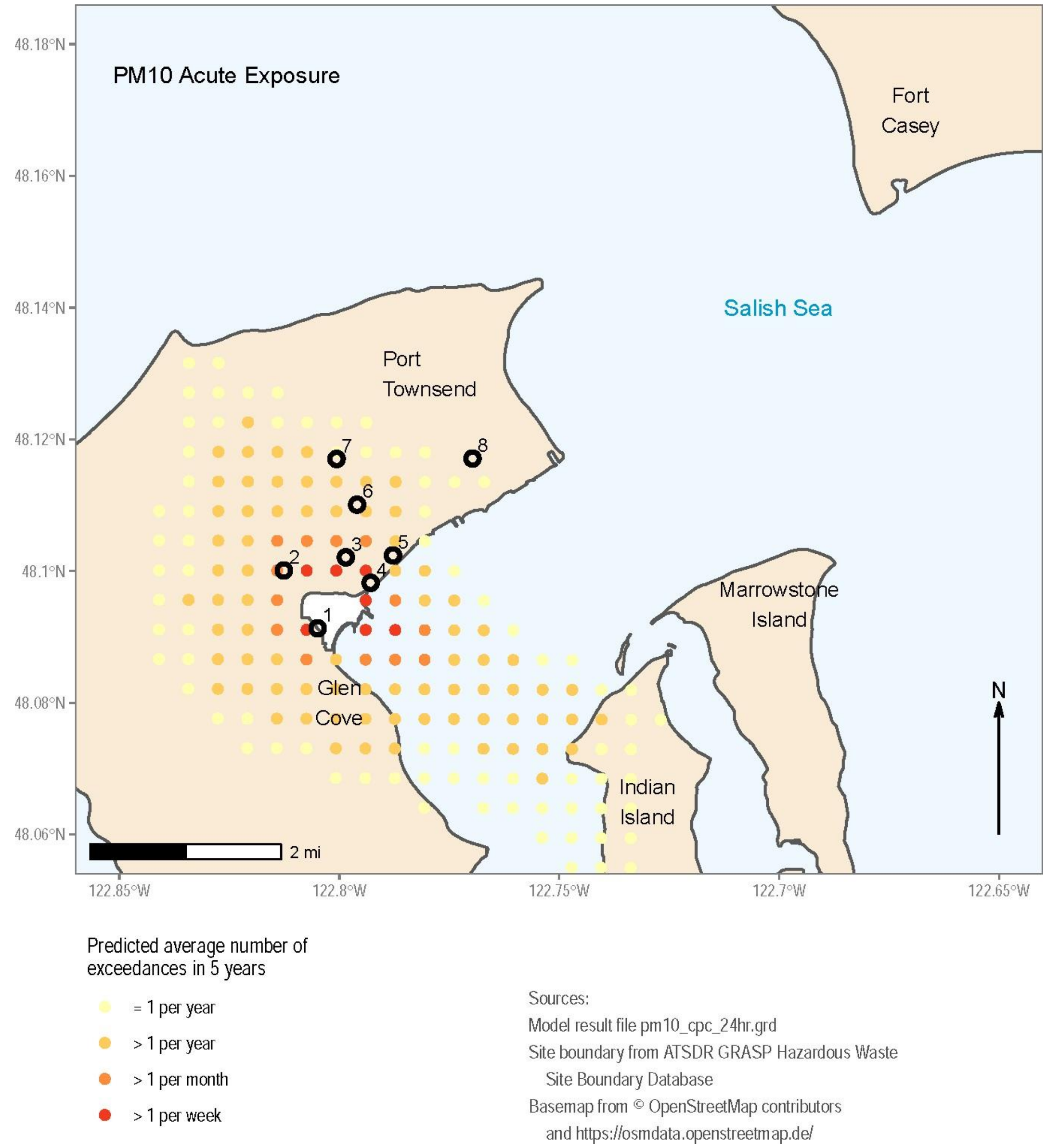
*Cancer Risk is calculated from emission factors from the National Council for Air and Stream Improvement (NCASI).

†The risk was based on three compounds: formaldehyde, aldehyde, and hexavalent chromium. The risk was dominated by aldehyde, and the total sum of the cancer risk was similar to that of aldehyde alone [ATSDR 2017].

Figure B2. CALPUFF Modeled PM_{10} Acute Exposure*†

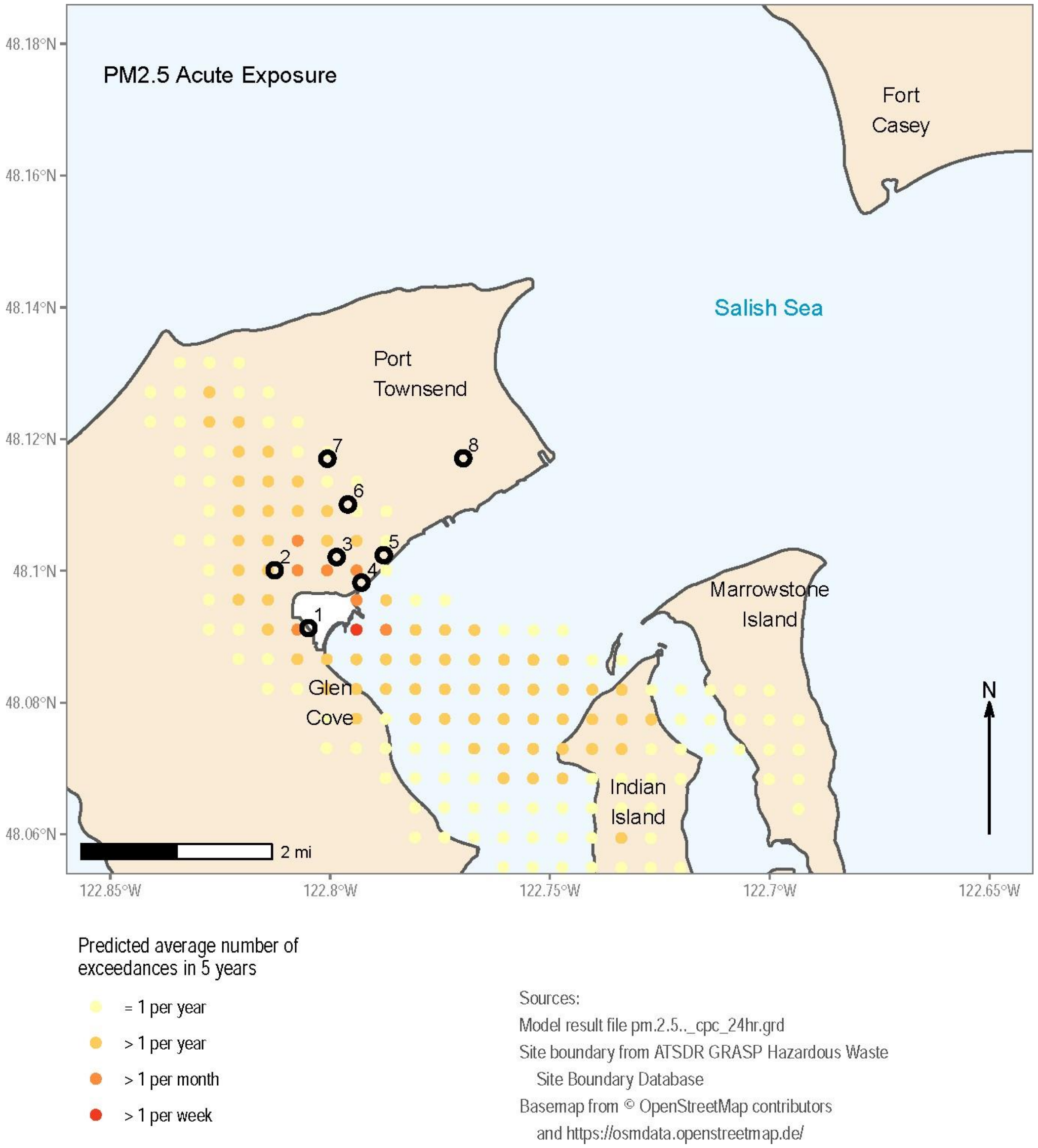


Sources:
Model result file pm10_cpc_24hr.grd
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Basemap from © OpenStreetMap contributors and https://osmdata.openstreetmap.de/

*PM10- particulate matter 10 micrometers or smaller

†Predicted number of 24-hour exceedances of acute screening level (the World Health Organizations air quality guideline of 20 µg/m³, which was current at the time of modeling) using emission rate distribution.

Figure B3. CALPUFF Modeled $PM_{2.5}$ Acute Exposure*†

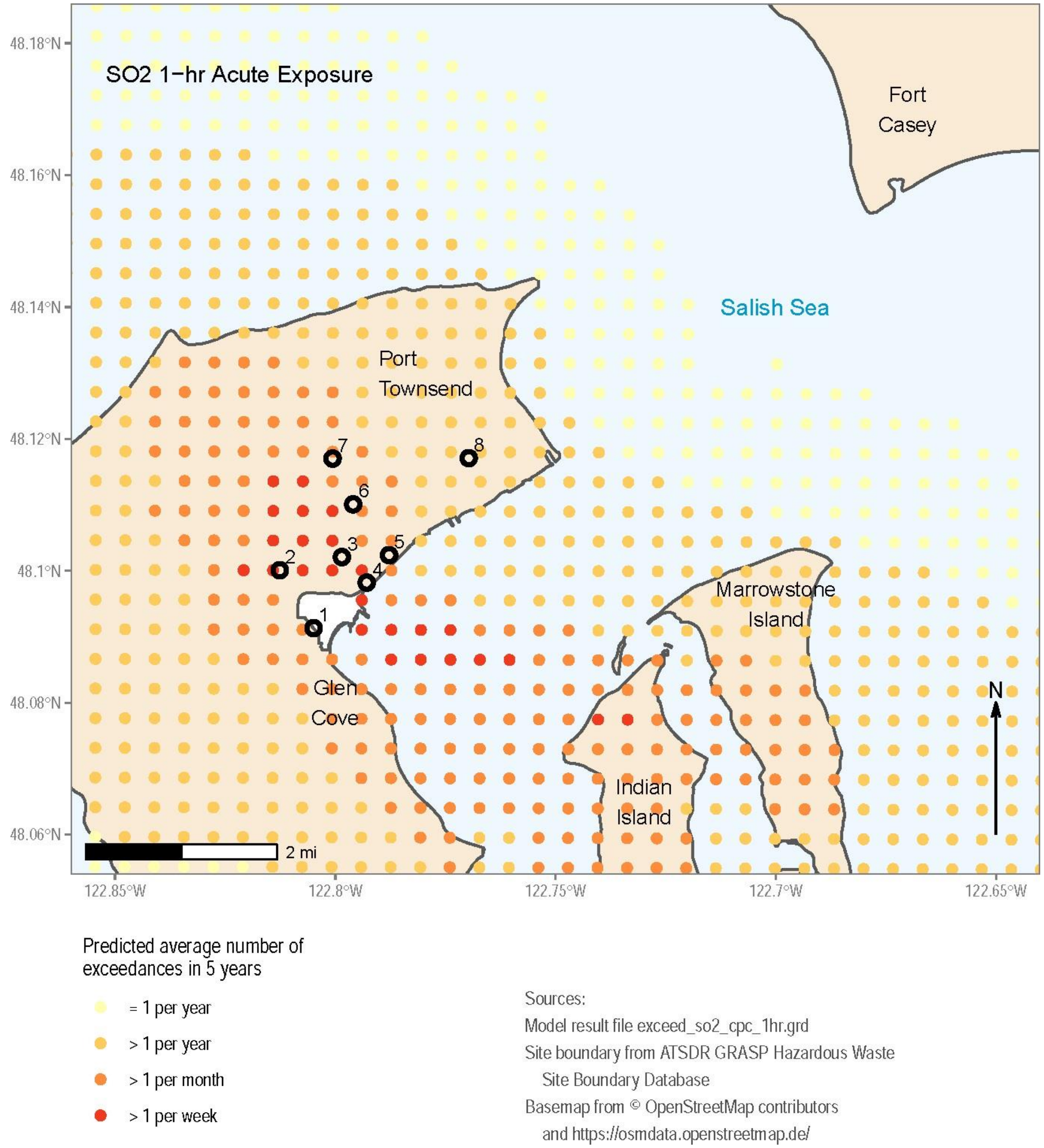


Sources:
Model result file pm.2.5.._cpc_24hr.grd
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Basemap from © OpenStreetMap contributors and https://osmdata.openstreetmap.de/

*PM2.5- particulate matter 2.5 micrometers or smaller

†Predicted number of 24-Hour exceedances of acute screening level (the World Health Organizations air quality guideline of 10 µg/m³, which was current at the time of modeling) using emission rate distribution

Figure B4. CALPUFF Modeled Sulfur Dioxide Acute Exposure*†

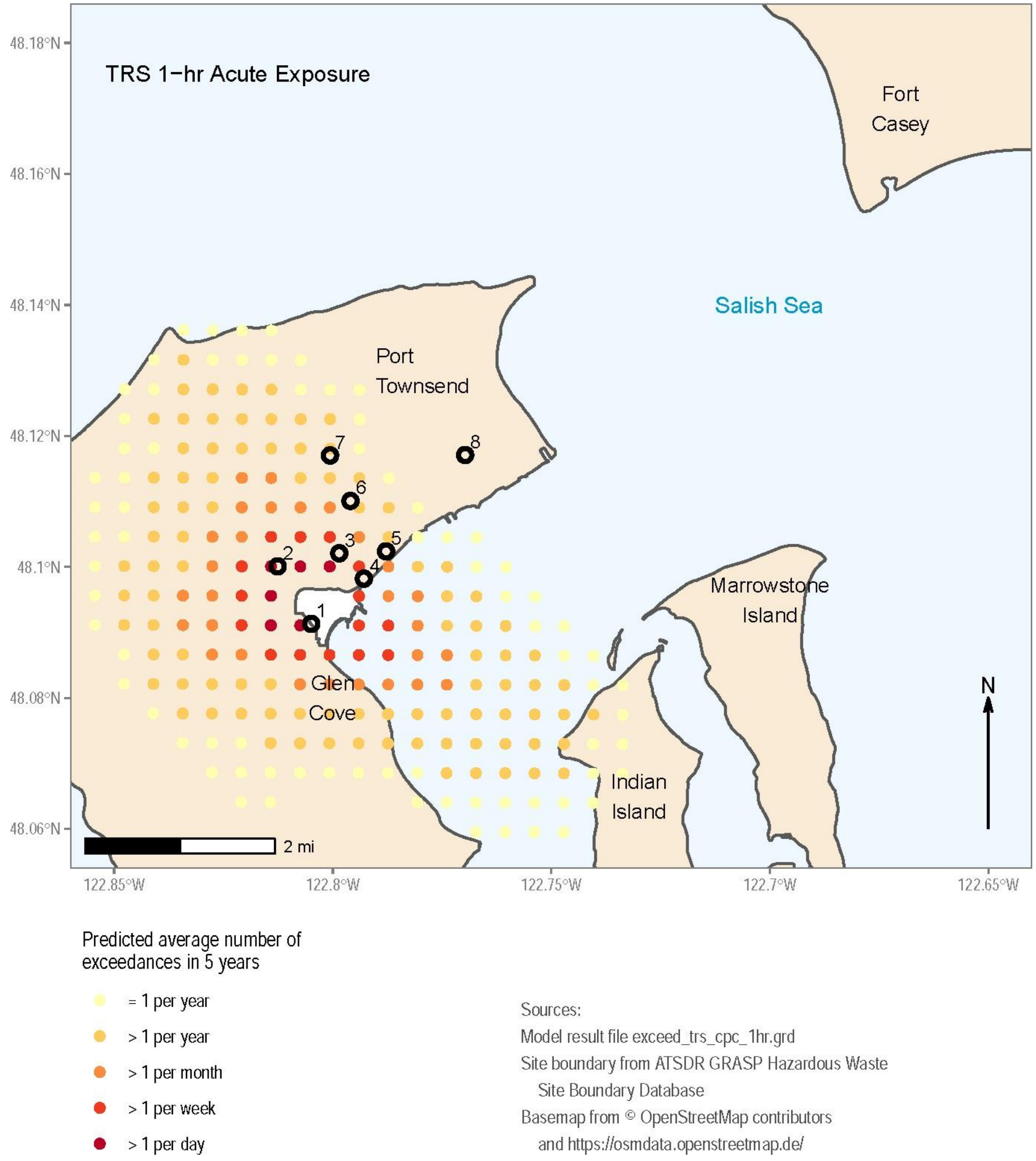


Sources:
Model result file exceed_so2_cpc_1hr.grd
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Basemap from © OpenStreetMap contributors and https://osmdata.openstreetmap.de/

*SO2- sulfur dioxide

†Predicted number of 1-hour exceedances of the acute screening level (the Agency for Toxic Substances and Disease Registry's acute minimal risk level of 26 µg/m^3) using emission rate distribution

Figure B5. Modeled Total Reduced Sulfur Compounds Acute Exposure*†



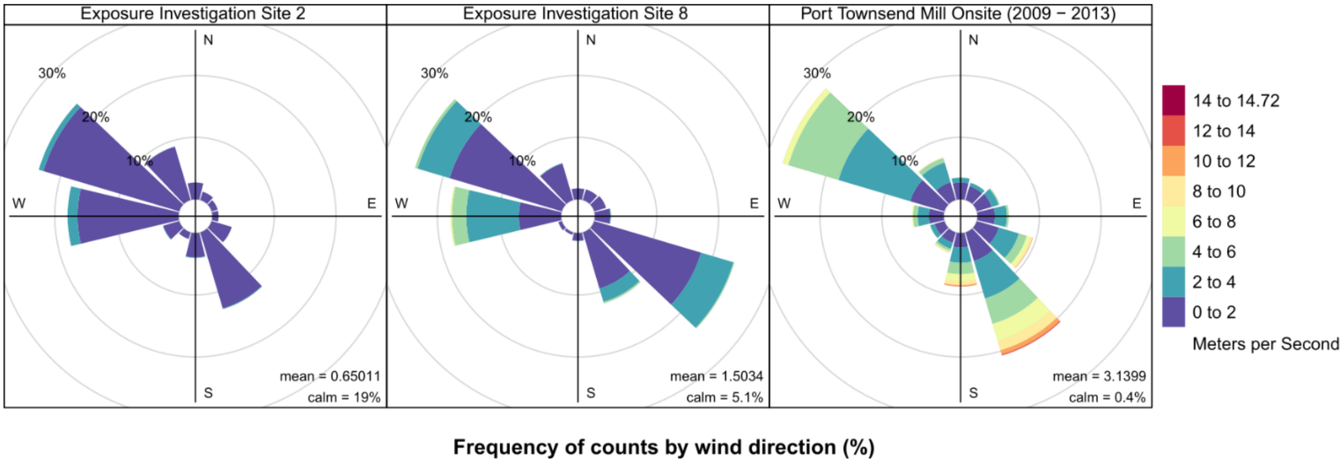
Sources:
Model result file exceed_trs_cpc_1hr.grd
Site boundary from ATSDR GRASP Hazardous Waste Site Boundary Database
Basemap from © OpenStreetMap contributors and https://osmdata.openstreetmap.de/

*TRS- total reduced sulfur

†Predicted number of 1-hour exceedances of the acute screening level (the Agency for Toxic Substances and Disease Registry's acute minimal risk level of 98 µg/m^3) using emission rate distribution

Meteorological towers were located at 2 sites during the EI. See Figure B6 below. The modeled estimates above incorporated data from a 2009-2013 that was developed using an onsite monitor at Port Townsend Paper Mill. ATSDR notes that the setting of the tower at PTPC is different than the EI meteorological towers. At PTPC the tower is much higher (10 m) and located on a dock, which may account for the higher wind speeds measured at PTPC. Wind direction was similar across the three sites.

Figure B6. Meteorological Data Collected Prior to and During the Exposure Investigation



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Appendix C. Screening Levels Used in the Exposure Investigation

The purpose of this appendix is to provide information about the comparison values (CVs) and screening levels (SLs) used for screening purposes in the EI. For further information on ATSDR's public health evaluation process and CVs, please refer to the ATSDR guidance manual available at https://www.atsdr.cdc.gov/pha-guidance [ATSDR 2022a].

SLs are intended to protect the general public from adverse health effects for specific durations of exposure. They are used to screen out contaminants that are measured at concentrations that are generally safe (below the SL). A concentration above the SL does not necessarily mean that an adverse effect will occur, but it is an indication that the specific contaminant should be further investigated and compared to the health effects and doses documented in scientific literature. ATSDR, in cooperation with the U.S. Environmental Protection Agency (U.S. EPA), has developed a priority list of hazardous substances found at hazardous waste sites, as directed under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendment and Reauthorization Act of 1986 (SARA). For those substances commonly found in the environment, ATSDR has prepared Toxicological Profiles that include an examination, summary, and interpretation of available toxicologic and epidemiologic data. Using those data, ATSDR has derived health and environmental guidelines called CVs. In the absence of ATSDR derived CVs, SLs from other health agencies may be recommended for screening measured contaminant concentrations. ATSDR's recommended CVs are listed in their Public Health Assessment Site Tool (PHAST) available online at https://csams.cdc.gov/PHAST/Home/Index [ATSDR2022b].

ATSDR Minimal Risk Levels (MRLs)

MRLs are substance-specific doses or concentrations derived using toxicologic information. Where adequate dose-response data exist, MRLs are derived for both the ingestion and inhalation routes of exposure. MRLs are derived for specific durations of exposure: Acute MRLs for exposures lasting 1-14 days; intermediate MRLs for exposures greater than 14 days but less than 1 year; and chronic MRLs for exposure greater than 1 year.

ACGIH Threshold Limit Values

Threshold Limit Values (TLV®)- Short-term exposure levels (STELs) and Biological Exposure Indices (BEIs®) are health-based values established by committees that review existing published and peer-reviewed literature in various scientific disciplines (e.g., industrial hygiene, toxicology, occupational medicine, and epidemiology). They represent the opinion of the scientific community that exposure at or below the level of the TLV®–STEL or BEI® does not create an unreasonable risk of disease or injury [ACGIH 2021]. Since TLV®–STELs and BEIs are based solely on health factors, there is no consideration given to economic or technical feasibility. TLV®–STELs are developed to protect individuals in a work environment and are not set to protect the most sensitive populations. In this evaluation, TLV®–STELs were used in screening only when other, more protective levels were not available. While not completely protective of community exposures, TLV®–STELs provide perspective and can be used to identify exposures of greater concern.

TLV®–STELs do not represent a fine line between a healthy versus an unhealthy work environment or the point at which material impairment of health will occur. TLV®–STELs will not adequately protect all workers. Some individuals may experience discomfort or even more serious adverse health effects when exposed to a chemical substance at the TLV®–STEL or even at concentrations below the TLV®–STEL.

TLV®–STELs and BEIs® are not standards. They are guidelines designed for use by industrial hygienists in making decisions regarding safe levels of exposure to various chemical substances and physical agents found in the workplace. In using these guidelines, industrial hygienists are cautioned that the TLV®–STELs and BEIs® are only one of multiple factors to be considered in evaluating specific workplace situations and conditions.

EPA Reference Concentrations (RfCs)

The EPA developed chronic reference concentrations (RfCs) for inhalation. These are estimates of daily exposures to a substance likely without a discernible risk of adverse effects to the general human population (including sensitive subgroups) during a lifetime of exposure. RfCs assume that certain toxic effects have thresholds, such as for cell death or organ damage. RfCs also assume exposure to a single substance in a single media. RfCs are only derived for noncarcinogenic health effects. Doses less than the RfC are not expected to be associated with health risks.

The derivation of RfCs for each chemical are described in EPA's Integrated Risk Information System available online at https://cfpub.epa.gov/ncea/iris2/atoz.cfm [EPA 2013].

WHO Air Quality Guidelines (AQGs)

The World Health Organization (WHO) develops air quality guidelines (AQGs) to offer guidance in reducing the health impacts of air pollution. ATSDR screened PM concentrations using the World Health Organization's (WHO's) air quality guidelines (AQGs) for PM_{10} and $PM_{2.5}$ [WHO 2021; ATSDR 2020].

WHO has the following AQGs for PM:

PM_{10}: The WHO annual average AQG is 15 µg/m^3 and the 24-hour AQG is 45 µg/m^3.

$PM_{2.5}$: The WHO annual average AQG is 5 µg/m^3 and the 24-hour AQG is 15 µg/m^3.

Although WHO acknowledges that $PM_{2.5}$ is a better indicator of long-term health effects than PM_{10}, they maintained an annual PM_{10} AQG of 15 µg/m^3 to protect against the harmful effects of coarse particle ($PM_{2.5}$-PM_{10}) exposures [WHO 2021]. WHO considers the quantitative evidence insufficient to derive a PM_{10} guideline from chronic studies. There are no cancer risk guidelines for PM.

EPA Air Quality Index

EPA's Air Quality Index (AQI) online tool, "AIRNow AQI Calculator" (AQI) was used to estimate potential health effects from 24-hour averages of PM_{10} and $PM_{2.5}$ measured near Port Townsend Paper Corporation (see https://www.airnow.gov/aqi/aqi-calculator/) [EPA 2016]. This tool offers guidance to the potential health effects associated with long-term exposure to specific concentrations of PM. The AQI categorizes 24-hour PM concentrations into six categories: *good*, *moderate, unhealthy for sensitive populations, unhealthy, very unhealthy*, and *hazardous*. The concentration ranges for each category, the associated public health statements, and relevant SLs are given in Table C1 below.

The AQI is a tool used by U.S. EPA to categorize air quality threats in real time to local populations across the United States and is not intended to be used as a surrogate for a presentation of the scientific literature in health assessments. ATSDR uses the AQI only for the purposes of qualitatively assessing the frequency of poor air quality days that may affect different segments of the population. AQI data can be used to support health conclusions made by evaluation of exceedances of screening values, an assessment of how exposures compare to those in the toxicological literature, and an assessment of other data that put these exceedances into context (such as background data or upwind data vs. downwind data, spatial analysis, etc.).

National Ambient Air Quality Standard (NAAQS)

The U.S. EPA's national ambient air quality standards (NAAQS) are enforceable standards. The Clean Air Act, last amended in 1990, requires U.S. EPA to set NAAQS for wide-spread pollutants from numerous and diverse sources considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards:

- Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly.

- Secondary standards set limits to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation, and buildings.

U.S. EPA has set NAAQS for six principal "criteria" pollutants. These criteria pollutants are carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide. The Clean Air Act requires periodic review of the science on which the standards are based and the standards themselves.

U.S. EPA must designate areas as meeting (attainment) or not meeting (nonattainment) the standard. The Clean Air Act requires states to develop a general plan to attain and maintain the NAAQS in all areas of the country and a specific plan to attain the standards for each area designated nonattainment for a NAAQS. The current NAAQS for the six criteria pollutants, are available online at https://www.epa.gov/criteria-air-pollutants [EPA 2024].

Cancer Risk Evaluation Guides (CREGs)

ATSDR's cancer risk evaluation guides (CREGs) are media-specific CVs that are used to identify concentrations of cancer-causing substances that are unlikely to result in an increase of cancer rates in an exposed population. ATSDR develops CREGs using U.S. EPA's cancer slope factor (CSF) or inhalation unit risk (IUR), a target risk level (10^{-6}), and default exposure assumptions. The target risk level of 10^{-6} represents a possible risk of one excess cancer case in a population of one million.

To derive the air CREGs, ATSDR uses IURs developed by U.S. EPA. Because toxicity studies of inhalation exposures express doses as concentrations, the IURs are estimates of the possible risk of cancer associated with a carcinogen expressed in concentration units. As such, to derive CREGs for inhalation exposure, no exposure parameters are needed for intake rate or body weight. Nevertheless, ATSDR assumes that exposure is continuous and occurring for 24 hours a day, every day.

Derivation of a CREG for Inhalation

CREG = TR / IUR

where,

CREG = cancer risk evaluation guide (µg/m^3)

TR = target risk level (10^{-6})

IUR = inhalation unit risk [(µg/m^3)$^{-1}$]

CREGs are substance- and medium-specific values for which cancer effects are unlikely, even with a lifetime of exposure. CREGs serve as a screening tool for evaluating concentrations of carcinogens during an environmental assessment. CREGs are based on possible estimates of cancer risk. Therefore, CREGs should serve only as a screening tool and not that cancer is indicated, expected, or predicted.

Screening Mixtures of Contaminants

ATSDR's noncancer *quantitative* approach evaluates a mixture of contaminants by assuming they have an additive toxic effect. ATSDR also considers the possibility of other joint interactions (greater than or less than additive effects), as appropriate via reviews of its chemical-specific interaction profiles and the Health Effects chapter in each contaminant's toxicological profile.

To conduct the noncancer chemical mixtures analyses, ATSDR calculates hazard quotients (HQs) for each contaminant and a hazard index (HI) for exposure to the group of contaminants. HQs and HIs were calculated for both acute and chronic effects where applicable.

The calculations of the HQs and HIs are as follows:

The HQ is the ratio of exposure to an individual contaminant and the SL, the level at which no harmful health effects are expected. An HQ of less than 1 means harmful noncancer health effects are unlikely assuming exposure to the individual contaminant alone. To calculate the HQ, ATSDR divides the contaminant's measured EPC for each exposure duration by its SL for that same exposure duration.

Individual HQ = $\text{EPC}_{\text{Exposure Duration}} / \text{SL}_{\text{Exposure Duration}}$

The HI is the sum of the individual contaminant HQs for each exposure duration. ATSDR considers that overall HI values less than 1 indicate no hazard from the combined exposure of the contaminant mixture. In general, HIs equal to and greater than 1 indicate the agency should evaluate target-organ exposures. To calculate the overall HI, the agency sums the individual HQs for each exposure duration.

Overall HI = Individual $\text{HQ}_{\text{Contaminant 1}}$ + Individual $\text{HQ}_{\text{Contaminant 2}}$ + … Individual $\text{HQ}_{\text{Contaminant n}}$

Table C1. EPA Air Quality Index (AQI) Categories [EPA 2018]*†

AQI Category (Description of Air Quality)	Air Quality Index Range and Cautionary Statement			Outdoor Air Standards and Screening Levels
	PM_{10} 24-hr Average Concentration ($\mu g/m^3$)§	$PM_{2.5}$ 24-hr Average Concentration ($\mu g/m^3$)§	Sulfur Dioxide 1-hr and 24-hr Average Concentration (ppb)¶	
Good **(Air quality is satisfactory, and air pollution poses little or no risk.)**	0 – 54 No Cautionary Statement	0 – 12.0 No Cautionary Statement	0-35 No Cautionary Statement	45 $\mu g/m^3$ (PM_{10} 24-hr AQG) 15 $\mu g/m^3$ (PM_{10} Annual AQG) 5 $\mu g/m^3$ ($PM_{2.5}$ Annual AQG) 35 $\mu g/m^3$ ($PM_{2.5}$ 24-hr NAAQS) 10 ppb (Sulfur Dioxide ATSDR MRL)
Moderate **Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.**	55 – 154 Unusually sensitive people should consider reducing prolonged or heavy exertion	12.1 – 35.4 Unusually sensitive people should consider reducing prolonged or heavy exertion.	36-75 No Health Effects Statement	15 $\mu g/m^3$ ($PM_{2.5}$ 24-hr AQG) 150 $\mu g/m^3$ (PM_{10} 24-hr NAAQS) 75 ppb (Sulfur Dioxide 1-hr NAAQS)

AQI Category **(Description of Air Quality)**	**Air Quality Index Range and Cautionary Statement**			**Outdoor Air Standards and Screening Levels**
	PM_{10} 24-hr Average Concentration (µg/m^3)§	**$PM_{2.5}$ 24-hr Average Concentration (µg/m^3)§**	**Sulfur Dioxide 1-hr and 24-hr Average Concentration (ppb)¶**	
Unhealthy for Sensitive Groups **(Members of sensitive groups may experience health effects. The general public is less likely to be affected.)**	155 – 254 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion	35.5 – 55.4 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion	76-185 People with asthma should consider limiting outdoor exertion	NA
Unhealthy **(Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.)**	255 – 354 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.	55.5 – 150.4 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.	186-304 Children, people with asthma, or other lung diseases, should limit outdoor exertion	NA

AQI Category **(Description of Air Quality)**	**Air Quality Index Range and Cautionary Statement**			**Outdoor Air Standards and Screening Levels**
	PM_{10} 24-hr Average Concentration (µg/m^3)§	**$PM_{2.5}$ 24-hr Average Concentration (µg/m^3)§**	**Sulfur Dioxide 1-hr and 24-hr Average Concentration (ppb)¶**	
Very Unhealthy **(Health alert: The risk of health effects is increased for everyone.)**	355 – 424 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	150.5 – 250.4 People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	305-604 Children, people with asthma, or other lung diseases should avoid outdoor exertion; everyone else should reduce outdoor exertion.	NA
Hazardous **(Health warning of emergency conditions: everyone is more likely to be affected.)**	425 – 604 Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children, and people of lower socioeconomic status should remain indoors and keep activity levels low.	250.5 – 500.4 Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children, and people of lower socioeconomic status should remain indoors and keep activity levels low.	Greater than 605 Children, people with asthma, or other lung diseases, should remain indoors; everyone else should avoid outdoor exertion	NA

*Table provides particulate matter ranges and the associated health statement compared to outdoor air standards and guidelines. The AQI is a tool used by U.S. EPA to categorize air quality threats in real time to local populations across the United States and is not intended to be used as a surrogate for a presentation of the scientific literature in health assessments. ATSDR uses the AQI only for the purposes of qualitatively assessing the frequency of poor air quality days that may affect different segments of the population. AQI data can be used to support health conclusions made by evaluation of exceedances of screening values, an assessment of how exposures compare to those in the toxicological literature, and an assessment of other data that put these exceedances into context (such as background data or upwind data vs. downwind data, spatial analysis, etc.).

†AQG – World Health Organization (WHO) air quality guidelines, AQI – EPA's air quality index, SL for particulate matter data, EPA – U.S. Environmental Protection Agency, hr – hour; NA – not applicable, NAAQS – EPA National Ambient Air Quality Standards, PM – particulate matter for particulates smaller than 10 microns (PM_{10}) or 2.5 microns ($PM_{2.5}$); µg/m^3 – micrograms per meter cubed

§Sensitive Groups- For PM, people with heart or lung disease, older adult, children, and people of lower socioeconomic status. are the most at risk.

¶Sensitive Groups- For sulfur dioxide, children and people with lung disease are the most at risk.

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Appendix D: Data Collection Methods, Data Quality Objectives and Results (Including Supplemental Tables and Figures)

Sampling Methodologies

ATSDR and its contractor, Eastern Research Group (ERG), transported and installed sampling equipment and measurement systems at the established sites. Once installations were completed, all measurement systems were tested to ensure that damage had not occurred during transport. Sampling at each EI site commenced after that location's measurement systems were determined to be operating correctly. If a system was not functioning correctly, the field team repaired or replaced the instrument as quickly as possible and returned it to service.

As shown in Table D1, and summarized in the sections that follow, measurement analysis for the EI varies by the individual pollutant and collection method.

Table D1. Sampling Methods and Range of Detection*†

Measurement Type	***Measurement Device***	***Measurement Range***
Hydrogen sulfide	Honeywell single point monitor (SPM)	1 to 90 ppb
2-Butyl mercaptan, diethyl sulfide, dimethyl disulfide, dimethyl sulfide, ethyl mercaptan, ethyl methyl sulfide, hydrogen sulfide isobutyl mercaptan, isopropyl mercaptan, methyl mercaptan, n-butyl mercaptan, n-propyl mercaptan, sulfur dioxide, tert-butyl thiol, and tetrahydrothiophene	$_{\text{TRS}}$MEDOR® ppb	≤1-1,000 ppb in amp-3 ≤ 10-10,000 ppb in amp-2 ≤100-100,000 ppb in amp-1 (Also see compound-specific limits of quantitation [LOQs] in this measurement's methodology section below)
$PM_{2.5}$, PM_{10}	Met One Environmental Beta Attenuation Monitor (E-BAM)	-5 to 65,530 µg/m^3
Sulfur dioxide	Thermo Scientific™ Model 43i Analyzer	<1 to 5,000 ppb
Meteorology	R.M. Young AQ Wind Monitor	Wind speed: 0 to 50 m/s, 0.4 m/s starting threshold Wind direction: 0 to 360 degrees, 0.5 m/s starting threshold

	Onset HOBO U30 Weather Station	Ambient temperature: -40°C to 75°C Relative humidity: 0 to 100% at -40° to 75°C
Measurement Type	***Measurement Device***	***Method Detection Limits (MDLs)****
Acetaldehyde, formaldehyde, propionaldehyde	Dinitrophenylhydrazine (DNPH) cartridge, EPA Method TO-11A (EPA, 1999)	Acetaldehyde: 0.042 µg/m^3 (0.023 ppb) Formaldehyde: 0.062 µg/m^3 (0.050 ppb) Propionaldehyde: 0.014 µg/m^3 (0.006 ppb)

*Range of detection based on a 1,000-liter sample volume.

†µg/m^3 = micrograms per cubic meter; ppb = parts per billion; °C = degrees Celsius; m/s = meters per second

Throughout the EI, at least one ERG field staff member was resident in the area to visit the sites daily to assess the functional status of the pollutant and meteorological measurement equipment and correct any problems identified. During the EI, the field staff maintained a field notebook which includes information pertaining to the sampling equipment operation, system audit and calibration data, and observations related to the EI. For example, the field staff recorded any observations that could potentially influence particulate level measurements (e.g., nearby fires, smells of smoke, lawn mowing), and logged information pertaining to odors in the field notebook [ERG 2019].

The following description of the parameters for each measured contaminant include the method used, frequency of collection, duration of collection, and how data were aggregated if applicable.

Aldehydes (Acetaldehyde, Formaldehyde, and Propionaldehyde)

Aldehyde air samples were collected every other day at Site 2. ATSDR collected 24-hour integrated samples using sampling pumps fitted with cartridges filled with dinitrophenylhydrazine (DNPH) coated resin and analyzed using high pressure liquid chromatography (HPLC) analysis with ultraviolet detection according to the EPA standard methods [EPA 1999, 2016; ERG2018]. For analysis, samples were shipped from the field to ERG's laboratory in Research Triangle Park, North Carolina. For the best comparison to the studies that are the basis for the derivation of the CVs, 24-hour averaged concentrations of aldehydes were used in the health assessment.

Sulfur Dioxide

A Thermo Scientific^{TM} 43i Sulfur Dioxide Analyzer (Thermo) was used to collect continuous measurements at Site 2. The 43i analyzer is a Federal Equivalent Method monitor approved to meet or exceed all of EPA's National Ambient Air Quality Standard (NAAQS) requirements for automated sulfur dioxide measurement, as listed in 40 CFR Part 58 – Ambient Air Quality Surveillance. The outdoor air samples for the EI were collected across 1-minute averaging periods. For the best comparison to the studies that are the basis for the derivation of the CVs, 10-minute averaged concentrations of sulfur dioxide were used in the health assessment.

Particulate Matter (PM)

ATSDR used real-time Environmental Beta Attenuation Monitors (E-BAMs) manufactured by Met One Instruments, Inc. to collect 10-minute and 1-hour volumetric mass measurements of PM. ATSDR collected measurements of $PM_{2.5}$ at Sites 2, 3, and 4, and PM_{10} at Sites 1, 2, and 3. The E-BAM is a portable self-contained unit that meets or exceeds all EPA requirements for automated particulate measurement. For the best comparison to the studies that are the basis for the derivation of the SLs, 24-hour averaged concentrations of PM were used in the health assessment.

Hydrogen Sulfide

ATSDR used Honeywell single point monitors (SPMs) to collect continuous 1-minute instantaneous measurements of hydrogen sulfide at eight sites (i.e., numbered Site 1 through Site 8). ChemKeys (i.e., programmable read-only memory chips) were used to set the measurement range on each instrument. For the best comparison to the studies that are the basis for the derivation of the SLs, 30-minute averaged concentrations of hydrogen sulfide were used in the health assessment.

Sulfur Compounds

A $_{TRS}$MEDOR® ppb (MEDOR) was deployed at Site 2 and housed inside a shelter to collect continuous measurements of the following sulfur compounds: 2-butyl mercaptan, diethyl sulfide, dimethyl disulfide, dimethyl sulfide, ethyl mercaptan, ethyl methyl sulfide, hydrogen sulfide, isobutyl mercaptan, isopropyl mercaptan, methyl mercaptan, n-butyl mercaptan, n-propyl mercaptan, sulfur dioxide, tert-butylthiol, and tetrahydrothiophene. The MEDOR is an online gas chromatograph, which operates continuously with automatic sampling, analysis, data processing and storage. This method produces 20-min averaged concentrations which were used in the health assessment.

Meteorology

Each minute, ATSDR measured wind speed and direction using a An R.M. Young AQ wind monitor, temperature using a resistance temperature detector, and relative humidity using a resistance/capacitance wire-wound salt-coated bobbin assembly. Measurements were made at a height of approximately 10 feet (3 meters) above grade (to approximate breathing height without ground level interferences) or rooftop level (site dependent) using Onset HOBO Wind Speed and Direction Smart Sensors (Model: S-WCA-M003) with Onset Temperature/Relative Humidity Sensors (S-TMA).

Data Quality Objectives

Data quality objectives (DQOs) are measures used to determine how good data must be to achieve the project goals. For this EI, there were both operational and technical DQOs specified in the EI protocol. These DQOs help ATSDR determine if the data collected are of sufficient quality to achieve the EI project's specific technical goals and objectives.

This EI used DQOs to develop the criteria that the data collection design should satisfy, including where and when to conduct sampling, the number of sites, measurement frequency, and acceptable measurement precision and accuracy. The operational and technical DQOs (see Table D2), as outlined in the EI Protocol, are consistent with the goals and objectives of this EI, considering the contaminants of concern and sampling logistics. A discussion of each DQO follows:

Table D2. Data Quality Objectives (DQOs) for the Port Townsend EI*

DQO Type	***Element***	***Objective***
Operational DQOs	Where to conduct sampling (siting)	All sampling locations must be near the potentially impacted population
	Number of sites required (siting)	3-6 sites will provide a representative and direct relationship to the potentially impacted population (e.g., private residences, businesses)
	When to conduct sampling (duration)	Daily from 00:00 to 23:59 hours across 8 continuous weeks during late summer/autumn
	Frequency of sampling (measurement intervals)	• Continuous sub-hourly data collection for hydrogen sulfide, sulfur dioxide, reduced sulfur compounds, $PM_{2.5}$ and PM_{10} to allow assessment of short duration excursions and calculations of hourly and daily average concentrations • 24-hour average every other day collection for aldehydes • Continuous for meteorological parameters
Technical DQOs	Overall measurement completeness	80% data capture or greater from start to finish for the sampling event
	Acceptable measurement precision for hydrogen sulfide using SPMs	±20% coefficient of variation for measurements >3 ppb
	Acceptable measurement accuracy hydrogen sulfide using SPMs	±15% percent error
	Acceptable measurement precision for $PM_{2.5}$ and PM_{10} using E-BAMs	±20% coefficient variation of measurements >3 $\mu g/m^3$
	Acceptable measurement accuracy for $PM_{2.5}$ and PM_{10} using E-BAMs	• Flow ±2% of set point • Temperature sensors ±2 °C • Ambient pressure ±10 mmHg • Leak check ≤1.5 LPM drop • Self-test = pass • Span (membrane) test = pass (Based on manufacturer recommendations and Appendix A of 40 Code of Federal Regulations [CFR] Part 58 for $PM_{2.5}$)

DQO Type	Element	Objective
	Acceptable measurement precision for aldehydes using Method TO-11A	• ≤20% RPD of primary sample for concentrations ≥ 0.5 µg/cartridge for duplicates • ≤10% RPD of primary sample for concentrations ≥ 0.5 µg/cartridge for replicates
	Acceptable measurement accuracy for aldehydes using Method TO-11A	±20% RPD
	Acceptable measurement accuracy for reduced sulfur compounds using the TRSMEDOR® ppb	±20% error
	Acceptable measurement accuracy for sulfur dioxide using the Thermo Scientific™ 43i Analyzer	≤±3% error for zero check at full scale ≤±10% error for span check at 80% of full scale

*°C- degrees Celsius; Environmental Beta Attenuation Monitor (E-BAM); LPM- liters per minute; µg/m^3- micrograms per cubic meter; mmHg- millimeter of mercury, $PM_{2.5}$ - particulate matter with an aerodynamic diameter of 2.5 micrometers or smaller; PM_{10}- particulate matter with an aerodynamic diameter of 10 micrometers or smaller; ppb- parts per billion; RPD- relative percent difference; SPM- single point monitor

Operational DQOs

The Port Townsend EI met all its specified operational DQOs. Detailed operational DQO performance information is presented below.

Siting: This includes DQOs for where to conduct sampling and the number of sites required. For this EI, site locations included private residences, a business, and a public school facility in Port Townsend, Washington. ATSDR satisfied this DQO with a total of eight sampling sites that directly represented the potentially impacted population.

Duration: The sampling occurred during late summer/autumn, beginning on August 30, 2018, and ending on November 10, 2018. The EI had a total duration of 10 weeks. Though the EI duration in the protocol was 8 weeks, ATSDR decided to extend the investigation period to accommodate a 1-week shutdown of PTPC operations and the week following the shutdown when PTPC operations would resume. The duration DQO was therefore met.

Measurement intervals: Measurements of reduced sulfur compounds, $PM_{2.5}$, PM_{10}, sulfur dioxide, and meteorological parameters occurred continuously throughout the day, and aldehydes occurred as 24-hour averages every other day, meeting the EI DQO.

Technical DQOs

The technical DQOs for the Port Townsend EI evaluated measurement completeness, measurement precision, and measurement accuracy. The Port Townsend EI met some, but not all the technical DQOs. A description of the technical DQOs and where DQOs were not met is presented below. And detailed technical DQO performance is summarized in the sections that follow.

- Measurement completeness: For this EI, completeness was defined as the number of valid measurements collected, compared to the number of possible measurements expected. Monitoring programs that consistently generate valid results tend to have higher measurement completeness than programs that consistently invalidate samples. Therefore, the completeness of an air monitoring program is a qualitative measure of the reliability of air sampling and the efficiency with which the field program was managed.

Hydrogen sulfide and sulfur dioxide did not meet all DQOs for completeness. This was due to equipment maintenance (hydrogen sulfide) and improperly working equipment (sulfur dioxide) during the EI that prevented sample collection.

- Measurement precision: For this EI, measurement precision was defined as the ability to acquire the same concentration from two independent instruments with an acceptable level of uncertainty, while concurrently sampling the same air parcel. In other words, precision characterizes the repeatability of measurements made by a particular sampling approach.

  PM_{10} measurements did not meet the DQO for precision due to improper settings on the collocated PM_{10} monitor at site 3.

- Measurement accuracy: For this EI, measurement accuracy was defined as the ability to acquire the correct concentration measurement from an instrument or an analysis within an acceptable level of uncertainty. Accuracy was assessed to determine whether systematic deviations occurred from the true concentrations being reported.

  In the final of 3 calibration assessments for the MEDOR instrument, several reduced sulfur compounds did not meet the DQO for accuracy. This final calibration is performed after the instrument is returned from deployment to the lab, which can impact instrument accuracy.

  PM_{10} and $PM_{2.5}$ monitors were generally functioning properly during the EI, with some exceptions on days with cold weather.

Screening Analysis

Since the release of the protocol for this EI, some screening levels have changed based on the most recent science and screening methodology. ATSDR used a different screening approach for sulfur compounds than described in the protocol for the EI. The range of sulfur compounds measured do not have non-occupational health-based screening levels designed to protect the general public. In the protocol, ATSDR initially proposed that all sulfur compounds without a nonoccupational SL be screened with the SLs for hydrogen sulfide, which is orders of magnitude more toxic than some of the other sulfur compounds. To more accurately estimate the potential for adverse health effects, ATSDR screened the individual sulfur compounds with occupational screening levels from the American Conference of Governmental Industrial Hygienists (ACGIH). These screening levels are based on the pungent odors of the sulfur compounds that occur below levels that cause health effects. Since the sulfur compounds were not detected frequently enough to assess chronic exposure, ATSDR used the occupational screening levels from ACGIH to determine the potential for harmful effects from acute exposures.

Results

Table D3. Aldehyde Sample Results (24-hour samples collected at Site 2)*

Pollutant	Plant Operating Status	Number Valid Samples	Number Exceed Lowest SL (SL Type)	Median (Range)	Mean (95% Upper Confidence Interval)†	Wilcoxon Rank Sum Difference in Location (95% confidence interval)	Wilcoxon Rank Sum p value (2-sided less than alternative)	HEM-4 Model Predicted Mean
Acetaldehyde	Operating	30	22 (CREG)	0.582 (0.34 – 1.2)	0.621 (0.684)	0.23 (0.068 – 0.39)	0.004	0.233
Acetaldehyde	Shutdown	5	1 (CREG)	0.358 (0.28 – 0.47)	NA	NA	Reference	Not Applicable
Formaldehyde	Operating	30	30 (CREG)	1.27 (0.55 – 4.31)	1.64 (1.92)	0.82 (0.44 – 1.6)	0.0009	0.0395
Formaldehyde	Shutdown	5	5 (CREG)	0.432 (0.32 – 0.86)	NA	NA	Reference	Not Applicable
Propionaldehyde	Operating	30	0 (RfC)	0.117 (0.075 – 0.22)	0.123 (0.133)	0.037 (0.015 – 0.065)	0.005	0.0468
Propionaldehyde	Shutdown	5	0 (RfC)	0.0732 (0.072 – 0.11)	NA	NA	Reference	Not Applicable

*Results in micrograms per cubic meter; CREG: cancer risk evaluation guide; RfC: reference concentration

†95 UCL could not be calculated for the samples during the PTPC shutdown due to small sample size

Table D4. Hydrogen Sulfide Results (SPM)*

Site	Plant Operating Status	Number Valid 30 Minute Averages	Number of 30-min Averages above the detection limit (DL) (Percent Detection)	Number Exceed Lowest SL †	Median (Range)‡ ppb	Mean (95% Upper Confidence Interval)	Wilcoxon Rank Sum Test p value§
Site 1	Operating	1,979	932 (47.1)	680	< DL (1.01—48.9)	1.79 (2.06)	0.05
Site 1	Closed	481	161 (33.5)	133	<DL (1.01—10.2)	1.12 (1.2)	Reference
Site 2	Operating	2,867	1,246 (43.5)	909	<DL (1—48)	2.56 (3)	0.18
Site 2	Closed	481	313 (65.1)	186	1.2 (1 - 23.5)	1.64 (1.85)	Reference
Site 3	Operating	2,922	874 (29.9)	569	<DL (1—58.2)	0.993 (1.1)	0.71
Site 3	Closed	481	153 (31.8)	92	< DL (1.02—5.76)	1.02 (1.1)	Reference
Site 4 Primary	Operating	2,875	810 (28.2)	506	< DL (1—52.3)	1.07 (1.4)	1.6×10^{-5}
Site 4 Primary	Closed	451	39 (8.65)	16	< DL (1 – 3.54)	0.394 (0.4)	Reference
Site 4 Collocated	Operating	1,969	437 (22.2)	276	< DL (1 – 22.1)	0.84 (0.9)	0.006
Site 4 Collocated	Closed	451	44 (9.76)	19	< DL (1 – 3.18)	0.495 (0.5)	Reference
Site 5	Operating	2,060	597 (29)	301	< DL (1 – 12.4)	0.88 (0.9)	0.69

Site	Plant Operating Status	Number Valid 30 Minute Averages	Number of 30-min Averages above the detection limit (DL) (Percent Detection)	Number Exceed Lowest SL †	Median (Range)‡ ppb	Mean (95% Upper Confidence Interval)	Wilcoxon Rank Sum Test p value§
Site 5	Closed	481	156 (32.4)	56	< DL (1.02 – 6.67)	0.828 (1.0)	Reference
Site 6	Operating	2,108	417 (19.8)	265	< DL (1 – 31.5)	0.734 (0.8)	0.16
Site 6	Closed	481	146 (30.4)	62	< DL (1 – 7.95)	0.833 (0.91)	Reference
Site 7	Operating	1,765	651 (36.9)	328	< DL (1 – 72.3)	1.05 (1.1)	0.15
Site 7	Closed	481	141 (29.3)	65	< DL (1 – 6.3)	0.819 (0.9)	Reference
Site 8	Operating	2,040	1,618 (79.3)	1,054	1.41 (1 – 31.8)	1.98 (2.13)	0.006
Site 8	Closed	481	381 (79.2)	143	1.38 (1 – 5.22)	1.38 (1.49)	Reference

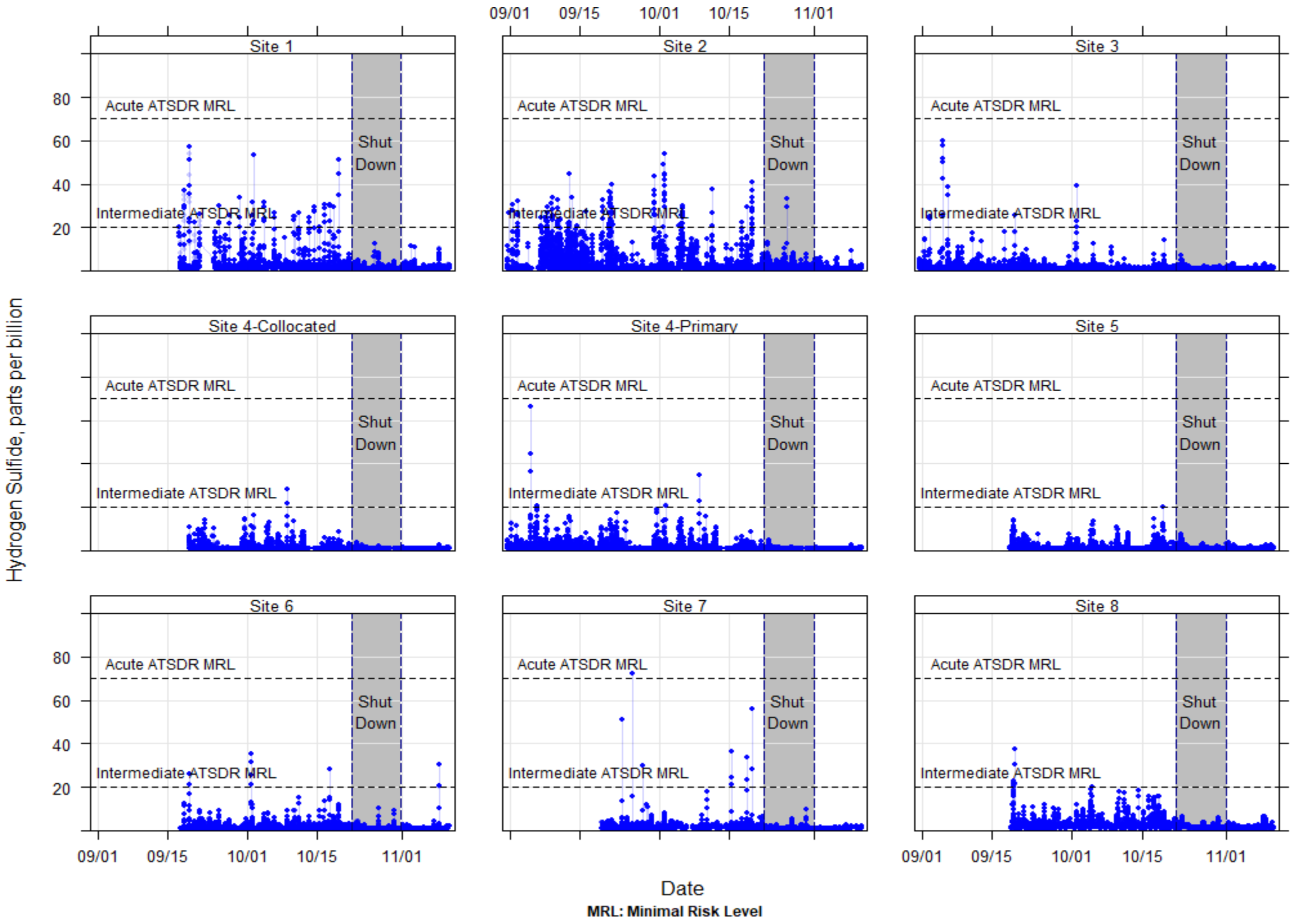
*Results in parts per billion (ppb) 30-minute averages of one-minute results.

†SL: screening level (EPA reference concentration)

‡Range shown is based on samples above the detection limit.

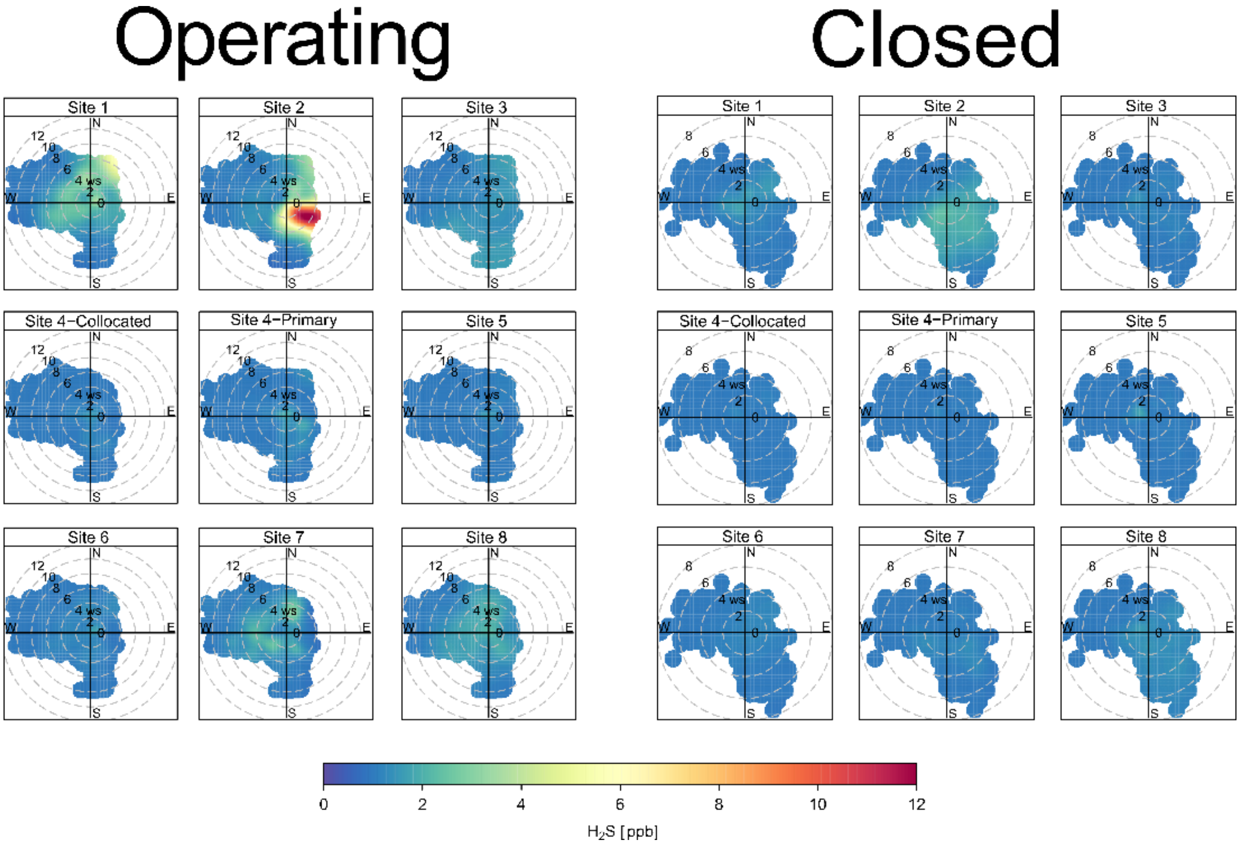
§Wilcoxon Rank Sum test is against a two-sided alternative test using 30-minute samples and an autocorrelation regressive model. Estimator of location shift is not calculated due to high rate of nondetections.

Figure D1: Hydrogen Sulfide Timeplot 30 – Minute Samples (SPM) in parts per billion*



*ATSDR- Agency for Toxic Substances and Disease Registry; MRL- Minimal Risk Level

Figure D2. Hydrogen Sulfide Polar Plots (SPM)*



*Polar plots were derived using the measured meteorological data at Site 2 and concentrations of hydrogen sulfide measured alone at each site during operation and shutdown of PTPC.

Table D5. Particulate Matter Results (24-hour samples)*†

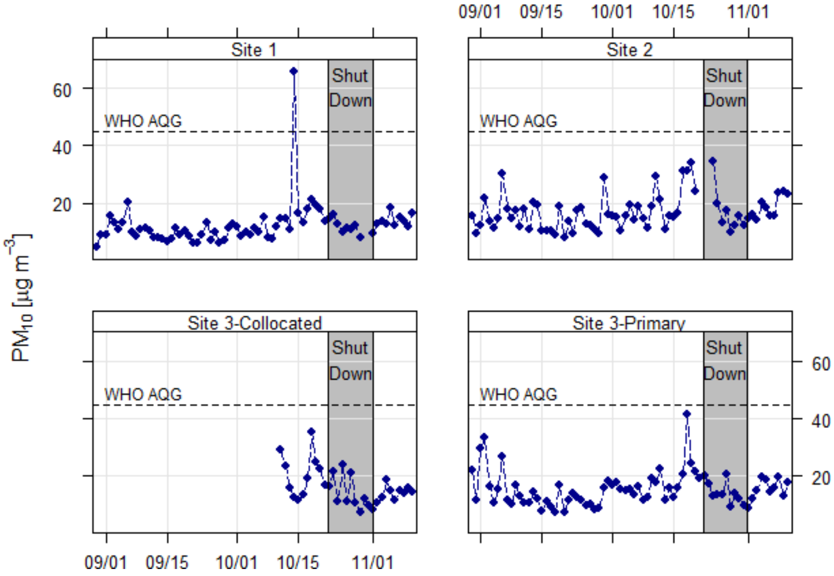
Pollutant	Site	Plant Operating Status	Number of Valid Averages (Number missing)	Number Detected (% Detects Out of Valid Averages	Number of samples above (WHO 24-hr AQG)	Median (Range)	Mean (95% Upper Confidence Interval)	Wilcoxon Rank Sum Difference in Location (95% Confidence Interval)	Wilcoxon Rank Sum p value (1-sided less than alternative)
$PM_{2.5}$	Site 2	Operating	61 (1)	58 (95.1)	11	9.33 * (5.43—34.7)	11.2 (12.8)	3.67 (-0.66-10.3)	0.082
$PM_{2.5}$	Site 2	Closed	9 (2)	8 (88.9)	0	6.39 * (6.07—10.3)	7.31 (8.1)		
$PM_{2.5}$	Site 3	Operating	62 (0)	61 (98.4)	3	7.5 (5.12—30.3)	8.84 (9.83)	-1.24 (-3.3-2.4)	0.531
$PM_{2.5}$	Site 3	Closed	11 (0)	11 (100)	1	8.39 (4.48—15.4)	8.64 (10.8)		
$PM_{2.5}$	Site 4	Operating	62 (0)	61 (98.4)	5	7.12 (3.03—26.3)	8.7 (10.1)	1.3 (-3.4-8.3)	0.749
$PM_{2.5}$	Site 4	Closed	11 (0)	11 (100)	0	7.86 (4.43—12.7)	8.18 (9.57)		
PM_{10}	Site 1	Operating	62 (0)	61 (98.4)	1	11.1 (6.05—66.1)	12.3 (13.8)	0.254 (-4.1-3.9)	0.865
PM_{10}	Site 1	Closed	9 (2)	8 (88.9)	0	11.3 (7.9—16)	11.5 (13)		
PM_{10}	Site 2	Operating	61 (1)	58 (95.1)	0	15.3 * (8.07—33.9)	16.6 (18.1)	3.29 (-0.11-14.2)	0.0524

Pollutant	Site	Plant Operating Status	Number of Valid Averages (Number missing)	Number Detected (% Detects Out of Valid Averages	Number of samples above (WHO 24-hr AQG)	Median (Range)	Mean (95% Upper Confidence Interval)	Wilcoxon Rank Sum Difference in Location (95% Confidence Interval)	Wilcoxon Rank Sum p value (1-sided less than alternative)
PM_{10}	Site 2	Closed	9 (2)	8 (88.9)	0	13 * (9.64—19.9)	13.2 (14)		
PM_{10}	Site 3-Collocated	Operating	20 (0)	19 (95)	0	15.3 * (10.6—35.3)	16.9 (19.8)	3.52 (-9.8-19.2)	0.786
PM_{10}	Site 3-Collocated	Closed	11 (0)	9 (81.8)	0	10.7 * (7.44—21.5)	12.7 (15.1)		
PM_{10}	Site 3-Primary	Operating	62 (0)	61 (98.4)	0	14.6 * (7.09—41.3)	15.4 (17)	2.17 (-3.2-7.5)	0.409
PM_{10}	Site 3-Primary	Closed	11 (0)	11 (100)	0	13.4 (8.53—20.7)	13.7 (15.6)		

*Values for median and range used imputation of nondetects with robust regression on order statistics.

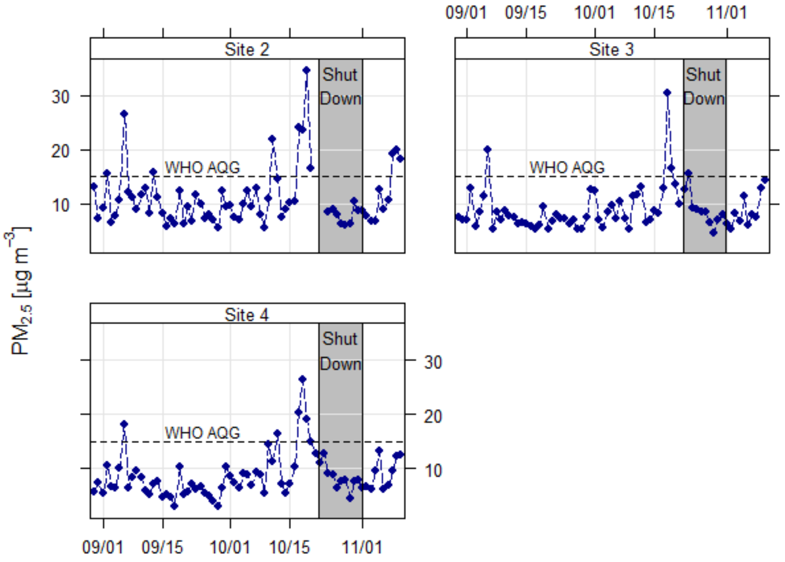
†Results in micrograms per cubic meter; AQG: Air Quality Guideline

Figure D3. PM_{10} Time Plot 24-Hour Averages*



*Dotted lines represent the WHO Air Quality Guideline (45 µg/m^3); µg /m^3: micrograms per cubic meter.

Figure D4. $PM_{2.5}$ Time Plot 24-Hour Averages*



*Dotted lines represent the WHO air quality guideline (15 µg/m^3). µg/m^3: micrograms per cubic meter.

Table D6. Sulfur Dioxide Measurements, Site 2 (10-minute averages in ppb) using Thermo Scientific Model 43i Analyzer*

Plant Operating Status	Number of Averages (number missing)	Number Exceed Acute SL (SL Type)	Median (Range)	Mean (95% Upper Confidence Interval)	Percent of Averages with *Good* AQI	HEM-4 Model Predicted Mean
Operating	4,148 (685)	28 (Acute MRL)	2.06 (0.358 – 15.6	2.11 (3.05)	100%	2.15
Shutdown	1439 (4)	0 (Acute MRL)	2.15 (1.59 – 4.57)	2.2 (2.71)	100%	Not applicable

*Sulfur dioxide was also measured as total reduced sulfides using a $_{\text{TRS}}$MEDOR® sampler. The mean values during operation and shutdown were 3.56 ppb and 1.80 ppb, respectively, and were significantly different.

Table D7. Concentrations of Sulfur Compounds Measured by MEDOR (20-min averages collected continuously)*

Sulfur Compound	Plant Operating Status	Number Valid Samples (Number missing)	Number Detects (% detects out of valid measurements)	Range Detected (ppb)	Number Detected Values over SL	Screening Level (ppb)	Screening Level Source
2-Butyl mercaptan	Operating	3817 (1313)	19 (0.498)	1.42 – 68.2	0	Not Available	Not Available
2-Butyl mercaptan	Closed	647 (71)	1 (0.155)	2.93	0	Not Available	Not Available
Diethyl sulfide	Operating	3801 (1329)	42 (1.1)	1.91 – 83.6	0	Not Available	Not Available
Diethyl sulfide	Closed	649 (71)	8 (1.23)	3.48 – 7.49	0	Not Available	Not Available
Dimethyl disulfide	Operating	3755 (1373)	358 (9.53)	3.48 –4,390	17	500	ACGIH TLV®–STEL[†]
Dimethyl disulfide	Closed	651 (69)	56 (8.6)	4.16 – 48	0	500	ACGIH TLV®–STEL[†]
Dimethyl sulfide	Operating	3705 (1423)	505 (13.6)	1.18 – 444	0	10,000	ACGIH TLV®–STEL[†]
Dimethyl sulfide	Closed	653 (67)	75 (11.5)	1.5 – 22.4	0	10,000	ACGIH TLV®–STEL[†]
Ethyl mercaptan	Operating	3819 (1309)	5 (0.131)	2.52 – 5.77	0	Not Available	Not Available
Ethyl mercaptan	Closed	658 (62)	1 (0.152)	3.53 – 3.53	0	Not Available	Not Available
Hydrogen sulfide	Operating	3791 (1337)	143 (3.77)	1.28 – 490	140	1.4	EPA RfC
Hydrogen sulfide	Closed	656 (64)	28 (4.27)	1.77 – 58.6	28	1.4	EPA RfC
Isobutyl mercaptan	Operating	3806 (1324)	19 (0.499)	1.69 – 19.3	0	Not Available	Not Available
Isobutyl mercaptan	Closed	653 (67)	5 (0.766)	4.2 – 2,300	0	Not Available	Not Available

Sulfur Compound	Plant Operating Status	Number Valid Samples (Number missing)	Number Detects (% detects out of valid measurements)	Range Detected (ppb)	Number Detected Values over SL	Screening Level (ppb)	Screening Level Source
Isopropyl mercaptan	Operating	3792 (1336)	16 (0.422)	1.73 – 649	0	Not Available	Not Available
Isopropyl mercaptan	Closed	653 (67)	0 (0)	Not Applicable	0	Not Available	Not Available
Ethyl methyl sulfide	Operating	3807 (1323)	17 (0.447)	1.32 – 21.8	0	Not Available	Not Available
Ethyl methyl sulfide	Closed	653 (67)	4 (0.613)	1.99 – 14.6	0	Not Available	Not Available
Methyl mercaptan	Operating	3736 (1392)	212 (5.67)	0.45 – 34.5	0	500	ACGIH TLV®–STEL†
Methyl mercaptan	Closed	652 (68)	8 (1.23)	0.7 – 3.73	0	500	ACGIH TLV®–STEL†
n-Butyl mercaptan	Operating	3810 (1320)	27 (0.709)	1.79 – 92.8	0	Not Available	Not Available
n-Butyl mercaptan	Closed	652 (68)	3 (0.46)	3.96 – 8.98	0	Not Available	Not Available
n-Propyl mercaptan	Operating	3161 (1967)	6 (0.19)	3.58 – 287	0	Not Available	Not Available
n-Propyl mercaptan	Closed	630 (90)	1 (0.159)	3.65 – 3.65	0	Not Available	Not Available
Sulfur dioxide	Operating	3722 (1406)	1327 (35.7)	1.25 – 739	76	10	ATSDR Chronic MRL
Sulfur dioxide	Closed	613 (107)	200 (32.6)	1.92 – 31	2	10	ATSDR Chronic MRL
tert-Butylthiol	Operating	3773 (1355)	13 (0.345)	2.39 – 41.5	0	Not Available	Not Available
tert-Butylthiol	Closed	654 (66)	3 (0.459)	3.26 – 3.49	0	Not Available	Not Available
Tetrahydrothiophene	Operating	3817 (1311)	31 (0.812)	0.6 – 566	0	Not Available	Not Available

Sulfur Compound	Plant Operating Status	Number Valid Samples (Number missing)	Number Detects (% detects out of valid measurements)	Range Detected (ppb)	Number Detected Values over SL	Screening Level (ppb)	Screening Level Source
Tetrahydrothio-phene	Closed	654 (66)	3 (0.459)	1.71 – 3.35	0	Not Available	Not Available

*ATSDR- Agency for Toxic Substances and Disease Registry; MRL- minimal risk level; ACGIH- American Conference of Governmental Industrial Hygienists; TLV®–STEL — Threshold Limit Value – Short Term Exposure Limit; ppb- parts per billion; EPA- U.S. Environmental Protection Agency; RfC- reference concentration; SL- screening level

†ACGIH TLVs are occupational standards that were used in the absence of other SLs but are not necessarily protective of community exposures.

Figure D5. Correlation Between Detected Thermo Scientific$^{\text{TM}}$ 43i Analyzer and $_{\text{TRS}}$MEDOR Sulfur Dioxide Samples

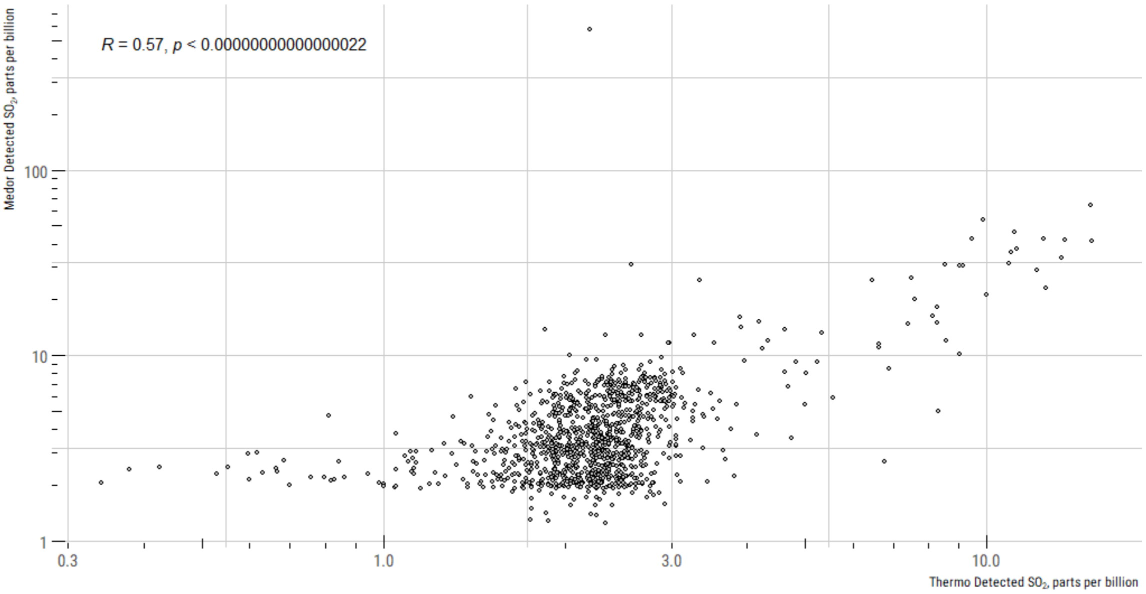


Figure D6. Comparison of Sulfur Dioxide (SO_2) Timeplots from $_{TRS}$MEDOR® Analyzer and Thermo Scientific^{TM} 43i Analyzer

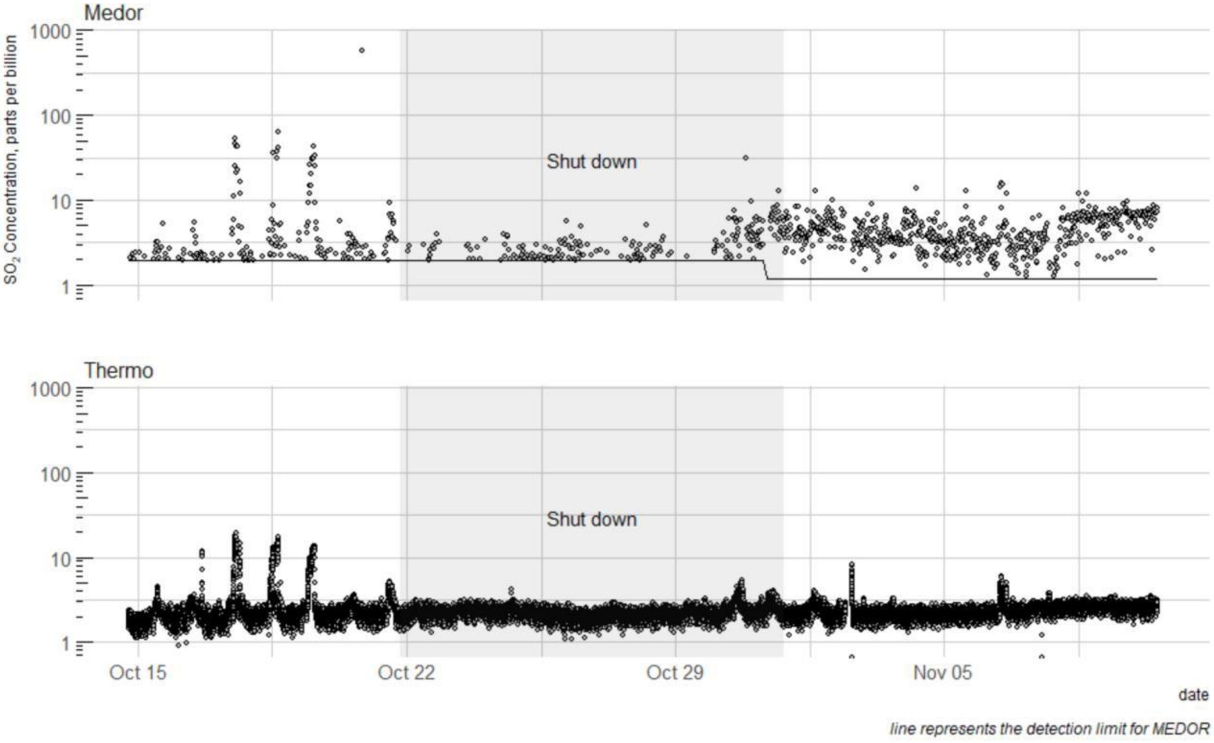


Figure D7. Correlation Between Detected Single Point Monitor (SPM) and Detected $_{TRS}$MEDOR® Hydrogen Sulfide (H_2S) Measurements

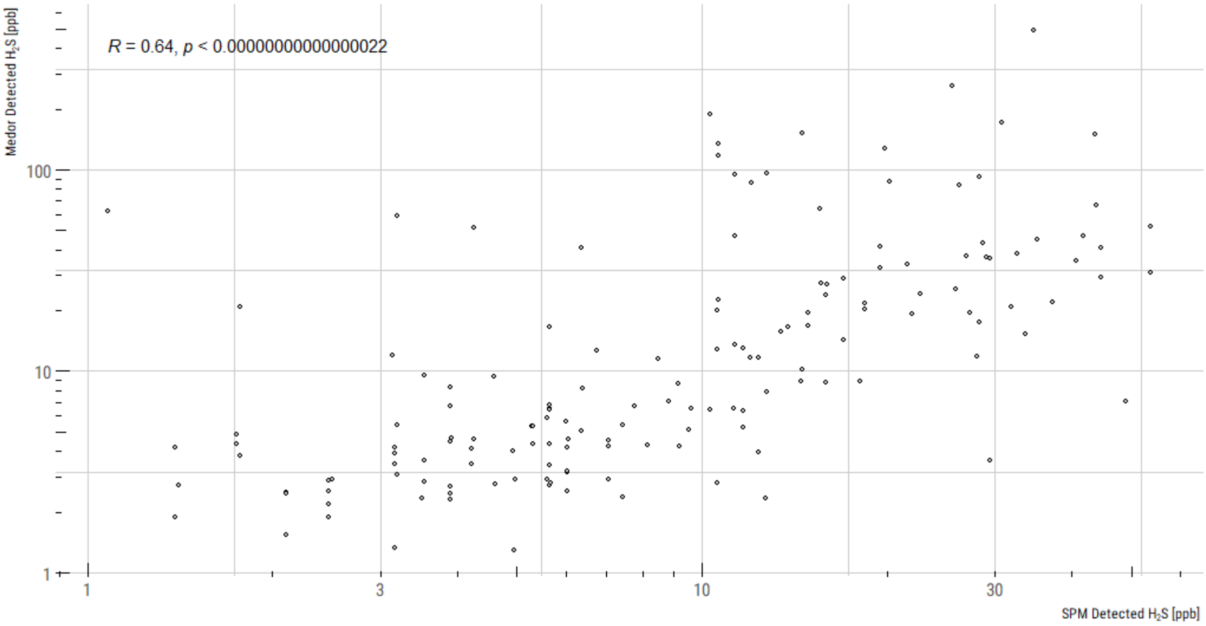


Figure D8. Comparison of Single Point Monitor (SPM) and $_{TRS}$MEDOR® Analyzer Timeplots for Hydrogen Sulfide

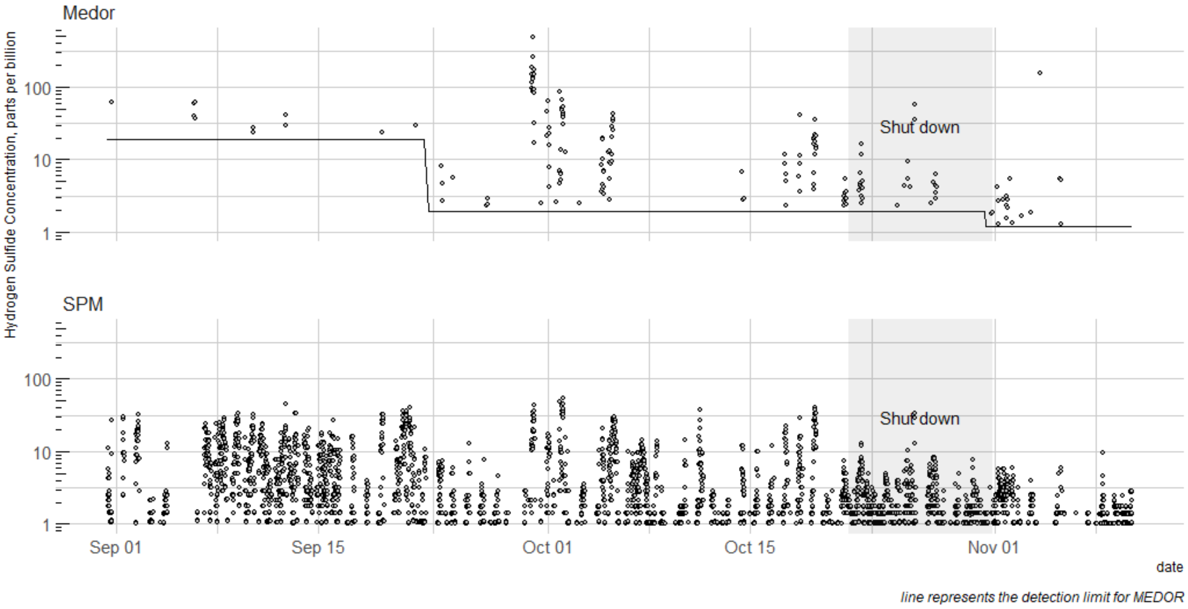
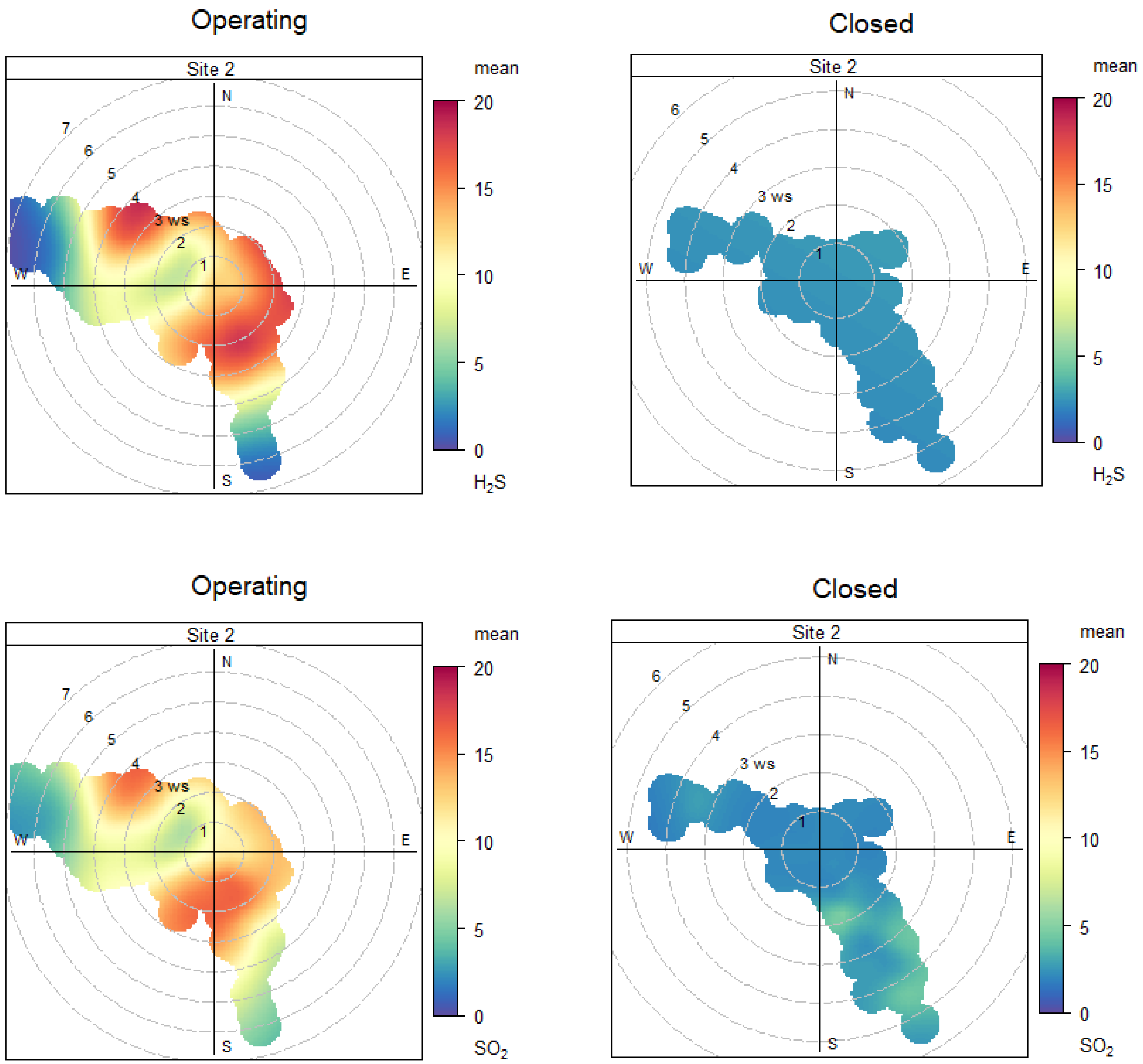


Figure D9. Polar Plots for Hydrogen Sulfide (H_2S) and Sulfur Dioxide (SO_2) Measured With the MEDOR



Appendix E. Health Effects of Environmental Odors

Chemicals with offensive odors can affect health by more than one mechanism [Schiffman and Williams 2005]. Odors are detected when the odorous chemical stimulates the olfactory nerve in the nasal passage. If odors are considered offensive, this mechanism may be associated with headache, nausea, or vomiting [Schiffman et al. 1995]. If malodorous chemicals are present in higher concentrations (i.e., generally, concentrations 10 to 100 time higher than the odor threshold), stimulation of other cranial nerves may cause irritation, including a burning, stinging, or itching sensation in the eyes, nose, or throat. Irritation of the respiratory tract may be accompanied by changes in respiration, including changes in breathing rate, or increased airflow resistance in the upper or lower respiratory tract [Schiffman et al. 2000; Schiffman and Williams 2005]. Combinations of low concentrations of malodorous chemicals may also cause irritation. The health effects of breathing mixtures of malodorous chemicals are not well understood.

With repeated exposures to a malodorous chemical, people can develop learned responses to the odor of that chemical [Schiffman and Williams 2005]. For example, if breathing malodorous sulfur-based compounds at sufficient exposure levels previously caused an asthma attack, perception of the odor of those compounds may subsequently trigger an attack. Repeated exposure to irritating, malodorous chemicals (and other environmental air pollutants including particulate matter, nitrogen oxides, and ozone) may induce chronic respiratory illnesses including asthma, especially in children and elderly adults, although the relevant pollutant mixtures and exposures are not well understood [Clark et al. 2010; Schiffman and Williams 2005; Tétreault et al. 2016]. Repeated exposure to offensive odors perceived as unpredictable or uncontrollable may also add significantly to individuals' stress levels and affect quality of life [Schiffman and Williams 2005]. Chronic stress can harm people's health in a variety of ways, as discussed in the following section.

Generally, symptoms subside once odors dissipate and do not require medical attention. However, symptoms may last longer if odors are persistent or if malodorous chemicals reach irritation levels. Respiratory symptoms that may not subside include shortness of breath, chest tightness, or breathing discomfort, especially in people with chronic cardiopulmonary disease or chronic respiratory disease such as asthma [ATSDR 2014]. MDHSS recommends that individuals seek medical advice for any persistent symptoms that do not subside when the odors dissipate.

People's perception of odors and their responses to those perceptions may vary. Factors that can influence olfaction and the perception of odors include genetics, gender, and age [Greenberg et al. 2013]. Women tend to be more sensitive than men to odors, and younger people tend to be more sensitive than older people to odors. Pregnant women may be more likely to experience nausea in response to offensive odors. Sensitivity to odors may also be influenced by an individual's health. Individuals with chronic respiratory diseases like asthma may be more likely to experience chest tightness or difficulty breathing in response to offensive odors [ATSDR 2014].

Numerous community studies have found chronic exposure to malodorous sulfur emissions may cause adverse health effects, negative emotions, and decreased quality of life [Campagna et al. 2004; Haahtela et al. 1992; Kilburn and Warshaw 1995; Jaakkola et al. 1999; Legator et al. 2001; Marttila et al. 1994; Partti-Pellinen et al. 1996], including in communities downwind of landfills [Heaney et al. 2011].

Stress Due to Hazardous Waste Sites and Odors

Individuals living near hazardous waste sites are at increased risk of experiencing stress and the negative health effects associated with chronic stress. Offensive odors that are perceived as unpredictable or uncontrollable raise individuals' stress levels. Other causes of stress can include frustration with lengthy cleanup times at sites and the perception that health threats do not diminish over time. Individuals may be stressed by uncertainties regarding their current or future health, the current or future health of their children, and the impact of environmental exposures on their health.

Increased stress can be accompanied by a variety of negative emotions, including anxiety, depression, anger, and confusion [Schiffman et al. 1995; Schiffman and Williams 2005]. Over a long period of time, stress and the negative emotions that are generated from increased stress can affect people's health in a variety of ways, due to the interaction of the central nervous, immune, and endocrine systems in the body [Glaser and Kiecolt-Glaser 2005]. Health issues induced by chronic stress can include increased susceptibility to infection, increased severity of infectious diseases, or increased inflammatory responses that may be associated with many common diseases such as coronary artery disease and irritable bowel syndrome [Glaser and Kiecolt-Glaser 2005]. Indirect effects of stress (e.g., poor sleep, poor eating habits, less exercise, increased smoking, and alcohol consumption) put people at even greater risk of developing health problems.

Uncertainty In Odor Thresholds

Odor thresholds for some chemicals are often reported over wide concentration ranges due to differences in testing methodology and in people's ability to perceive odors. Odor thresholds are also often based on limited data. For example, AIHA's ERPG-1 for dimethyl sulfide (500 ppb), is based on odor thresholds from a single study, in which individuals perceived a faint odor at a concentration of 84 ppb and easily noticed odor at a concentration of 1,900 ppb [AIHA 2004].

In addition, odor thresholds are often not well defined. Studies indicate there is a 2-to 10-fold difference between a chemical's lowest odor threshold (i.e., the concentration at which at least one person in a study perceived an odor) and 100% recognition odor threshold (i.e., the concentration at which everyone perceived an odor) [Ruth 1986]. Reported odor thresholds are not always defined as a low odor threshold or a 100% recognition odor threshold. Without both values, the span between them is not known, and it is difficult to estimate the percentage of the population who might be bothered by an odor.

Individuals can often smell contaminants with a strong odor well before they have reached a concentration that might cause a toxic effect. Thus, the perception of offensive odor does not necessarily mean that the chemical(s) causing the odor pose(s) a toxic threat to people's health. However, offensive odors can quickly become a nuisance and may be the direct cause of some health symptoms even in concentrations below levels of toxicity [Schiffman and Williams 2005].

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