2020 Community-Scale Air Toxics Monitoring Study

Characterization of Volatile Organic Air Toxic Compound Levels in Communities Located Adjacent to the Port of Providence

Final Report

Rhode Island Department of Environmental Management
Office Of Air Resources

December 2023

Introduction

In 2020, the United States Environmental Protection Agency (EPA) awarded the Rhode Island Department of Environmental Management, Office of Air Resources (RIDEM OAR) a Community-Scale Air Toxics (CSAT) Monitoring grant to conduct a study entitled "Characterization of Volatile Organic Air Toxic Compound Levels in Communities Located Adjacent to the Port of Providence."

The CSAT monitoring project measured levels of air toxics near the Port of Providence to characterize the risks those exposures pose to people who live, work, go to school, or seek medical care in nearby neighborhoods. Air quality near the Port is impacted by emissions from diesel trucks, marine vessels, oil and gas storage and distribution, asphalt and cement processing, metals recycling, natural gas and utility service, and large heating plants.

This study focused on volatile organic compounds (VOCs), in particular benzene, 1,3 butadiene, and other components of petroleum product vapors and diesel exhaust. At least one year of VOC data was collected at each site. In addition, RIDEM operated low-cost sensors that measured fine particulate matter (PM2.5) and nitrogen dioxide (NO_2) at the VOC monitoring sites. The monitoring was completed at the end of October 2022. As part of the comprehensive study of Port air impacts, RIDEM also collected chemical and fuel use data for sources in the Port area and conducted compliance inspections at those facilities.

The EPA requires recipients of CSAT grants to submit interim and final reports documenting study progress and findings. RIDEM submitted an interim report for the Rhode Island project in March 2023. This document, which includes findings and recommendations, will serve as the final report.

Study Elements

Quality Assurance Project Plan

RIDEM submitted a draft Quality Assurance Project Plan (QAPP) to EPA in October 2021. EPA approved the final QAPP in March 2022. The QAPP described the project design, responsible parties, projected timeline, and how the project would be completed. The study met the criteria identified in the QAPP.

Monitoring Locations

In an effort to best capture emissions from Port-related activities, RIDEM selected five monitoring locations based on proximity to the Port, representativeness of community exposure, and prevailing wind directions. At the end of September 2021, RIDEM relocated the monitors at two of the original sites selected, the Vartan Gregorian Elementary School and a residence on Washington Avenue in Providence, due to problems at those locations. Issues at the Vartan Gregorian School included tampering with the equipment, vandalism, and ultimately theft of the power supply cords. That site was moved to the Seastreak Ferry Depot, which is on the northern edge of Narragansett Bay, north and east of the Port area. At the Washington Avenue residence,

the power to the monitoring shelter was at times disconnected, resulting in lost VOC runs. RIDEM moved that site to a residence on Ohio Avenue, approximately ¼ mile west-northwest of the original location.

RIDEM collected VOC samples for at least a one year period (October 2021- September 2022) at the final sites, which were:

Providence Community Health Center (CH)
695 Eddy Street
Providence, RI 02905
Monitoring equipment at this site was located on the roof of a one-story community health building in the medical district. The site is representative of air quality in the northern portion of the Port area and is just west of asphalt production and oil storage facilities that have been identified as potential odor sources. The site is generally upwind of the highway but is impacted by heavy passenger vehicle and ambulance traffic on nearby streets. Impacts from the heavy duty diesel truck traffic associated with Port activities is less likely at this location, although it may be affected by the moderate truck traffic associated with hospital activities.

Providence Animal Shelter (AS)
200 Terminal Road
Providence, RI 02905
This site is centrally located near heavy truck traffic, storage tanks, and industry. The property was one of the few publicly owned sites in the Port that could securely house monitoring equipment and provided data on-Port pollutant levels.

Seastreak Ferry Depot (SS)
25 India Street
Providence, RI 02903
This site is northeast of the Port area at the RIPTA Ferry Terminal. The monitoring equipment is positioned very close to Upper Narraganset Bay/Providence River, less than 40 feet from the water. and is downwind of the Port of Providence on predominant SW, WSW, and S wind flows. The site is also south of I-195, so it would likely be impacted by highway emissions only when there is a less common northerly wind flow. The equipment was moved to this site from the Vartan Gregorian School for logistical reasons and is more likely to be impacted by Port emissions than the original location.

Residence (OH)
215 Ohio Avenue
Providence, RI 02905
RIDEM partnered with a community activist to monitor at this private residence. The residence is in the heart of the Washington Park neighborhood and is intended to be representative of air quality experienced by residents in that neighborhood, which is south and west of most Port industry. The site is at least ½ a mile from I-95, so it is unlikely to be substantially impacted by the highway and is well away from Port truck traffic on Allens Avenue.

SUEZ Pump Station (SZ)
525 Veterans Memorial Parkway
East Providence, RI 02914
This site is directly across the Providence River from the major portion of Port activities, less than ½ mile across from ProvPort. The equipment faced SW and is open to predominant westerly flows from across the Port and sea breezes. The equipment was located along the fence of the pump station and at least 80 feet from Veterans Parkway.

This document also includes VOC data collected concurrently at four sites in RIDEM's permanent air monitoring network. Those comparison sites are: (1) Vernon Street (VE), which is in a residential area of Pawtucket adjacent to I-95; (2) the Liston Campus of the Community College of Rhode Island (CCRI), which is approximately 0.3 miles west southwest of the CH study site in South Providence; (3) a monitoring trailer next to the Myron Francis School in East Providence (EP), a suburban site often downwind of the Providence metropolitan area; and (4) a rural background site at the Alton Jones campus of the University of Rhode Island (AJ) in West Greenwich. Figure 1 shows the locations of the original and final study sites and the CCRI and EP comparison sites.

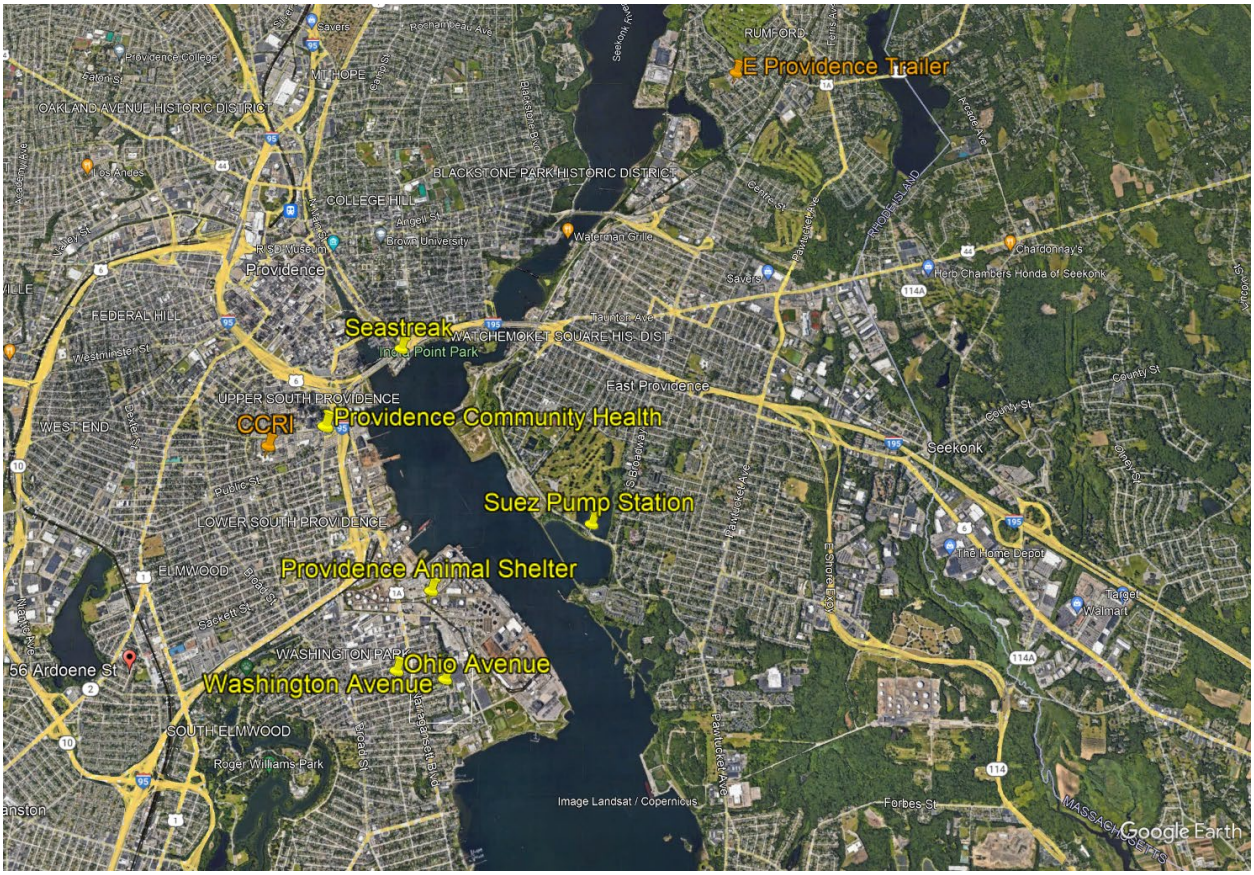

Figure 1. Location of study monitoring sites (yellow) and nearby comparison monitoring sites (orange)

Monitoring Equipment and Methods

PM2.5/NO_2

RIDEM selected Clarity Node-S air sensors for monitoring PM2.5 and NO_2. These units are self-powered, weatherproof, and contain cellular modems that push continuous data to a custom interface, which shows real time data and allows for data downloads. These sensors are not Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitors, which are used to determine whether an area is in compliance with EPA's National Ambient Air Quality Standards (NAAQS). Evaluations by EPA and the South Coast Air Quality Management District in California have demonstrated that the Clarity sensors produce PM2.5 data that correlate quite well with FRM/FEM data while tending to be slightly higher than FEM measurements, especially at lower concentrations.[1,2]

Prior to installing the sensors at the sites, RIDEM co-located all five Clarity units with a Beta Attenuation Mass Monitor (BAM) FEM at RIDEM's near-road monitoring site on Park/Hayes Street in Providence for approximately 30 days during October 2020. Clarity staff used the co-location data, along with temperature and relative humidity measurements, to create custom correction factors for each unit.

RIDEM deployed the Clarity Node-S units at all the sites on November 20, 2020. As noted above, due to logistical challenges, RIDEM moved the units at two sites, VG and WA, mid-study to the SS and OH sites, respectively. RIDEM operated the Clarity sensors for a two year period, until the contract with Clarity ended in November 2022. The unit at the OH site failed on September 26, 2022 due to a clogged intake and could not be replaced because the wait time for new equipment extended beyond the end of the study. RIDEM has retained possession of the hardware.

Upon ending the Clarity Node-S field monitoring, RIDEM staff met with Clarity technicians to discuss the data set. Clarity staff evaluated the data and determined that the PM2.5 data collected during the monitoring period was stable and did not require further calibration or co-location. RIDEM and Clarity both expressed concerns about the NO_2 data collected by the Clarity Node-S. Clarity stated that the NO_2 measurement with their sensors is still considered developmental. Those measurements are highly sensitive to temperature and relative humidity which, according to Clarity, tends to result in an overestimation of NO_2 levels in the early day and evenings and large decreases in measurements (including negative values) with daytime heating. That pattern is consistent with the NO_2 sensor data generated at the study sites. Due to the lack of confidence in the accuracy and comparability of these measurements, NO_2 data are not assessed in this report.

---

[1] Frederick, S., K. Johnson, C. Johnson, R. Yaga, and A. Clements. Performance Evaluations of PM2.5 sensors in Research Triangle Park, NC: PurpleAir PA-II-SD, Aeroqual AQY, Applied Particle Technology Maxima, Vaisala AQT420, Sens-it RAMP, and Clarity Node-S. Presented at EPA Air Sensors Brownbag, Research Triangle Park, NC, February 12, 2020. Available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=CEMM&dirEntryId=348487.

[2] South Coast Air Quality Management District Air Quality Sensor Performance Evaluation Center (AQ-SPEC), PM Sensor Evaluation for Clarity Nodes. Available at: https://www.aqmd.gov/docs/default-source/aq-spec/summary/clarity-node---summary-report.pdf?sfvrsn=18.

Meteorological Equipment

RIDEM used Rainwise MK4-C equipment to measure meteorological parameters at three study locations (AS, SZ, and CH) from June 2021 through October 2022. The equipment measured temperature, dewpoint, wind direction, wind speed, wind gusts, and barometric pressure. Like Clarity Node-S, the Rainwise data were pushed by a cellular modem to an interface with real time and downloadable data capability. The data were evaluated for quality and downloaded weekly from the online database.

The Rainwise equipment also experienced technical problems. Communication with the Rainwise unit at SZ was lost on January 19, 2022 and repaired by February 16, 2022. Similarly, communication with the Rainwise equipment at the AS site was lost on January 26, 2022 and repaired by February 24, 2022.

VOC Monitoring Equipment

During the study, 24-hour VOC samples were collected every 6th day at all five study locations using Xonteck Model 910 Canister Samplers housed in monitoring shelters. The sample collection schedule corresponded to that used for RIDEM's permanent VOC monitoring sites, which were used as comparison sites. The Rhode Island Department of Health (RIDOH) Air Pollution Laboratory (APL) analyzed samples from study and comparison sites according to EPA Method TO-15A using an Agilent Gas Chromatography/Mass Spectrometry (GC/MS) instrument purchased for the study. The EPA method quantifies concentrations of approximately 60 VOCs in the canister samples. RIDEM collected VOC samples between June 2021 and October 2022.

The new GC/MS analyzer was installed on June 23, 2021 and the Entech Preconcentrator used in conjunction with that instrument was upgraded on July 21-23, 2021. Tuning the new instrument required resolution of communication issues and software problems and reinstallation of a computer. Calibration was officially completed on July 27, 2021 and canister samples were run on the system beginning on July 28, 2021.

In addition, problems with the VOC sample collection equipment also occurred. The fleet of Xonteck samplers used for the study consisted of both previously owned units and units that were newly purchased with grant funds. The purchase of the new units was complicated by the pandemic and communication issues with the Xonteck staff, resulting in major delays in receiving the new units. Once received, it was determined that some of the new units had toluene contamination, poorly installed and loose-fitting parts, and other issues requiring RIDOH APL to return that equipment to the manufacturer.

Additionally, some sampling runs were missed or failed due to power failures, flow rate issues, or low final pressure in the cannisters. The APL voided any samples that did not meet the data quality criteria specified in the QAPP. Data capture is discussed further in the data analysis section below.

Community Outreach Activities

RIDEM presented information on this project to the Port Community Working Group on August 18, 2022 and December 7, 2022. This group is moderated by Abby Swaine, the Ports Initiative contact for EPA Region 1, and David Everett, Principal Planner for the City of Providence, and includes community members and representatives of state agencies, universities, non-governmental organizations, ProvPort, and industry.

RIDEM also initiated direct contact with a variety of stakeholders to provide updates on the project and to solicit input on planning further monitoring initiatives based on the preliminary data. At the request of community members and other stakeholders, RIDEM formed an Air Quality Monitoring working group to discuss this project and other air quality issues in the Port area and other City neighborhoods. The kickoff virtual meeting occurred on February 8, 2023 and included community members, representatives of non-governmental agencies and Brown University, and a variety of staff from RIDEM and RIDOH. The group will continue to meet periodically.

RIDEM went live with a website specific to this project at the start of the study. The site provides background for the project, including maps of demographic characteristics and childhood asthma rates in areas around the Port, an interactive map that shows the location of Port emission sources and the land use of surrounding areas, a list of source inspections that have been conducted in conjunction with the study, and links to emissions inventory data. A map showing real time PM2.5 data was available on the site while the Clarity Node-S units were operating. RIDEM is continuing to update the website as further information becomes available.

Compliance Activities

Point Source Inspections

As part of this project, RIDEM compiled a list of 62 facilities in the Port area to be inspected to determine compliance with air pollution control regulations. As of November 21, 2023, inspections had been completed at 43 of these facilities. The facilities that have been inspected are listed on the RIDEM Port Study webpage.

Odor Checks

Driven by a combination of public complaints, RIDEM staff were regularly in the area working on the equipment as part of this study, as well as making random visits along Allens Avenue. RIDEM inspectors logged 149 odor observations between March 2021 and November 2023.

The 149 observations yielded the following results:

- 33 detected no odor
- 5 detected “objectionable” odors
- 90 detected an “asphalt” odor

- 16 detected “wastewater/sewage” type odor
- 15 detected “gas/petroleum/propane” type odor
- 7 detected “visible dust/debris” from Narragansett Improvement

As a result of the detection of objectionable odors, RIDEM issued a source a Notice of Noncompliance and continues to monitor odors in the vicinity of that source. Odor checks and enforcement actions will continue around the Port for the foreseeable future. The RI Attorney General’s Office has also began assisting RIDEM in the enforcement effort.

Study Results

PM2.5

Annual average PM2.5 levels measured at the study sites with the Clarity Node sensors and at two comparison RIDEM network sites using Federal Equivalent Method (FEM) monitors are shown in Figure 2. Data were collected for the entire calendar year of 2021 but operating of the nodes was discontinued in October 2022, so Figure 2 shows averages for the 2021 calendar year and for the 12-month period of October 2021 through September 2022. As discussed above, Clarity Sensor data tend to read somewhat higher than FEM monitors, and thus cannot be directly compared to the National Ambient Air Quality Standards (NAAQS). However, that all annual average PM2.5 concentrations measured are lower than the annual average NAAQS for PM2.5, which EPA recently revised from 12.0 to 9.0 micrograms per cubic meter (µg/m^3).

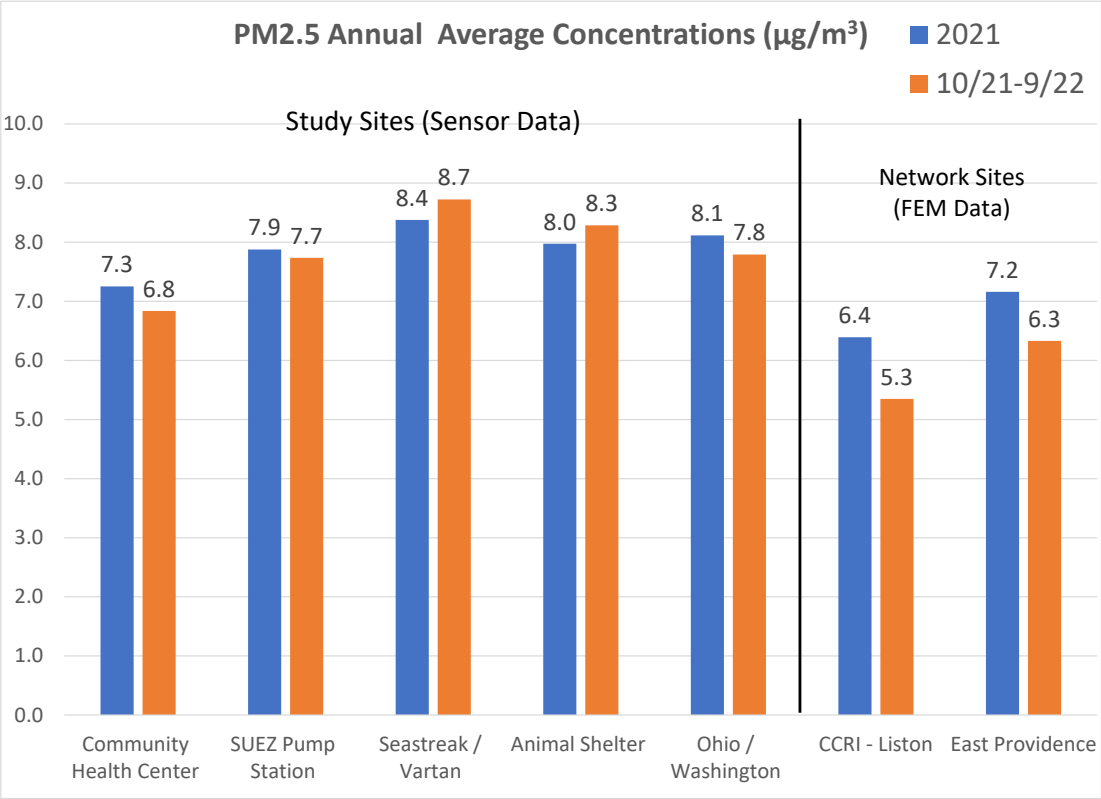

Figure 2. Annual average PM2.5 concentrations for study and comparison sites for calendar year 2021 and for the last 12 months of sensor operation (October 2021-September 2022). Study site PM2.5 levels were measured with Clarity Node-S sensors and comparison site PM2.5 with FEM monitors.

The short-term (24-hour) NAAQS for PM2.5 is 35 µg/m^3, measured as the average of the 98th percentile 24-hour values for three consecutive years. Figure 3 shows the 98th percentile 24-hour PM2.5 concentrations for the same time periods as in Figure 2, the 2021 calendar year and the 12 month period of October 2021-September 2022, that were measured by the study site sensors and the comparison site FEM monitors. As noted previously, the sensors tend to read somewhat higher than the FEMs and cannot be directly compared to the NAAQS. Note, however, that the

24-hour PM2.5 concentrations at all sites were substantially lower than the 24-hour PM2.5 NAAQS.

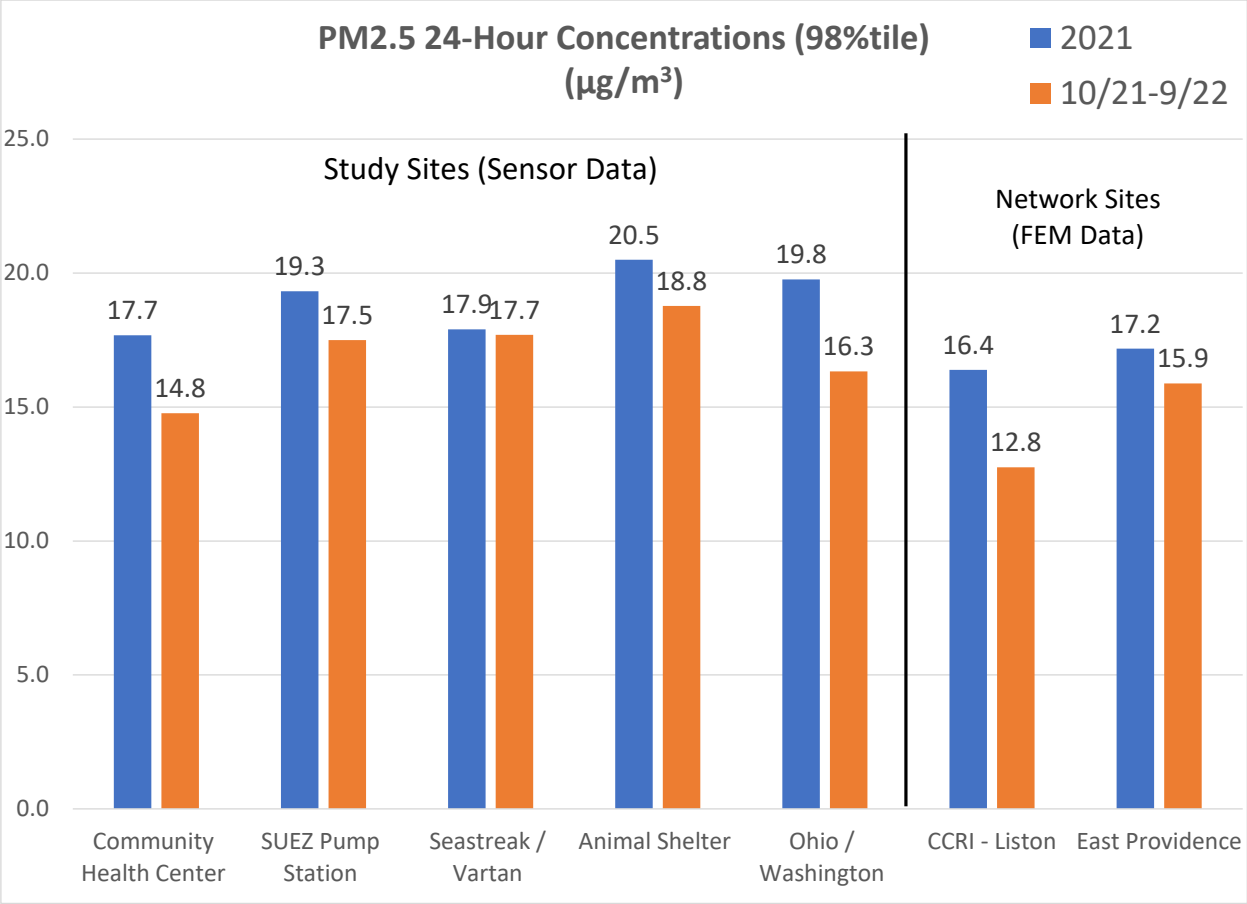

Figure 3. 98th percentile 24-hour PM2.5 concentrations at study and comparison sites for calendar year 2021 and for the last 12-months of sensor operation (October 2021-September 2022). Study Site PM2.5 Levels were measured with Clarity Node-S sensors and comparison sites with FEM monitors.

As shown in Figure 4, PM2.5 concentrations showed a high correlation between study sites on most days. Table 1 shows the correlation of determination, abbreviated as r^2, between each pair of sites. The r^2 value is the portion of the variability in concentrations at one site that can be explained by the variability at the other site. All r^2 values are 0.94 or higher, an extremely high level of correlation. This is consistent with the results of other studies. Ambient PM2.5 concentrations tend to be similar throughout an area, varying largely according to the concentrations in the air masses entering the region from upwind locations. Local sources tend to add a relatively small additional portion of PM2.5 to those concentrations.

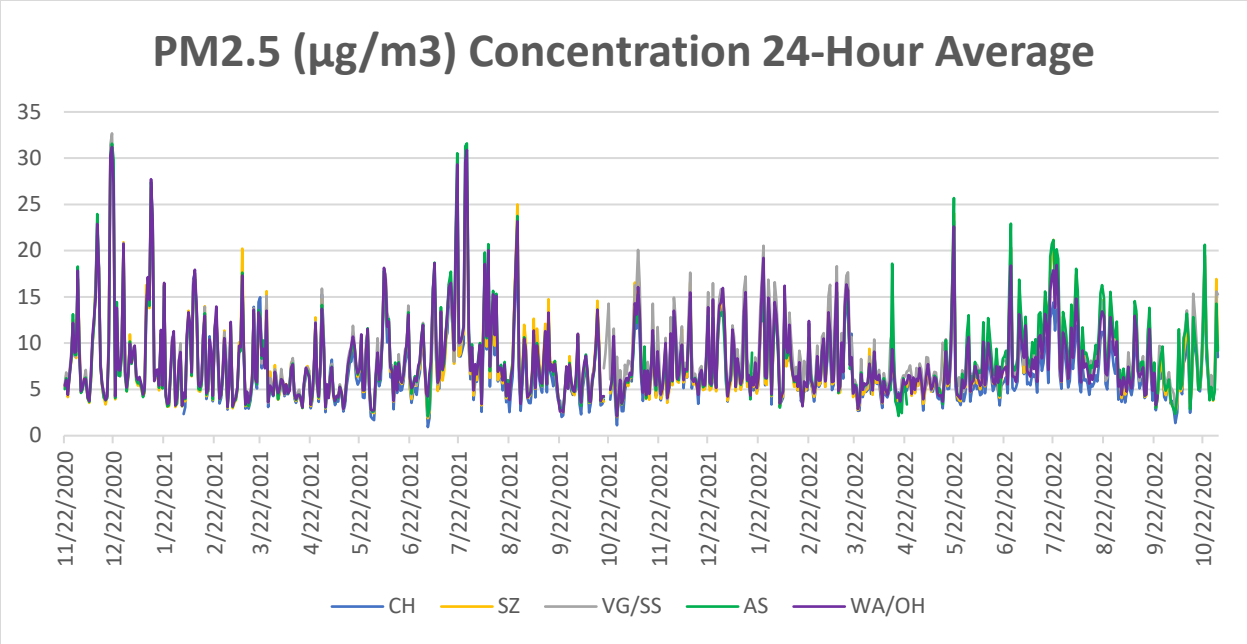

Figure 4. 24-Hour PM2.5 concentrations at study sites. Note that the Clarity sensor at the Ohio Avenue site did not operate after 9/24/22.

Table 1. Correlation (r^2) between daily PM2.5 concentrations at study sites.

	CH	SZ	VG/SS	AS	WA/OH
CH	1.00	0.92	0.91	0.88	0.96
SZ		1.00	0.95	0.96	0.97
VG/SS			1.00	0.91	0.95
AS				1.00	0.95
WA/OH					1.00

Figure 5 shows the average hourly PM2.5 on weekdays and weekends at each of the study sites by time of day. Concentrations at all sites showed a peak at 7:00 AM on weekdays that did not occur on weekends, an indication that PM2.5 levels in the area are affected by morning rush hour traffic. On both weekdays and weekends, concentrations tended to drop during the day, as warming occurs and vertical mixing height of air increases. Concentrations increase again in the evenings when the air cools and the mixing height decreases.

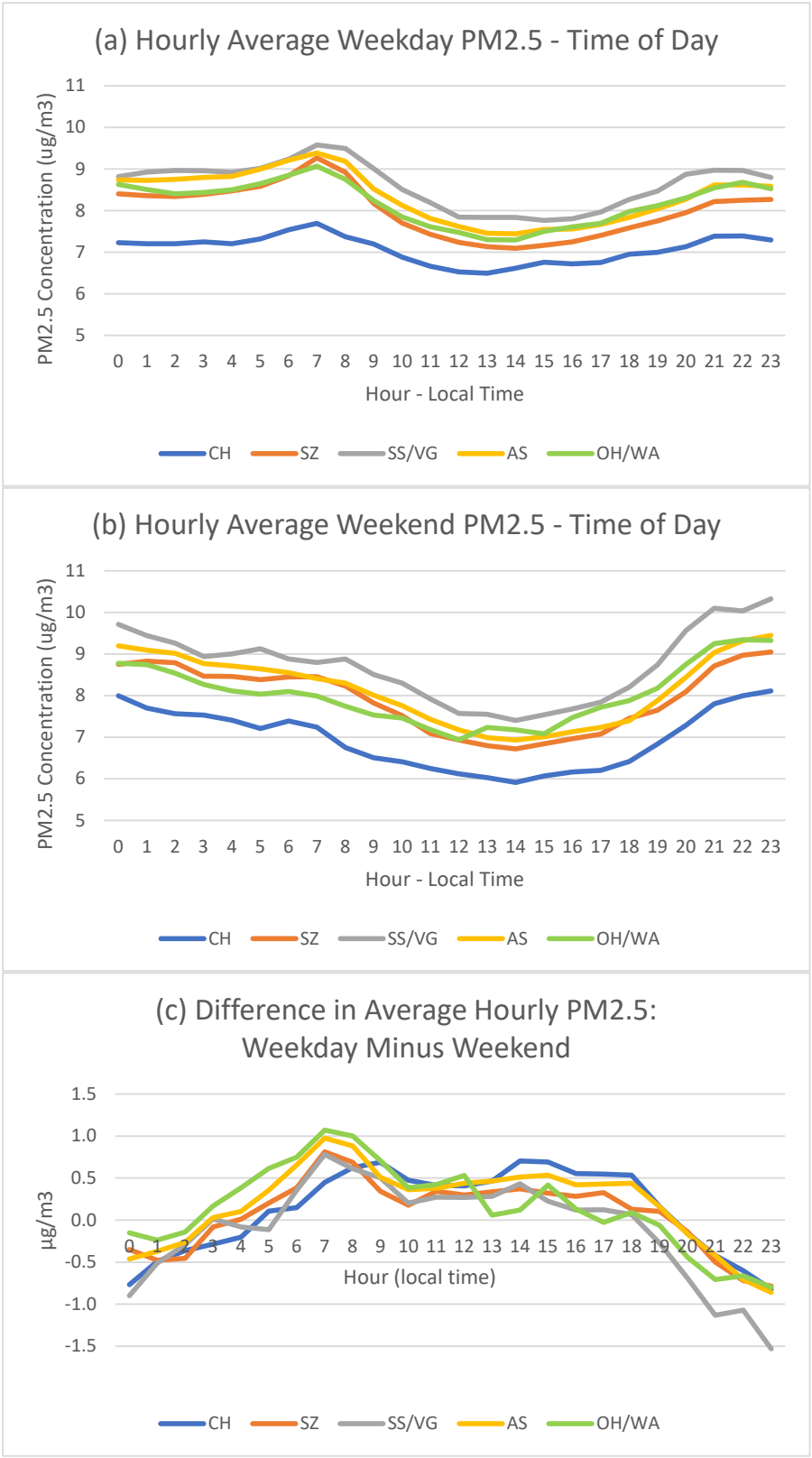

Figure 5. Average hourly PM2.5 concentrations at study sites on (a) weekdays, (b) weekends, and (c) differences between weekday and weekend averages.

While the VOC samples represent an average concentration over the 24-hour period in which the sample is collected, the sensors record hourly averages for PM2.5. In the analysis of the VOC data presented below, we used the hourly PM2.5 data, along with the meteorological data, to try to identify possible activity near or upwind of the monitoring site on days that VOC concentrations were elevated. We also attempted to use the NO_2 data for that purpose but, due to uncertainties in those data, comparison of those results between sites or over time was not possible.

VOC Data Analysis

As discussed above, RIDOH APL voided the results of VOC samples that did not meet the criteria specified in the study QAPP. RIDEM used the results of all valid VOC samples collected during the study period to evaluate potential health impacts of short-term exposures and to attempt to identify sources of elevated impacts. Annual average concentrations were calculated for samples collected from October 1, 2021 through September 30, 2022 and used to evaluate cancer risk and chronic noncancer health impacts. That period was chosen for the annual average calculation because it had the best data capture; 91% of total samples at study sites during that period were valid. Table 2 shows the number of valid samples collected at each site during the study, as well as the number and percent of valid samples collected at each site during the time period that was used to calculate annual averages.

Table 2. VOC Data Capture.

	Site	Operating Period	Total # Valid Samples	# Valid Samples 10/1/21-9/26/22	Data Capture- 10/1/21-9/26/22
Sites Operated throughout the Study	AS	6/3/21- 10/20/22	79	58	95%
	CH	6/3/21-10/2/22	74	54	89%
	SZ	6/3/21-10/8/21	74	58	95%
Other Final Sites	OH	10/1/21-10/14/22	59	57	93%
	SS	10/7/21-10/8/22	53	51	84%
Discontinued Initial Sites	WA	6/3/21-9/25/21	17	0	0%
	VG	6/3/21-9/19/21	14	0	0%
Total - All Study Sites			370	278	91%

The VOC analysis method used by RIDOH APL quantifies concentrations of approximately 60 VOCs. The maximum concentration of each substance measured at each site on any day in the study period are shown in Table A-1 in the Appendix. Note that WA and OH are grouped together in that table, as are VG and SS. As shown in Table 2, above, samples were collected at WA and VG samples in June to September of 2021. Those sites were moved to OH and SS, respectively, at the beginning of October 2021 and operated at those locations until October 2022, the end of the study. Average concentrations of each substance at each site for the one-year period of October 1, 2021 through September 26, 2022 are shown in Table A-2 in the Appendix. The WA and VG monitors were moved to OH and SS, respectively, prior to this period.

To identify the VOCs that were present in levels that may be associated with health impacts, the annual average concentrations in Table A-2 were compared to cancer benchmarks derived by EPA and the state of California (CA) and noncancer chronic health benchmarks derived by EPA, CA, and the U.S. Department of Health and Human Services' Agency for Toxic Substances and Disease Registry (ATSDR). Maximum daily concentrations at each site, as listed in Table A-1, were compared to health benchmarks derived by those agencies for shorter exposure periods.

Cancer Risk

EPA and CA have developed cancer unit risk values for 23 of the VOCs measured in this study.[3] The EPA and the National Toxicology Program (NTP)[4] have classified five of those substances as known human carcinogens; those VOCs are vinyl chloride; benzene; 1,3-butadiene; ethylene oxide; and trichloroethylene. Thirteen VOCs have been classified by one or both of those agencies as probable or reasonably anticipated to be human carcinogens - acrylonitrile; acetaldehyde; chloroform; 1,2-dichloroethane; bromoform; 1,3-dichloropropene; naphthalene; p-dichlorobenzene; dichloromethane; carbon tetrachloride; 1,2-dibromoethane; tetrachloroethylene; and 1,1,2,2-tetrachloroethane. Four of the remaining five substances −1,1-dichloroethane; 1,1,2-trichloroethane; 1,1,1,2-tetrachloroethane; and ethylbenzene −are classified as possible human carcinogens by EPA or the International Agency for Research on Cancer (IARC).[5] The remaining substance, methyl-t-butyl ether (MTBE) did not meet any of those criteria but was included in this analysis for completeness.

The EPA and CA unit risk factors were used to calculate the concentrations of those pollutants, in units of micrograms per cubic meter ($\mu g/m^3$), associated with a one in one million (10^{-6}) cancer risk with lifetime exposure. Those values were then converted parts per billion (ppb), the units used to report the monitored concentrations. The EPA and CA 10^{-6} cancer risk health benchmarks, along with the EPA and NTP cancer classifications and the unit conversion factors, are listed in Table A-3 in the Appendix.

Table 3 shows the cancer risk for each of the 23 study VOCs with EPA or CA cancer risk values. To calculate those risks, the average monitored values listed in Table A-2 were divided by the corresponding one in one-million cancer health benchmarks (in ppb) in Table A-3. For substances with both EPA and CA cancer health benchmarks, the more stringent was used. As can be seen in Table 3, concentrations of 11 VOCs were at or above the cancer benchmark (lifetime cancer risk at or greater than one in one-million) at one or more study sites. Those substances are discussed further below in the section on Health-Significant VOCs.

Table 3. Lifetime cancer risk for VOCs at study and comparison sites (risk per one million people exposed). Values at or over the one in one-million benchmark are highlighted.

[3] EPA cancer classifications, unit risk values, and noncancer benchmarks are available on EPA's *Integrated Risk Information System (IRIS)* at: https://www.epa.gov/iris. California cancer risk values and noncancer benchmarks are listed in the *Consolidated Table of OEHHA/CARB Approved Risk Assessment Health Values*, available at: https://ww2.arb.ca.gov/resources/documents/consolidated-table-oehha-carb-approved-risk-assessment-health-values.
[4] See the list from the NTP's *15th Report on Carcinogens* at: https://ntp.niehs.nih.gov/sites/default/files/ntp/roc/content/listed_substances_508.pdf.
[5] IARC classifications are at: https://monographs.iarc.who.int/list-of-classifications/.

	AS	CH	OH	SS	SZ	AJ	CC	EP	VE
VOCs with risk greater than or equal to one in one-million at one or more study sites									
ethylene oxide	**409**	**757**	**411**	**514**	**1052**	**222**	**381**	**509**	**382**
acetaldehyde	**31**	**24**	**29**	**22**	**57**	**15**	**17**	**17**	**32**
benzene	**28**	**14**	**17**	**16**	**19**	**8**	**13**	**12**	**28**
1,3-butadiene	**22**	**7.5**	**9.3**	**8.1**	**6.1**	**2.4**	**7.7**	**5.9**	**12.1**
carbon tetrachloride	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**
naphthalene	**11**	**1.5**	**2.0**	**2.1**	**2.4**	**1.6**	**1.7**	**1.2**	**4.5**
trichloroethylene	0.5	0.2	0.3	0.2	**4.9**	0.1	0.2	0.2	0.3
chloroform	**2.6**	**2.4**	**2.7**	**2.4**	**2.7**	**2.0**	**2.4**	**2.5**	**2.3**
1,2-dichloroethane	**1.6**	**1.3**	**1.5**	**1.3**	**1.4**	**1.2**	**1.3**	**1.3**	**1.4**
acrylonitrile	0.0	0.0	0.0	**1.6**	0.0	0.0	0.0	0.3	0.3
ethylbenzene	**1.1**	0.5	0.6	0.5	0.4	0.1	0.4	0.3	0.6
VOCs with risk less than one in one-million at all study sites									
dichloromethane	0.3	0.3	0.4	0.3	0.3	0.3	2.0	0.4	0.5
p-dichlorobenzene	0.4	0.3	0.7	0.3	0.3	0.2	0.4	0.2	0.4
tetrachloroethylene	0.6	0.6	0.6	0.5	0.6	0.2	0.6	0.4	0.5
1,2-dibromoethane	0.2	0.2	0.1	0.2	0.5	0.4	0.1	0.1	0.0
vinyl chloride	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2
1,1,2-trichloroethane	0.03	0.04	0.04	0.04	0.04	0.06	0.05	0.05	0.04
bromoform	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02
1,1-dichloroethane	0.009	0.008	0.009	0.008	0.009	0.008	0.008	0.008	0.009
1,1,2,2-tetrachloroethane	0.000	0.000	0.004	0.000	0.007	0.003	0.000	0.000	0.000
1,3-dichloropropene	0.001	0.001	0.001	0.001	0.002	0.001	0.000	0.001	0.000
1,1,1,2-tetrachloroethane	0	0	0	0	0	0	0	0	0
methyl-t-butyl ether	0	0	0	0	0	0	0	0	0

Chronic Noncancer Effects

Health benchmarks for chronic noncancer health effects were available from EPA, CA, and/or the US Agency for Toxic Substances and Disease Registry (ATSDR)[6] for 36 of the VOC species measured. Those benchmarks, which are listed in Table A-4 of the Appendix, were compared to the average concentrations of those VOCs at each study and comparison site. As with the cancer assessment, when more than one chronic noncancer benchmark was available for a substance, the most stringent was used for the comparison. As shown in Table 4, concentrations of only two of the VOCs, acrolein and acetaldehyde, exceeded a chronic health benchmark. Those substances are discussed further in the section on Health-Significant VOCs.

[6] ATSDR Minimal Risk Levels (MRLs) for Hazardous Substances are available at: https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx.

Table 4. Average VOC concentrations at study and comparison sites divided by chronic noncancer benchmark. A value greater than one means that the concentration exceeded the benchmark.

	AS	CH	OH	SS	SZ	AJ	CC	EP	VE
VOCs that exceeded chronic noncancer benchmark at one or more study sites									
acrolein	**31**	**18**	**27**	**19**	**73**	**13**	**16**	**15**	**35**
acetaldehyde	1.3	1.0	1.2	0.9	**2.3**	0.6	0.7	0.7	1.3
VOCs that did not exceed the chronic noncancer benchmark									
trichloroethylene	0.06	0.03	0.03	0.02	0.58	0.02	0.02	0.02	0.04
benzene	0.31	0.16	0.19	0.18	0.21	0.09	0.15	0.13	0.31
1,2,4-trimethylbenzene	0.11	0.04	0.06	0.05	0.03	0.01	0.03	0.02	0.05
naphthalene	0.10	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.04
1,3-butadiene	0.07	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.04
1,3,5-trimethylbenzene	0.04	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01
chloromethane	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
xylenes	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
carbon tetrachloride	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
bromomethane	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ethylene oxide	0.004	0.008	0.005	0.006	0.012	0.002	0.004	0.006	0.004
toluene	0.010	0.002	0.003	0.002	0.003	0.001	0.002	0.002	0.011
acetonitrile	0.005	0.004	0.005	0.005	0.007	0.007	0.006	0.005	0.004
1,2-dichloropropane	0.003	0.003	0.004	0.003	0.005	0.003	0.004	0.003	0.004
dichloromethane	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.001	0.001
tetrachloroethylene	0.003	0.003	0.003	0.002	0.003	0.001	0.003	0.002	0.002
hexane	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.001
acrylonitrile	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.001
ethylbenzene	0.002	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.001
chloroform	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
p-dichlorobenzene	0.001	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.001
1,2-dibromoethane	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000
1,1-dichloroethene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
methyl ethyl ketone	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
styrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,2-dichloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
cyclohexane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
methyl isobutyl ketone	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
chlorobenzene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
vinyl chloride	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
chloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,3-dichloropropene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,1,1-trichloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
methyl-t-butyl ether	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Short-term Effects

EPA, CA, or ATSDR short-term health benchmarks were available for 32 of the VOC species measured. Those benchmarks are listed in Table A-5 in the Appendix. The most stringent of the short-term benchmarks available for each VOC was compared to the maximum concentration measured at each study and comparison site. As shown in Table 5, maximum concentrations of three of the VOCs, acrolein, trichloroethylene, and benzene, exceeded the short-term health benchmark at one or more sites. Those substances are discussed in the section on Health-Significant VOCs.

Table 5. VOC concentrations at study and comparison sites divided by short-term noncancer benchmark. A value greater than one means that the concentration exceeded the benchmark.

	AS	CH	WA/OH	VG/SS	SZ	AJ	CC	EP	VE
VOCs that exceeded a short-term benchmark at one or more study sites									
acrolein	**2.7**	**3.1**	**2.4**	**3.8**	**42.3**	**1.1**	**1.2**	**1.6**	**3.3**
trichloroethylene	0.3	0.09	0.1	0.2	**10.8**	0.02	0.08	0.06	0.1
benzene	**1.9**	0.4	0.5	**1.9**	**1.0**	0.3	0.4	0.4	0.8
VOCs that did not exceed short-term benchmarks									
1,2,4-trimethylbenzene	0.9	0.07	0.6	0.1	0.07	0.01	0.05	0.05	0.05
acetaldehyde	0.09	0.2	0.2	0.1	0.8	0.07	0.1	0.2	0.1
1,3,5-trimethylbenzene	0.3	0.02	0.23	0.04	0.03	0.004	0.01	0.01	0.01
1,3-butadiene	0.3	0.02	0.02	0.01	0.03	0.008	0.02	0.02	0.02
toluene	0.03	0.004	0.2	0.09	0.02	0.001	0.003	0.003	0.02
dichloromethane	0.0005	0.0007	0.001	0.0004	0.0005	0.0004	0.07	0.007	0.004
ethylene oxide	0.009	0.04	0.03	0.02	0.02	0.003	0.02	0.02	0.006
xylenes	0.007	0.0008	0.002	0.001	0.02	0.0002	0.0007	0.0006	0.001
tetrachloroethylene	0.009	0.01	0.01	0.008	0.02	0.003	0.01	0.007	0.007
1,2-dichloropropane	0.003	0.003	0.003	0.003	0.01	0.006	0.003	0.003	0.003
bromomethane	0.005	0.001	0.002	0.001	0.002	0.0007	0.001	0.001	0.001
1,1-dichloroethene	0.001	0.002	0.004	0.001	0.003	0.001	0.001	0.0008	0.002
carbon tetrachloride	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
acetone	0.001	0.002	0.002	0.002	0.003	0.0008	0.001	0.003	0.002
methyl ethyl ketone	0.0008	0.001	0.001	0.001	0.002	0.0006	0.0006	0.001	0.001
chloroform	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001
chloromethane	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002
acrylonitrile	0.0002	0.0002	0.0001	0.001	0.0009	0.0001	0.0001	0.0002	0.0001
1,1,2-trichloroethane	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.001
ethylbenzene	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
1,3-dichloropropene	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
p-dichlorobenzene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
vinyl chloride	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
styrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
trans-1,2-dichloroethene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,2-dichloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,1,1-trichloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

methyl-t-butyl ether	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
chloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Health-Significant VOCs

Average concentrations of 12 of the VOC species measured exceeded the cancer or chronic noncancer health benchmark at one of more study sites. The maximum concentration of three of those substances also exceeded the short-term health benchmark at one or more of the study sites. Those substances and the benchmark exceeded are listed in Table 5 and discussed below. Note that the cancer benchmarks, which correspond to a one in one-million cancer risk, are, in most cases, much more stringent than noncancer benchmarks.

Table 5. VOCs that exceeded cancer, chronic noncancer, or short-term benchmarks.

	Cancer	Chronic Noncancer	Short-term
acetaldehyde	X	X	
acrolein		X	X
acrylonitrile	X		
benzene	X		X
1,3-butadiene	X		
carbon tetrachloride	X		
chloroform	X		
1,2-dichloroethane	X		
ethylbenzene	X		
ethylene oxide	X		
naphthalene	X		
trichloroethylene	X		X

Acetaldehyde

Acetaldehyde is classified by EPA as a probable human carcinogen based on evidence of increased incidence of nasal and laryngeal tumors in animal inhalation studies. EPA also has set a very stringent chronic noncancer inhalation reference concentration (RfC) for acetaldehyde to prevent nervous and respiratory system effects, specifically degeneration of olfactory epithelium (the tissue inside the nasal cavity involved in smell). As shown in Figure 6, average (mean) concentrations of acetaldehyde were above the 10^{-6} cancer benchmark at all sites, including the AJ rural comparison site, and were at or near the chronic noncancer benchmark at the study sites and the VE comparison site in Pawtucket.

Acetaldehyde is present in wood smoke and exhaust from vehicles, lawn and garden equipment, and construction, mining, and industrial equipment. It is also formed in the atmosphere by reactions of other pollutants.[7]

[7] EPA EnviroAtlas Fact Sheet: Acetaldehyde Air Toxics. Available at: https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/Supplemental/Acetaldehydeairtoxics.pdf.

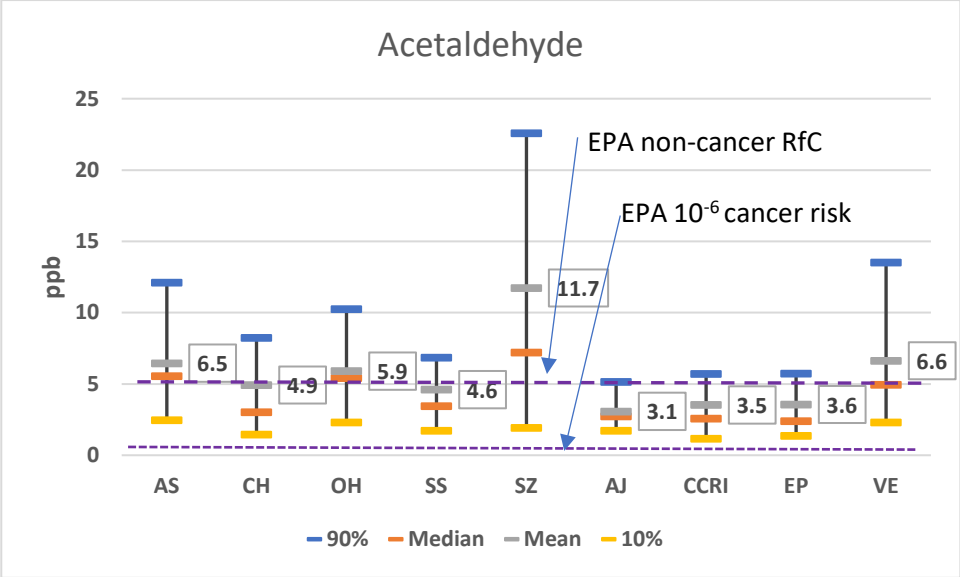

Figure 6. Distribution of acetaldehyde concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

The average concentration of acetaldehyde was particularly high at the SZ site, which is at the SUEZ pump station in East Providence, across the bay from the Port. As shown in Figure 7, the elevated average concentration of acetaldehyde at that site is largely due to very high concentrations measured in the July 16, 2022 sample and continued elevated levels in the subsequent weeks. Elevated levels of several other VOCs were also measured at the SZ site in that period. The VOC levels at SZ are discussed later in the "Elevated levels of multiple pollutants at the SZ site" section.

Apart from SZ, the highest acetaldehyde levels were, on average, at the AS site, which is the on-Port location, and the VE comparison site, which is in a residential area in Pawtucket adjacent to I-95, likely due to the presence of acetaldehyde in vehicle and equipment exhaust. Acetaldehyde concentrations at the OH site were, on average, higher than at the SS and CH sites and the other comparison sites. Higher acetaldehyde levels at that site did not correspond to days with higher acetaldehyde levels at the AS on-Port site.

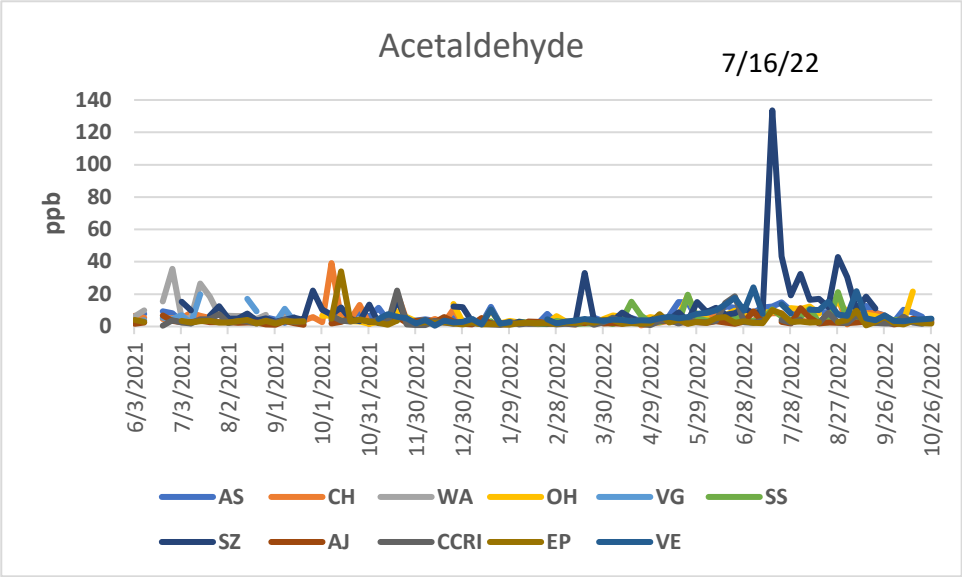

Figure 7. Acetaldehyde concentrations (ppb)in 24-hour VOC samples at study and nearby comparison sites (6/3/21-10/20/22).

Acrolein

As shown in Figures 8 and 9, acrolein levels had a pattern similar to that of acetaldehyde; the highest average acrolein concentration was at the SZ site, due to the highly elevated levels of that pollutant at that site on July 16, 2022 and the continued higher than normal levels in subsequent weeks.

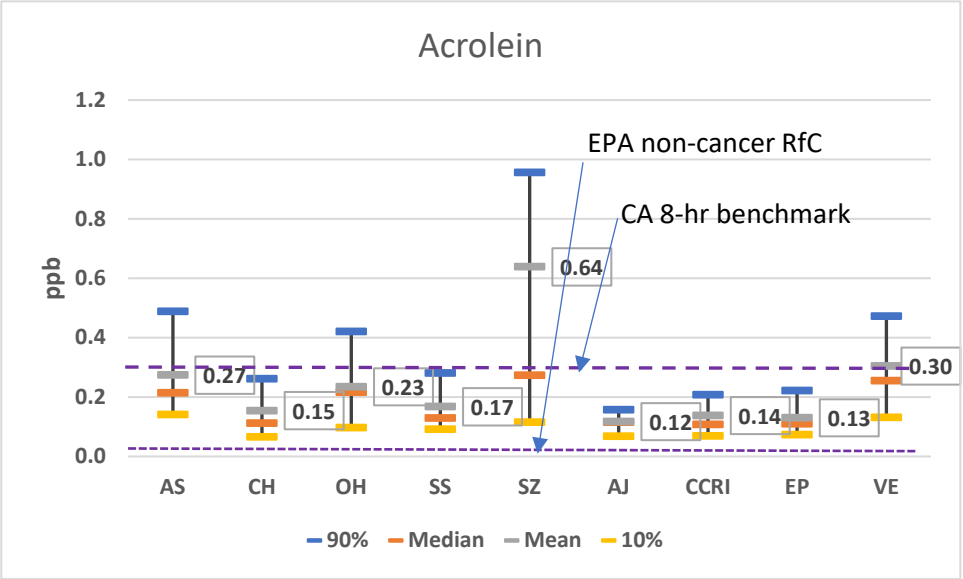

Figure 8. Distribution of acrolein concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

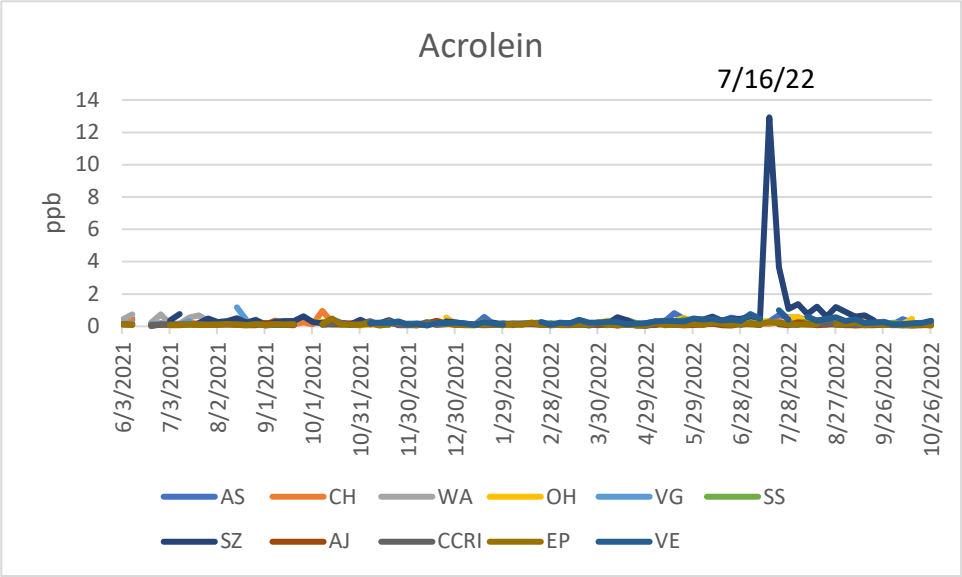

Figure 9. Acrolein concentrations (ppb)in 24-hour VOC samples at study and nearby comparison sites (6/3/21-10/20/22).

Acrolein is not classified as a carcinogen, but the average concentrations at all sites, including the rural AJ comparison site, were considerably above EPA's noncancer chronic RfC, which is set to prevent respiratory effects. As with acetaldehyde, average acrolein levels at sites other than SZ were highest at the VE and AS sites and higher at OH than at the SS and CH sites and the CCRI and EP comparison sites.

Acrolein and acetaldehyde also have similar sources. Acrolein is a component of vehicle exhaust and wood smoke and is emitted by power plants and other industrial sources. It is also present in tobacco smoke and can be formed in the air as a photochemical reaction product.[8] Daily concentrations of acrolein tended to correlate well with acetaldehyde concentrations at the urban sites.

24-hour average concentrations of acrolein at study sites and the VE comparison site also frequently exceeded CA's 8-hour Reference Exposure Level (REL), which is set to protect from respiratory effects associated with short-term exposures to acrolein. Figure 10 shows the percentage of samples at each site with acrolein concentrations above that level.

[8] EPA EnviroAtlas Fact Sheet: Acrolein Air Toxics. Available at: https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/Supplemental/Acroleinairtoxics.pdf.

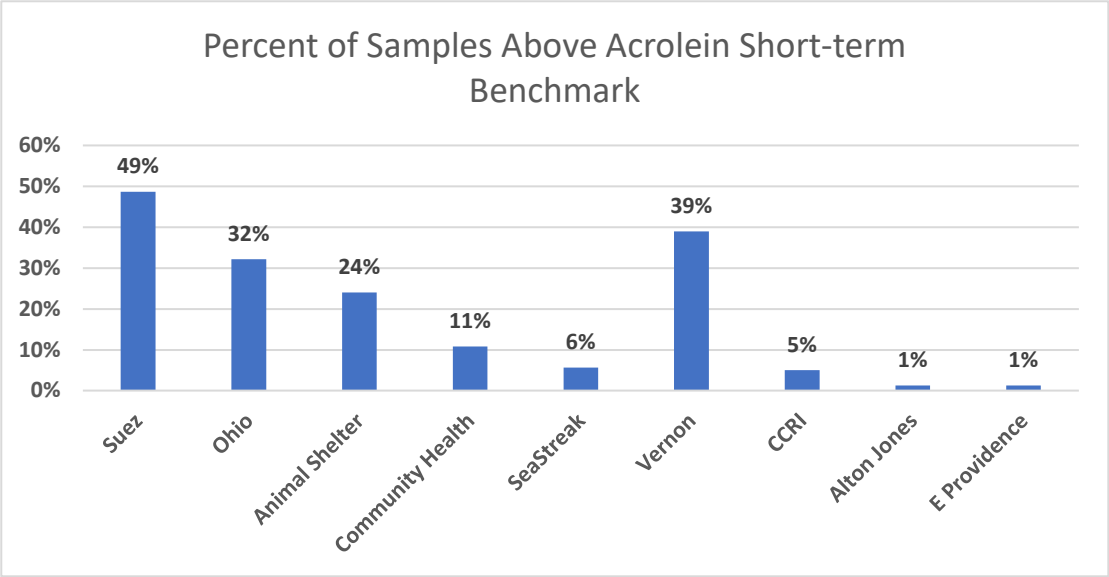

Figure 10. Percentage of samples at each site with acrolein concentrations above short-term health benchmark.

Acrylonitrile

Acrylonitrile, which is classified as a probable human carcinogen, was not detected in the vast majority of samples from the study and comparison sites. However, the acrylonitrile level measured on November 18, 2021 at the SS site was high enough to cause the average concentration at that site to exceed the 10^{-6} cancer risk level. The source of the elevated level at SS on that day is not known; acrylonitrile is not naturally occurring and is used primarily in manufacturing products like synthetic fibers, resins, plastics, elastomers, and rubber. It is also present in cigarette smoke.[9] Note that benzene levels were also very high at SS on that day, as discussed in the following section.

Benzene

EPA classifies benzene as a known human carcinogen based on clear human and animal study evidence that benzene exposure causes leukemia. Benzene is a component of gasoline and other petroleum products and is produced in the combustion of wood and other fuels, so it is always present in ambient air. Concentrations tend to be somewhat higher in colder months due to less efficient operation of vehicle engines, increased combustion of wood and other fuels for heat, and meteorological factors. Levels in urban areas and near busy roadways tend to be higher than in more rural areas.

Average benzene levels at all study and comparison sites exceeded the levels that EPA and CA associate with a one-in-one million (10^{-6}) cancer risk, which are 0.041 and 0.011 ppb,

[9] NTP Report on Carcinogens, 15th Edition. Acrylonitrile. Available at: https://ntp.niehs.nih.gov/sites/default/files/ntp/roc/content/profiles/acrylonitrile.pdf.

respectively. Figure 11 shows the distribution of benzene levels at those sites in the samples taken between October 1, 2021 – September 26, 2022.

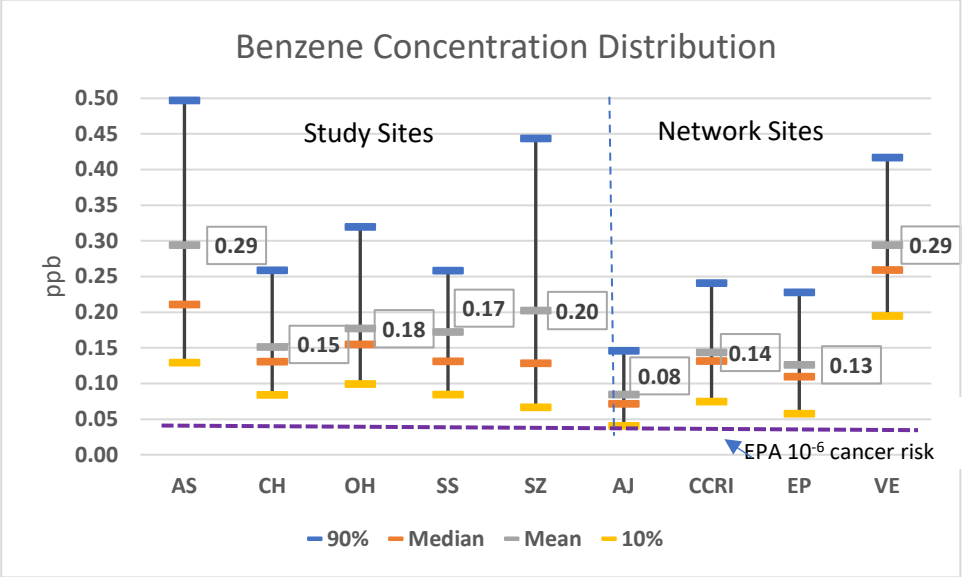

Figure 11. Distribution of benzene concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

Mean (average) concentrations were highest at the AS study site, which is the on-site Port location, and the VE comparison site, which is in a residential area immediately adjacent to I-95 in Pawtucket. Note that the distribution of concentrations at the AS site was wider than at VE, an indication that AS experienced very high benzene levels on some days and much lower levels on others, while the levels at the VE site were more consistent from day to day. As would be expected, levels were lowest at AJ, the rural comparison site. Benzene levels at the SZ site were elevated on some days, resulting in a mean concentration at that site higher than at the other off-Port study sites (CH, OH, and SS).

Figure 12 shows the daily 24-hour benzene concentrations at the study and the two closest comparison sites (CCRI and EP) throughout the study period.

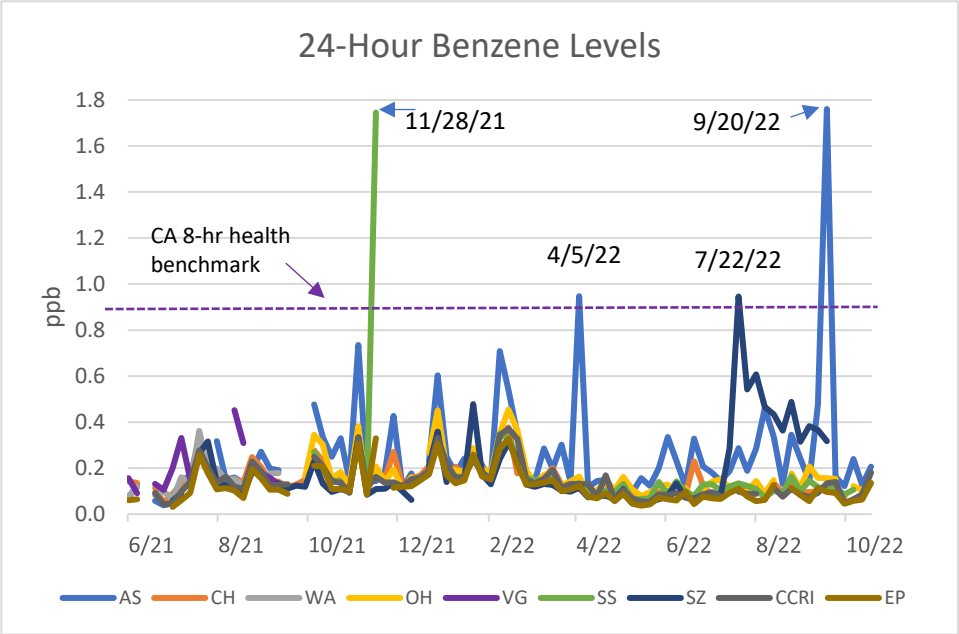

Figure 12. Benzene concentrations (ppb)in 24-hour VOC samples at study and nearby comparison sites (6/3/21-10/20/22).

Benzene levels at the study sites exceeded CA's 8-hour REL health benchmark of 0.9 ppb (3 µg/m^3) on four days. That RELis based on hematologic effects. As was the case with acrylonitrile, the benzene concentration at the SS site on Thursday, November 18, 2021,was highly elevated. Benzene levels at the SS site on all other sampling days were similar to those at the comparison sites.

For most of the day on November 18, 2021, the wind was from the SSW – SW, so the site was downwind of the Port. PM2.5 levels were in a typical range at all sites, but were higher at SS than at the other study sites for most of the day, as shown in Figure 13. Levels of other gasoline/petroleum constituents, including the other BTEX compounds (benzene, toluene, ethylbenzene, and xylenes), were not unusually elevated at SS or the other sites on that day but the level of acetonitrile, along with acrylonitrile and benzene, was very high at SS on that day. All three of those substances are present in automobile exhaust and tobacco smoke, as well as in some solvents and plastic-based materials. The source of the elevated levels on that day is not known. However, a high concentration that occurs once and does not recur is an indicator that an unusual situation may have occurred on that day, often very close to the monitor.

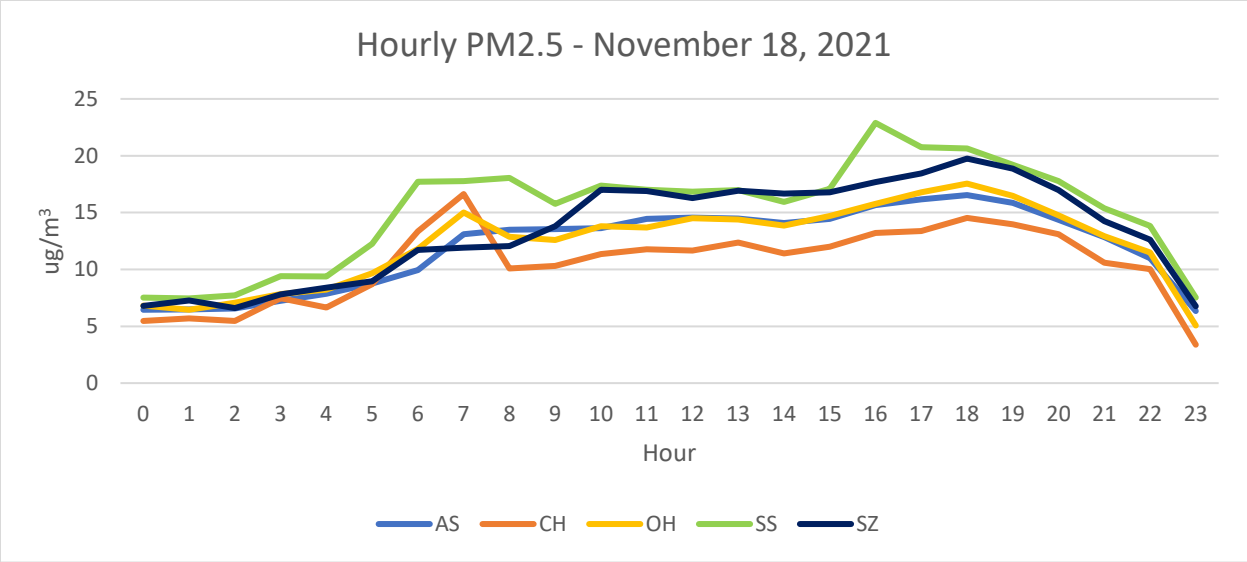

Figure 13. Hourly PM2.5 concentrations (µg/m^3) at study sites on November 18, 2021. Concentrations of benzene, acetonitrile, and acrylonitrile at the SS site were highly elevated on that day.

Benzene levels at the AS site exceeded the CA 8-hour benchmark on two days in 2022, Tuesday, April 5 and Tuesday, September 20. As shown in Figure 12, in the first several months of the study, higher benzene levels at AS generally occurred on days when levels were also somewhat elevated at other sites. However, beginning in March 2022, levels at other sites were not elevated on days that peak AS benzene concentrations occurred. Wind directions were variable on both April 5 and September 20, 2022. On April 5, 2022, winds were from the W in the morning and moved to a SE to S direction in the afternoon, while on September 20, 2022, winds were from the WSW in the morning and ENE later in the day. The VOC samples are collected over a 24-hour period, so it is more difficult to determine the source of elevated concentrations on days with variable wind directions. A wide range of mobile and stationary sources and activities in the Port area emit benzene.

PM2.5 levels at the AS site were similar to those at the other sites and in a normal range on both of the days with peak benzene levels. As shown in Figure 14, levels of all of the BTEX compounds at the AS site were higher in the September 20 sample than on any other study days. In addition, maximum concentrations of several other petroleum vapor constituents occurred on that day; hexane, heptane, cyclohexane, trimethylbenzenes, and octane. In contrast, the BTEX compounds, with the exception of benzene and, to a lesser extent, toluene, were not elevated in the April 5 sample. On that day, levels of smaller sized petroleum constituents than those seen in the September sample were elevated; butane, pentane, and hexane. This suggests that the source of the high levels of benzene on September 20, 2022 was different from the source on April 5, 2022. The RIDEM complaint investigation log for September 20, 2022 notes that strong asphalt and gas odors were observed near the Sprague terminal on that day. Odors were recorded as barely detectable of April 5, 2022. As shown in Figure 15, the elevated benzene concentrations at the AS site on those days did not result in elevated levels at the nearest off-Port sites; the CH and OH study sites and the CCRI comparison site, which are all in South Providence.

Note also that AS levels of 1,3-butadiene, which is also a known human carcinogen, was also highly elevated on September 20, 2022, as well as in the previous sample, on September 14, 2022. That pollutant was not elevated in the April 5, 2022 sample at AS. 1,3-Butadiene is not a constituent of petroleum products but is present in combustion emissions, including vehicular exhaust. 1,3-Butadiene is discussed further below.

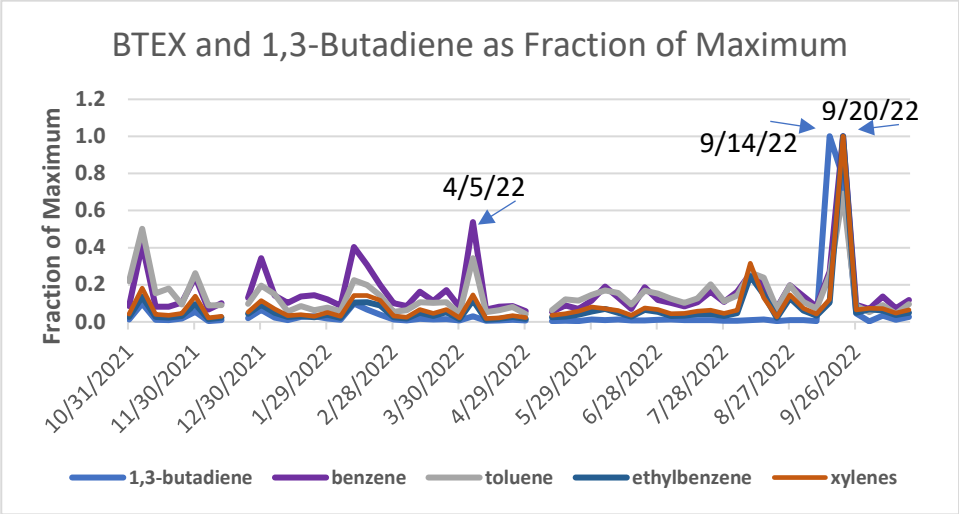

Figure 14. Concentrations of the BTEX compounds and 1,3-butadiene at the AS site as a fraction of the maximum levels of those compounds measured in study samples.

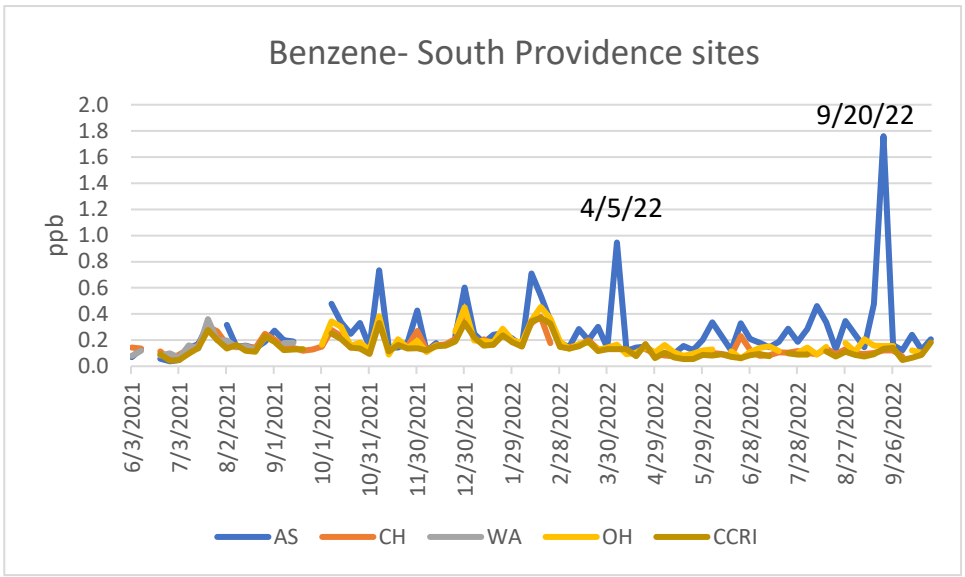

Figure 15. Benzene concentrations at study and comparison sites in South Providence.

A 24-hour benzene concentration above the CA 8-hour health benchmark also occurred at the SZ site on July 22, 2022 and concentrations of that VOC remained elevated at that location for the remainder of the study, as shown in Figure 12. Several other compounds were elevated at SZ

during that period. The elevated VOC concentration at the SZ in the last months of the study are discussed further below.

1,3-Butadiene

As shown in Figure 16, average (mean) levels of 1,3-butadiene exceeded the health benchmarks corresponding to EPA's 10^{-6} risk levels at all study and comparison sites except the rural AJ site.

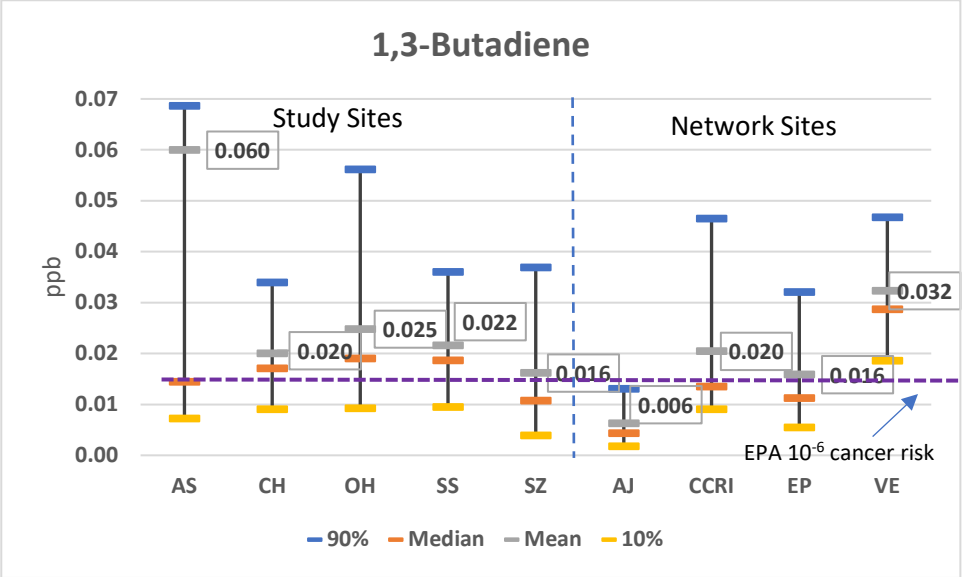

Figure 16. Distribution of 1,3-butadiene concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

The mean concentration was highest at the AS site; however that average was largely affected by highly elevated concentrations at that site on September 14 and 20, 2022, as shown in Figure 17. Note that on most days, 1,3-butadiene levels were highest at the VE comparison site, which is adjacent to residential area next to I-95 in Pawtucket.

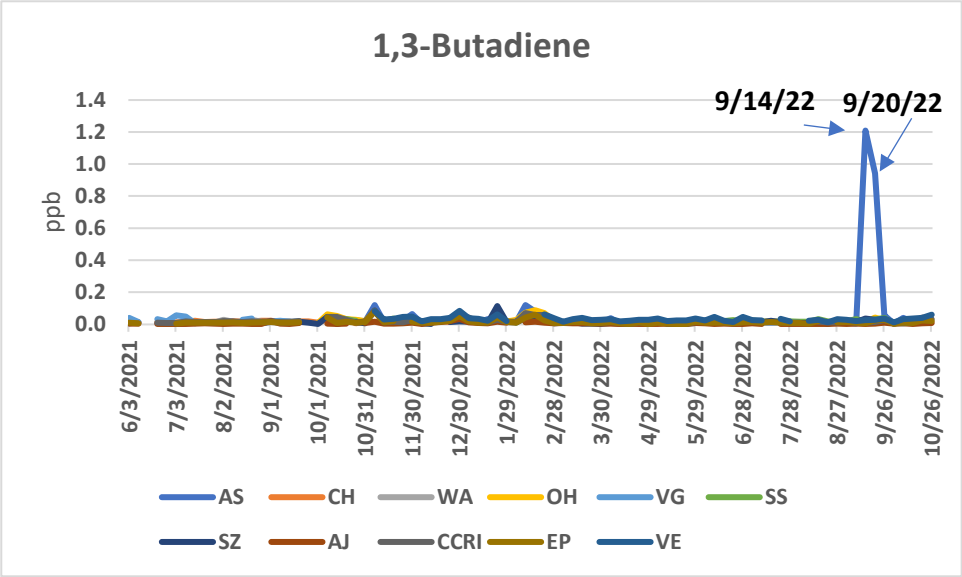

Figure 17. 1,3-Butadiene concentrations at study and comparison sites (ppb).

The wind was from the W at the AS site on September 14, 2022 and, as discussed above, winds were variable on September 20, 2022. PM2.5 concentrations were not elevated on either day. As discussed above, levels of several VOCs were elevated on September 20, 2022, including several constituents of petroleum products. That was not the case on September 14, 2022; concentrations of VOCs other than 1,3-butadiene were not elevated on that day.

Sources of 1,3-butadiene include motor vehicle exhaust, manufacturing and processing facilities, forest fires or other combustion, and cigarette smoke.[10] The source of the exceedingly high concentration of 1,3-butadiene during this time period at AS is not known. As noted above, strong asphalt and gas odors were observed near the Sprague terminal on September 20, 2022. Odors were recorded as barely detectable on April 5, 2022.

Carbon tetrachloride, chloroform, and 1,2-dichloroethane

As shown in Figure 18, concentrations of carbon tetrachloride, which is classified by the EPA as likely to be a human carcinogen, exceeded the EPA one in one-million cancer risk benchmark at all study and comparison sites. Concentrations were very consistent from site to site and from day to day. Carbon tetrachloride was formerly widely used in dry cleaning, degreasing, fumigation, consumer goods, and other applications.[11] Most uses of this chemical have been

[10] EPA fact sheet for 1,3-butadiene. Available at: https://www.epa.gov/sites/default/files/2016-08/documents/13-butadiene.pdf.
[11] ATSDR *ToxFAQs for Carbon Tetrachloride*. Available at https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=195&toxid=35#:~:text=Highlights,%2C%20kidneys%2C%20and%20nervous%20system.

banned for many years, but because carbon tetrachloride is very stable, background levels in ambient air similar to those seen in this study remain throughout the country.[12]

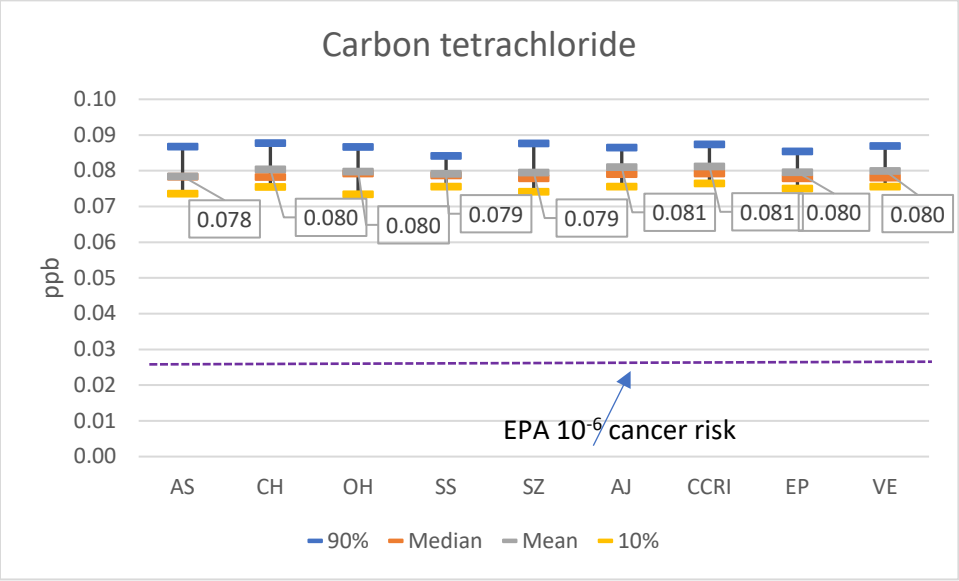

Figure 18. Distribution of carbon tetrachloride concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

Figure 19 shows the distribution of levels of chloroform at the study and comparison sites. Average concentrations of this probable human carcinogen at all sites were above the EPA one in one-million risk benchmark. Like carbon tetrachloride, chloroform breaks down slowly in the atmosphere, resulting in background levels of this pollutant in all ambient air samples. Chloroform is formed when chlorine is added to water as a disinfectant and can evaporate into indoor air during showering and other uses, and into outdoor air from wastewater at sewage treatment plants, chlorinated swimming pools, etc.

[12] EPA, 2019 AirToxScreen: Assessment Results. Available at: https://www.epa.gov/AirToxScreen/2019-airtoxscreen-assessment-results.

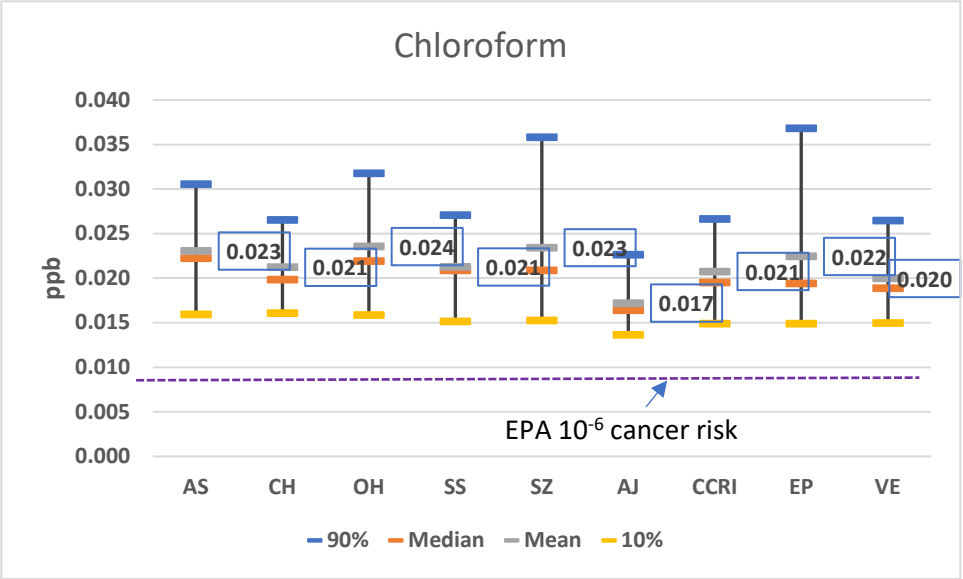

Figure 19. Distribution of chloroform concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

As shown in Figure 20, levels of 1,2-dichloroethane (also known as ethylene dichloride), a probable human carcinogen, exceeded EPA's one in one-million health benchmark at all sites, including the AJ rural comparison site. 1,2-Dichloroethane is used in chemical production and is added to leaded gasoline as a lead scavenger.[13] Figure 21 shows that with the exception of AS, daily levels of 1,2-dichloroethane tended to be similar at all study and comparison sites, an indication that those levels are associated with background concentrations. Levels of 1,2-dichloroethane were higher at AS than at the other sites on several of the study days, with the highest level occurring on April 5, 2022, a day that the concentration of benzene and several other petroleum product constituents were elevated at that site, but odors were recorded as barely detectable, as discussed above. The concentration of 1,2-dichloroethane, along with several other VOCs, was also somewhat elevated at the SZ site on July 22, 2022 and will be further discussed below.

[13] EPA factsheet for Ethylene Dichloride (1,2-Dichloroethane). Available at: https://www.epa.gov/sites/default/files/2016-09/documents/ethylene-dichloride.pdf.

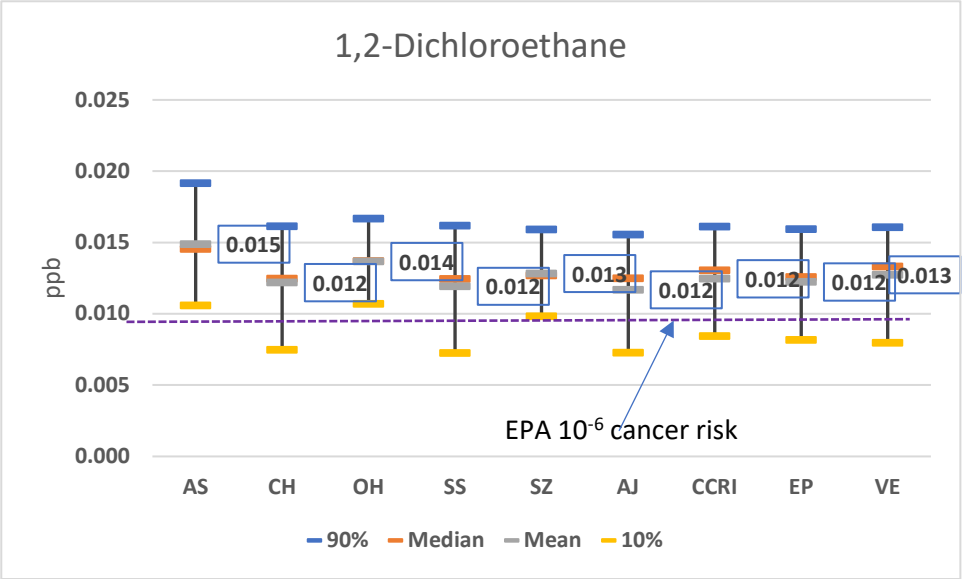

Figure 20. Distribution of 1,2-dichloroethane concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

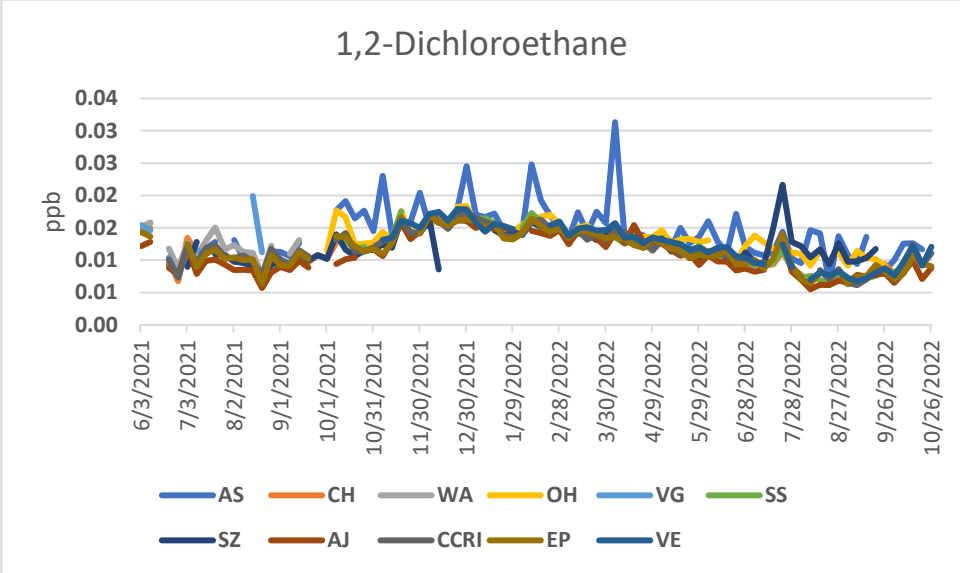

Figure 21. 1,2-Dichloroethane concentrations at study and comparison sites (ppb).

Ethylbenzene

EPA's IRIS database lists ethylbenzene as Group D, not classifiable as to human carcinogenicity. However, IARC has determined that it is possibly carcinogenic to humans. As shown in Figure 22, average ethylbenzene levels exceeded the one in one-million risk level derived by CA at only one site, the on-Port AS site. Ethylbenzene levels at the AS site were similar to those at the other urban sites on most days but the average AS ethylbenzene concentration was substantially influenced by very high levels recorded on September 20, 2022 and, to a lesser extent, on August 9, 2022.

Note that, as discussed above in the benzene discussion, all of the BTEX compounds, as well as several other petroleum vapor constituents; including hexane, heptane, cyclohexane, trimethylbenzenes, and octane; were elevated in the September 20, 2022 AS sample. Therefore, it is likely that the elevated AS ethylbenzene levels on that day are due to activity that caused excess release of gasoline or another petroleum product.

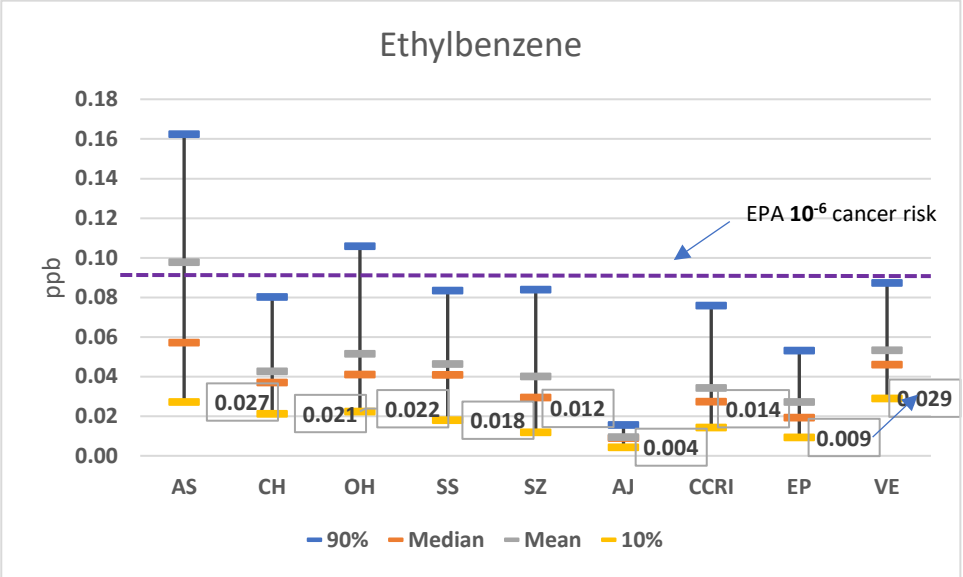

Figure 22. Distribution of ethylbenzene concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021- September 26, 2022

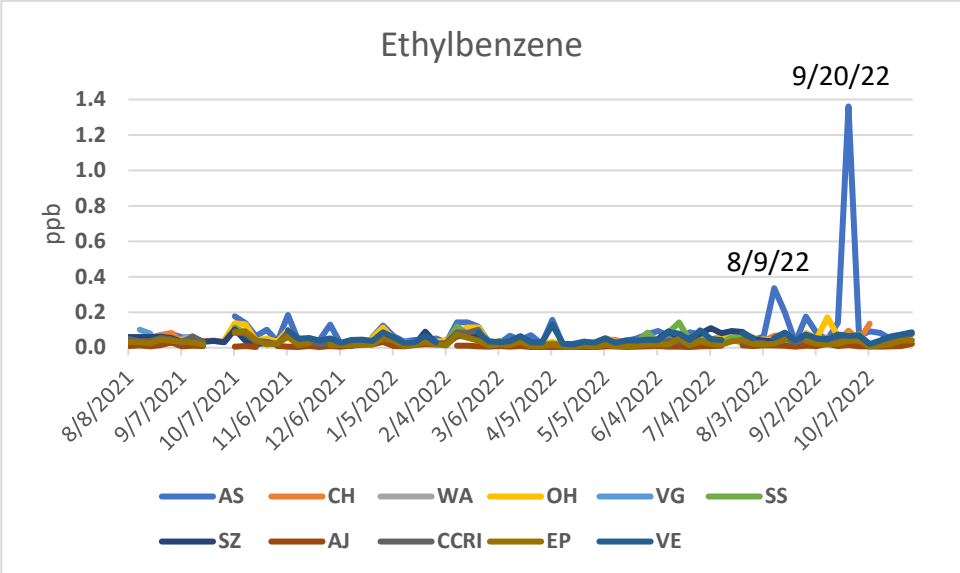

Figure 23. Ethylbenzene concentrations at study and comparison sites (ppb)

Ethylene oxide

Concentrations of the human carcinogen ethylene oxide exceeded EPA's very stringent one in one-million cancer risk benchmark for that pollutant at all study and comparison sites. EPA has identified chemical manufacturing facilities and sterilizing units as the primary sources of air emissions of this pollutant.[14] However, ethylene oxide is detected in areas across the country that are not near those sources. Emissions from combustion, including motor vehicles, may contribute to those levels. Ethylene oxide is also formed in the atmosphere by photochemical reactions.

As shown in Figures 24 and 25, average ethylene oxide levels and levels of that pollutant on several study days were highest at the SZ site. The reason for the higher levels at that site is not known but may be due to a local source of that pollutant. Note that higher concentrations occurred at the CH site in October 2021, particularly on Thursday, October 7, 2021. It is possible that operation of medical sterilizing equipment in the area near that monitor contributed to those levels. As shown in Figure 25, elevated ethylene oxide levels did not recur at that location during the remaining year of the study.

Note also that ethylene oxide is a notoriously difficult pollutant to measure accurately. RIDOH APL has shown that levels in ethylene oxide in canisters can increase over time, so concentrations may be affected by how soon the sample was analyzed after it was taken. RIDOH APL has also shown that the ethylene oxide growth occurs more readily in some canisters than in others. Therefore, although RIDOH APL has implemented measures to attempt to standardize ethylene oxide measurements, the results for this pollutant should be used with caution.

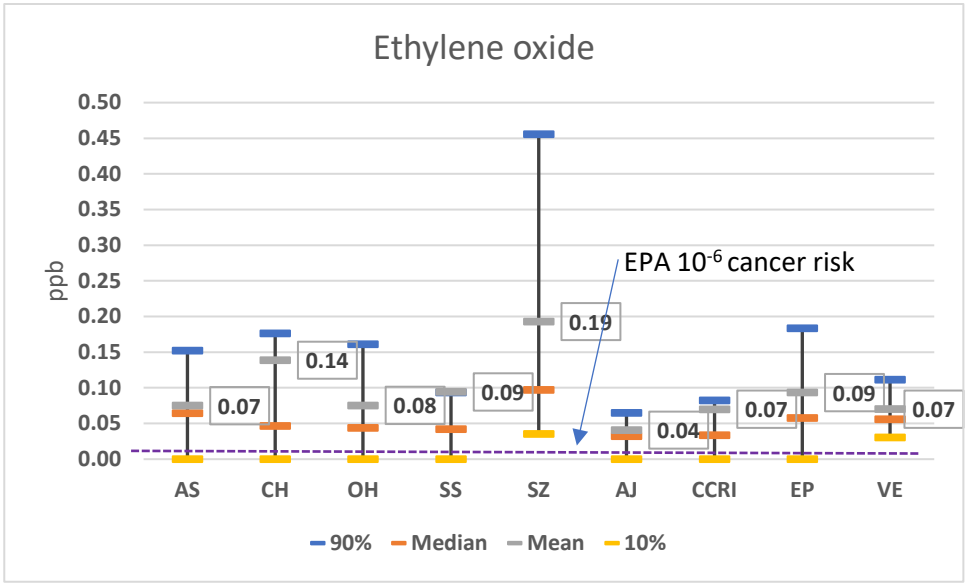

Figure 24. Distribution of ethylene oxide concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

[14] EPA's Ethylene Oxide webpage. Available at: https://www.epa.gov/hazardous-air-pollutants-ethylene-oxide/our-current-understanding-ethylene-oxide-eto.

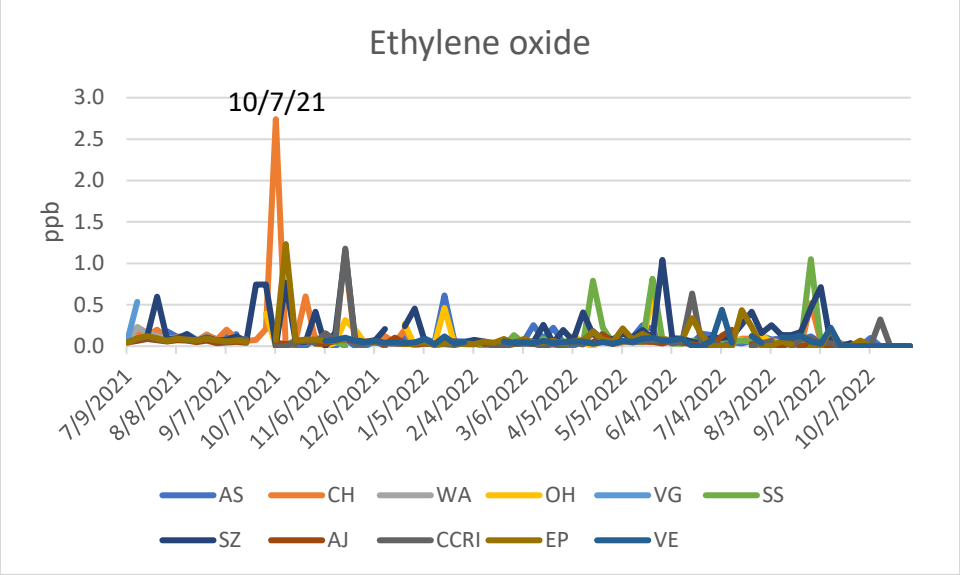

Figure 25. Ethylene oxide concentrations at study and comparison sites (ppb).

Naphthalene

Naphthalene is emitted by a variety of sources, including "the chemical and primary metals industries, biomass burning, gasoline and oil combustion, tobacco smoking, the use of mothballs, fumigants and deodorizers."[15] Naphthalene is classified by EPA as a Group C, possible human carcinogen and by the NTP as reasonably anticipated to be a human carcinogen. EPA has not developed a quantitative estimate of the carcinogenic risk associated with exposure to naphthalene. As shown in Figure 26, the average naphthalene concentration at the AS site is slightly higher than the 10^{-6} cancer risk derived from the CA unit risk factor. Levels at the other study and comparison sites are considerably below that level, although the average concentration at the VE site is approximately twice that of the other off-Port study and comparison sites, probably due to impacts from the nearby highway. Levels at all sites, including AS, are considerably lower than non-cancer health benchmarks.

[15] Jia C., Batterman S. A critical review of naphthalene sources and exposures relevant to indoor and outdoor air. Int J Environ Res Public Health. 2010 Jul;7(7):2903-39. doi: 10.3390/ijerph7072903. Epub 2010 Jul 20. Erratum in: Int J Environ Res Public Health. 2011 Aug;8(8):3191. PMID: 20717549; PMCID: PMC2922736. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2922736/.

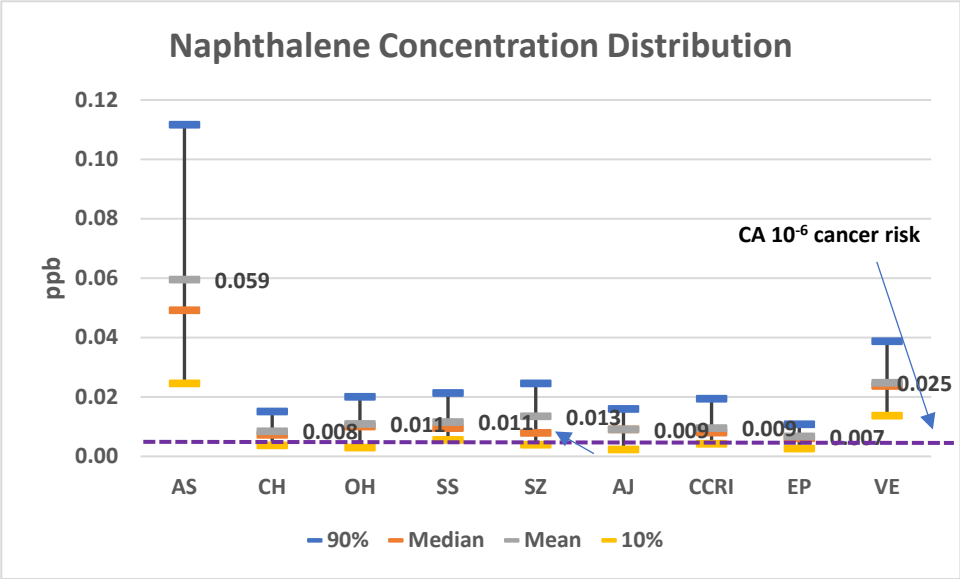

Figure 26. Distribution of naphthalene concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

Naphthalene was elevated at AS relative to the other sites on most days, particularly during the spring and summer of 2022, as shown in Figure 27. The source of those elevated levels is not clear. There is no correlation between the variation of daily naphthalene levels at AS and those levels at the other sites, so it appears that the AS source does not have measurable off-Port impacts.

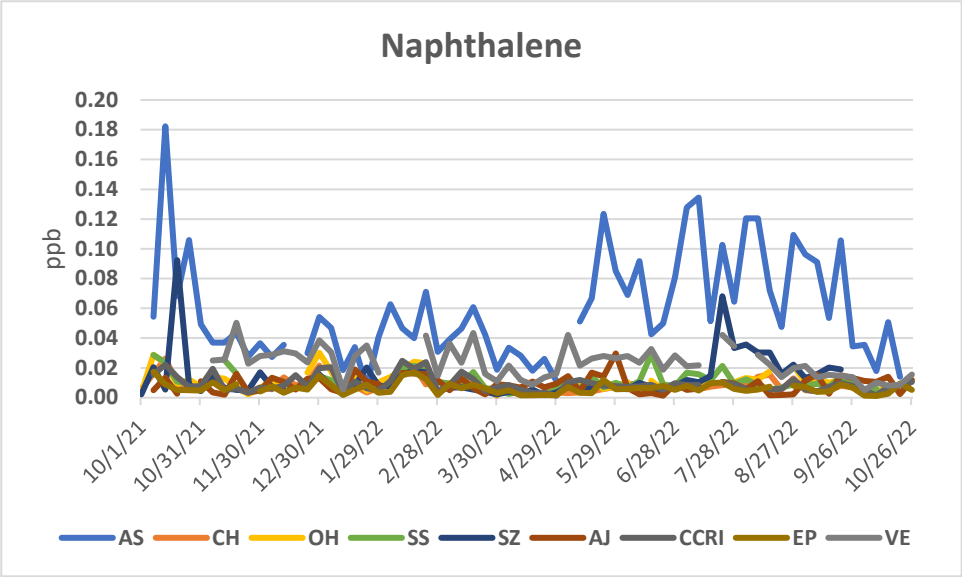

Figure 27. Naphthalene concentrations at study and comparison sites (ppb).

Trichloroethylene

The average concentration of trichloroethylene, a known human carcinogen, exceeded the EPA one in one-million benchmark at only one site, SZ, as shown in Figure 28. The primary sources of air emissions of trichloroethylene are metal cleaning and degreasing operations.[16] Use of trichloroethylene has decreased substantially in the past decades. In October 2023, EPA proposed to ban the manufacture (including import), processing, and distribution in commerce of trichloroethylene for all uses.[17]

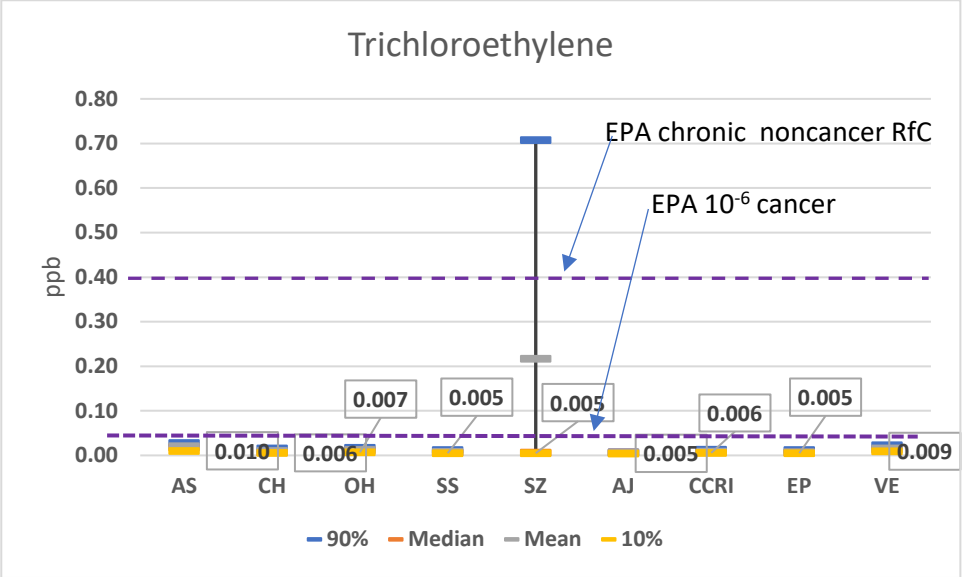

Figure 28. Distribution of trichloroethylene concentrations (ppb) in 24-hour VOC samples at study and comparison sites October 1, 2021 - September 26, 2022.

As shown in Figure 29, trichloroethylene concentrations at SZ were similar to those at the other sites until July 22, 2022. Levels remained higher than normal at that site through the end of the study period in September 2022. Trichloroethylene was one of several VOCs with elevated concentrations at SZ during that period. That phenomenon is discussed further in the following section.

[16] EPA webpage: *Sources, Emission And Exposure To Trichloroethylene (TCE) And Related Chemicals*, Available at: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=21006.
[17] EPA webpage: *Risk Management for Trichloroethylene (TCE).* Available at: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-trichloroethylene-tce.

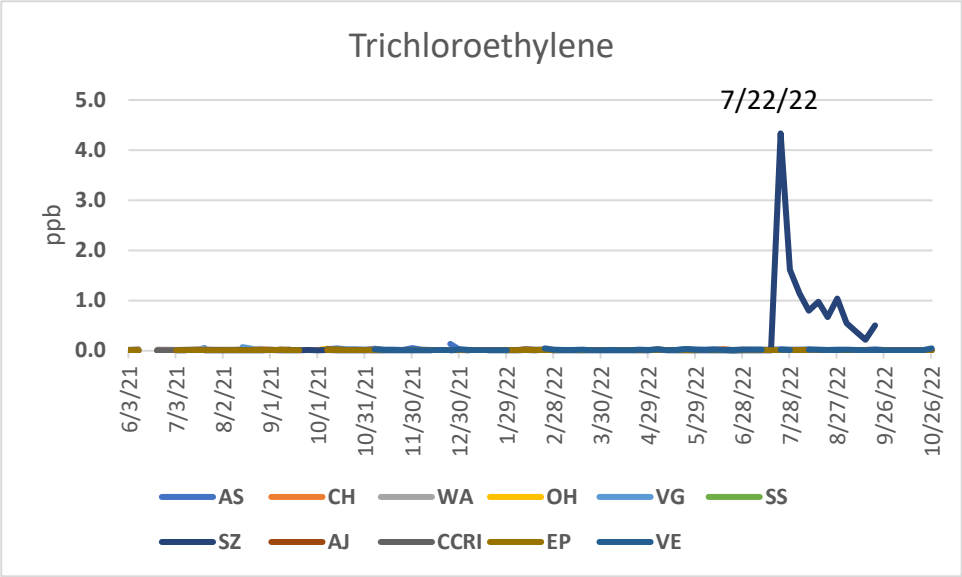

Figure 29. Trichloroethylene concentrations at study and comparison sites (ppb).

Elevated levels of multiple pollutants at the SZ site

Concentrations of several VOCs were very high at the SZ site in the July 16, 2022 sample, the July 22, 2022, or both, as shown in Figure 30. Concentrations of those pollutants decreased after those peaks but, in many cases, remained higher than had been previously recorded for the remainder of the study period.

The peak concentrations on those two days may be the result of different, although possibly related, events. For instance, the very high acetaldehyde and acrolein levels on July 16, 2022 suggest that some sort of combustion activity may have been occurring very close to the monitor on that day and the high solvent levels on July 22, 2022 could be related to maintenance activities at the pump station. It is also possible that some issue occurred with the operation of the pump station in that period or with a nearby vessel on the Bay.

The SZ site is downwind of the Port when the wind has a westerly component. On July 16, 2022, SW winds were observed at this site in the early morning (2:00 – 9:00 AM) and shifted to the S-SSE for the rest of the day. On July 22, 2022, S-SSE winds until 9:00 AM shifted to W to SW winds for the rest of the day. Therefore, it is not possible to rule out Port emissions as a possible source. However, the extremely high levels of several pollutants measured at SZ and the fact that levels of those pollutants were not elevated at any of the other sites on those days is indicative of a more local source.

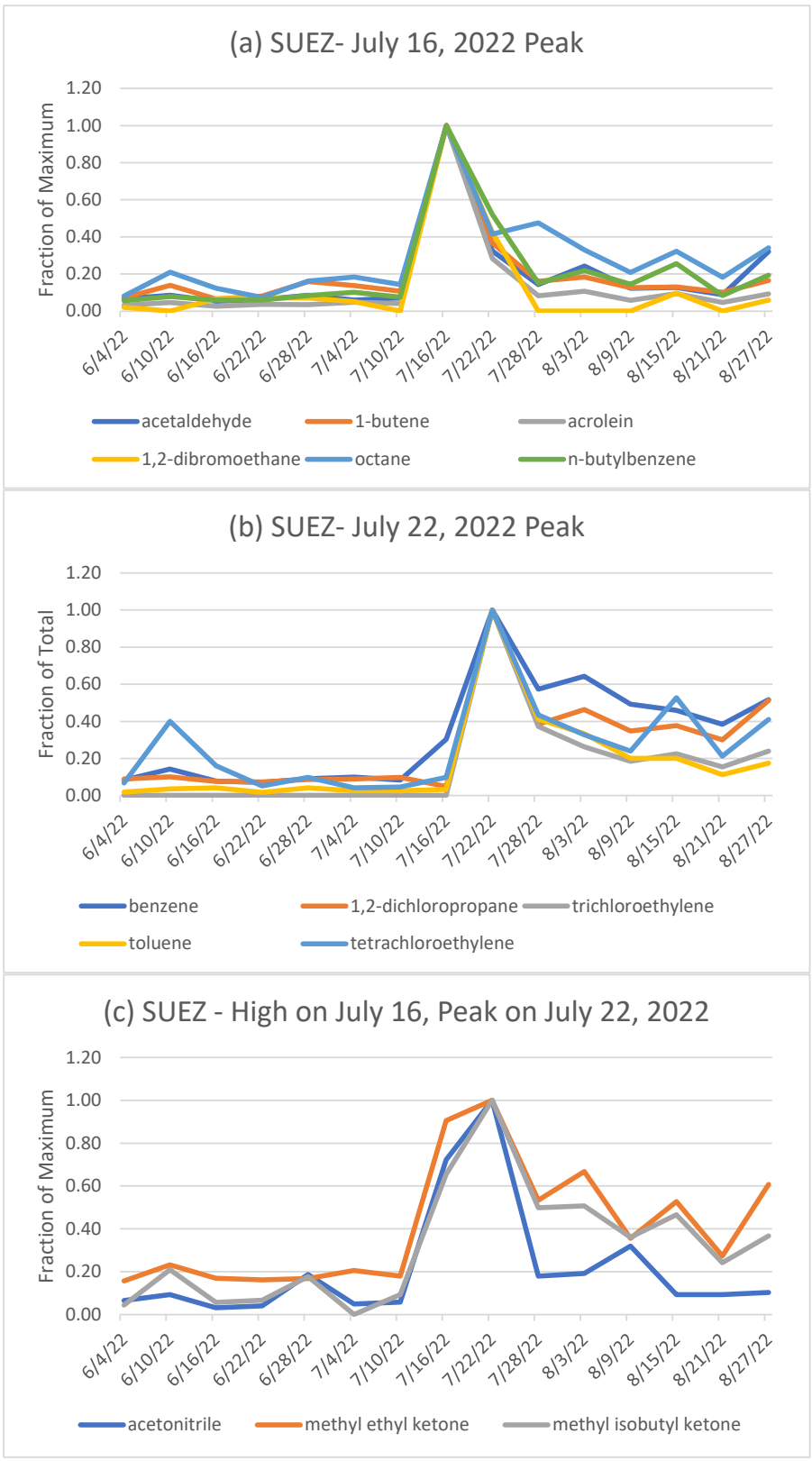

Figure 30. Elevated VOC levels at the SZ site on (a) July 16, 2022, (b) July 22, 2022, and (c) both days.

Conclusions and Recommendations

This study, which combined air quality monitoring with surveys and inspections of facilities in the area, generated a large amount of information useful for identifying sources in the Port area that may impact neighborhood air quality. Stationary sources in the Port area include oil and gas storage and distribution facilities, asphalt and cement processing, metals recycling, natural gas and utility service, and large heating plants. Air quality in the area is also affected by emissions from the extensive truck traffic related to Port operations, along with other land and marine vehicles and equipment.

Average PM2.5 levels measured at the AS site were only slightly higher than at the other study sites and daily PM2.5 measurements correlated well with those at the other sites. More substantial PM impacts may be seen at that site if a parameter more specific to diesel exhaust (e.g., black or elemental carbon) or a smaller particle size (e.g., ultrafine particles, which are generally measured as particle count) were measured. Note, however, that EPA has not set National Ambient Air Quality Standards for those parameters.

As would be expected, concentrations of VOCs that are petroleum constituents tended to be higher at the AS than at the other sites, resulting in higher cancer risks at that location. Concentrations of some of those VOCs, like naphthalene, were elevated at that site throughout the study period. A follow up survey may identify a naphthalene source that routinely operates close to the AS site.

Although it is difficult to reconstruct past activities, it may be useful to investigate the reason for the very high levels of benzene levels that were observed at the AS site on April 5, 2022 and September 20, 2022. The constellation of other VOCs that were also elevated on those dates may be helpful in identifying the source of those emissions. If, for instance, it is determined that tank cleaning or maintenance occurred on a day that benzene concentrations were elevated, that finding would support requiring further controls on those operations. Note also that levels of 1,3-butadiene, which is formed by combustion and is a constituent of vehicle exhaust, were also very elevated at the AS site on September 20, 2022, as well as on the previous sampling day, September 14, 2022. The RIDEM complaint investigation log for September 20, 2022 notes that strong asphalt and gas odors were observed near Sprague terminal on that day. Odors were recorded as barely detectable of April 5, 2022.

As discussed above, it appears that nearby activities caused extremely high levels of several VOCs in the samples taken at the SUEZ site on July 16, 2022 and July 22, 2022. As with AS, the constellation of VOC species that were elevated on each day may aid in the identification of the source of that elevation. Although concentrations of those pollutants decreased after those peaks, in many cases, levels remained higher than had been previously recorded for the remainder of the study period. It may be appropriate to take a few more samples at that site in the future to ascertain that VOC concentrations have returned to the levels observed before the incident.

In most cases, the study was not able to link elevated levels of health-significant pollutants at the AS on-Port site with higher levels of those pollutants at off-site locations on those days. However, average concentrations of several of those pollutants, including acetaldehyde, acrolein,

benzene, and 1,3-butadiene, were higher at the study sites in the South Providence area that at the CCRI comparison site, which is also in the South Providence area but farther from the Port. That finding provides further evidence to support RIDEM's efforts to focus on reducing Port emissions.

Output Goals and Objectives and Outcomes

Documentation of how the study met the output goals and objectives and achieved the short- and mid-term project outcomes identified in the grant application is presented below.

Outputs

The output goals and objectives achieved include:

- All valid VOC data collected at the five study monitoring stations have been input into the EPA's Air Quality System (AQS) database.
- All relevant pollutant measurements and meteorological data were uploaded onto Excel workbooks. Those data were used in the analysis of study results in this report and are available to researchers and other interested parties on request.
- A profile of each sampling location, including a site description, and an analysis of sources and meteorological conditions that may affect air pollutant levels at that location is included in this report.

Outcomes

Short term project outcomes completed and/or ongoing include:

- RIDEM discussed this project with the Port Community Working Group on August 18, 2022 and December 7, 2022. RIDEM also initiated direct contact with a variety of stakeholders to provide project updates and preliminary data and to solicit input on further monitoring initiatives. At the request of community members and other stakeholders, RIDEM formed an Air Quality Monitoring Working Group to discuss this project and other air quality issues in the Port area and other City neighborhoods. The kickoff virtual meeting occurred on February 8, 2023.
- Approximately two years of PM2.5 and meteorological data and 14 months of VOC data were collected at the study sites. Those data were used to evaluate the impact of the Port on air quality in nearby communities.
- RIDEM will continue to work with the community partners to identify concerns about air quality in the Port area and will present the study findings to the workgroups and to other interested parties.

Mid-term:

- The Mobile Sources Section of the RIDEM OAR will consider the findings of this study in the implementation of diesel emission reduction strategies through Diesel Emissions Reduction Act (DERA) grant assistance program.

- RIDEM conducted compliance inspections at 43 facilities and logged 149 odor observations in the Port area between March 2021 through November 2023. Enforcement actions and additional odor observations will continue into the future.
- RIDEM analyzed the data collected at study and comparison sites to understand the impacts of emissions from Port activities at sensitive receptors located near the Port and the factors that affect those impacts. The results of that analysis are presented in this final report.
- Preliminary study data has been disseminated to the Port Community and Air Quality Monitoring workgroups. The results of the final analysis in this report will be presented at future meetings of those groups and to other interested parties and will be available on the RIDEM web page established for this study.
- Data collected in the study will be used to inform mitigation procedures and for siting of future sensitive receptors.
- RIDEM OAR is currently evaluating options for future and long-term monitoring around the Port.
- Preliminary data have been provided, as available, to interested parties. Final data are available on request.

Additional completed work outcomes, not specifically noted in the grant proposal include:

- NO_2 data were collected using the Clarity sensors. However, due to lack of confidence in the accuracy and comparability of those measurements, NO_2 data are not assessed in this report.
- RIDEM OAR is aware that additional community monitoring projects are taking place in the same geographical area. RIDEM OAR will continue to coordinate with research partners (Brown University and RIDOH) to exchange relevant information
- RIDEM OAR has recently partnered with the RI Attorney General's Office to increase enforcement in the Port area and will continue to work with the Attorney General's office to support their compliance activities.
- RIDEM OAR continues to seek funding opportunities to explore future monitoring work and/or monitoring tools to support compliance activities, such as mobile Total VOC (TVOC) monitoring.

Appendix

Table A-1 Maximum VOC Concentrations at Study and Comparison Sites (ppb) 6/3/21 – 10/20/22.

	Study Sites					Comparison Sites			
	AS	CH	WA/OH [18]	VG/SS	SZ	AJ	CCRI	EP	VE
chloromethane	0.692	0.657	0.696	0.691	0.867	0.704	0.675	0.697	0.761
acetaldehyde	15.16	39.21	35.67	21.15	133.56	11.32	22.17	33.94	24.24
vinyl chloride	0.005	0.003	0.005	0.004	0.005	0.003	0.002	0.003	0.003
1-butene	491.07	22.34	51.38	33.30	69.08	11.44	24.82	13.44	13.24
1,3-butadiene	1.209	0.067	0.088	0.057	0.114	0.033	0.086	0.080	0.083
butane	70.088	5.446	47.646	8.765	6.134	0.945	10.757	2.910	2.811
ethylene oxide	0.613	2.740	2.368	1.050	1.146	0.198	1.178	1.233	0.439
bromomethane	0.108	0.021	0.032	0.020	0.043	0.014	0.027	0.021	0.024
chloroethane	0.360	0.041	0.091	0.053	0.131	0.012	0.010	0.013	0.421
acetonitrile	0.543	0.504	0.599	0.781	2.545	3.954	0.666	1.879	0.453
acrolein	0.814	0.953	0.748	1.168	12.926	0.350	0.372	0.489	1.000
acetone	11.82	15.70	13.93	16.80	23.43	6.70	9.75	23.56	19.05
trichlorofluoromethane	0.243	0.260	0.270	0.239	0.355	0.274	0.265	0.255	0.234
acrylonitrile	0.022	0.016	0.012	0.130	0.086	0.006	0.008	0.023	0.013
pentane	17.228	1.413	1.517	1.701	1.483	0.415	1.251	0.729	0.591
1,1-dichloroethene	0.001	0.002	0.004	0.001	0.003	0.001	0.001	0.001	0.002
dichloromethane	0.162	0.195	0.420	0.133	0.152	0.109	21.452	2.220	1.282
trans-1,2-dichloroethene	0.012	0.010	0.011	0.011	0.013	0.005	0.010	0.029	0.016
1,1-dichloroethane	0.010	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
methyl-t-butyl ether	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
methyl ethyl ketone	0.812	1.051	1.201	1.167	2.139	0.650	0.586	1.102	1.103
hexane	3.664	0.321	0.429	0.432	0.328	0.100	0.284	0.228	0.203
chloroform	0.049	0.049	0.065	0.050	0.058	0.032	0.051	0.050	0.037
1,2-dichloroethane	0.031	0.017	0.018	0.020	0.022	0.017	0.017	0.017	0.018
1,1,1-trichloroethane	0.005	0.055	0.004	0.006	0.012	0.002	0.003	0.003	0.007
benzene	1.760	0.377	0.454	1.744	0.945	0.247	0.371	0.330	0.786
carbon tetrachloride	0.096	0.100	0.100	0.091	0.105	0.103	0.102	0.103	0.097
cyclohexane	3.421	0.136	0.223	0.165	0.110	0.041	0.117	0.111	0.110
1,2-dichloropropane	0.006	0.005	0.006	0.005	0.026	0.012	0.006	0.005	0.007
trichloroethylene	0.133	0.035	0.047	0.072	4.336	0.009	0.033	0.022	0.046
2,2,4-trimethylpentane	0.872	0.286	0.339	0.292	0.166	0.055	0.260	0.158	0.159
heptane	2.238	0.242	0.235	0.183	0.121	0.048	0.118	0.116	0.134
methyl isobutyl ketone	0.119	0.066	0.122	0.371	0.372	0.062	0.150	0.081	0.222
1,1,2-trichloroethane	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
toluene	6.342	0.835	50.402	20.012	5.076	0.242	0.721	0.603	3.549

[18] Note that the WA and VG VOC monitors were moved to OH and SS, respectively, on October 1, 2021.

	Study Sites					Comparison Sites			
	AS	CH	WA/OH [18]	VG/SS	SZ	AJ	CCRI	EP	VE
1,2-dibromoethane	0.000	0.001	0.001	0.000	0.002	0.000	0.000	0.000	0.001
octane	2.145	0.284	0.626	0.094	0.170	0.020	0.059	0.065	0.101
tetrachloroethylene	0.052	0.057	0.064	0.049	0.092	0.018	0.060	0.042	0.042
1,1,1,2-tetrachloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
chlorobenzene	0.015	0.007	0.034	0.008	0.012	0.004	0.004	0.005	0.006
ethylbenzene	1.361	0.135	0.322	0.143	1.307	0.032	0.101	0.093	0.131
bromoform	0.009	0.009	0.009	0.010	0.009	0.009	0.008	0.009	0.009
styrene	0.138	0.031	0.040	0.401	0.554	0.015	0.814	0.088	0.108
1,1,2,2-tetrachloroethane	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000
alpha-pinene	0.092	0.087	0.134	0.077	0.242	2.254	0.140	0.180	0.325
1,3,5-trimethylbenzene	0.545	0.031	0.370	0.061	0.049	0.006	0.024	0.024	0.023
1,2,4-trimethylbenzene	1.517	0.110	0.980	0.202	0.117	0.021	0.082	0.081	0.086
m-dichlorobenzene	0.005	0.004	0.005	0.004	0.005	0.005	0.003	0.004	0.004
p-dichlorobenzene	0.019	0.023	0.084	0.020	0.015	0.017	0.032	0.012	0.029
p-isopropyltoluene	0.032	0.016	0.052	0.018	0.020	0.031	0.010	0.011	0.013
o-dichlorobenzene	0.006	0.005	0.006	0.004	0.007	0.007	0.004	0.006	0.005
n-butylbenzene	0.037	0.014	0.021	0.032	0.043	0.003	0.005	0.005	0.008
1,2,4-trichlorobenzene	0.013	0.010	0.012	0.021	0.013	0.011	0.009	0.010	0.011
naphthalene	0.182	0.031	0.043	0.145	0.240	0.030	0.025	0.017	0.050
bromofluorobenzene	133	116	119	110	119	146	118	118	110
1,3-dichloropropene	0.003	0.001	0.002	0.002	0.005	0.002	0.001	0.001	0.001
xylenes	4.409	0.458	1.457	0.773	9.725	0.130	0.437	0.348	0.606

Table A-2. Average VOC Concentrations (ppb) at Study and Comparison Sites 10/1/21 – 9/26/22.

	AS	CH	OH	SS	SZ	AJ	CC	EP	VE
chloromethane	0.516	0.522	0.523	0.530	0.531	0.527	0.521	0.523	0.527
acetaldehyde	6.456	4.923	5.905	4.604	11.732	3.076	3.533	3.557	6.627
vinyl chloride	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
1-butene	35.33	5.352	7.001	5.458	7.921	4.035	4.647	4.349	6.738
1,3-butadiene	0.060	0.020	0.025	0.022	0.016	0.006	0.020	0.016	0.032
butane	7.998	1.037	1.391	1.165	0.777	0.286	1.036	0.710	0.702
ethylene oxide	0.075	0.139	0.075	0.094	0.193	0.041	0.070	0.093	0.070
bromomethane	0.010	0.010	0.010	0.010	0.013	0.008	0.010	0.009	0.010
chloroethane	0.103	0.008	0.026	0.010	0.026	0.006	0.006	0.006	0.130
acetonitrile	0.165	0.143	0.167	0.165	0.237	0.238	0.203	0.188	0.150
acrolein	0.274	0.154	0.235	0.168	0.638	0.117	0.138	0.130	0.304
acetone	4.006	3.417	3.922	3.128	5.112	2.672	2.959	3.415	5.381
trichlorofluoromethane	0.206	0.211	0.210	0.209	0.210	0.211	0.214	0.210	0.207
acrylonitrile	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
pentane	2.626	0.406	0.490	0.384	0.266	0.104	0.348	0.237	0.274
1,1-dichloroethene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
dichloromethane	0.094	0.098	0.109	0.095	0.097	0.081	0.586	0.129	0.136
trans-1,2-dichloroethene	0.002	0.002	0.002	0.003	0.003	0.001	0.002	0.003	0.002
1,1-dichloroethane	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
methyl-t-butyl ether	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
methyl ethyl ketone	0.359	0.254	0.306	0.264	0.443	0.201	0.223	0.259	0.409
hexane	0.596	0.119	0.146	0.130	0.088	0.029	0.092	0.081	0.107
chloroform	0.023	0.021	0.024	0.021	0.023	0.017	0.021	0.022	0.020
1,2-dichloroethane	0.015	0.012	0.014	0.012	0.013	0.012	0.012	0.012	0.013
1,1,1-trichloroethane	0.002	0.003	0.002	0.001	0.002	0.001	0.001	0.001	0.002
benzene	0.294	0.151	0.177	0.172	0.202	0.085	0.143	0.126	0.294
carbon tetrachloride	0.078	0.080	0.080	0.079	0.079	0.081	0.081	0.080	0.080
cyclohexane	0.243	0.046	0.053	0.049	0.031	0.009	0.034	0.031	0.041
1,2-dichloropropane	0.003	0.003	0.003	0.003	0.005	0.003	0.003	0.003	0.003
trichloroethylene	0.021	0.010	0.012	0.008	0.217	0.006	0.009	0.007	0.016
2,2,4-trimethylpentane	0.166	0.065	0.088	0.079	0.050	0.016	0.059	0.046	0.073
heptane	0.190	0.060	0.071	0.063	0.043	0.014	0.045	0.038	0.056
methyl isobutyl ketone	0.044	0.020	0.043	0.024	0.048	0.017	0.020	0.015	0.073
1,1,2-trichloroethane	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.000
toluene	1.084	0.257	0.390	0.267	0.385	0.063	0.221	0.174	1.175
1,2-dibromoethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
octane	0.130	0.033	0.034	0.035	0.029	0.009	0.022	0.019	0.037
tetrachloroethylene	0.016	0.015	0.016	0.013	0.016	0.006	0.015	0.010	0.012
1,1,1,2-tetrachloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	AS	CH	OH	SS	SZ	AJ	CC	EP	VE
chlorobenzene	0.004	0.002	0.013	0.003	0.003	0.002	0.001	0.002	0.003
ethylbenzene	0.098	0.043	0.052	0.046	0.040	0.010	0.034	0.027	0.053
bromoform	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.002
styrene	0.039	0.007	0.011	0.009	0.048	0.004	0.026	0.010	0.044
1,1,2,2-tetrachloroethane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
alpha-pinene	0.030	0.018	0.032	0.022	0.031	0.317	0.022	0.041	0.030
1,3,5-trimethylbenzene	0.030	0.009	0.012	0.011	0.007	0.002	0.007	0.005	0.012
1,2,4-trimethylbenzene	0.093	0.031	0.049	0.040	0.023	0.005	0.025	0.017	0.043
m-dichlorobenzene	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
p-dichlorobenzene	0.006	0.005	0.011	0.004	0.004	0.004	0.006	0.003	0.006
p-isopropyltoluene	0.008	0.005	0.007	0.005	0.006	0.008	0.005	0.005	0.007
o-dichlorobenzene	0.002	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.001
n-butylbenzene	0.007	0.003	0.003	0.004	0.004	0.002	0.002	0.002	0.005
1,2,4-trichlorobenzene	0.004	0.002	0.001	0.001	0.002	0.005	0.002	0.001	0.002
naphthalene	0.059	0.008	0.011	0.011	0.013	0.009	0.009	0.007	0.025
bromofluorobenzene	98.91	97.99	98.98	95.57	98.38	99.91	99.02	96.57	97.36
1,3-dichloropropene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
xylenes	0.389	0.166	0.211	0.190	0.186	0.029	0.136	0.103	0.241

Table A-3. Cancer Health Benchmarks.

	Conversion Factor: 1 ppb= X µg/m^3	Cancer Class		10^{-6} Cancer Risk			
		EPA[19]	NTP[20]	EPA µg/m^3	CA µg/m^3	EPA ppb[21]	CA ppb
chloromethane	2.07	D	`				
acetaldehyde	1.80	B2	R	0.45	0.37	0.25	0.21
vinyl chloride	2.56	A	K	0.11	0.013	0.043	0.0051
1-butene	2.29						
1,3-butadiene	2.21	H	K	0.033	0.0059	0.015	0.0027
butane	2.38						
ethylene oxide	1.80	H	K	0.00033	0.011	0.00018	0.0061
bromomethane	3.89	D					
chloroethane	2.64						
acetonitrile	1.68	D					
acrolein	2.29	D					
acetone	2.38	D					
trichlorofluoromethane	5.62						
acrylonitrile	2.17	B1	R	0.015	0.0034	0.0069	0.0016
pentane	2.95						
1,1-dichloroethene	3.97	C					
dichloromethane	3.47	L	R	100	1	29	0.3
trans-1,2-dichloroethene	3.97	D					
1,1-dichloroethane	4.05	C			0.63		0.16
methyl-t-butyl ether	3.61				3.8		1.1
methyl ethyl ketone	2.95	D					
hexane	3.53	D					
chloroform	4.88	B2	R	0.043	0.19	0.0088	0.039
1,2-dichloroethane	4.05	B2	R	0.038	0.048	0.0094	0.012
1,1,1-trichloroethane	5.46	D					
benzene	3.19	A	K	0.13	0.034	0.041	0.011
carbon tetrachloride	6.29	L	R	0.17	0.024	0.027	0.0038

[19] Note that in reviews conducted after 2005, EPA began using narrative statements instead of letter cancer classifications. The current "carcinogenic to humans" classification (indicated as "H" in this table) description is essentially equivalent to the earlier Group A (human carcinogens) and the current "likely to be carcinogenic to humans" (L) corresponds to the earlier Groups B1 (probable human carcinogen based on limited evidence of carcinogenicity in humans) and B2 (probable human carcinogen based on sufficient evidence of carcinogenicity in animals). Groups C and D are possible human carcinogens and not classifiable as to human carcinogenicity, respectively. Further discussion of EPA's cancer evidence classification system is available at: https://www.epa.gov/fera/risk-assessment-carcinogenic-effects.

[20] The National Toxicology Program (NTP) identifies chemicals that are "Known To Be Human Carcinogens" (indicated as "K" in the above table) and Reasonably Anticipated to Be Human Carcinogens (R). See: https://ntp.niehs.nih.gov/whatwestudy/assessments/cancer/completed/roc.

[21] For comparison with the monitored values, concentrations in units of µg/m^3 were converted to units of parts per billion (ppb) using the conversion factors listed in the table. Conversion factors were obtained from the Center for Disease Control's *NIOSH Pocket Guide to Chemical Hazards*, which is available at: https://www.cdc.gov/niosh/npg/default.html.

	Conversion Factor: 1 ppb= X µg/m^3	Cancer Class		10^{-6} Cancer Risk			
		EPA[19]	NTP[20]	EPA µg/m^3	CA µg/m^3	EPA ppb[21]	CA ppb
cyclohexane	3.44	D					
1,2-dichloropropane	4.62						
trichloroethylene	5.37	H	K	0.24	0.5	0.04	0.09
2,2,4-trimethylpentane	4.67	D					
heptane	4.10	D					
methyl isobutyl ketone	4.10	D					
1,1,2-trichloroethane	5.46	C		0.063	0.063	0.012	0.012
toluene	3.77	D					
1,2-dibromoethane	7.69	L	R	0.0016	0.014	0.00021	0.0018
octane	4.67						
tetrachloroethylene	6.78	L	R	3.8	0.17	0.56	0.025
1,1,1,2-tetrachloroethane	6.87	C		0.14		0.020	
chlorobenzene	4.61	D					
ethylbenzene	4.34	D			0.4		0.09
bromoform	10.34	B2		0.91		0.088	
styrene	4.26		R				
1,1,2,2-tetrachloroethane	6.87	L			0.017		0.0025
alpha-pinene	5.57						
1,3,5-trimethylbenzene	4.92	D					
1,2,4-trimethylbenzene	4.92	D					
m-dichlorobenzene	6.01	D					
p-dichlorobenzene	6.01	D	R		0.091		0.015
p-isopropyltoluene	5.49						
o-dichlorobenzene	6.01	D					
n-butylbenzene	5.49						
1,2,4-trichlorobenzene	7.42	D					
naphthalene	5.24	C	R		0.029		0.0055
bromofluorobenzene	7.16						
1,3-dichloropropene	4.54	B2	R	0.25		0.055	
xylenes	4.34	D					

Table A-4. Chronic Noncancer Health Benchmarks.

	1 ppb= X µg/m^3	EPA µg/m^3	CA µg/m^3	ATSDR ppb	EPA ppb	CA ppb
chloromethane	2.07	90		30	43	
acetaldehyde	1.80	9	140		5	78
vinyl chloride	2.56	100			39	
1-butene	2.29					
1,3-butadiene	2.21	2	2		0.9	0.9
butane	2.38					
ethylene oxide	1.80		30			17
bromomethane	3.89	5	5	1.0	1.3	1.3
chloroethane	2.64	10,000	30,000		3,788	11,364
acetonitrile	1.68	60			36	
acrolein	2.29	0.02	0.35		0.009	0.2
acetone	2.38					
trichlorofluoromethane	5.62					
acrylonitrile	2.17	2	5		0.9	2
pentane	2.95					
1,1-dichloroethene	3.97	200	70	1	50	18
dichloromethane	3.47	600	400	300	173	115
trans-1,2-dichloroethene	3.97					
1,1-dichloroethane	4.05					
methyl-t-butyl ether	3.61	3,000	8,000	1,000	831	2,216
methyl ethyl ketone	2.95	5,000			1,695	
hexane	3.53	700	7,000	600	198	1,983
chloroform	4.88		300	20		61
1,2-dichloroethane	4.05		400			99
1,1,1-trichloroethane	5.46	5,000	1,000			183
benzene	3.19	30	3	3	9	0.9
carbon tetrachloride	6.29	100	40	30	16	6
cyclohexane	3.44	6,000			1,744	
1,2-dichloropropane	4.62	4			0.9	
trichloroethylene	5.37	2	600	0.4	0.4	112
2,2,4-trimethylpentane	4.67					
heptane	4.10					
methyl isobutyl ketone	4.10	3,000			732	
1,1,2-trichloroethane	5.46					
toluene	3.77	5,000	420	1,000	1,326	111
1,2-dibromoethane	7.69	9	0.8		1.2	0.1
octane	4.67					
tetrachloroethylene	6.78	40	35	6	6	5
1,1,1,2-tetrachloroethane	6.87					
chlorobenzene	4.61		1,000			217

	1 ppb= X µg/m^3	EPA µg/m^3	CA µg/m^3	ATSDR ppb	EPA ppb	CA ppb
ethylbenzene	4.34	1,000	2,000	60	230	461
bromoform	10.34					
styrene	4.26	1,000	900	200	235	211
1,1,2,2-tetrachloroethane	6.87					
alpha-pinene	5.57					
1,3,5-trimethylbenzene	4.92	60	4		12	0.8
1,2,4-trimethylbenzene	4.92	60	4		12	0.8
m-dichlorobenzene	6.01					
p-dichlorobenzene	6.01	800	800	10	133	133
p-isopropyltoluene	5.49					
o-dichlorobenzene	6.01					
n-butylbenzene	5.49					
1,2,4-trichlorobenzene	7.42					
naphthalene	5.24	3	9	0.7	0.6	2
bromofluorobenzene	7.16					
1,3-dichloropropene (c&t)	4.54	20		7	4	
xylenes	4.34	100	700	50	23	161

Table A-5. Shorter-Term Noncancer Health Benchmarks.

		EPA[22]	CA		ATSDR[23]		EPA	CARB	
	1 ppb= X µg/m³	ST µg/m³	8-hr µg/m³	Acute µg/m³	Acute ppb	Inter. ppb	ST ppb	8-hr ppb	Acute ppb
chloromethane	2.07				500				
acetaldehyde	1.80		300	470				167	261
vinyl chloride	2.56			180,000	500	20			70,313
1-butene	2.29								
1,3-butadiene	2.21		9	660				4	299
butane	2.38								
ethylene oxide	1.80				400	70			
bromomethane	3.89			3,900		20			1,003
chloroethane	2.64				15,000				
acetonitrile	1.68								
acrolein	2.29		0.7	2.5	3			0.3	1.1
acetone	2.38				8,000				
trichlorofluoromethane	5.62								
acrylonitrile	2.17				100				
pentane	2.95								
1,1-dichloroethene	3.97					1			
dichloromethane	3.47			14,000	600	300			4,035
trans-1,2-dichloroethene	3.97				200	200			
1,1-dichloroethane	4.05								
methyl-t-butyl ether	3.61				2,000	1,000			
methyl ethyl ketone	2.95			13,000	1,000				4,407
hexane	3.53								
chloroform	4.88			150	100	50			31
1,2-dichloroethane	4.05				300				
1,1,1-trichloroethane	5.46	6000		68,000	1,000	700	1,099		12,454
benzene	3.19		3	27	9	6		0.9	8
carbon tetrachloride	6.29			1,900		30			302
cyclohexane	3.44								
1,2-dichloropropane	4.62				20	2			
trichloroethylene	5.37					0.4			
2,2,4-trimethylpentane	4.67								
heptane	4.10								
methyl isobutyl ketone	4.10								
1,1,2-trichloroethane	5.46				30	2			
toluene	3.77		830	5,000	2,000			220	1,326
1,2-dibromoethane	7.69								
octane	4.67								
tetrachloroethylene	6.78			20,000	6	6			2,950
1,1,1,2-tetrachloroethane	6.87								
chlorobenzene	4.61								
ethylbenzene	4.34				5,000	2,000			
bromoform	10.34								
styrene	4.26			21,000	5,000				4,930
1,1,2,2-tetrachloroethane	6.87								
alpha-pinene	5.57								
1,3,5-trimethylbenzene	4.92	200	8	2,400			41	2	488
1,2,4-trimethylbenzene	4.92	200	8	2,400			41	2	488
m-dichlorobenzene	6.01								
p-dichlorobenzene	6.01				2,000	200			
p-isopropyltoluene	5.49								
o-dichlorobenzene	6.01								
n-butylbenzene	5.49								
1,2,4-trichlorobenzene	7.42								
naphthalene	5.24								

[22] EPA's IRIS database lists short-term inhalation reference concentrations (RfCs) for a few substances. The 1,1,1-trichloroethane value listed here is for 24-hour exposures. The trimethylbenzene values apply to subchronic exposures.

[23] ASTDR's acute Minimal Risk Level (MRL) applies to exposures of 1-14 days and the intermediate MRL to >14-364 days.

		EPA[22]	CA		ATSDR[23]		EPA	CARB	
	1 ppb= X µg/m^3	ST µg/m^3	8-hr µg/m^3	Acute µg/m^3	Acute ppb	Inter. ppb	ST ppb	8-hr ppb	Acute ppb
bromofluorobenzene	7.16								
1,3-dichloropropene	4.54					8			
xylenes	4.34			22,000	2,000	600			5,069