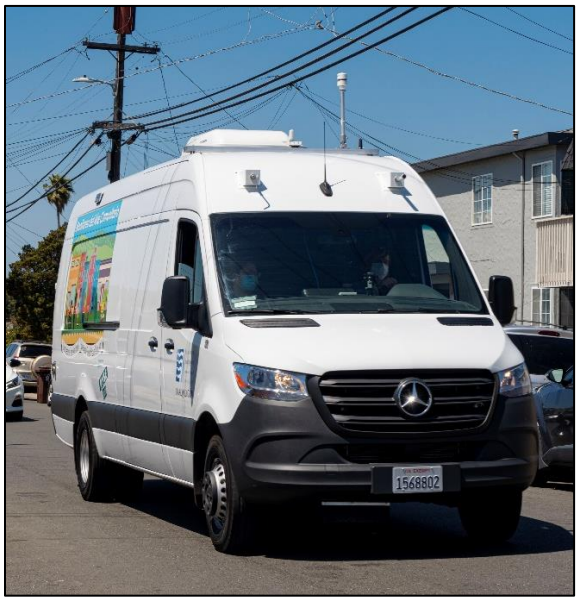

Technical Support Document for the Path to Clean Air CAMP Air Toxics Monitoring Study

November 2023

RICHMOND - NORTH RICHMOND - SAN PABLO COMMUNITY PATH TO CLEAN AIR

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

Contents

Executive Summary

This document describes the technical work conducted during an air toxics monitoring study in the Richmond-North Richmond-San Pablo, CA, area, as part of the Path to Clean Air Community Air Monitoring Plan (CAMP).[1] The primary objective of this work was to identify areas with higher levels of certain gas air toxics, and more specifically, volatile organic compounds (VOCs), that may be opportunities for reducing pollution emissions and exposure. Some VOCs are associated with significant health effects, depending on exposure.

This air toxics monitoring study was performed in support of the CAMP pursuant to Assembly Bill 617 (AB 617). AB 617 was enacted by the State of California in 2017 to help address air quality issues in communities that have historically faced environmental injustices and are disproportionately affected by air pollution.[2] Under AB 617, local air districts, in consultation with the California Air Resources Board (CARB), are tasked with partnering with community groups and other stakeholders to develop a community-focused framework for reducing air pollution emissions and exposure.

In 2018, the Bay Area Air Quality Management District (Air District) recommended the Richmond-North Richmond-San Pablo area for development and implementation of a CAMP to help provide additional information that can help identify and prioritize strategies to reduce air pollution emissions and exposure. A Community Steering Committee (CSC), in partnership with the Air District, led the development of the CAMP. The CSC considered and selected different air monitoring projects to include in the CAMP, with each project intended to inform different questions and concerns around air quality. The air toxics monitoring study described in this document is one of the air monitoring projects that the CSC selected for the CAMP.

For the air toxics monitoring study, air monitoring was conducted using a van equipped with specialized instrumentation for measuring multiple air pollutants with high spatial resolution. Monitoring was conducted around known sources of VOCs and air quality concerns noted by the community, as well as in adjacent residential areas.

This study found numerous occurrences of higher than typical levels of different VOCs. Occurrences of relatively higher levels of different VOCs were detected near or downwind of specific facilities and operations in the study area, including (but not limited to) refinery operations, tank terminals, plastics manufacturing, gas stations, auto body shops, and commercial bakeries. Some of the occurrences of higher levels of VOCs were likely associated with combustion-related emissions sources, while others were not. The results may point to unknown or potentially under-controlled sources of air pollution and can inform emissions or exposure reductions.

The Air District's Air Monitoring Projects and Technology (AMPT) and Ambient Air Quality Analysis (AAQA) sections, both in the Meteorology and Measurement division, led this air monitoring study.

[1] AB 617 Path to Clean Air Community Air Monitoring Plan: https://www.baaqmd.gov/~/media/files/ab617-community-health/richmond/richmondsanpabloairmonitoringplanjuly2020-pdf.pdf?la=en

[2] CARB webpage for the AB 617 Community Air Protection Program: https://ww2.arb.ca.gov/capp

Project Background

The Richmond-North Richmond-San Pablo area, hereafter referred to as the study area, is a historically redlined community that experiences disproportionate cumulative health impacts and includes a high density of complex pollution sources. Industrial sources of pollution include a large petroleum refinery (Chevron), a chemical plant, a coal and petroleum coke terminal, organic liquid storage and distribution facilities, wastewater treatment plants, a landfill, organic waste and metal facilities, and other industrial and manufacturing plants of various sizes. In addition, numerous smaller commercial sources of air pollution are located throughout the study area, including auto body shops, paint shops, gas stations, and restaurants. The study area also includes high-volume roadways such as I-80, I-580, Richmond Parkway, and other busy roadways that cut through residential neighborhoods, as well as truck operations associated with large distribution centers and industrial facilities. Additional sources of air pollution include marine and seaport operations, railways and railyards, and numerous construction sites. There are more than 250 facilities with permitted emissions sources in the study area.

Community Engagement and Project Selection

A robust and comprehensive community engagement framework was needed before technical work could begin on developing and implementing an air monitoring plan. In November 2018, the Air District held a summit attended by interested residents, members of community organizations, and community leaders to launch this effort and leverage the power and wisdom of the local community to collaboratively build a process for participation. From this summit, a Community Design Team (CDT) was formed, consisting of eleven community members and assisted by two Air District staff members. The CDT developed the engagement framework, including the organizational structure, membership balance, and charter for the CSC that would lead the process of developing a CAMP in partnership with the Air District. The CSC had 35 members, a majority of whom were local residents or represented community-based organizations. The CSC also included representatives from government, business and industry, and the educational sectors. The CSC generally met monthly from April 2019 to July 2020 to oversee the development of the CAMP. Some primary tasks for the CSC included building collective knowledge around air quality topics (such as air monitoring approaches and air quality and health), identifying and prioritizing community air quality concerns, considering and selecting air monitoring projects to inform those concerns, and community outreach efforts. The CSC was assisted by a Co-Lead Team, made up of five community members from the CSC. The Co-Lead Team met weekly with Air District staff to provide crucial engagement and technical support to the larger CSC by planning CSC meeting agendas and activities, responding to CSC member and public requests, and planning outreach events. An Air District contractor also assisted with meeting facilitation and meeting logistics. More information on the community engagement framework, including the CSC charter and membership, is in the CAMP document.

A critical component of the CSC's work was identifying community air quality concerns. Through several mapping activities, the CSC and members of the public provided input on air quality concerns and ideas for where and how air monitoring data could support actions to improve air quality. This community-generated dataset on air quality concerns, containing community members' lived experiences around air quality, served as the foundation for development and consideration of air monitoring projects.

The community's air quality concerns were wide ranging and highlighted the need for a multi-pronged approach to air monitoring. Since no single air monitoring project can inform all possible aspects of air quality, the CSC considered and selected several projects, each aimed at collecting data to inform different

high priority air quality concerns. In summer 2019, the CSC selected three initial air monitoring projects to collect exploratory measurements of particulate matter (PM) and other pollutants across the study area. Two of these projects used sensor networks that also provided real-time data, which was an important data need identified by the community.[3,4] Another project, conducted by Aclima, used mobile monitoring to screen the study area for certain pollutants over a three-month period.[5] The community air quality concerns and the projects the CSC selected are described in more detail in the CAMP document.

In early 2020, while the initial air monitoring projects were implemented, the CSC considered more specific air pollution concerns and other air monitoring projects to help inform those concerns. As themes and categories of air quality concerns emerged, the Air District prepared initial scopes of air monitoring projects for the CSC to consider, from which the CSC would select one for the Air District to move forward with. The proposed projects would utilize the Air District's air monitoring van for community air monitoring projects, which at the time was pending buildout. Briefly, the three proposed projects focused on 1) PM measurements related to mobile pollution sources, 2) PM measurements related to coal operations in the study area, and 3) gas air toxics measurements near stationary pollution sources of concern. The CSC voted to move forward with the project focused on measurements of gas air toxics, to help fill information gaps in our understanding of the emissions of certain pollutants and their resulting concentrations and impacts in the community. This air toxics study would also provide data for different pollutants and inform different air quality concerns than the initial air monitoring projects were designed for. The initial scoping of the air toxics study, as well as the other projects considered by the CSC, are described in appendices in the CAMP.

Objectives and Scoping

The main objectives of this monitoring study were to:

- Identify areas near pollution sources of concern where gas air toxics levels are higher than in surrounding areas;
- Compare levels of gas air toxics within communities close to sources of concern; and
- Relate findings to opportunities for emissions and exposure reduction strategies.

The primary pollutants of interest for the air toxics study were VOCs. There are numerous sources of VOCs in ambient air in the study area, such as refinery and refinery-related operations (including storage and transport), waste and water management facilities, auto body shops, gas stations, restaurants and other food operations, various small industrial or commercial businesses, mobile sources (traffic, rail, and marine operations), and residential sources such as wood smoke. Some pollution sources, such as traffic, are found throughout the study area, while many of the facility-based sources are in or adjacent to residential areas or other locations where people spend time.

Some VOCs are air toxics with significant health effects. People are regularly exposed to various air toxics in their daily lives since these pollutants have many common sources. The health risk from a specific air toxic compound depends on how hazardous (or potent) the compound is and how much of the compound a person is exposed to over a certain amount of time. Some air toxics are known carcinogens. Over time,

[3] Groundwork Richmond Air Rangers website: http://www.groundworkrichmond.org/air-rangers.html
[4] PSE website for the Richmond Air Monitoring Network and Final Report: https://www.psehealthyenergy.org/our-work/programs/environmental-health/richmond/
[5] Aclima's Richmond-San Pablo $PM_{2.5}$ Hotspot Report: https://rspreport.aclima.tools/

long-term (chronic) exposure to air toxics can lead serious health effects including damage to the respiratory, nervous, immune, and reproductive systems and neurological and developmental disorders. Short-term (acute) exposure to high levels of air toxics can also cause acute health effects such as headaches, nausea, respiratory irritation and asthma episodes, and irritation of the eyes, nose, throat, and skin.

An initial list of target VOCs was informed by emissions inventories, the California Office of Environmental Health Hazard Assessment's (OEHHA) Analysis of Refinery Chemical Emissions and Health Effects[6], Air District knowledge of emissions sources and community air quality concerns within the study area, and monitoring instrumentation capabilities. The final list of target VOCs for the study is in **Table 1**. Some of these VOCs, such as benzene, toluene, ethylbenzene, and xylene (BTEX) are common in urban areas due to their association with burning of fossil fuels, while other VOCs may be associated with specific facilities or operations within the study area. Some of the target VOCs, including benzene, 1,3-butadiene, and ethylene oxide, are known carcinogens. Much of the background information provided in this document on the target VOCs, including typical emissions sources and health effects, was gathered from EPA's Health Effects Notebook for Hazardous Air Pollutants, OEHHA's Air Chemical Database, and Air District knowledge.[7,8]

Table 1. *Target VOCs for the air toxics monitoring study.*

1,3-butadiene	Dichlorobenzene	Styrene
Acetaldehyde	Ethylbenzene	Toluene
Benzene	Ethylene oxide	Trimethylbenzene
Benzo[a]pyrene	Naphthalene	Xylene

While development of the CAMP was underway, the Air District was beginning build-out of its new air monitoring van, which is equipped with air quality and meteorological monitoring instrumentation for use in helping to characterize and understand community-scale air quality. The mobile monitoring approach used in this study allows for the ability to screen relatively large geographic areas for multiple pollutants at 1-second time resolution and can measure pollutants near facilities or sources where fixed-site monitoring is not feasible. Additionally, conducting multiple drive surveys in the same area can provide some indication as to whether observed air quality issues are recurring. The Proton Transfer Reaction-Time-of-Flight-Mass Spectrometer (PTR-ToF-MS) onboard the air monitoring van can measure concentrations of multiple VOCs simultaneously. This instrumentation, along with instrumentation for supporting measurements of air monitoring van position and speed, additional air pollutants, and meteorological parameters are described in the Data Collection section of this document. While monitoring in motion at typical traffic speeds means that measurements in any one location are limited in duration, often to only a few seconds of data, the measurements do allow for detection of locally higher levels of pollutants, such as when the monitoring van intercepts a plume. On-board measurements of multiple pollutants, including target VOCs and combustion indicators such as carbon monoxide (CO) and nitrogen oxides (NO_x), can then help inform identification and source attribution of plumes.

[6] California OEHHA Analysis of Refinery Chemical Emissions and Health Effects, 2019: https://oehha.ca.gov/air/analysis-refinery-chemical-emissions-and-health-effects
[7] Environmental Protection Agency Health Effects Notebook for Hazardous Air Pollutants: https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants
[8] California OEHHA Air Chemicals Database: https://oehha.ca.gov/air/chemicals

As with any monitoring effort, a single monitoring approach or project cannot inform every aspect of air quality issues in a community. Pollution events that occur outside the time and location of the measurements will not be reflected in the data. The 1-second data collected in this type of project is not directly comparable to health metrics, which are typically based on much longer averaging periods. The collected data do not provide enough information to estimate a health risk exposure or compare the health risk between different air quality issues that may be observed. Additionally, given the multitude of diverse and complex emissions sources in the study area, this monitoring study alone cannot realistically explain and characterize impacts from all of these sources.

The entire Richmond-North Richmond-San Pablo CAMP study area is over 25 square miles and contains hundreds of miles of roadway. While mobile monitoring can greatly expand the geographic area in which data can be collected, given constraints on staff and equipment resources, it would not be feasible to robustly conduct and analyze measurements across this entire area. To help balance these constraints with project objectives, four target monitoring areas were scoped, each centered around locations of sources of gas air toxics and community air quality concerns. Each target area also includes neighborhoods adjacent to these sources to gather data across a range of land uses and places where people live, work, and spend time. The four target monitoring areas (North Richmond, the Refinery Area, the 23rd Street Corridor, and Richmond Harbor) are shown in **Figure 1**.

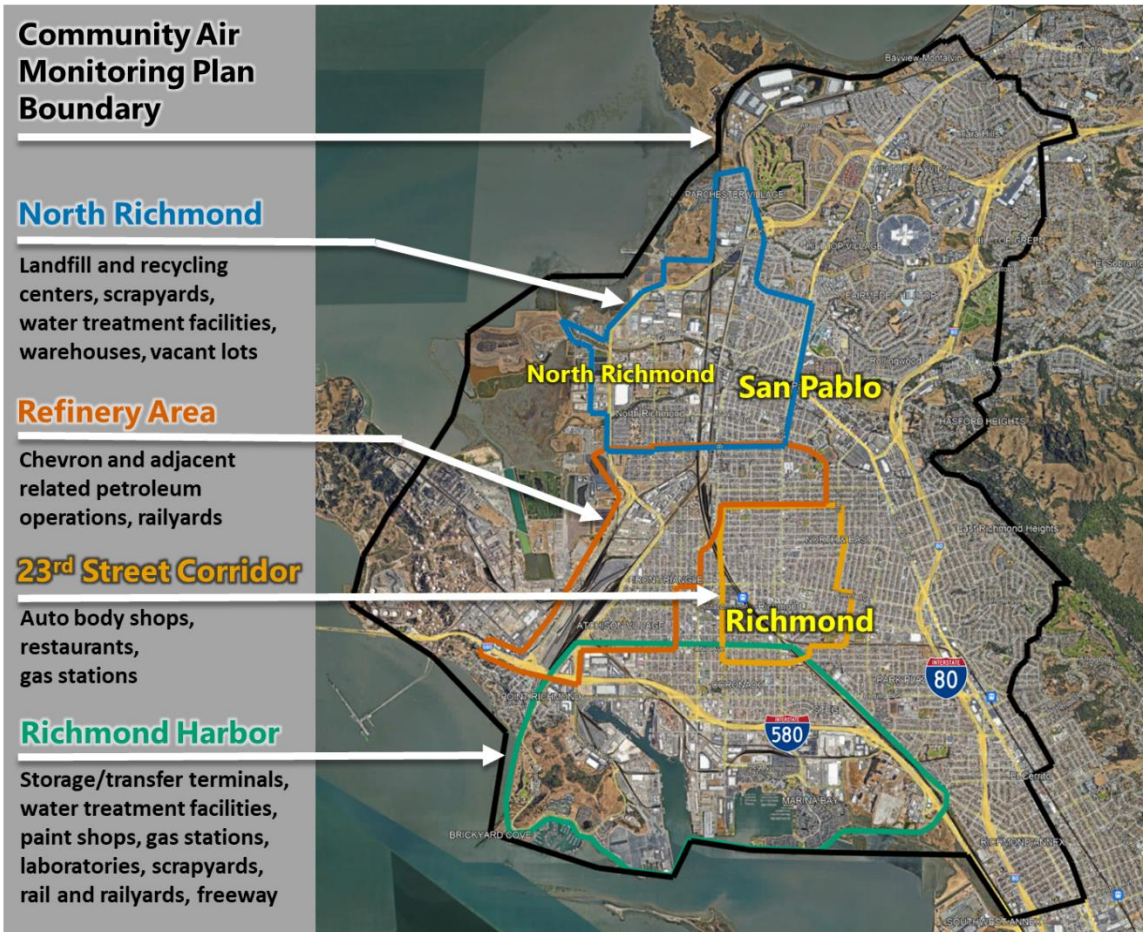

Figure 1. *Map of the four target monitoring areas and examples of pollution sources in each area. Background map generated in Google Earth.*

Data Collection

Following the CSC's decision to move forward with an air toxics monitoring study using a mobile monitoring approach, the Air District proceeded with building out the air monitoring van. This included purchasing of the van, its instrumentation and supporting infrastructure, installation, and thorough testing of the entire mobile monitoring system before monitoring began in the study area. Decals for the exterior of the air monitoring van were designed by young artists from RYSE Richmond community organization (**Figure 2**) to highlight the purpose of the air monitoring van in the local community. RYSE also had a representative on the CAMP CSC.

As described previously, the air toxics monitoring study used a source-oriented monitoring approach where the air monitoring van was focused on CSC-identified community air quality concerns and sensitive receptors, such as schools and nursing homes. Four target monitoring areas were mapped spatially and sized so they could be driven in a single day. Each of the four target monitoring areas was driven four times over two and a half months (late January to early April 2022), resulting in 16 total drives. Monitoring was conducted on weekdays and typically began between 9-11 a.m. and ended between 3-5 p.m. Some days were not suitable for driving due to rain in the sample lines impacting instruments and data.

Figure 2. *Exterior photo of the air monitoring van.*

Instrumentation

The air monitoring van was developed for fast, in-motion measurements of air pollutants to improve the spatial resolution of air quality data at the community scale in the Bay Area. The air monitoring van can measure a range of pollutants at 1-second time resolution to accurately associate measurements with where they occurred along the road. With VOCs being the primary focus of this monitoring project, the key measurement was of select speciated VOCs via Proton Transfer Reaction-Time-of-Flight-Mass Spectrometry (Ionicon 6000X PTR-ToF-MS), explained more below. Supporting measurements of NO_x (NO_2

+ NO) via chemiluminescence (Thermo Scientific 42iQ in NO_x mode to achieve 1-second measurements) and CO via cavity ringdown spectroscopy (Picarro G2401) were also made to help identify when VOCs were combustion related. All pollution data were timestamp-aligned based on individual instrument response times to ensure accurate GPS tagging of the location of each individual measurement.

Ancillary data such as wind speed, wind direction, vehicle speed, and vehicle location were provided by a roof-mounted weather and GPS sensor (Airmar 200WX). In-motion wind data are not valid due to inaccurate wind speed and direction measurements when impacted by vehicle motion. A subset of wind data are valid from properly sited, stationary measurement periods.

Data were collected and visualized via a custom networked server and data acquisition system which allowed the air monitoring van operator to view instrument data and key operational parameters while monitoring. Data were reviewed and quality controlled in real-time and *post-hoc* using a custom built Shiny-based web app and an R script, respectively.

VOC Measurements with the PTR-ToF-MS

The primary instrument for this air monitoring project, the PTR-ToF-MS, uses a real-time analytical method that relies on an ion source containing water (H_2O) to produce hydronium, or protonated water (H_3O^+). Hydronium then reacts with incoming VOCs which, if the VOC is suitable, will accept the H^+ proton from the hydronium in a "proton transfer reaction (PTR)", as shown by the reaction below.

$$H_3O^+ + VOC \rightarrow H_2O + VOC\text{-}H^+$$

The protonated VOC-H^+ then enters the "time-of-flight (ToF)" mass analyzer, where the time it takes the charged VOC-H^+ to accelerate through an electric field is directly related to the molecular mass. The ability to detect and identify a specific VOC depends on the physical characteristics of the VOC. For example, proton affinity, a characteristic that defines how easily the proton transfer reaction occurs, dictates the detectability of a compound by PTR-ToF-MS. VOCs with proton affinity greater than H_2O will gain protons from hydronium and be detected, while those with proton affinity lower than H_2O will not be protonated and will therefore not be detected. A VOC's molecular mass is also critical for being able to differentiate one compound from another. Though this is an identifying characteristic of a VOC, compounds with the same molecular mass will move through the ToF at the same rate and appear identical to the detector. Of the target VOCs in this study, the molecular mass of acetaldehyde is the same as that of ethylene oxide, and the molecular mass of ethylbenzene is the same as xylene, so the PTR-ToF-MS could not differentiate between those compounds and results were reported as combined concentration measurements.

Operation

Each day prior to data collection, assigned staff performed daily instrument checks upon system start-up to verify that all instruments were operating as intended, the air monitoring van was safe to drive, and data were of high quality.

Start-up included:

- Checklist of approximately 100 tasks taking 90 minutes for two operators to complete collaboratively,
- Physical inspection of equipment and van,

- Flow and zero quality control checks on instrumentation,
- Initiating data logging, and
- Reviewing metadata, such as manifold pressure, instrument temperatures, and sample line flow, which are indicators of instrument and system health.

Shut-down at the end of the day also required a set of standardized procedures including:

- Approximately 50 steps taking 45 minutes for two operators to complete collaboratively,
- Switching the air monitoring van to shore power,
- Flow and zero quality control checks on instruments,
- Terminating data logging,
- Transferring and processing data, and
- Putting certain instruments into standby mode.

The air monitoring van required two people to operate safely: a Mission Control Operator and a Driver. The Mission Control Operator was responsible for watching data in real-time; monitoring instruments for proper function; making log comments of observations of the environment such as construction, odors, or visible smoke; and spotting the Driver during lane changes, backups, and turns. The Driver was responsible for navigating the study polygon using a navigation app that outlines the polygon and logs the GPS coordinates of the drive. When appropriate, Drivers used the right-hand box method (**Figure 3**), which consists of using exclusively right-hand turns and reducing left turns and lane changes, thereby improving driving efficiency and safety. The right-hand box method was only used to drive through neighborhoods that have grid-like streets and have no road closures or "No Outlet" streets.

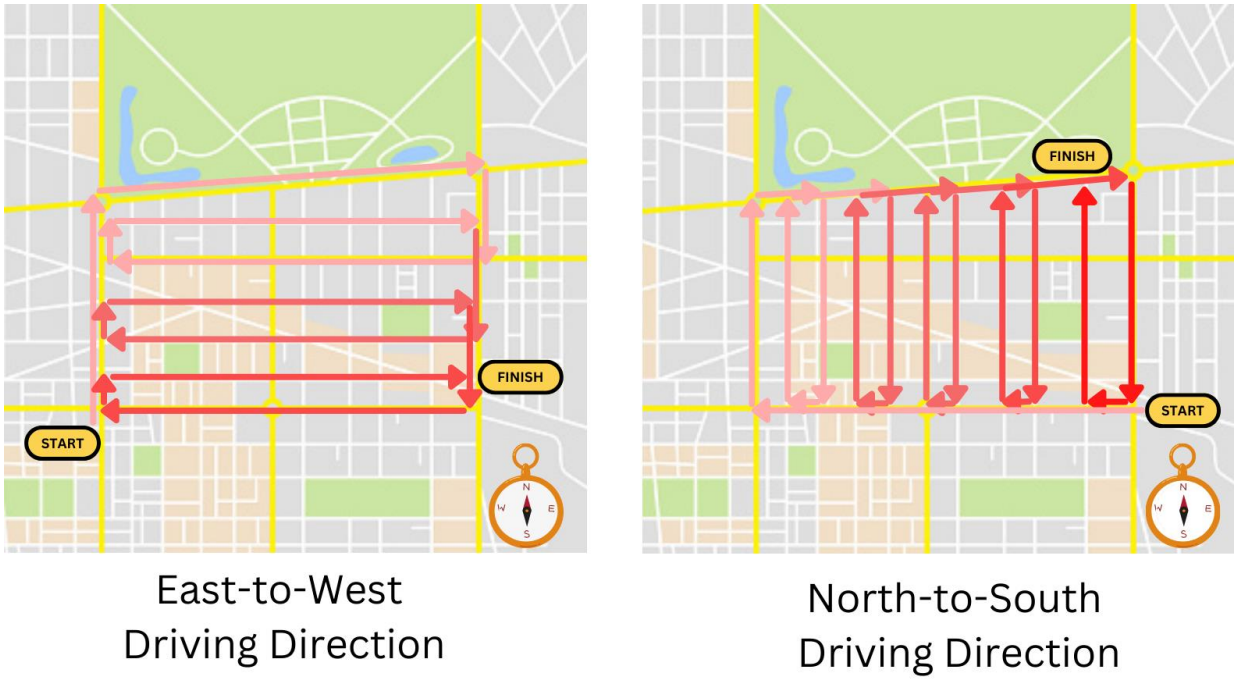

Figure 3. *Right-Hand Box Method. The lighter colored arrows indicate earlier in the drive and the darker arrows indicate later in the drive.*

Quality Assurance/Quality Control

Data collection was conducted following guidance outlined in a Quality Assurance Project Plan (QAPP). To ensure all instruments were performing up to standards, one week per month was designated for quality control (QC) and maintenance of all air monitoring van instrumentation. Routine monthly QC was assigned by instrument to specific operators who were responsible for following QC/maintenance schedules and procedures in the associated Standard Operating Procedures (SOPs). QC checks and maintenance vary per instrument but generally include replacing filters, performing calibration verifications, cleaning components, and doing flow, pressure, and temperature verifications. The QAPP and relevant SOPs for instrumentation operated during this campaign can be requested via an online public records request, with attention to Meteorology & Measurement's AMPT section.

After the day's mission and shut down procedures were completed, *post-hoc* data review was performed. Initially, an R-script applied several auto-QC checks to flag instrument metadata that fell outside of an expected range. During auto-QC, a metric called Global Op Code was used to indicate periods when the air monitoring van could be self-sampling its own exhaust plume. Criteria for the Global Op Code were based on the van being stationary or near-stationary (traveling at speeds below 3 mph) or backing up. The primary data reviewer, typically the Mission Control Operator, reviewed all auto-QC and Global Op Code flags, as well as reviewed all pollutant and instrument metadata in detail. Operators were trained to identify unexpected or concerning data trends such as sharp jumps or drops, consistent baseline drifting, periodic cycling, repeated values, or self-sampling signals, any of which could indicate a problem with an instrument or measurement. If the concentration or environmental data were determined to be erroneous by identifying an instrument issue, the data were invalidated and instrument repair procedures were initiated. No data were invalidated unless there was a clear issue with the associated instrument. After the primary reviewer completed their review, the secondary reviewer, typically the Driver, performed a complete secondary review of the data. The two reviewers then compared their resulting datasets and any contradictory QC coding was discussed and consulted with AMPT leadership. Data review can take up to a full day per reviewer, per drive.

Data that were below an instrument's Method Detection Limit (MDL) are flagged with an associated data qualifier code. According to the EPA, the MDL is defined as the minimum measured concentration of a substance that can be reported as distinguishable from method blank results with 99% confidence.[9] The Reportable Detection Limit (RDL) is defined as the limit which can *reliably* be measured.[10] Unlike the MDL, the RDL is not defined in federal regulations and is particular to each laboratory.

MDLs for NO_x (in parts per billion, or ppb), CO (in parts per million, or ppm), and specific VOCs monitored by the PTR-MS (in ppb) were determined during a test drive while sampling air that had NO_x, CO, and VOCs removed. Concentration data were analyzed for each of the compounds. The data were filtered to remove instances when vehicle speed was less than 3 mph. Filtering was performed to harmonize the calculated MDLs with mobile data categorized with the Global Op Code of 0, indicating that during those times vehicle exhaust self-sampling was expected to be negligible. Following this filtering, the 1-second standard

[9] 40 CFR Appendix B to Part 136 - Definition and Procedure for the Determination of the Method Detection Limit, Revision 2: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-136#Appendix-B-to-Part-136

[10] EPA, Office of Air Quality Planning and Standards, More Ado About Next to Nothing: Brining Minimum Detection Levels into Focus. https://www3.epa.gov/ttnemc01/meetnw/2015/moreado.pdf

deviation, σ_i, of each of these species was determined over the course of the entire drive according to Eqn. 1 below:

$$\sigma_i = \sqrt{\frac{\sum|x_i - \mu_i|^2}{N_i}} \quad \text{Eqn. 1}$$

Where for each compound x_i is each individual 1-second concentration data point, μ_i is the average concentration of filtered data for compound *i* over the course of drive, and N_i is the total number of data points.

The MDL was then determined by multiplying σ_i for each compound by the Student's *t*-value, $t_{(n-1,\ 1-\alpha=0.99)}$ appropriate for a single-tailed 99th percentile *t* statistic and a standard deviation estimate with n-1 degrees of freedom and adding this value to the average concentration for compound *i* as shown in Eqn. 2 below. The value for the Student's *t*-value metric (2.327 for this dataset) was determined from commonly available statistical tables.

$$MDL_i = Avg_i + t_{(n-1,\ 1-\alpha=0.99)*}\sigma_i \quad \text{Eqn. 2}$$

The RDL was then determined according to equation 3 below:

$$RDL_i = MDL_i * 3 \quad \text{Eqn. 3}$$

Where RDL_i, is the Reportable Detection Limit for compound *i*. The factor of 3 was determined to be lowest multiplier that allows all compounds to be reliably measured.

Measurements with values below the MDL for a given compound have higher uncertainty and are not statistically distinguishable from method blank results. Measurements with values above the MDL but below the RDL likely indicate the confirmation of the compound in question but that its concentration may not be reliably quantified. Therefore, measurements below these limits should be considered cautiously and judiciously for data analysis and interpretation.

MDLs and RDLs for NO_x, CO, and each target VOC for the test and during the drive periods are provided in Table A-1 in the Appendix.

Final Dataset

Final, quality assured (QA'd) datasets containing speciated VOCs, NO_x, CO, ambient temperature, wind, and GPS data were made available for internal analysis and interpretation as soon as data review was complete. Only QA'd data that were valid, above a certain monitoring van speed threshold, and not during vehicle backups were used in the internal analysis by the Air District. Data collected while the vehicle was operating at low speeds (less than 3 miles per hour) or while backing up were excluded from analysis to limit potential measurement contamination by self-sampling exhaust plumes produced by the air monitoring van, as flagged by the Global Op Code metric. Final, QA'd datasets containing valid data used in the internal analysis were made available to the public on the Air District's CAMP website.[11] A README file containing descriptions of all data parameters, data quality control logic, and other details necessary to interpret the data was developed and included with the final public datasets.

[11] Air District website for the Path to Clean Air CAMP: https://www.baaqmd.gov/community-health/community-health-protection-program/richmond-area-community-health-protection-program/community-air-monitoring

Data Analysis and Findings

The final dataset of 16 drive days was evaluated and analyzed primarily using R-based tools. For the bulk of the analysis, an R-based exploratory dashboard was developed with functionality to filter data by drive period, drive area of interest, and data validity codes, and to view data in different visualizations, such as boxplots, histograms, scatterplots, time-series, and spatially on maps.

To locate and investigate occurrences of higher VOC levels, each drive day was treated as its own subset of data and was considered independently, as each drive day has different background meteorological and air quality conditions that preclude aggregation without more complex analytical efforts. Importantly, aggregating the data across multiple drive days, such as developing spatially averaged maps of different compounds across drive days, was not necessary to inform the primary objective of this project.

For each drive day, the analyst viewed each compound spatially on maps and noted locations of occurrences of relatively higher levels of different VOCs, including patterns that emerged of locations where multiple VOCs appeared to be higher and where higher levels of VOCs occurred on multiple drive days. Some compounds were also viewed on a logarithmic scale to better reveal some of the underlying spatial pollution structure and help identify corridors of relatively higher levels of different compounds. Given the amount of data collected during this study, there are inevitably far more occurrences of relatively higher levels of different VOCs than can be reasonably evaluated given available time and resources. Thus, several more-notable occurrences of higher VOC levels were selected for more detailed examination and source attribution. CO and NO_x data were also evaluated to help differentiate combustion and non-combustion sources of VOCs, since higher levels of CO and NO_x concurrent with VOCs typically indicates combustion, while their absence may indicate non-combustion VOC emissions, such as a facility leak.

Several factors were considered in selecting examples of more-notable occurrences of higher VOC levels for this additional analysis, including:

- Occurrences of higher levels of VOCs near sources or locations identified by the community
- Locations where higher levels of VOCs occurred on multiple drive passes or drive days
- Air quality issues that were noted by the air monitoring team, such as smoke or odors
- Concentrations of a compound that were the highest of a drive day or of any drive day

Synoptic weather maps and data from nearby fixed-site meteorological monitors were reviewed to inform a general understanding of meteorological conditions, such as temperature ranges and wind patterns, on each drive day.[12,13] Additionally, wind data collected by the air monitoring van were used, when possible, to help contextualize and identify possible sources for occurrences of higher measured VOC levels. Wind data from the monitoring van were only considered when the van was not in motion and were compared with data from area fixed-site meteorological monitors as an additional check.

[12] NOAA Weather Prediction Center Daily Weather Maps website: https://www.wpc.ncep.noaa.gov/dailywxmap/

[13] Historical data from the NOAA-operated RCMC1 (Richmond-Long Wharf) and PPXC1 (Point Potrero) meteorological monitoring sites are available from the Mesowest website: https://mesowest.utah.edu/. Data from the Chevron-Gertrude Ground Level Monitor were also reviewed.

General Insights

Averages, ranges, and percentiles of each target VOC across the 16 drive days are provided in **Table 2**. For most VOCs, most of the measured values were above the MDLs for the compound. For benzo[a]pyrene and dichlorobenzene, over 95% of the data were below the MDLs. For some comparison with other VOC measurements in the study area, mean concentrations of benzene and toluene measured on a 1-in-12 day schedule at the Air District's fixed-site air monitoring station in San Pablo (Rumrill Blvd.) from January to March 2022 were 0.201 ppb and 0.473 ppb, respectively.[14] While the data from 24-hour integrated canister samples collected at the fixed-site air monitoring stations are not directly comparable to the averages of 1-second data collected by the air monitoring van on different days over different time periods, the values were encouragingly close between the two methods.

Table 2. *Summary statistics for each target VOC across the 16 drive days. Concentrations below the MDL are underlined. Concentrations are in parts per billion (ppb).*

Compound	Mean	5th %	25th %	Median	75th %	95th %	Maximum
Acetaldehyde + Ethylene Oxide	2.853	1.402	1.930	2.738	3.496	4.768	85.904
Benzene	0.302	0.115	0.169	0.250	0.346	0.575	60.186
Benzo[a]pyrene	0.001	0	0	0.001	0.002	0.004	0.049
1,3-Butadiene	0.115	0	0	0	0.164	0.479	15.297
Dichlorobenzene	0.005	0.001	0.002	0.004	0.006	0.010	0.633
Ethylbenzene + Xylene	0.309	0.039	0.097	0.178	0.320	0.733	230.482
Naphthalene	0.040	0.016	0.025	0.035	0.049	0.077	1.836
Styrene	0.069	0.013	0.022	0.034	0.059	0.209	75.378
Toluene	0.340	0.055	0.125	0.220	0.366	0.795	185.805
Trimethylbenzene	0.169	0.027	0.058	0.101	0.173	0.420	127.084

Distributions of 1-second measurements of each target VOC by drive day are provided in the Appendix. As is generally typical for distributions of air pollutant measurements, the distributions of measurements in this study are strongly right-skewed, with a vast majority of measurements falling in the lower end of the measured range of concentrations for each compound and drive day, but with several occurrences of much higher values. It is these occurrences of higher concentrations, or peaks, that are of most interest in this study in identifying possible VOC sources and opportunities for emissions reductions.

Several of the measured VOCs were highly correlated, meaning that when one compound was relatively higher in concentration, other compounds were also higher (**Figure 4**). This can indicate co-emission of multiple VOCs and other pollutants from the same or similar types of sources. The BTEX compounds and trimethylbenzene had the highest correlations, which is typical in urbanized areas as these compounds are all co-emitted through burning of fossil fuels and from evaporation and leaks from fossil fuel storage and distribution networks. The correlations across the BTEX compounds and trimethylbenzene were statistically significant ($p < 0.05$). Naphthalene, 1,3-butadiene, and acetaldehyde, which are also emitted through burning of fossil fuels, were also moderately correlated with BTEX and trimethylbenzene. CO, and to a lesser extent, NO_x, were also moderately correlated with several VOCs, indicating the prevalence of

[14] More information on the Air District's fixed-site air monitoring network is available in the Air District's Annual Air Monitoring Network Plan: https://www.baaqmd.gov/about-air-quality/air-quality-measurement/ambient-air-monitoring-network

combustion sources of VOCs, such as traffic, that are ubiquitous throughout the study area. Some of the correlation across pollutants is likely also attributable to other factors, like during periods when meteorological conditions are conducive to higher concentrations of pollutants generally.

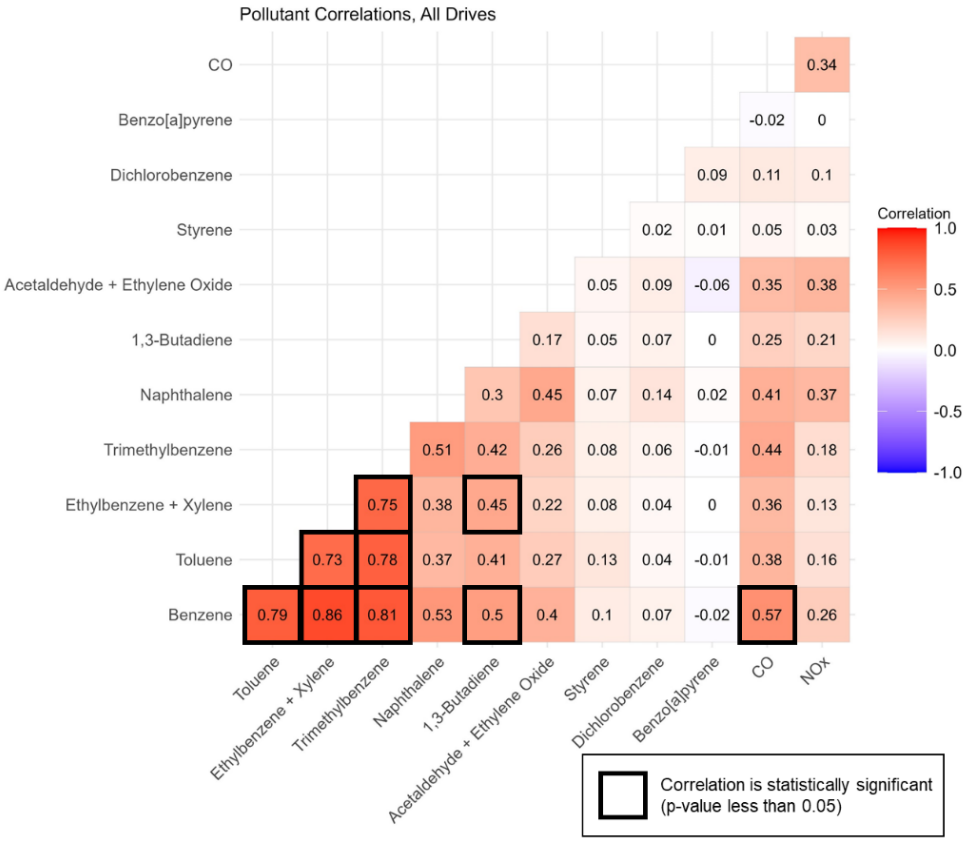

Figure 4. *Correlation matrix for target VOCs, CO, and NO_x across all drive days. Darker red shading indicates a higher positive correlation. Bolded squares indicate that the correlation is statistically significant.*

Many of the individual occurrences of higher levels, or peaks, of a particular VOC coincided with higher levels of other VOCs (particularly BTEX and trimethylbenzene) and CO, indicating combustion-related pollution sources. Often these occurrences were on busy roadways or at intersections, as well as in commercial areas with traffic, restaurants, and other VOC sources. For example, generally higher levels of BTEX coincident with higher levels of CO were noted on several high-traffic and/or commercial corridors, such as 23rd Street, Barrett Ave., Macdonald Ave., Rumrill Blvd., Brookside Dr., Parr Blvd., Fred Jackson Way, Richmond Pkwy., Pittsburg Ave., Cutting Blvd., Spring St., Canal Blvd., Ohio Blvd., Harbour Way, and Castro St., among others. Many of these roadways were also noted as air quality concerns by the CSC, including streets that commuters may take through neighborhoods to bypass traffic on other roadways. Additionally, occurrences of higher VOC levels that appeared to be combustion related were also sometimes noted in residential areas, where combustion sources could include idling vehicles, diesel generators, wood smoke, and food preparation, among others.

There were several instances of peaks in different VOCs in the absence of combustion indicators, likely indicating non-combustion emissions sources. In some cases, only one VOC showed a peak in concentrations while the other target VOCs remained at background levels. Normalized ratios of certain

VOCs to CO, such as toluene to CO and styrene to CO, were calculated and assessed visually on maps to help locate occurrences of higher levels of VOCs that may be caused by non-combustion sources, and whether those occurrences were recurring on multiple drive passes or drive days.

Several instances of relatively higher levels of styrene were noted in the vicinity of specific facilities and operations in the absence of peaks in other VOCs and CO. While styrene is produced through combustion of fossil fuels and other combustion sources, its amounts are typically relatively low in urban areas compared to other VOCs like BTEX; therefore, styrene was found to be a useful tracer for possible non-combustion sources of VOCs in this study. A major use of styrene is to produce plastics and resins. Peaks in styrene in this study were found near tank terminals and near a plastics manufacturing facility. EPA does not have a carcinogen classification for styrene due to inconclusive evidence.[15] Additional examples of peaks of one or more VOCs that appear to be driven by non-combustion sources include higher levels of BTEX and other compounds near a gas station, toluene in the vicinity of auto body shops, acetaldehyde in the vicinity of bakery operations, and 1,3-butadiene near the refinery and railyard.

Occurrences of Higher VOC Concentrations Near Pollution Sources

This section describes examples of occurrences of relatively higher concentrations of different VOCs that were measured near certain pollution sources. Each example includes annotated maps of the area surrounding the higher concentrations of VOCs, time-series plots of VOC and CO concentrations, and tables with peak VOC concentrations. Drive dates of the example occurrences are also provided to help differentiate peaks in VOCs that occurred in or near the same locations on multiple drive days.

Harbor Area and Tank Terminals

Peaks in one or several VOCs were noted on multiple drive passes and drive days in the vicinity and downwind of different tank terminals and harbor-related facilities in the harbor area. These peaks appear to be associated with non-combustion sources of VOCs since collocated levels of CO and NO_x were comparatively low. Some of the peaks in VOCs included several compounds, while other peaks were predominantly of styrene and toluene.

There are several tank terminals in Richmond's harbor area that are used for storing and transporting various products. Operations at these facilities can result in the release of VOCs into ambient air, particularly during filling or emptying of liquids into or out of tanks and from volatilization and leaking of gases during storage. There are other facilities and operations in the harbor area as well, including marine engine and body repair shops, general port operations like tugboat activity and unloading and loading of ships, rail and truck activity, a coal terminal, a metal recycler, and a yacht club.

Peaks in styrene and toluene were detected along Wright Avenue on March 29 (**Figure 5**, **Figure 6**, **Table 3**). This peak included the highest concentrations of styrene measured during the study (75 ppb). The peak concentrations of styrene and toluene occurred immediately adjacent to a tank terminal. Winds were from the south-southeast, from the direction of the tank terminal. There was also evidence of a plume extending northward from this location, across I-580 into residential areas. While concentrations decreased downwind, this example illustrates how such plumes can extend well beyond their origins.

[15] EPA Health Effects Fact Sheet for Styrene, from the EPA Health Effects Notebook for Hazardous Air Pollutants: https://www.epa.gov/sites/default/files/2020-05/documents/styrene_update_2a.pdf

Figure 5. *Map view of styrene concentrations measured near a tank terminal along Wright Avenue, 3/29/2022.*

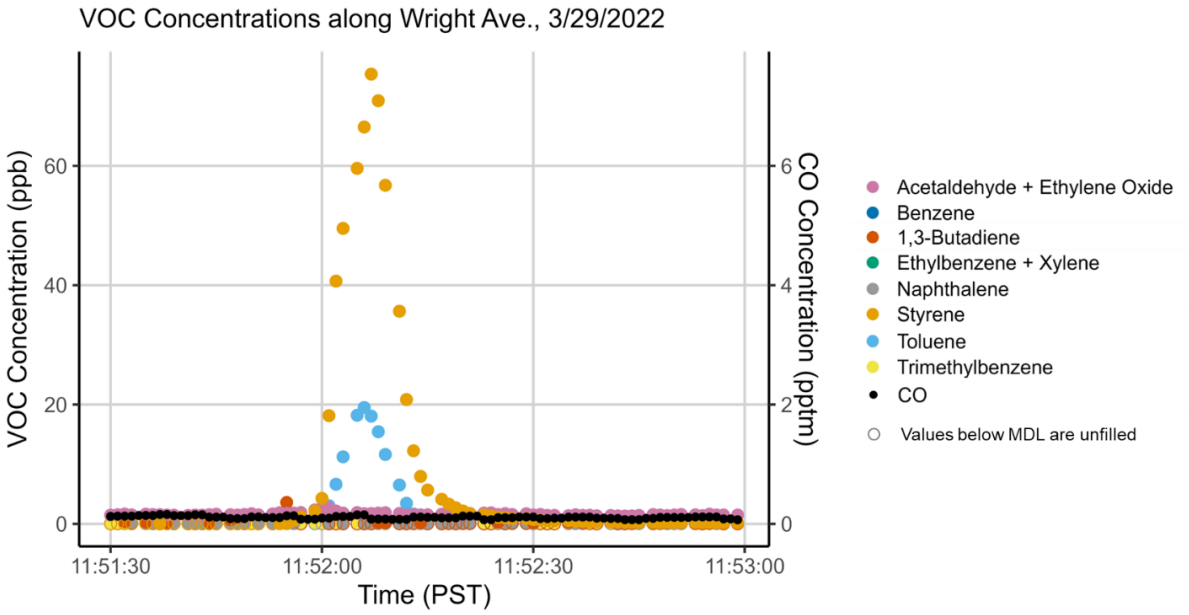

Figure 6. *Time-series of VOC and CO concentrations measured near a tank terminal along Wright Avenue, 3/29/2022.*

Table 3. *VOC concentrations measured near a tank terminal along Wright Avenue on 3/29/2022.*

VOC Concentrations (ppb) along Wright Avenue, 3/29/2022		
Pollutant	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	2.71	1.98
Benzene	1.19	0.17
1,3-Butadiene	3.59	0.08
Ethylbenzene + Xylene	0.88	0.12
Naphthalene	0.05	0.03
Styrene	75.37	0.08
Toluene	19.50	0.15
Trimethylbenzene	0.36	0.08

Additionally in the harbor area, peaks in several VOCs were noted along several drive passes and drive days (January 31, March 16, March 29) along Cutting Boulevard east of Canal Boulevard, as shown in **Figure 7**, **Figure 8**, and **Table 4**. For example, on January 31, several peaks of different VOCs were noted on two monitoring passes roughly one hour apart. In both passes, peaks in trimethylbenzene were collocated with smaller peaks in BTEX. Additional peaks in different VOCs were also noted slightly to the east of the primary peaks; some of these additional peaks included trimethylbenzene, benzene, and 1,3-butadiene. There were also separate peaks in acetaldehyde + ethylene oxide. The eastbound pass included peaks in CO that were not evident in other passes. These multiple peaks of different VOCs, with and without peaks in combustion indicators, may indicate plumes from different emissions sources, which is not unexpected given the complex mix of emissions sources in this area. In these examples, the peaks in trimethylbenzene and BTEX were downwind of marine repair facilities along Cutting Blvd. and tank terminals across the ship canal.

Figure 7a. *Map view of trimethylbenzene concentrations measured along Cutting Boulevard near tank terminals and marine operations on 1/31/2022.*

Figures 7b and 7c. *Map views of trimethylbenzene concentrations measured along Cutting Boulevard near tank terminals and marine operations on b) 3/16/2022 and c) 3/29/2022.*

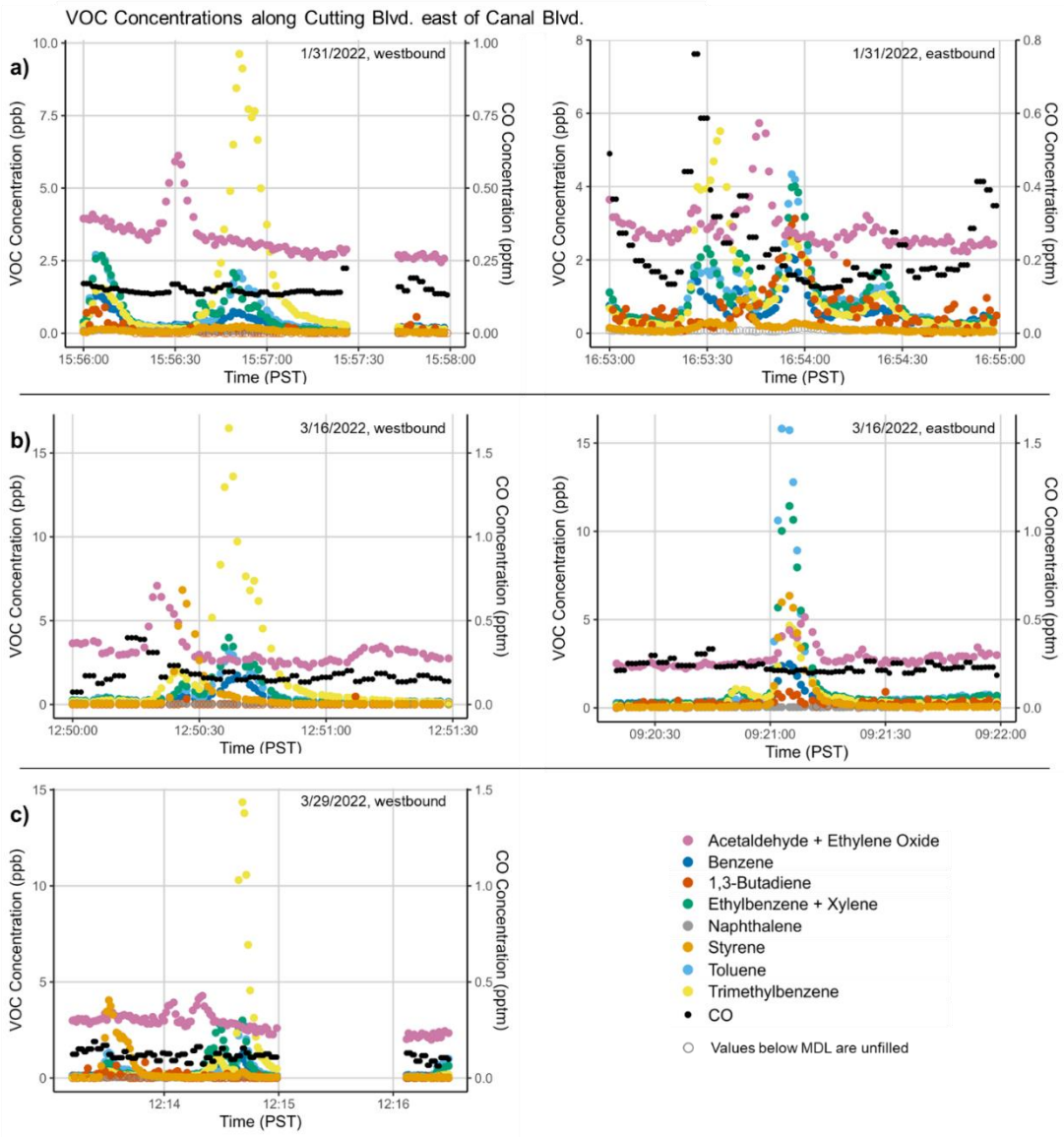

Figure 8. *Time-series of VOC and CO concentrations along Cutting Boulevard measured near tank terminals and marine operations on a) 1/31/2022, b) 3/16/2022, and c) 3/29/2022.*

Table 4. *VOC concentrations measured along Cutting Boulevard near tank terminals and marine operations on 1/31/2022, 3/16/2022, and 3/29/2022.*

VOC Concentrations (ppb) along Cutting Boulevard east of Canal Boulevard						
	1/31/2022		3/16/2022		3/29/2022	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	6.12	2.41	7.09	2.49	4.28	1.98
Benzene	2.06	0.29	2.48	0.28	1.23	0.17
1,3-Butadiene	3.13	0.21	0.91	0.05	0.36	0.08
Ethylbenzene + Xylene	4.01	0.26	11.40	0.35	3.00	0.12
Naphthalene	0.15	0.04	0.17	0.04	0.04	0.03
Styrene	0.93	0.04	6.83	0.04	0.32	0.08
Toluene	4.34	0.31	15.80	0.37	2.95	0.15
Trimethylbenzene	9.62	0.17	16.50	0.21	14.35	0.08

Plastics Fabrication

Higher levels of styrene were detected on several drive passes and drive days (February 10, March 17, April 1) near the intersection of Richmond Parkway and Goodrick Avenue, in the vicinity of the ATS Products, a facility that works with plastics for fabricating ductwork (**Figure 9**, **Figure 10**, and **Table 5**). The higher levels of styrene occurred without notable collocated peaks in other VOCs or combustion indicators. The peaks in styrene occurred generally downwind of the plastics fabricator during each pass. There are also other potential sources of VOCs in this area, including an electric motor repair facility, a tank cleaner, a landscaping business, and an equipment rental company.

Figure 9. *Map views of styrene concentrations measured along Richmond Parkway and Goodrick Avenue near a plastics ductwork fabrication facility on a) 2/10/2022, b) 3/17/2022, and c) 4/01/2022.*

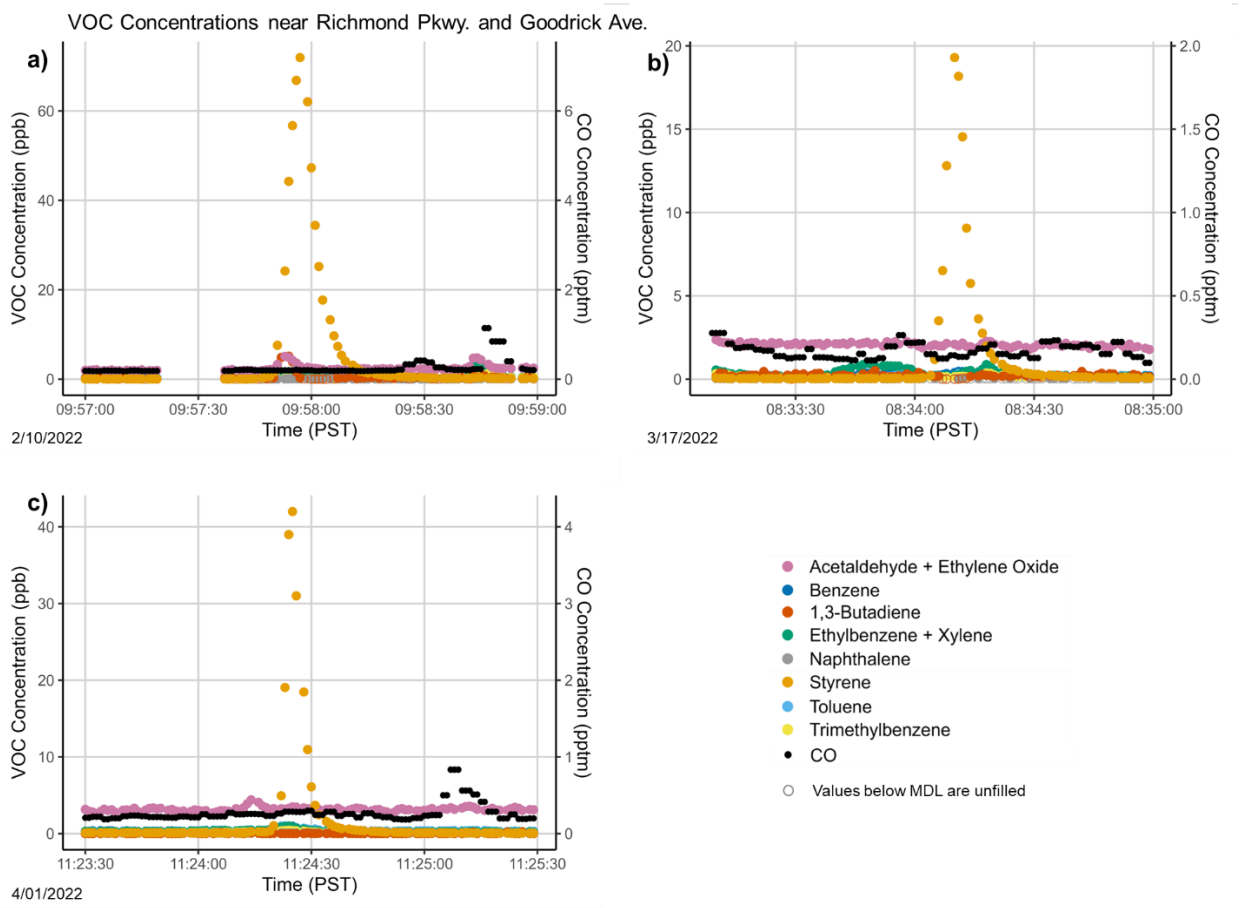

Figure 10. *Time-series of VOC and CO concentrations measured along Richmond Parkway and Goodrick Avenue near a plastics fabrication facility on a) 2/10/2022, b) 3/17/2022, and c) 4/01/2022.*

Table 5. *VOC concentrations measured along Richmond Parkway and Goodrick Avenue near a plastics fabrication facility on 2/10/2022, 3/17/2022, and 4/01/2022.*

VOC Concentrations (ppb) near Richmond Parkway And Goodrick Avenue						
	2/10/2022		3/17/2022		4/01/2022	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	5.11	3.30	2.36	2.12	4.40	3.41
Benzene	2.72	0.31	0.47	0.23	0.96	0.38
1,3-Butadiene	5.15	0.13	0.53	0.13	0.24	0.18
Ethylbenzene + Xylene	3.53	0.26	0.96	0.22	0.99	0.39
Naphthalene	0.11	0.04	0.04	0.03	0.09	0.06
Styrene	71.95	0.10	19.30	0.04	41.99	0.13
Toluene	4.27	0.37	0.74	0.21	1.01	0.44
Trimethylbenzene	1.62	0.15	0.38	0.10	0.45	0.20

Gas Stations

Evaporation of gasoline and other liquid fuels at gas stations results in emissions of VOCs. Emissions from gas stations can be higher when vapor recovery systems are not functioning properly, during times when the station is being refueled, and when fuel is mishandled or inadvertently spilled.

Higher levels of several VOCs including BTEX, trimethylbenzene, and 1,3-butadiene were detected outside the Top Food and Gas station located at the corner of Rumrill Boulevard and Pine Avenue in San Pablo on a drive pass on February 8 (**Figure 11**, **Figure 12**, **Table 6**). The gas station was being refueled at the time and a gasoline odor was noted. This gas station is adjacent to residences and an outdoor sports park.

In response to the higher levels of VOCs that were measured, the Air District's Source Test team inspected the station, which resulted in several violation and mitigation referrals to the Air District's Compliance and Enforcement division.

Figure 11. *Map view of benzene concentrations measured near a gas station along Pine Avenue, 2/08/2022.*

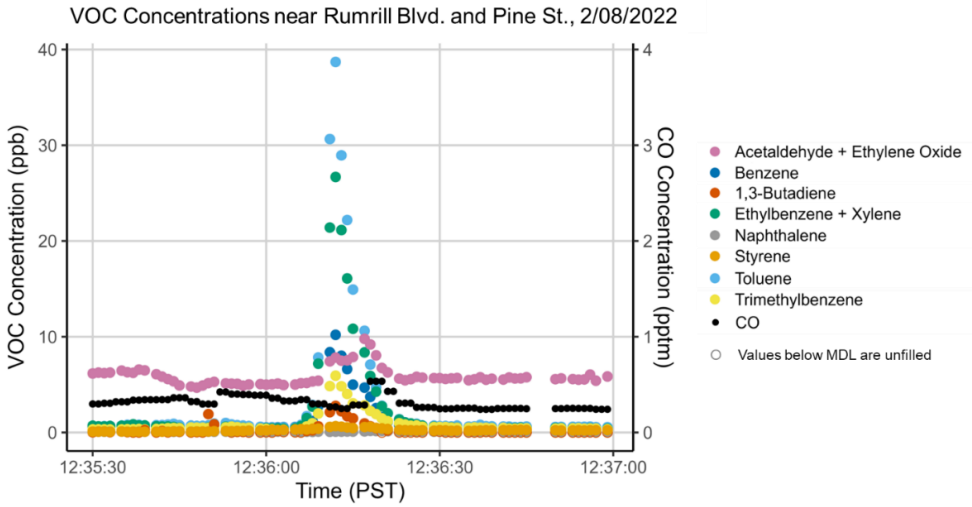

Figure 12. *Time-series of VOC and CO concentrations measured near a gas station along Pine Avenue, 2/08/2022.*

Table 6. *VOC concentrations measured near a gas station along Pine Avenue on 2/08/2022.*

VOC Concentrations (ppb) near Gas Station, 2/08/2022		
Pollutant	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	9.78	4.44
Benzene	10.20	0.51
1,3-Butadiene	2.78	0.13
Ethylbenzene + Xylene	26.69	0.66
Naphthalene	0.17	0.06
Styrene	0.66	0.16
Toluene	38.70	0.59
Trimethylbenzene	5.93	0.27

Refinery Area

Higher levels of VOCs were detected at times in the vicinity of the Chevron refinery and adjacent related facilities. Operations associated with oil and gas refining, processing, transport, and storage can produce VOCs. The refinery is the largest facility-based source of VOCs in the Richmond area and is supported by several nearby supporting facilities and operations that also produce VOCs.

Two examples of relatively higher levels of different VOCs that were found near the refinery are shown in **Figure 13**, **Figure 14**, and **Table 7**. One occurred along Ohio Avenue downwind of the refinery and adjacent railyard, which featured a peak in 1,3-butadiene. The second occurred south of the refinery area and included peaks in several VOCs, including BTEX, trimethylbenzene, and 1,3-butadiene. An odor was also noted at the time of these peaks. In both examples, levels of combustion indicators were comparatively lower, likely indicating non-combustion sources of VOCs.

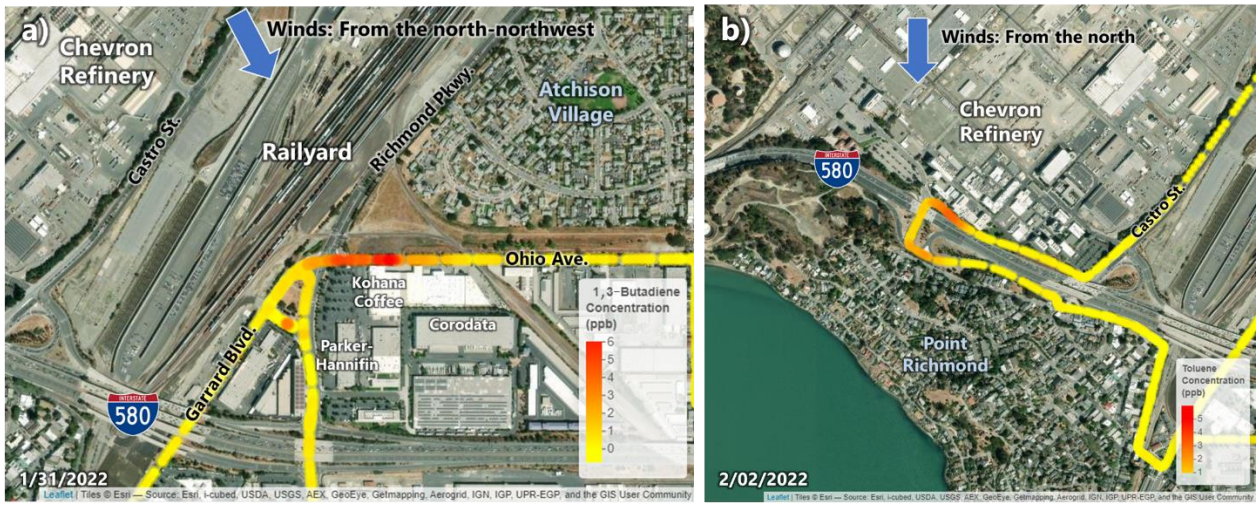

Figure 13. *Map views of measured a) 1,3-butadiene concentrations along Ohio Avenue on 1/31/2022 and b) toluene concentrations near the Chevron Refinery on 2/02/2022.*

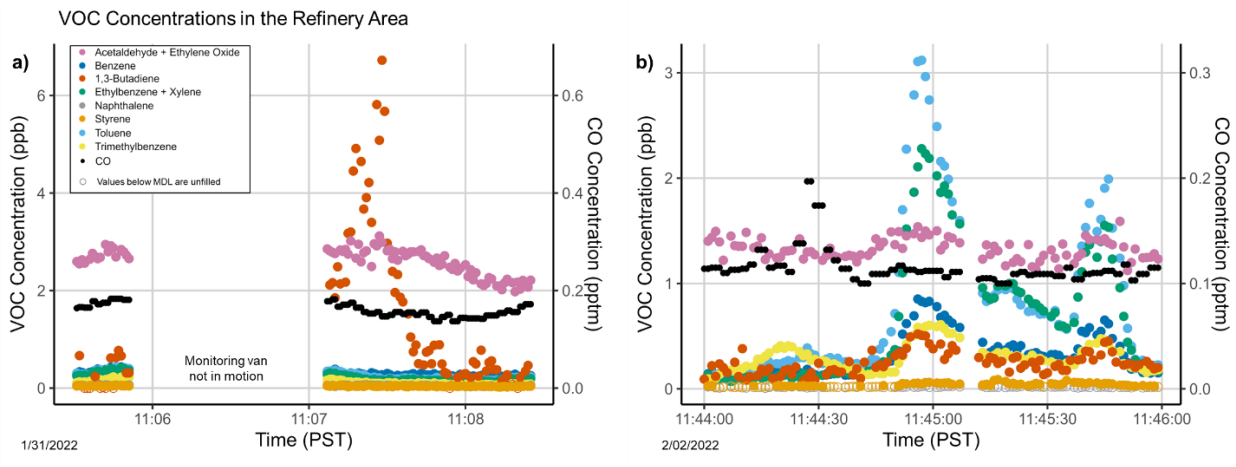

Figure 14. *Time-series of VOC and CO concentrations measured a) along Ohio Avenue on 1/31/2022 and b) near the Chevron Refinery on 2/02/2022.*

Table 7. *VOC concentrations measured a) along Ohio Avenue on 1/31/2022 and b) near the Chevron Refinery on 2/02/2022.*

VOC Concentrations (ppb) near Refinery Area				
	1/31/2022		2/02/2022	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	3.12	2.41	1.59	1.66
Benzene	0.43	0.28	0.85	0.18
1,3-Butadiene	6.72	0.21	0.52	0.16
Ethylbenzene + Xylene	0.42	0.26	2.28	0.19
Naphthalene	0.07	0.04	0.03	0.02
Styrene	0.06	0.04	0.09	0.06
Toluene	0.43	0.31	3.12	0.22
Trimethylbenzene	0.23	0.16	0.61	0.10

Auto Body Shops

There are numerous auto body shops in the study area, including over 40 with air quality permits. VOCs can enter the air from products like paints, solvents, and cleaners that are used at auto body shops. Higher levels of certain VOCs were detected in the vicinity and downwind of some auto body shops (**Figure 15**, **Figure 16**, and **Table 8**). Some of the local peaks in VOCs included several compounds, while others were predominantly of toluene. For example, peaks in VOCs were noted along Giant Highway in San Pablo on two different drive days. On one drive pass (March 17), peaks in several VOCs (particularly in toluene and ethylbenzene + xylene) were detected, while on another drive pass (April 1), the peak was largely in toluene, and to a lesser extent, trimethylbenzene. In both cases, levels of CO were comparatively lower, suggesting non-combustion sources of VOCs. The peaks in VOCs were detected downwind of an auto body shop and other automotive related facilities. In a separate example, higher levels of toluene were noted downwind of an auto body shop in the vicinity of Market Avenue and 22nd Street in San Pablo.

Figure 15. *Map views of toluene concentrations measured in the vicinity of auto body shops along a) Giant Highway on 3/17/2022, b) Giant Highway on 4/01/2022, and c) Market Avenue on 4/01/2022.*

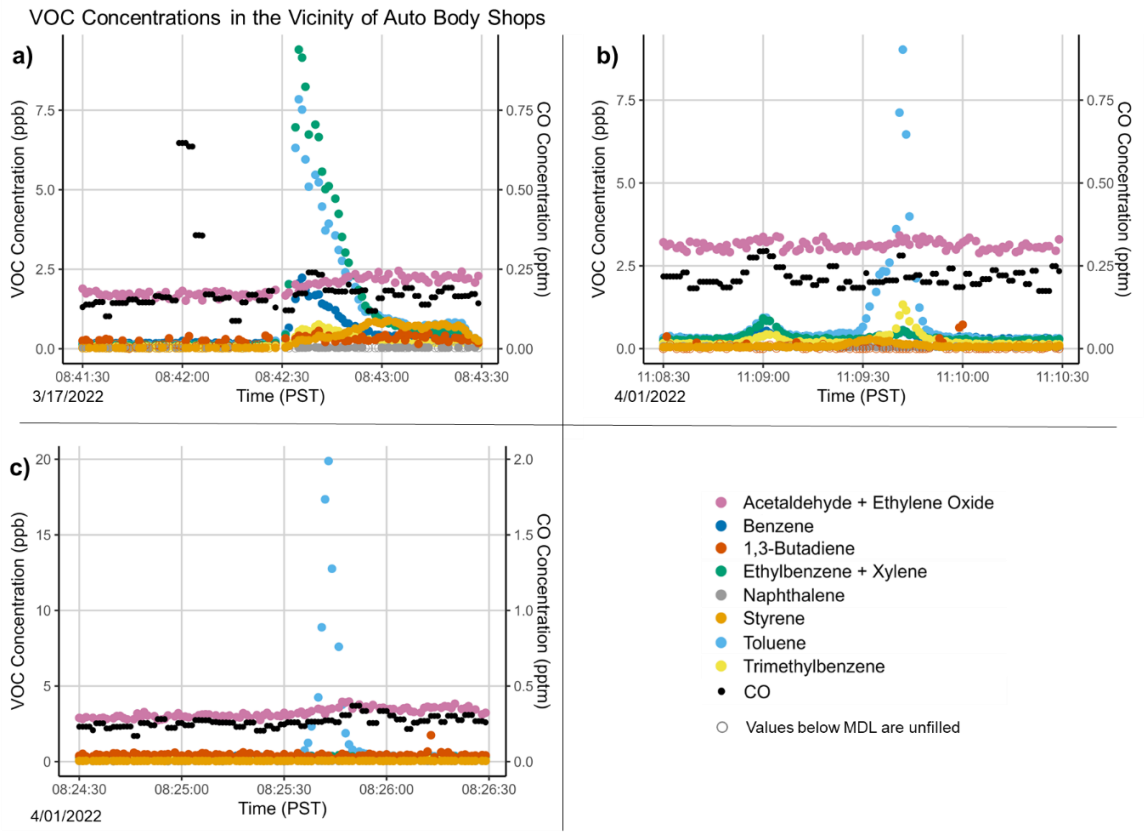

Figure 16. *Time-series of VOC and CO concentrations measured in the vicinity of auto body shops along a) Giant Highway on 3/17/2022, b) Giant Highway on 4/01/2022, and c) Market Avenue on 4/01/2022.*

Table 8. *VOC concentrations measured in the vicinity of auto body shops along Giant Highway on 3/17/2022, Giant Highway on 4/01/2022, and Market Avenue on 4/01/2022.*

VOC Concentrations (ppb) near Auto Body Shops						
	3/17/2022 Giant Highway		4/01/2022 Giant Highway		4/01/2022 Market Avenue	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	2.45	2.12	3.42	3.41	3.97	3.41
Benzene	2.23	0.23	0.56	0.38	0.44	0.38
1,3-Butadiene	0.56	0.13	0.72	0.18	1.75	0.18
Ethylbenzene + Xylene	9.41	0.22	0.91	0.39	0.43	0.39
Naphthalene	0.06	0.03	0.08	0.06	0.07	0.06
Styrene	0.88	0.04	0.29	0.13	0.08	0.13
Toluene	7.84	0.21	9.03	0.44	19.88	0.44
Trimethylbenzene	0.77	0.10	1.33	0.20	0.20	0.20

Commercial Bakeries

Exhaust from commercial bakeries can contain acetaldehyde and other VOCs, produced along with carbon dioxide during fermentation of dough. Higher levels of acetaldehyde were detected on several drive passes and drive days in the vicinity and downwind of two commercial bakeries in the study area, one in the Marina Bay area and one near North Richmond. While the monitoring instrumentation is unable to differentiate between acetaldehyde and ethylene oxide because they have the same molecular weights, higher concentrations measured in these areas are likely associated with acetaldehyde given the nearby emissions sources. Baking odors were also noted in some cases. In the Marina Bay example, several peaks in acetaldehyde were noted outside the Safeway Bread Plant (**Figure 17**, **Figure 18**, and **Table 9**). The peaks appeared in different locations on different days, generally occurring directly downwind of the bakery. The peaks in acetaldehyde are also of roughly the same magnitude and were not collocated with peaks in other VOCs or with CO.

Figure 17. *Map views of acetaldehyde + ethylene oxide concentrations measured in the vicinity of the Safeway Bread Plant on a) 1/31/2022, b) 2/18/2022, and c) 3/29/2022.*

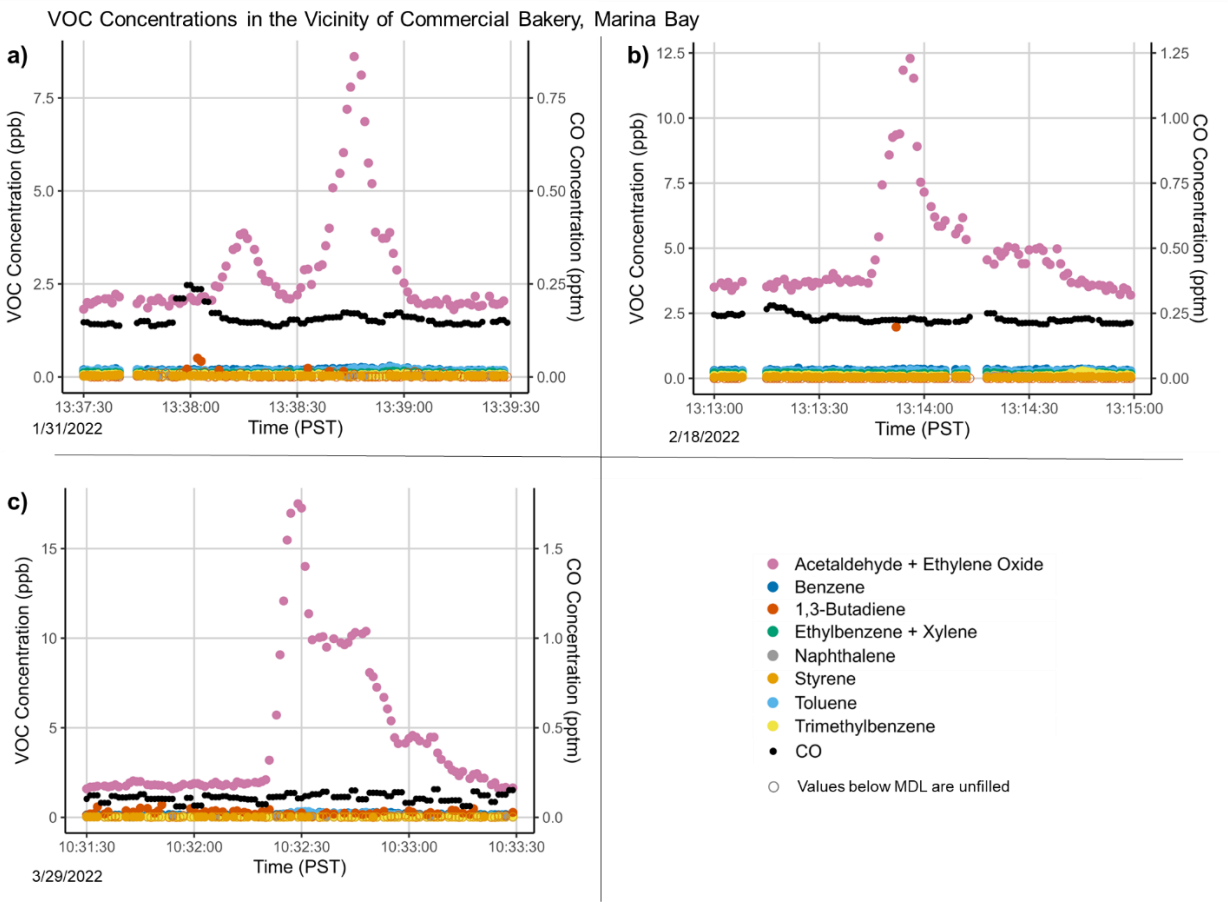

Figure 18. *Time-series of VOC and CO concentrations measured in the vicinity of a commercial bakery in Marina Bay on a) 1/31/2022, b) 2/18/2022, and c) 3/29/2022.*

Table 9. *VOC concentrations measured in the vicinity of a commercial bakery in Marina Bay on 1/31/2022, 2/18/2022, and 3/29/2022.*

VOC Concentrations (ppb) near Commercial Bakery, Marina Bay						
	1/31/2022		2/18/2022		3/29/2022	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	8.61	2.41	12.29	3.61	17.50	1.98
Benzene	0.29	0.28	0.39	0.37	0.32	0.16
1,3-Butadiene	0.50	0.21	1.97	0.02	0.71	0.08
Ethylbenzene + Xylene	0.15	0.26	0.24	0.34	0.09	0.12
Naphthalene	0.05	0.04	0.08	0.05	0.04	0.03
Styrene	0.06	0.04	0.07	0.06	0.03	0.08
Toluene	0.26	0.31	0.34	0.42	0.33	0.15
Trimethylbenzene	0.09	0.16	0.29	0.18	0.05	0.08

Peaks in acetaldehyde + ethylene oxide were also noted on several drive days near a commercial baking facility near North Richmond (**Figure 19**, **Figure 20**, and **Table 10**). The peaks occurred generally very near or downwind of the bakery. Unlike the previous example, the peaks in acetaldehyde were sometimes collocated with peaks in CO, while levels of other VOCs remained low.

Figure 19. *Map views of acetaldehyde + ethylene oxide concentrations measured in the vicinity of a commercial bakery near North Richmond on a) 2/10/2022, b) 3/17/2022, and c) 4/01/2022.*

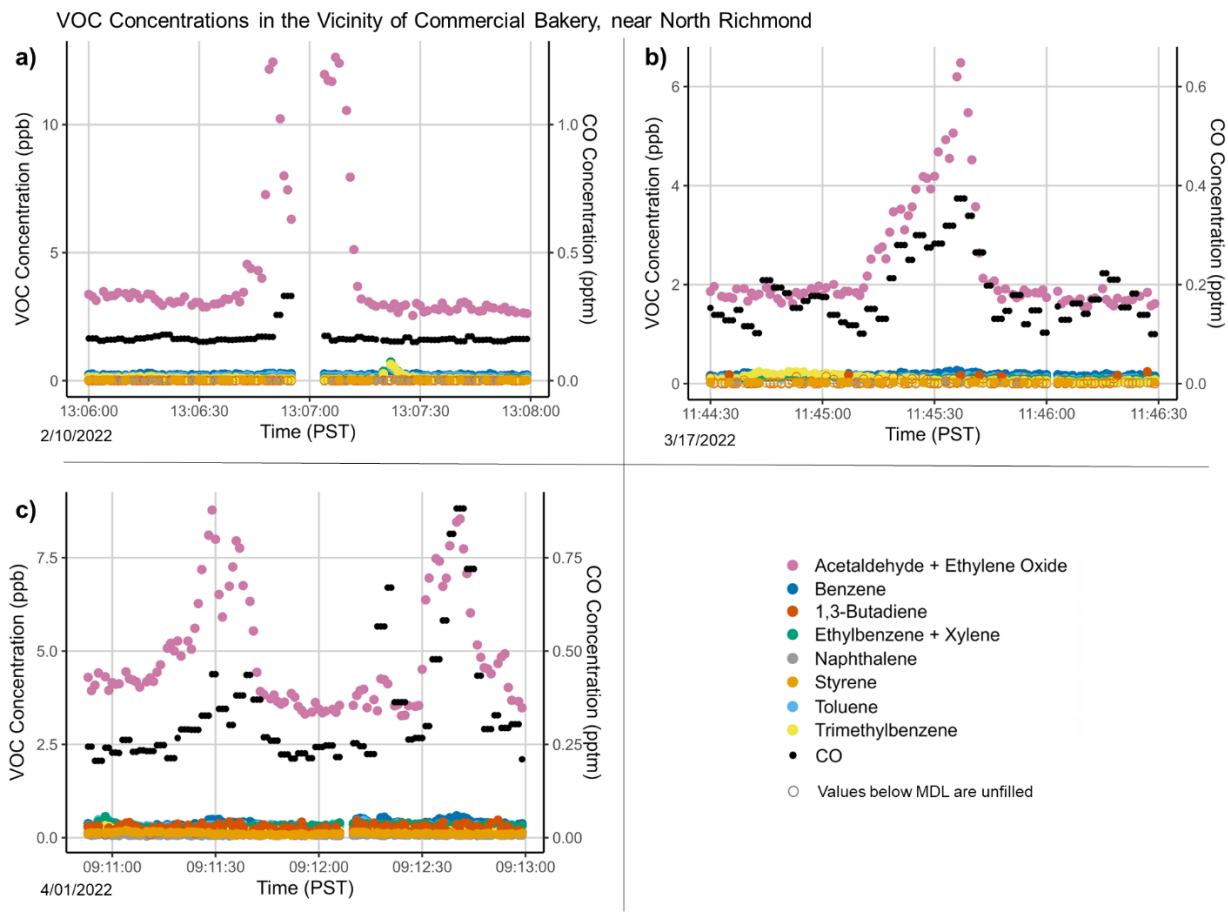

Figure 20. *Time-series of VOC and CO concentrations measured in the vicinity of a commercial bakery near North Richmond on a) 2/10/2022, b) 3/17/2022, and c) 4/01/2022.*

Table 10. *VOC concentrations measured in the vicinity of a commercial bakery near North Richmond on 2/10/2022, 3/17/2022, and 4/01/2022.*

VOC Concentrations (ppb) near Commercial Bakery, North Richmond						
	2/10/2022		3/17/2022		4/01/2022	
Pollutant	Local Peak	Drive Day Average	Local Peak	Drive Day Average	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	12.63	0.13	6.48	2.12	8.78	3.41
Benzene	0.37	0.31	0.27	0.23	0.59	0.38
1,3-Butadiene	0.14	0.13	0.24	0.13	0.47	0.18
Ethylbenzene + Xylene	0.73	0.26	0.17	0.22	0.57	0.39
Naphthalene	0.05	0.04	0.04	0.03	0.10	0.06
Styrene	0.05	0.10	0.03	0.04	0.19	0.13
Toluene	0.52	0.37	0.17	0.21	0.49	0.44
Trimethylbenzene	0.64	0.15	0.24	0.10	0.32	0.20

Light Industrial Park

There are many light industrial parks across the study area that may include a variety of facilities and operations. Some of these industrial parks are adjacent to or within residential areas. Higher levels of several VOCs (in particular, toluene) were noted in the vicinity and downwind of a light industrial park in the Marina Bay area (**Figure 21** and **Table 11**). There are several businesses in this area that may be sources of toluene and other VOCs, including a cabinet maker and paint, graphics, and art shops. This area is also in the vicinity of former industrial lots, some of which are undergoing remediation for future development. In this example, there was no collocated peak in CO, likely indicating a non-combustion source of the VOCs.

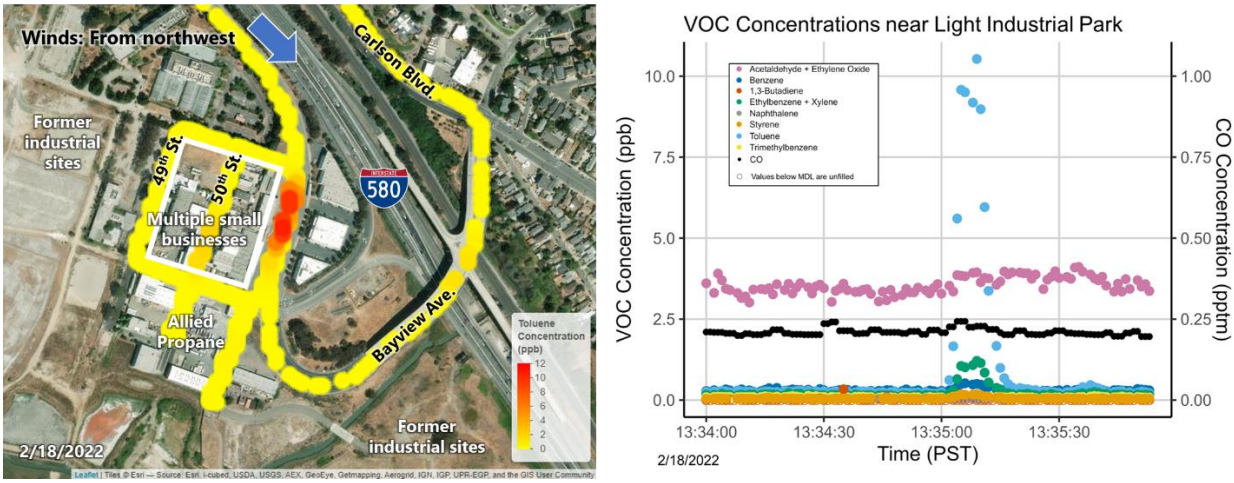

Figure 21. *Map view of measured toluene concentrations (left) and time-series of measured VOC and CO concentrations (right) near a light industrial park off I-580, 2/18/2022.*

Table 11. *VOC concentrations measured near a light industrial park off I-580, 2/18/2022.*

VOC Concentrations (ppb) near Light Industrial Park, 2/18/2022		
Pollutant	Local Peak	Drive Day Average
Acetaldehyde + Ethylene Oxide	4.11	3.61
Benzene	0.52	0.37
1,3-Butadiene	0.33	0.02
Ethylbenzene + Xylene	1.21	0.34
Naphthalene	0.06	0.05
Styrene	0.18	0.06
Toluene	10.53	0.42
Trimethylbenzene	0.13	0.18

Additional Examples of Peaks in VOCs

This section contains examples of occurrences of locally higher VOC concentrations, which featured some of the highest concentrations of different compounds that were measured during the study. The higher VOC concentrations in these examples did not have obvious sources based on the available data, preliminary analysis, and knowledge of known nearby pollution sources.

The four examples depicted below in **Figure 22** and **Table 12** occurred at:

a. Sanford Avenue near Battery Street in North Richmond (January 31)
b. 25th Street near Barrett Avenue in Richmond (February 4)
c. Rheem Avenue near 23rd Street in Richmond (February 8)
d. Cutting Boulevard near 26th Street (March 16)

In these examples, peaks were noted in most of the measured VOCs, and particularly for BTEX, trimethylbenzene. Except for the example on Rheem Ave. on February 8, the other examples of local peaks in VOCs were collocated with peaks in CO, indicating combustion sources near those locations. The peak in VOCs along Rheem Ave. did not have a collocated peak in CO, likely indicating a non-combustion source. The highest concentrations of benzene, trimethylbenzene, ethylbenzene + xylene, acetaldehyde + ethylene oxide, and 1,3-butadiene that were measured during the entire study occurred along Cutting Blvd. near 26th Street on the March 16 drive. The second highest concentrations of toluene and naphthalene during the study were also measured at this time and location. These examples of peaks in VOCs occurred in largely residential areas without obvious known sources of combustion or non-combustion VOCs.

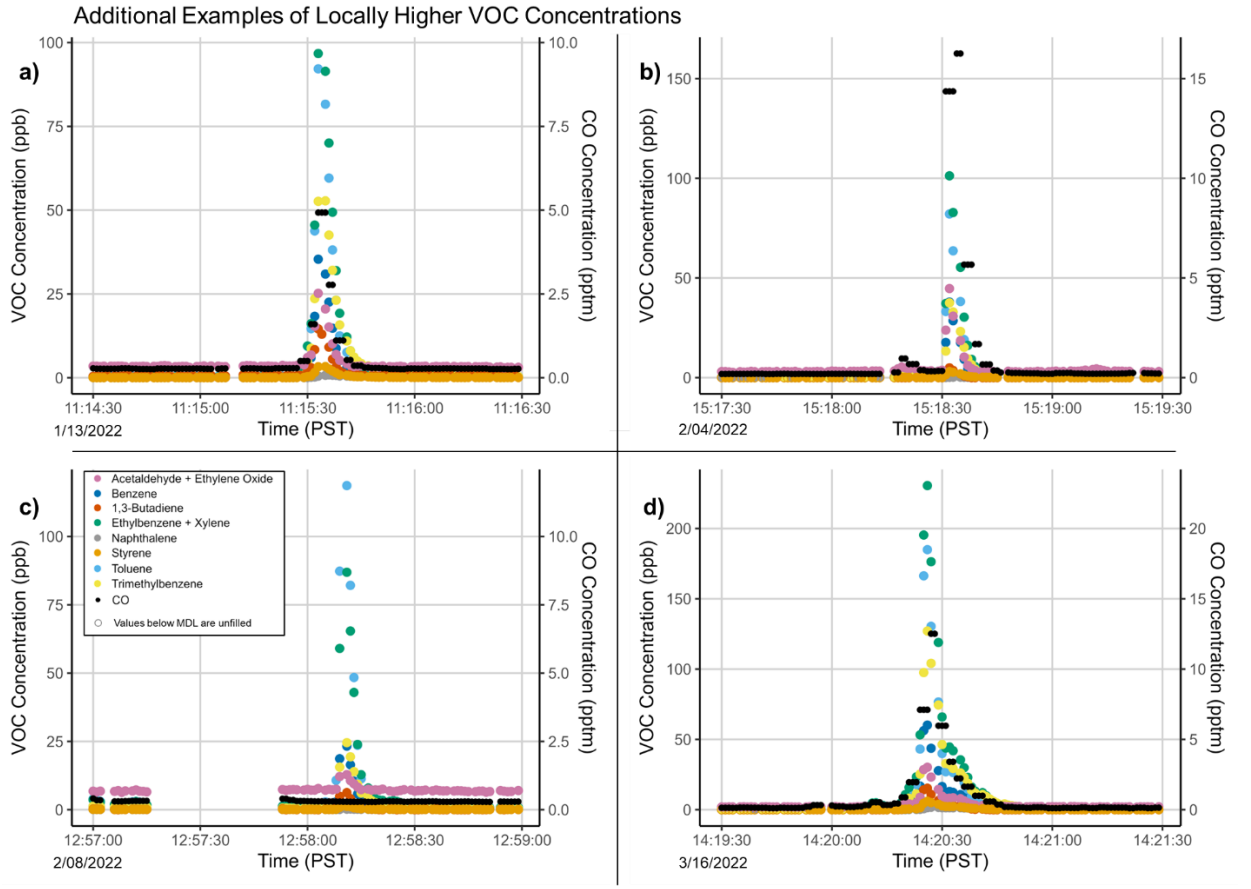

Figure 22. *Time-series of VOC and CO concentrations measured during additional examples of peaks in VOCs, measured along a) Sanford Avenue on 1/13/2022, b) 25th Street on 2/04/2022, c) Rheem Avenue on 2/08/2022, and d) Cutting Boulevard on 3/16/2022.*

Table 12. *VOC concentrations during additional examples of peaks in VOCs, measured along Sanford Ave. on 1/13/2022, 25th St. on 2/04/2022, Rheem Ave. on 2/08/2022, and Cutting Blvd. on 3/16/2022.*

Additional Examples of Locally Higher Concentrations of VOCs								
	1/13/2022 (Sanford Ave.)		2/04/2022 (25th St.)		2/08/2022 (Rheem Ave.)		3/16/2022 (Cutting Blvd.)	
Pollutant	Local Peak	Drive Day Avg.	Local Peak	Drive Day Avg.	Local Peak	Drive Day Avg.	Local Peak	Drive Day Avg.
Acetaldehyde + Ethylene Oxide	25.20	3.71	44.70	3.93	12.85	4.44	30.21	2.49
Benzene	35.37	0.47	37.92	0.37	23.28	0.51	60.19	0.28
1,3-Butadiene	14.58	0.20	4.92	0.00	6.27	0.13	15.30	0.05
Ethylbenzene + Xylene	96.74	0.56	101.27	0.30	86.90	0.66	230.48	0.35
Naphthalene	0.84	0.06	0.21	0.05	0.24	0.06	1.77	0.04
Styrene	3.32	0.08	3.05	0.04	1.19	0.16	6.05	0.04
Toluene	92.16	0.59	82.11	0.34	118.61	0.59	184.93	0.37
Trimethylbenzene	52.78	0.32	37.49	0.18	24.53	0.27	127.08	0.21

For two compounds, dichlorobenzene and benzo[a]pyrene, the vast majority of measurements were below method detection limits.

Dichlorobenzene is used in products such as mothballs and certain deodorizers, particularly for toilets; therefore, it is often considered primarily as an indoor air pollutant. However, it is also used as an insecticide, for water treatment operations, and as a chemical production intermediate.[16] The Air District's emissions inventory for the study area includes dichlorobenzene for some water treatment and waste management facilities and operations. While most measurements of dichlorobenzene were below the MDL, some occurrences of relatively higher levels of the compound were measured in the same locations on multiple drive days. One such example was in Richmond's North and East neighborhood on 32nd Street between Nevin Avenue and Barrett Avenue, where relatively higher levels of dichlorobenzene were measured on the January 19 and February 4 drives. Additional examples include along 26th Street north of Cutting Boulevard (January 31 and February 18 drives) and in the vicinity of 8th St. between Maine Avenue and Florida Avenue (January 31, February 18, March 16 drives). Higher levels of dichlorobenzene were measured on two drive passes on March 23 along Macdonald Avenue near the BART and Amtrak rail overpass. The highest levels of dichlorobenzene measured during the study (0.63 ppb) occurred along Wilcox Avenue just west of 23rd Street and Richmond High School (February 2 drive). Except for the Macdonald Avenue example, these occurrences were all in largely residential areas away from industrial or commercial sources of dichlorobenzene.

Benzo[a]pyrene is a polycyclic aromatic hydrocarbon (PAH) with ubiquitous sources, including car exhaust, wood smoke, tobacco smoke, oil and gas products, and grilled meats.[17] It is also a known carcinogen. Benzo[a]pyrene was included in the study target list given its commonly found sources in urban

[16] EPA Health Effects Fact Sheet for Dichlorobenzene, from the EPA Health Effects Notebook for Hazardous Air Pollutants: https://www.epa.gov/sites/default/files/2016-09/documents/1-4-dichlorobenzene.pdf

[17] EPA Integrated Risk Information System (IRIS) Toxicological Review of Benzo[a]pyrene: https://iris.epa.gov/static/pdfs/0136tr.pdf

environments and it was listed by OEHHA as a candidate for air monitoring related to refinery chemical emissions. The only measurements of benzo[a]pyrene that were above the MDL occurred on the February 10 drive along Mission Avenue near 14th Street in San Pablo, which is a residential area within one to two blocks of a commercial corridor with cooking operations on Rumrill Blvd. Peaks in other VOCs and CO were also observed coincident with this peak in benzo[a]pyrene, likely indicating a combustion source of these pollutants.

Conclusion

A crucial piece of this study, being part of a community-developed air monitoring plan, was communication of the data and contextualized findings with the public. When the CSC concluded its work in developing the CAMP in July 2020, it selected a subset of members from the CSC to participate on a community Monitoring Outreach Team (MOT). The MOT was tasked with partnering with the Air District during the implementation of the CAMP by helping develop and review public-facing materials containing updates and findings from the different air monitoring projects in the CAMP and by conducting outreach efforts. The final effort for the MOT was helping review and conduct outreach for the public-facing GIS StoryMap that summarized findings from this air toxics monitoring study.[18] Members of the MOT included Dr. Henry Clark, Oscar Garcia, Kevin G. Ruano Hernandez, Dr. Julia Walsh, and Linda Whitmore. Matt Holmes previously served as a member of the team. The MOT was essential in helping share air monitoring project information with the community and their efforts and commitments are greatly appreciated.

This air toxics monitoring study found numerous occurrences of higher than typical levels of different VOCs throughout the study area. Some of the measured VOCs are air toxics with significant health effects. Correlations between VOC levels and combustion signatures like CO and NO_x point to the prevalence of combustion-related pollution sources (e.g., traffic) throughout the study area. Numerous instances of higher-than-typical levels of VOCs were also found in the vicinity of specific facilities and operations as well. The Air District is investigating possible causes for the higher levels of VOCs that were found in this study. The results may point to unknown or potentially under-controlled sources of air pollution and can inform emissions or exposure reductions, such as through the Path to Clean Air Community Emissions Reduction Plan and through Air District enforcement, rule development, and permit review programs. For questions and comments regarding this study, please email analysis@baaqmd.gov.

[18] StoryMap for the Path to Clean Air CAMP Air Toxics Monitoring Study: https://storymaps.arcgis.com/stories/21c9cd2252fe4a7d8ab26ae2fa81ec47

Appendix

Table A-1. *Method Detection Limits (MDLs) and Reportable Detection Limits (RDLs) for target VOCs, CO, and NO_x, in parts per billion (ppb) unless noted otherwise.*

Pollutant	MDL (N = 3131)	RDL
Acetaldehyde + Ethylene Oxide	0.8	2.4
Benzene	0.05	0.15
Benzo[a]pyrene	0.01	0.03
1,3-Butadiene	0.1	0.3
Dichlorobenzene	0.02	0.06
Ethylbenzene + Xylene	0.02	0.06
Naphthalene	0.03	0.09
Styrene	0.02	0.06
Toluene	0.02	0.06
Trimethylbenzene	0.02	0.06
CO (ppm)	0.02	0.06
NO_x	0.2	0.6

Table A-2. *Reference Exposure Levels (RELs) in parts per billion (ppb) for target VOCs, as established by OEHHA. N/A indicates that a REL has not been established for that target compound and/or exposure metric.*

Pollutant	Acute (1-hour) REL	8-hour REL	Chronic (annual) REL
Acetaldehyde	420	160	80
Benzene	8	1	1
Benzo[a]pyrene	N/A	N/A	N/A
1,3-Butadiene	297	4	1
Dichlorobenzene	N/A	N/A	100
Ethylbenzene	N/A	N/A	400
Ethylene Oxide	N/A	N/A	18
Naphthalene	N/A	N/A	2
Styrene	N/A	N/A	200
Toluene	1300	220	110
Trimethylbenzene	N/A	N/A	N/A
Xylene	5000	N/A	200

The following figures show the distributions of each target VOC by drive date and target monitoring area. Each point represents a 1-second measurement. Reference Exposure Levels (RELs)[19] established by OEEHA for non-cancer health effects are also shown for context but note that the 1-second data collected by the air monitoring van are not directly comparable to RELs, which are based on acute (1-hour), 8-hour, or chronic (annual) exposures. However, the RELs can provide some context to the ranges of concentrations that were measured during this study. Drive-day average concentrations are included on some plots to help visualize variability in average concentrations on different drive days. For some compounds, a second plot is also included that focuses on the lower portion of the measured range of values.

[19] CA OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary: https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary

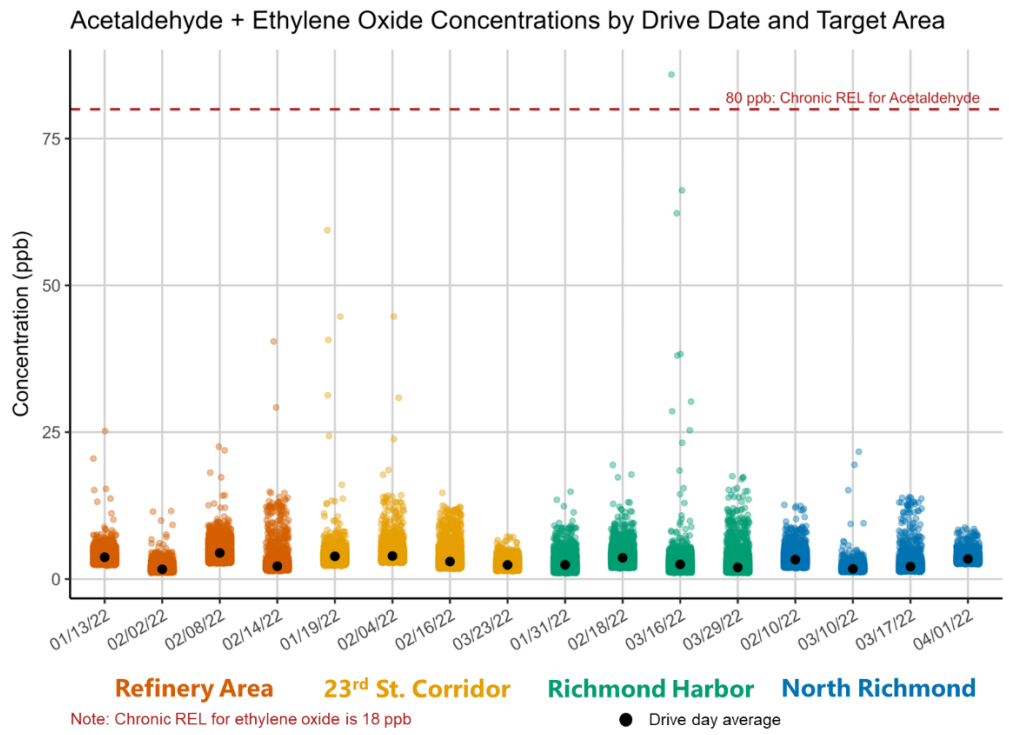

Figure A-1. *Instantaneous (1-second) acetaldehyde + ethylene oxide concentrations by drive date and target area. Chronic RELs are provided for reference but note that chronic RELs are based on long-term (annual) exposures.*

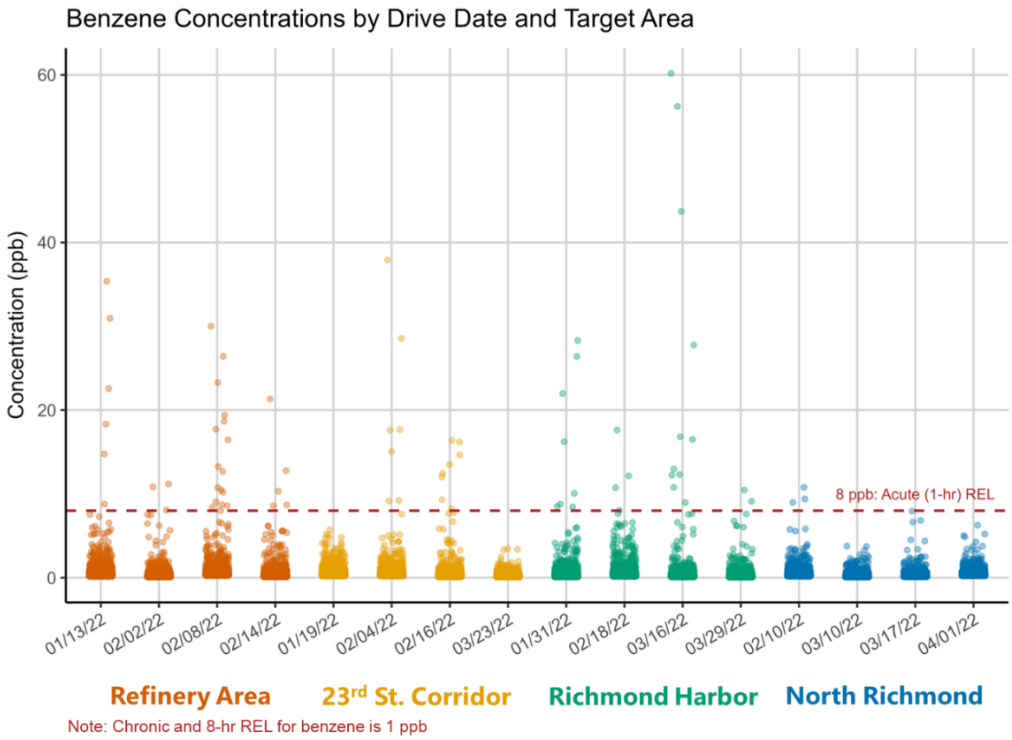

Figure A-2. *Instantaneous (1-second) benzene concentrations by drive date and target area. The acute REL for benzene is provided for reference but note that the acute REL is based on 1-hour exposures.*

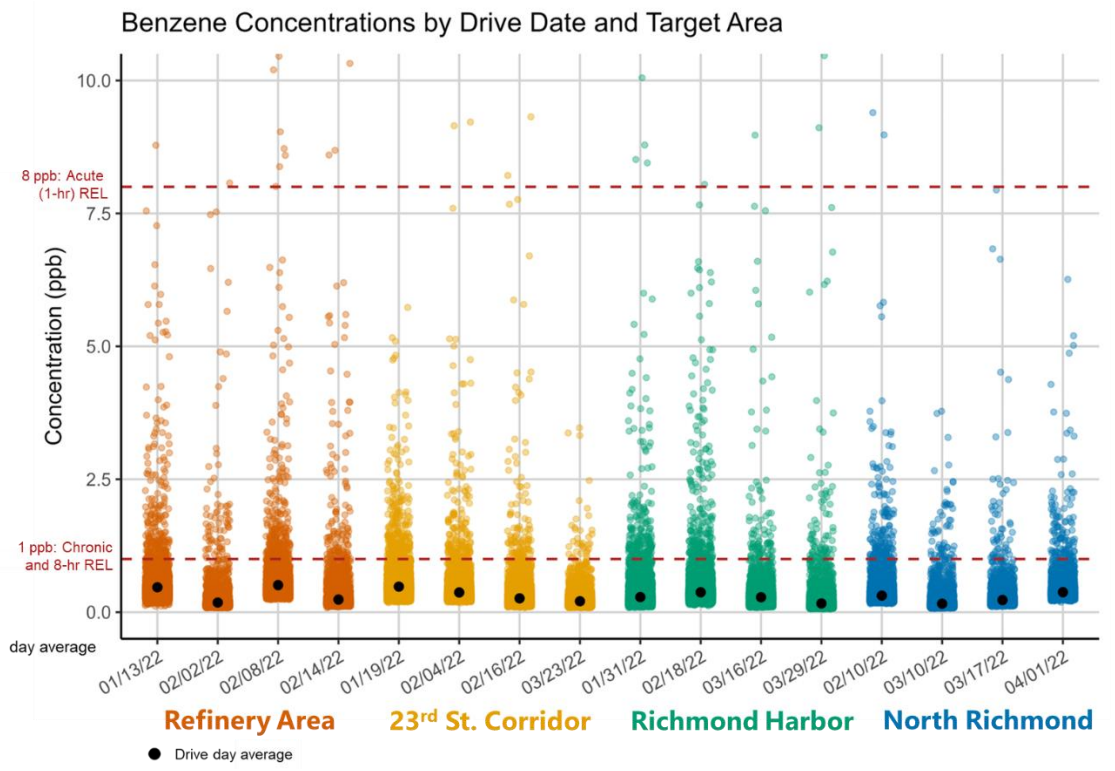

Figure A-3. *Similar to Figure A-2, instantaneous (1-second) benzene concentrations by drive date and target area, but zoomed in on concentrations below 10 ppb to better visualize variability in concentrations across drive days. The acute REL and chronic RELs for benzene are provided for reference but note that these are based on 1-hour and annual exposures, respectively.*

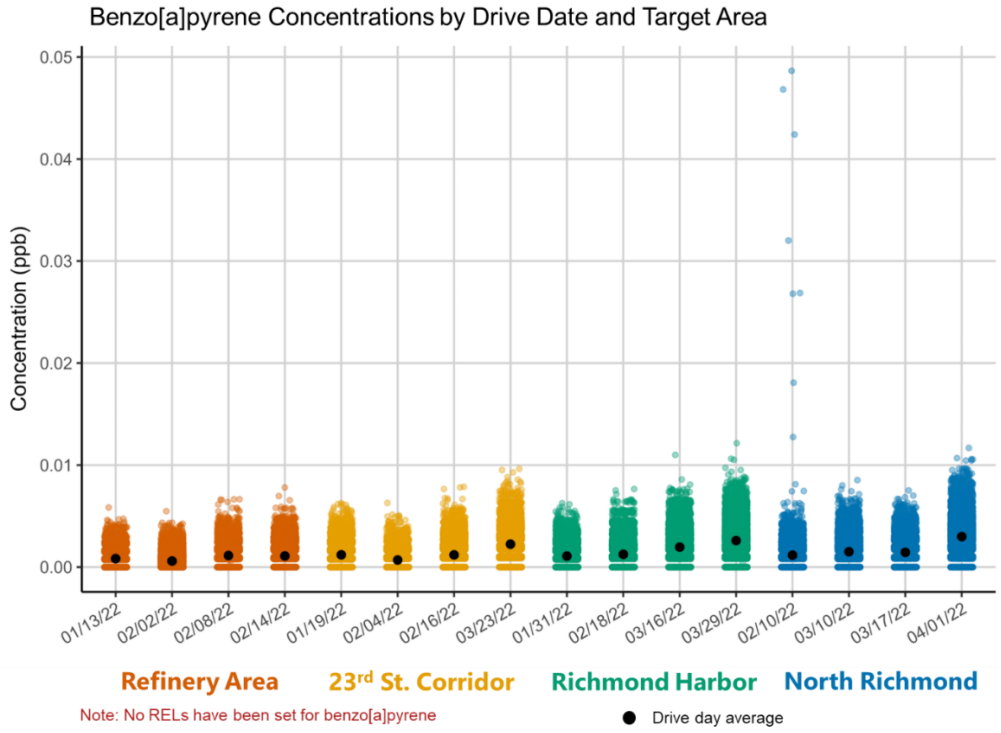

Figure A-4. *Instantaneous (1-second) benzo[a]pyrene concentrations by drive date and target area.*

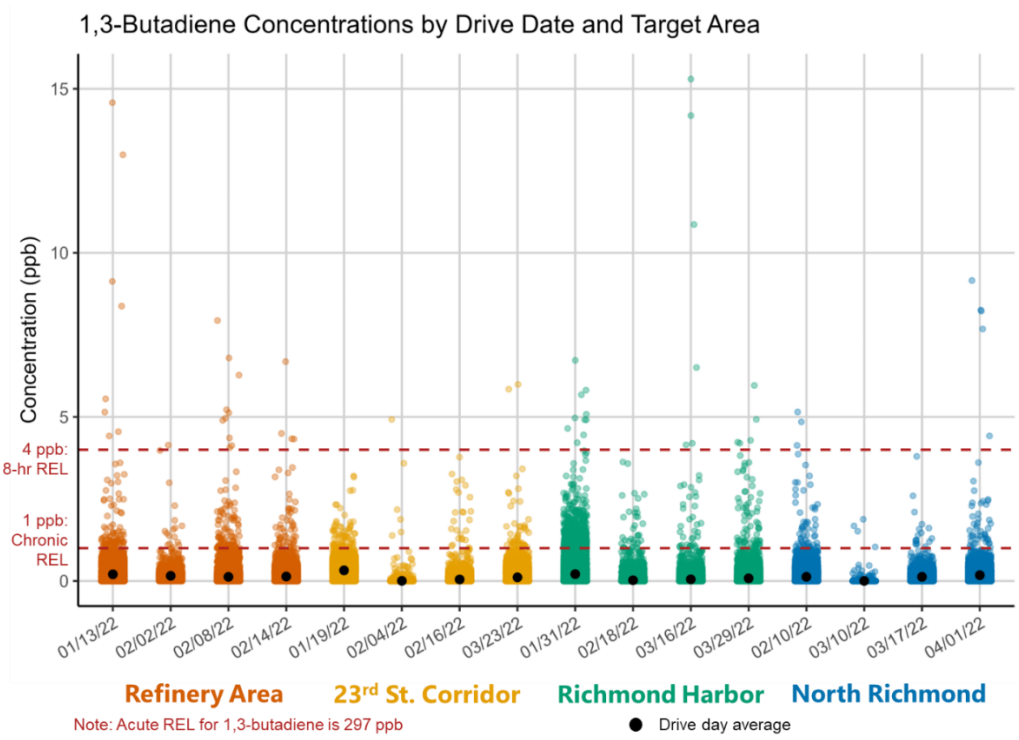

Figure A-5. *Instantaneous (1-second) 1,3-butadiene concentrations by drive date and target area. The acute and chronic RELs for 1,3-butadiene are provided for reference but note that these are based on 1-hour and annual exposures, respectively.*

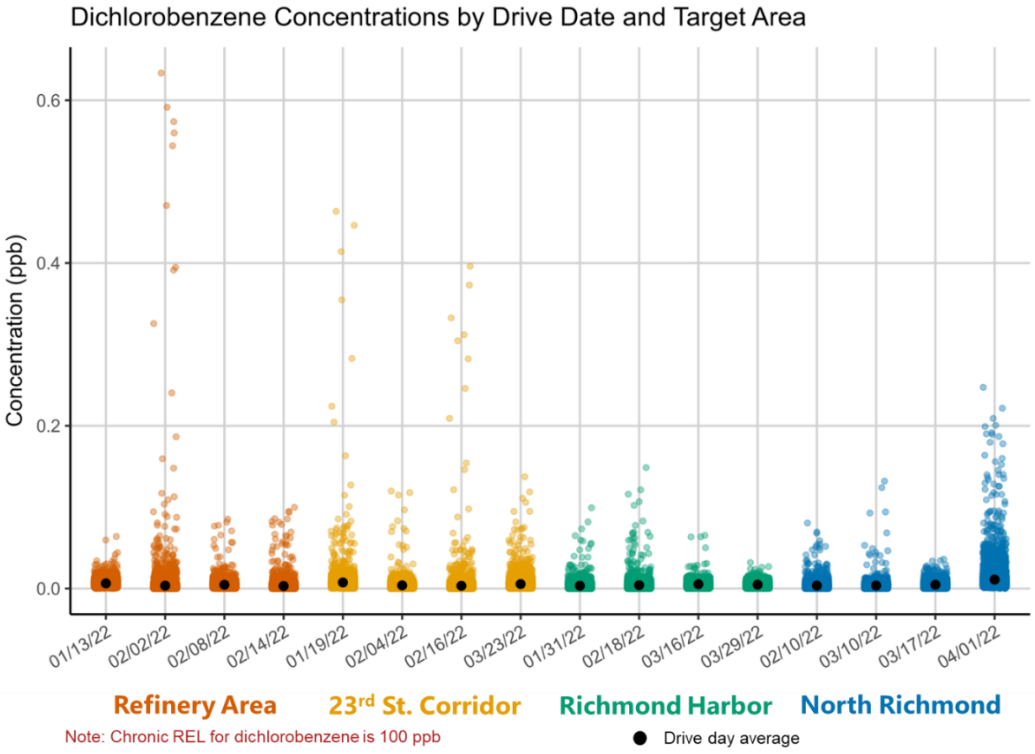

Figure A-6. *Instantaneous (1-second) dichlorobenzene concentrations by drive date and target area.*

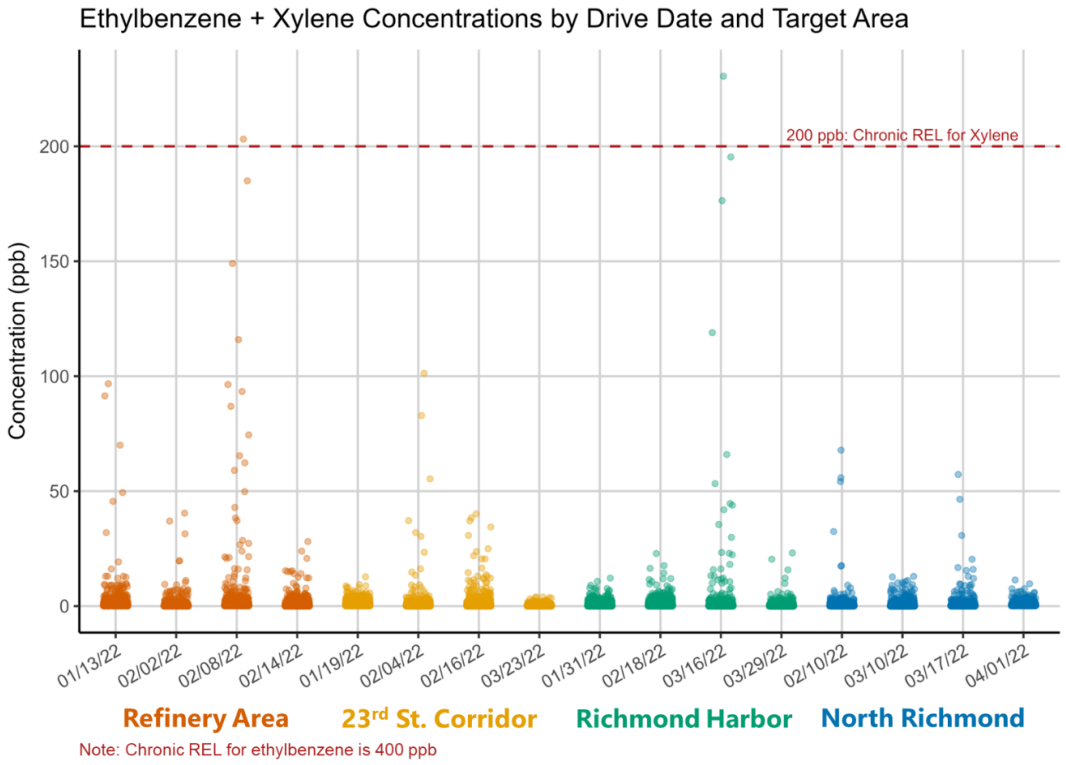

Figure A-7. *Instantaneous (1-second) ethylbenzene + xylene concentrations by drive date and target area. The chronic RELs for ethylbenzene and xylene are provided for reference but note that the chronic REL is based on annual exposures.*

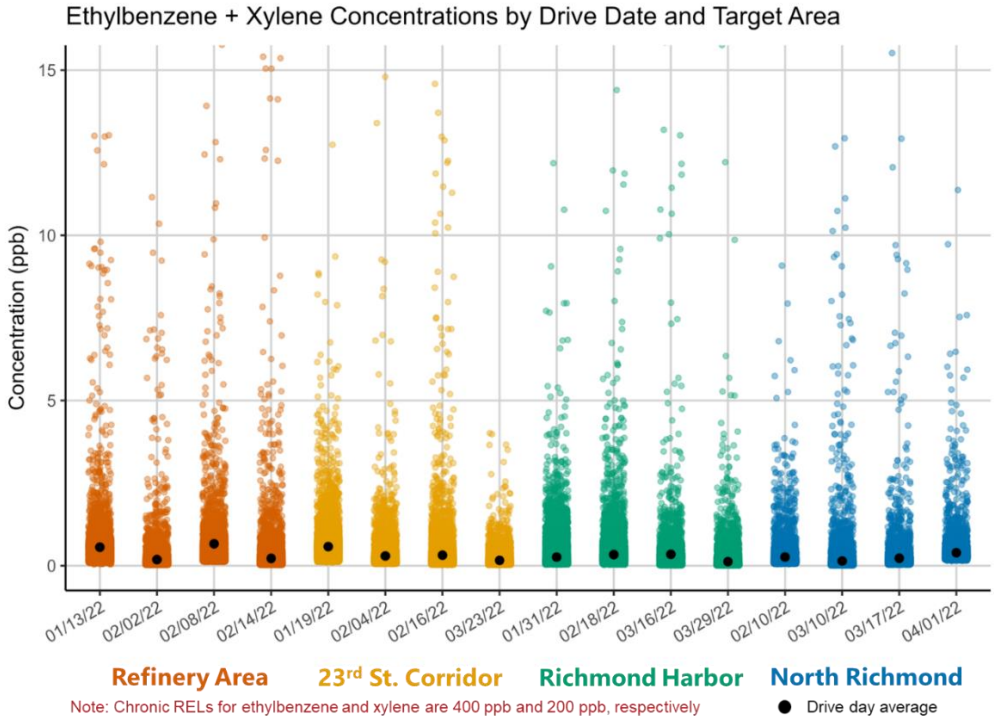

Figure A-8. *Similar to Figure A-7, instantaneous (1-second) ethylbenzene + xylene concentrations by drive date and target area, but zoomed in on concentrations below 15 ppb to better visualize variability in concentrations across drive days. The chronic RELs for ethylbenzene and xylene are provided for reference but note that the chronic REL is based on annual exposures.*

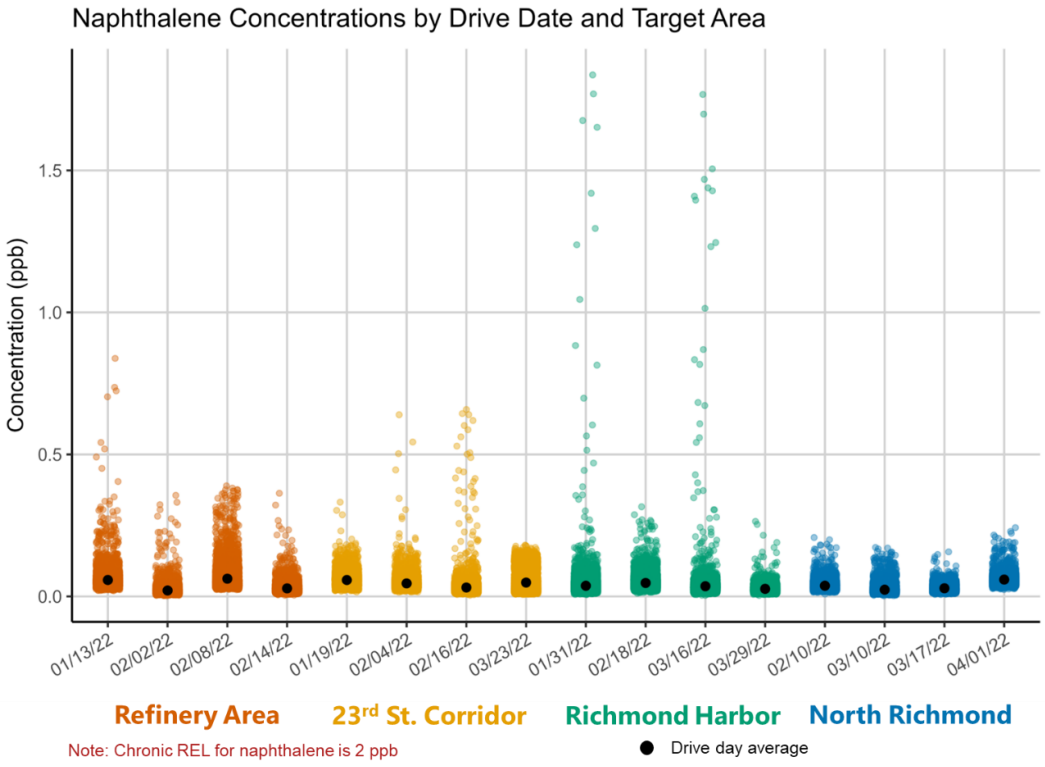

Figure A-9. *Instantaneous (1-second) naphthalene concentrations by drive date and target area. The chronic REL for naphthalene is provided for reference but note that the chronic REL is based on annual exposures.*

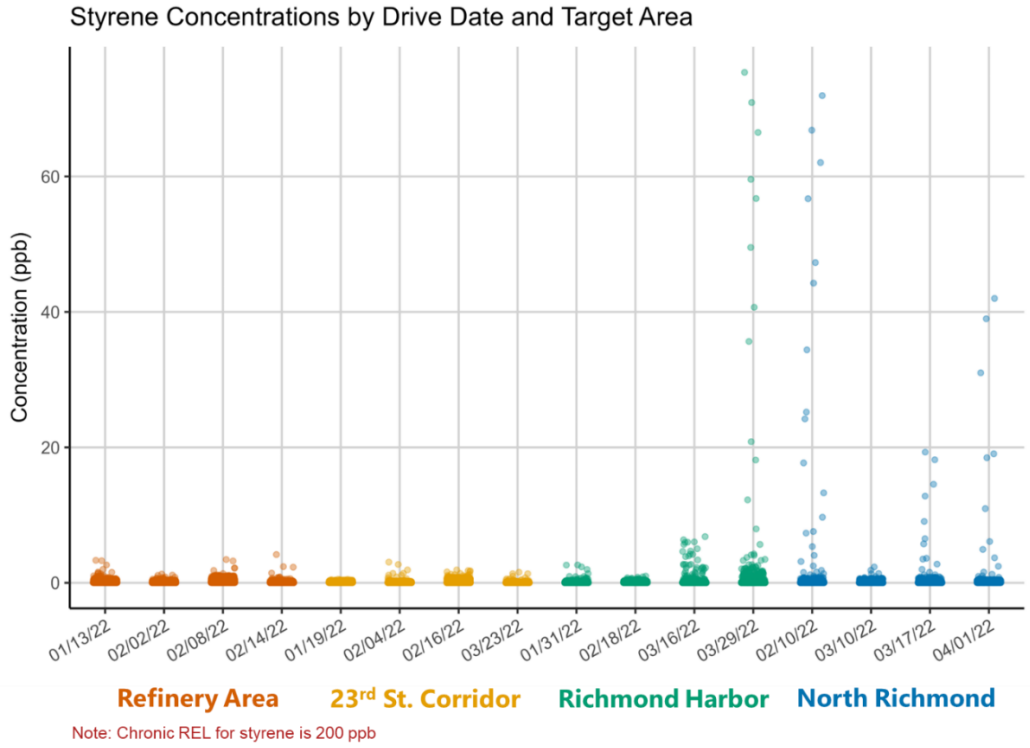

Figure A-10. *Instantaneous (1-second) styrene concentrations by drive date and target area. The chronic REL for styrene is provided for reference but note that the chronic REL is based on annual exposures.*

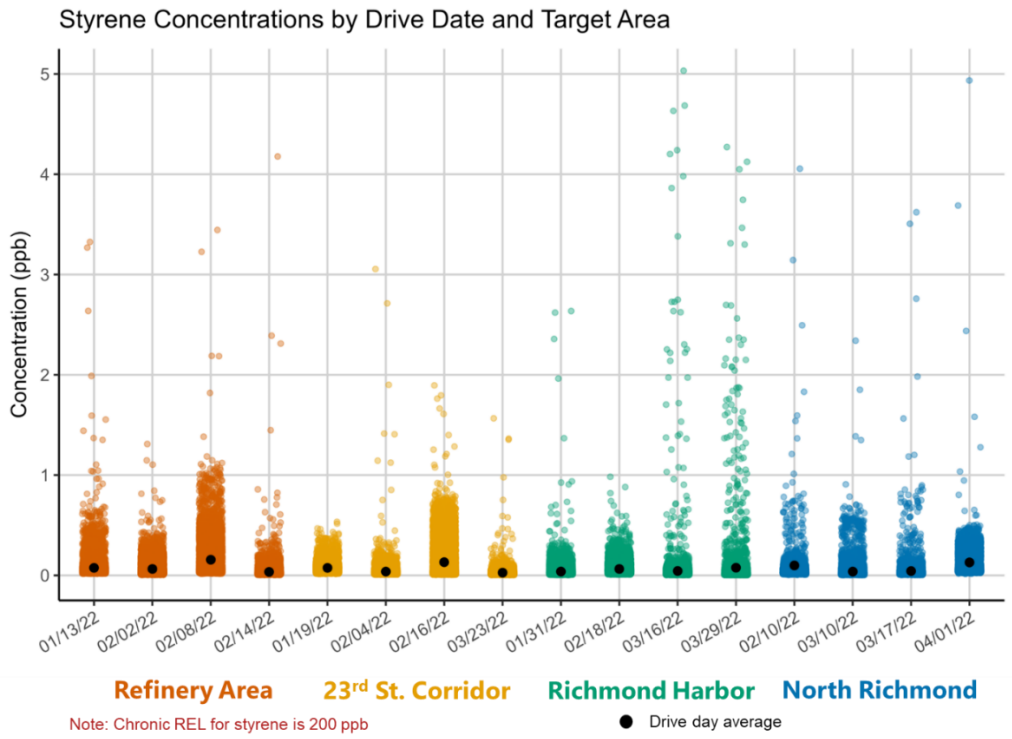

Figure A-11. *Similar to Figure A-10, instantaneous (1-second) styrene concentrations by drive date and target area, but zoomed in on concentrations below 5 ppb to better visualize variability in concentrations across drive days. The chronic REL for styrene is provided for reference but note that the chronic REL is based on annual exposures.*

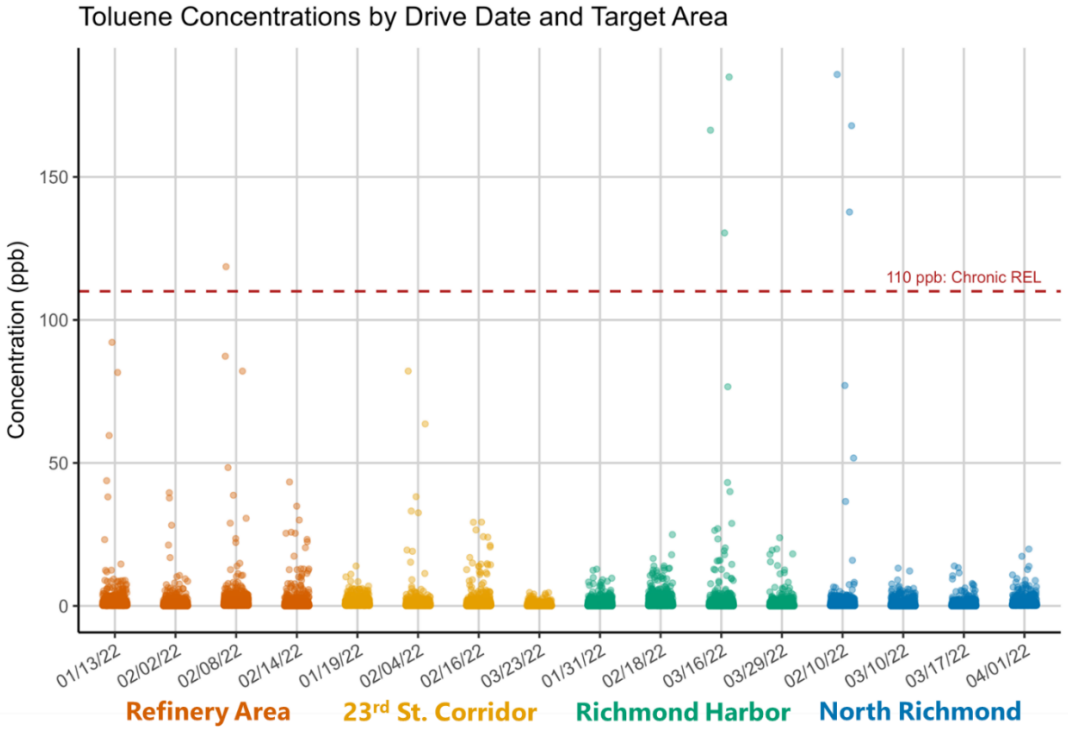

Figure A-12. *Instantaneous (1-second) toluene concentrations by drive date and target area. The chronic REL for toluene is provided for reference but note that the chronic REL is based on annual exposures.*

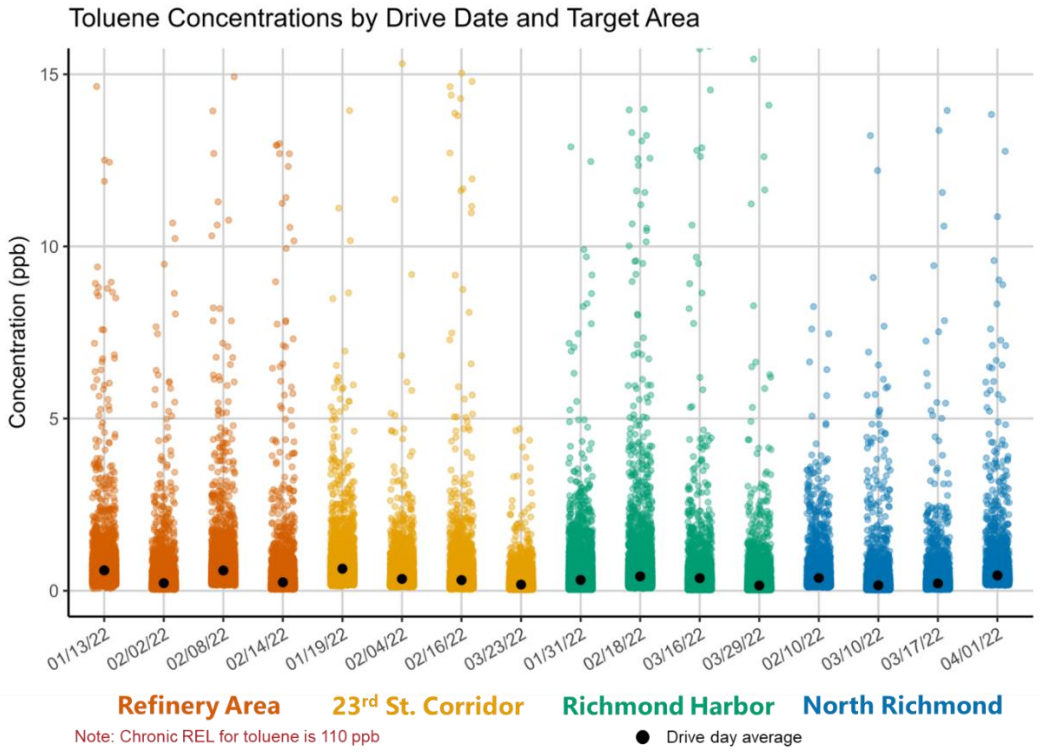

Figure A-13. *Similar to Figure A-12, instantaneous (1-second) toluene concentrations by drive date and target area, but zoomed in on concentrations below 15 ppb to better visualize variability in concentrations across drive days. The chronic REL for toluene is provided for reference but note that the chronic REL is based on annual exposures.*

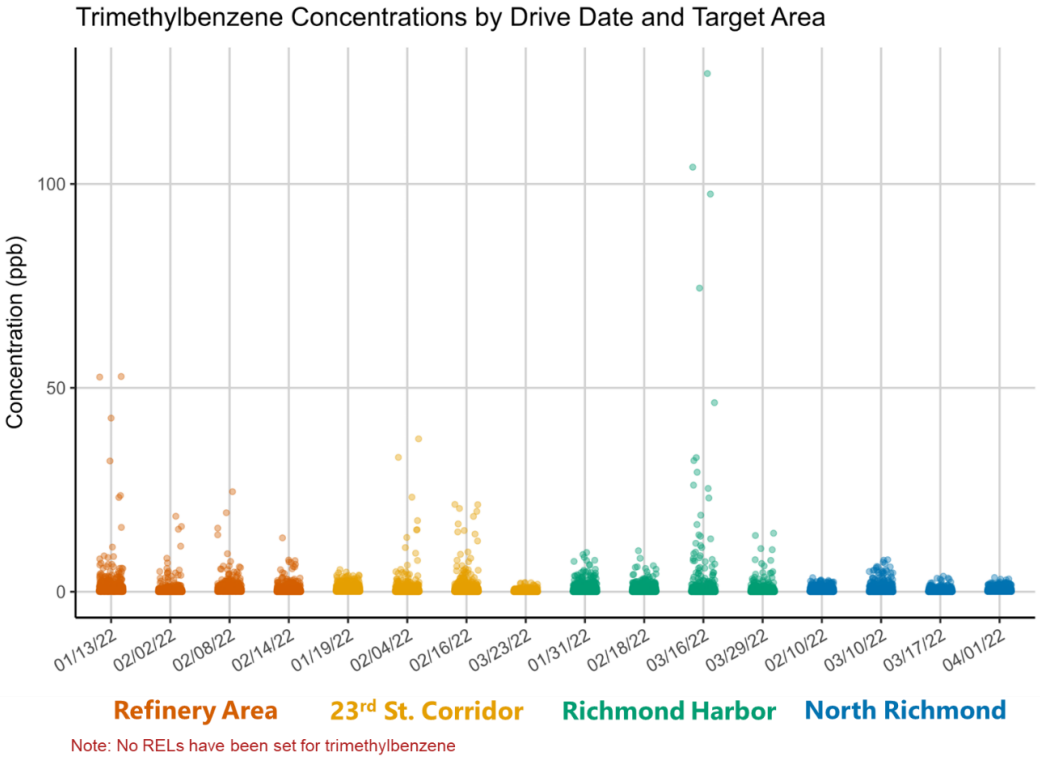

Figure A-14. *Instantaneous (1-second) trimethylbenzene concentrations by drive date and target area.*

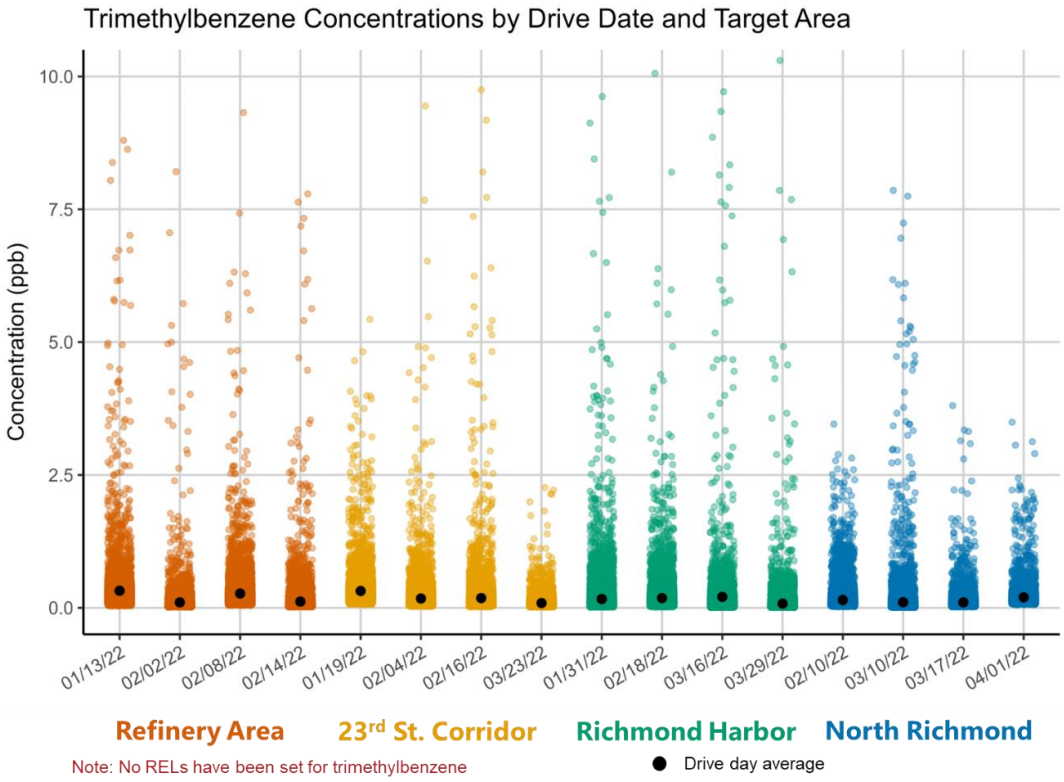

Figure A-15. *Similar to Figure A-14, instantaneous (1-second) trimethylbenzene concentrations by drive date and target area, but zoomed in on concentrations below 10 ppb to better visualize variability in concentrations across drive days.*