PUGET SOUND
Clean Air Agency

Tacoma and Seattle Air Toxics Trends Technical Report

In Fulfillment of EPA Grant XA01J87901

December 2023

Acknowledgements and contact information

We would like to thank the US EPA for funding this valuable work. We thank the Duwamish River Community Coalition for helping in outreach and gathering input for community-directed sampling and hosting an air monitoring site. We also want to thank the other air monitoring site hosts in the Seattle South Park and Georgetown neighborhoods, particularly the residents of South Park and Georgetown that volunteered to host, the South Seattle College-Georgetown Campus, and the Georgetown Steam Plant Community Development Authority. We also thank the Duwamish Moss Steering Committee, the South Park Neighborhood Association, and the Georgetown Community Council, and all the community members that provided input to the sampling process.

We also acknowledge the efforts of the Washington State Department of Ecology Air Quality Program (Ecology), including access and ability to sample at their monitoring locations at Tacoma S 36th Street and Seattle 10th & Weller. We want to particularly thank Beth Friedman and Eric Beamesderfer, both from Ecology, for their support in Quality Assurance.

We'd like to thank Jill Schulte, Gary Palcisko, Matthew Kadlec, and Christopher Atherly from Ecology and Elena Austin and Magali Blanco from the University of Washington for their input and review of this report.

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This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement 0X-02J27901-0 to the Puget Sound Clean Air Agency. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

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List of abbreviations

AQS	Air Quality System
ASIL	Acceptable Source Impact Level
BC	Black carbon
CFR	Code of Federal Regulations
CO	Carbon monoxide
DAS	Data Acquisition System
DQOs	Data Quality Objectives
EPA	Environmental Protection Agency
EtO	Ethylene Oxide
GIS	Geographical Information System
GPS	Global positioning system
IO	Inorganic (refers to methods for measuring inorganic compounds)
MQOs	Measurement Quality Objectives
m^3	Cubic meter
NAAQS	National Ambient Air Quality Standard
NATA	National Air Toxics Assessment
NATTS	National Air Toxics Trends Stations
N-FRM	Near - Federal Reference Method
ng	Nanogram (10^{-9} grams)
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides (NO + NO2)
NOy	Total reactive nitrogen. The sum of NOx, nitric acid, and organic nitrates.
PAHs	Polycyclic aromatic hydrocarbons
$PM_{2.5}$	Particulate matter less than 2.5 micrometers in diameter
PM_{10}	Particulate matter less than 10 micrometers in diameter
PMF	Positive Matrix Factorization
ppb	Parts per billion
ppm	Parts per million
PSCAA	Puget Sound Clean Air Agency
PUF	Poly-urethane foam
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan

SLAMS	State and Local Air Monitoring Stations
SOP	Standard Operating Procedures
STN	Speciation Trends Network
SVOC	Semi-Volatile Organic Compounds
TO	Toxic Organic (refers to methods to measure toxic organic compounds)
UFP	Ultrafine particles
VOCs	Volatile organic compounds
μg	Microgram (10^{-6} grams)

Executive summary

Air toxics are a broad group of chemicals found in air that are known to or suspected to cause serious health problems. Potential health effects are broad and include cancer, lung damage, and nerve damage, and more systemic effects.[1] Typical air toxics found in our region include individual chemicals like benzene and formaldehyde, but also include mixtures like diesel particulate matter and wood smoke. The Agency has made observations of air toxics for over two decades in partnership with the Washington State Department of Ecology and the US Environmental Protection Agency.

This study updates air toxics health risks and trends. This study also included community-directed air monitoring, which focused on metals (within dust size particles 10 micrometers in diameter or smaller known as PM_{10}) at the Duwamish Valley community's request.

We sampled at six sites over the course of a year spanning 2021-2022. These sites, which are in our routine regulatory network, were equipped with instruments that measure volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), PM_{10} metals, and metal and ion speciated fine particles (particles 2.5 micrometers or smaller known as $PM_{2.5}$).

Our study's main finding was that overall cancer risk from air toxics continues to be dominated by diesel particulate matter, with around 85% of the risk across all sites. The other 15% is split between estimated hexavalent chromium (~6%), wood smoke (~4%), and other compounds. A total of 12 compounds had a cancer risk over our health screening cancer threshold of one-per-million potential cancer risk. One compound was above the non-cancer health threshold, acrolein, though levels were similar to other sites across the country. All other air toxics monitored (n=26) were below both the cancer risk and non-cancer risk screening thresholds.

These air toxics contributions are consistent with our previous studies in our region dating back to 2003, showing that diesel particulate matter was and continues to be the major contributor to cancer risk from air pollution. We also found **wood smoke is still a contributor to air toxics risk in the region**, with levels of benzene and other air toxics at wood smoke sites being comparable or higher than industrial sites. Wood

[1] US EPA "What are Air Toxics" Module, extracted Oct 2023, https://airknowledge.gov/Mod/What_Are_Air_Toxics/Web/index.html#/

smoke levels have decreased from many efforts, including outreach, incentive programs to recycle older stoves, and enforcement.

Despite our region growing 30% in population, **air toxics levels have dropped by half since we started monitoring for them in 2003**. Improved technology standards, particularly for cleaner engines, fuels, and wood stoves have resulted in significant reductions in air toxics, particularly in diesel particulate matter.

In this report, we identified on-road diesel particulate matter exposure is not equitably distributed. **We found Black, Indigenous, and other people of color and lower income households have higher potential cancer risks from living near major freight corridors.** In our region, targeting diesel particulate matter can have a great impact on addressing socioeconomic differences in pollution exposure and health outcomes.

Ethylene oxide is a newly prioritized air toxic since its unit risk factor was updated in 2016 to be 34 times more protective. And in 2019, the Washington State Department of Ecology updated the acceptable source impact level for ethylene oxide to be 57 times more protective; incorporating age dependent factors to account for the extra impact to children. Past comparisons to other monitors around the country showed the lowest levels of ethylene oxide were in Western Washington (Seattle Beacon Hill and Lacey, WA). Our comparison in this study showed median levels to be uniform (with the lowest site within 32% of the highest site). From our results, **we could not conclude any obvious sources of ethylene oxide to our region**. Ethylene oxide sampling has two known issues: the limited ability to detect the very low concentrations of ethylene oxide in ambient air and issues with sampling canisters being contaminated by previous uses. Most of our ethylene oxide samples were flagged for these reasons. Therefore, we didn't include ethylene oxide potential cancer risk in the summary results. However, we did include concentration box plots within this report. When quality assurance methods improve, we will revisit estimating potential cancer risk from ethylene oxide.

For the **community-directed sampling,** we worked with a community partner, the Duwamish River Cleanup Coalition (DRCC), to gather community concerns, locations to sample, and types of pollution to sample. Throughout the analysis phase of the study, we shared initial results with the community. Now that the study is complete, we will continue to discuss the results with the community to understand their interpretation and discuss follow up actions.

The community was interested in sampling PM_{10} metals to build upon the metals-in-moss studies[2] performed by DRCC, the Duwamish Valley Youth Corp, Western Washington University, the US Forest Service, and others. In that study the Duwamish Valley Youth Corp took samples of moss from trees around the Duwamish Valley and sent samples to a lab to measure the amount of metals in the moss. While moss sampling may show gradients of metal levels, the values are not directly related to human exposure pathways and ambient air levels. This community-led sampling effort provided an opportunity to perform follow up air sampling for PM_{10} metals in areas that the community identified to be of concern from moss sampling.

The community chose five sites, two in industrial areas and two in residential areas in Georgetown and South Park and one next to King County International Airport (Boeing Field). Overall, **metals levels at the industrial and residential sites were similar to our longstanding Duwamish Valley air monitoring site**, which was established in 1971.

We estimated that **hexavalent chromium has the highest potential cancer risk of PM10 metals in ambient air in the Duwamish Valley**. Arsenic was next highest, with risks of 5 per million or less. The remaining metals were all below the one-in-a-million potential cancer risk screening level, and none were over non-cancer screening levels. To estimate hexavalent chromium, we applied the best available but outdated ratio based on a previous sampling[3] and a meta-analysis study[4]. **We will conduct a follow-up study starting in 2024 to measure current hexavalent chromium to total chromium ratios.** If the follow up study shows substantial differences, we will publish an addendum to this report to update potential cancer risk from hexavalent chromium.

Measured lead levels were well below the EPA health-based standard and health screening level. Additionally, lead levels were lowest at our near-airport site. Community and others have expressed recent concerns with leaded fuels from propeller planes still used at King County International Airport. The Duwamish Valley

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[2] Duwamish River Community Coalition, 2019, "Moss Study Community Fact Sheet", https://static1.squarespace.com/static/5d744c68218c867c14aa5531/t/5f10f3cae34eb20502407d57/1594946507283/Duwamish+moss+Fact+Sheet+final.pdf.

[3] PSCAA, 2013 Air Quality Data Summary, http://dl.pscleanair.org/Datasummaries/AQDS2013.pdf.

[4] Torkmahalleh M.A., Yu C.H., Lin L., Fan Z., Swift J.L., Bonanno L., Rasmussen D.H., Holsen T.M., Hopke P.K. (2013). "Improved atmospheric sampling of hexavalent chromium". J Air Waste Manag Assoc. 63(11):1313-23.

did have higher lead levels than other study sites, but still far below health benchmarks.

In our report, we hypothesize that **dust resuspended by vehicles is a main contributor to the metals found in our air samples and in moss samples**. The near-airport site had the lowest metal values overall and was set back furthest from any vehicle traffic.

Based on the findings from this report, **we will continue to focus on reducing diesel particulate matter in our region** through emissions reduction incentives. The Agency leverages grant funding to switch diesel vehicles to cleaner and electric vehicles and to remove old highly polluting wood stoves. This is work that we have been doing for many years, starting with our Diesel Solutions program—developed following the recommendations in the original 2003 air toxics study.

We will also continue to address wood smoke. We heavily invested in our wood stove programs following EPA designating Tacoma-Pierce County nonattainment in 2009 for $PM_{2.5}$. Today, we continue to support wood smoke reductions through outreach, incentives, and enforcement.

We also actively work with industry to comply with regulations through our inspection, permitting, and complaint response programs.

As we move forward with our 2030 Strategic Plan, we will use the information obtained through this study to help guide our work to address the most harmful air pollutants and reduce socioeconomic disparities in air pollution health risk.

Introduction

In 2020, the United States Environmental Protection Agency (EPA) awarded the Puget Sound Clean Air Agency (Agency) a Community Scale Air Toxics Grant to characterize the impacts of air toxics in communities in and around Seattle and Tacoma, Washington. The air toxics study includes updating baseline potential cancer risk values, looking at trends, and spatial analyses. The award also funded a community-directed portion to follow up on community concerns about metals in the Duwamish Valley. This grant was a three-year award.

Our Agency is a municipal corporation dedicated to healthy air, climate, and environmental justice for the benefit of all people in the Puget Sound region. The mission of the agency is to preserve, protect, and enhance air quality and public health, enforce the Clean Air Act, support policies that reduce climate change, and partner with communities to do this work equitably.

The purpose of this report is to analyze the long-term trends associated with air toxics risks, in the hopes of informing policymakers, educating the public, and focusing resources on where the pollution reductions can make the most impact to improve the health and well-being of all people in King, Pierce, Kitsap, and Snohomish counties.

In this study, we collected air toxics samples over one year in 2021 and 2022 in the Seattle and Tacoma areas. In our analysis, we also included various air toxics studies in the region over the last two decades to make comparisons. We also included data from the National Air Toxics Trends monitoring site at the Beacon Hill station that is run by the Washington State Department of Ecology (Ecology).

Background

The Agency has completed several air toxics studies and analyses over the years. This section gives a brief overview of the studies included in our analysis.

For this project, we built upon the results of our previous studies and community engagement work to characterize the impacts of air toxics in environmentally overburdened communities in Seattle and Tacoma.

Agency Overburdened Communities

We sampled in areas that are a priority for the Agency: all monitoring sites in this study were completed within our Agency Overburdened Communities Map. Our Community Air Tool shows that the area where we did community-directed sampling in the Duwamish Valley is one of the most disproportionately impacted areas in our region.

Community-directed sampling: community interest in metal sampling

Based on past air deposition studies, both the Seattle Duwamish Valley and Tacoma Tideflats industrial areas have higher levels of metals from atmospheric deposition compared to other areas.[5,6] A more recent metals-in-moss sampling study (in 2019, led by a group of Duwamish Valley partners including support from the US Forest Service and Duwamish Valley Community Coalition) in the Seattle Duwamish Valley found metal gradients in moss samples, and raised questions about how that translates to air quality health risks. [7]

We actively engaged with community members from the Georgetown and South Park neighborhoods of the Duwamish Valley to gather input. We engaged early in the planning process for this grant. This included gathering input online and through an in-person public workshop that resulted in the identification of pollutants of concern at five locations in the Duwamish Valley, including specific feedback telling us where to monitor in the Georgetown and South Park neighborhoods. The community also emphasized an interest in sampling for metals based on recent metals-in-moss sampling results collected by the Duwamish Valley Youth Corps.

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[5] King County Department of Natural Resources and Parks, Dec 2013, "Lower Duwamish Waterway Source Control: Bul Atmospheric Deposition Study Final-Data Report", https://your.kingcounty.gov/dnrp/library/wastewater/iw/SourceControl/Studies/Air/2013/LDW_BulkAirDepFinalDataReport_Dec2013.pdf.

[6] Washington State Department of Ecology, "Control of Toxic Chemicals in Puget Sound Phase 3: Study of Atmospheric Deposition of Air Toxics to the Surface of Puget Sound", Pub no 10-02-012, 2012, https://apps.ecology.wa.gov/publications/UIPages/documents/1002012.pdf.

[7] Duwamish River Community Coalition, 2019, "Moss Study Community Fact Sheet", https://static1.squarespace.com/static/5d744c68218c867c14aa5531/t/5f10f3cae34eb20502407d57/1594946507283/Duwamish+moss+Fact+Sheet+final.pdf.

Previous studies: diesel particulate matter is the highest priority air toxic

Previous studies have highlighted that traffic pollution is a significant source of air toxics risk nationally and in our region. In 2003, the Agency and Ecology completed a toxics study in the Seattle area.[8] This study found that the most important air toxics risk was from diesel particulate matter (with 70-85% of total potential cancer risk from air toxics) and wood smoke, with significant contributions from formaldehyde, hexavalent chromium, and benzene. This 2003 study did not include a near-road monitoring site.

In 2010, in partnership with the University of Washington, we completed another air toxics monitoring campaign that extended the evaluation to three sites in the Tacoma area and the industrial valley in Seattle.[9] This study identified vehicles, specifically diesel particulate matter, as the main source of air toxics risk in the region (with over 70% of the total potential cancer risk from air toxics). The study also confirmed that wood smoke was also an important contributing factor. The 2010 study confirmed much of the knowledge gained from the 2003 study, including the pollutants that drive air toxics risk in the region.

Our most recent air toxics study was completed in 2018 and looked at near-road emissions centered in Seattle's Chinatown-International District (CID).[10] We used novel approaches with positive matrix factorization (PMF) using air toxics data to identify two types of diesel emissions from highway traffic, a "fresh" near-road diesel factor and evidence of a "background" diesel factor. This project also included community-directed samples that showed an expected spatial gradient from the adjacent freeways and was dominated by diesel PM air toxics risk. In this study, diesel particulate matter contributed over 75% of the total potential cancer risk from air toxics.

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[8] Puget Sound Clean Air Agency, "Final Report: Puget Sound Air Toxics Evaluation", 2003, https://pscleanair.gov/DocumentCenter/View/2355/Puget-Sound-Air-Toxics-Evaluation-Final-ReportPDF?bidId=.

[9] Puget Sound Clean Air Agency, "Tacoma and Seattle Area Air Toxics Evaluation", 2010, https://pscleanair.gov/DocumentCenter/View/2361/Tacoma-and-Seattle-Area-Air-Toxics-Evaluation-Full-ReportPDF?bidId=.

[10] Puget Sound Clean Air Agency, "Near-road Air Toxics Study in the Chinatown-International District", 2018, https://pscleanair.gov/DocumentCenter/View/3398/Air-Toxics-Study-in-the-Chinatown-International-District-Full-Report.

Ethylene oxide

In 2016, the EPA Integrated Risk Information System (IRIS) updated the cancer risk factor for ethylene oxide,[11] listing it as significantly more carcinogenic than previously estimated. Also, EPA has recently included ethylene oxide in the standard suite of measured volatile organic compounds. Prior to this study, limited sampling at the Seattle Beacon Hill site showed a few values above the detection limit. However, because the cancer risk factor was increased, samples that just meet the detection limit now translate to cancer risk estimates in the hundreds per million potential cancer risk. In this study, we aimed to collect more ethylene oxide samples around the region to see how the Beacon Hill site compares and identify potential sources.

Sampling study design

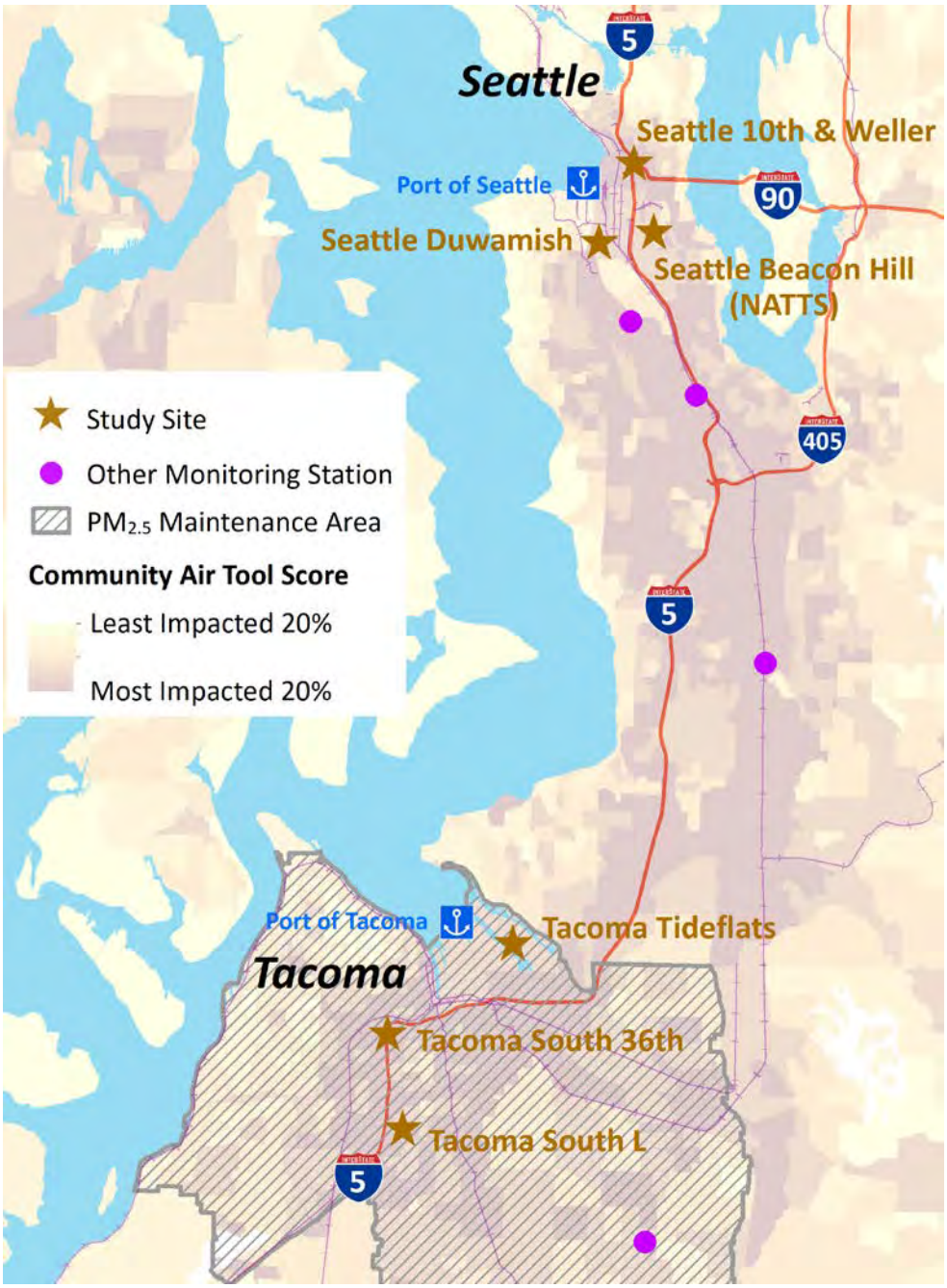
Overview

The sampling was primarily designed to update air toxics risks in the Puget Sound region. By studying areas where we have measured air toxics risks in previous campaigns, we also designed the study to evaluate long term trends. Additionally, we designed the study to better estimate risks from specific sources using $PM_{2.5}$ speciation data and source apportionment techniques.

Core fixed monitoring locations used in this study included three sites in Seattle and three sites in Tacoma. The sites included: Seattle Duwamish (industrial area), Seattle 10th & Weller (near-road), Seattle Beacon Hill (NATTS - National Air Toxics Trends Station), Tacoma Tideflats (industrial site), Tacoma South L Street (residential), and Tacoma South 36th Street (near-road). Seattle Beacon Hill and the near-road sites are operated by Ecology. The core monitoring site locations can be found on Figure 1 and further details in Appendix A. The core monitoring stations are already part of the approved Ecology State and Local Air Monitoring Stations (SLAMS) network.

[11] EPA Integrated Risk Information System, Ethylene Oxide, 2016, https://iris.epa.gov/ChemicalLanding/&substance_nmbr=1025.

Figure 1. Study sites, $PM_{2.5}$ maintenance area, and an Agency environmental justice map (Community Air Tool) scores.



Since the Seattle Beacon Hill site is a NATTS site, there is a historical record of air toxics since 2000 at this location. The Beacon Hill site data served as a consistent historical trend at the urban spatial scale. The urban spatial scale is defined by EPA as a site which can represent overall city conditions with dimensions on the order of 4 to 50 kilometers. Seattle Duwamish, Tacoma Tideflats, and Tacoma South L Street were also

used in the 2009 air toxics study. These sites are defined by EPA as neighborhood-scale sites, which represent concentrations within some extended area of the city that has relatively uniform land use with dimensions in the range of 0.5 to 4 kilometers.

The near-road monitoring sites were established by updated EPA requirement; Seattle 10th & Weller in 2014 and Tacoma South 36th Street in 2016. These sites were designed to collect data on mobile sources from nearby large freeways. We utilized the Seattle and Tacoma near-road sites to quantify air toxics from freeways. Near-road sites are generally considered microscale, defined as concentrations in air volumes associated with area dimensions ranging from several meters up to about 100 meters. The usefulness of the microscale sites is that they are designed to achieve an understanding of the highest concentrations of air pollutants. Near-road monitoring locations are helpful for characterization of air toxics emissions and risks from freeways.

Sampling details

Table 1 shows the sampling equipment that was added specifically for this study. More details can be found in the data completeness table located in Appendix B (Table B-1). The following table, Table 2, shows the sampling equipment that was already in-use at the study sites and could be leveraged.

Table 1. Sampling sites, parameters monitored, duration, and frequency.

Sites	Measured parameters	Duration	Monitoring Frequency
Tacoma S L Street (residential)	Select VOCs (Note A) Select aldehydes (Note B)	August 2, 2021 – Sep 2, 2022	1 in 6 1 in 6
Tacoma Tideflats (industrial)	Select VOCs (Note A) Select aldehydes (Note B) PM_{10} metals	August 2, 2021 – Sep 2, 2022	1 in 6 1 in 6 1 in 6
Tacoma S 36th street (near-road)	Select VOCs (Note A) Select aldehydes (Note B)	August 2, 2021 – Sep 2, 2022	1 in 6 1 in 6
Seattle 10th and Weller (near-road)	Select VOCs (Note A) Select aldehydes (Note B)	August 2, 2021 – Sep 2, 2022	1 in 6 1 in 6
Seattle Duwamish (industrial)	Select VOCs (Note A) Select aldehydes (Note B) PM_{10} metals (Note C) Polycyclic Aromatic Hydrocarbons (PAHs) (Note D)	August 2, 2021 – Sep 2, 2022	1 in 6 1 in 6 1 in 6 1 in 6
Community-directed sites	PM_{10} metals $PM_{2.5}$ sensors	Summer 2022 start dates varies between sites	Week-long samples per request to cover as much time as possible with no breaks

Note A: Benzene, 1,3 butadiene, carbon tetrachloride, tetrachloroethylene, ethylbenzene, acrolein, and ethylene oxide.
Note B: Formaldehyde and acetaldehyde.
Note C: Antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium.
Note D: Acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, coronene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, and pyrene.

Table 2. Sampling sites and leveraged monitoring parameters for analysis.

Sites	Leveraged parameters (not funded by this grant)	Procedure (see QAPP)
Tacoma S L Street (residential)	$PM_{2.5}$	$PM_{2.5}$ SOPs
	$PM_{2.5}$ speciation	CSN-Supplemental
	Temperature, winds	Met SOP
	Black carbon	Black carbon SOP
Tacoma Tideflats (industrial)	$PM_{2.5}$	$PM_{2.5}$ SOPs
	$PM_{2.5}$ speciation	CSN-Supplemental
	Temperature, winds	Met SOP
	Black carbon	Black carbon SOP
Tacoma S. 36th street (near-road)	NO_2, NO, NO_X	NOx SOPs
	$PM_{2.5}$	$PM_{2.5}$ SOPs
	Temperature, Winds	Met SOP
	Traffic Counts	WA DOT
	Black carbon	Black carbon SOP
Seattle 10th and Weller (near-road)	NO_2, NO, NO_X, CO	NOx, CO SOPs
	$PM_{2.5}$	$PM_{2.5}$ SOPs
	$PM_{2.5}$ speciation	CSN-Supplemental
	Temperature, Winds	Met SOP
	Traffic Counts	WA DOT
	Black carbon	Black carbon SOP
Seattle Duwamish (industrial)	$PM_{2.5}$	$PM_{2.5}$ SOPs
	$PM_{2.5}$ speciation	CSN-Supplemental
	Temperature, winds	Met SOP
	Black carbon	Black carbon SOP
Seattle Beacon Hill	Full suite of VOCs	PAMS and NATTS
	PAH	NATTS
	Aldehydes	PAMS and NATTS
	PM_{10} metals	NATTS
	NO_2, NO, NO_X, SO_2, CO	NCORE
	$PM_{2.5}$	$PM_{2.5}$ SOPs
	$PM_{2.5}$ speciation	STN and IMPROVE
	Temperature, Winds	Met SOP

Select Volatile Organic Compounds (VOCs) - We used an established Standard Operating Procedure (SOP) as described in Appendix A of the study Quality Assurance Project Plan (the School Air Toxics Program SOP for sampling VOC's using a passive regulator and timer for a 6L SUMMA canister). The equipment that we used was from Entech, which was equivalent to the equipment used in the SOP. The select VOCs that were sampled were based on prior air toxics monitoring of compounds that had potential cancer risks of one-in-a-million or higher. These compounds were benzene, 1,3 butadiene, carbon tetrachloride, tetrachloroethylene, ethylbenzene, acrolein, and ethylene oxide.

Select aldehydes - The Washington Department of Ecology (Ecology) previously used a carbonyl sampler called a XONTECK; and those samplers are no longer functional/available. Therefore, we acquired and tested the available ATEC samplers. We used an established SOP as described in Appendix B of the QAPP, and we used the same laboratory analytical methods so that our data can be comparable to historically collected data. The compounds measured were formaldehyde and acetaldehyde.

PM_{10} metals – We sampled for PM_{10} metals at two fixed industrial sites by using the Thermo (formerly Rupprecht & Patashnick) Model 2025 samplers that are already used in our state's Federal Reference Monitoring program. Our operators routinely operate these monitors using the Ecology SOP, and we followed the designation stated in Appendix I of the QAPP. These samplers were configured for collecting PM_{10} filters on a 1-in-6 sampling frequency for the year of the sampling campaign. We have a limited number of this model of instrument and due to their size, they could only be used at our primary sampling sites. For the PM_{10} Metals sampling at community determined sites, we used the N-FRM monitor provided by ARA per the procedure in Appendix L of the QAPP. The N-FRM monitors were tested and then configured for collecting filters for 1-week durations, which was the sampling period selected by the community. These samplers proved useful for collecting data in the five specific locations determined by the community. The metals sampled were Antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium.

Polycyclic Aromatic Hydrocarbons (PAHs) – We used a standard High Volume PUF sampler to collect samples for PAH analysis at the Duwamish industrial site per the SOP in Appendix C of the QAPP. This method is identical to the one used for the NATTS sites. The compounds sampled were acenaphthene, acenaphthylene, anthracene,

benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, coronene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, and pyrene.

Black carbon (BC) – We used the Aethalometer AE-33 model sampler to collect the 7-channel black carbon continuous data for use in the analysis at each of the study sites, to give us a surrogate measure for diesel particulate matter.

Laboratory analysis was conducted by Eastern Research Group (ERG), the national contract laboratory for the NATTS program.

Table 3 below shows the frequency of field blanks and collocated sampling. QC checks were performed monthly on the ATECs, Partisols (PM_{10} metals), AE-33s, and BAMs. Leak checks were performed on VOC canisters before and after every sample.

Table 3. Frequency of blanks and collocated samples.

Sampler	**Blanks**	**Collocated Samples**
VOC canister (ENTECH)	None	One per 10 samples
Carbonyl samples	1 every 10 samples	One per 10 samples for the only 2-channel sampler (ESWA).
PAH samples	1 every 5 samples	None
PM_{10} HAP metals	1 every 5 samples	None

The EPA-approved Quality Assurance Project Plan (QAPP) provides a high level of detail about the sites, pollutants, locations, chemicals, periodicity of the monitoring, as well as the detailed site descriptions. The QAPP is available upon request.

The results of the collocations, blanks, flow checks, and other quality assurance parameters mostly met quality thresholds as outlined in the QAPP for all the data used for analysis included in this report. For collocated samples, seven out of the nine ethylene oxide duplicates were outside of 80-120% recovery. For all other analytes there were 19 duplicate samples outside of the 80-120% recovery window, out of 445 duplicate samples. In most of these cases the sample concentrations were low and at least one of the samples was less than 3 times the method detection limit. Appendix Table B-5 shows the duplicate samples that were outside 80-120% recovery and had both primary and duplicate sample concentrations greater than 3x the MDL.

For blank samples there were some analytes which had blank concentrations close to sample concentrations, but in most of those cases the concentrations were close to or below detection limits. Appendix Table B-6 provides the mean ambient concentration, mean field blank concentration, and mean MDL concentration for all sites and analytes at which field blank samples were collected.

Community sampling

We reached out to community members to involve them in discussions around the nature and objectives for the community sampling. Ultimately five sites were chosen to perform additional monitoring of air toxic metals using a PM_{10} sampler which collected material on a filter, which was further analyzed for air toxic metals. Table 4 shows the community feedback, describing the locations where the community desired extra sampling. Table 5 below shows the interest of community in the types of areas to do monitoring. Figure 2 shows a map of outreach results and corresponding locations of where monitors were eventually placed (green stars) with the corresponding name of the site. The level of community interest is represented by the size of the blue circles.

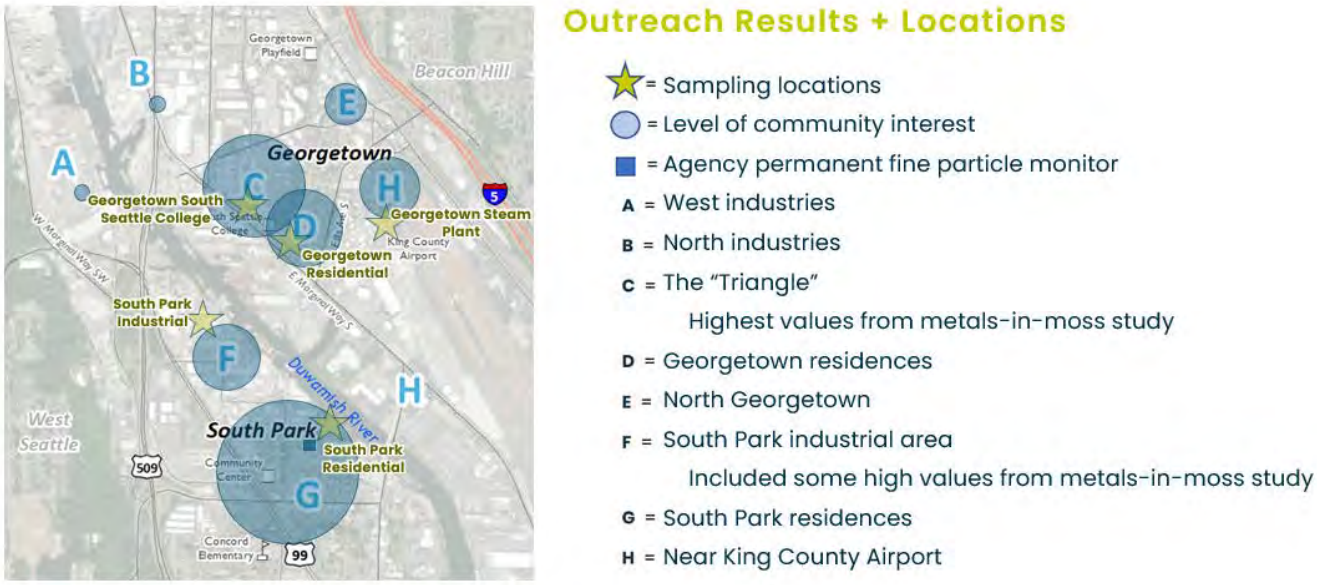
Table 4. Sampling locations selected by community.

Letter on Map	Location	Response
G	South Park residences	28%
C	The "triangle" (higher concentration from metals-in-moss study)	20%
D	Georgetown residences	15%
F	South Park industrial area (higher concentration from metals-in-moss study)	13%
H	Near King County Airport	11%
E	North Georgetown	8%
A	West industries	3%
B	North industries	3%

Table 5. Type of areas of interest to community.

Area type of interest	Response
Residential areas	34%
Higher concentration areas from the moss study (E Marginal Way S and northern South Park)	22%
Industrial sources	14%
How metal levels compare to other places with similar data, such as Tacoma or Beacon Hill in Seattle	11%
King County Airport	10%
Major roadways	8%

Figure 2. Map of outreach results and corresponding location of where monitors were placed.



Based on the community input, there were five temporary sampling locations which were chosen to sample for PM_{10} metals. Table 6 shows the sampling locations; community sites are in blue and core monitoring sites are in yellow. The community directed monitoring sites are considered middle-scale, which represents concentrations typical of areas up to several city blocks in size with dimensions ranging from about 100 meters to 0.5 kilometer.

The community indicated that for PM_{10} metals sampling, they preferred continuous monitoring to not miss any potential spikes in pollution during a week. Longer sample duration also helped collect enough sample that detection limit issues were less

common. Therefore, for the temporary community-directed PM_{10} metals samples, we collected samples for week-long periods, and adjusted our Quality Assurance Practices to accommodate that change.

Sampling locations

Table 6 below shows the site locations used in the study. More detailed information, site descriptions, and satellite imagery can be found in Appendix A.

Table 6. Site names and addresses with permanent monitoring sites (first 6 rows) and community-directed sites (last 5 rows).

Site common name	Site code	Site address*
Seattle 10th and Weller	BKWA	10th Ave S & S Weller St, Seattle, WA 98104
Seattle Beacon Hill	SEWA	4103 Beacon Ave S, Seattle, WA 98108
Seattle Duwamish	CEWA	4700 E Marginal Way S, Seattle, WA 98134
Tacoma Tideflats	EQWA	2301 Alexander Ave E, Tacoma, WA 98421
Tacoma 36th	YFWA	1802 S 36th St, Tacoma WA 98418
Tacoma South L St	ESWA	7802 S L St, Tacoma, WA 98408
Georgetown South Seattle College	UAWA	6737 Corson Ave S, Seattle, WA 98108
South Park Residential	UBWA	S Elmgrove St & 12th Ave S, Seattle, WA 98108
Georgetown Residential	UCWA	Carleton Ave S & S Willow St, Seattle, WA 98108
Georgetown Steam Plant	UDWA	6605 13th Ave S, Seattle, WA 98108
South Park Industrial	UEWA	S Fontanelle St. & 3rd Ave S, Seattle, WA 98108

* We only provide approximate locations for the residential community-directed sites.

Monitoring results

Most of our data come from monitoring we conducted between August 2021 and September 2022, but we were also able to leverage air toxics data from the Seattle Beacon Hill site and speciation data from Seattle 10th and Weller, Tacoma South L, and Tacoma Tideflats, with instruments maintained by the WA State Department of Ecology. The monitoring results in this section encompass the fixed sites and the community-directed sampling that occurred in the Seattle Georgetown and South Park neighborhoods in the summer of 2022. The data include air toxics (VOCs, Carbonyls, SVOC PAHs, PM_{10} metals), $PM_{2.5}$, black carbon, meteorology (barometric

pressure, ambient temperature, wind speed and direction), and $PM_{2.5}$ chemical speciation. Summary statistics for fixed sites can be found in Appendix P.

Data considerations

Impact of wildfire smoke

Wildfire smoke impacts occurred in our region on August 12-14, 2021. August 12th and 13th had regional impacts, whereas the 14th was primarily isolated to eastern Snohomish County. So, even though August 14th was a sample day, the impacts were deemed to be minimal.

Weather summary and representativeness

The full extent of sampling for this project was from August 2, 2021 to September 2, 2022. The core sites Seattle 10th & Weller, Seattle Beacon Hill, Seattle Duwamish, Tacoma South L, Tacoma Tideflats, and Tacoma S 36th included VOCs, carbonyls, $PM_{2.5}$ speciation, and black carbon. These data represent slightly more than a full calendar year. The community-directed PM_{10} metals samples were collected during the following times: two sites ran from late July 2022 through September 2, 2022, two other sites ran from July 1, 2022 through Sept 2, 2022, and one site ran from March 25 through September 2, 2022 (Appendix B, Table B-1). These samples would represent only summer conditions.

For both time periods, it is important to note the degree to which these represent A) a typical year, B) a typical late summer, and C) how representative a late summer is in relation to a full year.

The primary meteorological factors for consideration of representativeness in this study are temperature, wind speed and direction, and precipitation. Based on past analyses of regional weather patterns, longer term anomalies (more than just a few days) are almost always regional, and so would not be confined to a single monitor. Therefore, precipitation from the University of Washington Atmospheric Sciences Building (about 5 miles to the north), and temperature, wind speed, and wind direction from the Duwamish site should be sufficient to address the issue of temporal representativeness for all sites.

As can be seen in Figure C-1 in the Appendix, the temperatures tracked the 10-year average fairly well. There were only a few large departures beyond +/- 1 standard deviation that were relatively short. The only notable deviance from the average was the period from mid-April through late June that was mostly below or well below average temperatures. This is likely indicative of greater than normal cloud cover and precipitation. During the metals sampling period of July though the beginning of September, the temperatures were close to average with a normal amount and range of variation.

A similar plot for daily average wind speeds is shown in Figure C-2 in the Appendix. November and December appear to be moderately windier, while January through mid-March appear to be somewhat calmer than typical. During the metals sampling period, winds appear to be fairly typical for that time of year.

Wind directions also appear to be typical for the past decade. As shown in Figure C-3 in the Appendix, the wind rose of wind speeds and direction for the sampling year are very similar to the past 10 years. The biggest difference appears to be a slightly lower frequency of winds from the NW. For the metals sampling period, there is also a close similarity between the sampling period and previous years. Figure C-4 shows the metals sampling year and the previous year during the same period. Other years (not shown) are very similar to the previous year. The largest observable difference is slightly more southerlies and fewer SSW in the metals sampling period (Jul-Aug, 2022).

Weekly precipitation is shown in Figure C-5. The full sampling period had the second highest total precipitation out of the adjacent 10 years (in the same period of the calendar year). Ten weeks had the greatest weekly precipitation of the full 10-year comparison period (5 or 6 would be typical). There were four notable periods: well above normal precipitation in late October/early November and briefly in early January; mid-January through mid-February was atypically dry; and May into early June were modestly wetter than normal. The metals sampling period (July and August) was almost completely dry, as is typical. Deviations from typical precipitation that would be worthy of noting for air quality purposes would be extended below normal precipitation in the winter and extended above normal precipitation in the summer.

Since the wind directions and speeds were close to normal, it appears unlikely that any typical major contributors would have been missed, or that any atypical sources

would have been sampled. The only atypical meteorological factor that has the potential to influence or bias the results would be the greater than normal precipitation in the late fall and early winter. This may have reduced the amount of residential wood smoke that would have accumulated and been detected but could also have been offset by the relatively dry period from mid-January through mid-February. The other atypical weather pattern, modestly cooler temperatures and greater precipitation from mid-May through mid-June, could have reduced ozone production, but this would not impact any of the sample collection sites of this campaign.

Box plots

The box plots below show the 25th percentile (bottom of box), median (middle line in box), 75th percentile (top of box), and outliers (circles) for the compounds that we sampled. The whiskers are the furthest data point from the box within 1.5 times the inter-quartile range. The box plots are shaded only for aesthetic effect. Data from our sites are shown alongside data from 2019-2021 at all National Air Toxics Trend Stations (NATTS) sites. Only the sites which sampled for the given compound are shown. The dashed line is the minimum detection limit (MDL). Any values below the MDL may not be accurate. The asterisks next to site names indicate that a t-test showed the mean for that site was significantly ($p > 0.05$) different than the NATTS sites. In some graphs, very high outliers at NATTS sites are removed so that the boxes aren't shrunk so far that it makes them hard to compare visually. Boxplots for PAHs can be found in Appendix O. None of our sites had any PAH values above the MDL.

The purpose of the NATTS network is to provide long-term measurement of air toxics[12]. There are 26 NATTS sites; 21 urban and 5 rural. Some are located close to nearby air toxics sources and others measure primarily background concentrations. The NATTS network provides the most comprehensive national view of air toxics, however it is not strictly a national average.

[12] Air Toxics Ambient Monitoring, EPA. 2023. https://www.epa.gov/amtic/air-toxics-ambient-monitoring#natts.

Acetaldehyde

The EPA lists acetaldehyde as a probable human carcinogen. Acute exposure to high concentrations of acetaldehyde is also associated with irritation of the eyes, throat, and lungs.[13] Main sources of acetaldehyde include wood burning and car and truck exhaust. Agency efforts that target vehicle exhaust and wood stove emission reductions also reduce acetaldehyde emissions. Since 2000, we found a statistically significant drop in risk from acetaldehyde at a rate of about 0.1 per million per year at Seattle Beacon Hill.[14]

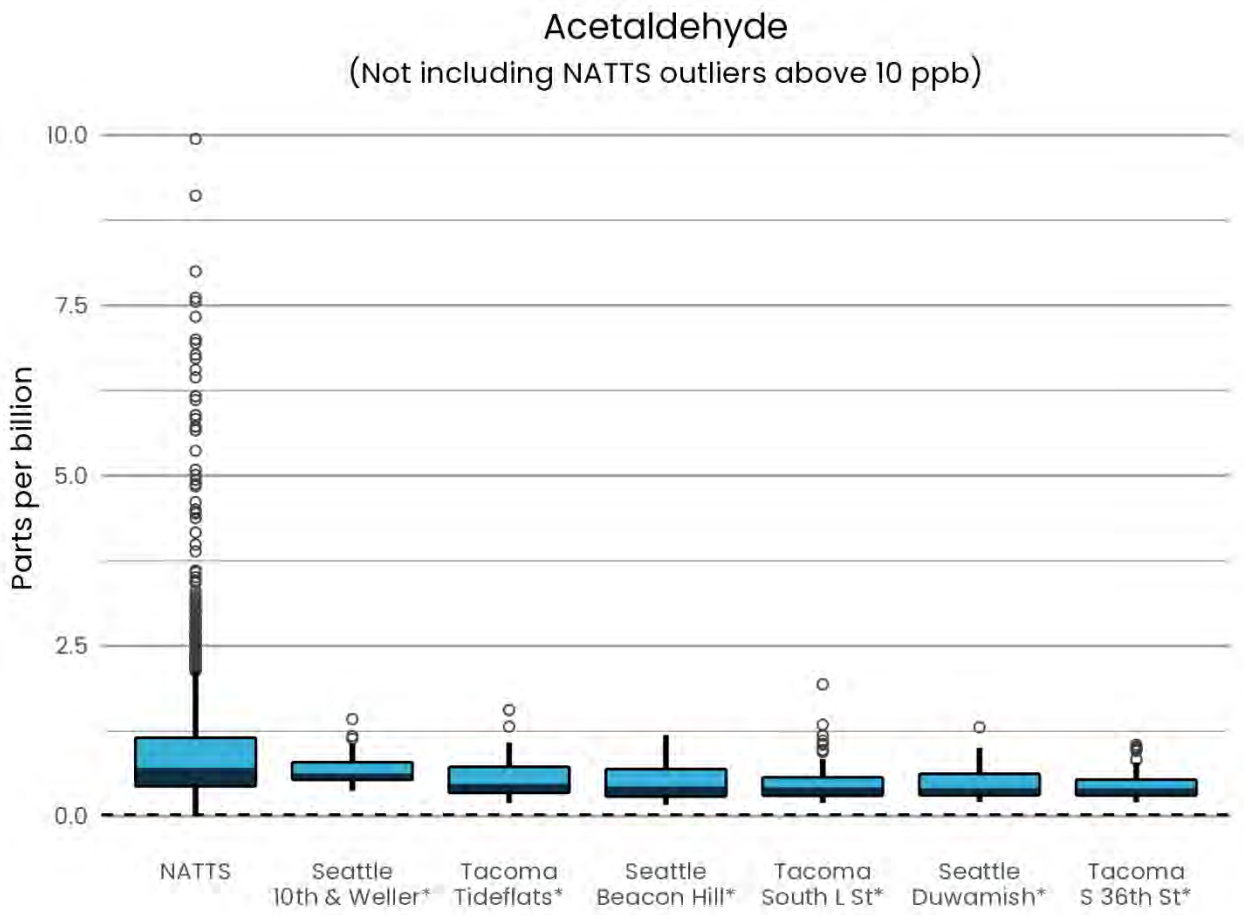
The box plot in Figure 3 shows that our fixed sites are lower than most of the NATTS concentrations. Like formaldehyde, acetaldehyde is also readily formed in the atmosphere. So, we would expect the concentration patterns to be similar to formaldehyde.

Appendix F shows the relationship between acetaldehyde and temperature. Generally, acetaldehyde increases with increasing temperature.

[13] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/acetaldehyde.pdf.

[14] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 3. Acetaldehyde box plot.



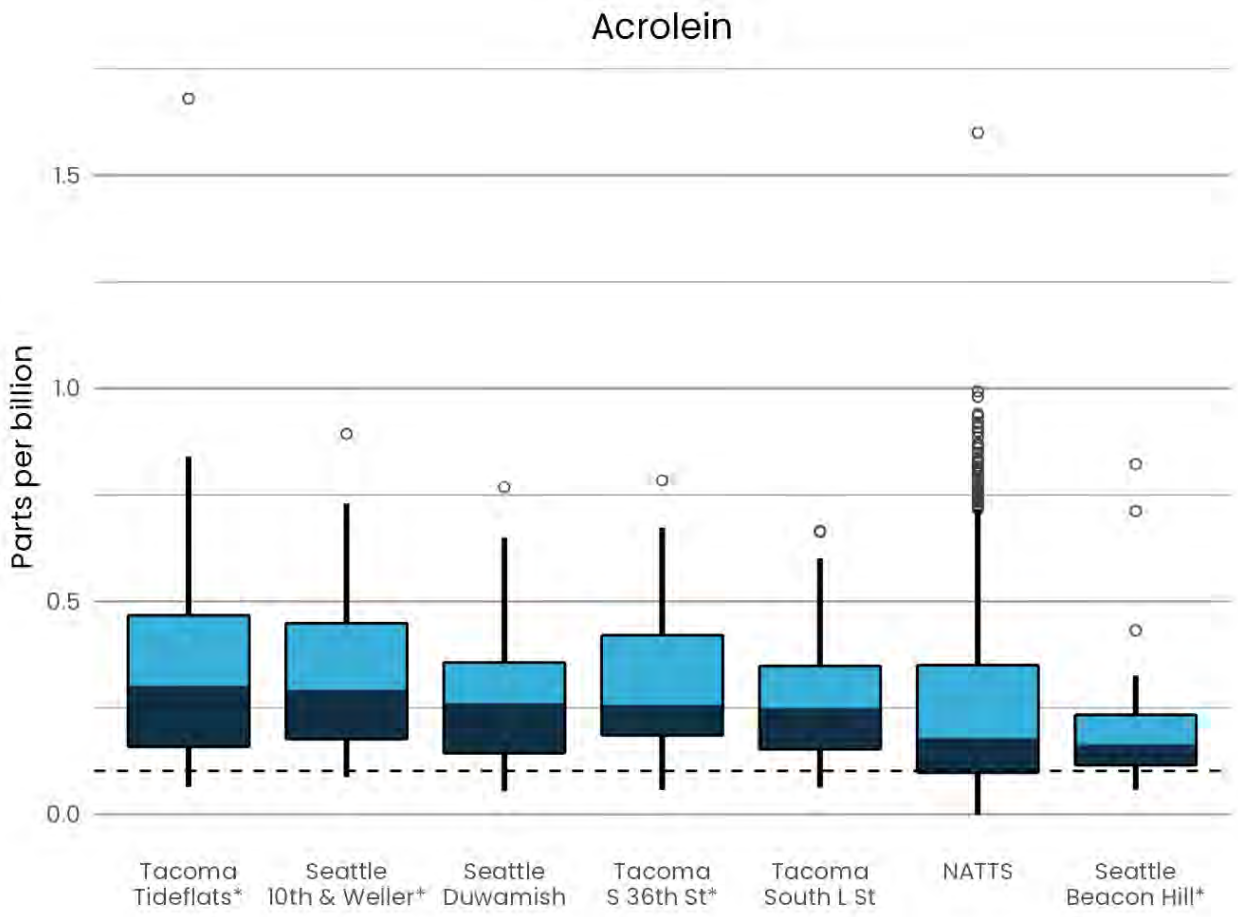
Acrolein

Only one air toxic, acrolein, failed the screen for non-cancer health effects, with measured concentrations consistently exceeding the reference concentration. Non-cancer health effects are measured using a parameter called the hazard quotient, where any value over 1 is beyond the reference concentration. A hazard quotient above 1 does not mean that health effects will definitely occur, however, a higher hazard quotient is associated with a higher likelihood of health effects. The average hazard quotient at our sites was 1.8, slightly higher than the NATTS average of 1.6. Acrolein is a byproduct of combustion of fossil fuels, high-temperature cooking of some foods, and cigarette smoking. It irritates the lungs, eyes, and nose.[15]

The box plot in Figure 4 below shows a higher median at most of our sites compared to NATTS sites, except for Beacon Hill.

[15] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-08/documents/acrolein.pdf.

Figure 4. Acrolein box plot.

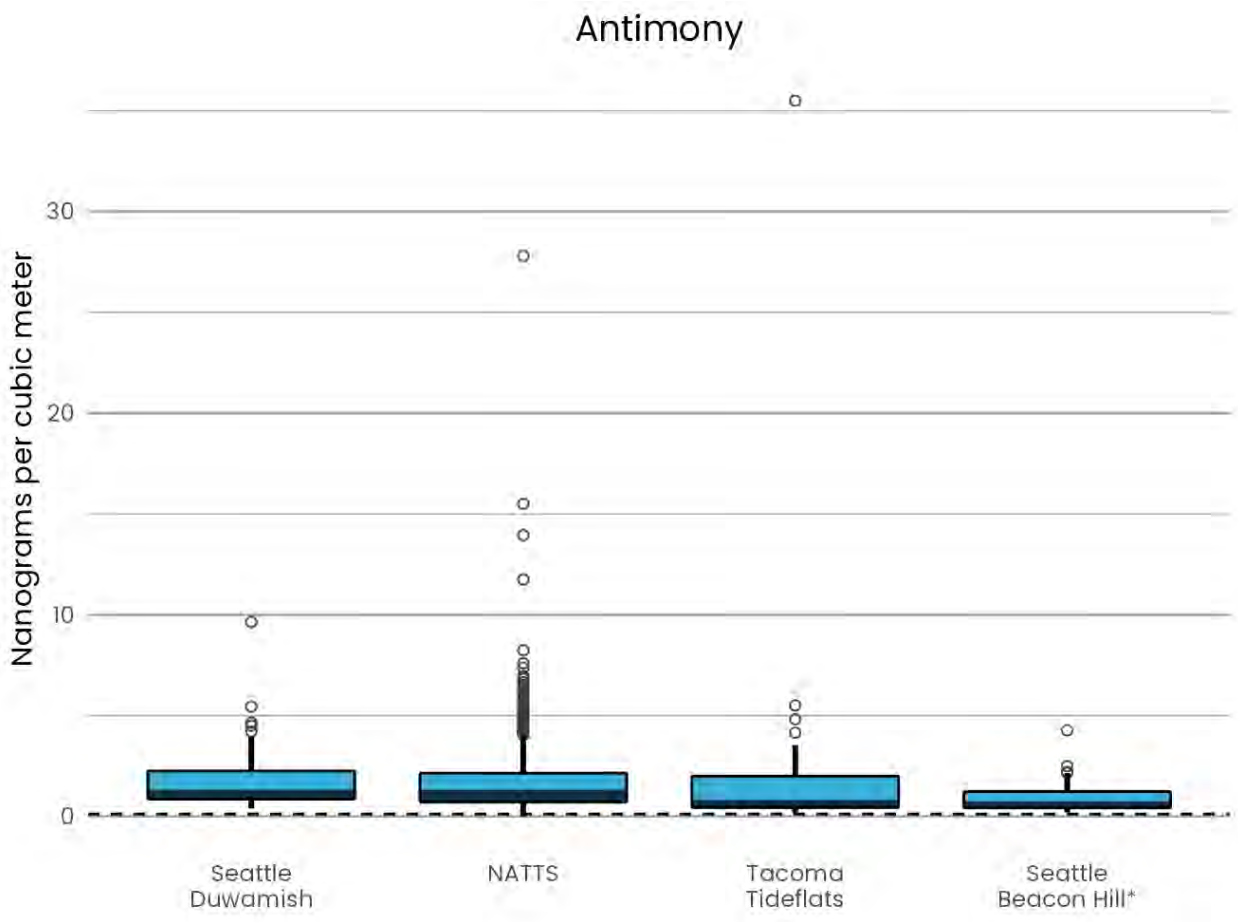


Antimony

Acute exposure to antimony can lead to irritation of the skin and eyes, while chronic exposure can cause lung inflammation and disease[16]. Antimony occurs naturally in the environment; however high levels can be produced by metal working industries. Many metal working businesses are regulated by our agency.

Figure 5 shows median antimony levels were higher at Duwamish than NATTS sites. However, Tacoma Tideflats and Beacon Hill were lower – with the exception of a single high sample at Tacoma Tideflats.

Figure 5. Antimony box plot.



[16] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/antimony-compounds.pdf.

Arsenic

EPA lists arsenic as a known carcinogen. Exposure to arsenic is also associated with skin irritation and liver and kidney damage.[17] Arsenic is used to treat wood and was historically used in glass coloring. Combustion of distillate oil is also a source of arsenic in the Puget Sound area. Since 2000, we found a statistically significant drop in risk from arsenic at a rate of about 0.05 per million per year at the Seattle Beacon Hill site.[18]

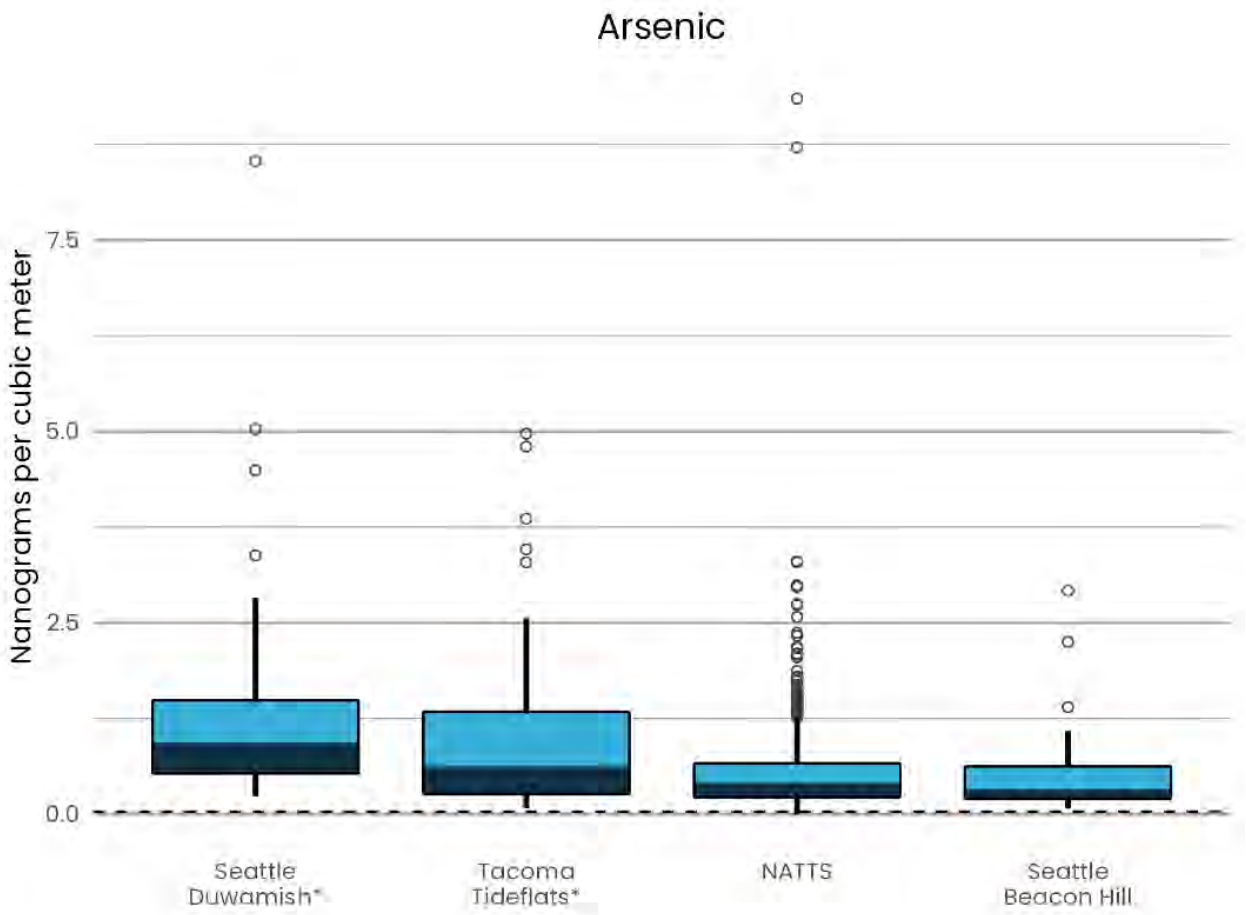
The Agency's permitting program also works with and regulates industrial sources of arsenic to reduce emissions. Illegal burning can also contribute to arsenic emissions in our area.

The box plot in Figure 6 shows that arsenic is higher at the Duwamish and Tacoma Tideflats sites compared to the NATTS sites. Beacon Hill has a similar median as the NATTS sites.

[17] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/arsenic-compounds.pdf.

[18] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 6. Arsenic box plot.



Benzene

The EPA lists benzene as a known human carcinogen. Benzene inhalation is also linked with blood, immune and nervous system disorders.[19] This air toxic comes from a variety of sources, including car and truck exhaust, cigarette smoking, wood burning, evaporation of industrial solvents, and other combustion.

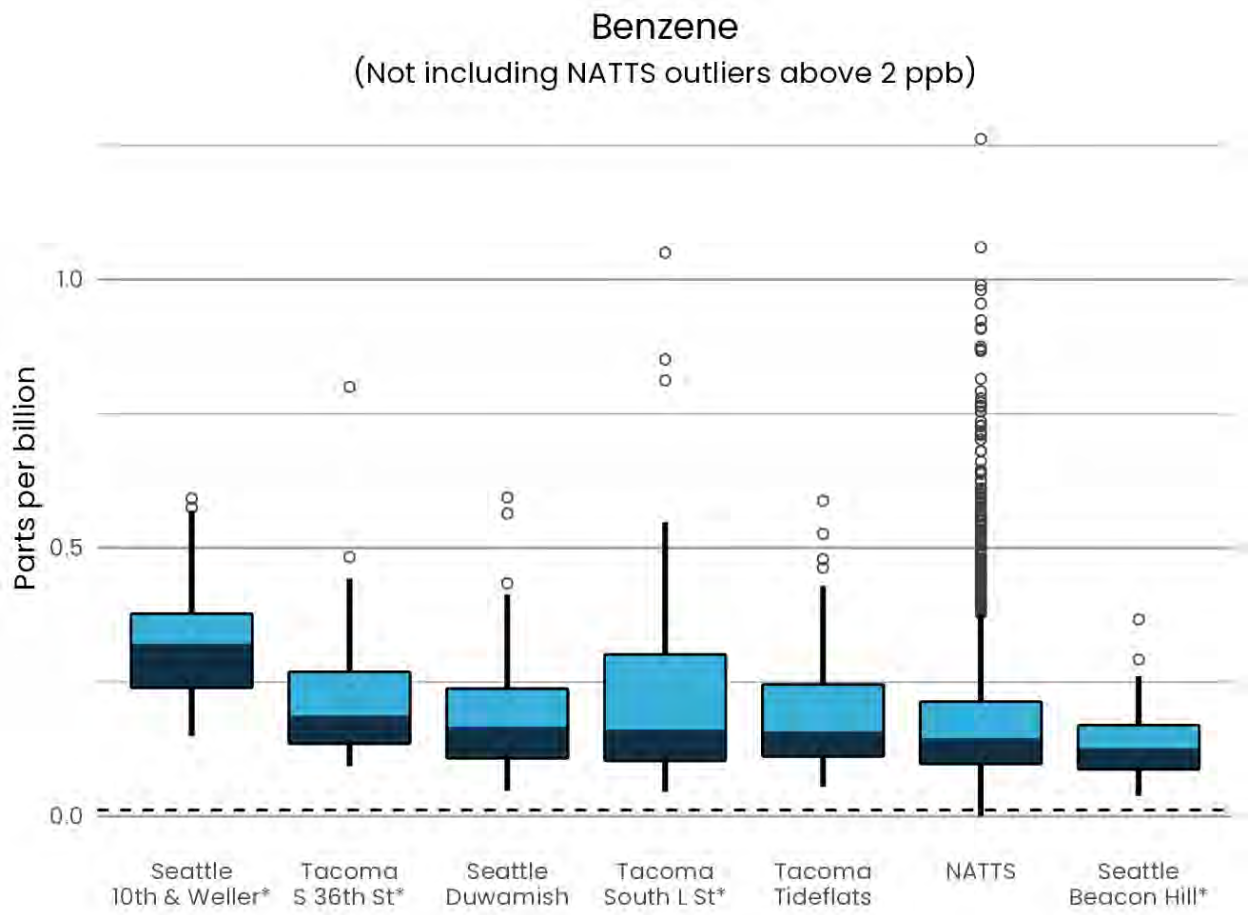
Benzene levels are likely decreasing in our area due to factors including less automobile pollution with cleaner vehicles coming into the fleet, better fuels, and fewer gas station emissions due to reduced vapor loss and spills (better compliance and use of control measures). At the Seattle Beacon Hill site, we found a statistically significant drop in risk from benzene at a rate of about 0.35 per million per year since 2000.[20]

Figure 7 below shows the box plot for benzene. The median benzene was highest at the near-road site, 10th & Weller, which is located approximately 50 feet from I-5. The median benzene was also high at the other near road site, Tacoma S 36th St. The residential Tacoma location, S L St, with significant impacts from wood smoke in the winter months, had median levels comparable to the industrial valleys on an annual average. Meanwhile most of those higher days fell in the winter heating months with significantly lower levels in the summer months. The median values at most of the sites were comparable to the NATTS sites.

[19] EPA Hazard Summary; https://www.epa.gov/sites/production/files/2016-09/documents/benzene.pdf.

[20] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 7. Benzene box plot.

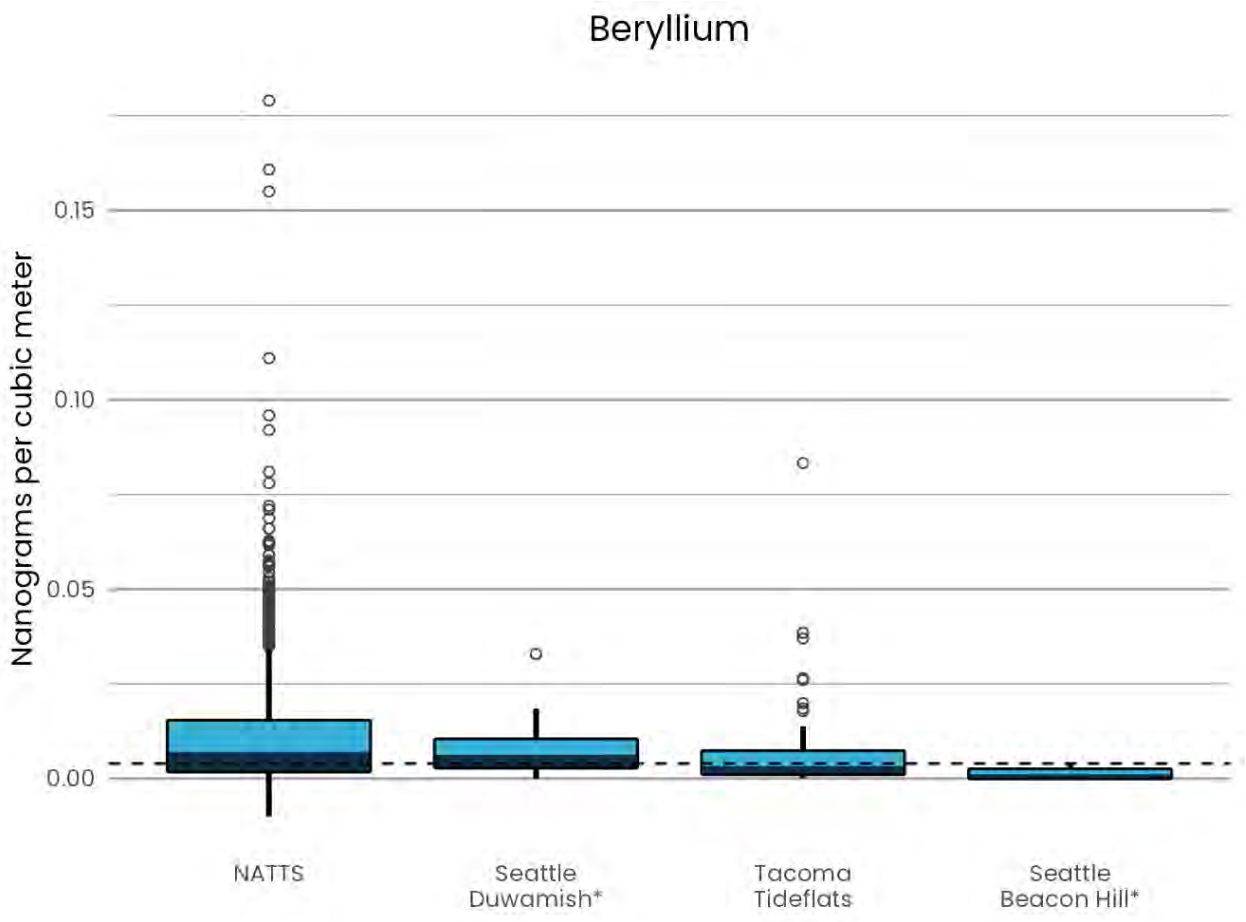


Beryllium

Acute exposure to high levels of beryllium can cause lung inflammation[21]. Chronic exposure can cause berylliosis, a disease characterized by non-cancerous lung lesions. EPA has classified beryllium as a probable human carcinogen. Beryllium occurs naturally in the environment. However, high levels can be produced by metal working industries. Many metal working businesses are regulated by our agency.

Figure 8 shows the median level of beryllium was higher at NATTS sites than our sites. However, Tacoma Tideflats did have a few days with higher concentrations.

Figure 8. Beryllium box plot.



[21] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/beryllium-compounds.pdf.

1,3-Butadiene

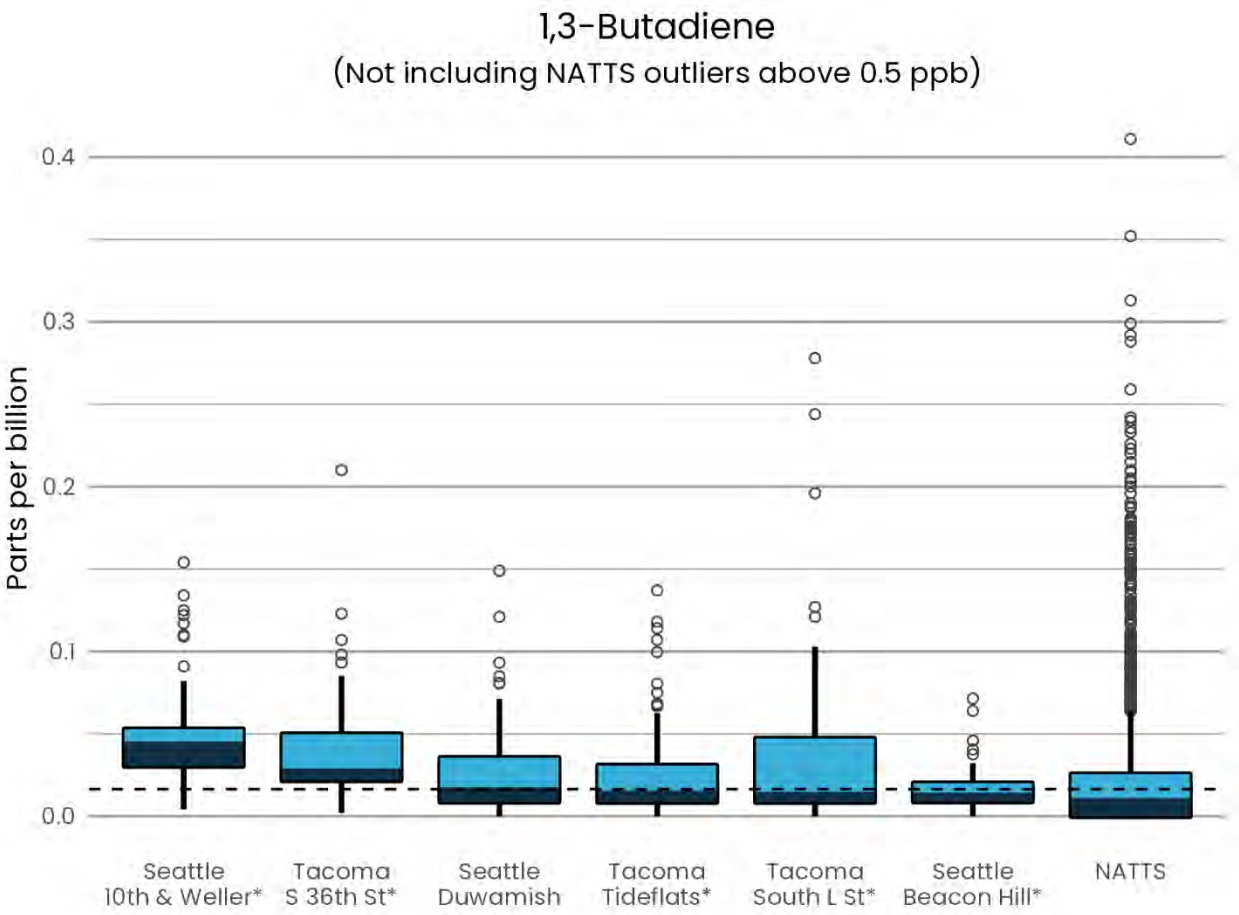
The EPA lists 1,3-butadiene as a known human carcinogen, and inhalation is also associated with neurological effects. [22] Primary sources include cars, trucks, buses, and wood burning. Our Agency has efforts that reduce vehicle exhaust and wood stove emissions, which helps reduce 1,3-butadiene emissions. Since 2000, we have found a statistically significant drop in risk from 1,3-butadiene at the Seattle Beacon Hill site at a rate of about 0.1 per million per year.[23]

For this study, all our 1,3-butadiene concentrations were higher than the median of the rest of the NATTS. The highest sites were our near-road sites, 10th & Weller and Tacoma S 36th St. With most of our sites near a major highway, heavy diesel traffic, or wood burning households, we expect to have higher levels than most other NATTS sites. The exception is Beacon Hill, which is higher in elevation, further from I-5/I-90, and generally has lower air toxics levels that come from fuel combustion. As expected, the inter quartile range (IQR) of the Seattle Beacon Hill data falls within the IQR of the NATTS. Also, note there is substantial uncertainty in the values with many medians near the detection limit (dashed line).

[22] EPA Hazard Summary; https://www.epa.gov/sites/production/files/2016-08/documents/13-butadiene.pdf.

[23] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 9. 1,3-butadiene box plot.



Cadmium

Acute exposure to cadmium can cause lung irritation[24]. Chronic exposure can cause kidney disease. EPA has classified cadmium as a probable human carcinogen. Cadmium is released by burning fossil fuels and incinerating municipal waste. We have programs that aim to reduce fossil fuel use and we regulate waste incinerators.

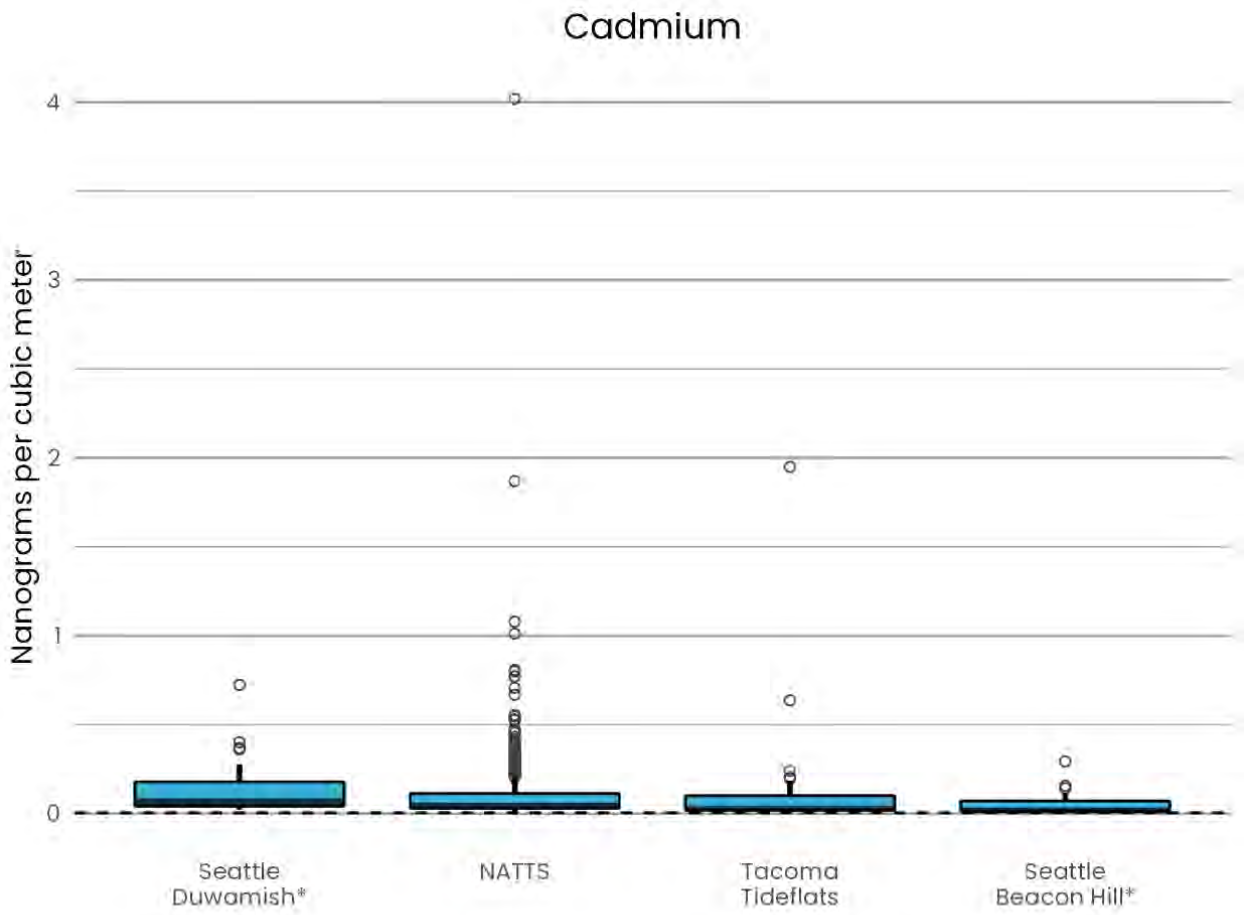
Since 2000, we have not found a statistically significant change in risk from cadmium.[25]

Figure 10 below shows the median level of cadmium was higher at Duwamish Valley than NATTS sites. Tacoma Tideflats had one day with a high concentration near two nanograms per cubic meter.

[24] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/cadmium-compounds.pdf.

[25] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 10. Cadmium box plot.



Carbon tetrachloride

The EPA lists carbon tetrachloride as a probable human carcinogen.[26] Carbon tetrachloride inhalation is also associated with liver and kidney damage. It was widely used as a solvent for both industry and consumers but was banned from consumer use in 1995. Trace amounts are still emitted by local sewage treatment plants. Carbon tetrachloride has a relatively long lifetime in the atmosphere, and since emissions have dropped significantly, it is well mixed in the atmosphere and concentrations are similar in urban and rural areas.

The Agency does not target efforts at reducing carbon tetrachloride emissions, as carbon tetrachloride has already been banned. At the Seattle Beacon Hill site, we have not found a statistically significant trend in carbon tetrachloride levels since 2000.[27]

Figure 11 below shows the box plot for carbon tetrachloride. The data show no significant differences across the sites in Seattle or nationally. Because carbon tetrachloride is a relatively constant background pollutant, we expect values to have a relatively small range.

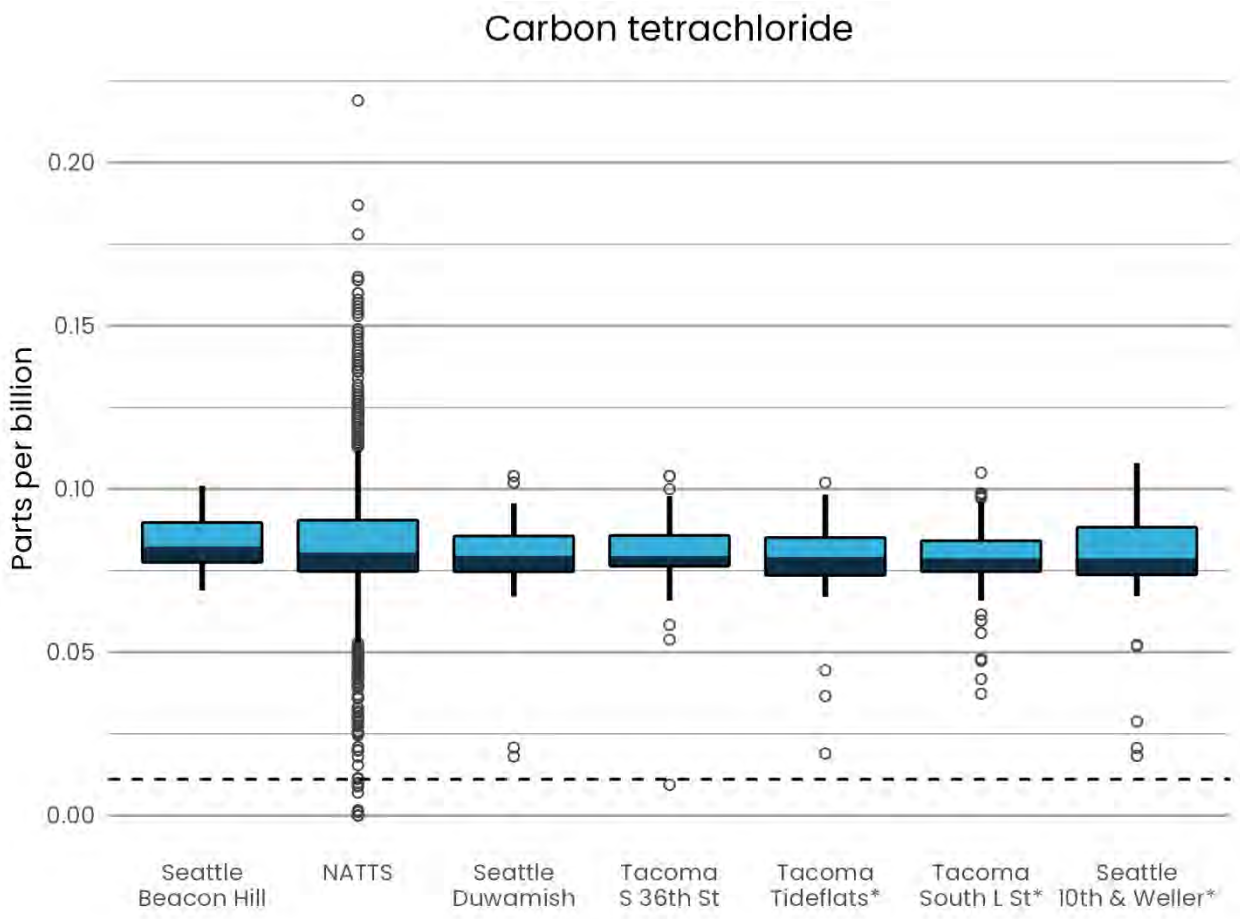
As shown in the graph, some samples had low carbon tetrachloride values. This occurred both at our sites and at the NATTS sites. This happened to approximately 2% of our samples. Those samples, when compared with the sample mean, were 20% lower when averaging across all other pollutants. It could be that there was an analysis issue for some of these samples; either only affecting carbon tetrachloride or affecting all compounds. However, with the small number of samples, we cannot decipher any difference. Visual analysis of graphs highlighting the low carbon tetrachloride days does not reveal any obvious pattern (Appendix E). And benzene and 1,3-butadiene, which used the same canister as carbon tetrachloride, did not show any difference on low carbon tetrachloride days compared to the mean. Days with low carbon tetrachloride had higher nickel, but with the very small number of samples (4), this was likely coincidental (Table E-1, Appendix E). Performing the same

[26] EPA Hazard Summary; https://www.epa.gov/sites/production/files/2016-09/documents/carbon-tetrachloride.pdf.

[27] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

comparison for all NATTS sites led to no strong positive associations and a strong negative association with 1,3-butadiene (Table E-2, Appendix E). We performed a sensitivity analysis by removing the samples that had low carbon tetrachloride. This resulted in a less than one-per-million change in our cancer risk estimate (<1% difference).

Figure 11. Carbon tetrachloride box plot.



Chromium

There are two main forms of chromium – Cr III (trivalent) and Cr VI (hexavalent). Trivalent chromium is an essential mineral for humans, while hexavalent chromium is highly toxic. EPA has classified hexavalent chromium as a carcinogen, and it has a very low unit risk factor; meaning that it is harmful in small amounts.[28] Aside from cancer, acute and chronic exposure to hexavalent chromium causes respiratory effects. Trivalent chromium occurs naturally in the environment, while hexavalent chromium is mostly produced by industrial processes. The Agency regulates businesses that emit chromium. At the Seattle Beacon Hill site, we have found in past years a statistically significant reduction in cancer risk due to estimated hexavalent chromium of 0.7 per million per year since 2000.[29]

Figure 12 below shows total chromium. Only a small amount of the total chromium in the air is hexavalent chromium. Since we did not have a speciated chromium sampler, we don't know the actual hexavalent chromium ratio, which could differ by site. A 2013 study at our Beacon Hill site showed hexavalent chromium to be 0.8% of total chromium.[30] In our cancer risk analysis that follows, we have chosen a more conservative value of 3% and applied that to all of our sites. A meta-analysis of hexavalent chromium sampling showed that the ratio can vary from about 1% up to 30%, when sampling next to large metal factories. [31]

Median total chromium levels were highest at Seattle Beacon Hill, where the 25th percentile was higher than the 75th percentile of NATTS sites. We do not know of an obvious source of chromium at this site. The Seattle Duwamish site also saw higher levels than NATTS sites. The Tacoma Tideflats site was comparable to the NATTS sites. However, we cannot infer much from the data as the results are all technically below the detection limits across the sites.

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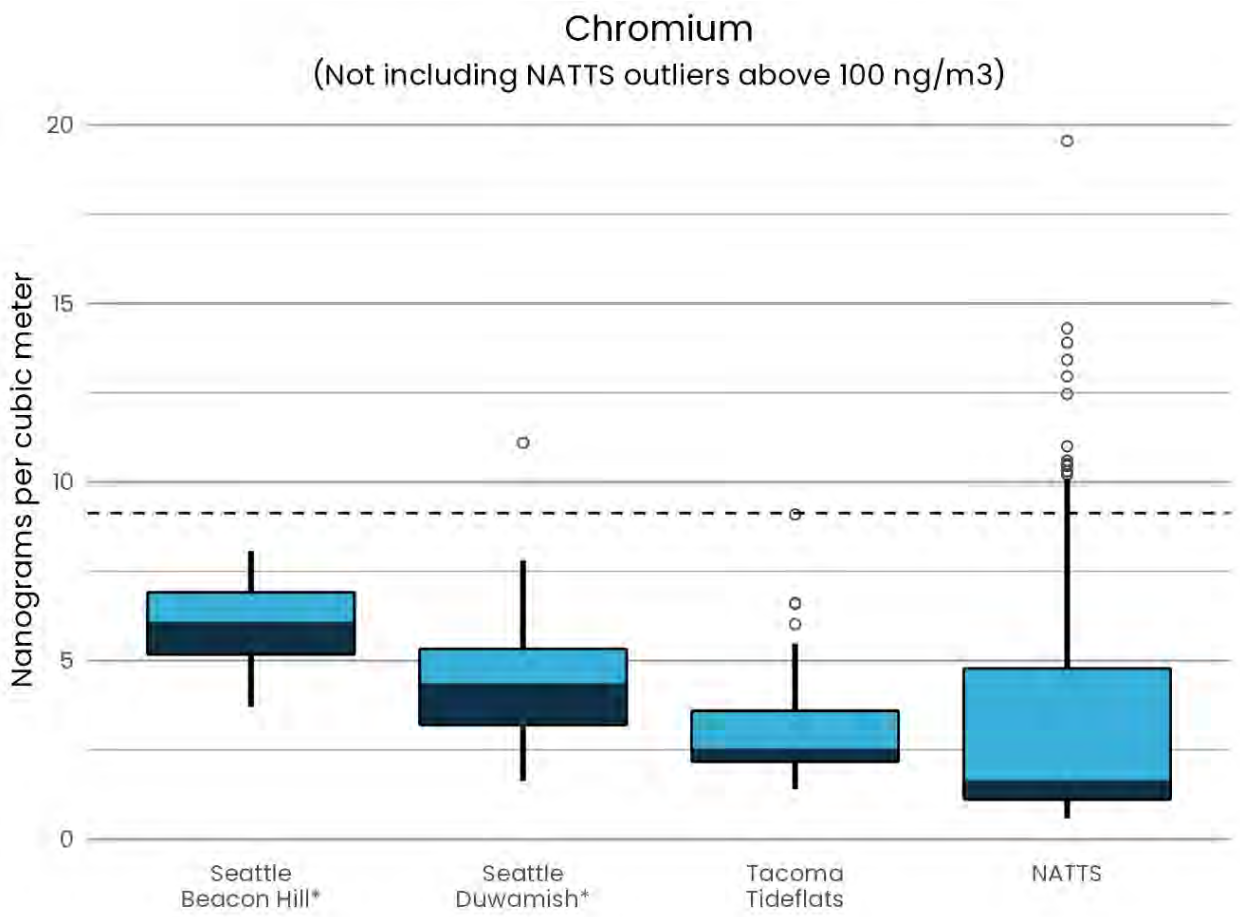
[28] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/chromium-compounds.pdf.

[29] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

[30] *ibid*, PSCAA 2013 Data Summary

[31] *ibid*, Torkmahalleh (2013)

Figure 12. Total chromium box plot.



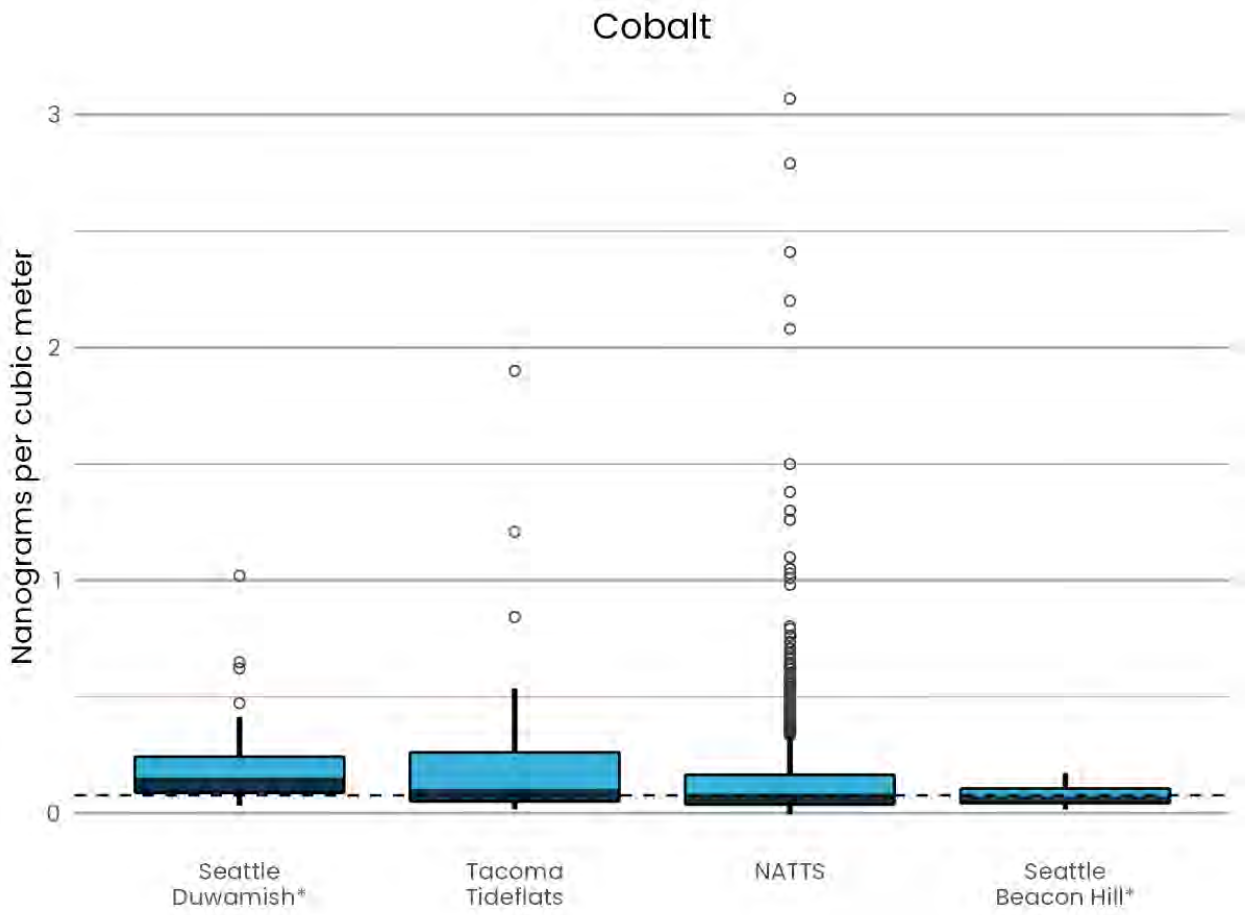
Cobalt

Cobalt is an essential element for humans, used in producing vitamin B_{12}. It is found naturally in the environment and can be found in high concentrations in some metal working industries.[32] Another potential source of cobalt could be from resuspended dust from cobalt-rich soils. Acute exposure to high levels of cobalt can cause lung damage. Chronic exposure can lead to more pronounced respiratory symptoms, cardiac effects, and organ congestion. Many metal working businesses are regulated by our agency.

Figure 13 below shows the median level of cobalt at the Duwamish site was close to the 75th percentile at NATTS sites. The Tacoma Tideflats had a lower median, but higher 75th percentile and outliers.

[32] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/cobalt-compounds.pdf.

Figure 13. Cobalt box plot.



Ethylbenzene

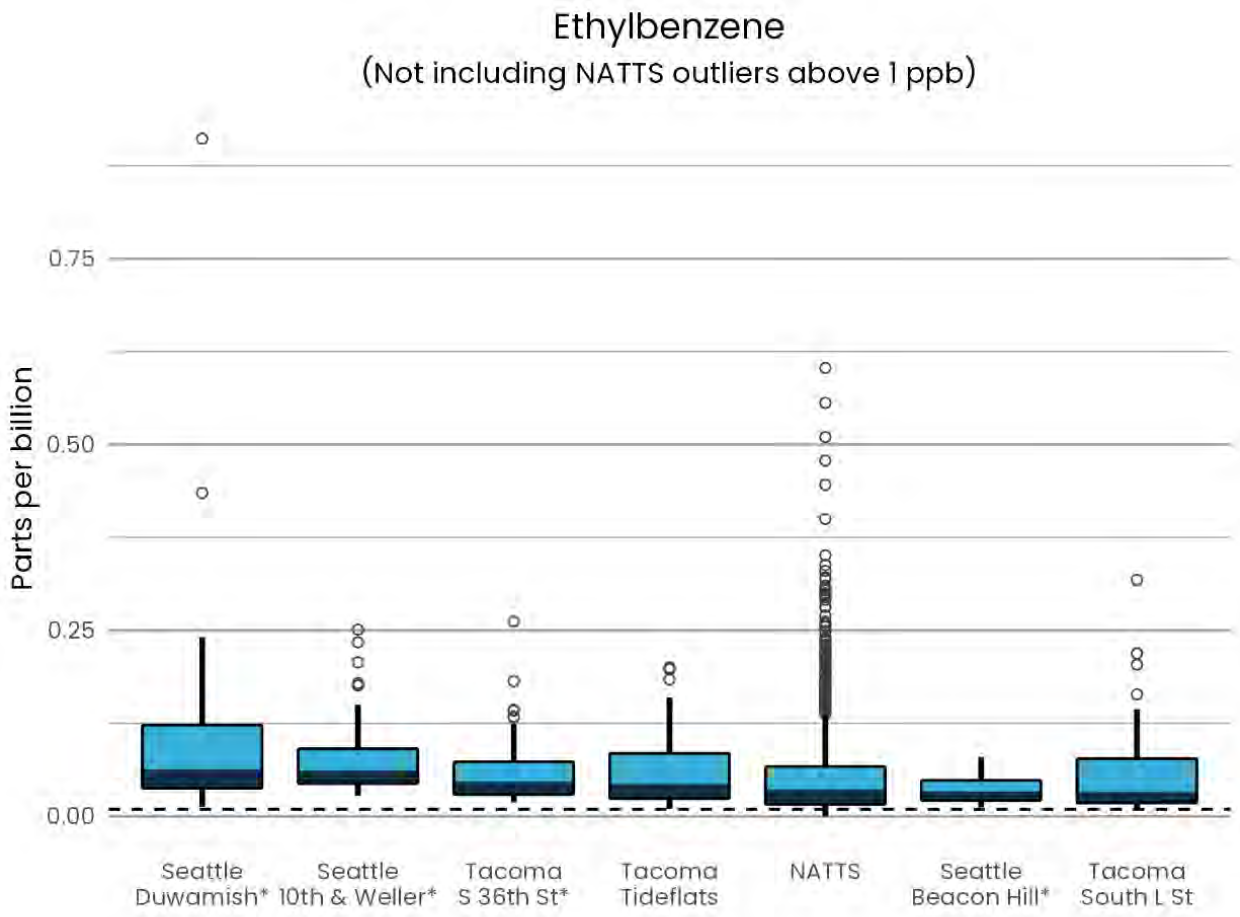
EPA lists ethylbenzene as a Group D pollutant, which is not classifiable as to human carcinogenicity due to limited data.[33] Chronic exposure to ethylbenzene may affect the blood, liver, and kidneys. Local sources of ethylbenzene are likely from combustion of fossil fuels and volatilization from fuels, asphalt, naphtha, and other solvents. It is also used in styrene production. At Seattle Beacon Hill, we did not find a statistically significant trend in ethylbenzene levels over the time frame that we had data.[34] The Agency works with and regulates solvent-using businesses to reduce ethylbenzene emissions.

Figure 14 shows slightly higher ethylbenzene at Duwamish and 10th & Weller compared to the NATTS sites. Our other sites were similar to the NATTS sites.

[33] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/ethylbenzene.pdf.

[34] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 14. Ethylbenzene box plot.



Ethylene Oxide

Ethylene oxide (EtO) is a flammable colorless gas with a sweet odor. It is primarily used to produce other chemicals including antifreeze, textiles, detergents, polyurethane foam, solvents, medicine, adhesive and other products[35]. In smaller amounts, it can be used as a pesticide and a sterilizing agent for medical purposes. EtO has the ability to damage DNA, which makes it effective as a sterilizing agent, but it also accounts for cancer-causing activity.

In industrial settings, ethylene oxide is used in closed systems. Occupational exposure risk is decreased if the chemical is used in more tightly closed systems. However, people can be exposed to EtO through uncontrolled emissions from industrial facilities, as a by-product of tobacco smoke, and the use of products that were sterilized by EtO such as medical products, cosmetics, and beekeeping equipment. In our jurisdiction there is only one registered source that currently has an EtO sterilizer. During the study, there was a second source that was rarely operating an EtO sterilizer, but they have since shut it down.

The Environmental Protection Agency has concluded that EtO is carcinogenic to humans by the inhalation route of exposure. Evidence in humans indicates that exposure to EtO increases the risk of lymphoid cancer and breast cancer.

EPA changed its toxicity value for EtO in December 2016 to be 34 times more protective.[36] Based upon that, in 2019 the Washington State Department of Ecology updated the acceptable source impact level for ethylene oxide to be 57 times more protective (from 0.0114 to 0.0002 µg/m^3). The new value, which we use in risk assessments, reflects our updated understanding that EtO is more toxic than in previous estimates. When the EPA released the 2018 National Air Toxics Assessment, this new information was included in the models. Since then, the EPA has included ethylene oxide in its list of chemicals that is monitored through the National Air Toxics Trends Laboratory Contract. This is the first air toxics study in the region estimated EtO concentrations.

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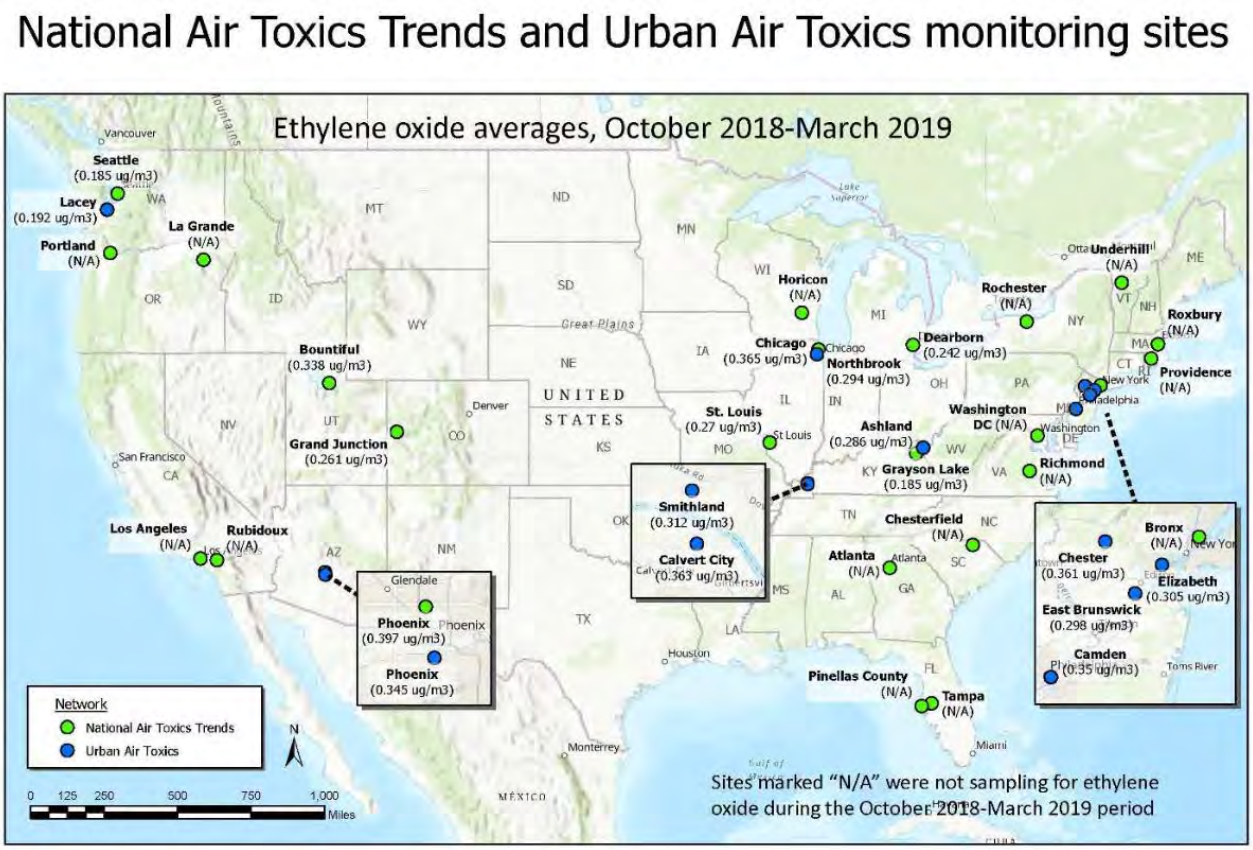
[35] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/ethylene-oxide.pdf.

[36] EPA, IRIS Evaluation of the Inhalation Carcinogenicity of Ethylene Oxide (Final Report), Aug 2023, https://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=329730.

EPA added ethylene oxide into the routine air toxics suite in 2019. A comparison study[37] across the country showed Seattle Beacon Hill had the lowest levels. The results are shown in the map below in Figure 15.

[37] EPA 2019. Map of ethylene oxide averages from NATTS/UAT Sites, https://www.epa.gov/sites/production/files/2019-11/documents/map_of_natts_uatmp.pdf

Figure 15. Results from EPA analysis of NATTS site data from late 2018 to early 2019 showing Seattle Beacon Hill's site with the lowest levels nationally.



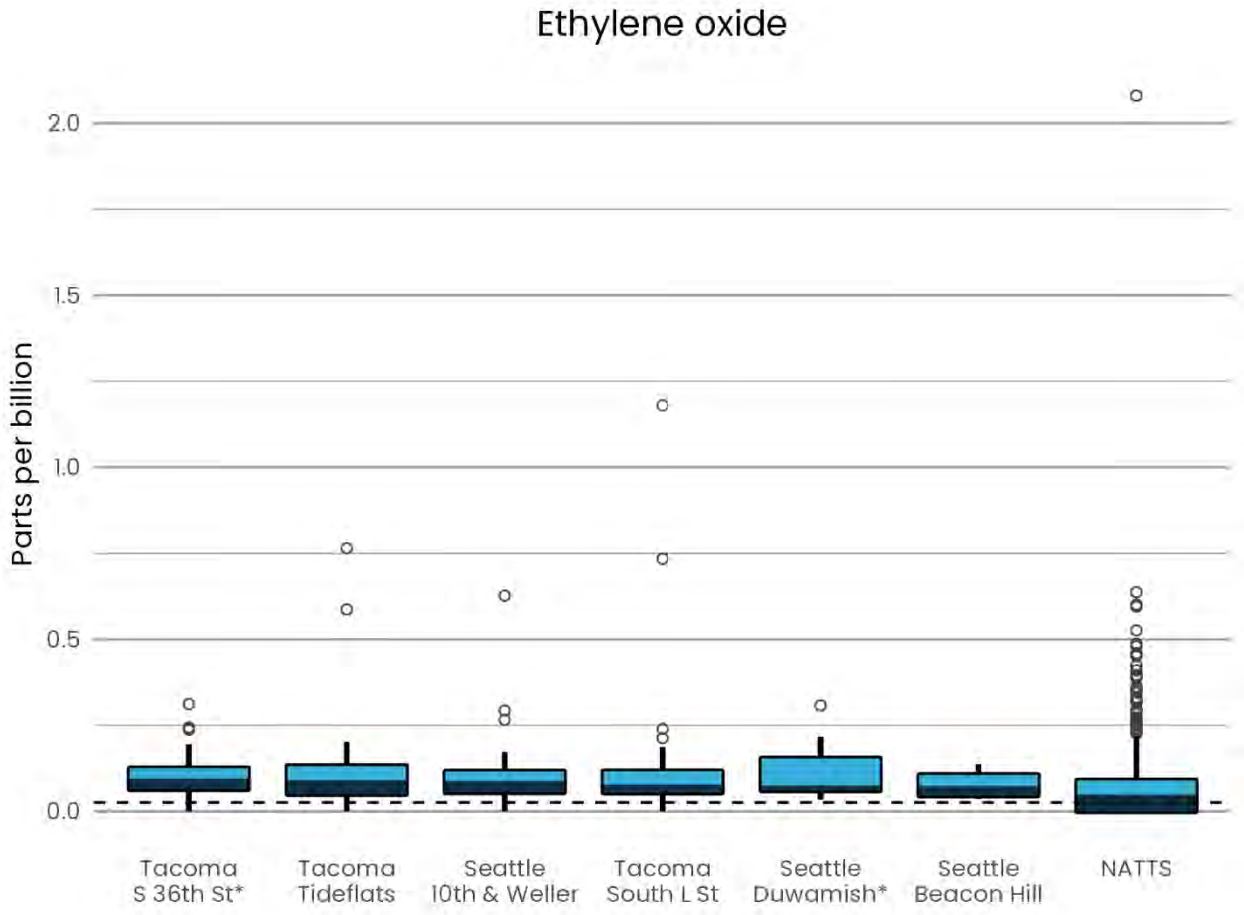
Current monitoring methods for ethylene oxide have multiple issues. The current sampling method is not sensitive enough to get adequate measurements to quantify effectively. The method detection limits equate to potential cancer risks in the hundreds per million. For 2021, we estimated the ethylene oxide average potential cancer risk estimate at Seattle Beacon Hill at 700 in one million. Ethylene oxide also tends to "stick" to the sampling canisters, which can carry over false readings into subsequent samples.[38] During our study, the contract lab flagged most of the samples for being potentially inaccurate for ethylene oxide.

[38] EPA 2020, EPA's Work to Understand Background Levels of Ethylene Oxide, https://www.epa.gov/system/files/documents/2021-10/background-eto-explainer-doument.pdf.

Despite high uncertainty, we created box plots (Figure 16) to compare sites. Samples below the MDL are shown as-is. Samples that were flagged for canister contamination were removed; this comprised about half of the samples and left about 20-30 samples per site. We generally saw uniform medians across all the sites, including the compiled national site data (NATTS). However, 75th percentiles are generally higher at the other sites compared to Seattle Beacon Hill and the NATTS sites. The Beacon Hill location generally has less pollution (e.g., fine particle and black carbon) than other monitoring site locations across Puget Sound.

We look forward to improvements in sampling methodology to better understand levels of EtO and related health risk in our region.

Figure 16. Ethylene oxide box plot.



Formaldehyde

The EPA lists formaldehyde as a probable human carcinogen. Inhalation is also associated with eye, nose, throat, and lung irritation.[39] Ambient formaldehyde can both be emitted directly from a source or formed in the atmosphere from emissions from plants and trees, automobiles, trucks, wood burning, cigarettes, and other combustion sources. Agency efforts that target vehicle exhaust and wood stove emission reductions also reduce formaldehyde emissions. Since 2000 at the Seattle Beacon Hill site, we found a statistically significant drop in risk from formaldehyde at a rate of about 0.35 per million per year, however the risk has been increasing slightly in recent years.[40]

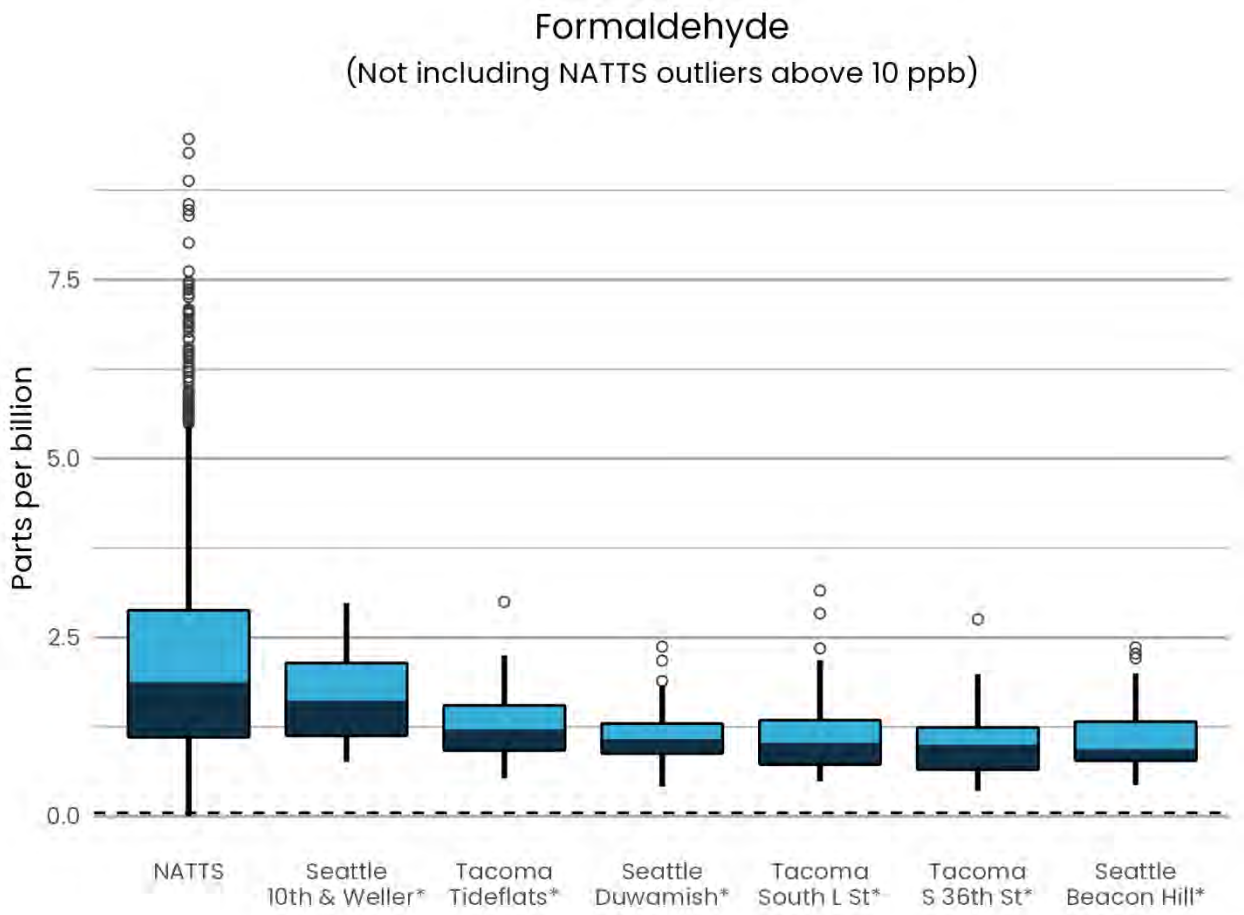
Figure 17 below shows the formaldehyde data as a box plot. Our sites are much lower than the median of the NATTS. This is likely due to formaldehyde being mostly generated as a byproduct of atmospheric chemical transformations of other pollutants. Our region is better ventilated by cleaner Pacific winds with less secondary chemistry and reactions than the rest of the country. Our airshed typically ventilates out daily, especially in the summer months, when temperatures are warmer and typically formaldehyde production is highest. This incoming background air has less direct emissions and less atmospheric formation than other parts of the country.

Appendix F shows the relationship between formaldehyde and temperature. Generally, formaldehyde increases with increasing temperature.

[39] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/formaldehyde.pdf.

[40] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 17. Formaldehyde box plot.



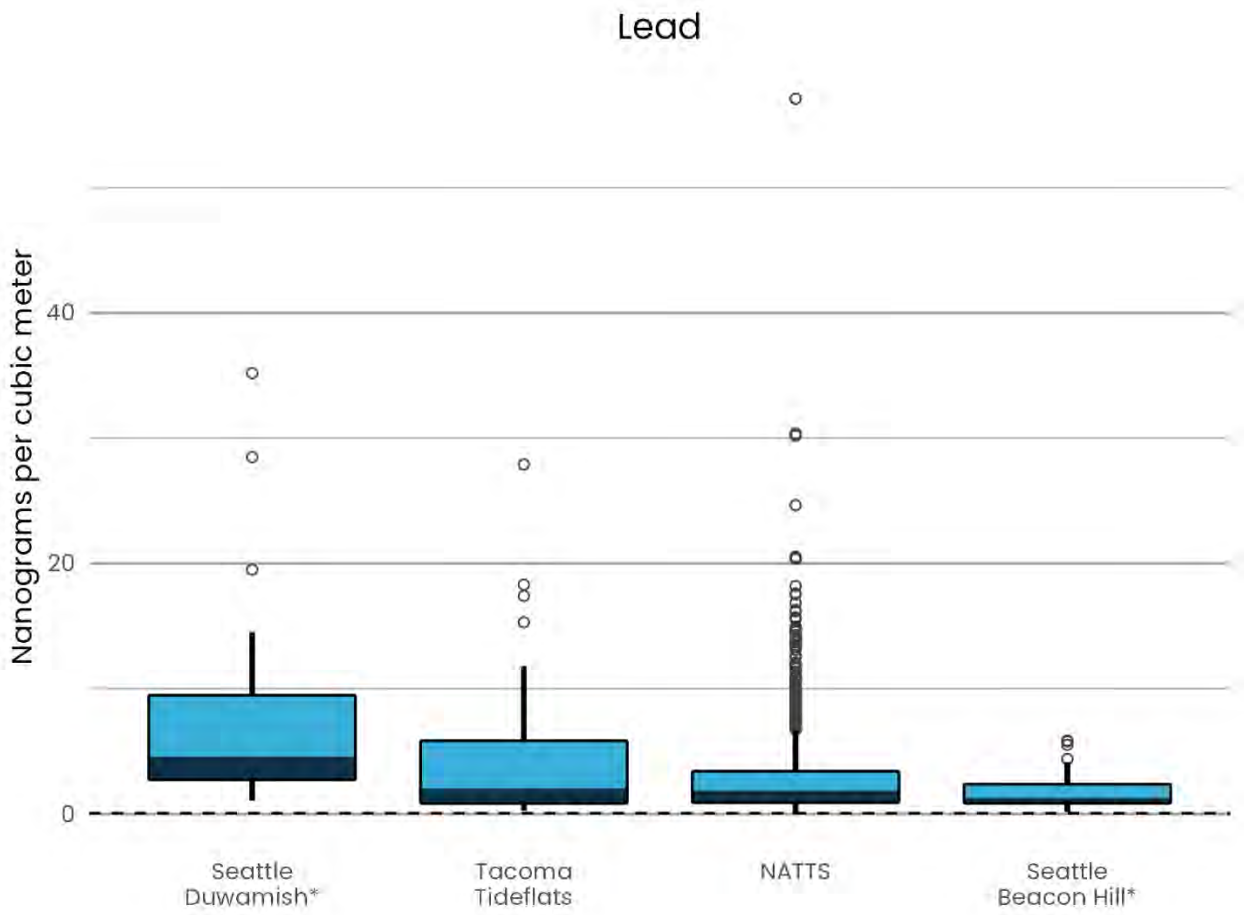
Lead

Chronic exposure can cause damage to the nervous, renal, cardiovascular, and immune systems and slow cognitive development in children. Acute exposure to high levels of lead can cause neurological deficiencies, injure the kidneys, and cause reproductive issues, and gastrointestinal symptoms.[41] EPA has concluded that lead is likely carcinogenic to humans. Lead can be emitted into the air from metal working industries, waste incineration, resuspended dust from contaminated soils, and small aircraft. Many metal working businesses are regulated by our agency.

Figure 18 shows the median level of lead at the Seattle Duwamish site was higher than the 75th percentile of NATTS sites. Duwamish also had some of the highest daily lead values. The Tacoma Tideflats site was also higher than NATTS sites. For health context and lead results from the community-directed sampling campaign, see section on "Community-directed monitoring" later in this report.

[41] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/lead-compounds.pdf.

Figure 18. Lead box plot (not including community-directed samples).



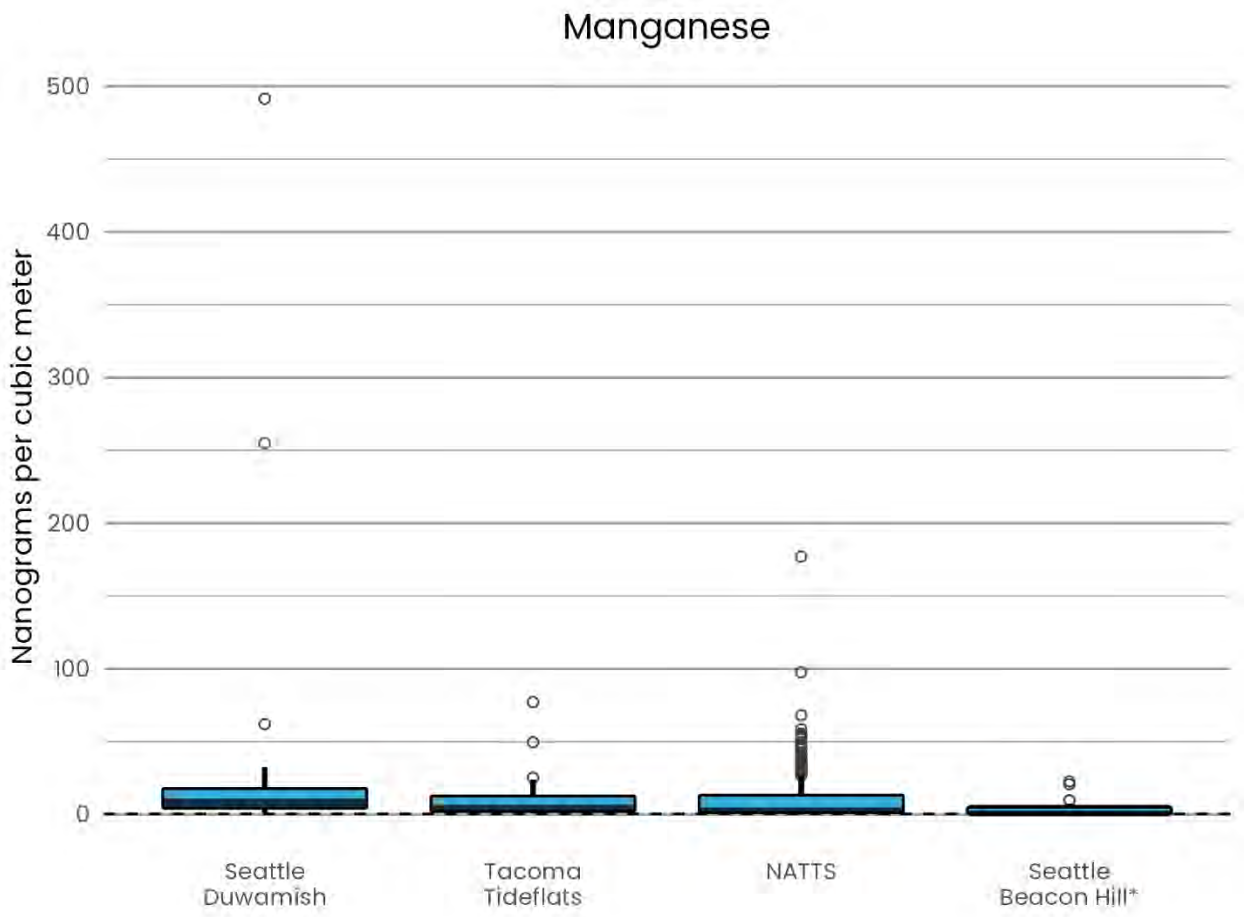
Manganese

Manganese is a necessary mineral for human nutrition and naturally occurs in the environment. However, chronic exposure to high levels can lead to central nervous system effects, respiratory effects, and a condition called manganism—characterized by weakness, tremors, and psychological issues.[42] Manganese can be emitted into the air from metal working industries and power plants. Many metal working businesses are regulated by our agency.

Figure 19 below shows the median level of manganese at the Duwamish site was close to the 75th percentile at NATTS sites. Duwamish also had two days with an order of magnitude higher concentration.

[42] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-10/documents/manganese.pdf.

Figure 19. Manganese box plot.



Mercury

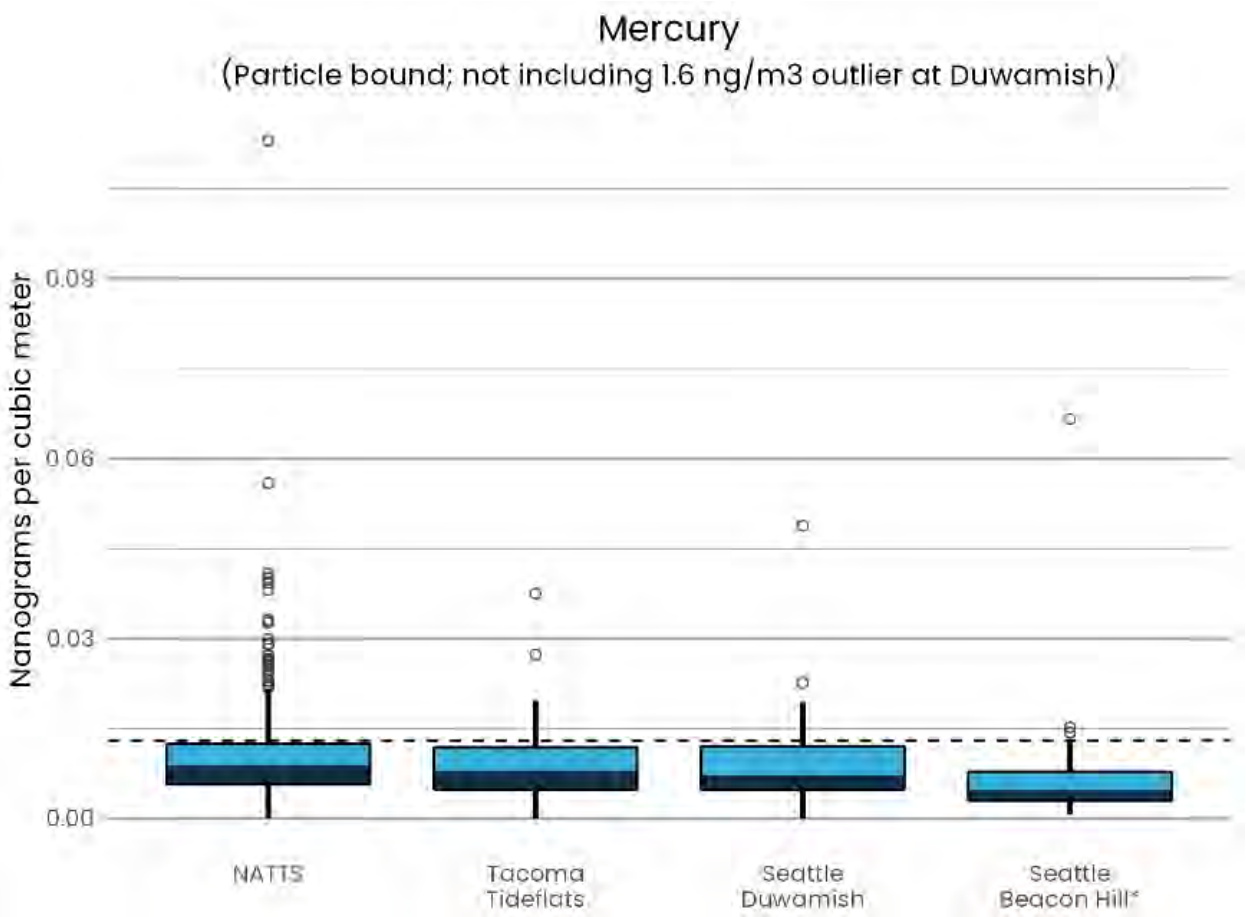
Mercury is found naturally in the soil and can be emitted into the air from metal working industries, waste incineration, and fossil fuel combustion.[43] Humans can also be exposed to mercury through dental fillings and by eating fish. Depending on the form of mercury (elemental, inorganic, or organic) acute effects include gastrointestinal problems, irritation of mucous membranes, central nervous system problems, and renal problems. Chronic effects are similar, with a more pronounced effect on the kidneys for inorganic mercury.

Many metal working and waste management businesses are regulated by our agency. We also work to reduce fossil fuel combustion by helping the transition to electric vehicles.

The mercury found in our analysis is particle-bound mercury, meaning it is adhered to small particles, and is likely mostly elemental mercury with some inorganic mercury. The median level of mercury at all our sites was lower than NATTS sites. There was one outlier of 1.6 ng/m^3 at the Seattle Duwamish site, which was removed from the graph for display. We have no definitive conclusion on the source of the outlier, but it may be a lab handling issue or other source.

[43] EPA Hazard Summary, https://www.epa.gov/system/files/documents/2021-12/mercury-compounds_12-3-2021_final.pdf.

Figure 20. Mercury box plot.

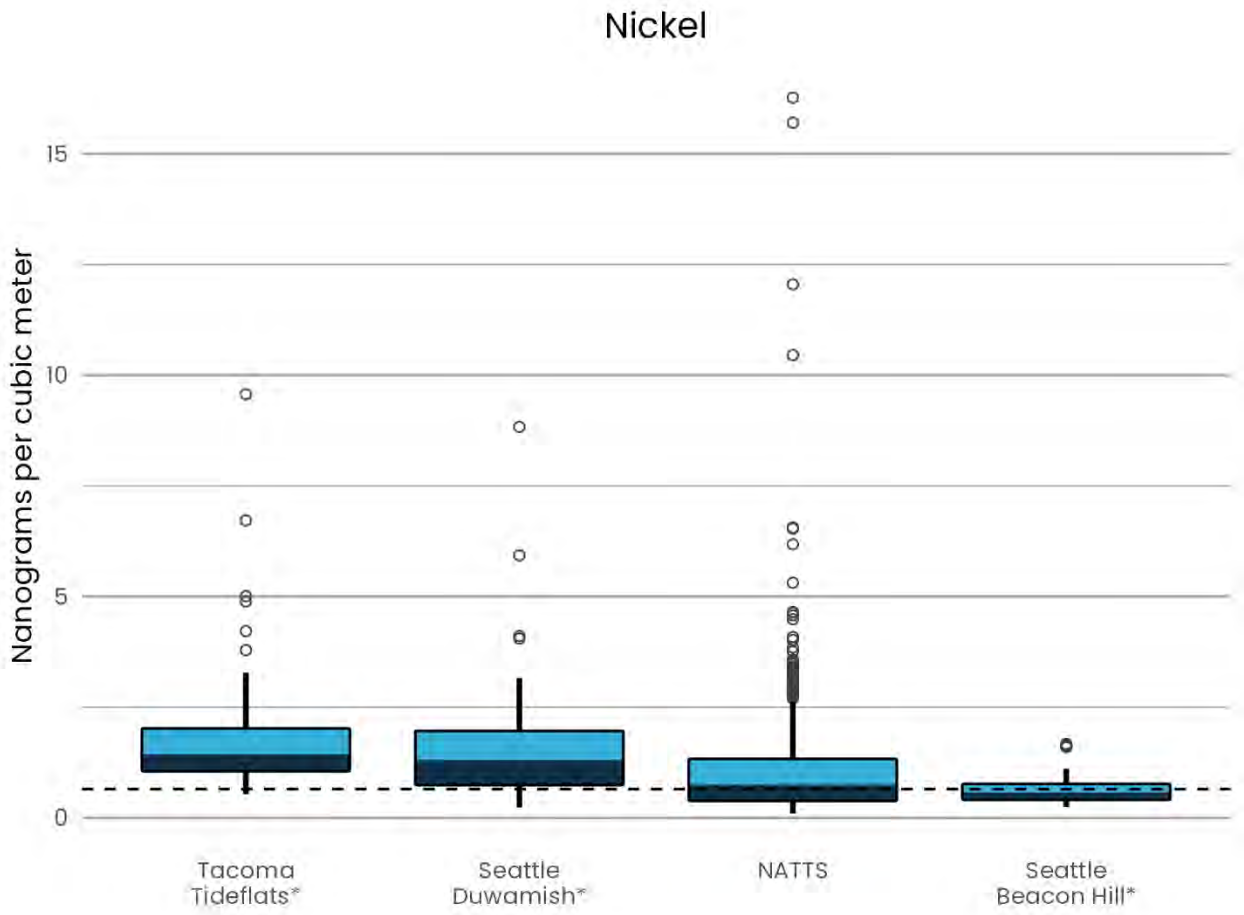


Nickel

EPA lists nickel as a known human carcinogen. Nickel is also associated with respiratory effects.[44] Combustion of gasoline and diesel fuels (car, truck, and vessel exhaust) is a main source of nickel in the Puget Sound area. Agency efforts that target reducing vehicle exhaust also reduce nickel emissions.

Figure 21 below shows the Duwamish and Tacoma Tideflats sites are higher than the NATTS sites and have some high daily values. Seattle Beacon Hill is lower than the NATTS sites.

Figure 21. Nickel box plot.



[44] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/nickle-compounds.pdf.

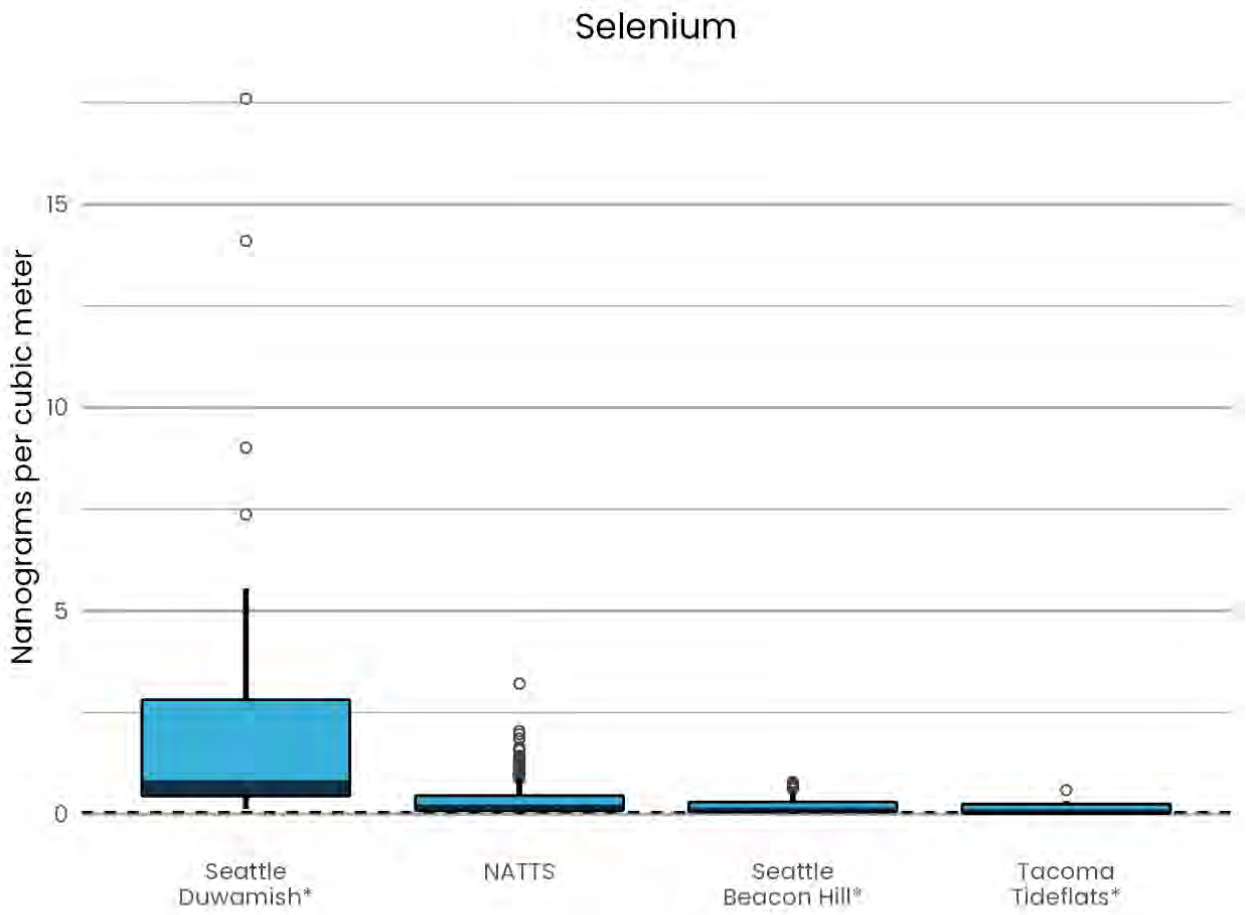
Selenium

Selenium is a necessary mineral for human nutrition and naturally occurs in the environment. However, it is harmful at high concentrations. Acute exposure can lead to irritation of the mucous membranes, gastrointestinal problems, and headaches.[45] Selenium can be emitted into the air from glass production, electronics production, and industries that work with selenium containing pigments. We regulate glass manufacturers and many types of painting businesses.

Figure 22 below shows the 25th percentile at the Seattle Duwamish site was higher than the 75th percentile at NATTS sites. The Duwamish site also had the highest daily values of selenium. Tacoma Tideflats and Beacon Hill were lower than NATTS sites. We did not conclude why the Seattle Duwamish had higher selenium levels than elsewhere.

[45] EPA Hazard Summary, https://www.epa.gov/sites/default/files/2016-09/documents/selenium-compounds.pdf.

Figure 22. Selenium box plot.



Tetrachloroethylene

EPA lists tetrachloroethylene, also known as perchloroethylene or "perc", as a probable human carcinogen. Tetrachloroethylene inhalation is also associated with central nervous system effects, liver and kidney damage, and cardiac arrhythmia.[46] Dry cleaners are the main source of tetrachloroethylene.

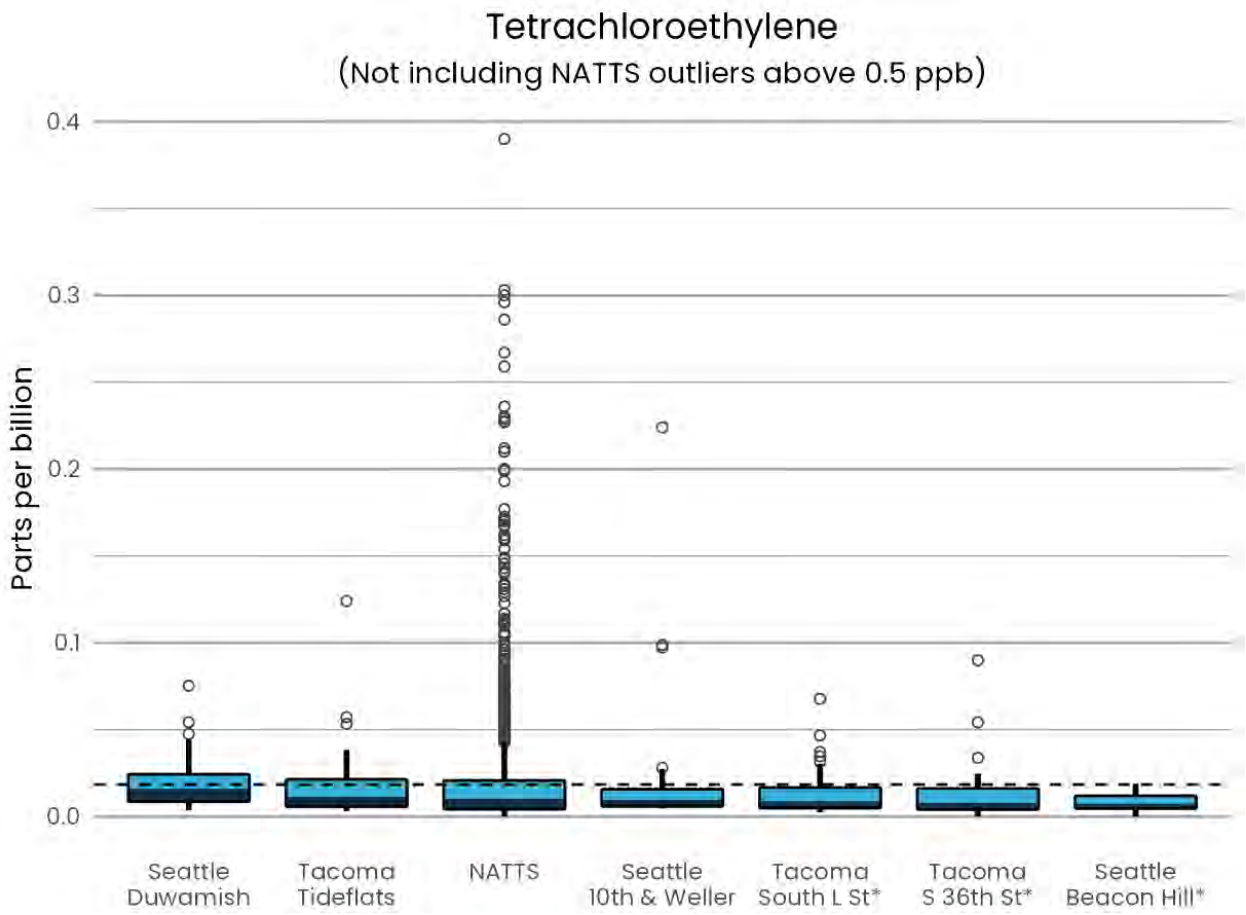
The Agency works with dry cleaners to monitor for and repair leaks in their equipment to reduce the release of tetrachloroethylene. Since 2000, we found a statistically significant drop in risk from tetrachloroethylene at a rate of about 0.04 per million per year.[47]

Figure 23 below shows that all of our sites are similar to or lower than the NATTS sites and most samples are below the minimum detection limit.

[46] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/tetrachloroethylene.pdf.

[47] Puget Sound Clean Air Agency, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF.

Figure 23. Tetrachloroethylene box plot.



Potential non-cancer risk

Table 7. Potential non-cancer hazard quotients by compound

	Seattle 10th & Weller	**Seattle Beacon Hill**	**Seattle Duwamish**	**Tacoma South L**	**Tacoma S 36th St**	**Tacoma Tideflats**
1,3-Butadiene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Acetaldehyde	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Acrolein	2	1.4	1.8	1.7	1.9	2.2
Arsenic		<0.1	<0.1			<0.1
Benzene	0.3	0.1	0.2	0.2	0.2	0.2
Beryllium		<0.1	<0.1			<0.1
Carbon tetrachloride	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ethylbenzene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Formaldehyde	0.2	0.1	0.1	0.1	0.1	0.1
Hexavalent Chromium		<0.1	<0.1			<0.1
Manganese		<0.1	0.2			0.1
Mercury		<0.1	<0.1			<0.1
Nickel		<0.1	0.1			0.1
Tetrachloroethylene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 7 shows the hazard quotient value across the primary study sites. This list includes compounds that have a chronic reference exposure level (REL) assigned by CA OEHHA [48]. A chronic reference exposure level is the "concentration of a chemical at or below which adverse noncancer health effects are not anticipated to occur" over the course of a lifetime[49]. To calculate the hazard quotient, the average concentration of each compound across the duration of the study is divided by the REL. A hazard quotient value over 1 indicates an elevated risk of non-cancer health impacts over a lifetime of exposure to that level of a compound. Lead has non-cancer health effects and has a national ambient air quality standard based on those health effects. Lead results are addressed later in this report under community-directed sampling. The only compound with a hazard quotient above 1 is acrolein, where the hazard quotient is between 1.4 and 2.2. See the Box Plot listing for acrolein above for a discussion of sources.

Compounds with a hazard quotient between 0.1 and 1 are benzene, formaldehyde, and, at some sites, manganese and nickel. All other compounds have a hazard quotient less than 0.1 or do not have an REL.

Hazard quotients can be added together for compounds that effect the same body system into a hazard index.

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[48] OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary. California Office of Environmental Health Hazard Assessment. Updated Oct 11, 2023. https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary.

[49] Technical Support Document for the Derivation of Noncancer Reference Exposure Levels. California Office of Environmental Health Hazard Assessment. 2008. https://oehha.ca.gov/media/downloads/crnr/noncancertsdfinal.pdf.

Table 8. Compounds and associated body systems for non-cancer effects

Compound	Target System
1,3-Butadiene	Reproductive
Acetaldehyde	Respiratory
Acrolein	Respiratory
Arsenic	Development; cardiovascular; nervous; respiratory; skin
Benzene	Hematologic
Beryllium	Respiratory; immune
Carbon tetrachloride	Alimentary; nervous; development
Ethylbenzene	Alimentary (liver); kidney; endocrine; development
Formaldehyde	Respiratory
Hexavalent Chromium	Respiratory
Manganese	Nervous
Mercury	Nervous; development; kidney
Nickel	Respiratory; hematologic
Tetrachloroethylene	Kidney; alimentary

Table 8 shows the relationship between air toxics and the body systems that they can impact due to non-cancer health effects[50]. "Development" stands for developmental effects.

Table 9. Potential non-cancer hazard indexes by body system

	Seattle 10th & Weller	Seattle Beacon Hill	Seattle Duwamish	Tacoma South L	Tacoma S 36th St	Tacoma Tideflats
Alimentary	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cardiovascular		<0.1	<0.1			<0.1
Development	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Endocrine	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

[50] *ibid*, OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary. 2023.

Hematologic	0.3	0.2	0.3	0.2	0.2	0.3
Immune		<0.1	<0.1			<0.1
Kidney	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nervous	<0.1	<0.1	0.3	<0.1	<0.1	0.2
Reproductive	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Respiratory	2.2	1.6	2.1	1.8	2.0	2.5
Skin		<0.1	<0.1			<0.1

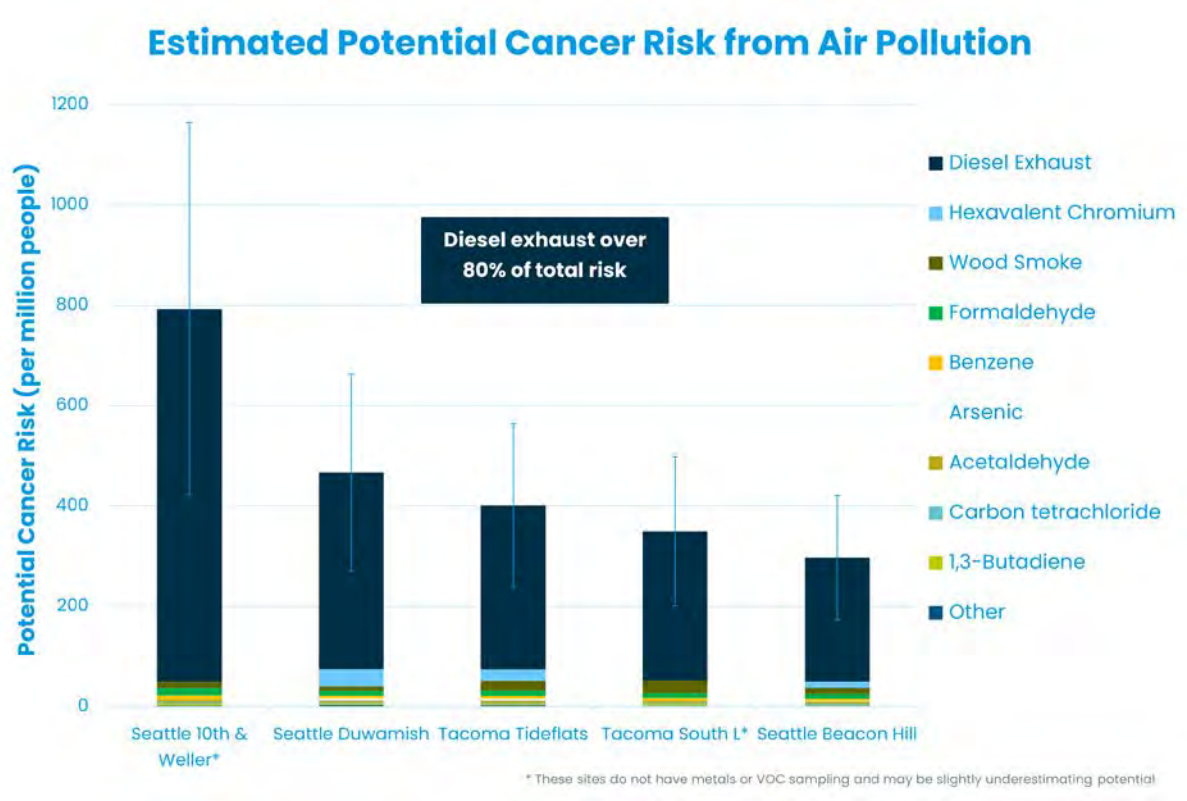
Table 9 shows the hazard index values for various body systems and developmental effects. The only body system with a hazard index above 1 is the respiratory system, which is almost completely due to the effect of acrolein. The hematologic system has hazard indexes above 0.1, primarily due to benzene. Finally, the nervous system has hazard indexes above 0.1 at some sites, due to primarily to manganese.

Potential cancer risk

Overall potential cancer risk estimates

We found the majority of cancer risk (82-94%, 86% on average) is due to diesel particulate matter across the sites. This is because of the high toxicity of diesel particulate matter and relatively high concentration (compared to metals and VOCs). Estimated hexavalent chromium is the second highest with approximately 6% of the risk. Figure 24 shows the estimated potential cancer risk at all of our sites that had $PM_{2.5}$ speciation data (which excludes the Tacoma near-road site at S 36th St).

Figure 24. Estimated total potential cancer risk from air pollution at 5 Sites.



Seattle 10th & Weller and Tacoma South L did not have metals or PAH samples and Tacoma Tideflats did not have any PAH samples, so the total cancer risk is slightly underestimated in those locations (less than 10 per million).

Potential cancer risk estimate methodology

The diesel particulate matter and wood smoke estimates are based on the Positive Matrix Factorization analysis reported later in this report. The diesel particulate matter unit risk factor, $3x10^{-4}$ risk per µg/m^3, is from California OEHHA.[51] The wood smoke unit risk factor, $1x10^{-5}$ risk per µg/m^3, is from Lewtas J. (1988).[52]

[51] OEHHA Chemical Database - Diesel Exhaust Particulate, https://oehha.ca.gov/chemicals/diesel-exhaust-particulate.

[52] Lewtas J. (1988). "Genotoxicity of Complex Mixtures: Strategies for the Identification and Comparative Assessment of Airborne Mutagens and Carcinogens from Combustion Sources". Funda and Appl Tox 10: 571-589.

Cancer risk estimates for other pollutants used the Washington State Acceptable Source Impact Levels updated in 2019.[53]

Hexavalent chromium estimates were from a 3% assumption of total chromium values for Duwamish and Tideflats. The 3% assumption is based on a range found in a meta-analysis.[54] We included a 1% error estimate to help cover some of the uncertainty in the hexavalent to total chromium ratio from the meta-analysis. Beacon Hill uses a 0.8% ratio based on our 2013 study at that site.[55]

Ethylene oxide risk estimates are not included due to potential detection limit issues and sampling canister cleaning problems as discussed in a recent EPA letter.[56]

The diesel cancer risk in the graph above combines two PMF factors: 1) "diesel + crustal" and 2) "sulfate rich". The diesel + crustal factor combines on-road diesel particulate matter with a crustal component. We attribute the combination of road dust (crustal) and diesel particulate matter to the trucks and other heavy vehicles that couldn't be statistically delineated separately. The sulfate-rich factor is associated with maritime diesel emissions.

The diesel + crustal estimates are multiplied by a site-specific adjustment factor to remove the crustal component. Comparing the ratio of diesel particulate matter to crustal factors from previous PMFs at our study sites, led to an adjustment factor of

[53] Washington State Acceptable Source Impact Levels, 2019, https://apps.leg.wa.gov/wac/default.aspx?cite=173-460-150.
[54] *ibid*, Torkmahalleh (2013)
[55] *ibid*, PSCAA 2013 Data Summary
[56] EPA, Technical Note: The Ethylene Oxide (EtO) Canister Effect, 2021, https://www.epa.gov/sites/default/files/2021-05/documents/technical-note-on-eto-canister-effect-052521.pdf.

0.56 at Duwamish; 0.33 at Tideflats; and 0.68 at Beacon Hill.[57,58,59,60] The uncertainty bars are set to the site-specific adjustment factor for diesel particulate matter.

This may not work well at the Tacoma Tideflats site, which had a much higher diesel + crustal factor compared to previous PMF studies. It was also much higher than expected in the analysis of other study sites and nearby truck tonnage. This could be due to the large amount of construction work happening during the study period that may have contributed significantly to the crustal component. The sulfate-rich maritime component generally agreed with previous studies at Beacon Hill and Duwamish but was lower at the Tideflats site. This could mean that the maritime part of the diesel estimate for Tideflats is an underestimate and was combined in the diesel + crustal factor.

At the Duwamish site, 27% of the total diesel was on-road (107 per million) and 73% was maritime (285 per million). At Tideflats, 35% was on-road (114 per million) and 65% was maritime (213 per million). At Beacon Hill, 51% was on-road (127 per million) and 49% was due to maritime (120 per million). At 10th & Weller, 61% was on-road (452 per million) and 39% was maritime (291 per million).

Potential cancer risk from VOCs, aldehydes, and PAHs

This section focuses on potential cancer risk from VOCs, aldehydes, and PAHs (with the diesel particulate matter, wood smoke, and metals risks removed). These findings are directly measurable air toxics, whereas diesel and wood smoke are mixtures estimated in other ways (e.g., PMF modeling). Metals are presented in the Community-directed monitoring section. We only included compounds that have greater than one-per-million potential cancer risk. The largest contributor is

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[57] Kotchenruther R. (2013). "A regional assessment of marine vessel $PM_{2.5}$ impacts in the U.S. Pacific Northwest using a receptor-based source apportionment method". Atmos Env 68: 103-111.

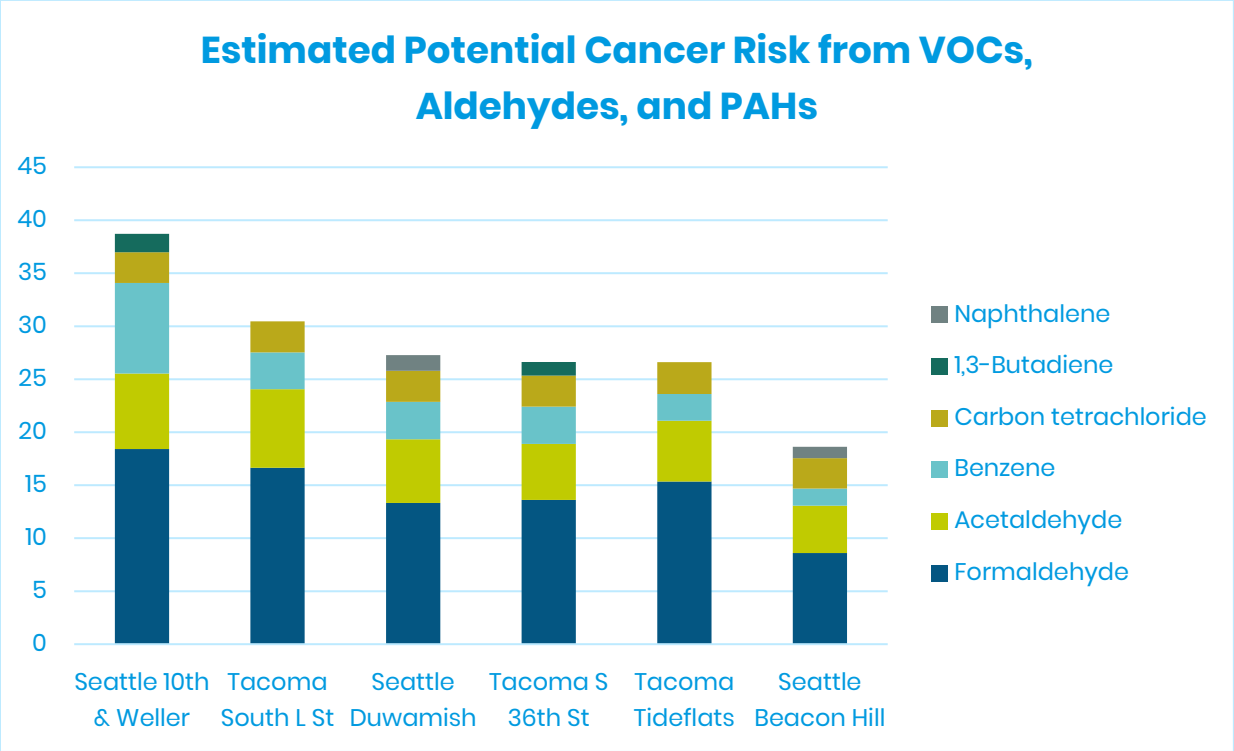
[58] Hopke P., Kim E. (2008). "Source characterization of ambient fine particles at multiple sites in the Seattle area". Atmos Env 42:6047-6056.

[59] Friedman, B. (2023). "Technical Report: Port of Tacoma Source Apportionment Study". WA Ecology, Publication 23-02-075. https://apps.ecology.wa.gov/publications/documents/2302075.pdf.

[60] Kotchenruther R. (2020). "Recent changes in winter $PM_{2.5}$ contributions from wood smoke, motor vehicles, and other sources in the Northwest U.S." Atmos Env 237:117724.

formaldehyde at around 9-18 per million. Then acetaldehyde with around 4-7 per million. The Seattle near-road site, 10th & Weller, is higher than other sites, largely due to higher benzene and formaldehyde. The only PAH that was above the 1 per million threshold was naphthalene. Figure 25 below summarizes these results.

Figure 25. Estimated potential cancer risk from VOCs, aldehydes, and PAHs only.



Air toxics trends

In this section, we compare this current study to previous studies in our region to understand long-term trends in air toxics. Overall, we saw air toxics cut in half or more over the last two decades.

Trends in VOCs and aldehydes

Over the past 20 years, the cancer risk from VOCs has decreased substantially. Most VOCs have seen a reduction in every subsequent study. One exception is carbon tetrachloride, which remains a national concern for potential cancer risk. Although this chemical has been banned from most applications for many years, low level

emissions continue to impact the area and country. The chemical is stable in the atmosphere, and there are no known reduction or mitigation methods available.

Acetaldehyde also did not see significant changes. Acetaldehyde is often the product of secondary chemistry, including dependence on temperature and meteorology. We expect the lack of change is due to complex photochemistry equilibria, but we did not pursue further investigation at this time.

The following five figures (Figure 26 through Figure 30) all show the potential cancer risks from VOCs and aldehydes.

Figure 26. Historical trend of VOCs and aldehydes at Seattle Beacon Hill.

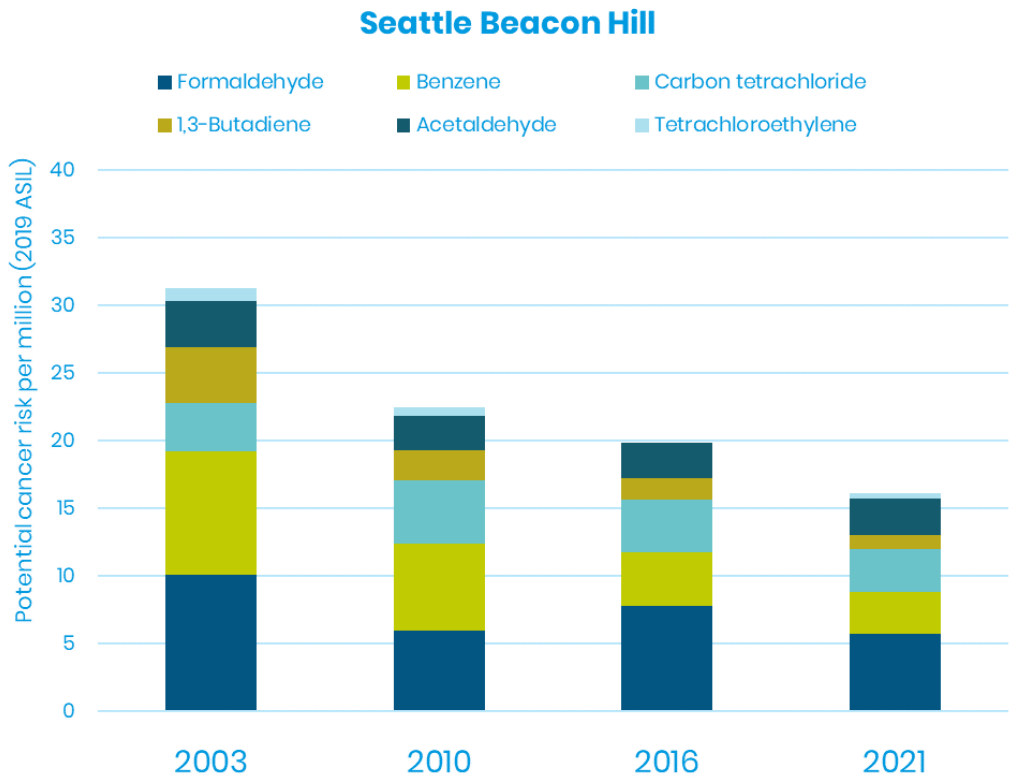


Figure 27. Historical trend of VOCs and aldehydes at Seattle Duwamish Valley.

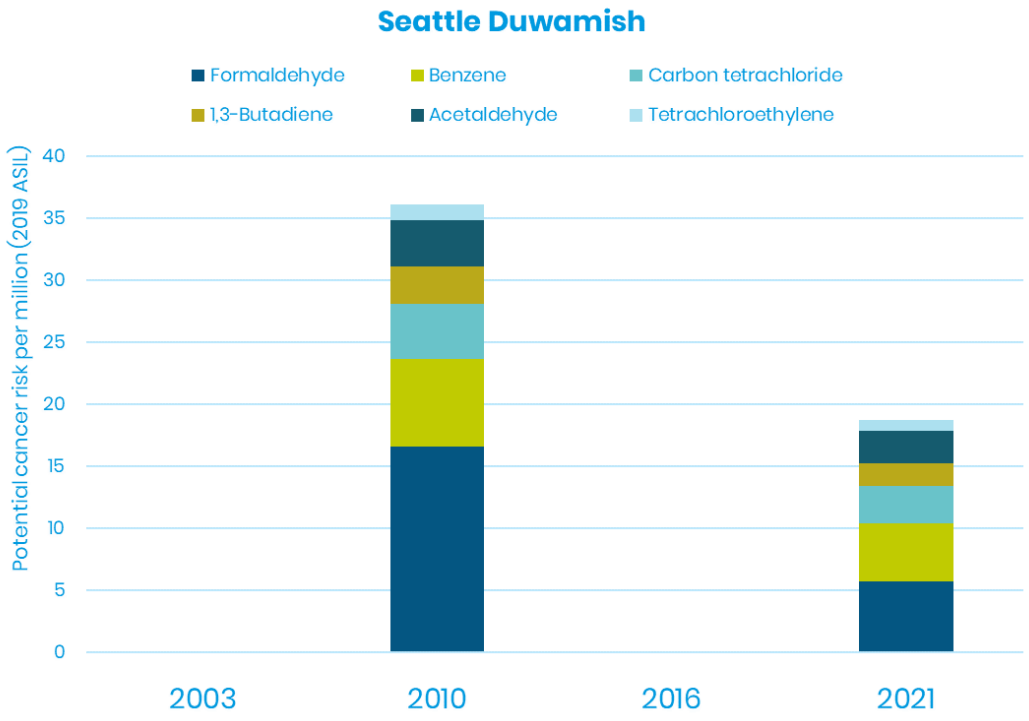


Figure 28. Historical trend of VOCs and aldehydes at Seattle 10th and Weller.

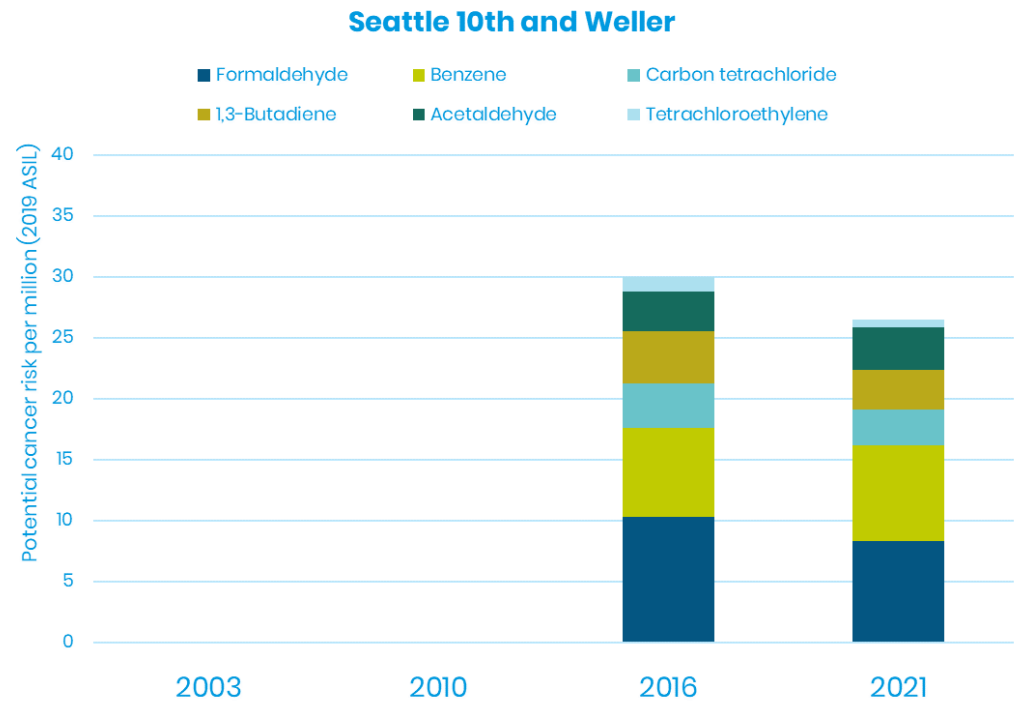


Figure 29. Historical trend of VOCs and aldehydes at Tacoma South L St.

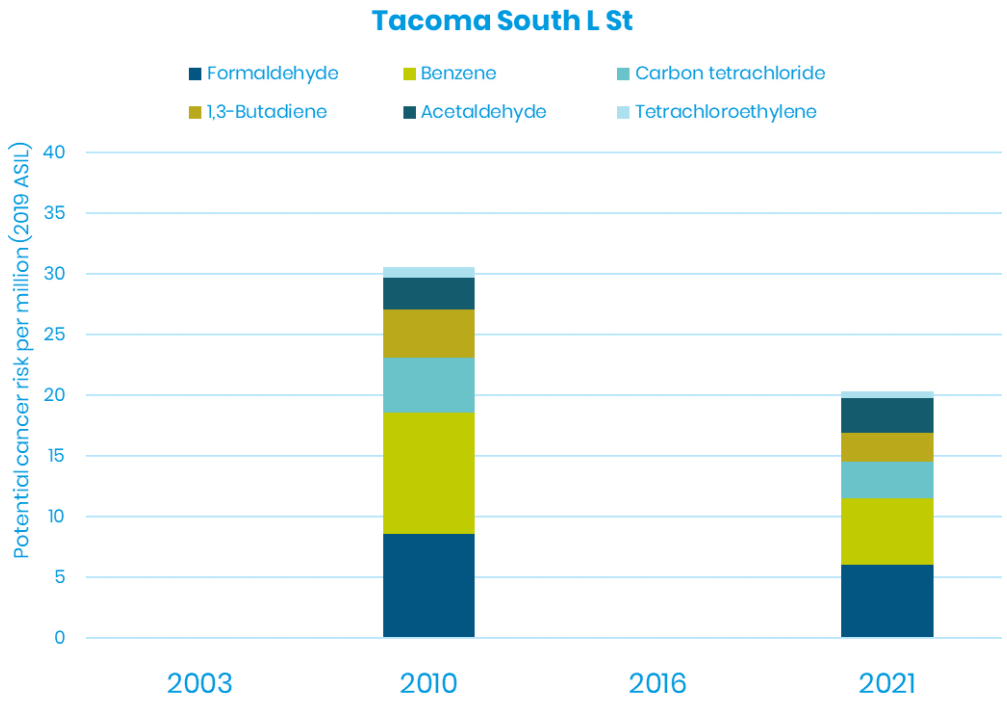
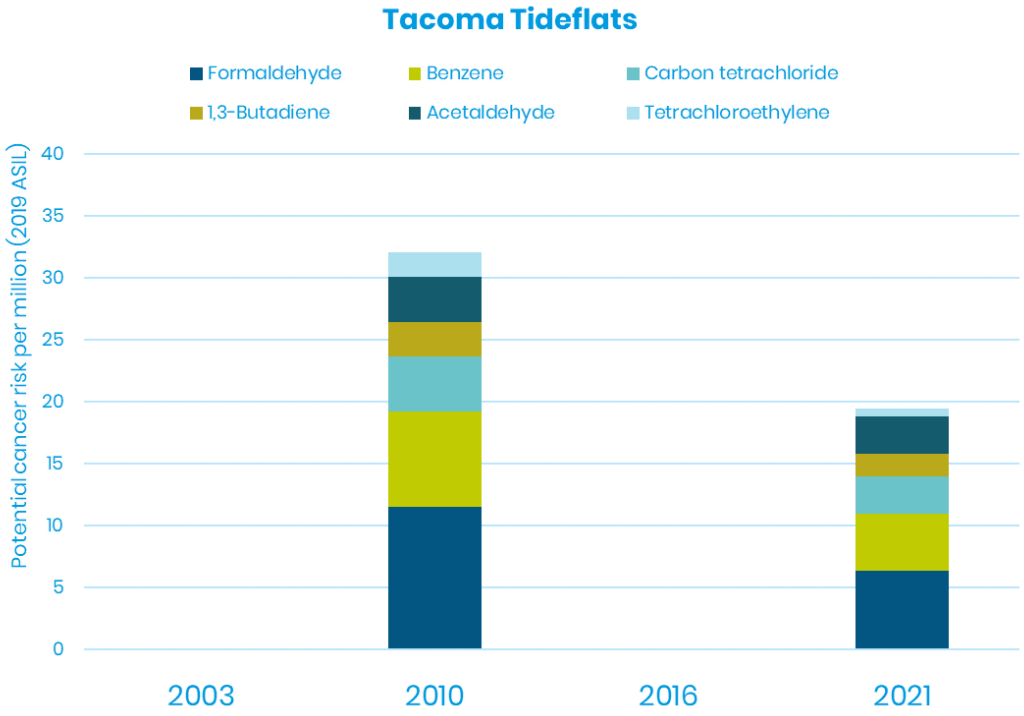


Figure 30. Historical trend of VOCs and aldehydes at Tacoma Tideflats.



Trends in wood smoke

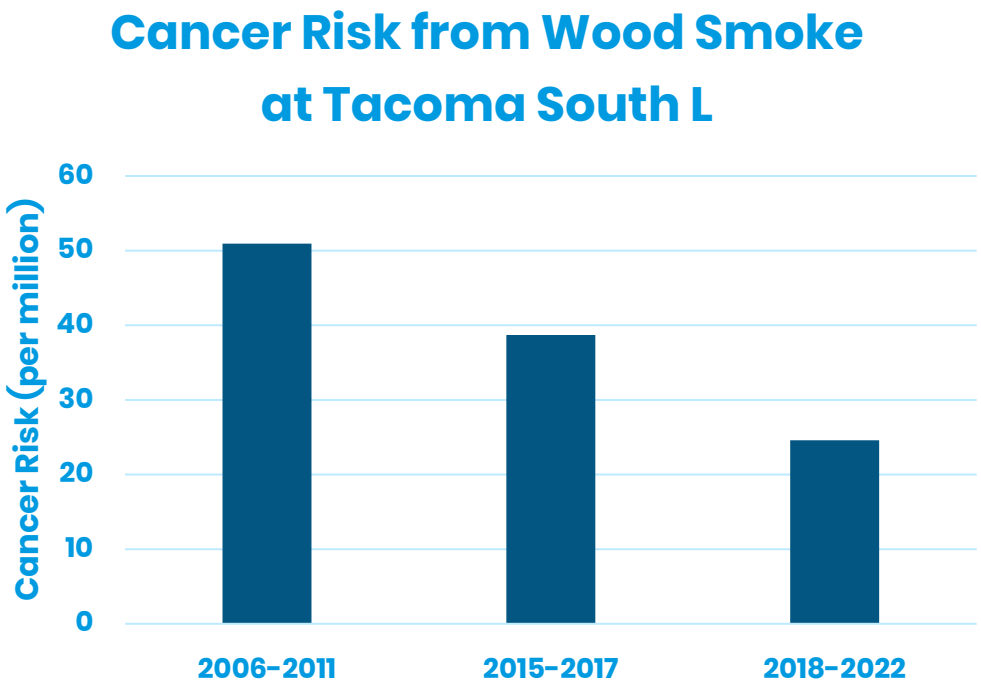
In this section, we describe the change in estimated potential cancer risk from wood smoke at our Tacoma South L site.

Figure 31 below shows our estimated potential cancer risk from wood smoke at the Tacoma South L Street site. The results show nearly half the wood smoke impact when comparing 2006-2011 to 2018-2021. The earliest studies show a cancer risk of 51 per million in the mid to late 2000s, consistent with the high levels of wood smoke at that time. After the Agency took many actions to reduce wood smoke in the area,[61] the potential cancer risk levels were significantly lower at 39 per million. And continued to drop as measured in our study to 25 per million.

Figure 31We estimated wood smoke levels by combining "fresh" and "aged" wood smoke factors from various PMF analyses.[62,63,64] The 2006-2011 category in the figure below represents the average of 3 studies. The 2018-2021 result is from the PMF completed and described later in this report.

[61] WA State Dept of Ecology and Puget Sound Clean Air Agency, "Progress in Reducing Fine Air Pollution in Tacoma-Pierce County", April 2019.
https://apps.ecology.wa.gov/publications/documents/1902009.pdf
[62] *ibid* Kotchenruther 2013
[63] *ibid* Kotchenruther 2020
[64] Ogulei D. (2010). "Sources of Fine Particles in the Wapato Hills-Puyallup River Valley $PM_{2.5}$ Nonattainment Area". WA Ecology, Publication 10-02-009.
https://apps.ecology.wa.gov/publications/documents/1002009.pdf.

Figure 31. Estimated wood smoke potential cancer risk trend at Tacoma South L.



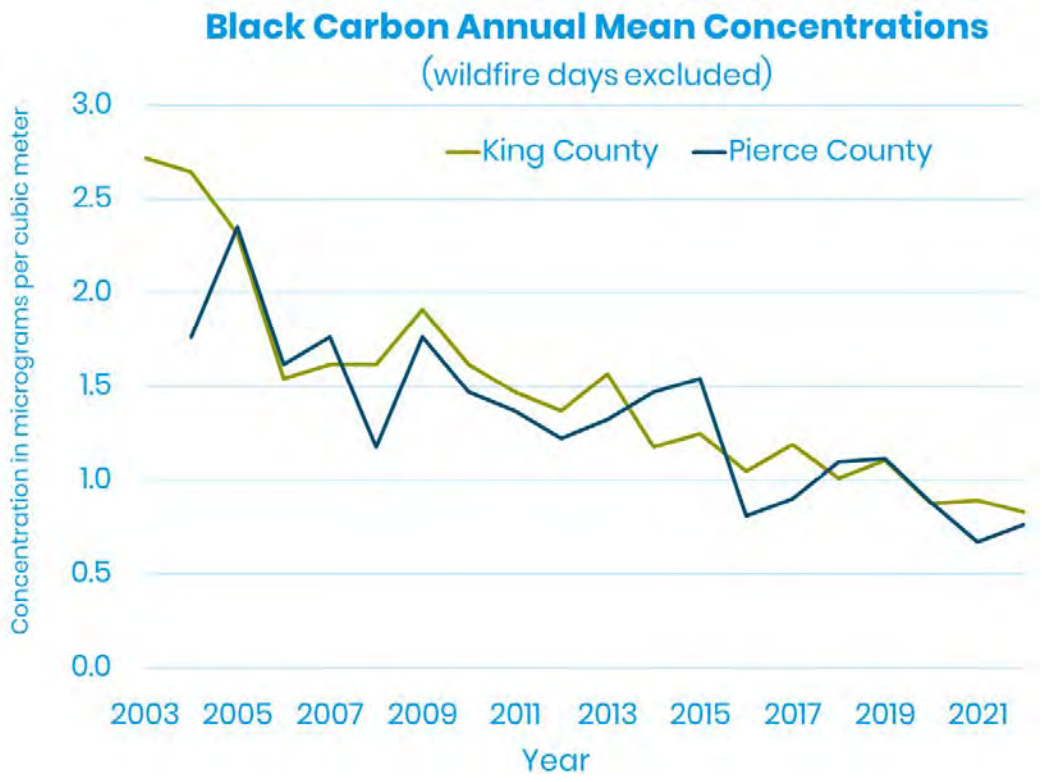
Trends in diesel particulate matter

Because of uncertainty between different PMF factors that represent diesel particulate matter, we did not do a comparison of PMF diesel particulate matter values as was done for the wood smoke section above.

However, we did include black carbon measurements over the last two decades. Black carbon can be a surrogate for diesel particulate matter and can give us more of an apples-to-apples comparison at our study sites.

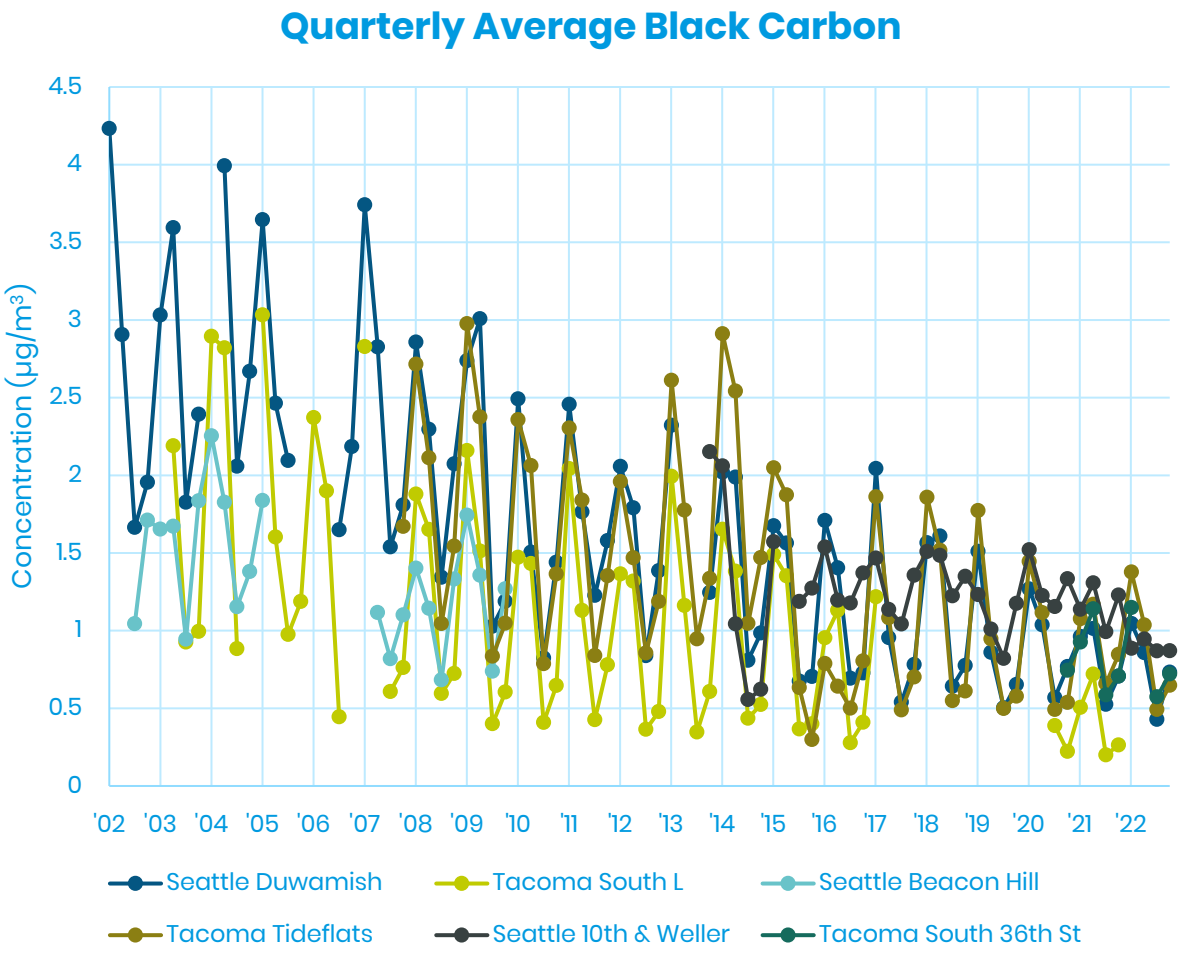
Figure 32 below shows the decreasing trend in black carbon over the past 20 years in King and Pierce Counties. This graph averages all sites within each county and excludes wildfire days. Over the last two decades, black carbon has decreased significantly, from an average of around 2.5 $\mu g/m^3$ to around 0.75 $\mu g/m^3$, a 70% reduction. Both diesel particulate matter and wood smoke contribute to black carbon, with diesel particulate matter year-round and wood smoke only in the winter months.

Figure 32. Annual black carbon trend.



We also included the quarterly trend in black carbon at our study sites since the fourth quarter of 2002 (Figure 33), also with wildfire days excluded. Black carbon has decreased in both the winter and summer, suggesting that both diesel and wood smoke have decreased over time.

Figure 33. Quarterly average black carbon trend.



How trends compare to population and vehicle miles traveled

In this section, we show changes in population growth and vehicle miles traveled.

This graph shows the total population for our four-county region, King, Kitsap, Pierce, and Snohomish Counties, from 2000 to 2022.[65,66,67] Over that period, the population has risen from 3.3 million to 4.3 million people, a 30% increase. Yet, air toxics levels fell by roughly 50% over that time.

Figure 34. Population of King, Kitsap, Pierce, and Snohomish Counties since 2000.

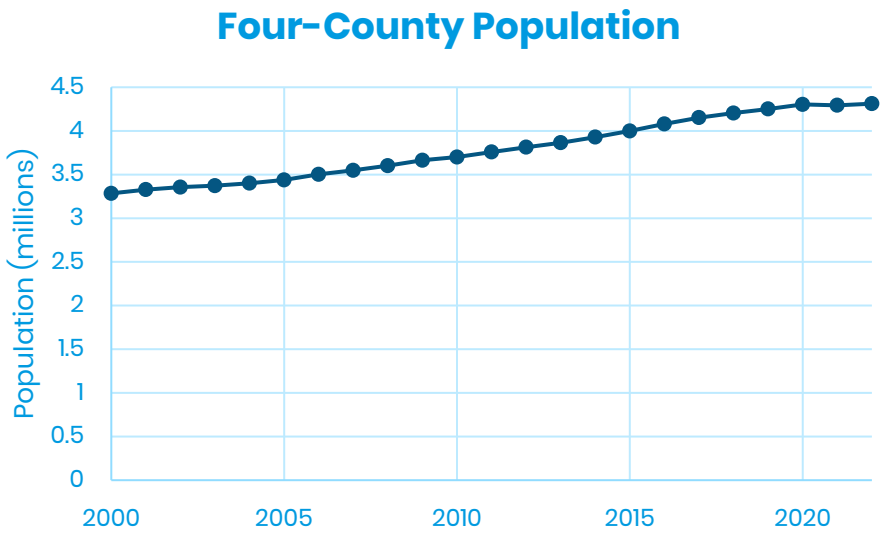


Figure 35 below shows the increase in daily vehicle miles traveled (VMT) in King, Kitsap, Pierce, and Snohomish Counties.[68] There was a 14% increase in daily VMT between 1999 and 2019. The COVID pandemic dramatically decreased daily VMT before starting to rebound in 2021. Even with a nearly flat comparison of VMT for 2022 vs the last two decades, we still saw pronounced reductions in air toxics.

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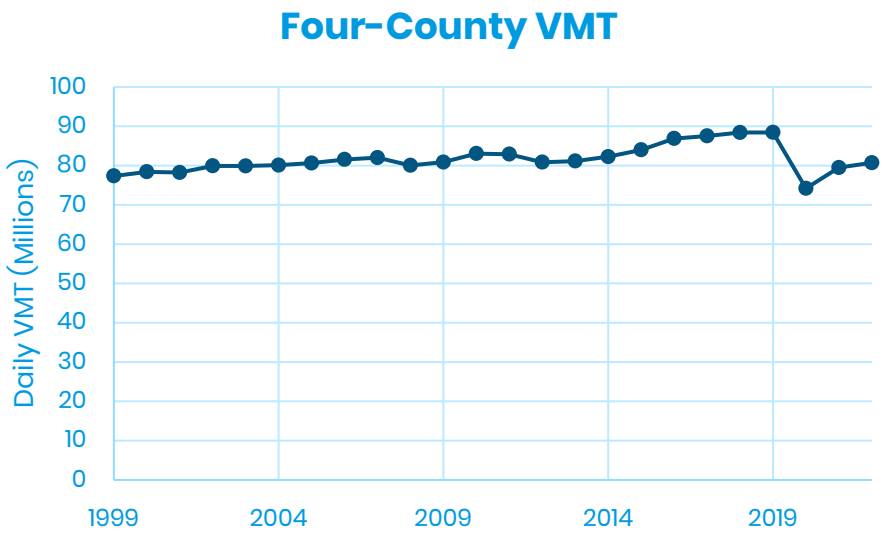
[65] U.S. Census Bureau (2012). County Intercensal Tables: 2000-2010. https://www.census.gov/data/tables/time-series/demo/popest/intercensal-2000-2010-counties.html.

[66] U.S. Census Bureau (2020). County Population Totals: 2010-2019. https://www.census.gov/data/tables/time-series/demo/popest/2010s-counties-total.html.

[67] U.S. Census Bureau (2022). County Population Totals and Components of Change: 2020-2022. https://www.census.gov/data/tables/time-series/demo/popest/2020s-counties-total.html.

[68] Washington State Department of Transportation, Highway Performance Monitoring System, received via email request to WSDOT in November 2023, https://wsdot.wa.gov/about/transportation-data/travel-data/annual-mileage-and-travel-information.

Figure 35. Daily vehicle miles traveled (VMT) for King, Kitsap, Pierce, and Snohomish Counties.



These results indicate that improved technology standards for vehicle engines, non-road equipment, fuels, and other emission reduction programs are the main reason for the significant reduction in air toxics in our region. In our region, we have also seen reductions for $PM_{2.5}$ generally, as can be seen in our latest annual data summary.[69]

AirToxScreen comparison

AirToxScreen (previously called the National Air Toxics Assessment or NATA) is a yearly product created by the EPA to model and display air toxics concentration and risk. It contains information at the census tract level. We can compare the AirToxScreen concentrations and cancer risks to our monitoring results using the census tracts that our monitors are located in. For this analysis, we have included AirToxScreen results from 2017, 2018, and 2019 (the latest publicly available at the time of writing).

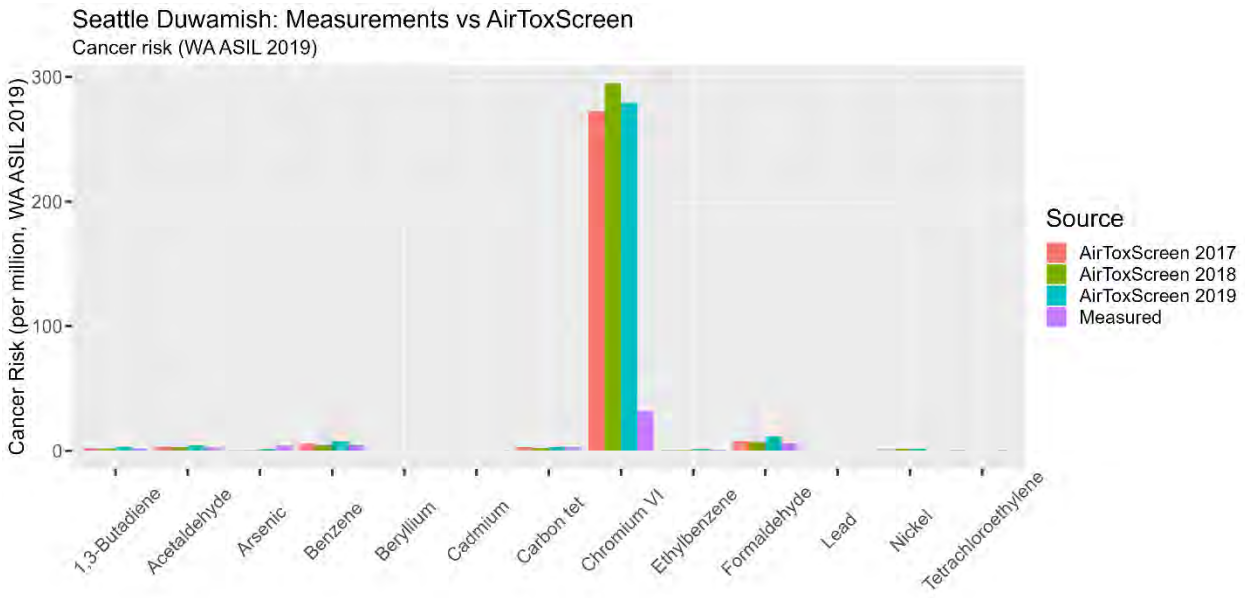
[69] PSCAA, 2021 Air Quality Data Summary, https://pscleanair.gov/DocumentCenter/View/4828/Air-Quality-Data-Summary-2021-PDF?bidId=.

In order to make the cancer risk estimates comparable, AirToxScreen cancer risks have been recalculated from AirToxScreen concentration data using the 2019 WA ASILs that were used for the cancer risk calculations for our data.

Seattle Duwamish Valley comparison

This graph in Figure 36 shows the cancer risk for AirToxScreen predictions and our measurements (in purple). AirToxScreen estimates most of the risk is born by hexavalent chromium. For this site, AirToxScreen predicts almost 10x more hexavalent chromium than what is estimated by our monitoring. This may be because AirToxScreen bases its models off self-reported emission from sources that is input into the National Emissions Inventory (NEI). For example, we know one of the three listed sources has had a significant decrease in production since the latest AirToxScreen. Another possible discrepancy is that we estimated hexavalent chromium levels from prior total chromium-to-hexavalent chromium ratios. Because of these results and to increase our certainty, we are planning on doing a follow-up hexavalent chromium study in the area to refine our estimates to ensure we have a more accurate assessment of the risk in the Duwamish Valley.

Figure 36. Seattle Duwamish AirToxScreen cancer risk comparison.

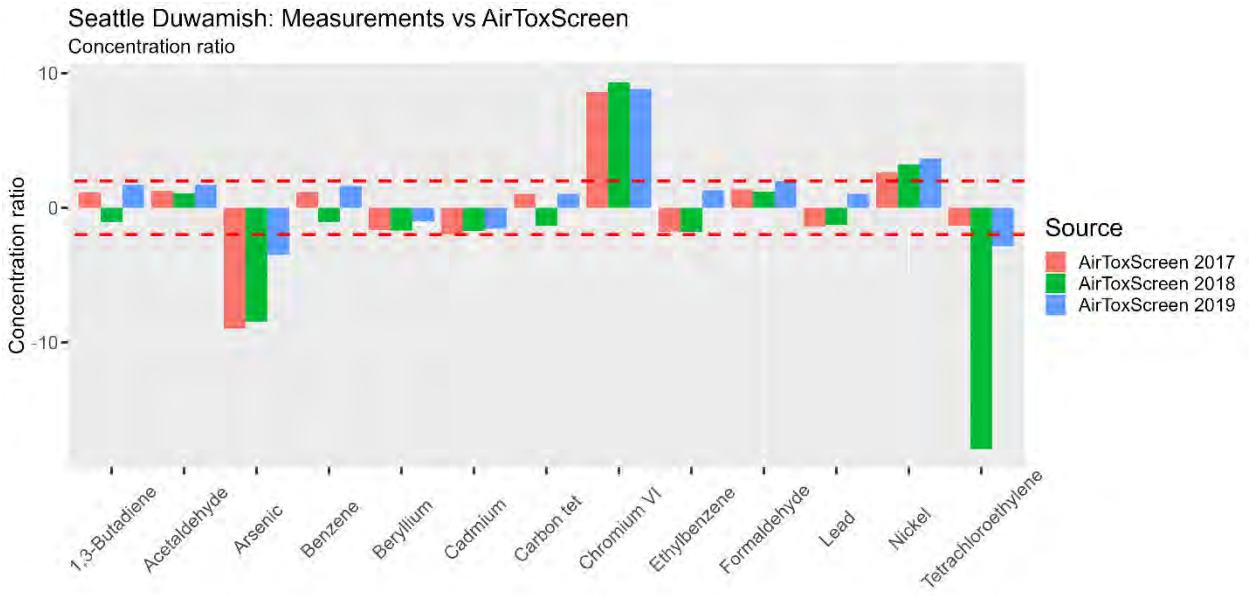


A note regarding the concentration ratio graphs below: If the bars are positive then AirToxScreen is overestimating, and if the bars are negative, then AirToxScreen is underestimating. The dotted red lines indicate when an AirToxScreen concentration

is more than 2x different from the measured value. If the AirToxScreen concentration is greater than or equal to the measured concentration, then the value is AirToxScreen/Measured. If the AirToxScreen concentration is less than the measured concentration, then the value is -1/(AirToxScreen/Measured). This means that a value of 5 can be read as "the pollutant is 5x higher on AirToxScreen" and a value of -5 can be read as "the pollutant is 5x lower on AirToxScreen".

Figure 37 below shows the ratio between AirToxScreen and our measurements for the Duwamish site. The graph shows that AirToxScreen overpredicts hexavalent chromium (as discussed above) and nickel, and underpredicts arsenic and tetrachloroethylene. Because hexavalent chromium carries most of the cancer risk the net result is an overestimate of cancer risk.

Figure 37. Seattle Duwamish AirToxScreen concentration comparison.



Nickel is likely overpredicted for the same reason as hexavalent chromium. That is, the results are dependent on self-reported emissions from sources that gets input into the NEI and may not reflect actual operations.

The largest arsenic source listed in the NEI is the rail yard. Arsenic in resuspended dust and soils would also be unaccounted for in AirToxScreen. At this time, we do not have a direct conclusion why arsenic is underreporting in the NEI.

The NEI does not have any significant sources for tetrachloroethylene listed within King County. Additionally, there are no open drycleaning businesses that use

tetrachloroethylene nearby. However, this underprediction is the case for all our sites. Therefore, it is likely that AirToxScreen's background estimate of tetrachloroethylene is generally too low for our region.

Seattle Beacon Hill comparison

Figure 38 below shows the cancer risk comparison for Beacon Hill. At this location, we estimated the hexavalent chromium value from total chromium results using a 0.8% ratio that we calculated from previous monitoring results there.[70] AirToxScreen also overestimated hexavalent chromium at the Beacon Hill site but improved somewhat with more recent versions of AirToxScreen.

Figure 38. Seattle Beacon Hill AirToxScreen cancer risk comparison.

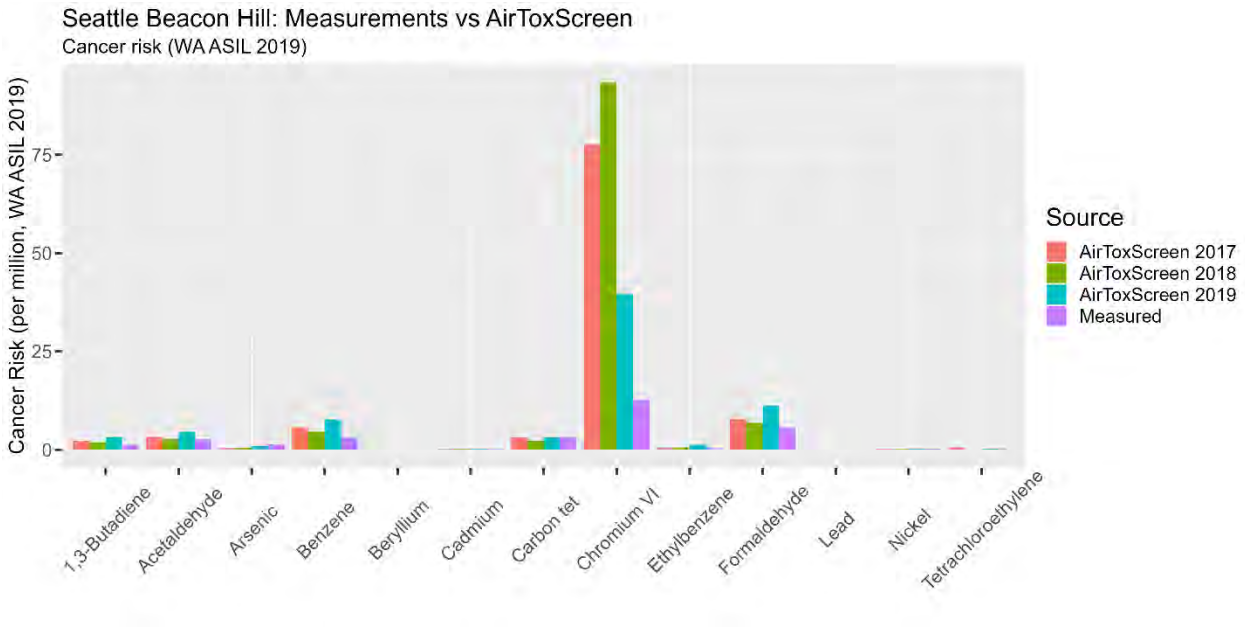
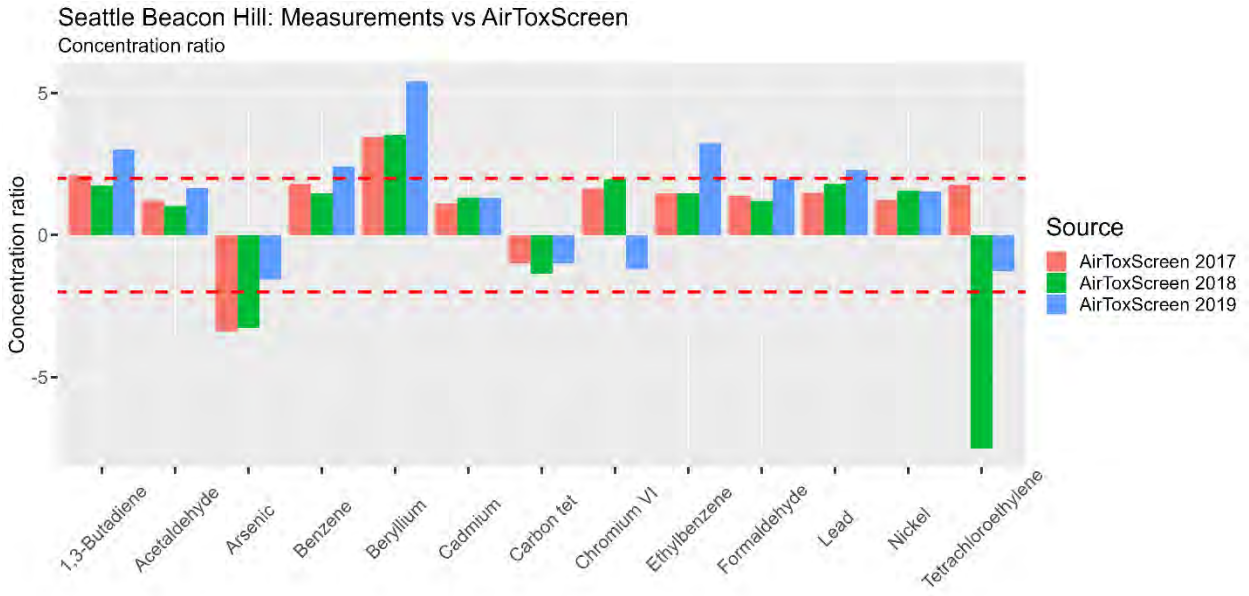


Figure 39 shows the Beacon Hill concentration ratios. The 2017 and 2018 AirToxScreen estimates of arsenic were low, but the latest version is closer. The AirToxScreen beryllium estimates are higher than our measurements. Generally, AirToxScreen is overpredicting for most of the air toxics generally at this location.

[70] Puget Sound Clean Air Agency, Air Quality Data Summary, 2013, http://dl.pscleanair.org/Datasummaries/AQDS2013.pdf.

Figure 39. Seattle Beacon Hill AirToxScreen concentration comparison.



Tacoma Tideflats comparison

Figure 40 and Figure 41 shows the results for the Tacoma Tideflats site. AirToxScreen underestimates arsenic, beryllium, and tetrachloroethylene. Beryllium values and tetrachloroethylene values are generally near the detection limit and will look variable. Arsenic is also underpredicted by AirToxScreen as we found in other sites.

Figure 40. Tacoma Tideflats AirToxScreen cancer risk comparison.

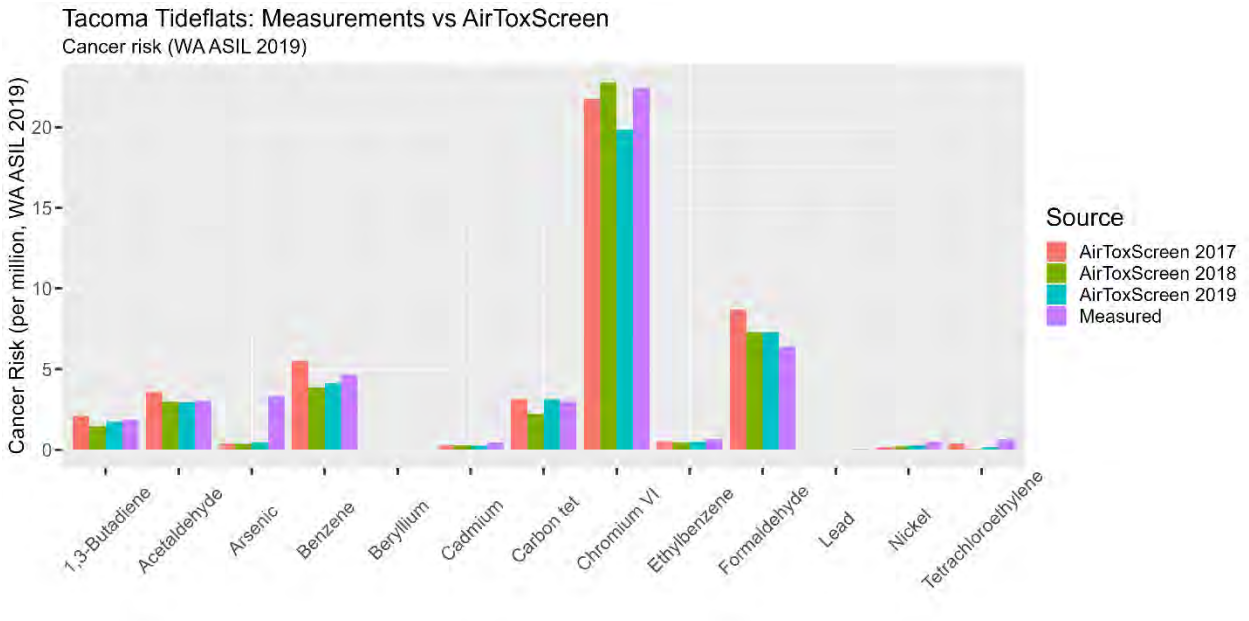
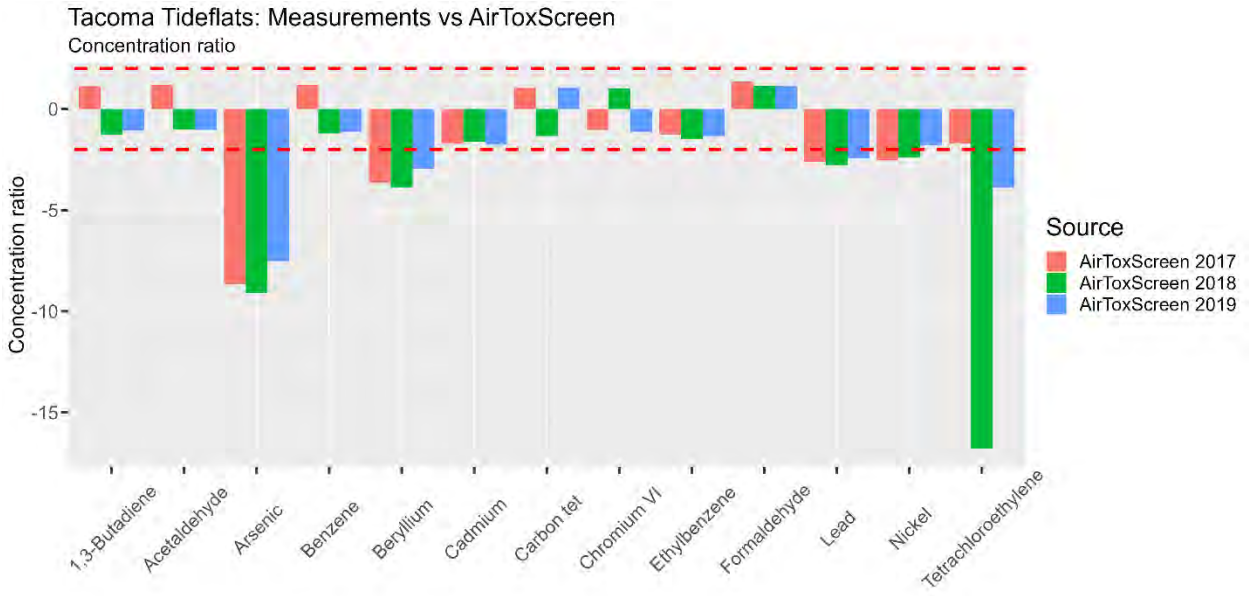


Figure 41. Tacoma Tideflats AirToxScreen concentration comparison.



Seattle 10th and Weller comparison

Figure 42 and Figure 43 show the Seattle 10th and Weller comparisons. AirToxScreen estimates were within two times the measured values and had generally close risk approximations at 10th & Weller. The only exception was tetrachloroethylene (which was discussed earlier).

Figure 42. Seattle 10th & Weller AirToxScreen cancer risk comparison.

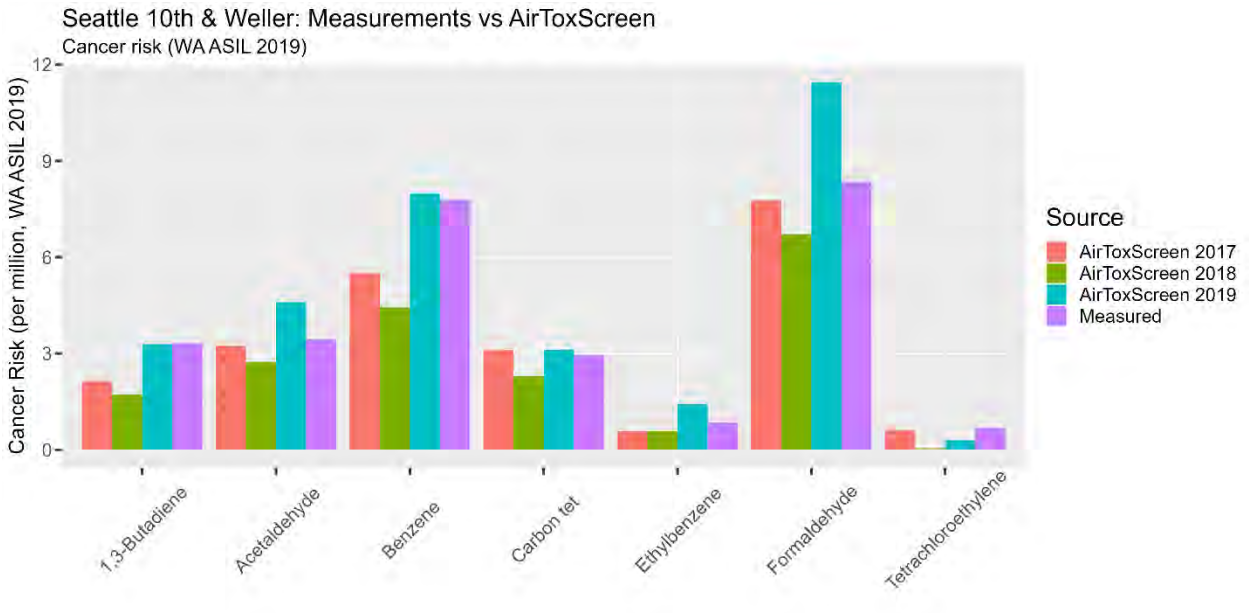
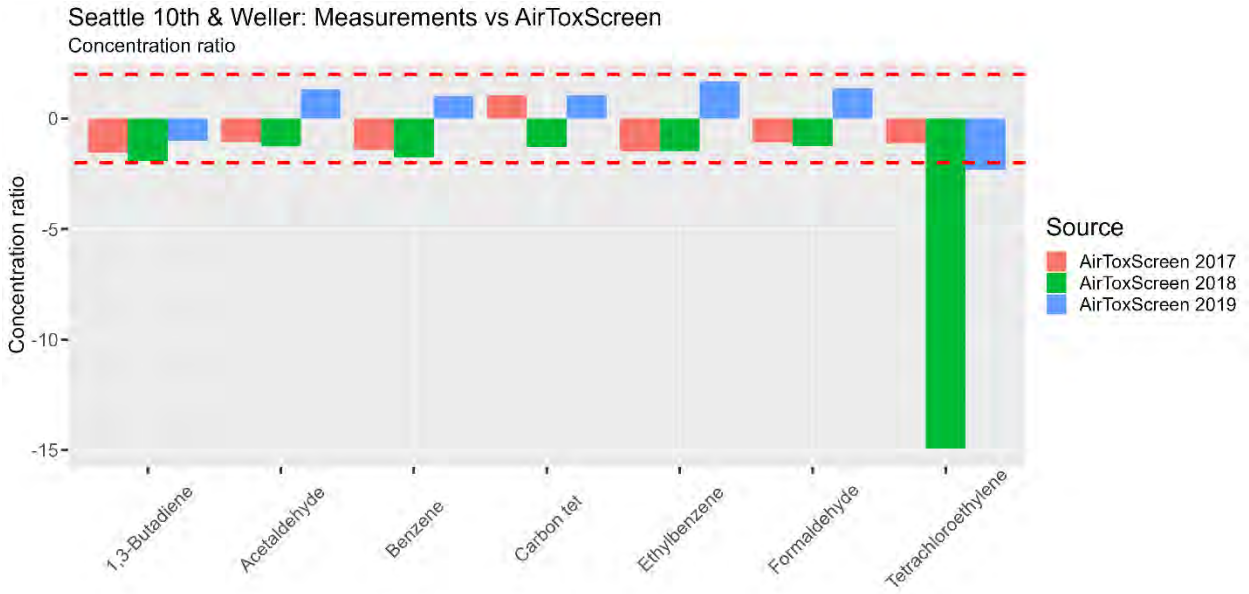


Figure 43. Seattle 10th & Weller AirToxScreen concentration comparison.



Tacoma South L Street comparison

Figure 44 and Figure 45 shows the results for Tacoma South L Street. AirToxScreen was within two times the measured values and resulted in generally close approximations for risk at Tacoma South L St. The only exception is tetrachloroethylene (which was discussed earlier).

Figure 44. Tacoma South L AirToxScreen cancer risk comparison.

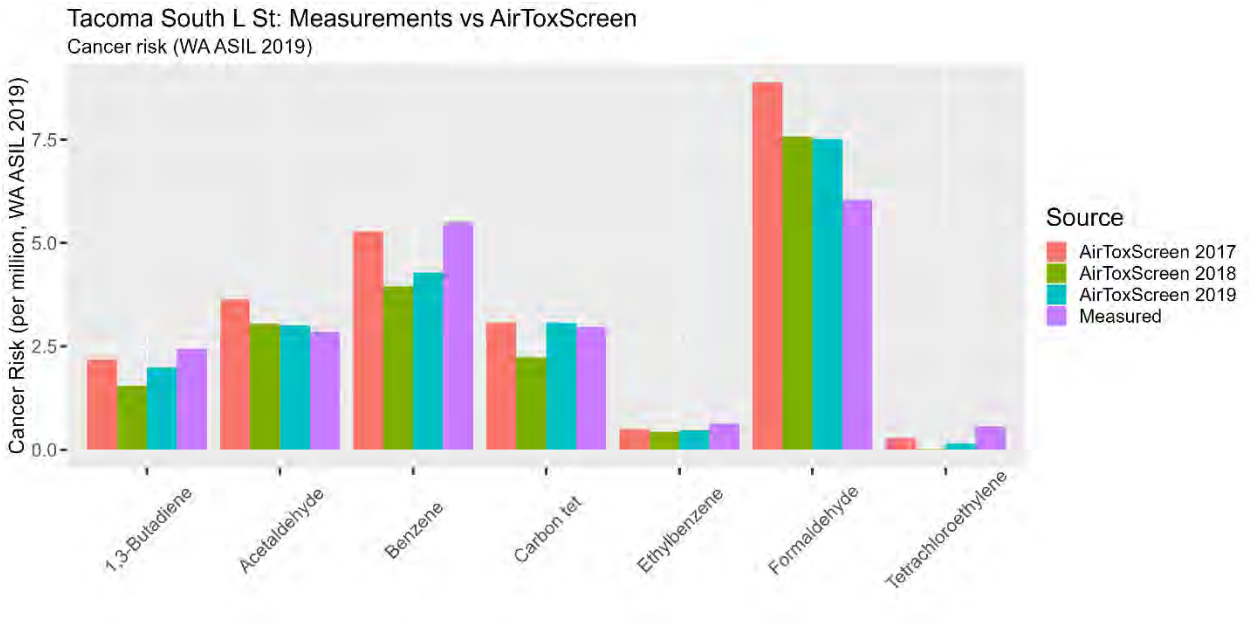
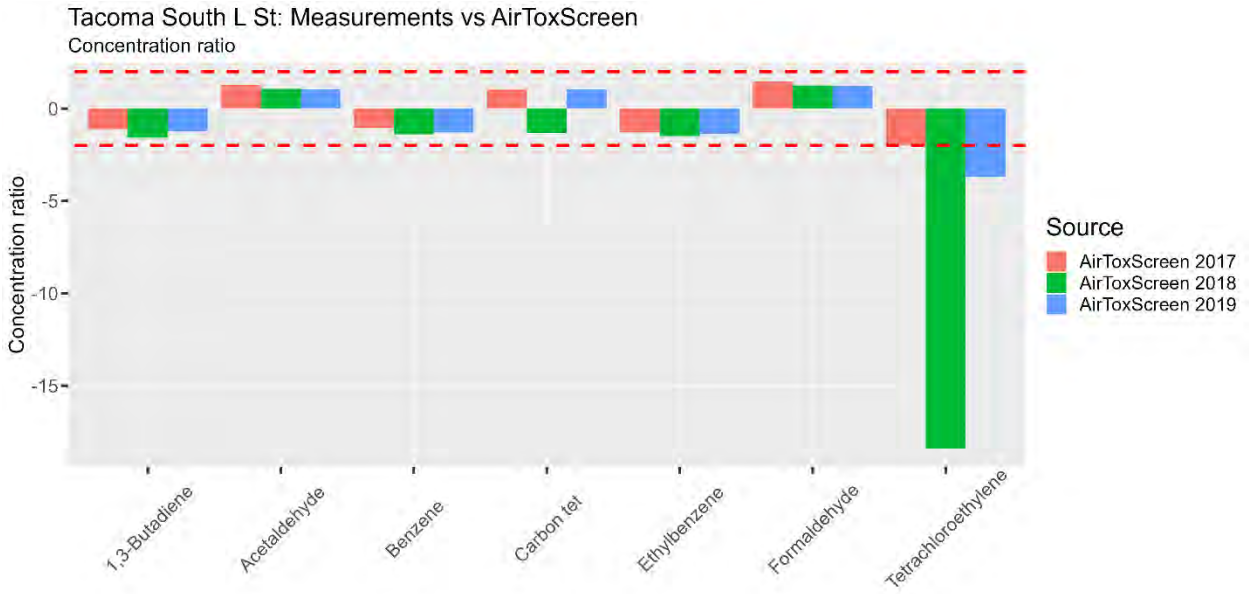


Figure 45. Tacoma South L AirToxScreen concentration comparison.



Tacoma S 36th St comparison

Figure 46 and Figure 47 show the results for the Tacoma S 36th St site. The risks and concentration ratios were generally in range, like the Tacoma South L and Seattle 10th and Weller locations.

Figure 46. Tacoma South 36th AirToxScreen cancer risk comparison.

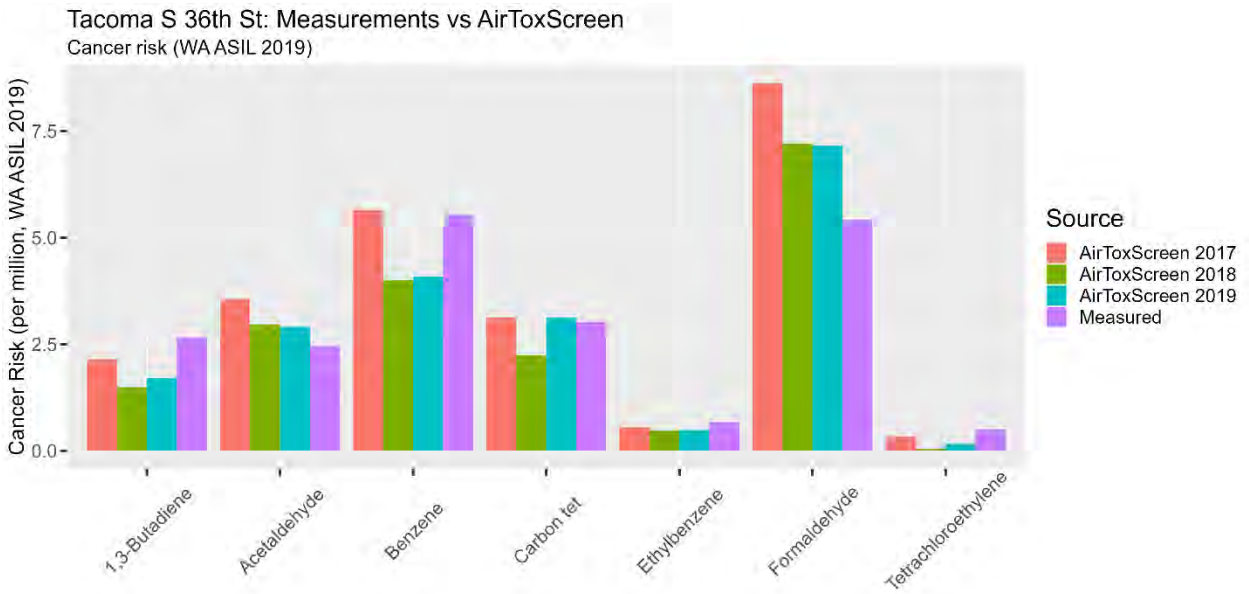
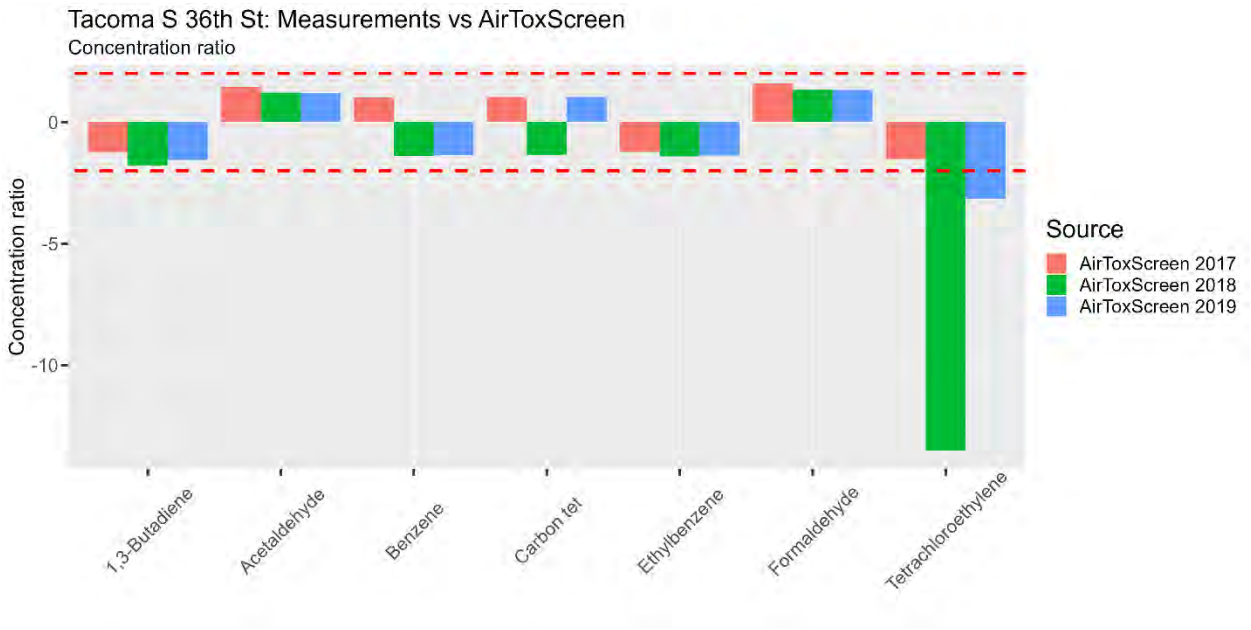


Figure 47. Tacoma South 36th AirToxScreen concentration comparison.



Source apportionment

About source apportionment

We completed source apportionment analyses on five of the study locations to better estimate risk from diesel particulate matter and wood smoke. Positive Matrix Factorization (PMF) is a widely used factor analysis tool used to identify source contributions in complex, mixed airsheds. PMF reduces a complex set of data into factors that have both a fingerprint comprised of differing amounts of each pollutant, and a time series of the factor showing the strength of that factor at any given time. Briefly, this modeling approach assumes 1) that a small number of source categories or factors (typically 5-10) are responsible for the vast majority of the chemical mass measured in a data set, 2) after being emitted, dispersion and mixing are the primary changes that occur and any loss or production is relatively consistent, 3) the contributions from each source add together to form the sum for each chemical, and 4) the source emissions profiles don't change significantly throughout the study period. The PMF algorithm identifies the individual factors (which can be associated with sources to varying degrees of completeness) that could generate the observed data set. The individual factors can be compared to known emission profiles and temporal activity profiles to test for consistency. If an underlying source changes in time, or there are changing losses or secondary

production, a source could be split into two or more factors that have temporal structure. The PMF approach has been widely used and is generally regarded as reliable to the extent that the underlying data are sufficiently extensive, of good quality, and the solutions are found to be robust with respect to sampling uncertainty and rotational ambiguity.[71,72]

Methodology

Source apportionment was done using EPA's PMF 5.0 model.[73] For our analysis, we used daily average (24-hour, midnight to midnight) values from $PM_{2.5}$ Chemical Speciation Network (CSN) data. PMF analysis was done separately for Seattle sites (10^{th} and Weller, Beacon Hill, and Duwamish) and Tacoma sites (South L and Tideflats). CSN samples are collected every 6 days at all sites except Beacon Hill, where samples are collected every 3 days. At Duwamish and 10^{th} and Weller, 24-hour average brown carbon (BrC) was added to the analysis. BrC is calculated as the black carbon (BC) minus the UV (ultraviolet absorption) channel measured by AE-33 aethalometers. Dataset descriptions for each site are in Table 10. Site dataset descriptions for PMF analysis.. The missing samples are all from March 2022 – August 2022 during Covid pandemic shutdowns.

Table 10. Site dataset descriptions for PMF analysis.

Site	Start date	End Date	# samples	Missing samples
Seattle Duwamish	8/12/2018	6/28/2022	237	29
Seattle 10th and Weller	8/12/2018	7/28/2022	242	30
Seattle Beacon Hill	8/12/2018	9/29/2022	506	60
Tacoma South L	8/12/2018	9/26/2022	252	29
Tacoma Tideflats	8/12/2018	2/10/2022	214	28

[71] Paatero P., Hopke P.K. Discarding or downweighting high-noise variables in factor analytic models. 2003. Anal. Chim. Acta 490: 277-289.
[72] Norris G., Duvall R., Brown S., Bai S. EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide. 2014. U.S. Environmental Protection Agency. EPA/600/R-14/108.
[73] EPA, Positive Matrix Factorization Model for Environmental Data Analyses, https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses.

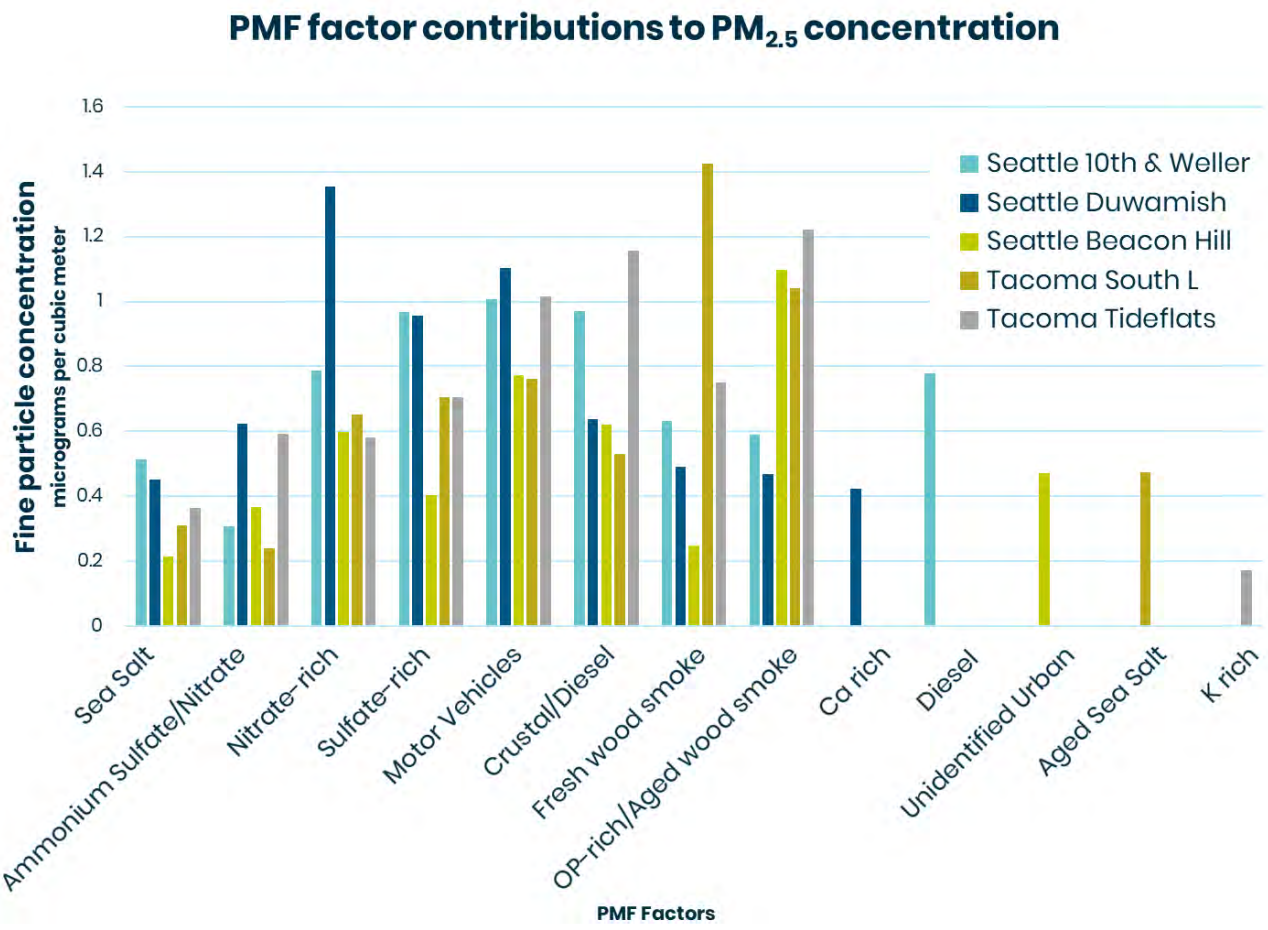
The CSN data was corrected for field blank concentration by subtracting the mean field blank concentration from the sample concentration. The PMF model requires an uncertainty for each sample. Sample values were not changed if they were below the method detection limit (MDL), but their uncertainty was calculated differently. For samples above the MDL, uncertainty was calculated as analytical uncertainty plus 1/3rd of the MDL. For samples below the MDL, uncertainty was calculated as 5/6th of the MDL. Missing and negative values were replaced with the species' median concentration, and the associated sample uncertainty was set to four times the species' median concentration. For species without an analytical uncertainty or MDL, the uncertainty was calculated as the measured value divided by 10. Species were not included in the dataset in the percentage of samples below the method detection limit (MDL) was greater than 75%. Unfortunately for our analysis, but fortunately for the health of the population, a majority of the metals have greater than 75% of samples below the MDL. The species not included in any analysis include nickel and vanadium, which are markers for residual fuel oil combustion and marine diesel. Certain chemical species measured are very similar (ex. sodium and sodium ion, chloride and chlorine, potassium and potassium ion), so in order not to double count the species, we selected those with the lower signal to noise ratio was discarded from the analysis. To avoid double counting sulfate/sulfur non-sulfate sulfur (NSS = SO4 - S) was calculated by subtracting the sulfur component of the measured sulfate concentration from the measured sulfur concentration and having NSS replace sulfur in the analysis. Similarly, EC1 was recalculated to remove the OP portion in EC1 (EC1=EC1-OP). Samples with high concentrations from fireworks and wildfires were excluded from the dataset. Species with a signal-to-noise ratio less than 0.5 were excluded from the dataset. Species with a signal-to-noise ratio between 0.5 and 1 were marked "weak" in the PMF analysis.

Results

Figure 48 below shows the factor specific $PM_{2.5}$ mass for each site. All sites shared eight common factors we identified and labeled as: Sea Salt, Ammonium Sulfate/Nitrate, Nitrate-rich, Sulfate-rich (potentially a maritime related factor), Crustal/Diesel (road dust and diesel particulate matter combined), Motor Vehicles – Gasoline, Fresh Wood Smoke, and OP-rich/Aged Wood Smoke. Each site also had its own unique factor. Seattle 10th & Weller had a separate diesel factor. Seattle Duwamish had a calcium (Ca)-rich factor, potentially associated with nearby cement plants. Seattle Beacon Hill had an Unidentified Urban factor with no obvious

source, but most closely related to secondary organic aerosols from fuel combustion. Tacoma South L had an Aged Sea Salt factor. Tacoma Tideflats had a potassium (K)-rich factor associated with fireworks. A full discussion of each factor and factor pie charts for each site can be found in Appendix K.

Figure 48. PMF contribution to $PM_{2.5}$ mass concentration.

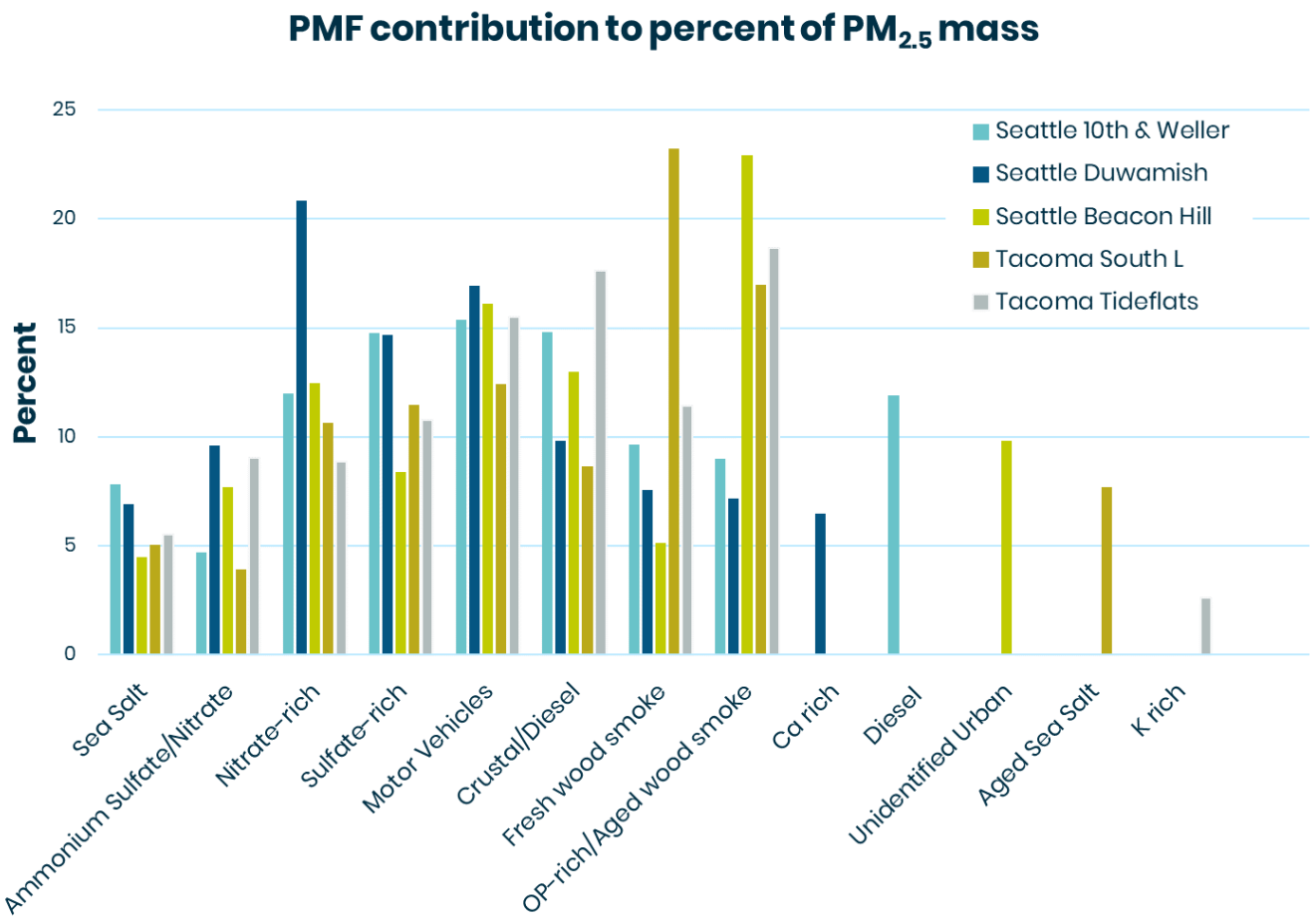


Generally, 10th & Weller, a near-road site, saw higher contributions from diesel, with both the Crustal/Diesel and Diesel factors. Tacoma South L, a residential wood smoke impacted site, saw higher contributions from fresh wood smoke and equal contributions from aged wood smoke. The crustal/diesel factor was also high at Tacoma Tideflats, possibly because there was a high amount of construction going on during the sampling period, which involved large trucks driving on dirt roads, contributing to the combined mix of diesel particulate matter and dust. Seattle Duwamish had a large contribution from the Nitrate-rich factor. This factor was higher in the winter for all sites, which potentially is secondary nitrate. Along with the presence of carbon species, this points to the presence of wood smoke. Seattle

Duwamish had the lowest contribution from aged wood smoke, so this may have balanced out by being factored into the larger contribution from the nitrate-rich factor.

Figure 49 shows the factor specific percentage contribution by site. This graph shows generally similar percent contributions by category. It also illustrates the observations outlined above more clearly as the total mass concentration of $PM_{2.5}$ differed by site.

Figure 49. PMF contribution to percent of $PM_{2.5}$.



Community-directed monitoring and community concerns

Community engagement summary

In addition to fixed sites detailed above, our EPA grant application included a component for community-directed sampling in the Duwamish Valley. We listened

to community concerns and found there was significant interest in knowing more about heavy metals levels in the Duwamish Valley following an earlier metals-in-moss study.

Before deploying the air toxics samplers, we worked with the Duwamish River Community Coalition (DRCC) over several weeks to find the best ways to talk to community members about air quality and collect input on the best locations to place air monitoring equipment.

On Tuesday August 17th, 2021, we hosted a community workshop in collaboration with DRCC in the South Park neighborhood of Seattle. We introduced information on air toxics, sources of air pollution in the area, and the health impacts of air pollution. We provided all participants with food and a box fan filter kit, and had interpretation available for Khmer, Spanish, Somali, and Vietnamese speakers.

We also invited high school students for the Duwamish Valley Youth Corps (DVYC) to share the results of their metals-in-moss sampling campaign. In 2019 and 2021, twenty-six students partnered with scientists from the US Forest Service (USFS) to sample moss from 80 locations in the Duwamish Valley and surrounding areas. The samples were analyzed for 25 heavy metals in a USFS laboratory.

Finally, we asked for participants input through four activities. The first had them explore a large map of the area and identify exact locations for monitoring air toxics. Second, we asked them to rank what additional areas were also a priority for them. Third, we taught them how to assemble and use a box fan filter and then gave them their own kit to take home. The fourth activity was a visioning exercise where participants added their thoughts and ideas with sticky notes.

Online community feedback

We invited community members to share their input and identify locations that should be prioritized for study. We gathered feedback online from August 6 - September 22, 2021, in English, Spanish, Somali, Vietnamese, and Khmer.

Community members could also provide feedback via internet connected tablets at Duwamish Riverfest—an in-person event. We also shared our request for feedback with multiple organizations, including Villa Comunitaria, Environmental Coalition of South Seattle (ECOSS), South Park Neighborhood Association, Georgetown Community Council, and DRCC.

Community feedback results

The community feedback results indicated community members were primarily interested in monitoring in residential areas, particularly in the South Park and Georgetown neighborhoods. Areas of interest also included locations with the highest values as identified by the moss study, industrial areas of South Park, and near the King County International Airport. Figure 50 below summarizes the results on a map. The map shows areas of increasing interest by size of circle. Green stars are where we placed monitors to correspond with the areas of interest. Figure 51 below also shows the types of areas of most interest. The areas with the highest values from the moss sampling study is "C" in the map.

Figure 50. Spatial community input results and eventual temporary monitoring locations.

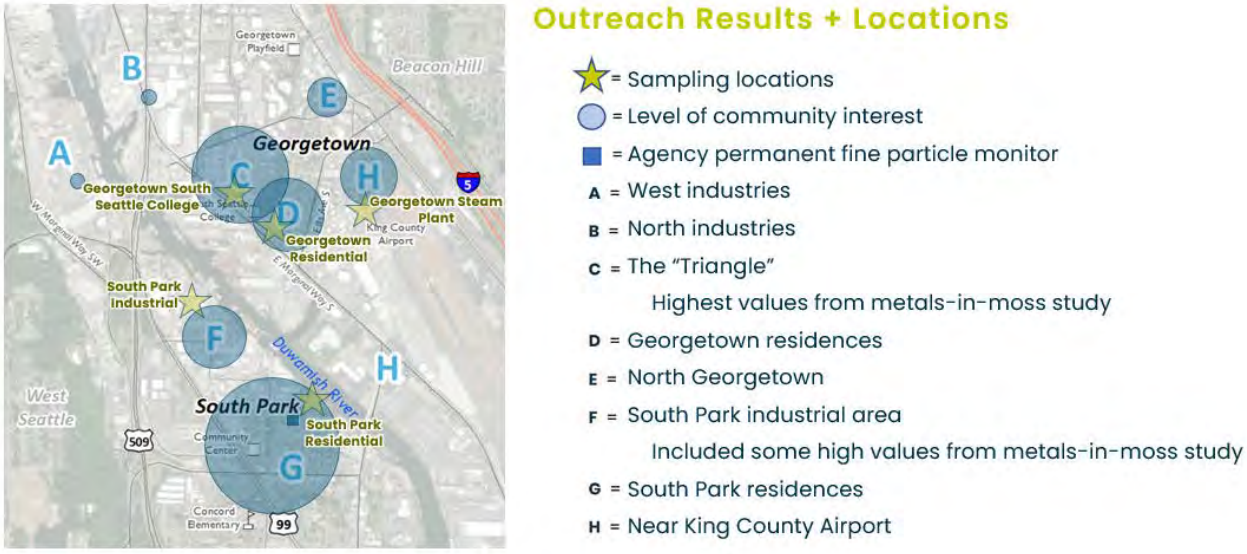
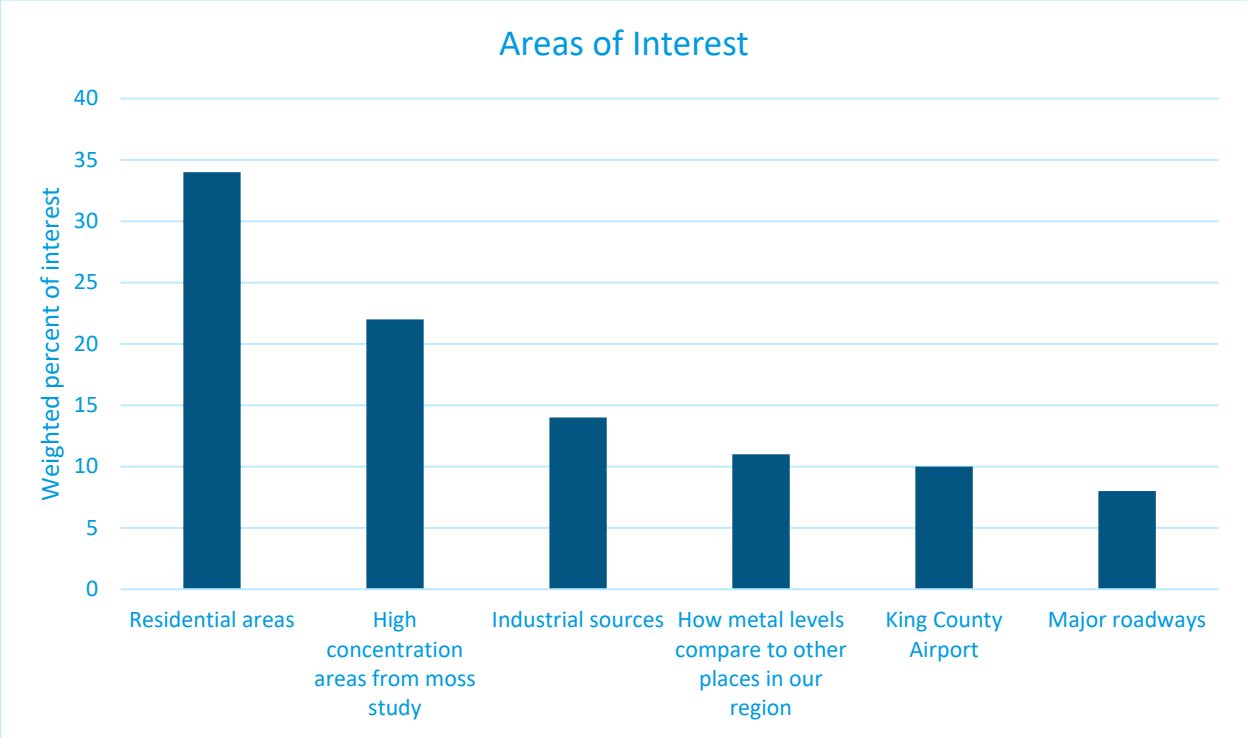


Figure 51. Community feedback on sampling locations.



$PM_{2.5}$ sensor measurements at community sites

Based on community feedback, we deployed small $PM_{2.5}$ sensors at five locations where the greatest interest was indicated. Two types of sensors were deployed, N-FRM and Purple Air (PA) – see Appendix G for details on data quality control and adjustments of these air sensors. The sampling dates are shown in Figure 52. The period from July 1 – Sept 1 when the $PM_{2.5}$ sensors were operating at all the community directed sites is called the 'intensive' period in this section.

Figure 52. The dates of sampling for $PM_{2.5}$ at locations based on community interest.

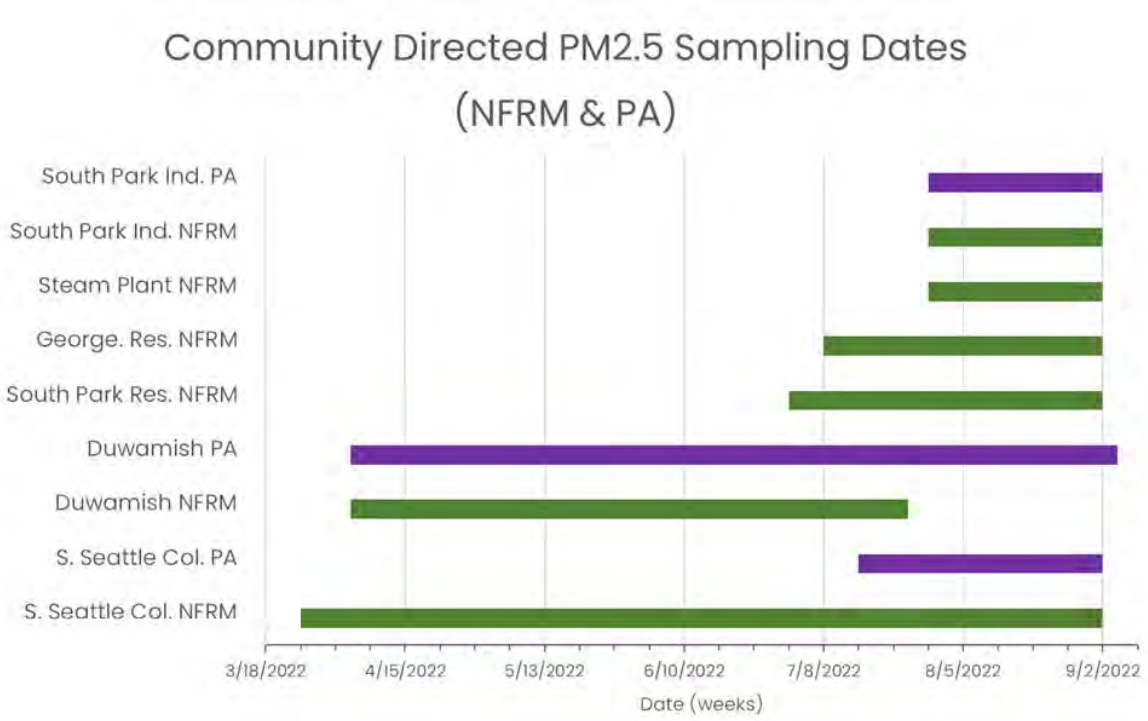
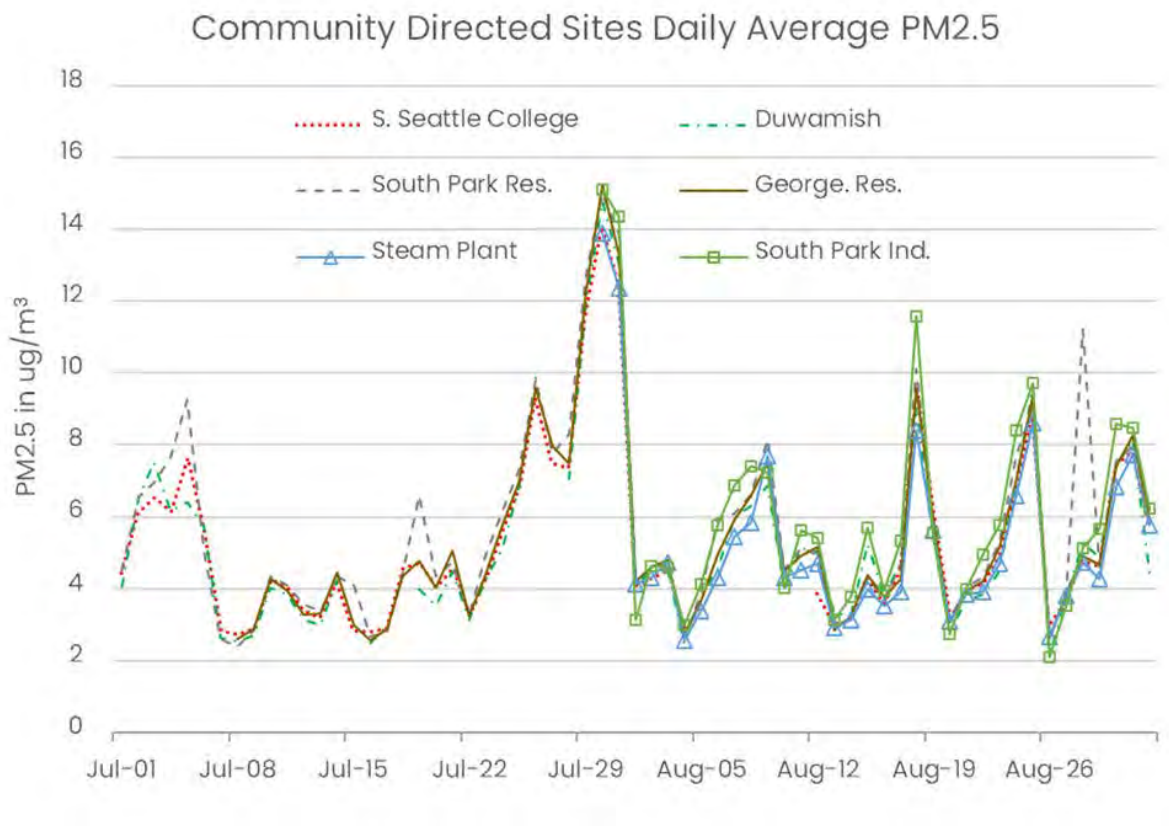
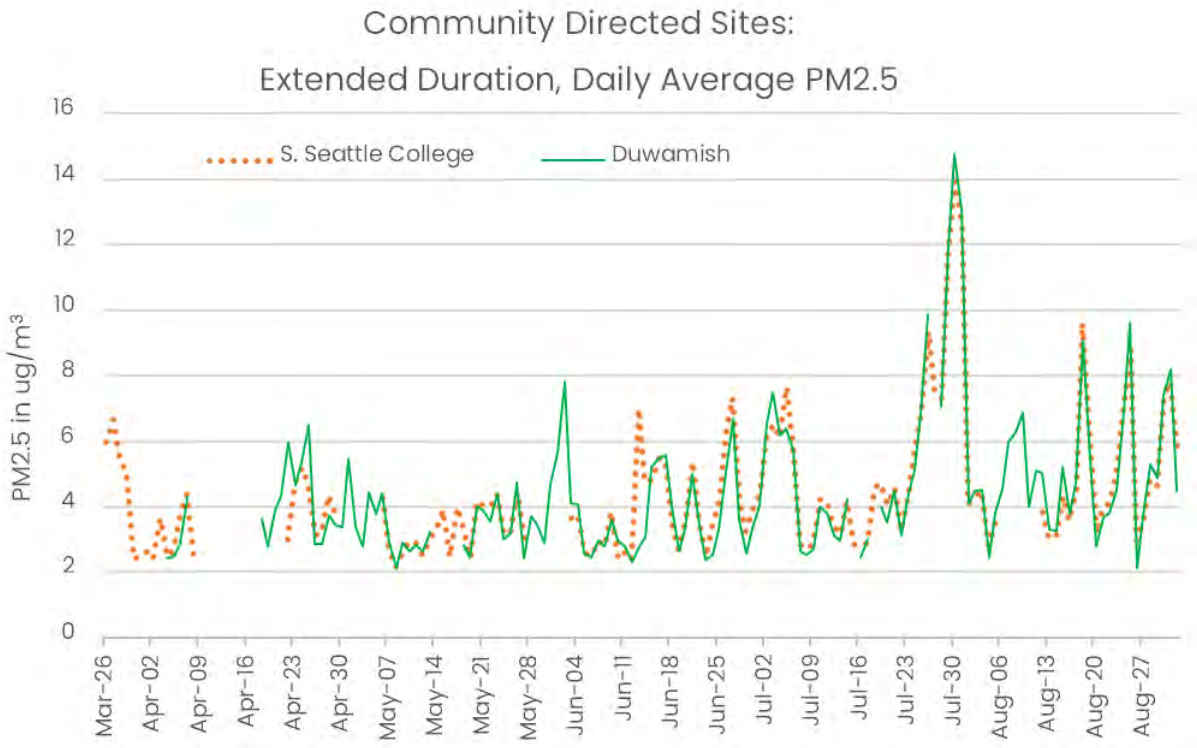


Figure 53. A timeseries of the $PM_{2.5}$ measurements at the community directed sites (all in 2022), shown as daily averages.



A time series of the $PM_{2.5}$ measurements at the community directed sites during the intensive sampling period, is shown in Figure 53. On most days, the values from all the sites are very similar and are difficult to visually distinguish in the figure, with the exception of South Park Residential, which on three days spiked above all of the other sites.

Figure 54. Community-directed $PM_{2.5}$ sites over an extended duration.



An extended timeseries of the small sensor $PM_{2.5}$ measurements is shown in Figure 54. Only the South Seattle College site was available for the extended duration, and a small sensor was also installed at the existing Duwamish site to provide some comparison data. This range also includes the intensive period shown in Figure 53 and used for Figure 55.

During the intensive sampling period (July 1 – Sept 1), the hourly average $PM_{2.5}$ concentrations were well correlated. All sites except for South Park Residential had very strong correlations (Pearson's R) > 0.96, while South Park Residential was still strong, > 0.91, with all of the other sites.

Figure 55. Distribution of daily average $PM_{2.5}$ concentrations for July 1 - Sept 1, 2022

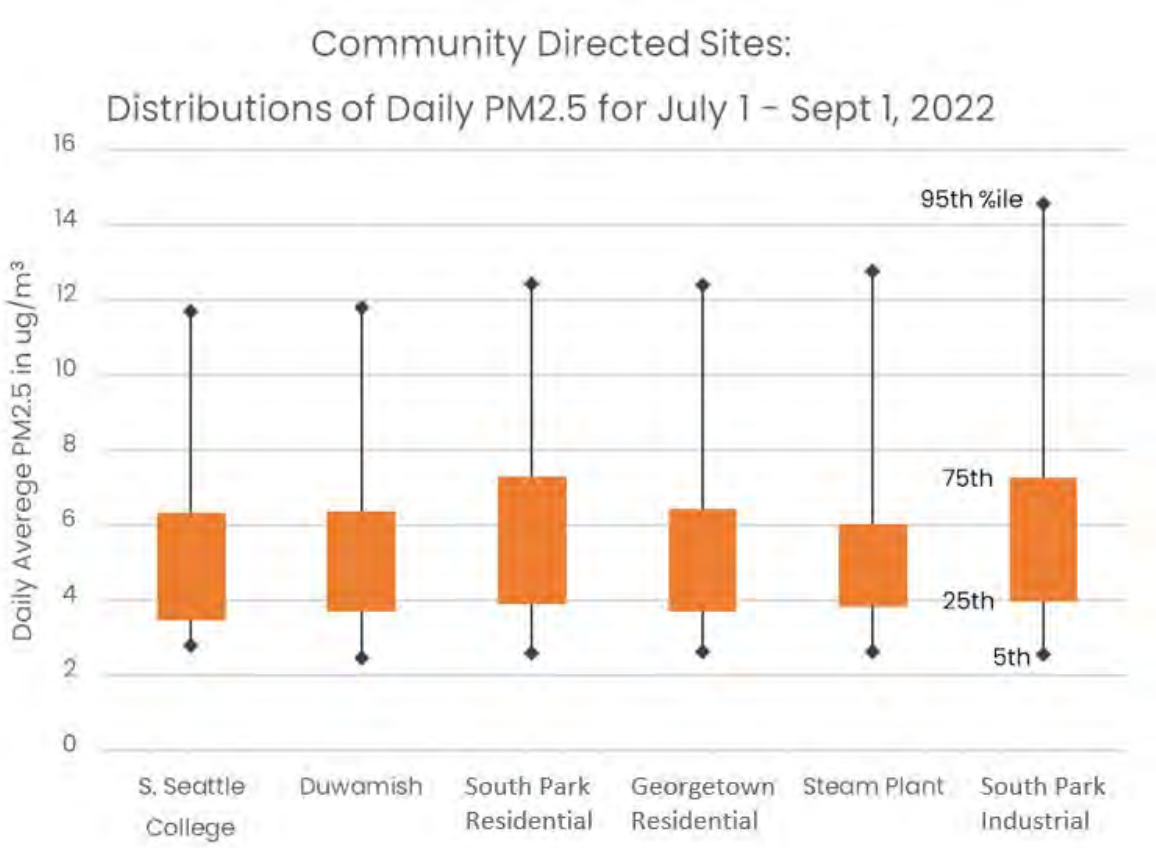
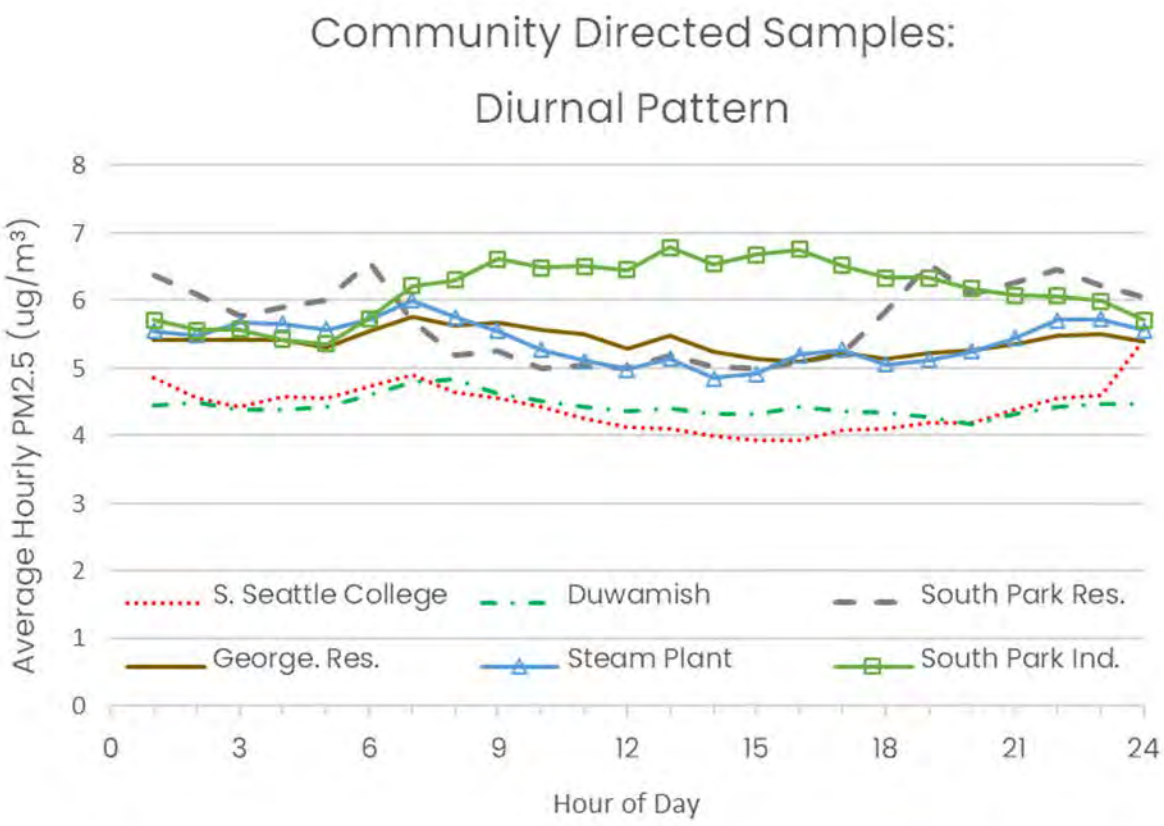


Figure 55 shows the distribution of $PM_{2.5}$ concentration data from only within the intensive period of July 1 – September 1, 2022. In this figure, the box represents the range of half of the data, going from the 25th percentile to the 75th percentile (aka the interquartile range). The extremes are represented by the lines above and below the box which extend to the 5th and 95th percentile. The South Park Residential and Industrial sites had similar, but slightly higher 75th percentile values, while the South Park Industrial site had a 95th percentile value above the other sites.

Figure 56. Diurnal (hour of the day, midnight to midnight) average for the community directed PM2.5 measurements.



The diurnal pattern (hour of the day average) for the community directed $PM_{2.5}$ samples during the intensive period is shown in Figure 56. Several noteworthy items in this figure include: South Park Residential appears to have a diurnal pattern with a spike in the early morning, and an elevation in the evening. Also, South Park Industrial rises in the early morning and then slowly declines in the late afternoon and evening. And, South Seattle College has a significant spike in the 11 pm-midnight hour, due to a single event on June 13 in which the hourly values exceed 100 $\mu g/m^3$. Lastly, South Seattle College and Duwamish are both offset (lower) from the other sites. This amount of offset is within the normal uncertainty in accuracy (bias) for these instruments.

Community-directed small sensor $PM_{2.5}$ discussion

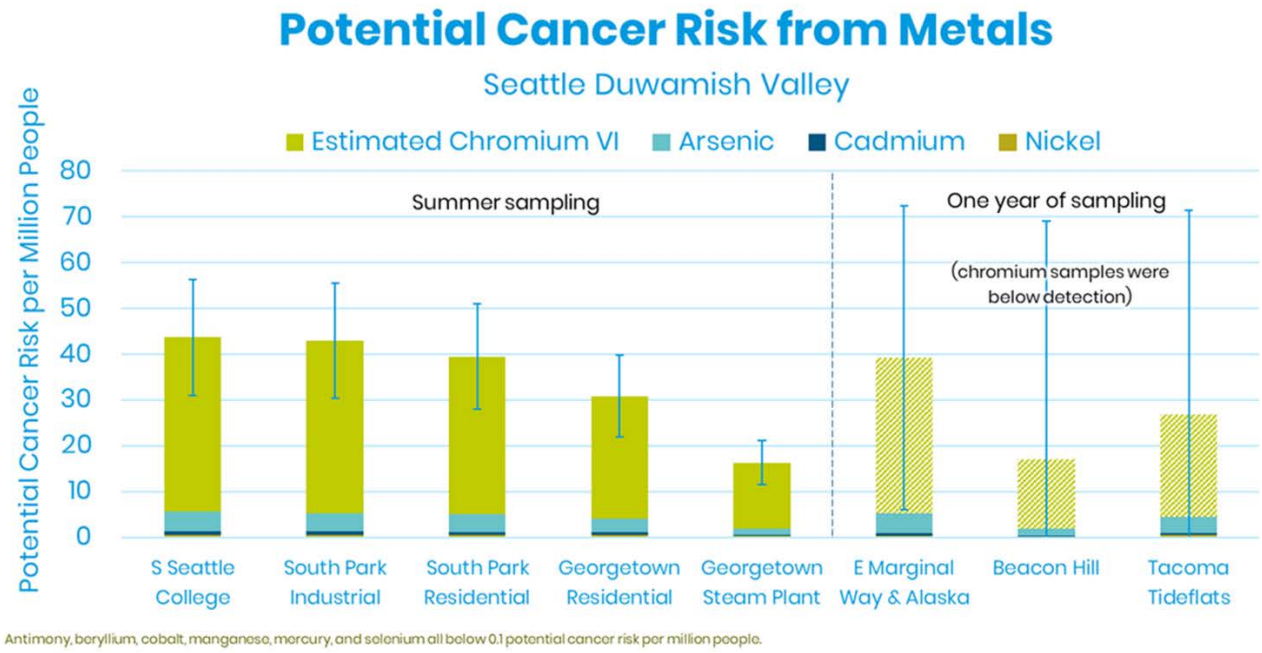
The daily average concentrations in the intensive period were very well correlated. This level of correlation would be consistent with an area that doesn't have any significant, localized $PM_{2.5}$ sources (that is, affecting only an area of less than a km), with the possible exception of near South Park Residential and South Park Industrial. Based on the diurnal patterns shown in Figure 56. Diurnal (hour of the day, midnight to midnight) average for the community directed PM2.5 measurements., the South Park Residential site may be experiencing a short early morning spike and small evening elevation, both about 1 ug/m^3 above other sites. This diurnal pattern is typical for the influence of residential wood burning but considering that the sampling period is the late summer, home heating is unlikely to be a major factor. It could also be due to vehicle traffic, including commuting/personal (early morning commute & commute home and personal travel) or delivery vehicles which leave in the early morning and return in the evening.

Also based on the diurnal patterns, the South Park Industrial site has the signature of a high-traffic highway or active industrial area, or both. The PM concentration increases in the early morning and stays high through the day and slowly decreases in the late afternoon and evening. Since this site was well correlated with the other sites, it is likely sampling the same general sources, but is closer and so experiences and is detecting a higher concentration of the same sources.

Duwamish Valley cancer risk from metals

Figure 57 shows cancer risk from metals sampled from July 29th, 2022 through Sept 2nd, 2022 at the Duwamish Valley community-directed sampling sites. The other sites to the right were sampled for the full year along with the other air toxics sampling described in this report above. Only compounds with greater than 0.1 per million cancer risk are shown. The primary contributor is estimated hexavalent chromium. Estimated hexavalent chromium contributes about 14-38 per million. The next highest contributor is arsenic at around 1-4 per million.

Figure 57. Estimated cancer risk from metals with risks over 0.1 per million.



Note, hexavalent chromium is estimated at 3% of total chromium for Duwamish sites and the Tideflats site. The error bars represent an additional 1% due to the uncertainty of the estimate being drawn from literature and past sampling in the area. These estimates are described in more detail in the "Overall potential cancer risk" section earlier in this report. Beacon Hill is shown here using a 0.8% estimate because we have a direct measurement for this ratio for the Beacon Hill site from a previous study.[74] Beacon Hill metals lab analysis lagged significantly and were past protocol holding times. Beacon Hill total chromium values were higher than the rest of the samples across all the regions. At the time of writing this report, we don't have a specific explanation for Beacon Hill's higher total chromium samples.

The samples with the annual averages were taken in 24-hour increments, which for chromium was below detection. The error bars in the graphic includes the total chromium method detection limit, which translates into roughly 70 per million with the 3% hexavalent assumption.

The Georgetown residential, Tideflats, and especially the Georgetown Steam Plant sites are lower than the other sites. The Steam Plant site had the lowest average cancer risk for chromium, arsenic, and nickel. This may be because it is further away

[74] *ibid*, PSCAA 2013 Data Summary

from the industrial areas and roadways than other sites. Elsewhere in this report, we hypothesize most of the trends in the metal concentrations to be a result of resuspended dust and soils from vehicle traffic.

Appendix H contains an analysis comparing the results from the prior moss studies performed by DRCC and partners with the air sampling from this study.

Community interest: Lead

As part of the community-led monitoring, we measured lead levels at the five temporary monitoring locations in the Duwamish, along with our one year of metals sampling at the Tacoma Tideflats and Seattle Duwamish sites for comparison.

Like many metals in this study, lead levels can result in non-cancer health impacts. For lead a main impact is cognitive development in children.[75] Lead is unique in that it is an both an air toxic as well as a criteria pollutant with a National Ambient Air Quality Standard.

The EPA is in the process of reviewing the national ambient air quality standard for lead (last retained at 0.15 µg/m^3 in 2016) and recently released an endangerment finding that lead from propeller aircraft "may reasonably be anticipated to endanger public health and welfare".[76]

The results of the study showed all the lead levels were well below the EPA ambient air standard.[77] The levels were also well below the Washington State Acceptable Source Impact Level screening level.[78] However, the results were higher in the Duwamish Valley compared to other locations such as the Tacoma Tideflats industrial area and the average of national monitors. You can see a summary of these results in Figure 58 below.

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[75] https://www.epa.gov/lead/learn-about-lead

[76] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-lead-emissions-aircraft

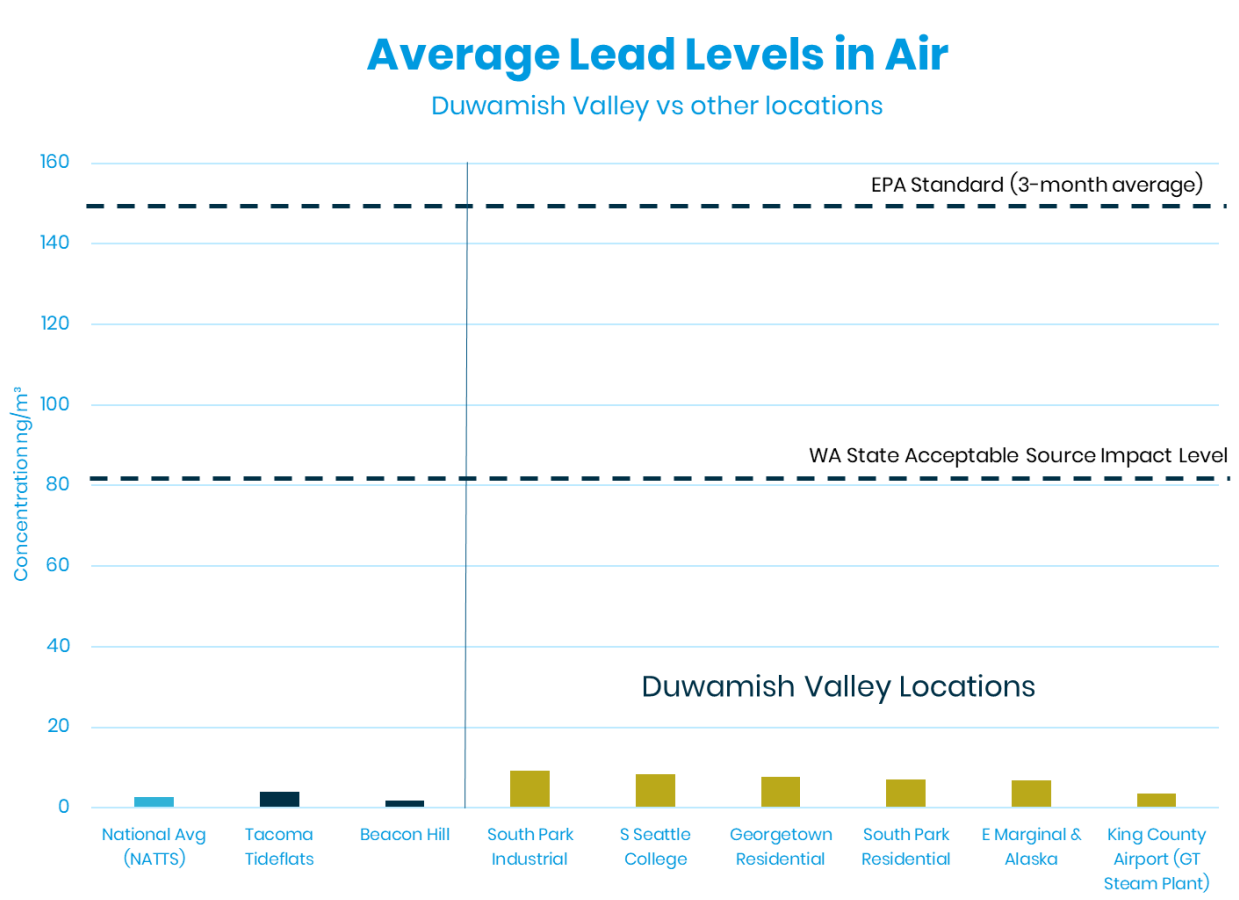
[77] https://www.epa.gov/lead-air-pollution/timeline-lead-pb-national-ambient-air-quality-standards-naaqs

[78] Washington Administrative Code 173-460-150, https://app.leg.wa.gov/wac/default.aspx?cite=173-460-150.

The result at the near-airport site was the lowest among the Duwamish Valley temporary monitoring locations. This result likely demonstrates that propeller aircraft isn't directly making a significant contribution of lead to the area. We hypothesize elsewhere in this report also, that the metals and lead deposition in the region is attributed to soil dust resuspension. The soils can resuspend from gusts of wind or vehicles driving over unpaved curbs and corners. The soils themselves in the Duwamish Valley are likely higher from a legacy of older leaded vehicle fuels and decades of older unregulated industry before the Clean Air Act existed. This is also evidenced by a King County Deposition Report that showed higher values in the Lower Duwamish Valley compared with other parts of King County.[79]

[79] King County DNRP, Lower Duwamish Waterway Source Control: Bulk Atmospheric Deposition Study Final-Data Report, Dec 2013, https://your.kingcounty.gov/dnrp/library/wastewater/iw/SourceControl/Studies/Air/2013/LDW_BulkAirDepFinalDataReport_Dec2013.pdf

Figure 58. Average lead levels sampled at temporary Duwamish Valley locations.



This figure shows the average lead levels sampled at temporary Duwamish Valley locations during the summer months of 2022, and the Seattle Duwamish Valley site, the Tacoma Tideflats site, Seattle Beacon Hill, and all National Air Toxics Trends Assessments sites sampled for a full year. The dashed bars represent the EPA National Air Quality Standard for lead[77] and the Washington State Acceptable Source Impact Level[78] for permit screening as established by the Washington State Clean Air Act.

Crosswalk of air lead levels to blood lead levels

To provide greater context to these results, we did a sensitivity comparison using the highest lead sample we collected at the highest monitoring location, using the most conservative (showing highest risk) of all the blood to air slope values.

This slope is a value that helps translate air samples to blood lead levels and was taken from the EPA Integrated Science Assessment[80] that comes with their review of

[80] EPA, Lead Integrated Science Assessment, 2013, page 584, https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=518908

the standard each cycle. Figure 59 below shows a portion of the table that lists seven different studies. The crosswalk value ranges from 3 to 9.

To estimate the respective blood lead level, we use the following equation:

(lead concentration in micrograms per cubic meter) x (blood to air slope value) = (blood lead level in micrograms per deciliter)

The highest site during our sampling was at the South Park Industrial Site, and it was 0.009 $\mu g/m^3$ (9 ng/m^3). If we use the most conservative slope of 9.3, we estimated a 0.08 $\mu g/dL$ increase in blood lead levels from the air at the highest site using the most conservative crosswalk value.

This is our best estimate, there is uncertainty in that the slopes are all from studies with much higher ambient lead levels (an order of magnitude). All our samples we collected were below all the levels in the studies from the table.

Similarly, using cautious values to estimate IQ scores, a value of less than 0.1 $\mu g/dL$ blood lead level less than a 0.1 children's IQ score change.[81]

The CDC updated their reference for action level to 3.5 $\mu g/dL$ blood lead level in 2021.[82] As a result, the most conservative estimate contributes to 2% of the CDC action level threshold.

In Appendix Q we present estimated daily lead intake for children using EPA's Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) software. The software comes with a set of default parameters that were used as-is, however the air concentration was updated to the highest value from this study (0.009 $\mu g/m^3$). Lead from air only contributed 0.05% of the overall lead intake; with most being from the ingestion of outdoor soil and indoor dust (74%) and diet (23%).

[81] Jusko et al, "Blood Lead Concentrations < 10µg/dL and Child Intelligence at 6 Years of Age", Environmental Health Perspectives, 2007, https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.10424.
[82] https://www.cdc.gov/nceh/lead/data/blood-lead-reference-value.htm

Figure 59. Portion of table showing blood lead to air lead slope factors from the most recent EPA Integrated Science Assessment.

Table 3-12 (Continued): Summary of estimated slopes for blood Pb to air Pb slope factors in humans.

Reference	Study Methods	Model Description	Blood Pb–Air Pb Slope[a]
Tripathi et al. (2001)	**Location:** Mumbai, India (multiple residential locations) **Years:** 1984-1996 **Subjects**: 6-10 yr (N = 544) **Analysis**: Regression of residential location-specific average blood Pb and air Pb data	**Model:** Linear **Blood Pb:** 8.6-14.4 µg/dL (GM range for residential locations) **Air Pb:** 0.10-1.18 µg/m^3 (GM range for residential locations)	3.6 (0.45)[i]
Children Populations – Air and Soil [j]			
Ranft et al. (2008)	**Location**: Germany **Years:** 1983-2000 (blood Pb and air Pb), 2000-2001 (soil Pb) **Subjects:** 6-11 yr (N = 843) **Analysis:** Pooled multivariate regression of 5 cross-sectional studies	**Model:** Log-Linear **Blood Pb:** 2.2-13.6 µg/dL (5th-95th percentile) **Air Pb:** 0.03-0.47 µg/m^3 (5th-95th percentile)	3.2, 6.4[k]
Mixed Child-Adult Populations			
Schwartz and Pitcher (1989), U.S. EPA (1986a)	**Location:** U.S. **Years:** 1976-1980 **Subjects**: NHANES II, 0.5-74 yr, whites (N = 9,987) **Analysis:** Multivariate regression of blood Pb with mass of Pb in gasoline (derived from gasoline consumption data and Pb concentrations in gasoline for the U.S.)	**Model:** Linear **Blood Pb:** 11-18 µg/dL[g] (mean range)[f] **Air Pb:** 0.36-1.22 µg/m^3 (annual maximum quarterly mean)[h]	9.3 (0.75)[l]

[a] Slope is predicted change in blood Pb (µg/dL per µg/m3) evaluated at ± 0.01 µg/m^3 from central estimate of air Pb for the study (shown in parentheses), with the exception of Ranft et al. (2008) in which the slope from the paper is provided because the regression equation was not available. The central estimate for Brunekreef (1984) is the median of air Pb concentrations since it was a meta-analysis; for all other studies the mean is presented. For multiple regression models, this is derived based only on air Pb coefficient and intercept. Depending on extent to which other variables modeled also represent air Pb, this method may underestimate the slope attributable to air pathways. In single regression models, the extent to which non-modeled factors, unrelated to air Pb exposures, exert an impact on blood Pb that covaries with air Pb may lead to the slope presented here to over represent the role of air Pb.

[b] ln(PbB) = ln(PbA) x 0.3485 + 2.853

[c] ln(PbB) = ln(PbA) x 0.2159 + 2.620

[d] ln(PbB) = ln(PbA) x 0.24 + 3.17

[e] PbB = PbA x 7.0, see Table 3-13 for more information.

[f] Observed blood Pb values not provided; data are for regressed adjusted blood Pb.

[g] PbB = PbA x 8.6

[h] Based on air Pb data for U.S. (1986 Pb AQCD) as a surrogate for Chicago.

[i] PbB = Pb A x 3.6

[j] Study that considered air Pb and soil Pb where the air Pb-blood Pb relationship was adjusted for soil Pb.

[k] Slope provided in paper with background blood Pb level of 1.5 and 3 µg/dL, respectively, and GMR of 2.55 for ambient air.

[l] PbB = PbA x 9.63

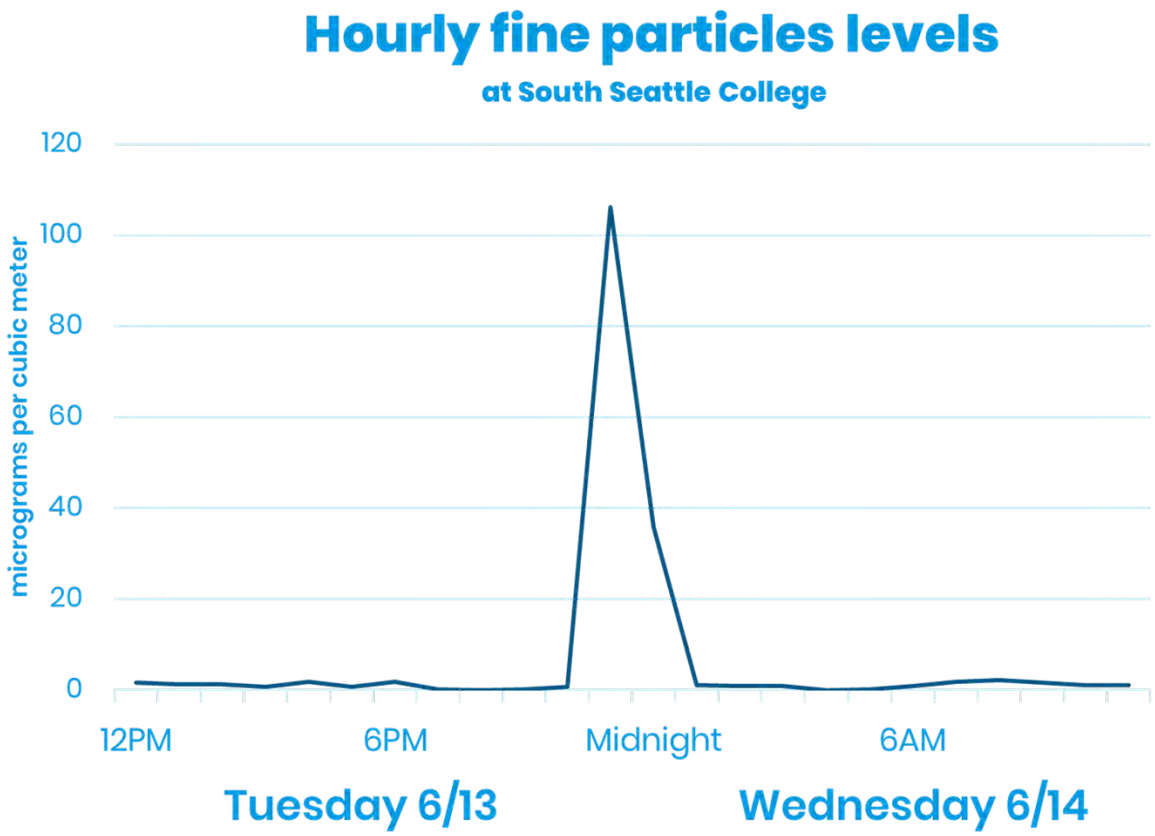
GM, geometric mean; GSD, geometric standard deviation; PbB, blood Pb concentration (µg/dL); PbA, air Pb concentration (µg/m^3)

Community interest: Local fire on June 13th, 2022

In the late evening of 6/13/2022, a fire broke out on the property of Seattle Iron and Metals from approximately 11PM to 1AM. The wind direction at time (Figure 60 below) shows our South Seattle College temporary air monitoring station was downwind at the time. Our metals samples sample for an entire week, so no significant difference was expected, and was confirmed to be true when we compared to other samples at that site or comparing to other locations sampled during the same week. Fine particle monitoring (via light scattering) is shown in Figure 61.

Figure 60. Wind direction during the hours of 6/13/22 11PM to 6/14/22 1AM and potential trajectory of smoke generated from a fire at the Seattle Iron and Metals facility.

Figure 61. Hourly fine particle (PM2.5) levels on 6/13/2022.



We responded to community concerns after the event and presented these results to the Georgetown Community Council on 6/20/2022. We shared that all EPA health categories are based on 24-hour exposures. The noon-to-noon average during the fire was still in the GOOD category of 6.9 micrograms per cubic meter.

With the short duration of this event (3 out of 168 hours sampled), the sampled metal concentrations for that week were not impacted in any measurable way.

Dust as a source of metals in Duwamish Valley air samples

We hypothesize that most of the metals in the air samples were coming from the soils across the Duwamish Valley more broadly. A likely contributor could be vehicles driving through roadways, especially unpaved shoulders and unpaved roads, which can cause dust to resuspend, particularly in dry episodes during the summer.

A recent study based on moss sampling in the Duwamish Valley found two factors from a principal component analysis. The main factor that explained most of the result showed strong correlation among all the metals broadly. This would point to no point specific sources, but a broader ubiquitous source, like soils.

A follow-up study of the moss sampling results identified traffic volume as the most consistent predictor of increasing heavy metals. Similarly, proximity to dirt roads predicter higher arsenic and chromium levels.

These studies do not identify an originating source of the metals to the soils in the valley. We can presume a legacy of over a hundred years of industrial activity and leaded fuels may have contributed.

To investigate this hypothesis with our air sampling, we performed correlations of various metals to compare to typical crustal soils. See Appendix M.

We found that arsenic, cadmium, and lead concentrations sampled at the Duwamish Valley monitoring sites had some correlation. We investigated these correlations and found that they generally matched crustal abundance ratios. Crustal abundance ratio is the ratio of the given elements in the earth's crust. These ratios can be used to represent dust in the atmosphere.

Spatial modeling to extrapolate risk from on-road diesel particulate matter and equity analysis

The PMF analysis resolved several factors. One that is directly linked to health, and contributes the majority of the cancer risk, is diesel particulate matter. The diesel particulate matter factor from the PMF analysis is a measure of near-road diesel particulate matter with some crustal elements from road dust. We identify specifically on-road diesel particulate matter, which means diesel particulate matter that was recently emitted and hasn't undergone secondary chemistry or from more

distant sources to form “aged diesel particulate matter”. Using this metric of on-road diesel particulate matter, we can apply the unit risk factor to the site averages to get an estimate of cancer risk from just the on-road portion.

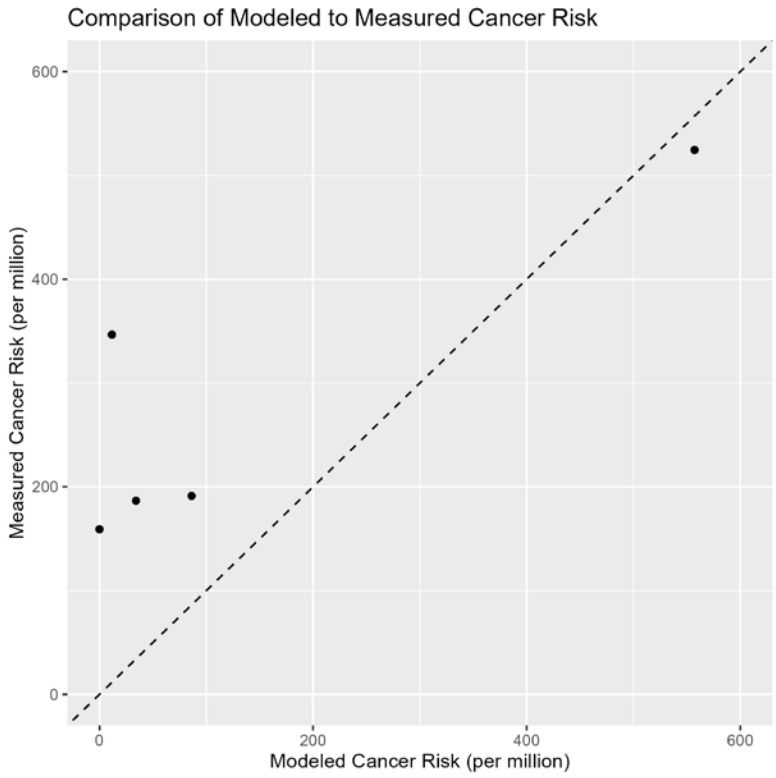
To understand the impact of diesel particulate matter on a larger scale, the potential cancer risk at our sites was correlated with measures of truck traffic and that calibration can be applied to all the blocks in our region. For this analysis, the measure of truck traffic we chose was the sum of truck tonnage within 500m of census block centroids. The sum of truck tonnage is a measure of the total weight of trucks for a given road segment. This estimate is provided by the Washington State Department of Transportation and encompasses most medium and large size roads, where there is appreciable truck traffic. The analysis was performed on the census block level, which is quite granular. Truck tonnage was summed only within 500m of the center of a block because some blocks in rural areas are quite large and summing within 500m of the entire block polygon would have included roadways that were at the edge of those rural blocks.

2020 census block shapefiles for our four-county region were downloaded from Puget Sound Regional Council. Demographic data for our four-county region was downloaded from data.census.gov. Specifically, the P5 table, “Hispanic or Latino origin by race”, from the 2020 decennial census at the block level and table B19013, “Median Household Income in the Past 12 Months (In 2021 Inflation-adjusted Dollars)”, from the 5-year American Community Survey 2021 at the block group level. For block groups where the median annual income is greater than $250,000 the ACS data file says “>$250,000”. This was adjusted so that those block groups had a value of exactly $250,000, however that is certainly an undercount. Though the effects of this are likely to only be seen on the very last data point for the income graphs.

The truck tonnage data layer was joined to block centroids, and PSCAA sites within 500m and summed. Then the PSCAA data were exported into R and a linear model was created (see Figure 62). The linear model had the intercept set to 0 so that blocks far away from roads did not end up with inflated “background” levels of on-road diesel potential cancer risk. The adjusted R^2 of the model was 0.56. (And a model without a set intercept had an adjusted R^2 of 0.64). In general, sites with lower cancer risk were slightly underpredicted (a facet of setting the intercept to 0). One site that stands out as quite different from the others is the Tacoma Tideflats site. This is the point in the model comparison graph at the center left. The model significantly underestimates on-road diesel particulate matter potential cancer risk

at Tacoma Tideflats. This could be because there is another source of diesel particulate matter other than trucks, such as maritime activities, which is not accounted for in the model. Or it could be that the PMF diesel particulate matter factor for that site is slightly different compared to other sites and is pulling in another source of pollution.

Figure 62. Estimated diesel particulate matter cancer risk model performance.



After the model was created, it was applied to the census block shapefile. This was then combined with the block level race and ethnicity data and the block group level income data and re-exported for analysis in R.

From the total population count per block and race/ethnicity specific population counts, the percent of each race/ethnicity was calculated for each block. Two types of analyses were performed: (1) a logistic regression model predicting whether a block was likely to be in the top 5% of potential cancer risk from air pollution by race, ethnicity, and income; (2) comparisons of race, ethnicity, and income versus average cancer risk. These analyses will be discussed along with associated graphs below.

The map below (Figure 63) shows the estimated potential cancer risk from on-road diesel particulate matter. The highest values are seen near large highways (I-5, I-405,

I-90). Lower values are seen near medium sized roads. Blocks not near large or medium size roads have a lower potential cancer risk.

Figure 63. Estimated on-road diesel particulate matter potential cancer risk map.

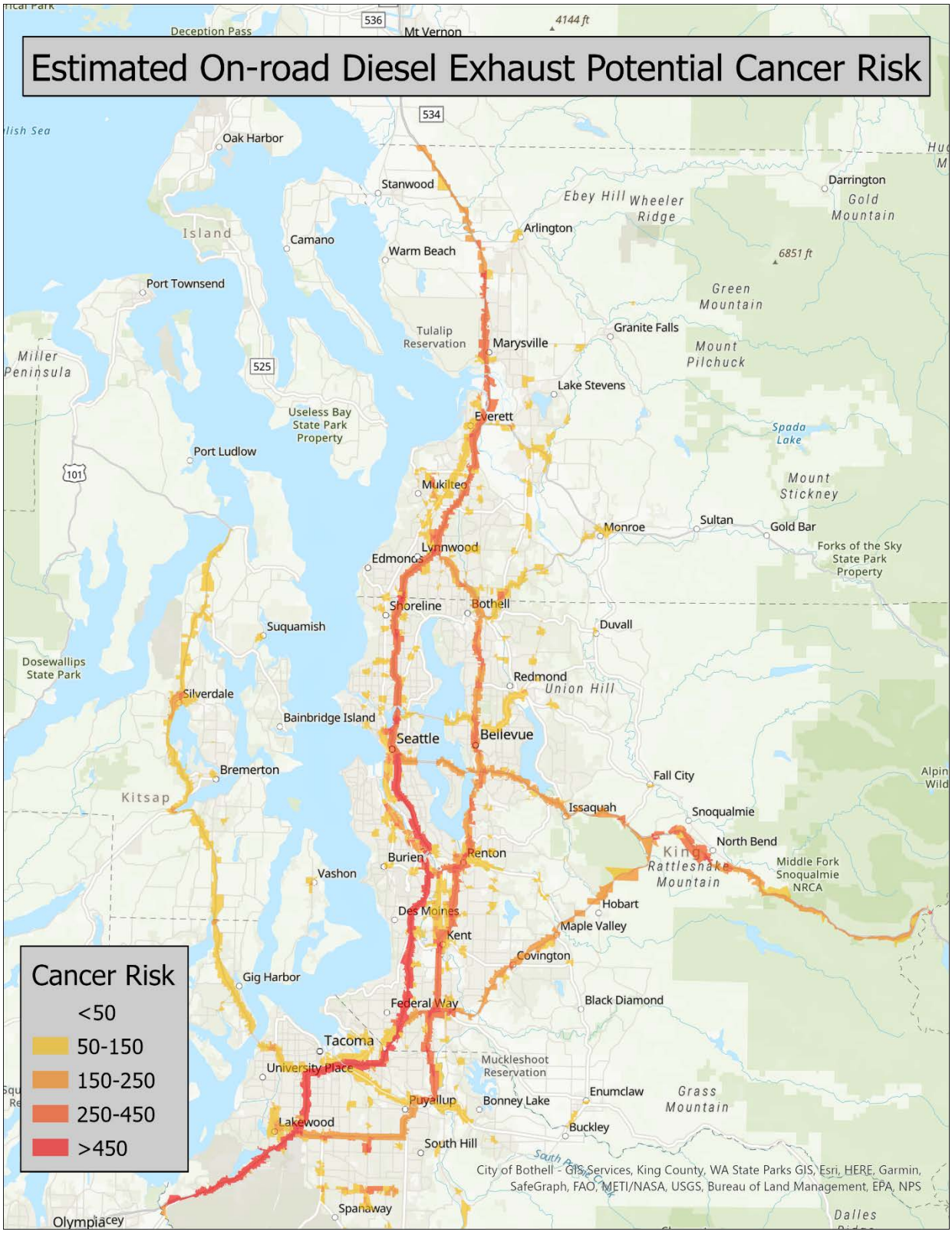


Figure 64 below shows the 5th, 25th, 50th, 75th, and 95th percentile of potential cancer risk from on-road diesel particulate matter for race, ethnicity, and income groups. Here, BIPOC includes all non-white race groups. These values are calculated on a per-person level (not a per-block level). So, for race and ethnicity, the potential cancer risk value for a block is assigned to each person in that block. Then the summary statistics are calculated. For income, each person in the block is assigned the median annual income and the block's potential cancer risk. Also, from that dataset the potential cancer risk percentiles are calculated.

Figure 64. On-road diesel particulate matter potential cancer risk statistics by race, ethnicity, and income.

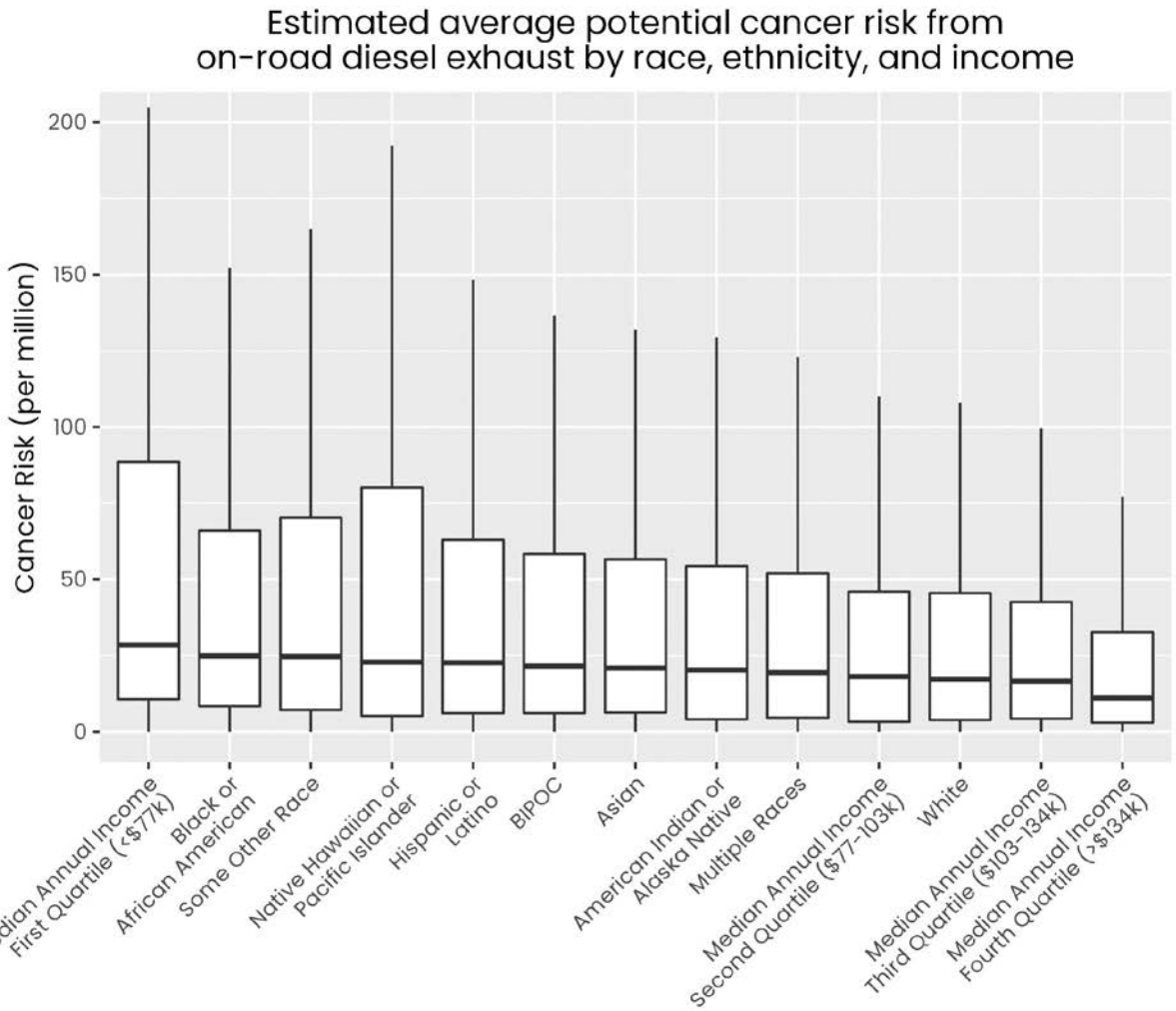


Figure 65 below shows the probability of living in the top 5% of cancer risk blocks by percent Black, Indigenous, People of Color (BIPOC) and median annual income.

BIPOC, for the purposes of the graphs in this section, is defined as any non-white census racial group. Hispanic is not a racial group in the 2020 census and is treated separately. This graph is based on a simple logistic regression model. In the graph, we can see the separate effects of race and income. With higher incomes less likely to be associated with higher potential cancer risk blocks. And, apart from income, blocks with more BIPOC residents are more likely to have high cancer risk. The 95th percentile for cancer risk is 333.5 per million. The low category for BIPOC is when the population is 0-26% BIPOC, the medium category is 26-46%, and the high category is above 46%.

Figure 65. Probability of living in top 5% potential cancer risk from on-road diesel particulate matter block by income and race.

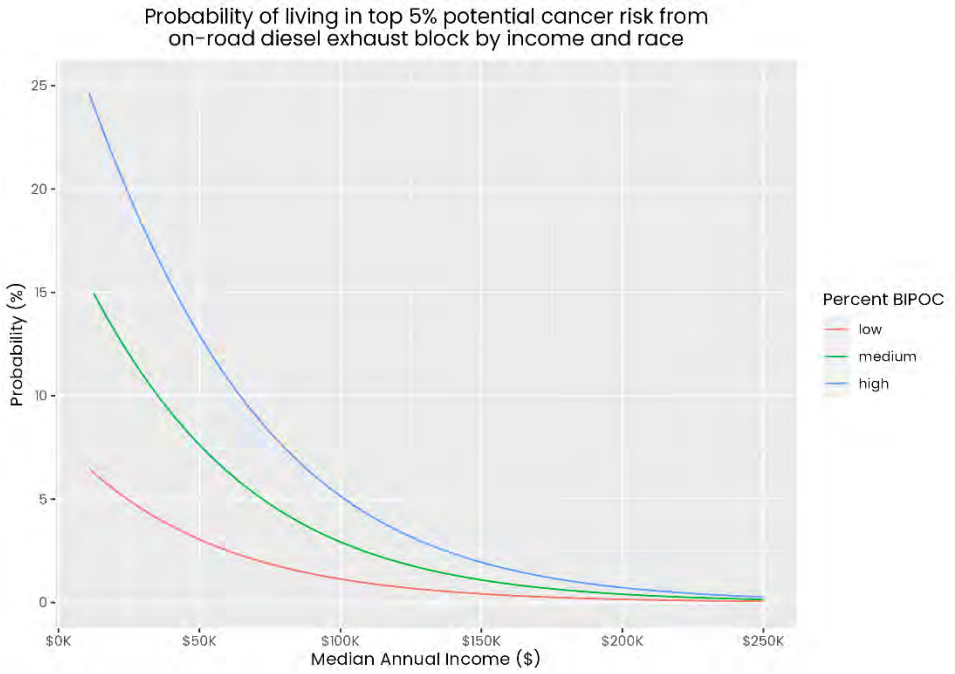
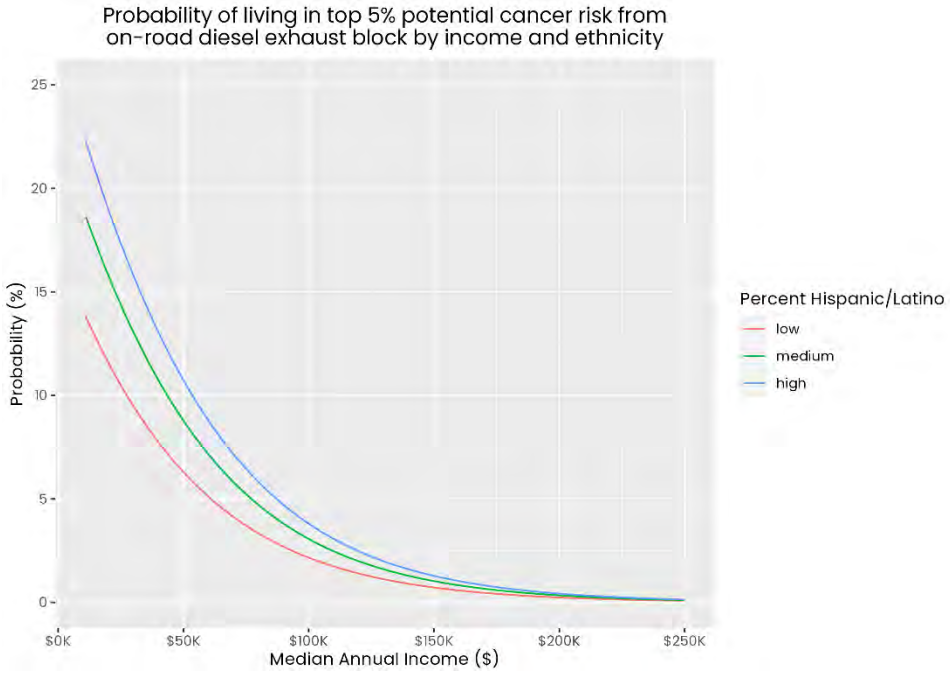


Figure 66 below shows the probability of living in the top 5% of potential cancer risk blocks by Hispanic/Latino and median annual income. The low category for Hispanic/Latino is when the population is 0-5% Hispanic/Latino, the medium category is 5-13%, and the high category is >13%. The graph also shows a separate effect for income and ethnicity, with areas with a higher percentage of Hispanic/Latino residents and lower income more likely to be in blocks with high potential cancer risk.

Figure 66. Probability of living in top 5% potential cancer risk from on-road diesel particulate matter block by income and ethnicity.



These graphs (Figure 67 to Figure 70) show average potential cancer risk from diesel particulate matter by race, ethnicity, and income. They only contain data from blocks with more than 11 people (greater than the 5th percentile). This was done to limit the effects of small numbers leading to large percentages and affecting the tails of the graphs. The dotted black line is the average overall potential cancer risk from on-road diesel. The dotted red line is a trendline; the trend equation and r^2 are shown on the graph. See Appendix N for all single-race graphs.

Figure 67. Potential cancer risk from on-road diesel particulate matter by race - BIPOC.

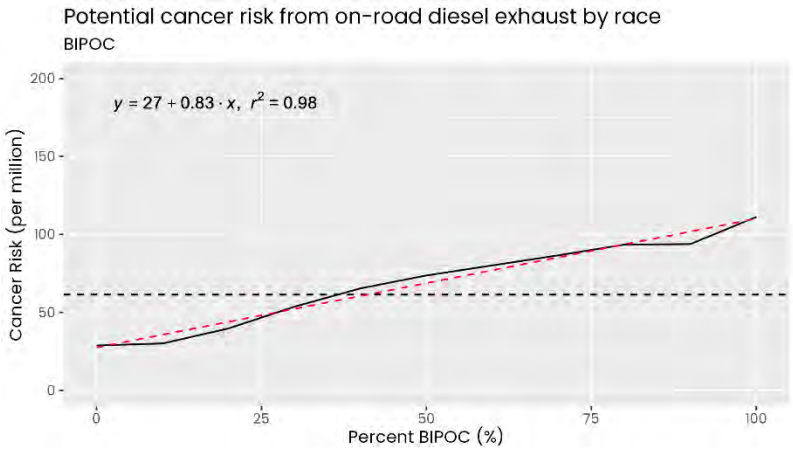


Figure 68. Potential cancer risk from on-road diesel particulate matter by ethnicity – Hispanic/Latino.

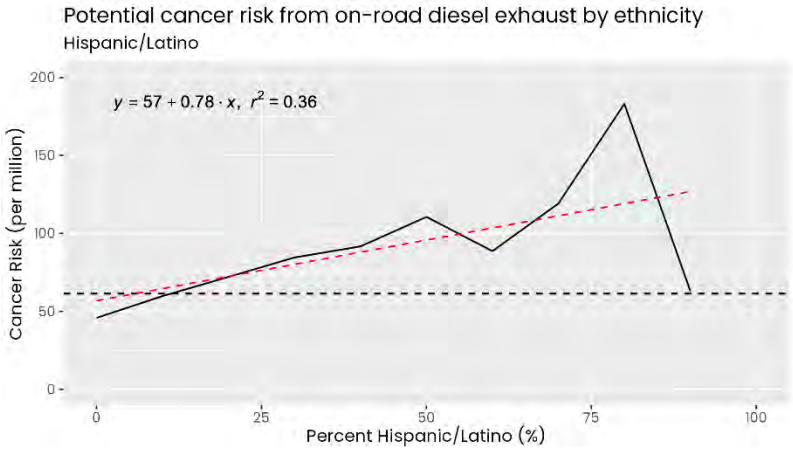


Figure 69. Potential cancer risk from on-road diesel particulate matter by race – White.

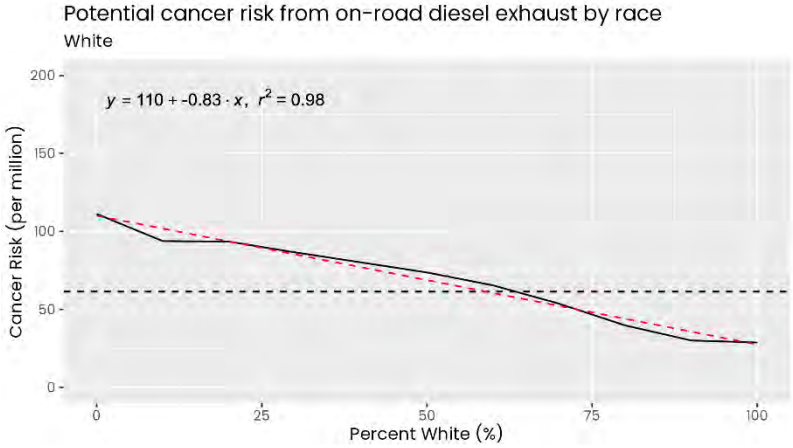
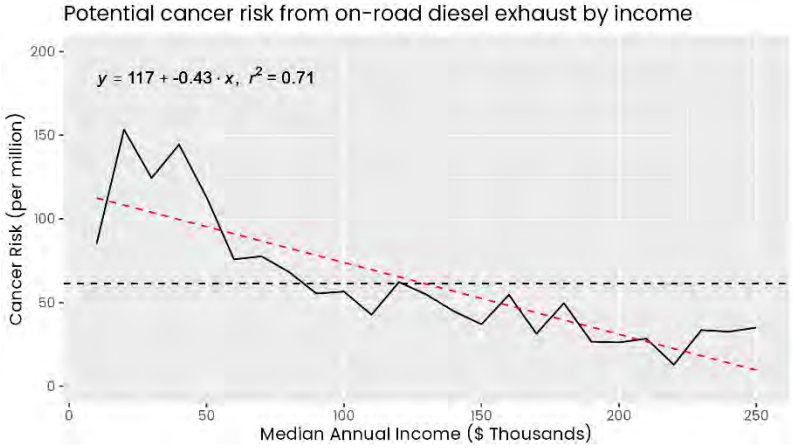


Figure 70. Potential cancer risk from on-road diesel particulate matter by income.



The average estimated cancer risk due to on-road diesel particulate matter for a block with no BIPOC population is 29 per million. For blocks with 100% BIPOC population the estimated cancer risk is 111 per million. The White graph is the inverse relationship by our definition, since BIPOC includes all non-White races. The Hispanic or Latino graph has a less straight line and the final datapoint may be swayed heavily by only having a small number of blocks. However, the general trend upwards, from a risk of 29 per million to around 119 per million at the highest. The first point on the income graph is lower than the following points, likely due to the lower number of blocks with that income level. However, the average cancer risk drops from about 140 per million to around 25 per million as income increases.

In summary, the population that lives near larger roads tends to be more non-White and have a lower income. This leads to a disproportionate health impact from on-road diesel particulate matter.

Conclusions

Consistent with our studies in 2003, 2010, and 2016, this report found that diesel particulate matter continues to be the primary contributor to the total potential cancer risk in the region. Most sites across those studies measured diesel particulate matter as being above 70% of the total potential cancer risk, much larger than the second highest pollutant.

Air toxics concentrations have been decreasing over time. Levels of VOCs have decreased by half at the Beacon Hill site over the past 20 years. All other sites presented have shown decreases in VOCs. Estimated wood smoke has been decreasing over time as well at our Tacoma South L site. This follows the large-scale effort to return to attainment of the national standards after being designated non-attainment in 2009. It also tracks with the updated wood stove standards and our efforts to recycle or replace older, more polluting wood stoves.

We estimate diesel particulate matter levels to be about half of what they were two decades ago, despite 30% population growth and corresponding increases in economic activity. In terms of tracking diesel particulate matter concentrations over time, PMF has become increasingly more challenging to use. One important factor is the increasingly smaller quantities of species we could include in the factor analysis due to lower and lower signal (ambient concentrations) with air quality

improvements. That is, many of these species are now below detection limits while in prior years, they were well above. Additionally, there are other variables that can make PMF more challenging such as choice of number of factors, robustness of the model, uncertainty, and co-emission of sources. In essence, while you may have a specific factor in mind to quantify, such as diesel particulate matter, that source can be co-emitted with other types of particles, such as road dust, and the two can become inseparable with PMF. However, if we use black carbon as a surrogate for diesel particulate matter the trends become clearer. All sites, with the exception of 10th & Weller, measured a decrease in black carbon over time. Seattle 10th & Weller, which is only a few feet from I-5, showed a static (no) trend. However, population and vehicle miles traveled (VMT) (apart from the impact of COVID) have been increasing over time (Figure 34 and Figure 35). So, having a flat measure of black carbon suggests a significant downward trend in emissions per vehicle.

EPA reporting[83] and internal analysis[84] suggests that diesel particulate matter emissions will continue to decrease over time. With a steady activity level (VMT) we would expect at least a 90% drop in diesel particulate matter by 2030, compared to before 2007.

Overall, places near large highways show the greatest potential cancer risk from air pollution, driven by diesel particulate matter. Our equity analysis showed that those locations often also have higher percent BIPOC and higher percent lower-income populations.

Residential wood smoke, while having decreased substantially over the past two decades, still presents an ongoing addition to potential cancer risk. Depending on the site, it is the second or third highest potential cancer risk and, unlike metals, contributes significantly to overall $PM_{2.5}$ mass, which is associated with cardiovascular risk and mortality.[85] Our work in this area continues with our wood stove recycling program, burn ban enforcement, and education and outreach.

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[83] EPA, 2000. Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. EPA420-R-00-026. See i.a. table II.B-5

[84] Based on MOVES data supplied by Sally Otterson (WA Dept of Ecology), in an email on May 1, 2019, in the file "IM_Sunset_documentation_Final.docx", and MOVES data supplied by Kelly McGourty (PSRC), in an email dated Feb 13, 2019, in the file "Final RTP emissions.pdf".

[85] EPA, Integrated Science Assessment for Particulate Matter, 2019. https://www.epa.gov/isa/integrated-science-assessment-isa-particulate-matter.

The community directed sampling showed that estimated hexavalent chromium had the highest risk of the metals sampled. The ratio used to estimate what fraction of total chromium is hexavalent chromium is drawn from literature and older studies in our region. We have received an EPA grant to perform a follow up study to do total and speciated chromium sampling in the Duwamish Valley region to get a more accurate ratio. This study will begin in mid-to-late 2024.

Lead, a major concern of the community, was higher in the Duwamish than other areas, but was well below state and federal standards and would be associated with only a minor increase in blood lead levels (less than 0.1 μg/dL using the most cautious estimates or less than 0.1 IQ score change in children[86]).

EPA's AirToxScreen model matched well with many monitoring results from this study. However, the model underpredicted arsenic and tetrachloroethylene and overpredicting hexavalent chromium at Seattle Duwamish and Seattle Beacon Hill. We make some suggestions in our report on how to make the model more accurate.

Ethylene oxide was analyzed separately from other compounds due to the high amount of uncertainty in its measurement and the large number of samples that were flagged. In 2016, EPA increased the unit risk factor for ethylene oxide by 34x. With the new unit risk factor, even results that are at the limit of detection lead to potential cancer risk estimates in the hundreds per million. Complicating this detection limit issue is a widespread sampling issue.[87] It is hypothesized that ethylene oxide can stick to the inside of the sampling canister since many samples ended up with failed duplicates and outliers with no found patterns. Many of the samples in this study were flagged for that issue. While there is much uncertainty, Beacon Hill has the lowest average ethylene oxide concentration of all NATTS sites. And the other sites in our study were at similar concentrations.

Mitigation recommendations and resources

Diesel particulate matter is the primary risk driver in our region. It is also one of the main areas of focus in our strategic plan. One of the primary goals of the strategic

[86] Jusko et al, "Blood Lead Concentrations < 10μg/dL and Child Intelligence at 6 Years of Age", *Environmental Health Perspectives*, 2007, https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.10424.
[87] EPA 2020, EPA's Work to Understand Background Levels of Ethylene Oxide, https://www.epa.gov/system/files/documents/2021-10/background-eto-explainer-doument.pdf.

plan is to "reduce harmful diesel pollution emissions and exposures."[88] This goal has targets related to replacing diesel equipment with electric, specifically electric drayage trucks, electric yard trucks, and electric equipment at rail yards.

This focus on diesel particulate matter is a continuation of our work in this area, which started as our "Diesel Solutions" program after the original 2003 air toxics study. There are several emissions reduction strategies that our Agency has been involved in over the years including administering grants to change out older more polluting diesel engines with newer cleaner models and helping ports install shore power so that idling ships can turn off their diesel engines. We have also worked with rail yards to convert their on-premise diesel equipment to electric. Much of the funding for these efforts have come through the state legislature and EPA Diesel Emissions Reduction Act (DERA) programs, Dept of Ecology budgets, and the NW Seaport Alliance. The benefit from these emissions reductions has the largest impact in near-road and near-port communities, which in turn are benefiting overburdened communities most. As shown in the spatial-demographic analysis of diesel emissions, these communities typically have higher percentages of BIPOC residents and lower median annual income.

The last federal heavy-duty engine standard with PM limits was for model year 2007 (and was fully implemented by 2010).[89] Since then, there have been two phases of standards to reduce greenhouse gas emissions and improve fuel efficiency, the first affecting model years 2014-2018 and the second affecting model years 2018-2027[90]. A third phase was proposed in 2023, which would take effect on model year 2027 and later vehicles[91]. In addition to federal regulation, in 2022 Washington State created the Clean Vehicles Program, which adopted standards developed by the California

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[88] PSCAA, 2030 Strategic Plan, https://pscleanair.gov/DocumentCenter/View/5038/2030-Strategic-Plan-Final-.

[89] EPA, Final Rule for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, 2023, https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-control-air-pollution-new-motor-vehicles.

[90] EPA, EPA Emission Standards for Heavy-Duty Highway Engines and Vehicles, 2023, https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-heavy-duty-highway-engines-and-vehicles.

[91] EPA, Proposed Rule: Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3, 2023, https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-greenhouse-gas-emissions-standards-heavy.

Air Resources Board.[92] This includes the Heavy-Duty Engine and Vehicle Omnibus rules that require lower PM, NOx, and GHG emissions from heavy-duty vehicles starting in model year 2026. It also includes Advanced Clean Cars II rule which requires a shift to EVs for passenger cars, light duty trucks, and medium duty vehicles starting in model year 2026 with a goal of 100% EV sales for new passenger vehicles by 2035.

In terms of maritime emissions standards, the EPA created the North American Emission Control Area for Marine Vessels (ECA), which put in place a fuel sulfur requirement in 2015 and NO_x standard in 2016.[93] Other efforts in the maritime space include installing shore power, which allows ships to run off electricity when docked, and switching the state's ferries over to hybrid electric.[94,95]

The top contributors to potential cancer risk from metals were estimated hexavalent chromium and arsenic. We will conduct a follow-up study to monitor hexavalent chromium directly and to calculate the percent of total chromium that is hexavalent. We will continue to enforce our regulations that impact businesses that work with metals, including chromium and arsenic.[96]

Lead results did not indicate that lead air pollution is a significant risk driver in our jurisdiction, but we continue to track regulatory actions, such as the EPA's efforts to eliminate lead in some aviation fuels,[97] lead based paint hazards, and clean-up sites that still suffer from lead contamination.

Ethylene oxide measurements had high uncertainty, canister issues, and no obvious trend across sites. However, its high unit risk factor leads to hundreds per million

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[92] WA Department of Ecology, Clean Vehicles Program, 2023, https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Rulemaking/WAC173-423-400Jan18.

[93] EPA, Designation of the North American Emission Control Area for Marine Vessels, 2023, https://www.epa.gov/regulations-emissions-vehicles-and-engines/designation-north-american-emission-control-area-marine.

[94] Northwest Seaport Alliance, Shore Power, https://www.nwseaportalliance.com/environment/clean-air/investing-cleaner-air.

[95] Washington State Department of Transportation, Ferry system electrification, https://wsdot.wa.gov/construction-planning/major-projects/ferry-system-electrification.

[96] PSCAA, Regulations, https://pscleanair.gov/219/PSCAA-Regulations.

[97] EPA, Regulations for Lead Emissions from Aircraft, 2023, https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-lead-emissions-aircraft.

cancer risk even for samples near the detection limit. We support EPA's efforts to reduce the use of ethylene oxide in sterilization of medical and other devices and reduce the amount of ethylene oxide being emitted from chemical production plants.[98]

Other combustion-related potential cancer risk drivers such as acetaldehyde, benzene, 1,3-butadiene, and formaldehyde could be reduced by continued effort in both reducing transportation emissions and wood smoke. We continue to support national programs that improve wood stove and transportation standards.

Efforts to reduce wood smoke emissions include our Wood Stove Reduction Program, which offers a cash incentive for people to recycle their old wood stoves; air quality burn bans; and our outdoor burning regulations.[99,100,101] We also have done outreach and education efforts, such as the Clean Burning Challenge, in which participants can get a free wood moisture meter after completing a quiz about how to burn cleaner.[102] Regulations also don't allow homes to smoke out their neighbors via smoke density (opacity) standards.[103]

There are also federal and state standards for wood heating devices. EPA promulgated the first New Source Performance Standard (NSPS) for wood heating devices in 1988.[104] Washington state adopted these standards (finalized in 1990) in WAC 173-443-100.[105] In 2015, EPA amended their wood heating device standards and reduced the PM emission limits. There is ongoing work into ensuring the effectiveness

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[98] EPA, Actions to Protect Workers and Communities from Ethylene Oxide (EtO) Risk, 2023, https://www.epa.gov/hazardous-air-pollutants-ethylene-oxide/actions-protect-workers-and-communities-ethylene-oxide-eto.

[99] PSCAA, Puget Sound Wood Stove Program, https://pscleanair.gov/409/Wood-Stove-Program.

[100] PSCAA, About Air Quality Burn Bans, https://pscleanair.gov/172/About-Air-Quality-Burn-Bans.

[101] PSCAA, Outdoor Burning, https://pscleanair.gov/328/Outdoor-Burning.

[102] PSCAA, Clean Burning Challenge, https://pscleanair.gov/622/Clean-Burning-Challenge.

[103] PSCAA, Regulation I Article 9, https://pscleanair.gov/DocumentCenter/View/162/Regulation-I-Section-911-PDF?bidId=.

[104] EPA, Final Standards of Performance for New Residential Wood Heaters and New Residential Hydronic Heaters and Forced-Air Furnaces, https://www.epa.gov/sites/default/files/2020-03/documents/wood_heaters_final_nsps_fact_sheet.pdf.

[105] Washington State Legislature, WAC 173-433-100, https://apps.leg.wa.gov/WAC/default.aspx?cite=173-433-100.

of the wood heating device testing program and making sure that the wood stove standards are updated every eight years, as required.

Beyond emissions reductions, another way to reduce health risk is to focus on exposure reduction. Even though most people spend a significant amount of time indoors, outdoor pollution can enter the indoor environment. This is most obvious in extreme cases such as heavy wildfire smoke, where the thick smoke can enter a building through a leaky building envelope or a poorly configured HVAC system. Also, diesel particulate matter can enter homes from living near a freeway.

Some techniques to reduce exposure to outdoor pollution indoors include: HVAC upgrades (especially a system that can use a MERV-13 or higher rated filter), air cleaners, and DIY filter fans. Alongside those methods of removing pollution, education regarding when to close or open windows and doors, use air cleaners, and where to check the latest air quality are also helpful.

Throughout this discussion of emissions and exposure reduction, it is critical to think of the populations that would benefit most from the interventions. For example, a high value location for HVAC upgrades may be a school located near a busy highway. Also, focusing on certain pollutants, such as diesel particulate matter, will have a higher benefit to near-road communities, which often have a higher percentage of people of color and lower median annual income.

Another aspect of mitigating exposure is the educational component to community engagement and outreach. One of the goals of our 2030 strategic plan is to "measure, analyze, and communicate air quality risk", with targets related to expanding community science engagement events and providing tools to clearly communicate air pollution risk information.[106] We participate in many community events, resource fairs, health fairs, youth education workshops, and presentations each year. And one of the main topics is explaining the main sources of air pollution, associated health risk, and measures that people can take to protect themselves. We will continue these efforts over the course of our 2030 strategic plan and expand them to reach all overburdened communities within our jurisdiction.

[106] *ibid*, PSCAA 2030 Strategic Plan.

Appendix

to the Tacoma and Seattle Air Toxics Trends Report (2023)

Contents

Appendix A. Monitoring site descriptions

Table A-1. Summary of site locations for the permanent monitoring and the community-directed temporary sites.

Site name	Site code	Site address*	Site main attribute	Latitude (°)	Longitude (°)	Elevation (m)
Seattle 10th and Weller	BKWA	10th Ave S & S Weller St, Seattle, WA 98104	Near road	47.5974	-122.3198	42
Seattle Beacon Hill	SEWA	4103 Beacon Ave S, Seattle, WA 98108	Residential, NATTS**	47.5682	-122.3086	102
Seattle Duwamish	CEWA	4700 E Marginal Way S, Seattle, WA 98134	Industrial	47.5599	-122.3382	5
Tacoma Tideflats	EQWA	2301 Alexander Ave E, Tacoma, WA 98421	Industrial	47.2655	-122.3850	1
Tacoma 36th	YFWA	1802 S 36th St, Tacoma WA 98418	Near road	47.2263	-122.4625	108
Tacoma South-L	ESWA	7802 S L St, Tacoma, WA 98408	Residential	47.1863	-122.4516	103
South Seattle College - Georgetown	UAWA	6737 Corson Ave S, Seattle, WA 98108	Community-directed	47.5418	-122.3257	4
South Park Residential	UBWA	S Elmgrove St & 12th Ave S, Seattle, WA 98108	Community-directed	47.5305	-122.3178	3
Georgetown Residential	UCWA	Carleton Ave S & S Willow St, Seattle, WA 98108	Community-directed	47.5411	-122.3222	6
Georgetown Steam Plant	UDWA	6605 13th Ave S, Seattle, WA 98108	Community-directed	47.5427	-122.3157	5
South Park Industrial	UEWA	S Fontanelle St. & 3rd Ave S, Seattle, WA 98108	Community-directed	47.5367	-122.3301	3

* We only provide the nearest cross street address for the community-directed sites.

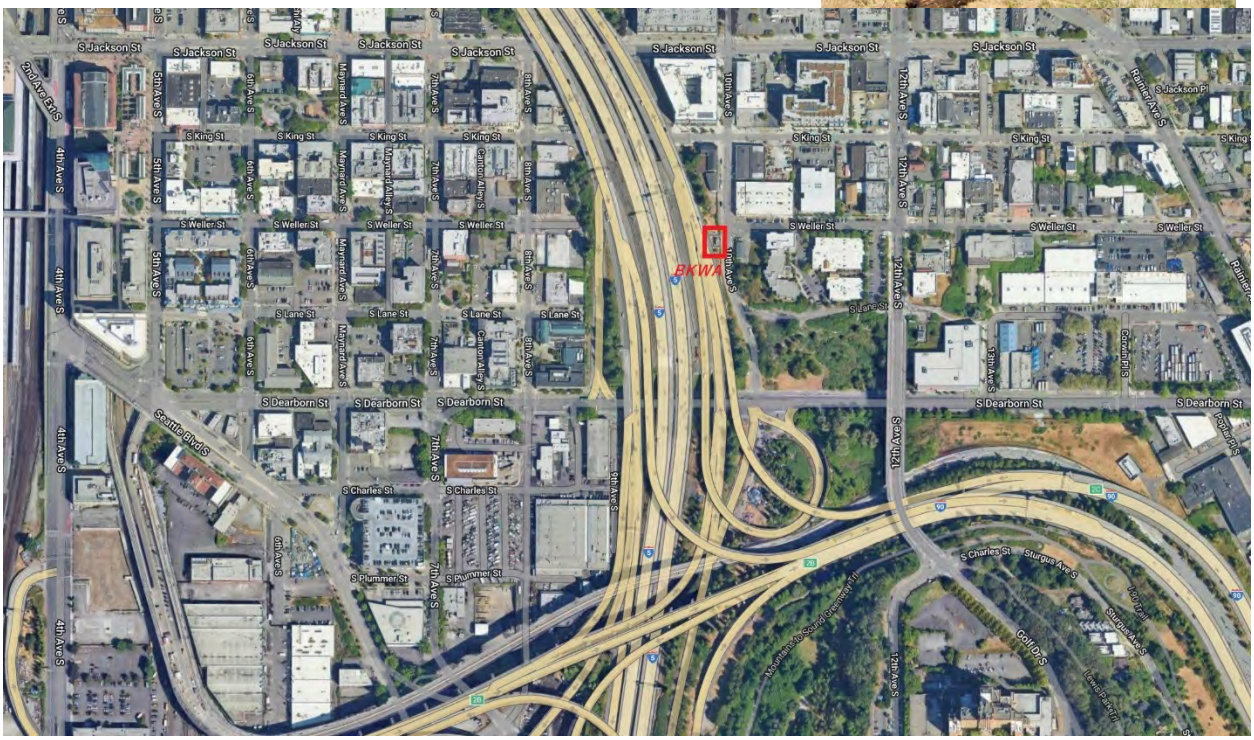
**NATTS: National Air Toxics Trends Station – network of stations providing long-term air toxics monitoring.

Seattle 10th & Weller (BKWA):

This station is Washington state's primary near-road monitoring site. Washington State Dept. of Ecology installed the site in April of 2014. The site is located within 10 meters from Interstate-5 highway and 350 meters from Interstate-90 highway. It has been routinely collecting CO, NO_2, NO_x, $PM_{2.5}$, and black carbon data, along with weather variables (wind & ambient temperature). The station has been used in several studies and is a common location for additional monitoring (e.g. $PM_{2.5}$ speciation, air toxics).

Figure A- 1. Seattle 10th and Weller monitoring site from Google Maps imagery.

Figure A-2. Seattle 10th and Weller Ecology air-quality monitoring site is located in the red square. Aerial imagery is from Google Earth Engine.



Seattle Beacon Hill (SEWA):

Figure A-3: Seattle Beacon Hill monitoring site from Google Maps imagery.

This site, also operated by WA State Department of Ecology, is located in the middle of Jefferson Park near the highest part of the ridge connecting Beacon Hill and North Beacon Hill. It is surrounded by a golf course and a public park with open grass fields and a playground. I-5 is approximately 0.8 km to the west at the bottom of a sharp, 100-meter slope that is the edge of Duwamish Valley and Beacon Hill. The road nearest the site with major traffic is Beacon Ave S, which is about 100 m to the east. The closest residences are about 350 m to the west. The site is run by WA Ecology and has been a primary monitoring station since at least 1979, although the location within Jefferson Park has changed. The station includes monitors for ozone, CO, SO_2, NO_y, $PM_{2.5}$, along with $PM_{2.5}$ speciation and weather data (wind and ambient temperature). It is also a part of the National Air Toxics Trends Stations (NATTS) network and continuously monitors air toxics (Carbonyls, VOCs, PAHs) for recording long-term trends.

Figure A-4. Seattle Beacon Hill Ecology air-quality monitoring site is located in the red square. Aerial imagery is from Google Earth Engine

Seattle Duwamish (CEWA):

The Seattle Duwamish monitoring site has been in place for about 50 years (since 1971) in the Duwamish industrial valley. This site is designed to be a neighborhood-scale site, representative of South Seattle neighborhoods and ambient exposure in the industrial valley. This site is influenced by a complex mixture of mobile sources, marine sources, industrial sources, winter home heating wood smoke, and other pollution sources. The site used to be located about 400

Figure A-5. Seattle Duwamish monitoring site from Google Maps imagery

meters NW of the current site. It is located about 80 meters East of E Marginal Way S, which is a main arterial for many large haul trucks, as well as service vehicles, and personal cars. The site collects continuous air quality data such as $PM_{2.5}$, Black carbon, along with weather variables (wind, ambient temperature and pressure, rain gauge (SPU – RG15)). Given its settings, it is also a common location for additional studies such as $PM_{2.5}$ speciation and/or air toxics (Carbonyls, VOCs, SVOCs, etc.)

Figure A-6. Seattle Duwamish air-quality monitoring site is located in the red square. Aerial imagery is from Google Earth Engine.

Tacoma Tideflats (EQWA):

This monitoring site has been in place since 1987 collecting air pollution data at the Port of Tacoma, also known as the Tacoma Tideflats. It is a large container port in North America and represents a critical hub for containers, heavy cargo, cars, and trucks. The main industrial activities at the port include manufacturing (metal, lumber, concrete, paper), oil refining, and large goods movement (warehouse, shipping/receiving). The port is also connected to railroads and the major roadways Hwy-509 and I-5 are located within 2 km and 2.7 km, respectively.

Figure A-7. Tacoma Tideflats air-quality monitoring site is located in the red square. Aerial imagery is from Google Earth Engine.

Tacoma S 36th St:

This monitoring site, operated by WA State Dept. of Ecology, corresponds to Tacoma's near-road air-quality monitoring site. It is located at 15 meters from Interstate-5 highway and is routinely collecting NO_2, NO_x and $PM_{2.5}$. We added a black-carbon monitor (Magee AE-33 aethalometer) when we started the 1-yr air-toxics monitoring campaign in the summer of 2021. Weather variables such as wind and ambient temperature are also recorded at this site.

Figure A-8: Tacoma S 36th monitoring site from Google Maps imagery.

Figure A-9. Tacoma S 36th air-quality monitoring site from the Department of Ecology is located in the red square. Aerial imagery is from Google Earth Engine.

Tacoma South L St:

This site has been in place since 1999 in the South part of Tacoma. It is a neighborhood scale site and aims to be representative of Tacoma residential area. The main source of air pollution comes from home heating using wood burning. The site is also around 1 km from any substantial traffic (I-5, Hwy-512, and neighborhood arterials). While there are other sources likely contributing to PM2.5 concentration, the majority is winter home heating from wood burning. This monitoring site has the highest design value in the Puget Sound region for PM2.5 for the 24-hr standard.

Figure A-10. Tacoma South L monitoring site photo

Figure A-11. Tacoma South L air-quality monitoring site is located in the red square. Aerial imagery is from Google Earth Engine.

Community-directed sites:

These sites were identified after consultation with the Duwamish Valley community (as described in the main report) to see what where their highest area of concern regarding air pollution and where they wanted to locate the air-quality instruments. These sites encompass various settings and aim to be representative of more industrial settings (UEWA), residential settings (UBWA & UCWA, for South Park and Georgetown, respectively), near regional airport (UDWA) and where a previous study reported highest levels of metals for the area (UAWA). Nearest intersections are shared in the main report.

Figure A-12. Locations of the 5 community-directed sites for the summer of 2022 where we collected weekly PM10 metal samples in the Georgetown and South Park neighborhoods. Aerial imagery is from Google Earth Engine.

Appendix B. Quality assurance

This appendix contains information on data completeness, non-detects (NDs), samples that were below the detection limit (MDL), any recorded sampling issues, collocated duplicate samples, and mean field blank values.

Table B-1. Data completeness and total sample collections for each studied site

Group of pollutants analyzed	Collection Start	Collection End	Time interval	Total samples collected	Data Completeness (%)
Tacoma South L (ESWA) 53 053 0029					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	64	95.5%
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	66	98.5%
$PM_{2.5}$ Speciation	Aug 2, 2021	Sep 2, 2022	1-in-6 days	67	100%
$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9216	96.7%
Black Carbon	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9370	98.3%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9468	99.4%
Tacoma S 36th (YFWA) 53 053 0024					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	62	92.5%
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	63	94%
$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	8880	93.2%
Black Carbon	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9515	99.9%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9518	99.9%
Tacoma Tideflats (EQWA) 53 053 0031					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	65	97%
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	63	94%
$PM_{2.5}$ Speciation	Aug 2, 2021	Feb 10, 2022	1-in-6 days	33	100%
$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous	9132	95.8%

			(hourly)		
Black Carbon	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9245	97%
PM_{10} Metals	Aug 2, 2021	Sep 2, 2022	1-in-6 days	65	97%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9352	98%
Seattle Duwamish (CEWA) 53 033 0057					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	62	92.5%
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	64	95.5%
$PM_{2.5}$ Speciation	Aug 2, 2021	Jun 28, 2022	1-in-6 days	56	100%
$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9366	98.3%
Black Carbon	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9480	99.5%
PM_{10} Metals	Aug 2, 2021	Sep 2, 2022	1-in-6 days	67	100%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9492	99.6%
SVOC PAH	Aug 2, 2021	Sep 2, 2022	1-in-6 days	62	92.5%
Seattle Beacon Hill (SEWA) 53 033 0029					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	62	92.5
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	67	100%
$PM_{2.5}$ Speciation	Aug 2, 2021	Sep 2, 2022	1-in-3 days	133	100%
$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9136	95.9%
PM_{10} Metals	Aug 2, 2021	Sep 2, 2022	1-in-6 days	98**	100%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	8989	94.2%*
SVOC PAH	Aug 2, 2021	Sep 2, 2022	1-in-6 days	72**	100%
Seattle 10th & Weller (BKWA) 53 033 030					
VOCs	Aug 2, 2021	Sep 2, 2022	1-in-6 days	64	95.5%
Carbonyls	Aug 2, 2021	Sep 2, 2022	1-in-6 days	63	94%
$PM_{2.5}$ Speciation	Aug 2, 2021	Jul 28, 2022	1-in-6 days	61	100%

$PM_{2.5}$	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9342	98%
Black Carbon	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9510	99.8%
Wind	Aug 2, 2021	Sep 2, 2022	Continuous (hourly)	9522	99.9%
South Seattle College (UAWA)					
PM_{10} Metals	Mar 4, 2022	Sep 2, 2022	weekly	26	100%
South Park Residential (UBWA)					
PM_{10} Metals	Jul 1, 2022	Sep 2, 2022	weekly	9	100%
Georgetown Residential (UCWA)					
PM_{10} Metals	Jul 1, 2022	Sep 2, 2022	weekly	8.2	100%
Georgetown Steam Plant (UDWA)					
PM_{10} Metals	Jul 29, 2022	Sep 2, 2022	weekly	5	100%
South Park Industrial (UEWA)					
PM_{10} Metals	Jul 25, 2022	Sep 2, 2022	weekly	5.6	100%

*Beacon Hill wind data were invalidated due to a 6-8° misalignment for 12/3/21 – 3/11/22. While slightly above our 5° tolerance, we still used the data in the wind/pollution rose analysis (Appendix D); since it did not impact substantially the wind direction binned averages.

**Beacon Hill SVOCs and PM_{10} metals had some extra samples (+ 5 and +31, respectively) collected over the study period which are included in the data analysis, but we capped the data completeness at 100%.

Table B-2. Air toxics log of instrument & sampling issues resulting in a missed sample, or a sample being rescheduled (within +/- 3 days of planned date).

Date	Site(s) affected (code)	Types	Sample	Reason(s)
Aug-2 2021	BKWA, CEWA, EQWA, YFWA	Carbonyl (TO-11A)	No	Not started
Aug-2 2021	CEWA	SVOCs (TO-13A)	No	Not started
Aug-2 2021	CEWA, EQWA	PM_{10} metals (IO-3.5)	No	Not started
Aug-5 2021	CEWA	Carbonyl (TO-11A)	Yes	Sample ran on 8/5 instead of 8/2

Aug-8 2021	BKWA, EQWA, YFWA	Carbonyl (TO-11A)	No	Not started yet
Aug-2 2021	CEWA	SVOCs (TO-13A)		Not started
Aug-14 2021	BKWA, CEWA, EQWA, YFWA, ESWA	VOCs (TO-15)	No	Skipped
Aug-14 2021	BKWA, CEWA, EQWA, YFWA, ESWA	Carbonyl (TO-11A)	No	Not started or skipped due to coordination with lab.
Aug-14 2021	CEWA	SVOCs (TO-13A)		Not started yet
Aug-20 2021	YWFA	VOCs (TO-15)	No	Sample voided – can cross threaded
Aug- 26 2021	YWFA	VOCs (TO-15)	No	No canister received from lab for collection
Aug-26 2021	SEWA	Carbonyl (TO-11A)	Yes	Sample ran on 8/29 instead of 8/26
Sep-7 2021	BKWA, CEWA, EQWA, YFWA, ESWA	VOCs (TO-15)	No	Skipped because of no canisters ready for sampling (shipping delays)
Sep-13 2021	ESWA	VOCs (TO-15)	No	Canister voided because reading ambient pressure at the lab (no vacuum left)
Sep-13 2021	SEWA	VOCs, SVOCs, Carbonyl	Yes	Samples ran on 9/16 instead of 9/13
Sep-19 2021	BKWA, CEWA	VOCs (TO-15)	No	Canister voided because reading ambient pressure at the lab (no vacuum left)
Sep-25 2021	SEWA	VOCs (TO-15)	No	Sample missing
Oct-13 2021	BKWA	VOCs (TO-15)	Yes	Canister voided (no vacuum at reception)

				but was able to use a different canister and still collect data for that day
Oct-25 2021	CEWA	Carbonyl (TO-11A)	No	Instrument malfunction
Oct-25 2021	SEWA	Carbonyl (TO-11A)	No	Void – power outage
Oct-25 2021	EQWA	VOCs (TO-15)	Yes	Final field vacuum = 0
Oct-31 2021	BKWA, CEWA, YFWA, ESWA	VOCs (TO-15)	Yes	Final field vacuum at 0 with time shut-off issues due to cold temperatures.
Nov-30 2021	CEWA	VOCs (TO-15)	No	Sample did not collect (valve remained close)
Nov-30 2021	SEWA	VOCs, SVOCs, Carbonyl	Yes	Samples ran on 12/1 instead of 11/30
Dec-30 2021	EQWA	PM_{10} metals (IO-3.5)	No	Sample did not collect (instrument did not run)
Jan-29 2022	BKWA	VOCs (TO-15)	Yes	TO-15 started at -12 inHg (instead of -30) vacuum.
Feb-28 2022	CEWA	VOCs (TO-15)	No	TO-15 voided, canister was not open for sampling
Feb-28 2022	EQWA	Carbonyl (TO-11A)	No	Instrument did not run
Mar-6 2022	YFWA	VOCs (TO-15)	No	Valve did not open – corrosion on timer.
Mar-18 2022	BKWA, CEWA	VOCs (TO-15)	Yes	Only ran for 13:50 and 14:50 hours, respectively
Mar-30 2022	SEWA	Carbonyl (TO-11A) & SVOCs (TO-13A)	Yes	Sample ran on 4/2 instead of 3/30

Apr-5 2022	SEWA	VOCs (TO-15)	Yes	Sample ran on 4/2 instead of 4/5
Apr-5 2022	YFWA	VOCs (TO-15)	Yes	TO-15 started at -25 inHg (instead of -30) vacuum.
Apr-11 2022	YFWA	Carbonyl (TO-11A)	No	Power outage
May-5 2022	BKWA	VOCs (TO-15)	Yes	TO-15 started at -24 inHg (instead of -30) vacuum.
May-29 2022	SEWA	VOCs (TO-15)	No	Sample did not run - received vacuum of 29.0 inHg at the lab
Jun-10 2022	SEWA	VOCs (TO-15)	No	Sample did not run - received vacuum of 29.0 inHg at the lab
Jun-22 2022	EQWA	Carbonyl (TO-11A)	Yes	Instrument off due to power outage. Make up sample ran on 6/30
Jun-22 2022	SEWA	VOCs (TO-15)	Yes	Sample ran on 6/25 instead of 6/22
Jul-1 2022	UCWA	PM_{10} metals (IO-3.5)	Yes	Sample ran for 25 hours instead of 1 week
Jul-4 2022	BKWA	Carbonyl (TO-11A)	No	Instrument did not run
Jul-10 2022	SEWA	Carbonyl (TO-11A)	No	Perhaps a low-sample time but would need to confirm with Ecology
Jul-10 & 16 & 22 2022	SEWA	VOCs (TO-15)	No	Samples did not run – received at high vacuum in lab.
Aug-3 2022	SEWA	SVOCs (TO-13A)	No	Voided by lab. Sample fails all surrogates

				likely due to an extraction error.
Aug-9 2022	SEWA	Carbonyl (TO-11A)	No	Sample did not run – monitoring or operation error.
Aug-9 & 15 2022	SEWA	VOCs (TO-15)	No	Samples did not run – received at high vacuum in lab.
July-29 2022	UEWA	PM_{10} metals (IO-3.5)	Yes	Sample ran for 5 days instead of 7 days
Sept-2 2022	CEWA	VOCs (TO-15)	Yes	Sample ended at -18 inHg somehow

Table B-3. Percentage (%) of non-detect (ND) samples for each chemical compound (analyte) measured per site.

Groups	**Analytes**	**BKWA**	**CEWA**	**EQWA**	**ESWA**	**SEWA**	**YFWA**
Carbonyls	Acetaldehyde	0	0	0	0	0	0
	Formaldehyde	0	0	0	0	0	0
VOCs	1,3-Butadiene	0	5	2	2	6	0
	Acrolein	2	0	0	2	0	3
	Benzene	0	0	0	0	0	0
	Carbon Tetrachloride	0	0	0	0	0	0
	Ethylbenzene	0	0	0	0	0	0
	Ethylene oxide	6	0	2	2	0	2
	Tetrachloroethylene	0	0	0	0	2	2
PM_{10} Metals*	Manganese		0	0		0	
	Lead		0	0		0	
	Chromium		0	0		0	

	Antimony		0	0		0	
	Nickel		0	0		0	
	Selenium		0	2		0	
	Arsenic		0	0		0	
	Beryllium		19	14		24	
	Cadmium		0	0		0	
	Cobalt		0	0		1	
	Mercury		4	6		0	
SVOCs	Naphthalene		0			0	
	Acenaphthene		31			38	
	Phenanthrene		0			0	
	Fluorene		0			0	
	Fluoranthene		0			0	
	Pyrene		0			4	
	Acenaphthylene		35			50	
	Anthracene		13			0	
	Benzo(a)anthracene		13			13	
	Benzo(a)pyrene		8			24	
	Benzo(b)fluoranthene		44			49	
	Benzo(e)pyrene		8			11	
	Benzo(g,h,i)perylene		10			16	
	Benzo(k)fluoranthene		21			38	
	Chrysene		61			65	
	Coronene		11			14	

	Dibenz(a,h)anthracene		87			83	
	Indeno(1,2,3-c,d)pyrene		15			21	
	Perylene		89			93	

*No non-detect (ND) samples were reported for the community-directed weekly samples at the UAWA, UBWA, UCWA, UDWA, UEWA sites.

Table B-4. Percentage (%) of samples below the method detection limit (MDL) for each chemical compound (analyte) measured per site. This percentage includes the non-detect samples (Table B-3).

Groups	**Analytes**	**BKWA**	**CEWA**	**EQWA**	**ESWA**	**SEWA**	**YFWA**
Carbonyls	Acetaldehyde	0	0	0	0	1	0
	Formaldehyde	0	0	0	0	1	0
VOCs	1,3-Butadiene	8	48	54	53	71	23
	Acrolein	17	23	17	22	29	13
	Benzene	0	0	0	0	0	0
	Carbon Tetrachloride	0	0	0	0	0	2
	Ethylbenzene	0	0	0	3	0	0
	Ethylene oxide	8	3	9	6	5	6
	Tetrachloroethylene	80	63	75	80	98	84
PM_{10} Metals*	Manganese		0	0		0	
	Lead		0	0		0	
	Chromium		97	98		90	
	Antimony		0	0		0	
	Nickel		12	3		48	
	Selenium		0	18		6	
	Arsenic		0	0		0	
	Beryllium		40	57		98	

	Cadmium		0	5		3	
	Cobalt		34	46		62	
	Mercury		81	82		93	
SVOCs	Naphthalene		0			0	
	Acenaphthene		31			38	
	Phenanthrene		0			0	
	Fluorene		0			0	
	Fluoranthene		0			0	
	Pyrene		0			4	
	Acenaphthylene		35			50	
	Anthracene		13			3	
	Benzo(a)anthracene		13			21	
	Benzo(a)pyrene		18			38	
	Benzo(b)fluoranthene		44			50	
	Benzo(e)pyrene		10			15	
	Benzo(g,h,i)perylene		16			22	
	Benzo(k)fluoranthene		39			53	
	Chrysene		61			67	
	Coronene		11			15	
	Dibenz(a,h)anthracene		89			85	
	Indeno(1,2,3-c,d)pyrene		15			24	
	Perylene		95			96	

*Samples reported below the MDL (method detection limit) for the community-directed weekly samples are presented in the table below. UCWA MDL percentages are due to a partial sample collected on Jul 1st of 25 hours instead of 7 days (table B-2).

Table B-5. Percentage (%) of samples below the method detection limit (MDL) for each chemical compound (analyte) measured per site.

Groups	Analytes	UAWA	UBWA	UCWA	UDWA	UEWA
PM_{10} Metals	Manganese	0	0	0	0	0
	Lead	0	0	0	0	0
	Chromium	4	0	11	0	0
	Antimony	0	0	0	0	0
	Nickel	4	0	0	0	0
	Selenium	0	0	0	0	0
	Arsenic	0	0	0	0	0
	Beryllium	0	0	11	0	0
	Cadmium	0	0	0	0	0
	Cobalt	4	0	0	0	0
	Mercury	4	0	11	0	0

Table B-6. Table of collocated duplicate samples with percent recovery greater than ± 20%. Samples were only included if the primary and duplicate concentrations were greater than 3x the method detection limit (MDL).

Site	Sample Date	Analyte	Primary Conc	Duplicate Conc	MDL	Units	Percent Recovery
SEWA	8/5/2021	Acenaphthylene	0.09	0.113	0.003	ng/m³	126
CEWA	2/16/2022	Beryllium	0.015	0.019	0.004	ng/m³	131
CEWA	11/18/2021	Cobalt	0.346	0.424	0.077	ng/m³	123
SEWA	7/15/2021	Dibenz(a,h)anthracene	0.021	0.016	0.005	ng/m³	78
EQWA	11/18/2021	Ethylene oxide	0.099	0.196	0.026	ppbv	199
ESWA	9/19/2021	Ethylene oxide	0.187	0.099	0.026	ppbv	53
YFWA	2/16/2022	Ethylene oxide	0.141	0.407	0.026	ppbv	289
EQWA	9/19/2021	Lead	0.744	0.905	0.065	ng/m³	122
CEWA	11/18/2021	Manganese	444	539	0.625	ng/m³	121

Table B-7. Mean ambient, field blank, and MDL concentrations for all Sites and Analytes for which blank values were collected. Field blank values were not collected for VOCs, and field blanks were not collected for the community-directed PM10 metals samples.

Site	Analyte	Type	Units	Median Ambient Conc	Mean Field Blank Conc	Mean MDL
BKWA	Acetaldehyde	Carbonyl	ug/m³ Air	1.243	0.020	0.031
BKWA	Formaldehyde	Carbonyl	ug/m³ Air	2.098	0.024	0.044
CEWA	Acetaldehyde	Carbonyl	ug/m³ Air	0.886	0.019	0.031
CEWA	Formaldehyde	Carbonyl	ug/m³ Air	1.336	0.020	0.044
CEWA	Antimony	Metal	ng/m³ Air	1.797	0.013	0.109
CEWA	Arsenic	Metal	ng/m³ Air	1.315	0.011	0.032
CEWA	Beryllium	Metal	ng/m³ Air	0.006	0.001	0.004
CEWA	Cadmium	Metal	ng/m³ Air	0.126	0.003	0.010
CEWA	Chromium	Metal	ng/m³ Air	4.514	1.988	8.890
CEWA	Cobalt	Metal	ng/m³ Air	0.191	0.010	0.098
CEWA	Lead	Metal	ng/m³ Air	6.800	0.082	0.084
CEWA	Manganese	Metal	ng/m³ Air	22.328	0.321	0.346
CEWA	Mercury	Metal	ng/m³ Air	0.033	0.002	0.013
CEWA	Nickel	Metal	ng/m³ Air	1.594	0.487	0.640
CEWA	Selenium	Metal	ng/m³ Air	2.036	0.009	0.050
CEWA	Acenaphthene	SVOC	ng/m³ Air	4.016	0.069	0.073
CEWA	Acenaphthylene	SVOC	ng/m³ Air	0.455	0.005	0.005
CEWA	Anthracene	SVOC	ng/m³ Air	0.295	0.008	0.023
CEWA	Benzo(a)anthracene	SVOC	ng/m³ Air	0.048	0.006	0.005
CEWA	Benzo(a)pyrene	SVOC	ng/m³ Air	0.048	0.008	0.008
CEWA	Benzo(b)fluoranthene	SVOC	ng/m³ Air	0.051	0.011	0.009
CEWA	Benzo(e)pyrene	SVOC	ng/m³ Air	0.067	0.008	0.008
CEWA	Benzo(g,h,i)perylene	SVOC	ng/m³ Air	0.092	0.010	0.005
CEWA	Benzo(k)fluoranthene	SVOC	ng/m³ Air	0.040	0.006	0.010
CEWA	Chrysene	SVOC	ng/m³ Air	0.021	0.008	0.007
CEWA	Coronene	SVOC	ng/m³ Air	0.056	NA	0.007
CEWA	Dibenz(a,h)anthracene	SVOC	ng/m³ Air	0.006	NA	0.005
CEWA	Fluoranthene	SVOC	ng/m³ Air	1.808	0.015	0.040
CEWA	Fluorene	SVOC	ng/m³ Air	3.537	0.021	0.054
CEWA	Indeno(1,2,3-c,d)pyrene	SVOC	ng/m³ Air	0.074	0.009	0.006
CEWA	Naphthalene	SVOC	ng/m³ Air	43.319	0.550	1.730
CEWA	Perylene	SVOC	ng/m³ Air	0.006	NA	0.009

Site	Analyte	Type	Units	Median Ambient Conc	Mean Field Blank Conc	Mean MDL
CEWA	Phenanthrene	SVOC	ng/m³ Air	8.045	0.055	0.143
CEWA	Pyrene	SVOC	ng/m³ Air	2.532	0.014	0.033
EQWA	Acetaldehyde	Carbonyl	ug/m³ Air	1.012	0.026	0.032
EQWA	Formaldehyde	Carbonyl	ug/m³ Air	1.526	0.022	0.044
EQWA	Antimony	Metal	ng/m³ Air	1.864	0.034	0.111
EQWA	Arsenic	Metal	ng/m³ Air	1.050	0.013	0.033
EQWA	Beryllium	Metal	ng/m³ Air	0.010	0.002	0.004
EQWA	Cadmium	Metal	ng/m³ Air	0.105	0.003	0.011
EQWA	Chromium	Metal	ng/m³ Air	2.989	1.644	9.000
EQWA	Cobalt	Metal	ng/m³ Air	0.207	0.012	0.099
EQWA	Lead	Metal	ng/m³ Air	3.995	0.097	0.085
EQWA	Manganese	Metal	ng/m³ Air	9.582	0.610	0.345
EQWA	Mercury	Metal	ng/m³ Air	0.009	0.002	0.013
EQWA	Nickel	Metal	ng/m³ Air	1.856	0.649	0.648
EQWA	Selenium	Metal	ng/m³ Air	0.150	0.017	0.051
ESWA	Acetaldehyde	Carbonyl	ug/m³ Air	0.961	0.019	0.032
ESWA	Formaldehyde	Carbonyl	ug/m³ Air	1.408	0.022	0.045
SEWA	Acetaldehyde	Carbonyl	ug/m³ Air	0.927	0.026	0.029
SEWA	Formaldehyde	Carbonyl	ug/m³ Air	1.308	0.044	0.043
SEWA	Antimony	Metal	ng/m³ Air	1.045	0.008	0.105
SEWA	Arsenic	Metal	ng/m³ Air	0.471	0.006	0.032
SEWA	Beryllium	Metal	ng/m³ Air	0.002	0.000	0.004
SEWA	Cadmium	Metal	ng/m³ Air	0.045	0.003	0.012
SEWA	Chromium	Metal	ng/m³ Air	6.293	4.991	8.688
SEWA	Cobalt	Metal	ng/m³ Air	0.101	0.040	0.098
SEWA	Lead	Metal	ng/m³ Air	2.376	0.030	0.089
SEWA	Manganese	Metal	ng/m³ Air	5.130	0.175	0.371
SEWA	Mercury	Metal	ng/m³ Air	0.007	0.001	0.013
SEWA	Nickel	Metal	ng/m³ Air	0.821	0.162	0.606
SEWA	Selenium	Metal	ng/m³ Air	0.249	0.005	0.050
SEWA	Acenaphthene	SVOC	ng/m³ Air	2.383	0.155	0.067
SEWA	Acenaphthylene	SVOC	ng/m³ Air	0.129	0.026	0.004
SEWA	Anthracene	SVOC	ng/m³ Air	0.130	0.008	0.022
SEWA	Benzo(a)anthracene	SVOC	ng/m³ Air	0.041	0.002	0.005
SEWA	Benzo(a)pyrene	SVOC	ng/m³ Air	0.044	NA	0.007

Site	Analyte	Type	Units	Median Ambient Conc	Mean Field Blank Conc	Mean MDL
SEWA	Benzo(b)fluoranthene	SVOC	ng/m³ Air	0.062	0.004	0.008
SEWA	Benzo(e)pyrene	SVOC	ng/m³ Air	0.051	0.004	0.007
SEWA	Benzo(g,h,i)perylene	SVOC	ng/m³ Air	0.056	NA	0.004
SEWA	Benzo(k)fluoranthene	SVOC	ng/m³ Air	0.031	NA	0.009
SEWA	Chrysene	SVOC	ng/m³ Air	0.024	0.004	0.006
SEWA	Coronene	SVOC	ng/m³ Air	0.029	NA	0.007
SEWA	Dibenz(a,h)anthracene	SVOC	ng/m³ Air	0.009	NA	0.005
SEWA	Fluoranthene	SVOC	ng/m³ Air	0.889	0.016	0.037
SEWA	Fluorene	SVOC	ng/m³ Air	2.334	0.024	0.052
SEWA	Indeno(1,2,3-c,d)pyrene	SVOC	ng/m³ Air	0.057	NA	0.005
SEWA	Naphthalene	SVOC	ng/m³ Air	26.939	0.665	1.132
SEWA	Perylene	SVOC	ng/m³ Air	0.010	NA	0.008
SEWA	Phenanthrene	SVOC	ng/m³ Air	3.892	0.063	0.136
SEWA	Pyrene	SVOC	ng/m³ Air	0.507	0.012	0.027
YFWA	Acetaldehyde	Carbonyl	ug/m³ Air	0.851	0.024	0.032
YFWA	Formaldehyde	Carbonyl	ug/m³ Air	1.285	0.065	0.045

Appendix C. Meteorology representativeness

Figure C-1 below shows the '10-yr History' line (blue), which is the 7-day running average of the daily average temperature for the past 10 years. The +/- 'stdv' lines are + and – 1 standard deviations, calculated daily, for each day of the daily average temperature for the past 10 years. The 'Sample Period' line (rust orange) is the daily average temperature for the sampling period of this study.

Figure C-1. Daily average temperatures at the Seattle Duwamish Valley site.

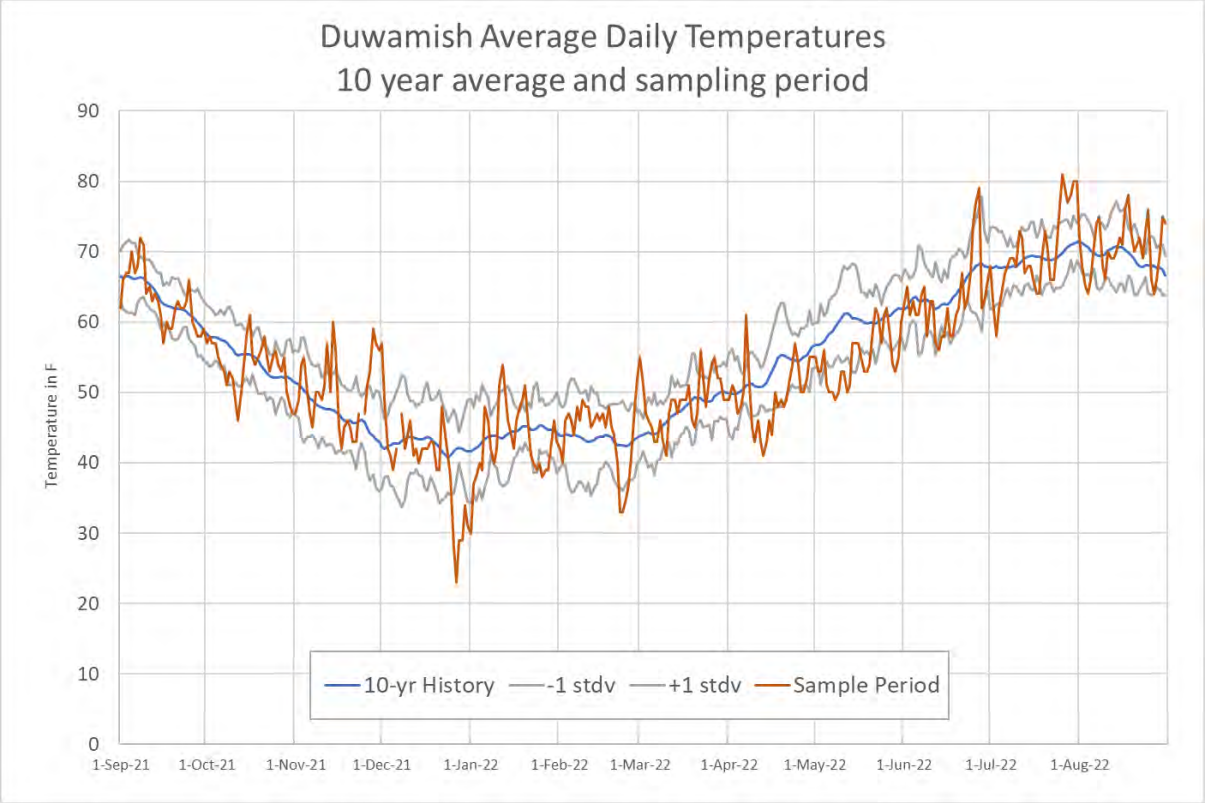


Figure C-2 below shows the '10-yr History' line (in blue) as the 7-day running average of the daily average wind speed for the past 10 years. The +/- stdv lines are + and – 1 standard deviations, calculated daily, for each day of the daily average wind speed for the past 10 years. The 'Sample Period' line (rust orange) is the daily average wind speed for the sampling period of this study.

Figure C-2. Daily average wind speed at the Seattle Duwamish Valley site.

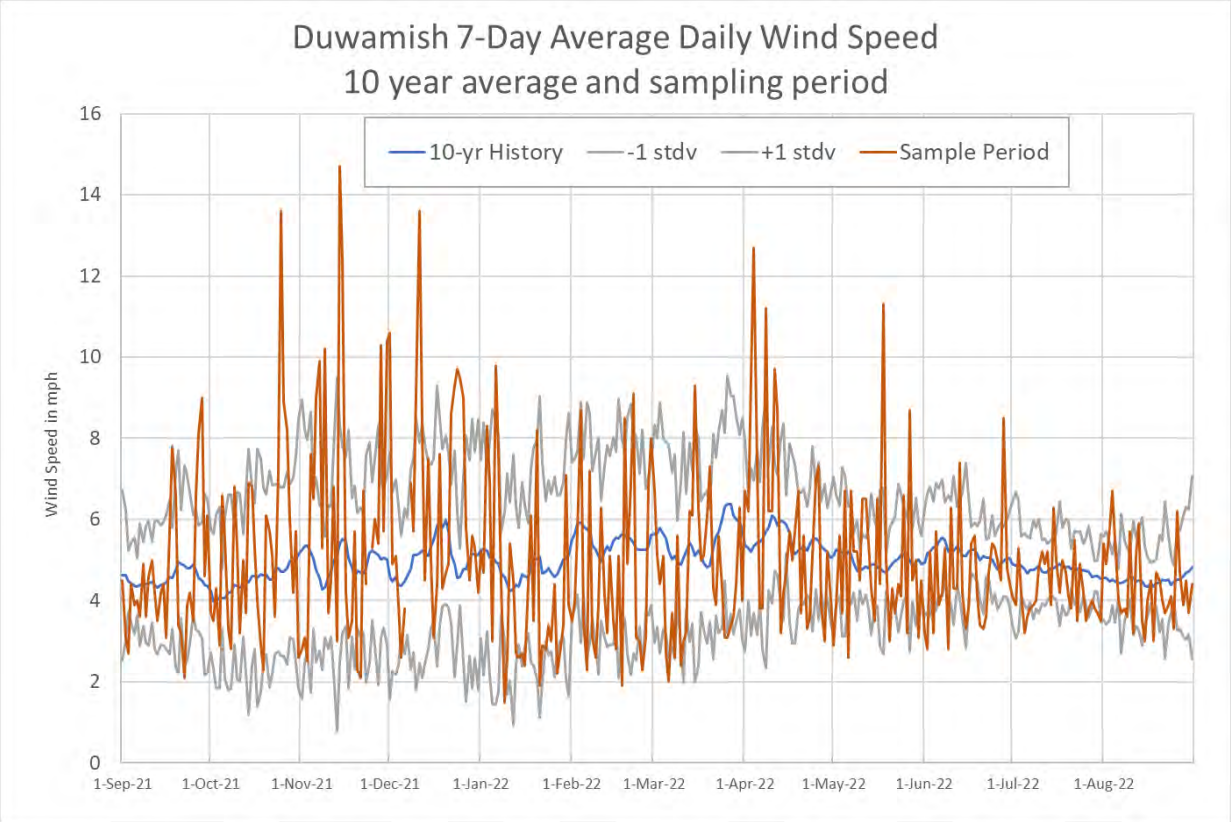


Figure C-3. Counts of hourly wind direction, colored by wind speed bin, for the past 10 years (below, top) and for the year of the toxics sampling campaign (below, bottom).

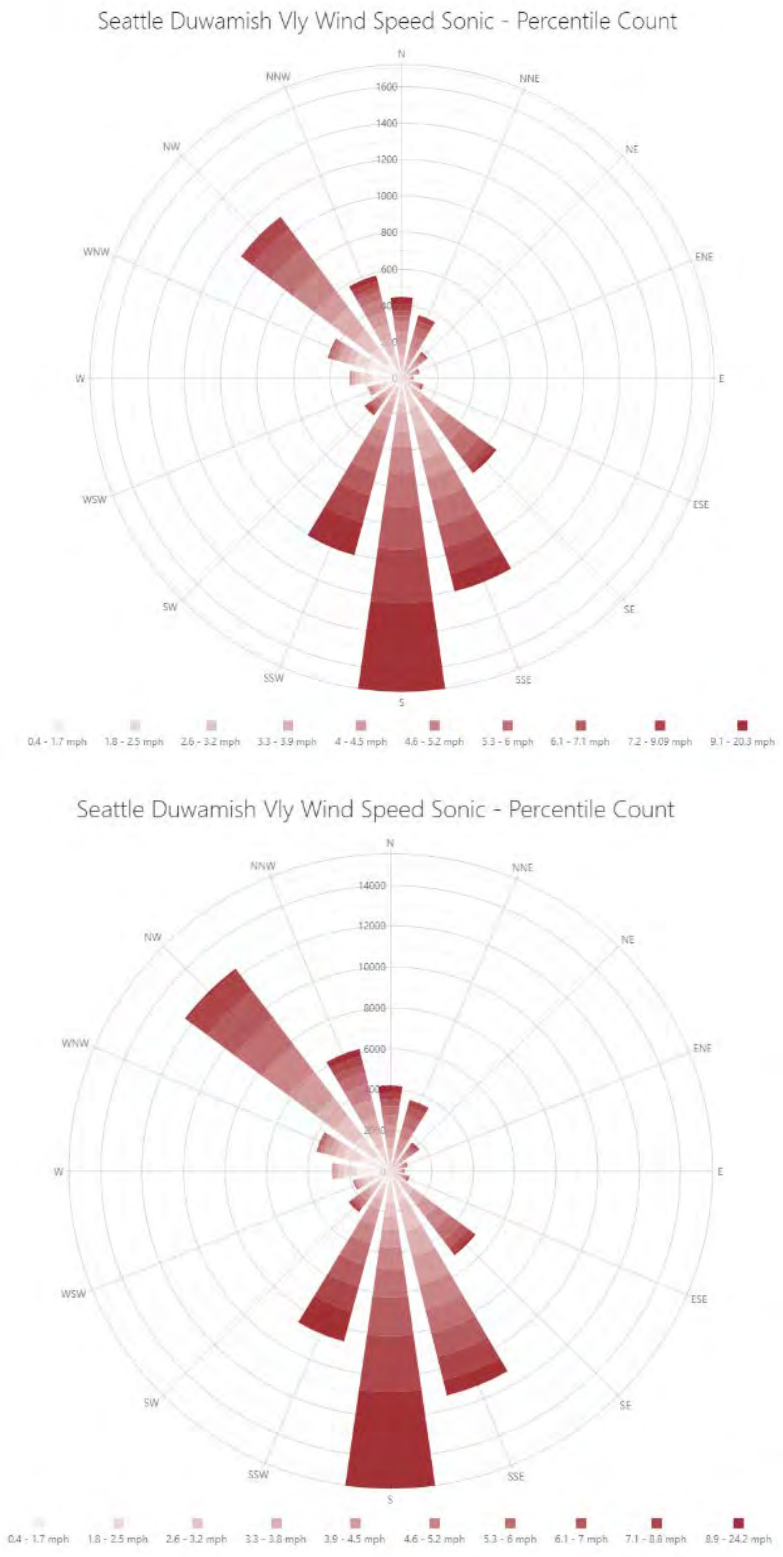


Figure C-4. Counts of hourly wind direction, colored by wind speed bin, for the July-Aug period for 2021 (below, top) and for July-Aug period of the toxics sampling campaign 2022 (below, bottom)

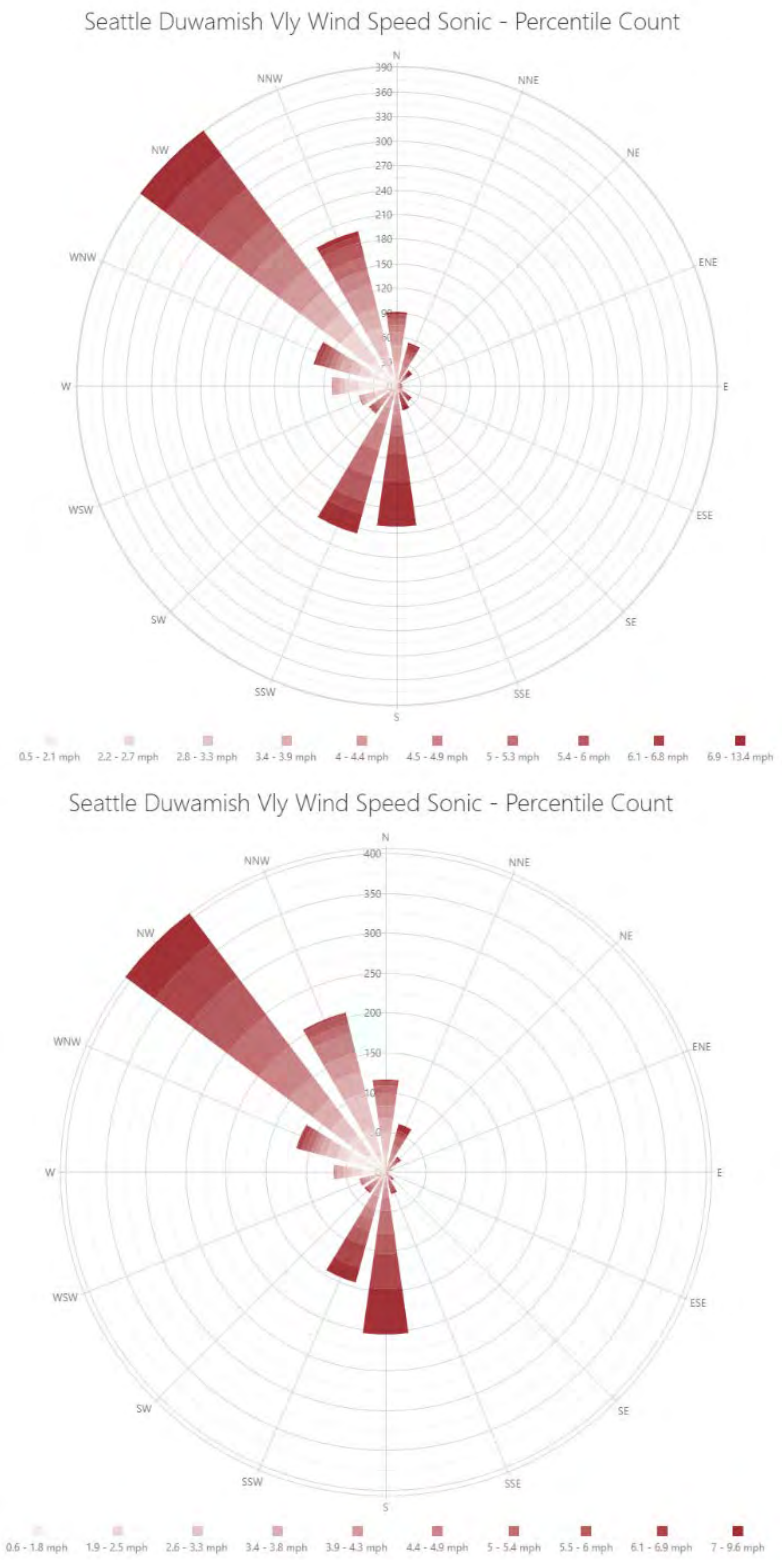
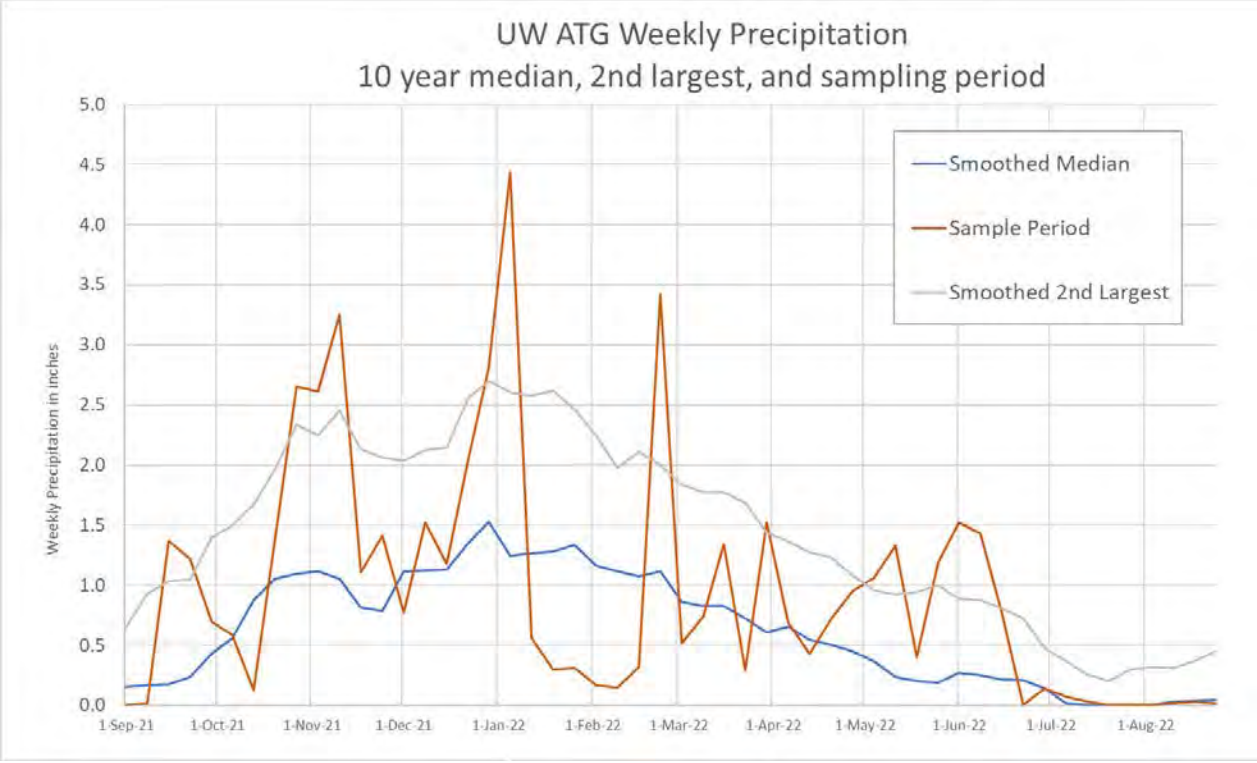


Figure C-5 below shows results from precipitation measured at the University of Washington Atmospheric Sciences building. Because precipitation is not distributed smoothly like many other parameters (it has many zeros and extreme values, so is not statistically 'normal'), the data must be treated differently to analyze for outliers and general trends. Here, this means not using extreme values, and averaging or smoothing daily values to longer periods. For identifying extreme events, the median and the second greatest weekly values were found for each week over the 10 years. The values were then smoothed with a 5-week running average, plotted at the center week. The median line shows a typical or central value, and the '2nd Largest' line shows a value that we would expect to be significantly exceeded 5 or 6 times in a typical year. Deviations from typical precipitation that would be worthy of noting would be extended below normal precipitation in the winter and extended above normal precipitation in the summer. The period from mid-January to mid-February was unusually dry, and May through mid-June was unusually wet.

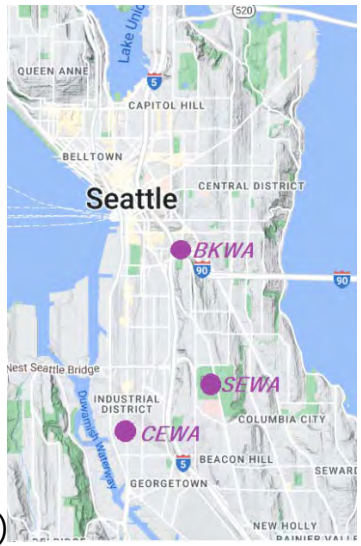
Figure C-5. UW Atmospheric Sciences-Geophysics Building precipitation values.



Appendix D. Pollution roses for $PM_{2.5}$ and black carbon

Figure D-1: Maps of the wind data collection in the Seattle area (A) and in the Tacoma area (B). The location codes can be identified as follow: Seattle 10th and Weller (BKWA), Seattle Duwamish (CEWA), Seattle Beacon Hill (SEWA), Tacoma Alexander Ave (EQWA), Tacoma 36th St (YFWA) and Tacoma South L St (ESWA). Background maps are from Google Earth Engine.

(A)



(B)

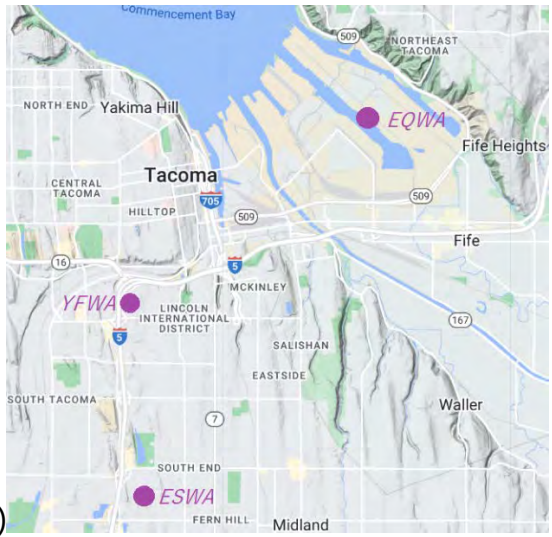


Figure D-2. Hourly wind roses (wind speed) coincident with air-toxics samples (1 every 6 days) between August 2021 and September 2022.

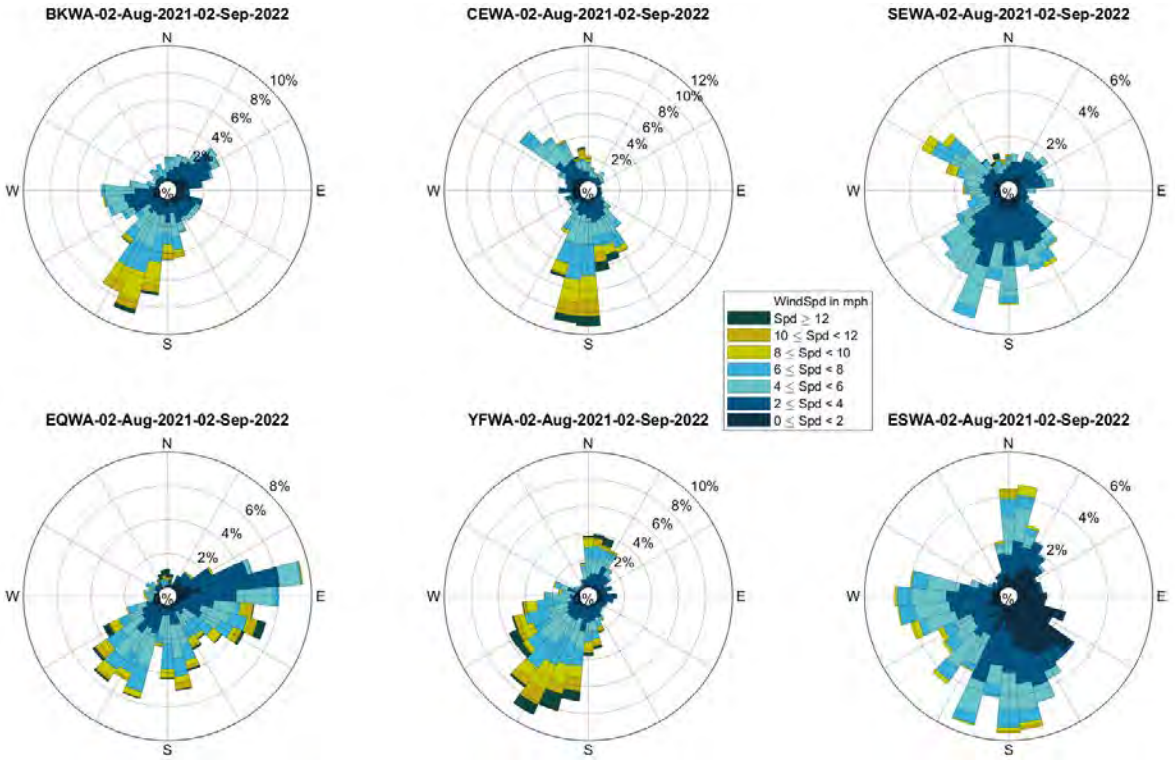


Figure D-3: Daily $PM_{2.5}$ times series (gray dots) at our 6 studied sites with teal colors representing 1-in-6 air-toxics sampling days between August 2021 and September 2022. The green line represents the 1-in-6-day average, and the black line represents the overall average for the entire sampling period.

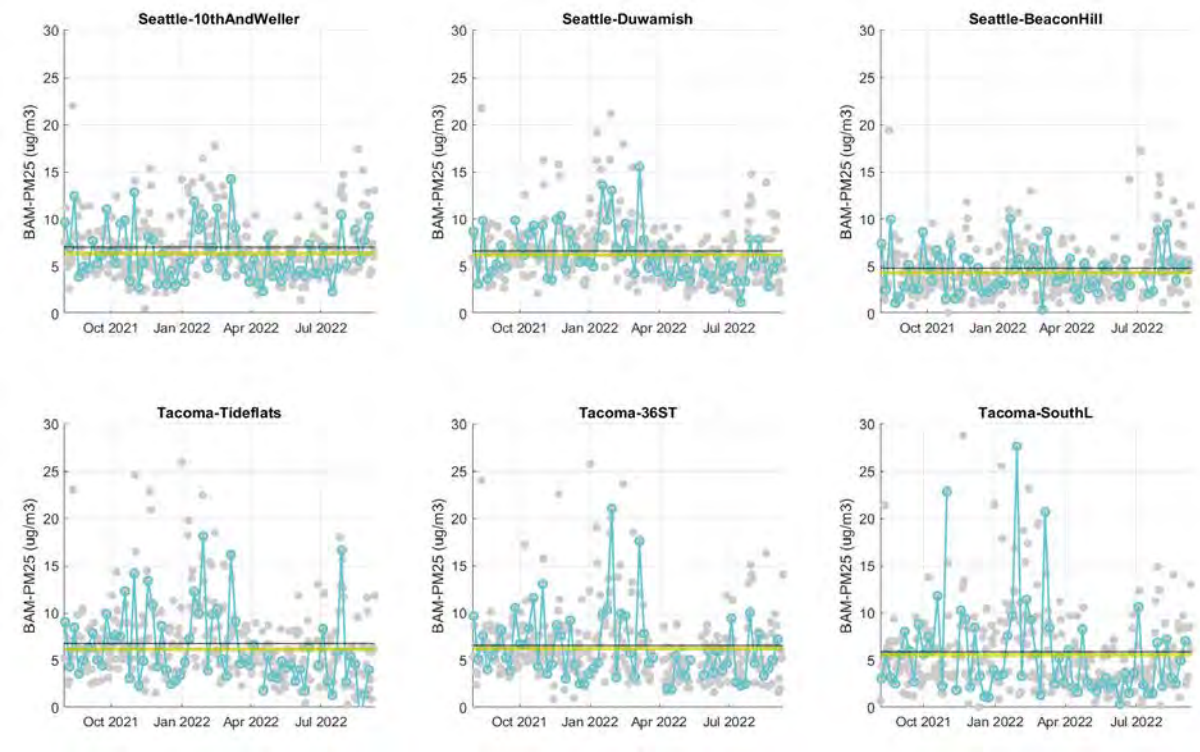


Figure D-4. Corresponding hourly pollution roses ($PM_{2.5}$) coincident with air-toxics samples (1 every 6 days) between August 2021 and September 2022.

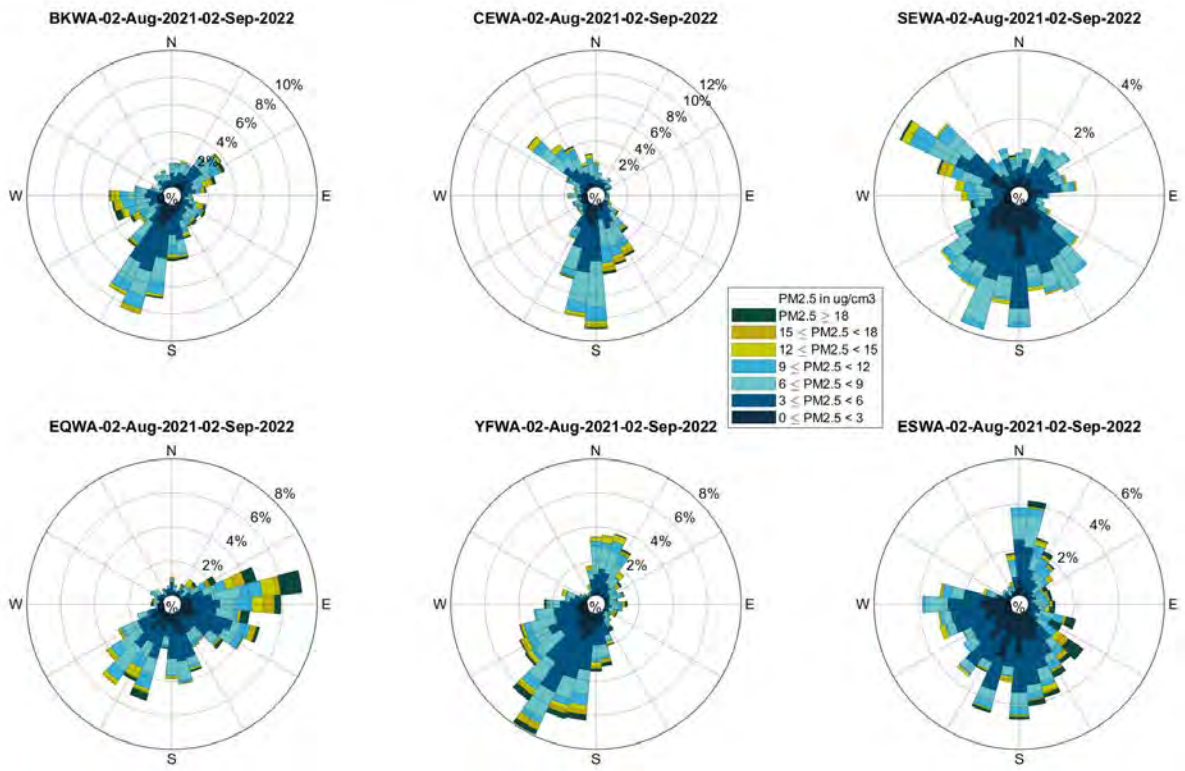


Figure D-5: Daily black carbon (BC) times series (gray dots) at our 6 studied sites with teal colors representing 1-in-6 air-toxics sampling days between August 2021 and September 2022. The green line represents the 1-in-6-day average, and the black line represents the overall average for the entire sampling period. Beacon Hill site (SEWA) does not record continuous black carbon concentrations.

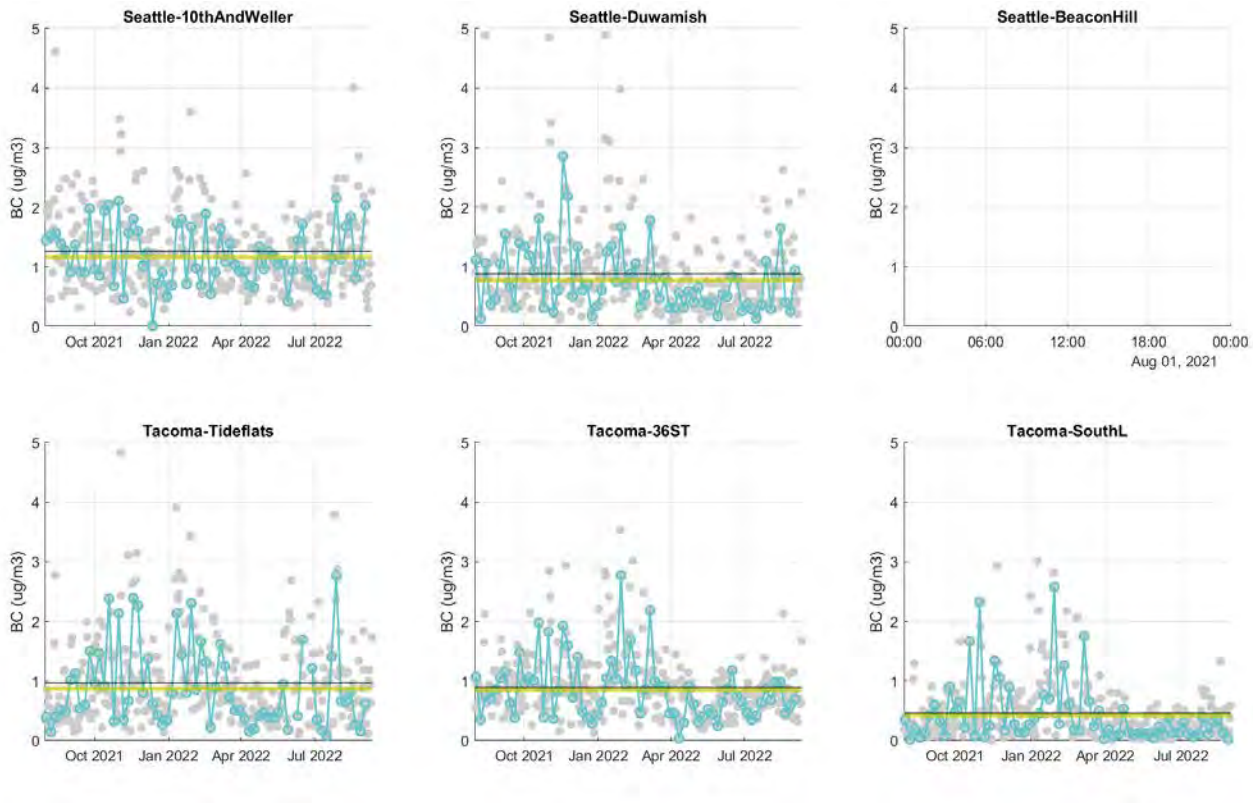


Figure D-6. Corresponding hourly pollution roses (black carbon - BC) coincident with air-toxics sample (1 every 6 days) between August 2021 and September 2022. Beacon Hill site (SEWA) does not record continuous black carbon concentrations.

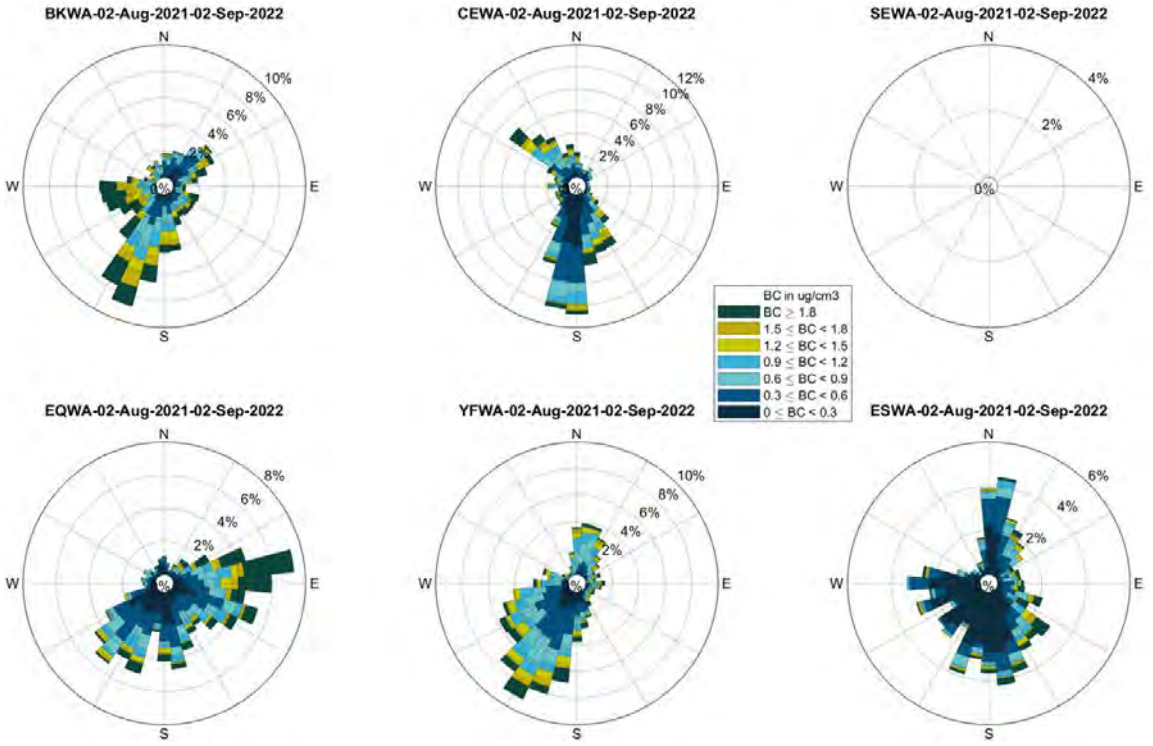


Figure D-7: (A) Map of the wind data collection in the Georgetown and South Park neighborhoods of Seattle. The location codes can be identified as follow: Seattle Duwamish (CEWA) & South Park (SEASPRK) are the two permanent air-quality monitoring sites. South Seattle College (UAWA), South Park Residential (UBWA), Georgetown Residential (UCWA), Georgetown Steam Plant (UDWA) and South Park Industrial (UEWA) are the community-directed temporary sites. Background map is from Google Earth Engine. (B) Comparison of Duwamish and Boeing Field wind roses for the summer of 2022. Note that Boeing Field wind sensor does not resolve wind speeds less than 3.5 mph assigning a value of 0 in both wind direction and speed, which are not included in the wind rose.

(A)

(B)

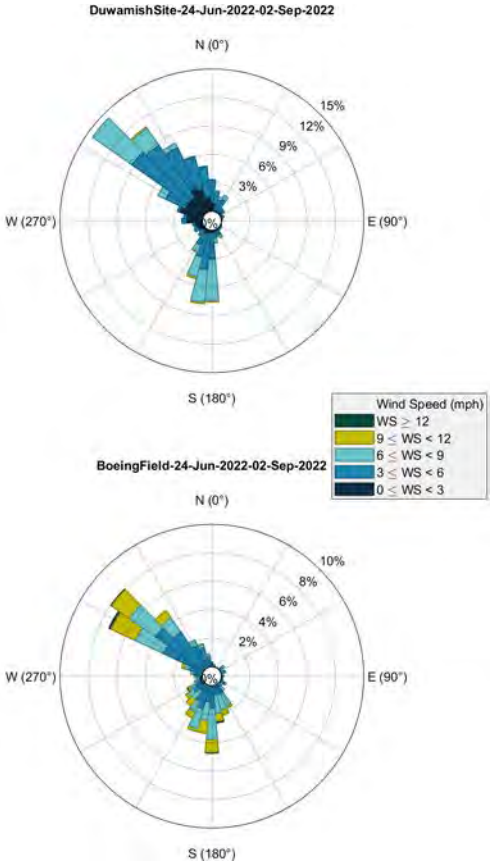


Figure D-8: Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 1: Jun 24th – Jul 1st. $PM_{2.5}$ and wind data are from our Seattle Duwamish regulatory site (CEWA). The blue horizontal bar represents the weekly detection limit in the PM_{10} metal bar plots. The CEWA PM_{10} metals represents a 1-day sample (green shade in time series) while the other sites are 7-day samples.

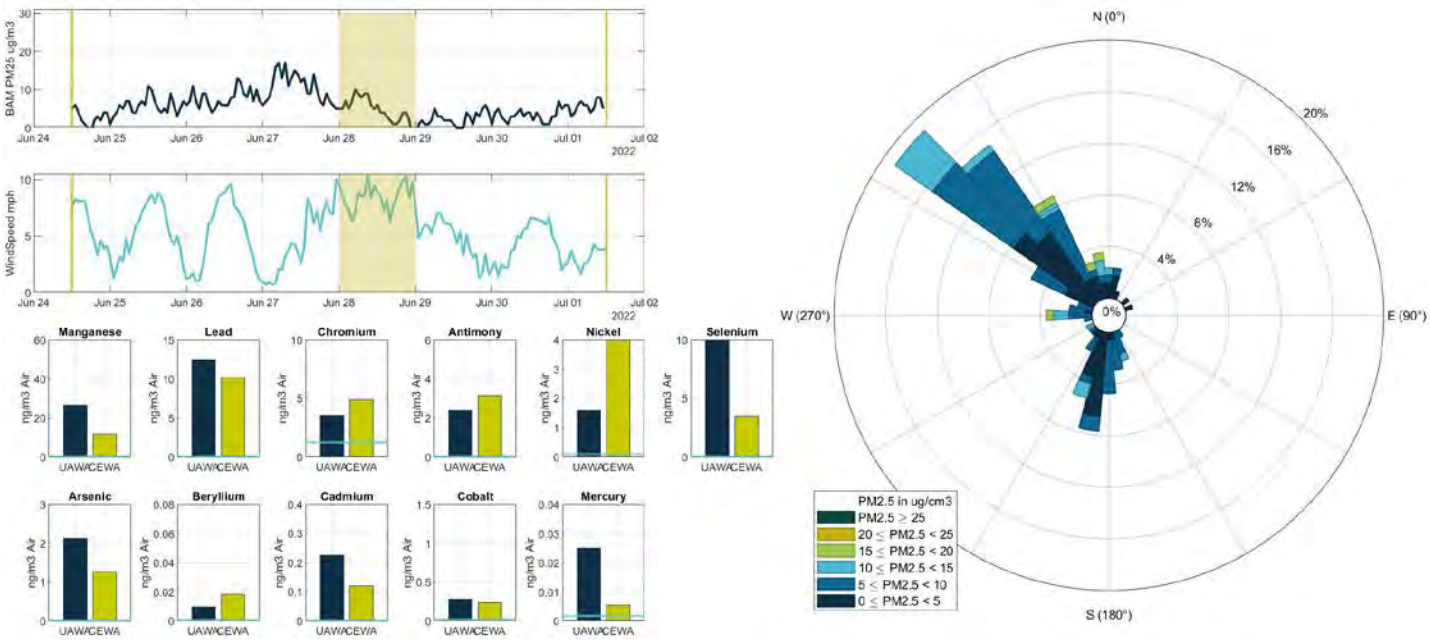


Figure D-9. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 2: Jul 1st – Jul 8th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

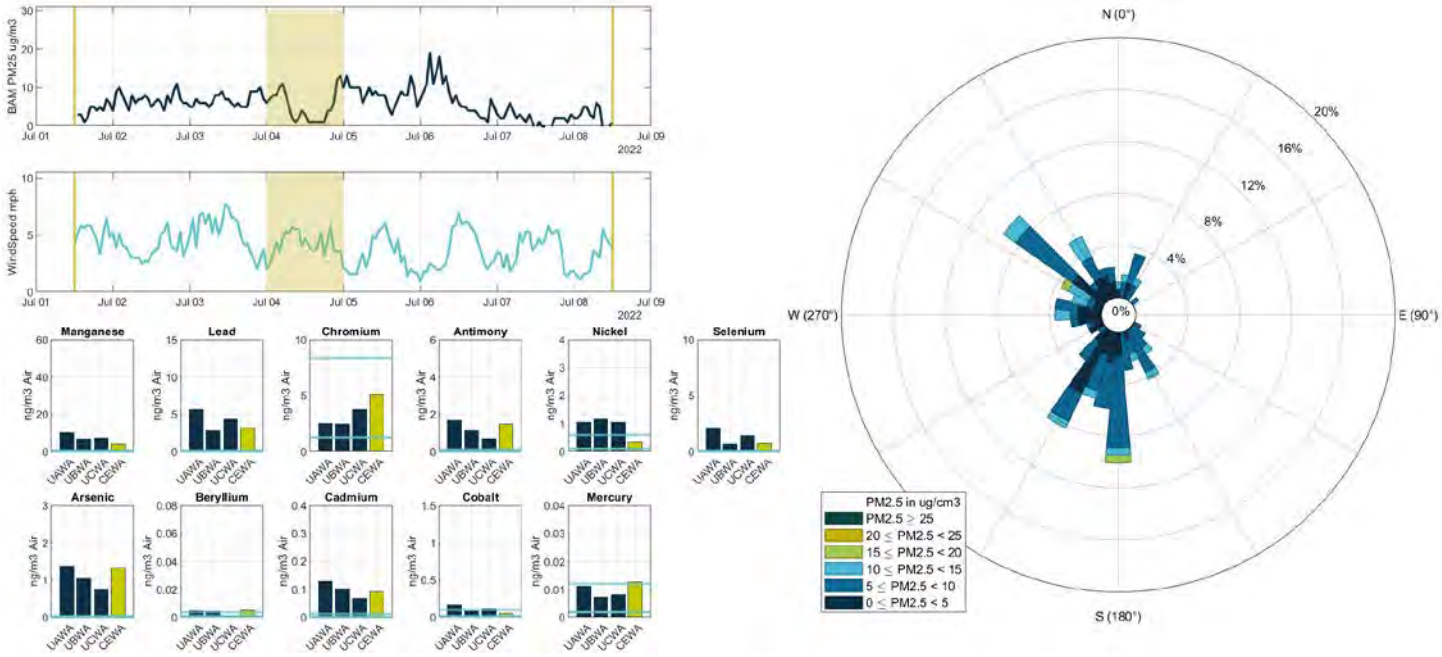


Figure D-10. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 3: Jul 8th – Jul 15th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

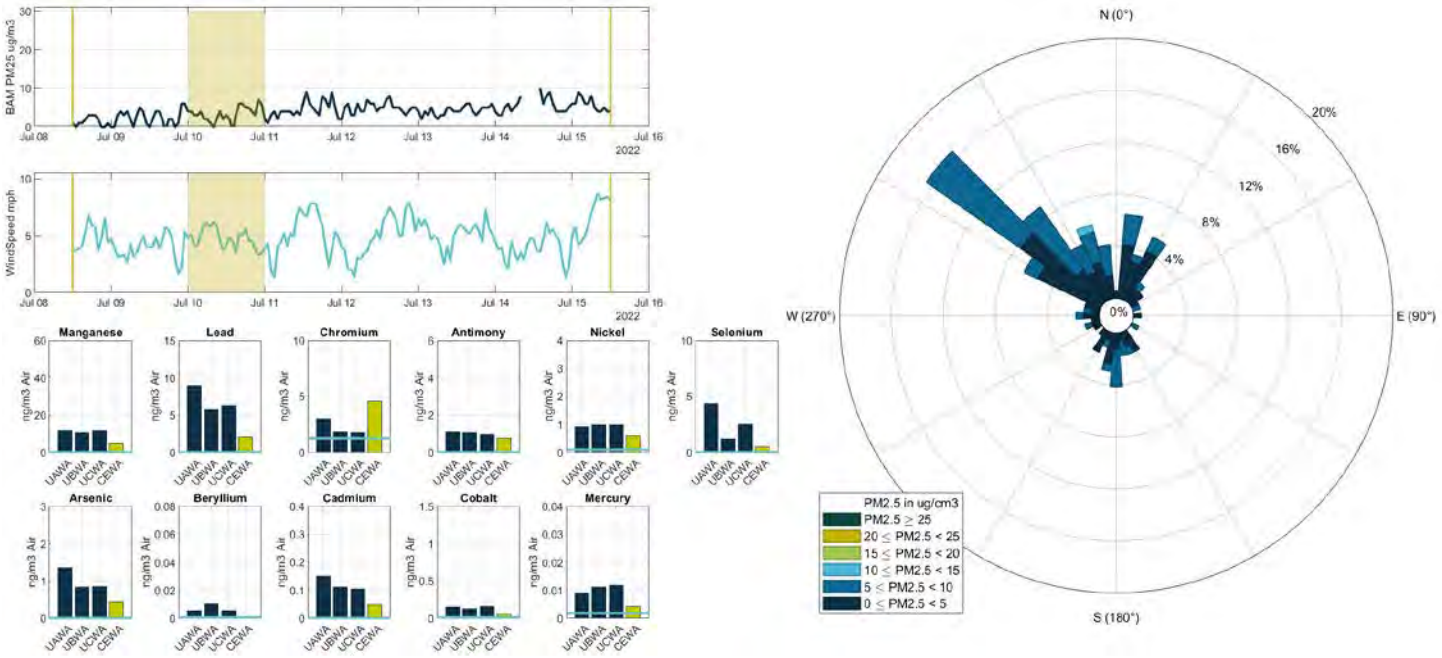


Figure D-11. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 4: Jul 15th – Jul 22nd. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

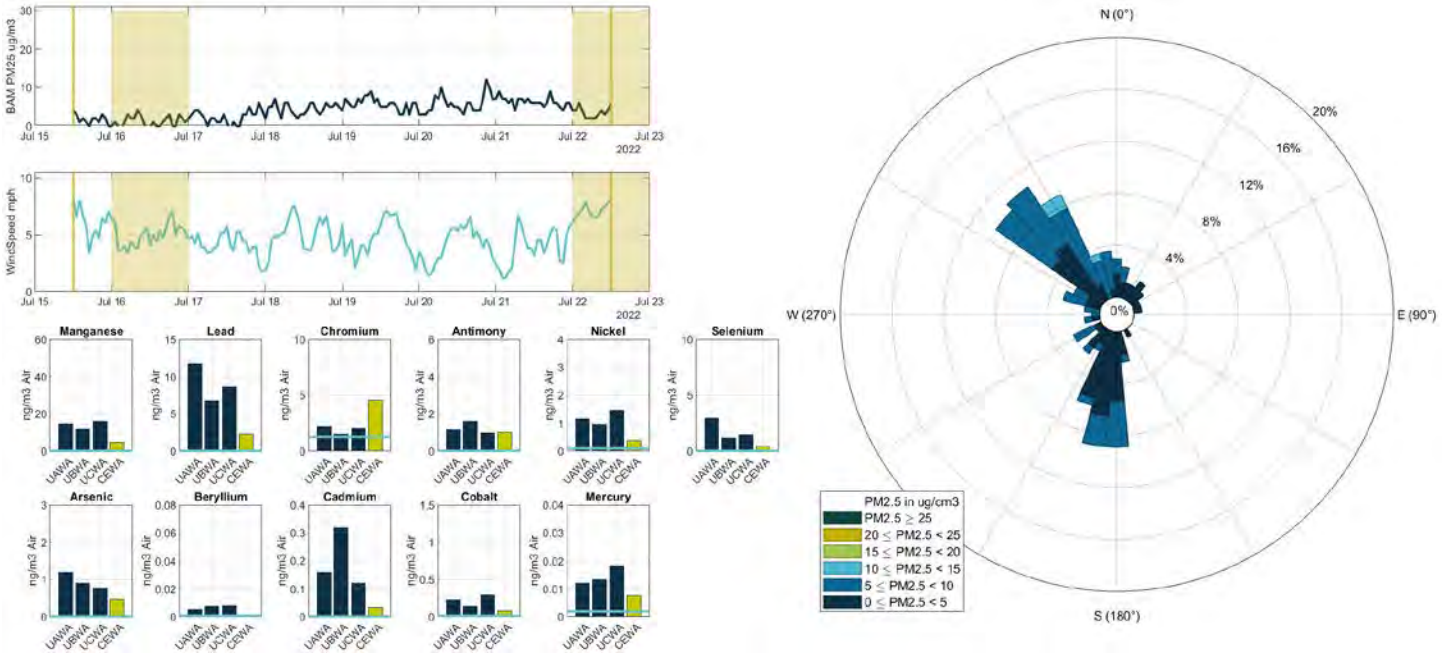


Figure D-12. Weekly evolution of the PM2.5 and PM10 metals at the community directed samples over the 2022 summer. Week 5: Jul 22nd – Jul 29th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

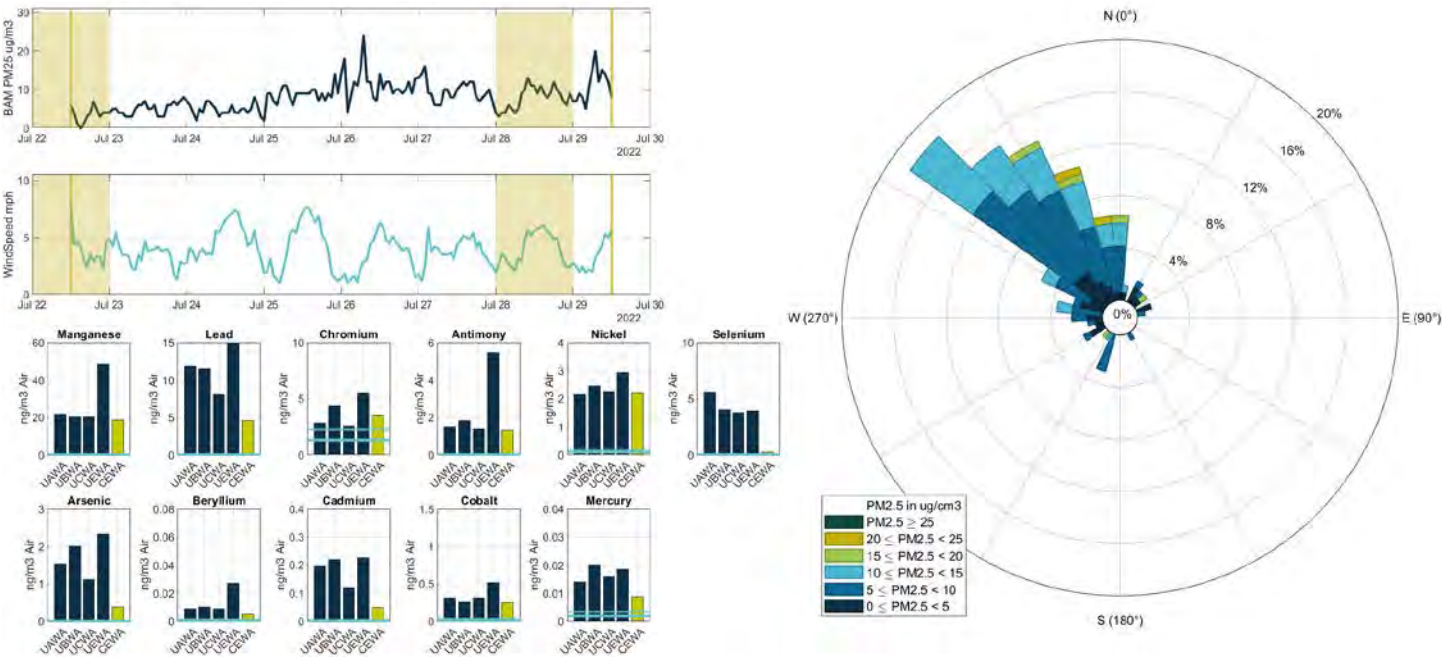


Figure D-13. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 6: Jul 29th – Aug 5th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

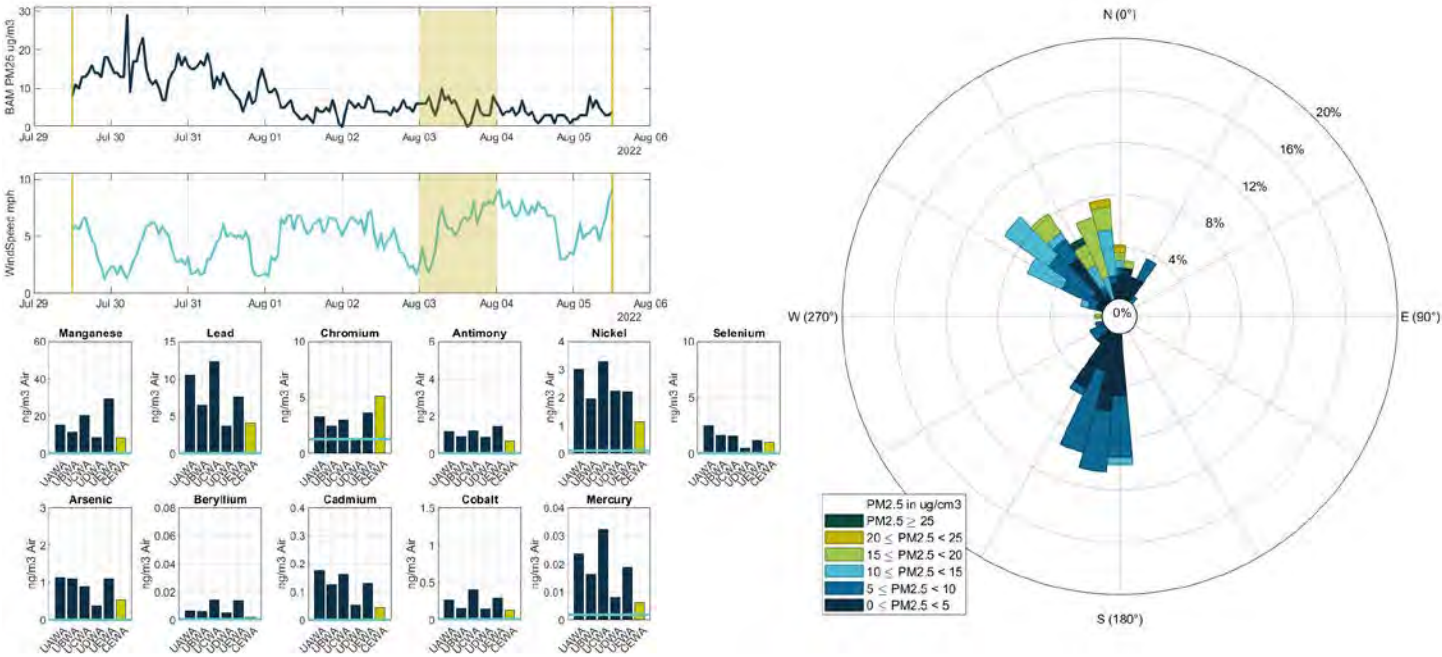


Figure D-14. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 7: Aug 5th – Aug 12th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

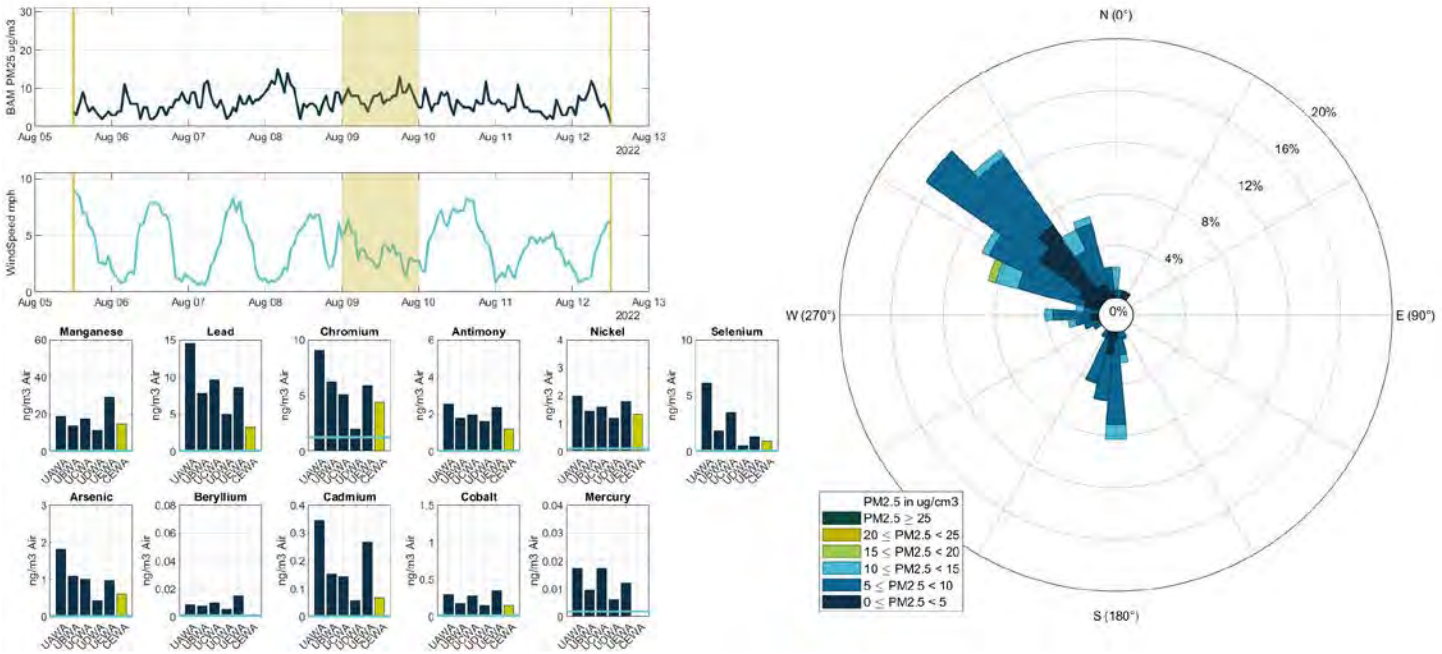


Figure D-15. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 8: Aug 12th – Aug 19th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

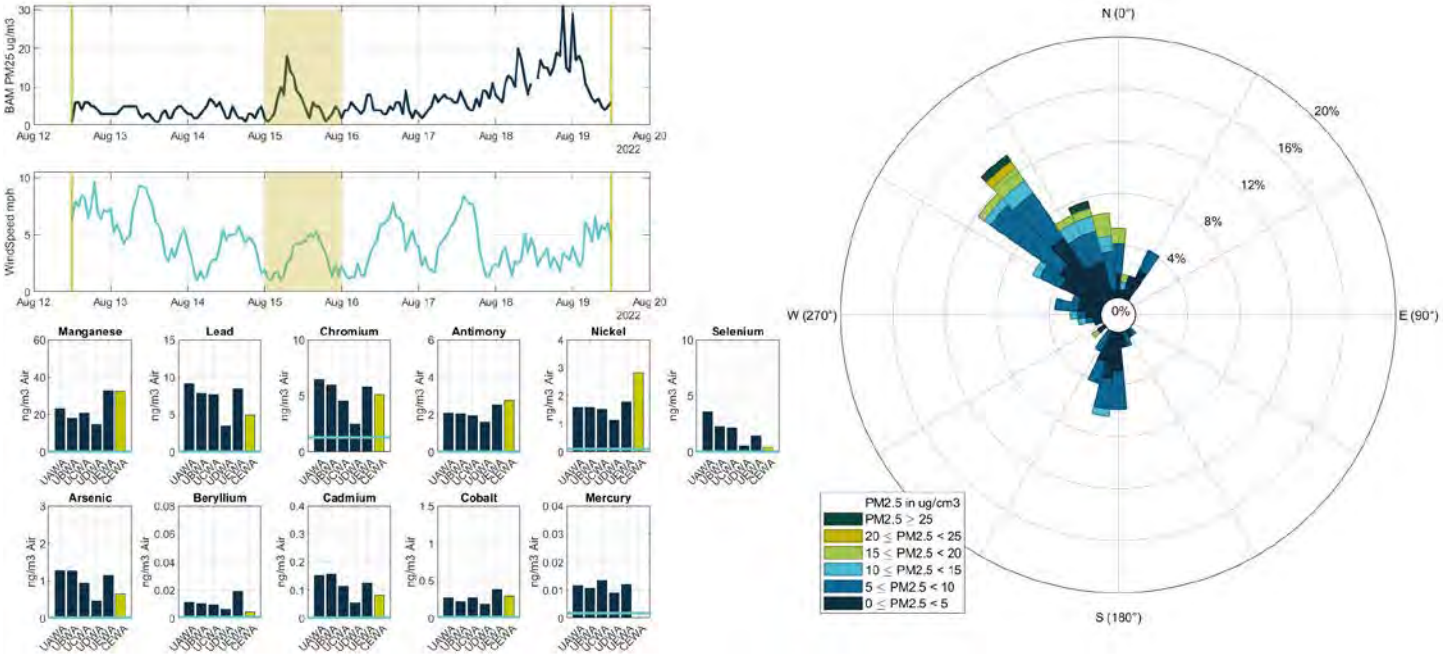


Figure D-16. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 9: Aug 19th – Aug 26th. See caption of Figure D-8 for more details (colors, shades, bars, etc.).

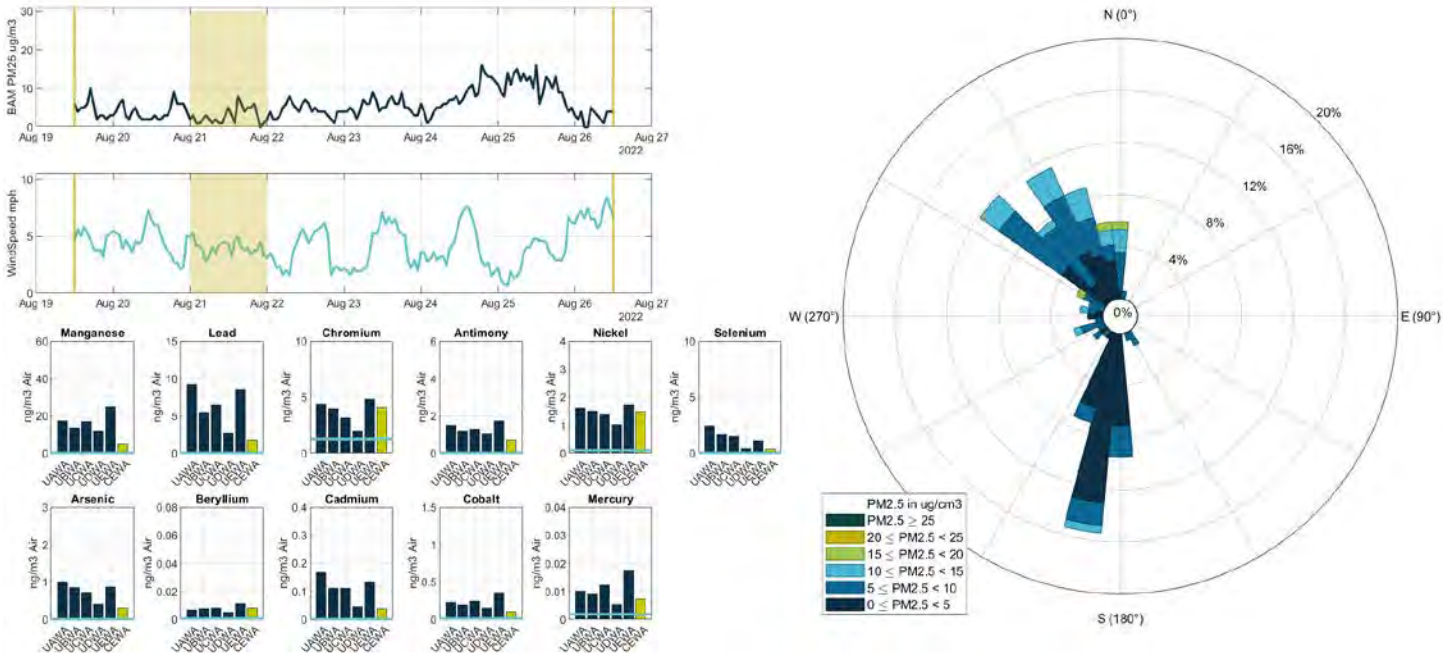
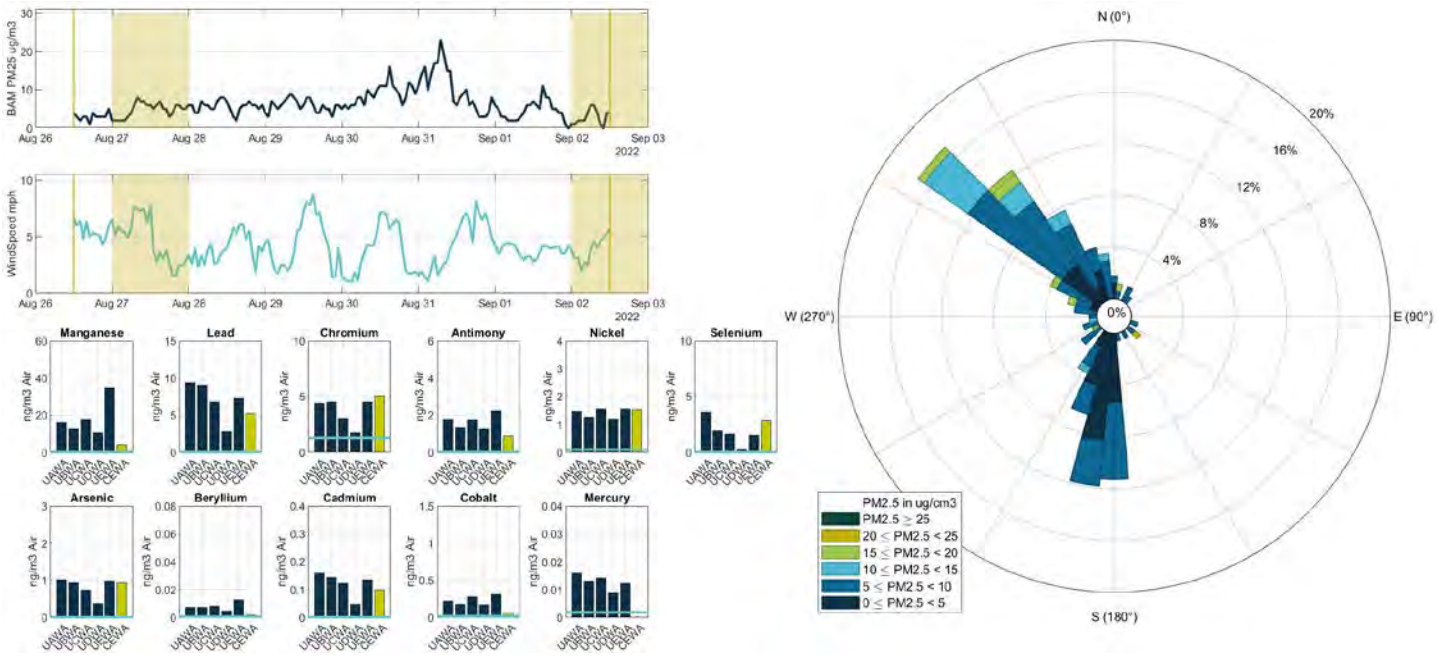


Figure D-17. Weekly evolution of the $PM_{2.5}$ and PM_{10} metals at the community directed samples over the 2022 summer. Week 10: Aug 26th – Sep 2nd. See caption of Figure D-8 for more details (colors, shades, bars, etc.).



Appendix E. Low carbon tetrachloride samples

Table E-1. Percent difference between samples on days with low carbon tetrachloride and study (annual) mean for PSCAA sites.

Pollutant	Percent Difference (%)	Number of Samples
Nickel	66	4
Chromium	16	4
Acrolein	10	19
Antimony	8	4
Benzene	2	19
1,3-Butadiene	0	19
Cobalt	-5	4
Manganese	-7	4
Ethylene oxide	-11	19
Arsenic	-16	4
Ethylbenzene	-21	19
Acetaldehyde	-28	19
Tetrachloroethylene	-31	19
Formaldehyde	-34	18
Cadmium	-38	4
Lead	-44	4
Selenium	-47	4
Beryllium	-56	4
Mercury	-68	4
Carbon tetrachloride	-75	19

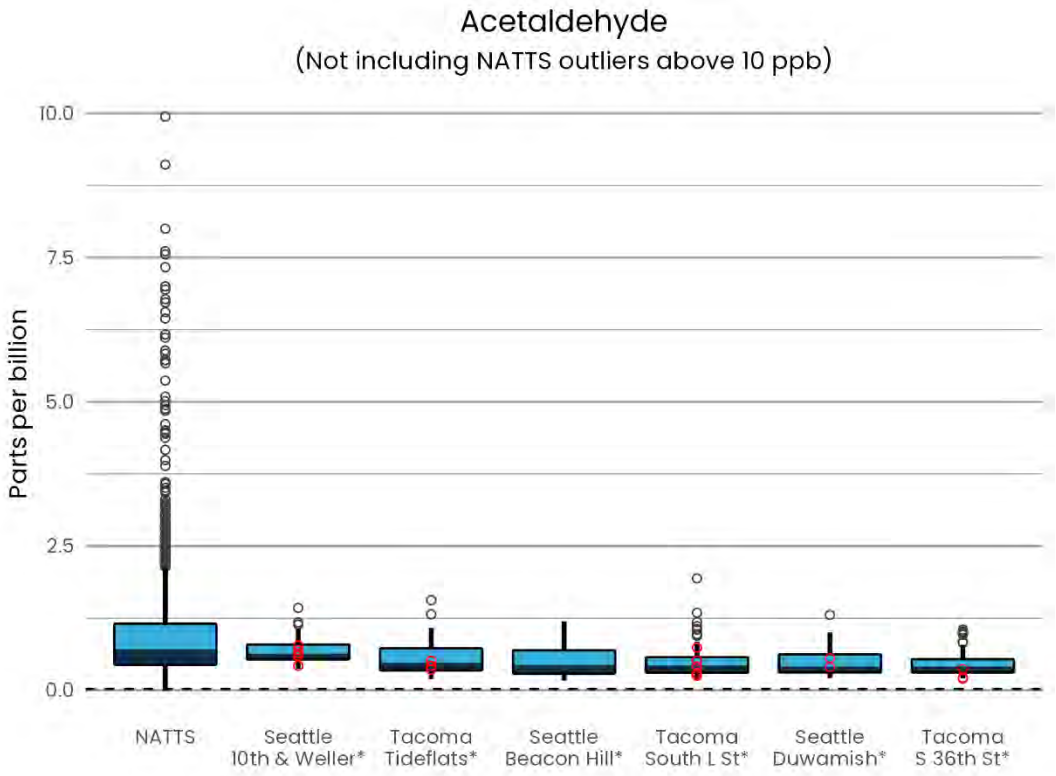
Table E-2. Percent difference between samples on days with low carbon tetrachloride and study (annual) mean for NATTS sites.

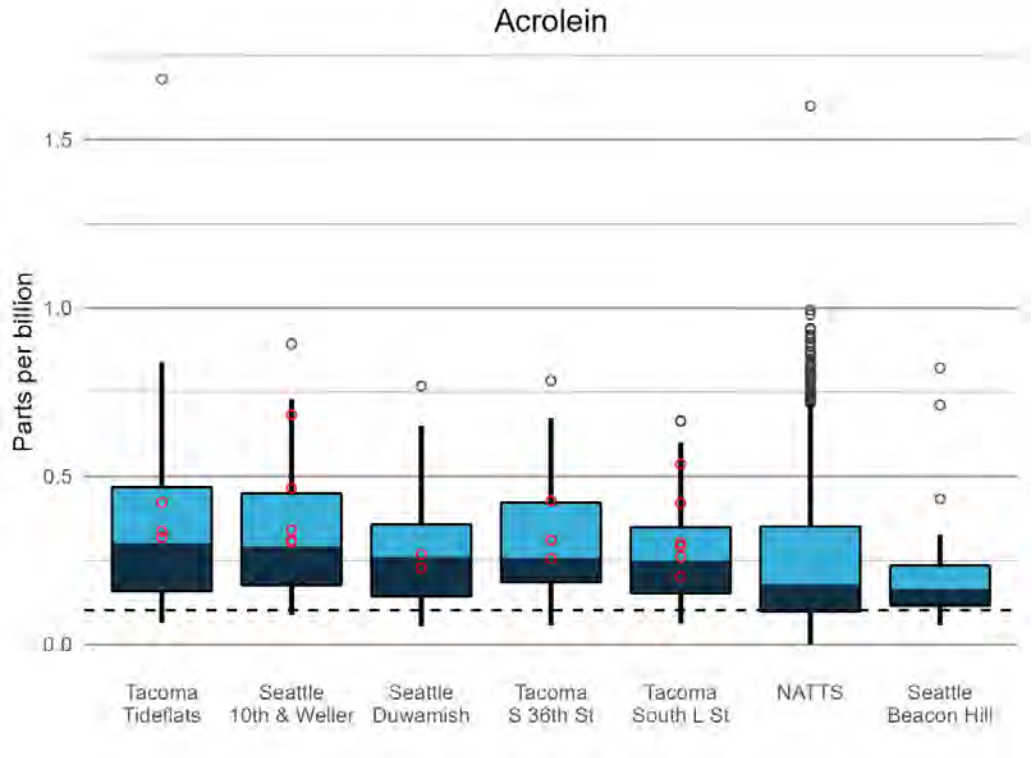
Pollutant	Percent Difference (%)	Number of Samples
Mercury	5	26
Acrolein	1	87
Acetaldehyde	-5	176
Benzene	-6	178
Chromium	-6	82
Nickel	-8	82
Cadmium	-13	82
Manganese	-13	77
Antimony	-14	28
Lead	-16	49
Arsenic	-20	84
Cobalt	-20	41
Formaldehyde	-20	180
Ethylene oxide	-27	80
Beryllium	-29	78
Ethylbenzene	-35	200
Selenium	-36	40
Tetrachloroethylene	-41	209
Carbon tetrachloride	-54	210
1,3-Butadiene	-81	158

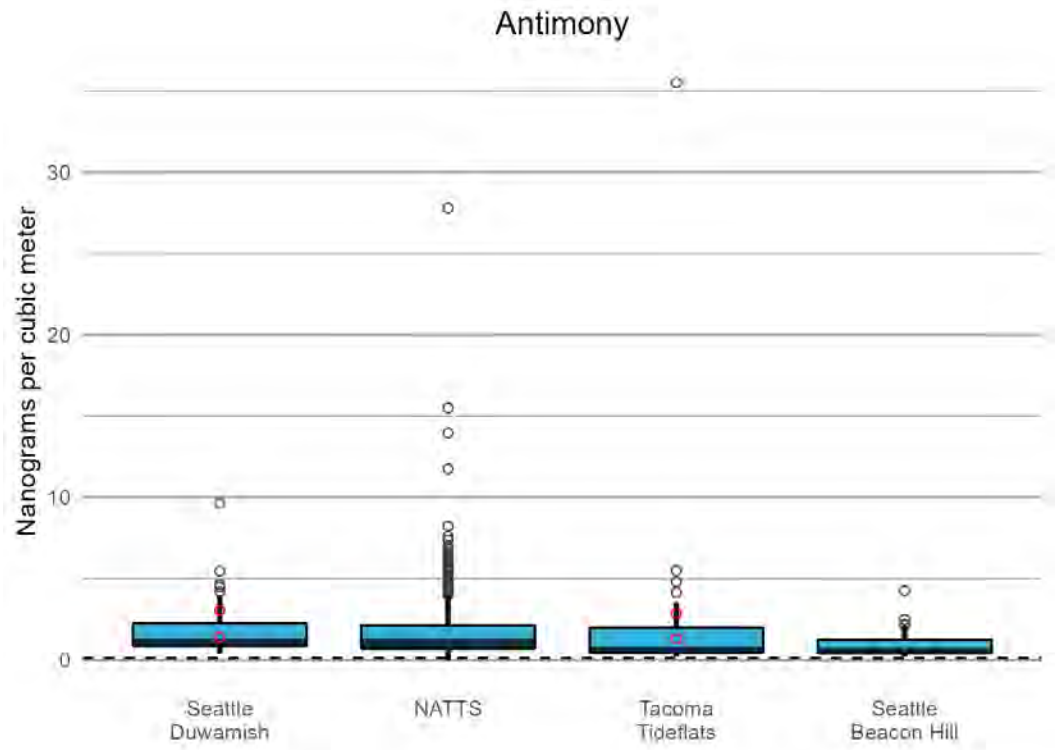
Note: This only includes NATTS data that overlapped with our sampling time.

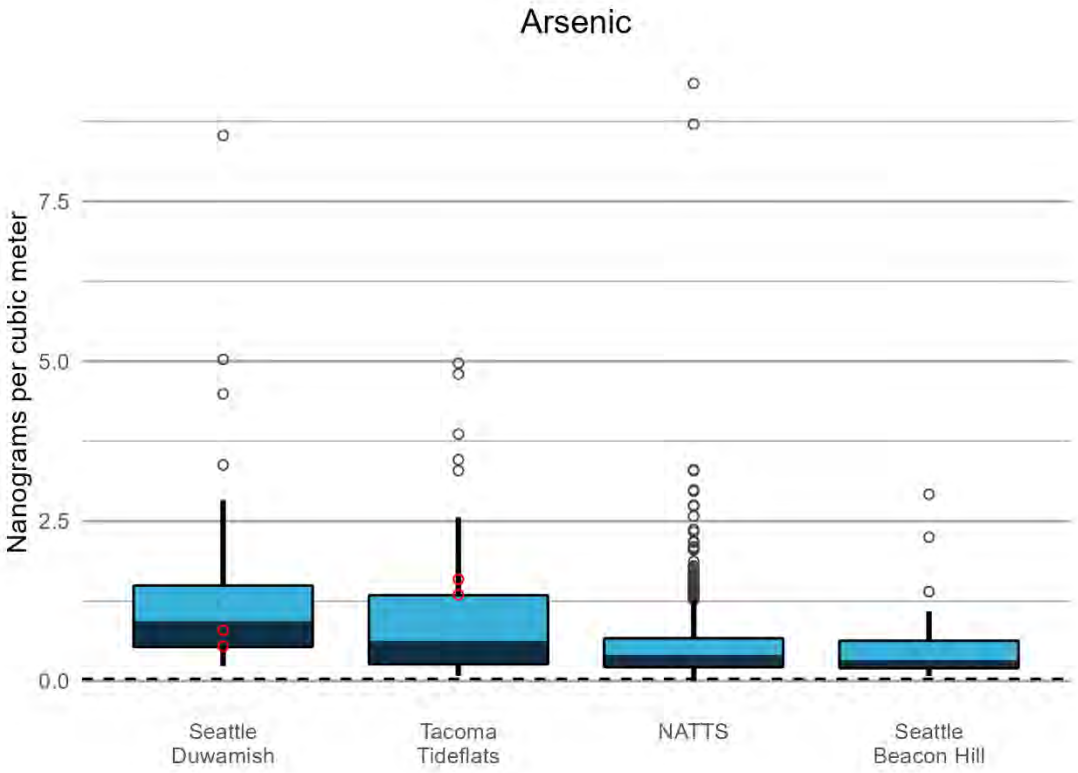
With the NATTS sites, there are no strong positive associations and one very strong negative association (1,3-Butadiene). Overall, the low carbon tetrachloride samples were 27% lower than the mean for all pollutants.

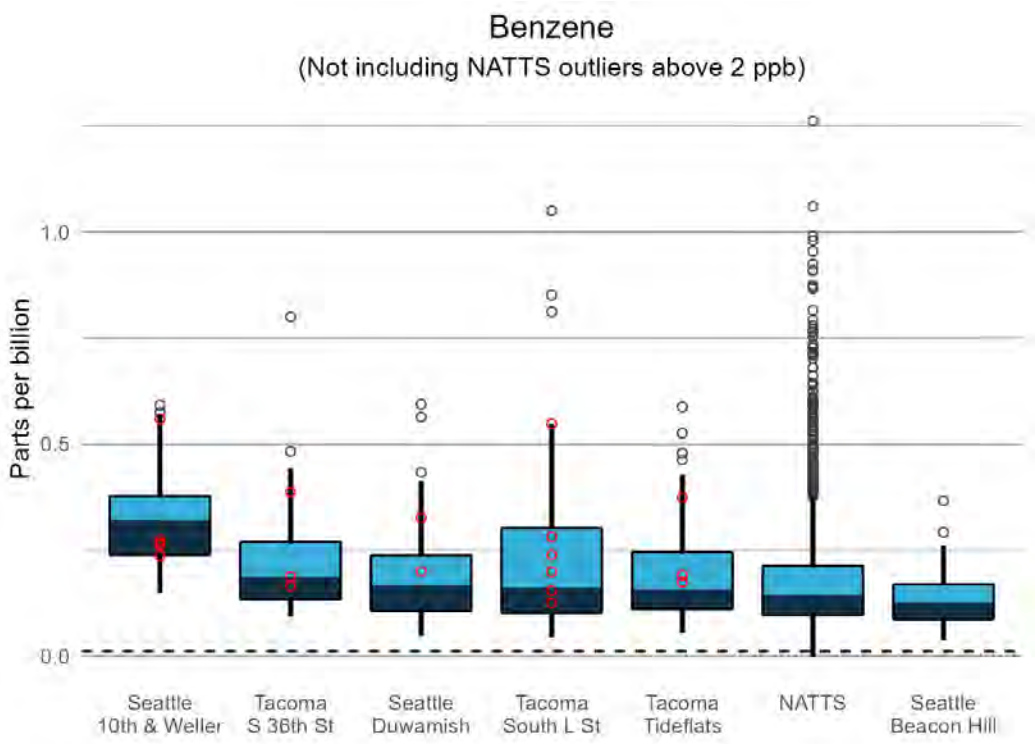
The following are boxplots showing the low carbon tetrachloride samples (in red) compared to the rest of the samples.

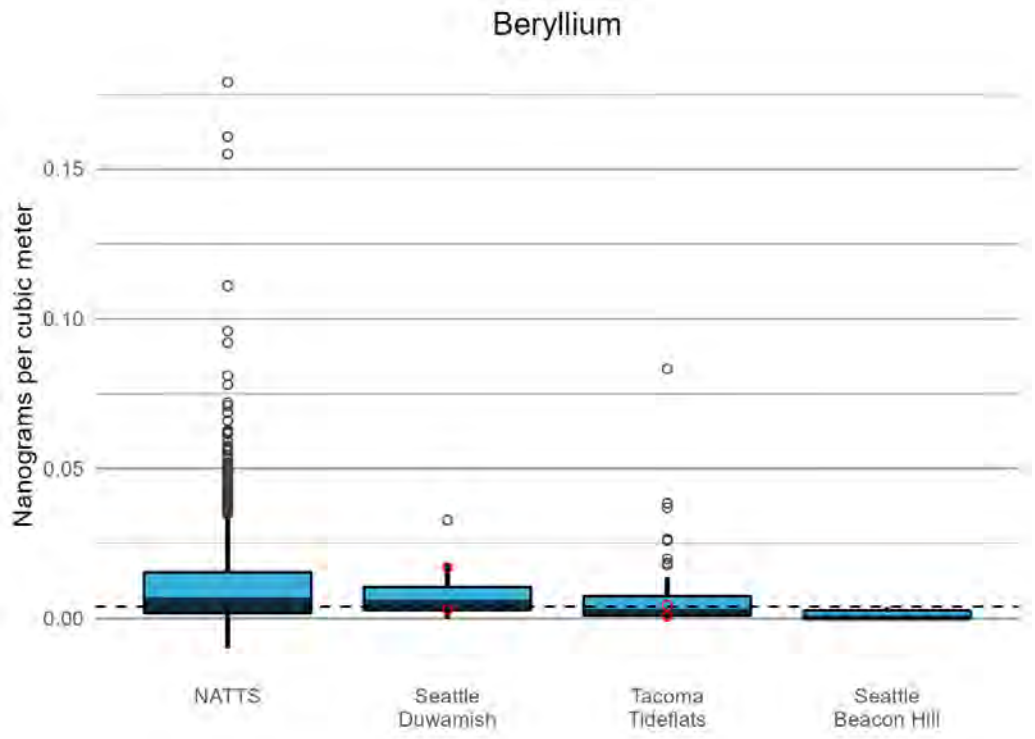


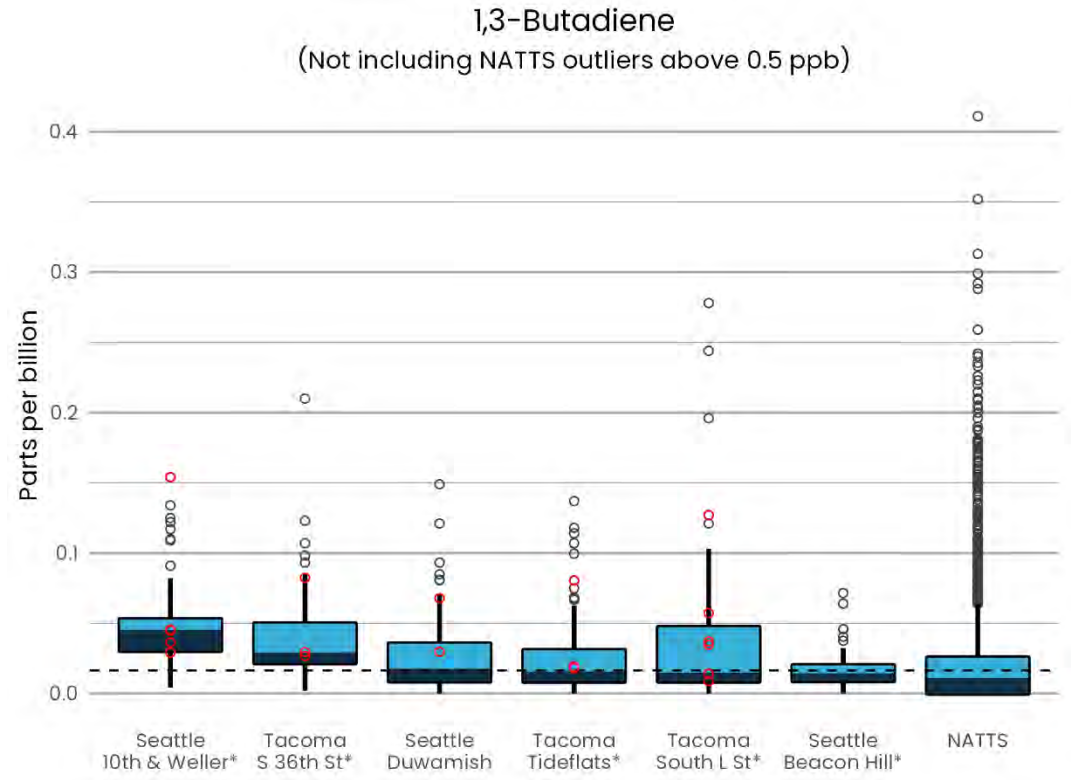


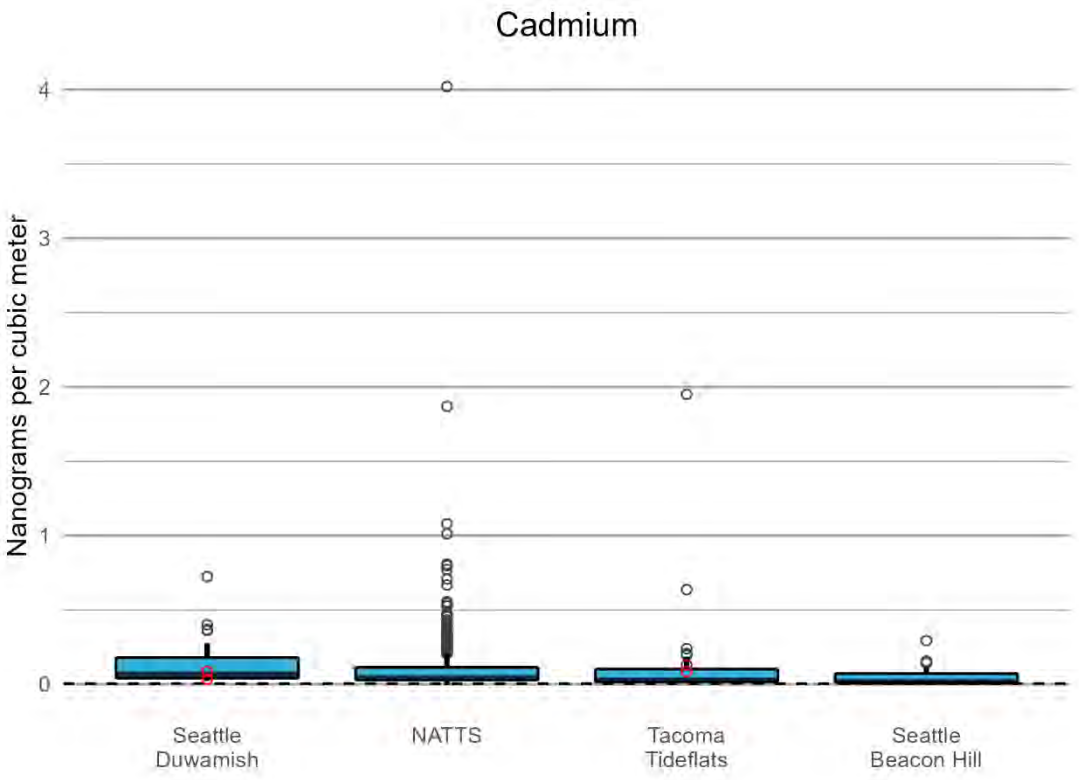

Antimony
Nanograms per cubic meter
30
20
10
0
Seattle Duwamish
NATTS
Tacoma Tideflats
Seattle Beacon Hill

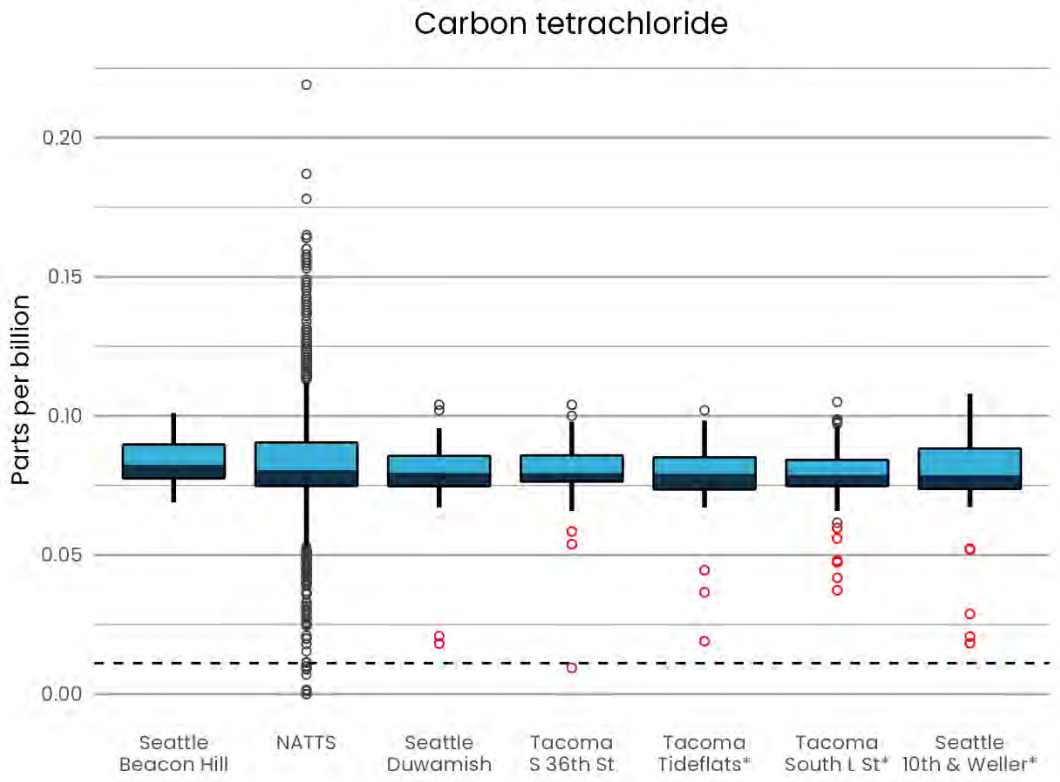

Arsenic
Nanograms per cubic meter
7.5
5.0
2.5
0.0
Seattle Duwamish
Tacoma Tideflats
NATTS
Seattle Beacon Hill

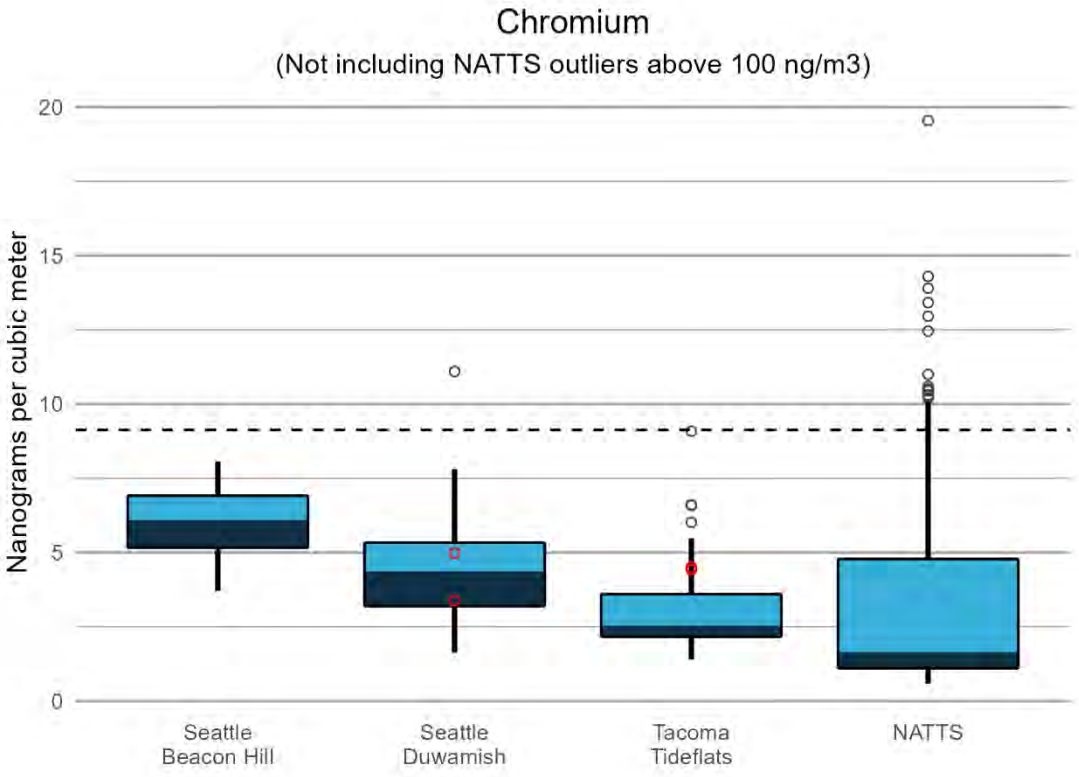

Benzene
(Not including NATTS outliers above 2 ppb)
Parts per billion
1.0
0.5
0.0
Seattle 10th & Weller
Tacoma S 36th St
Seattle Duwamish
Tacoma South L St
Tacoma Tideflats
NATTS
Seattle Beacon Hill

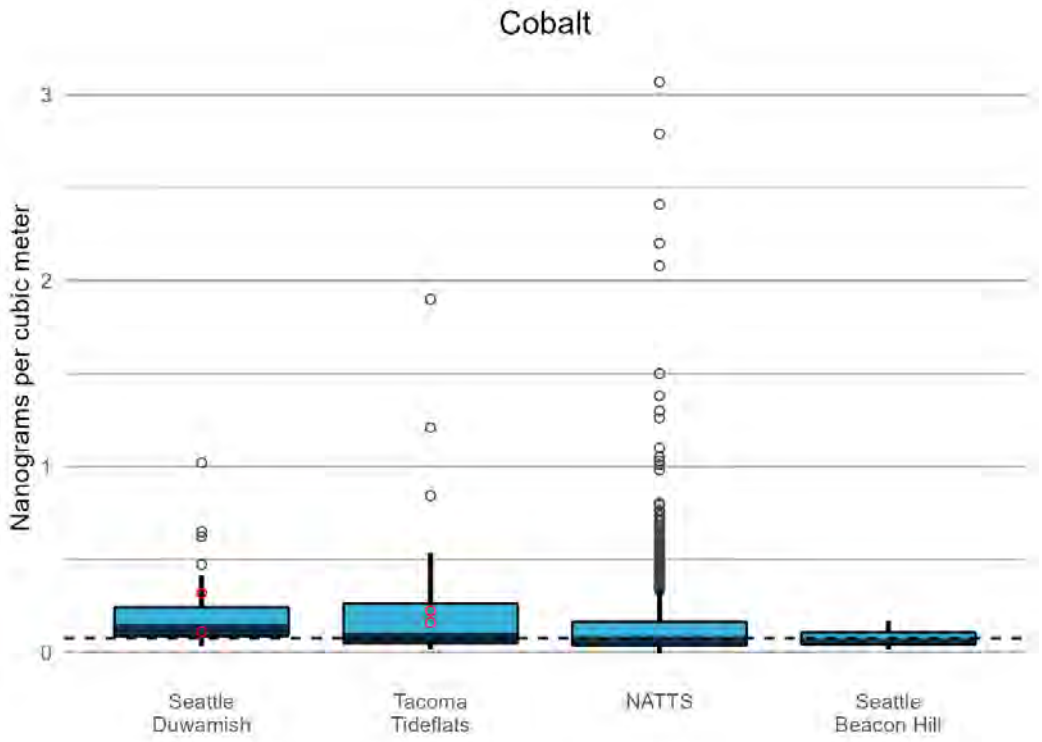

Beryllium
Nanograms per cubic meter
0.15
0.10
0.05
0.00
NATTS
Seattle Duwamish
Tacoma Tideflats
Seattle Beacon Hill

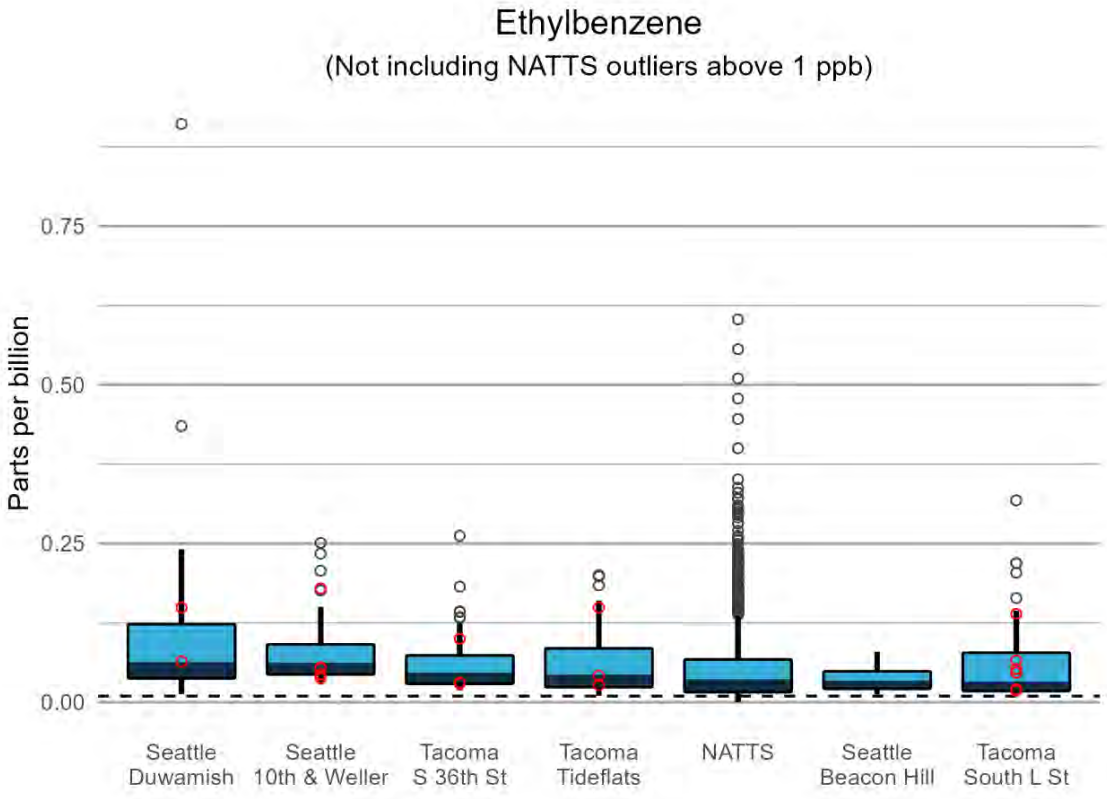

1,3-Butadiene
(Not including NATTS outliers above 0.5 ppb)
Parts per billion
0.4
0.3
0.2
0.1
0.0
Seattle 10th & Weller*
Tacoma S 36th St*
Seattle Duwamish
Tacoma Tideflats*
Tacoma South L St*
Seattle Beacon Hill*
NATTS


Cadmium
Nanograms per cubic meter
4
3
2
1
0
Seattle Duwamish
NATTS
Tacoma Tideflats
Seattle Beacon Hill

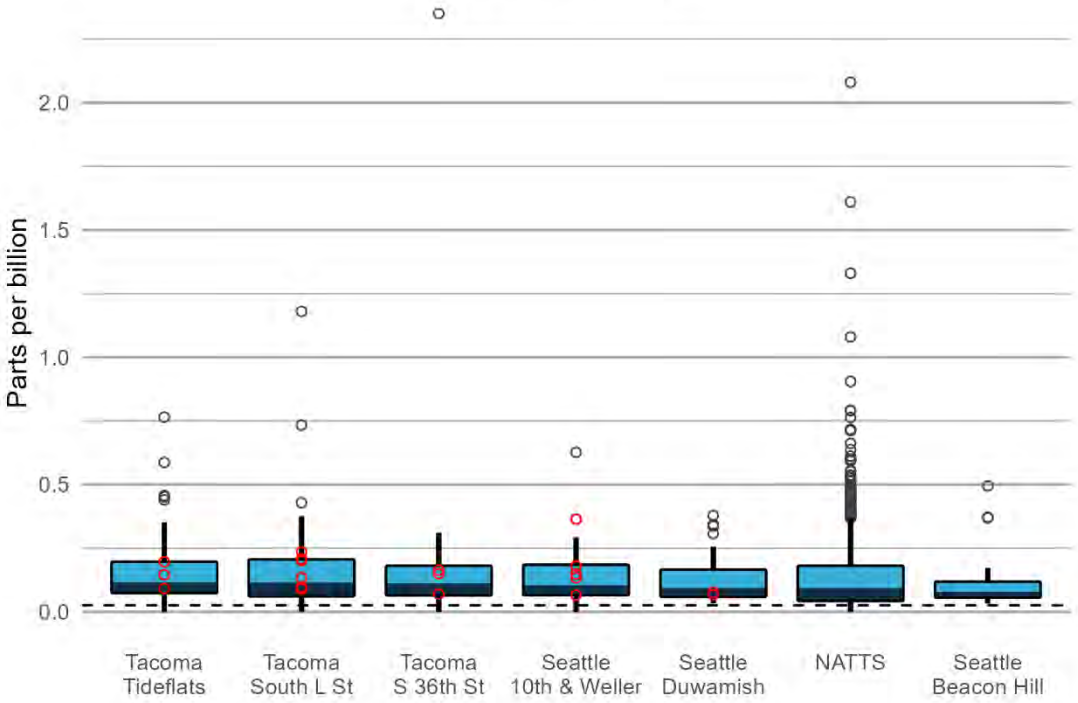

Carbon tetrachloride
Parts per billion
0.20
0.15
0.10
0.05
0.00
Seattle Beacon Hill
NATTS
Seattle Duwamish
Tacoma S 36th St
Tacoma Tideflats*
Tacoma South L St*
Seattle 10th & Weller*


Chromium
(Not including NATTS outliers above 100 ng/m3)
Nanograms per cubic meter
20
15
10
5
0
Seattle Beacon Hill
Seattle Duwamish
Tacoma Tideflats
NATTS


Cobalt
Nanograms per cubic meter
3
2
1
0
Seattle Duwamish
Tacoma Tideflats
NATTS
Seattle Beacon Hill

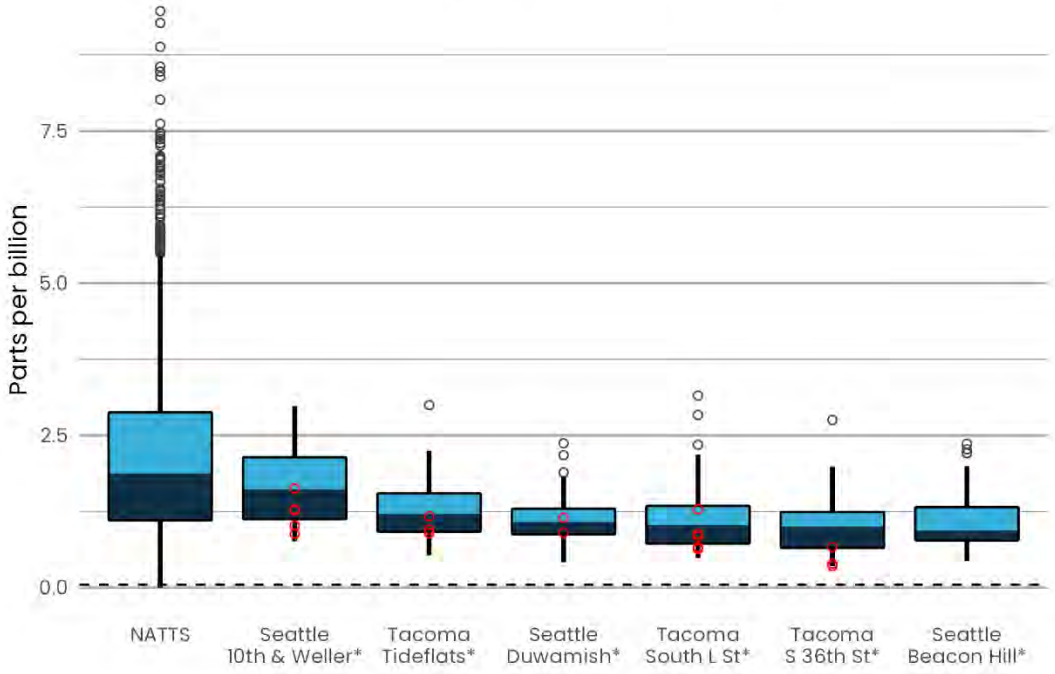

Ethylbenzene
(Not including NATTS outliers above 1 ppb)
Parts per billion
0.75
0.50
0.25
0.00
Seattle Duwamish
Seattle 10th & Weller
Tacoma S 36th St
Tacoma Tideflats
NATTS
Seattle Beacon Hill
Tacoma South L St

Ethylene oxide

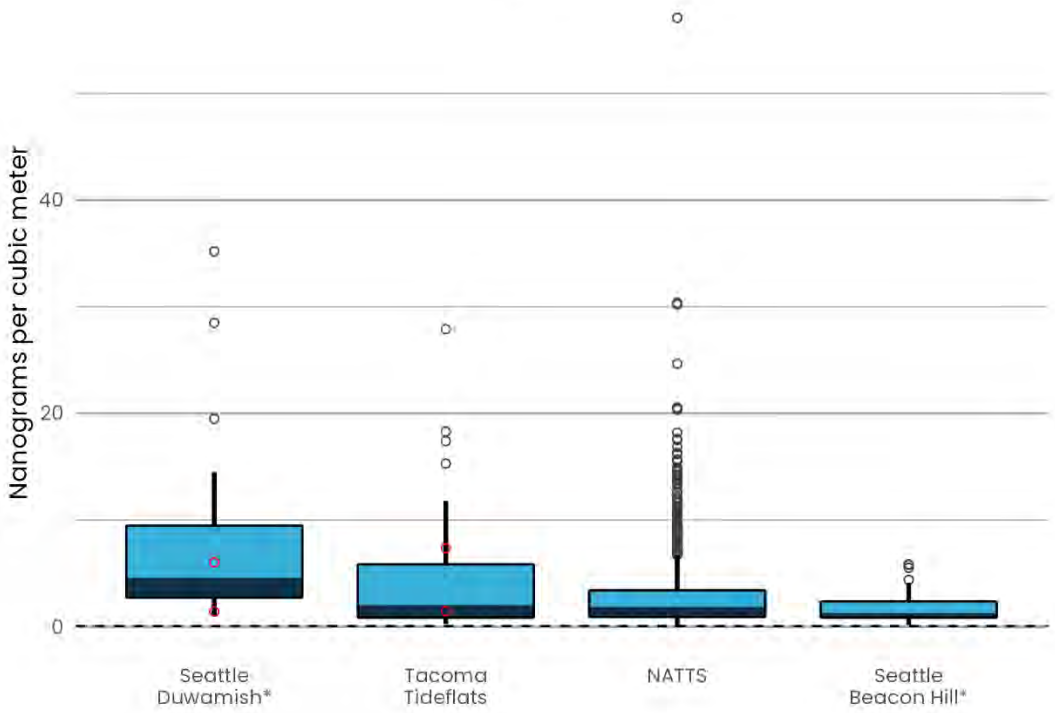


Formaldehyde

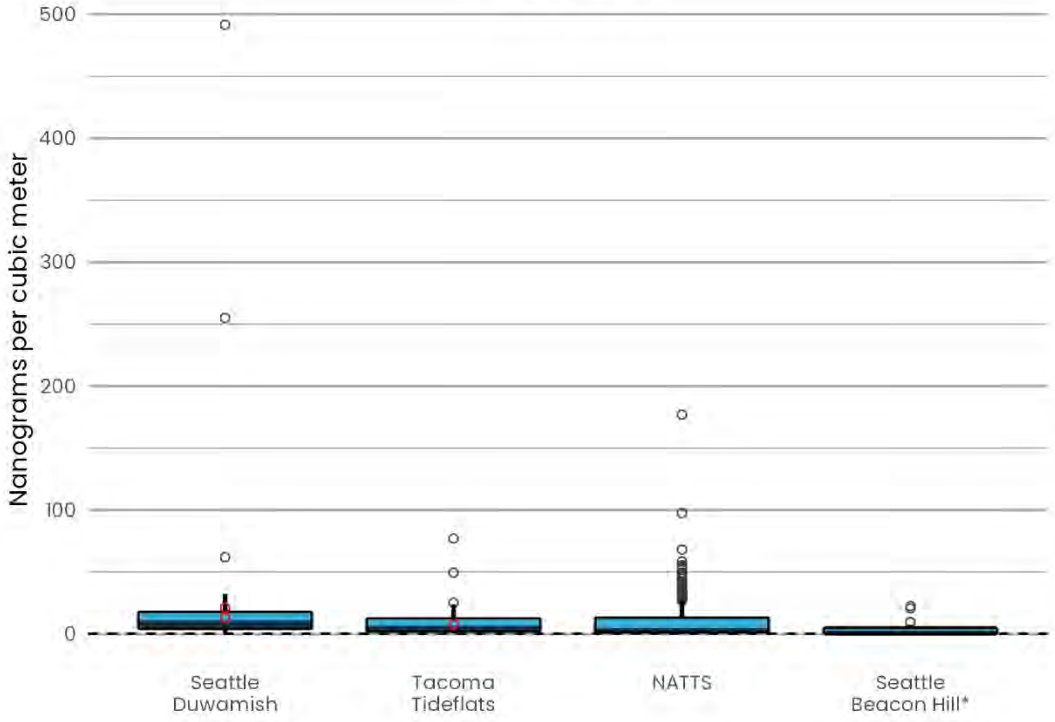
(Not including NATTS outliers above 10 ppb)

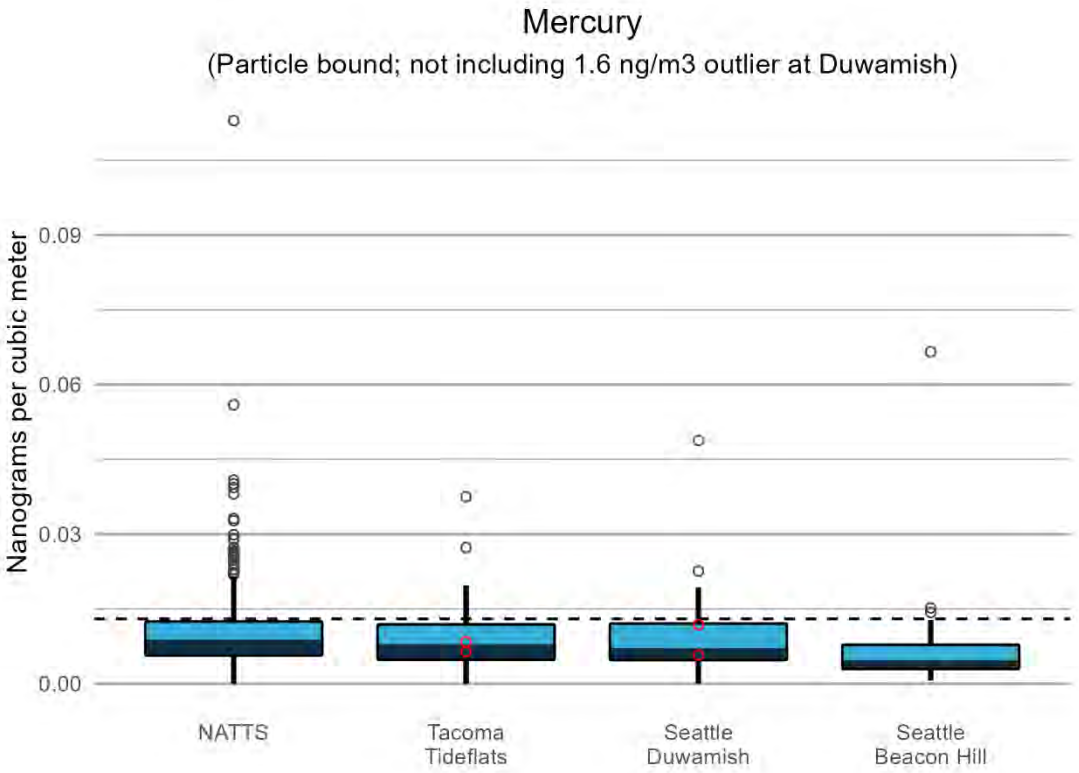


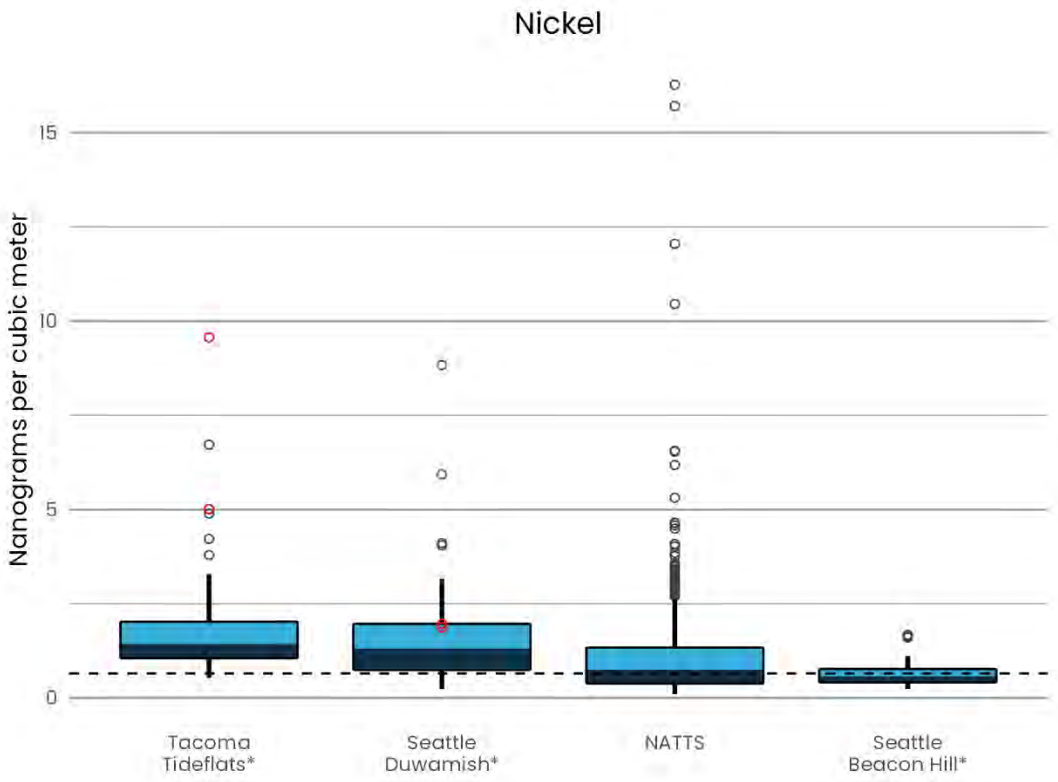
Lead

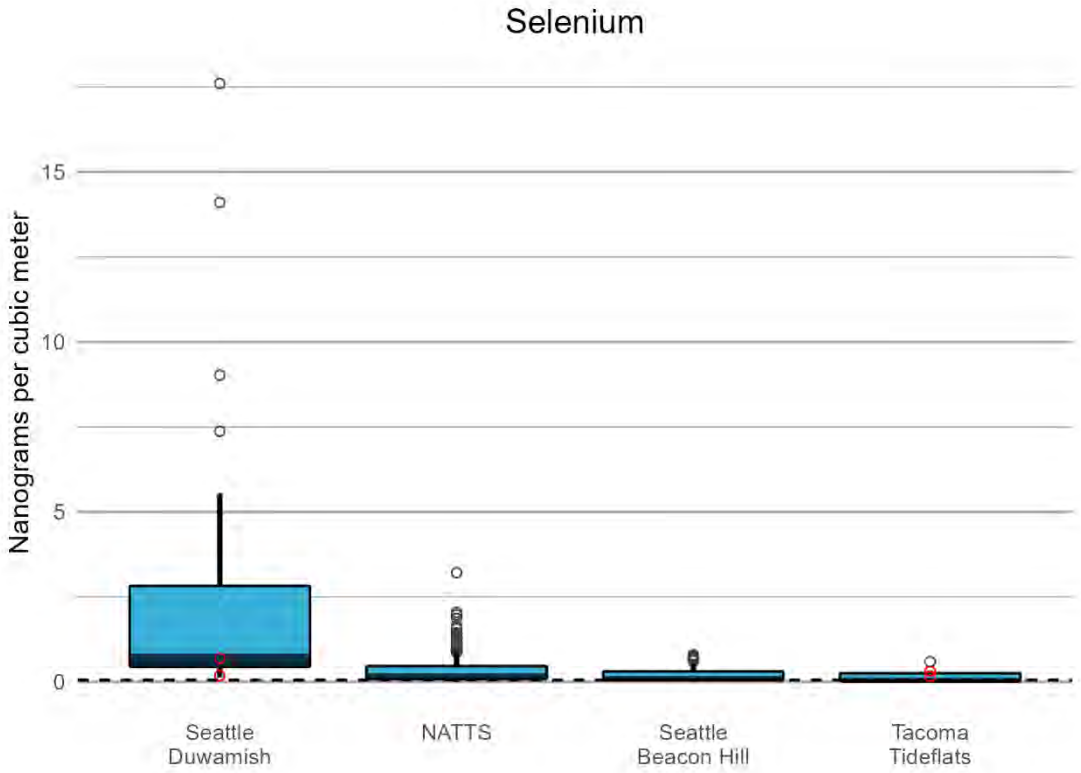


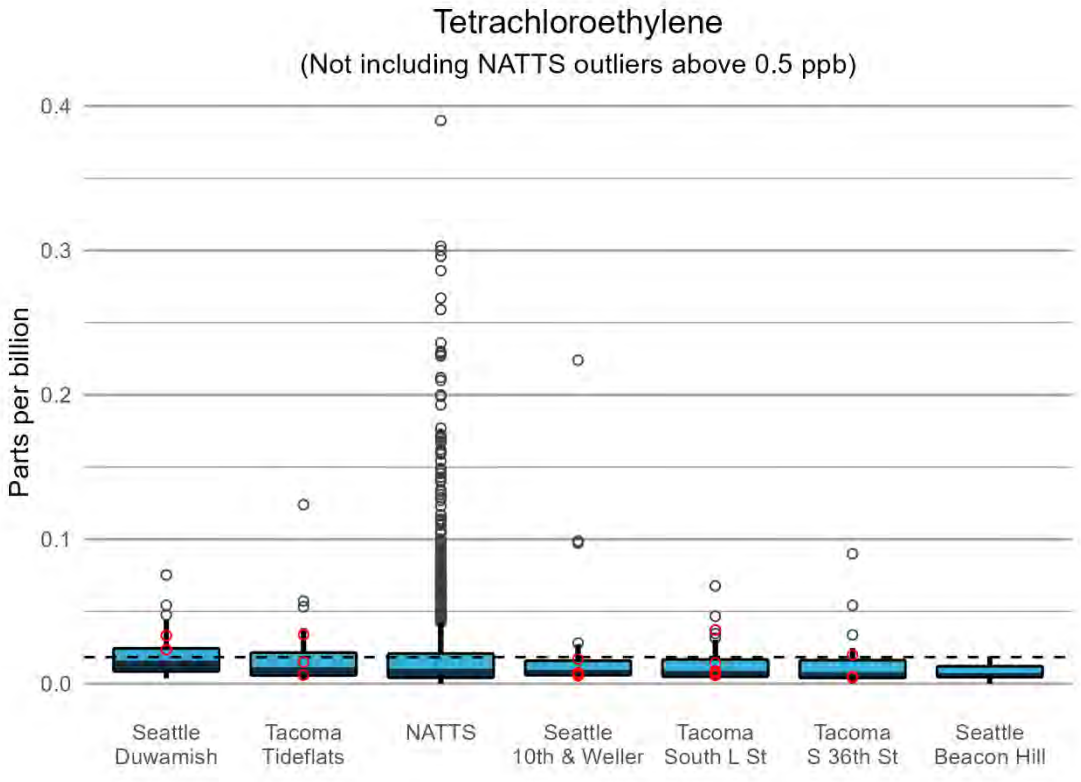
Manganese




Mercury
(Particle bound; not including 1.6 ng/m3 outlier at Duwamish)
Nanograms per cubic meter
0.09
0.06
0.03
0.00
NATTS
Tacoma Tideflats
Seattle Duwamish
Seattle Beacon Hill

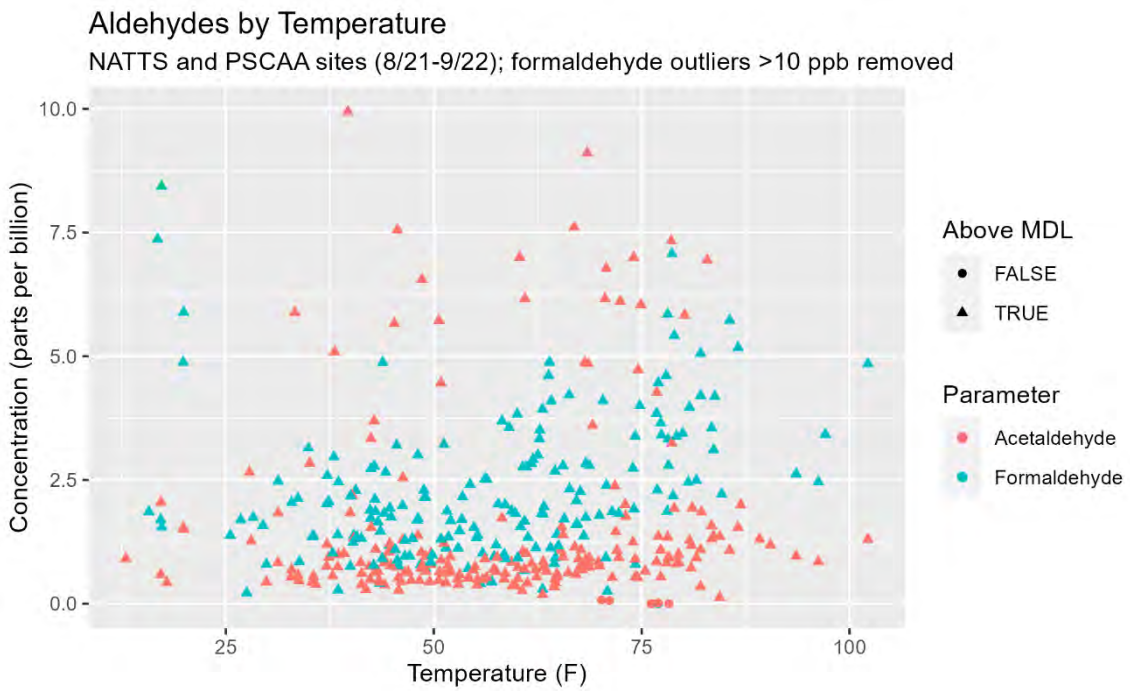

Nickel
Nanograms per cubic meter
15
10
5
0
Tacoma Tideflats*
Seattle Duwamish*
NATTS
Seattle Beacon Hill*


Selenium
Nanograms per cubic meter
15
10
5
0
Seattle Duwamish
NATTS
Seattle Beacon Hill
Tacoma Tideflats


Tetrachloroethylene
(Not including NATTS outliers above 0.5 ppb)
Parts per billion
0.4
0.3
0.2
0.1
0.0
Seattle Duwamish
Tacoma Tideflats
NATTS
Seattle 10th & Weller
Tacoma South L St
Tacoma S 36th St
Seattle Beacon Hill

Appendix F. The effect of temperature on aldehydes

Figure F- 1. Aldehydes by Temperature



This graph shows acetaldehyde (pink) and formaldehyde (blue) versus temperature. Data points that are above the minimum detection limit are triangles and those lower than the MDL are circles. This graph combines NATTS sites and PSCAA sites and shows data from August 2021 through September 2022. Formaldehyde concentrations above 10 ppb were removed. These all occurred at one NATTS site that is next to a water plant. Generally, aldehyde concentrations are modestly higher at higher temperatures.

Appendix G. Comparison of Purple Air data to NFRMs

In this Appendix, we present both Purple Air data and ARA N-FRM (Near-Federal-Reference-Method) RTP (Real-Time Particle profiler) sensor data (Figure G-1). Both air sensors use Plantower© light-scattering sensors (one for ARA-NFRM and two for Purple Air) to provide real-time data for two size ranges approximating PM_{10} and $PM_{2.5}$. While the PM_{10} data from the air sensors remain unfortunately inaccurate (see AQMD – AQ-SPEC field evaluation) and are not used in this study, the continuous $PM_{2.5}$ air sensor data, once its concentrations are adjusted using a reference monitor, shows relatively accurate trends. Overall, these Plantower sensors are low-cost compared to research-grade instruments, and their main intend is to show trends during the weekly sample runs, supplementing the PM_{10} metals filter data by providing higher temporal resolution.

Figure G-1: illustration of the N-FRM installation at our UEWA (Fontanelle St.) site, with Purple Air sensor added to the setup(left). The other two photos (borrowed from Purple Air© and ARA instruments© websites), provide a more detailed look at the N-FRM RTP (upper right) and Purple Air sensor (lower right).

Air sensor data adjustment process:

The N-FRM RTP sensor logs $PM_{2.5}$ concentrations at 5-min interval, while the Purple Air logs at 2-min interval. Both sensor data are averaged hourly. The Purple Air raw (PA_{cf_1}) $PM_{2.5}$ concentrations are adjusted using the following EPA's 2021 Purple Air correction equation: $PM_{2.5} = 0.52 \times PA_{cf\_1} - 0.086 \times RH + 5.75$ (Barkjohn et al., 2021).

During the study, we collocate an N-FRM RTP sensor with a Purple Air sensor at South Seattle College – Georgetown campus (Figure G-2) and at our Seattle Duwamish permanent monitor (Figure G-3), where we also have a BAM 1020 (Beta Attenuation Monitor) providing our most accurate PM2.5 concentrations.

Figure G-21. South Seattle College – Georgetown campus (UAWA) N-FRM RTP and Purple Air collocation. Both Purple Air channels have been adjusted using EPA's U.S. wide 2021 correction equation (Barkjohn et al., 2021).

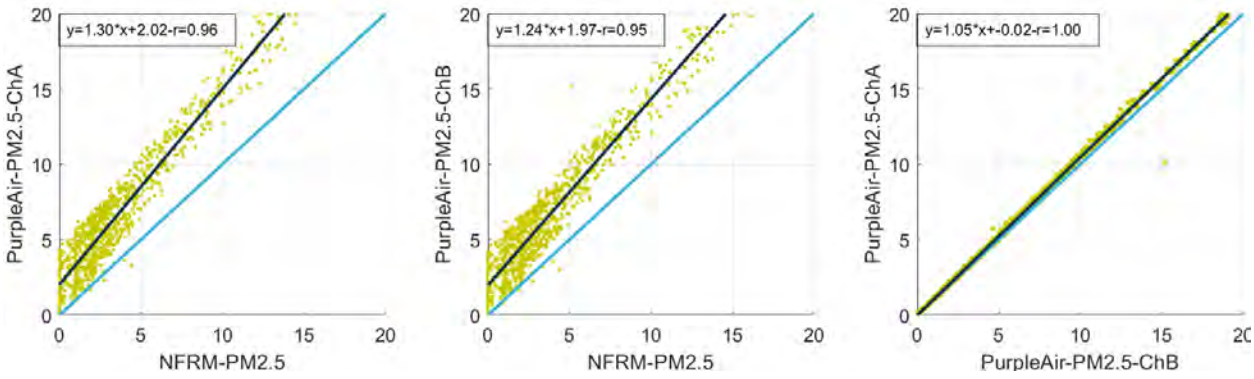
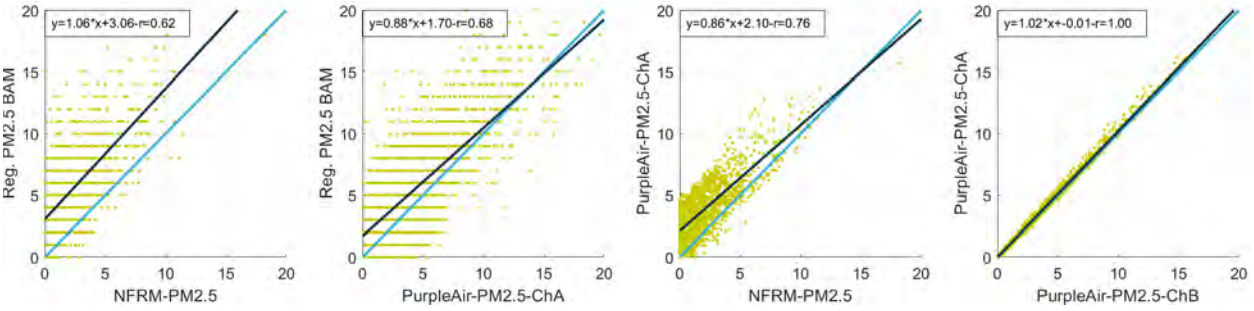


Figure G-3. Seattle Duwamish regulatory site (CEWA) BAM $PM_{2.5}$, N-FRM RTP and Purple Air collocation. Both Purple Air channels have been adjusted using EPA's U.S. wide 2021 correction equation (Barkjohn et al., 2021).

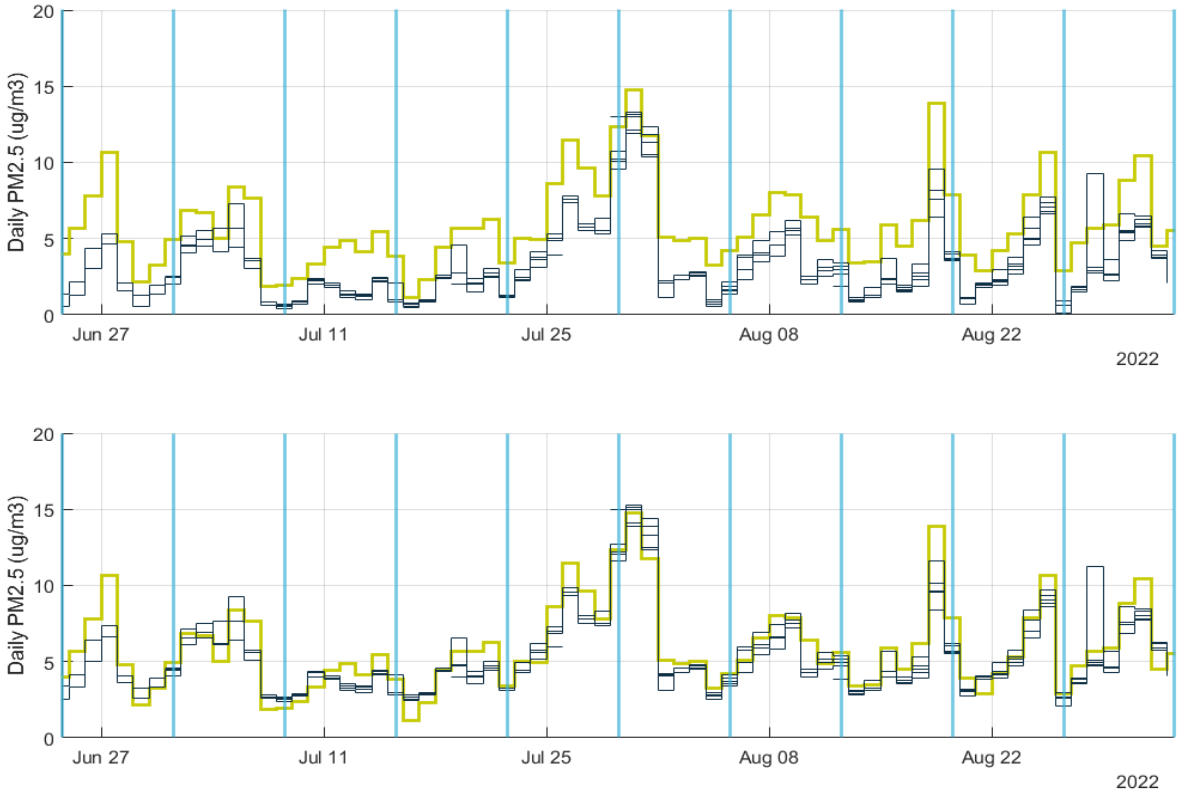


An initial data adjustment was made for the Fontanelle St. (UEWA) site where the N-FRM RTP sensor did not work; and we installed a Purple Air to estimate the N-FRM RTP PM2.5 concentrations. We obtained an ordinary least square regression equation

from the collocation between the Purple Air sensor and the N-FRM RTP at South Seattle College – Georgetown campus (UAWA), which showed a strong correlation coefficient of R=0.96 (Figure G-3). The equation: *N-FRM RTP PM2.5$_{estimate}$ = Purple Air PM2.5$_{EPAadjusted}$ / 1.3 – 2*; was then used to estimate the PM2.5 concentrations.

After comparing the BAM $PM_{2.5}$ data at our Duwamish site with the different N-FRM RTP $PM_{2.5}$ time series, we notice that adding 2 $\mu g/m^3$ to the entire N-FRM RPT dataset provided a sufficient adjustment at the different sites and showed overall agreement with the BAM PM2.5 time series (Figure G-4).

Figure G-4. Illustration of the N-FRM RTP overall data adjustment before adding 2 µg/m³ (top plot) and after (bottom plot) for the daily PM2.5 averages. The green time series represents the Duwamish BAM $PM_{2.5}$ data while the black time series represent the several N-FRM RTP time series. The blue vertical lines represent the start/end dates of the weekly samples.



Appendix H. Community interest: Attempt to spatially extrapolate moss study results to air samples

In 2019 and 2021, the Duwamish Valley Youth Corp collected samples of moss and had them analyzed for metals.[1] The group attempted to use moss sampling to provide information on the spatial distribution of metals by deposition. However, there are inherent limitations in this approach, including how long metals reside in the moss. That is, moss may leach metals with varying levels of precipitation, growth rates, and likely other variables. Therefore, inherently, linking moss samples directly to air samples the concentration is potentially flawed, and is seasonally effected.

Even with these inherent uncertainties, we attempted to match the moss samples with the air samples to estimate a potential cancer risk surface in the graph below. The first step was to krige the moss samples, combining both 2019 and 2021 data. The kriging predictions were calculated on a grid with 5m x 5m cells. The prediction closest to each of our air monitoring sites was chosen for comparison. A simple linear regression was calculated with the kriging predictions as the x variable and the average of the air monitoring data for each site as the y variable. Each linear model had 6 datapoints, one for each of our sites. The scatterplot below in Figure H-1 shows the model performance for chromium. The full set of model performance graphs can be found at the end of this section. Pearson correlations were above 0.5 for cobalt (0.91), nickel (0.88), cadmium (0.56), and arsenic (0.53) and lower for lead (0.31), chromium (0.27), manganese (0.24), and selenium (0.05). Despite low correlation for chromium, we still used it for the purpose of this demonstration as it may include the highest potential cancer risks depending on the ratio that is hexavalent chromium. The linear models were applied to all the moss sample results. Metals that had Washington State Acceptable Source Impact Levels were converted to potential cancer risk. Potential cancer risk was then summed across all metals for each community site. The combined estimated potential cancer risk was kriged and displayed in Figure I-12. Both the initial and final kriging were using ordinary kriging with the model parameters chosen by the R function autoKrige.

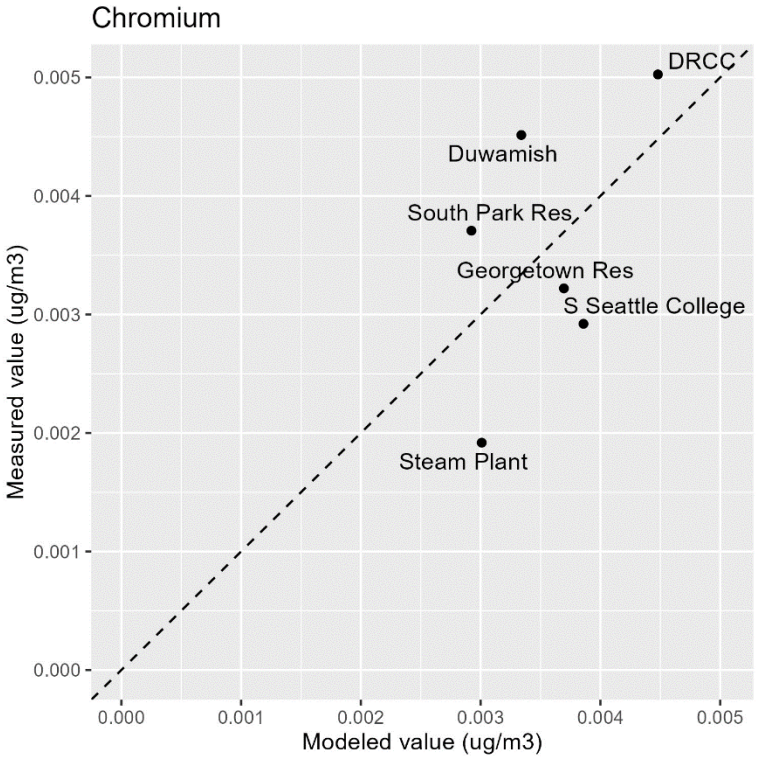
[1] Jovan S., Zuidema C., Derrien M., Bidwell A., Brinkley W., Smith R., Blahna D., Barnhill R., Gould L., Rodríguez A., Amacher M., Abel T., and López P. (2022). "Heavy metals in moss guide environmental justice investigation: A case study using community science in Seattle, WA, USA". Ecosphere.

For selenium, almost all 2019 moss samples and one 2021 result were below the detection limit and were removed.

One of the major limitations to this approach is that the moss samples were taken at a different time than the air samples and represent the cumulative exposure of the moss throughout its life.

It is also important to note the low correlation with chromium (0.27) since estimated hexavalent chromium contributes the largest amount to cancer risk from metals.

Figure H-1. Moss comparison model for chromium.

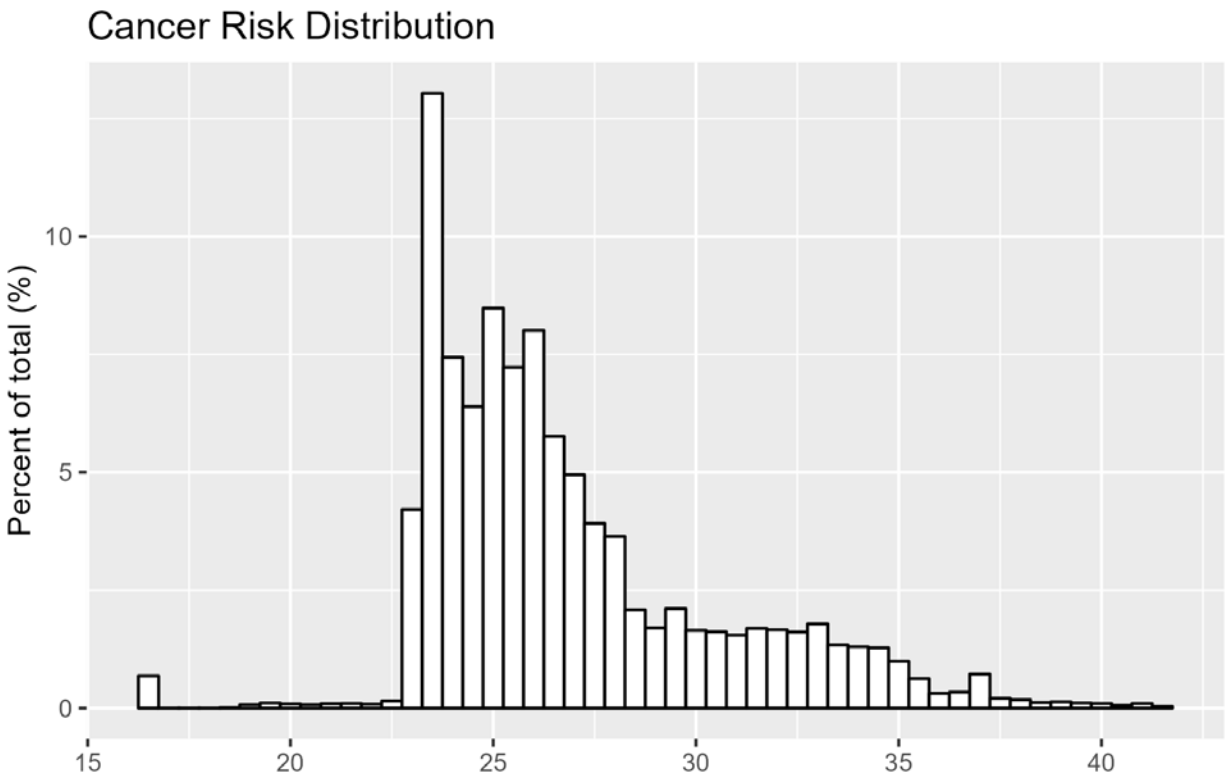


In Appendix I, Figure I-12 shows the estimated potential cancer risk from the metals that were sampled in both the moss studies and our study. These metals are arsenic, cadmium, estimated hexavalent chromium, lead, and nickel. Hexavalent chromium was estimated to be 3% of total chromium as referenced earlier in this report.

Estimated potential cancer risk from metals in the air was higher in the industrial area of north South Park, along E Marginal Way S, and along 1st Ave S. The highest estimated potential cancer risk was approximately ten times lower than the estimated diesel cancer risk as described earlier in this study.

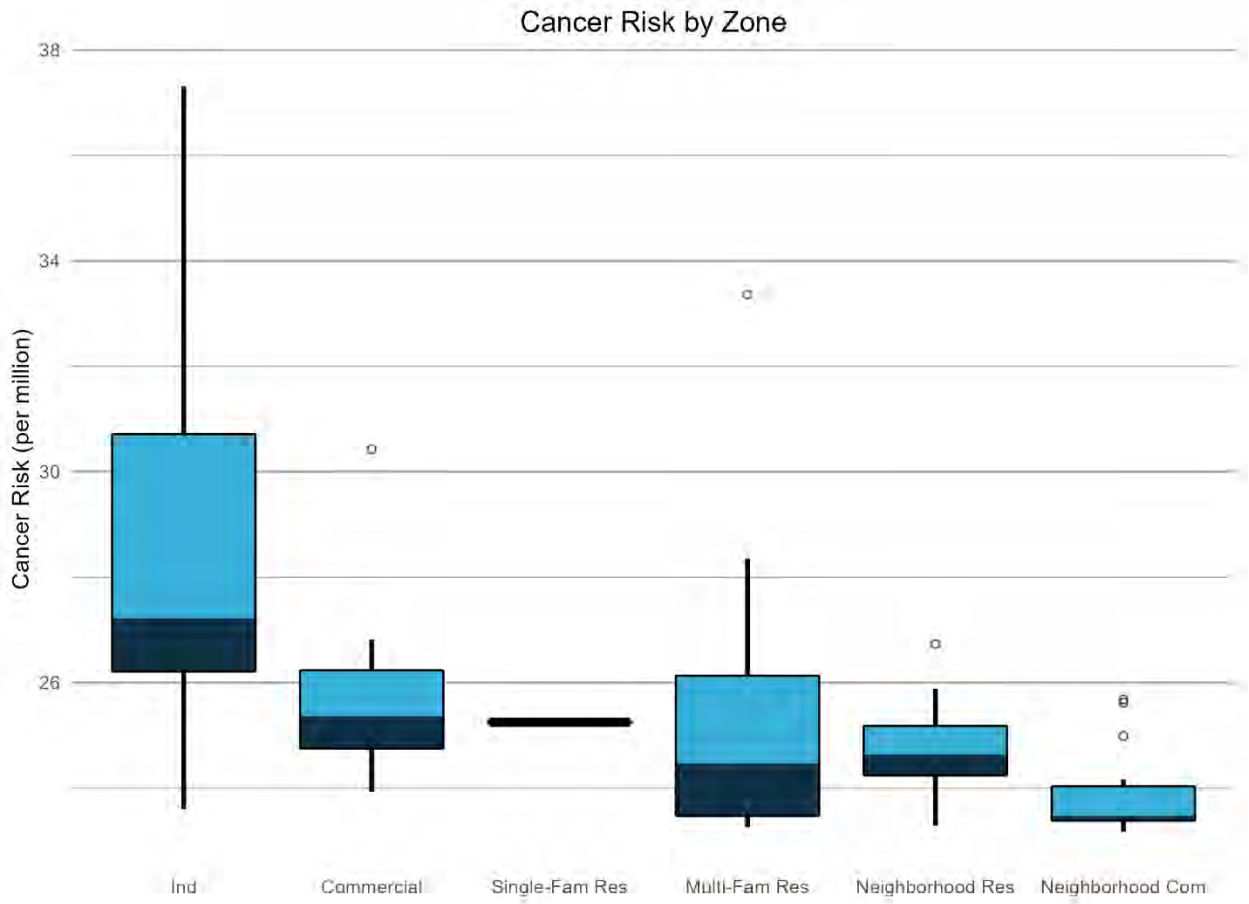
The graph shows the distribution of cancer risk values from the cancer risk raster. Most of the values are between 23 and 28 per million. The lower end of the cancer risk range (approximately 16-23 per million) is concentrated around the Georgetown Steam Plant site. That is because the Steam Plant site had significantly lower values than the other sites for chromium and arsenic. So, when interpreting the map, the residential areas of "background" risk east and west of the Duwamish River have a risk around 23 per million.

Figure H-2. Kriged metals estimated potential cancer risk distribution.



We also attempted to quantify the difference in potential cancer risk based on zoning. A zone shapefile for the City of Seattle was downloaded and the average cancer risk for each zone was calculated. The average cancer risk for commercial zones was 25 per million; residential, 25 per million; and industrial, 28 per million. When looking at the average cancer rate by detailed zone information, the industrial zones have a higher cancer risk than commercial and residential zones. The commercial and residential average cancer risk is close to the background risk of approximately 23 per million. See Figure I-1 in Appendix I for a detailed map of the zones overlayed on top of the potential cancer risk layer.

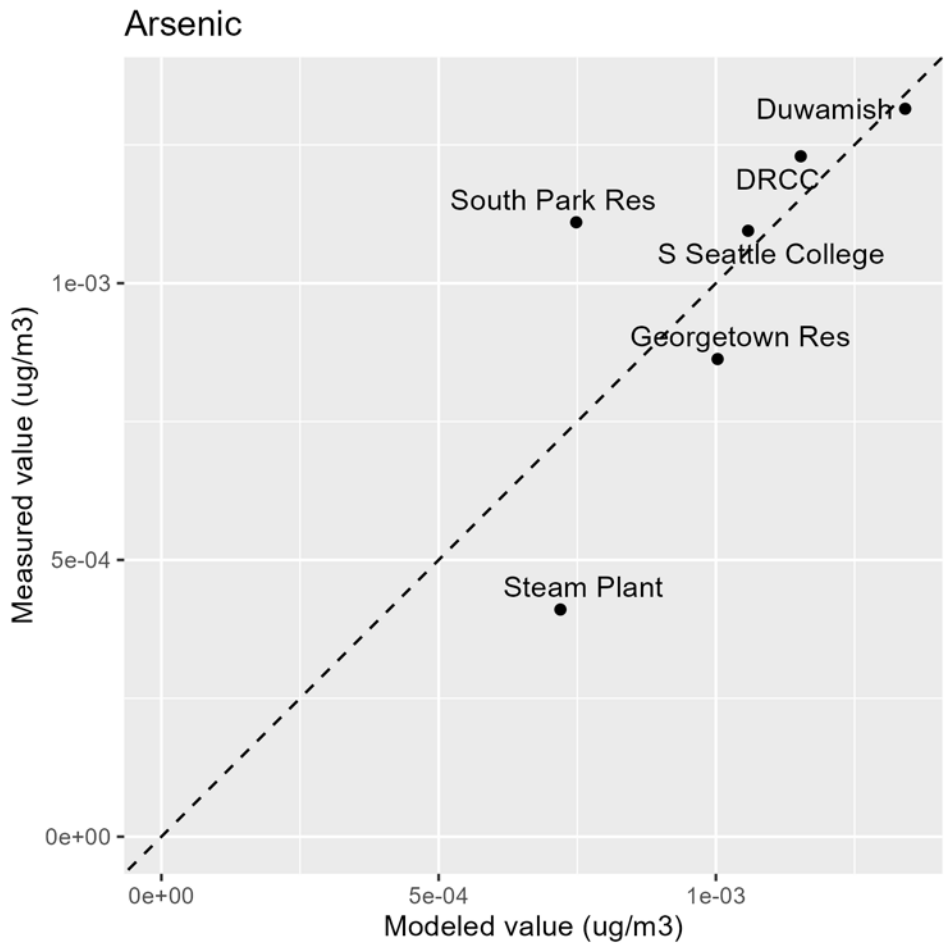
Figure H-3. Estimated metals potential cancer risk by land use zone.



This bar plot shows more detailed zoning categories and the associated potential cancer risk. The outlier for the commercial zone is a zone that encompasses the South Seattle College Georgetown campus, where we had a monitoring site. The multi-family residential outlier is a small area just south of the West Seattle Bridge (see Appendix I).

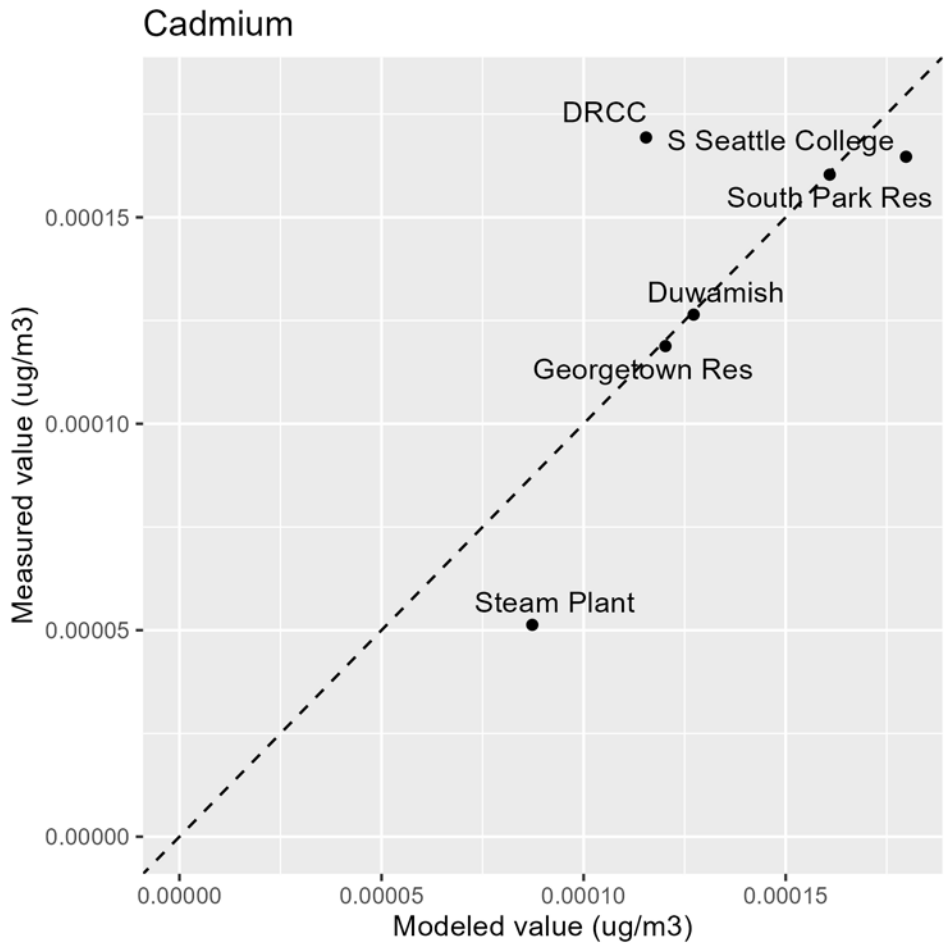
The following scatterplots show the model performance for the other metals.

Figure H-4. Moss Model Performance - Arsenic



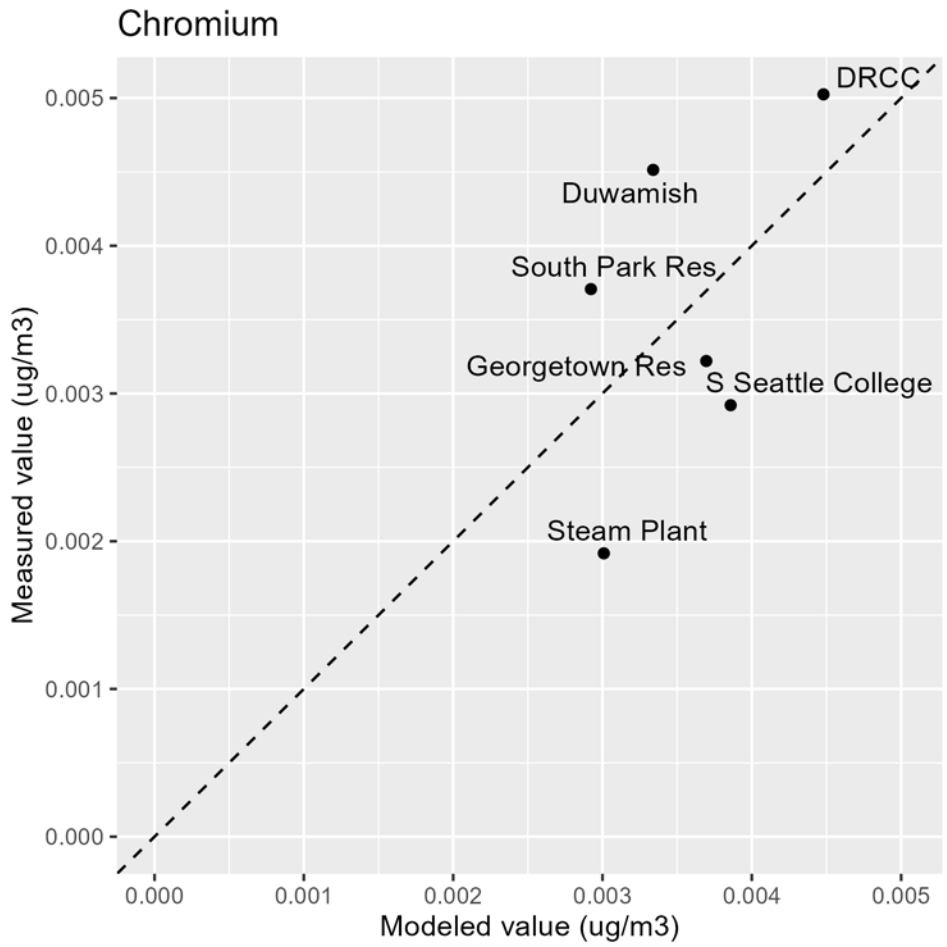
Summary statistics: R^2 = 0.53, adjusted R^2 = 0.41, RMSE = 0.21 ng/m^3, sample mean = 1 ng/m^3

Figure H-5. Moss Model Performance - Cadmium



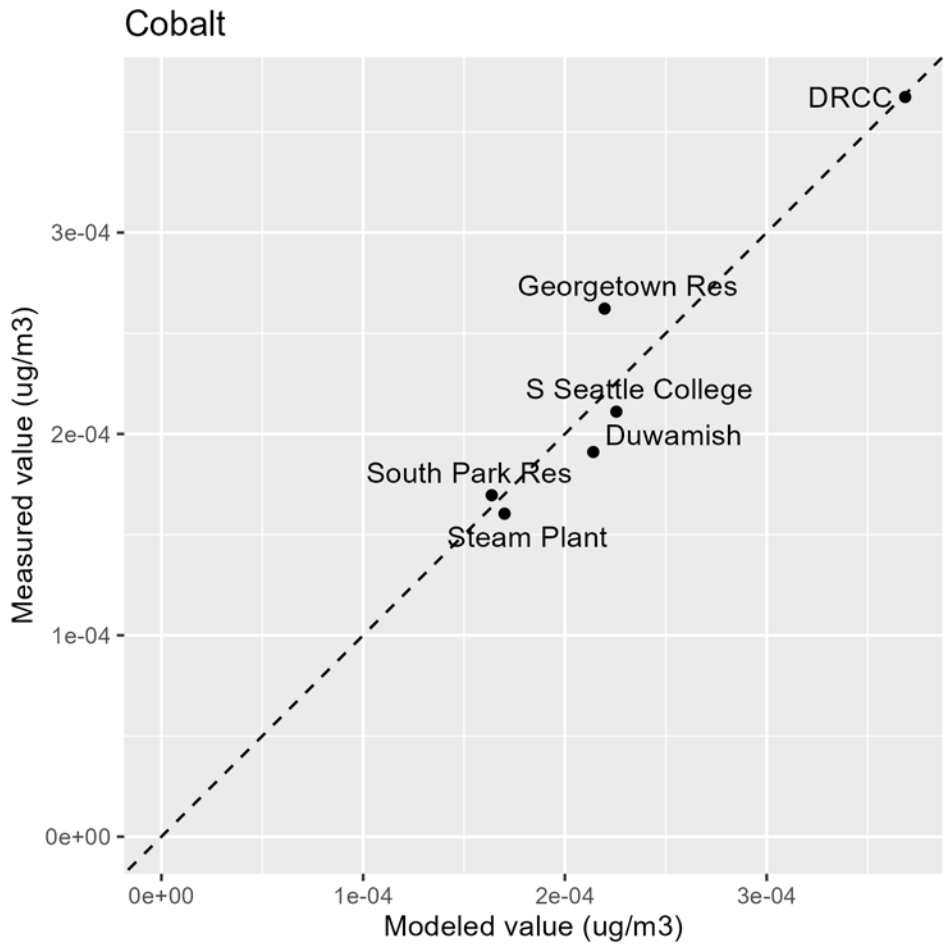
Summary statistics: R^2 = 0.56, adjusted R^2 = 0.45, RMSE = 0.03 ng/m^3, sample mean = 0.13 ng/m^3

Figure H-6. Moss Model Performance - Chromium



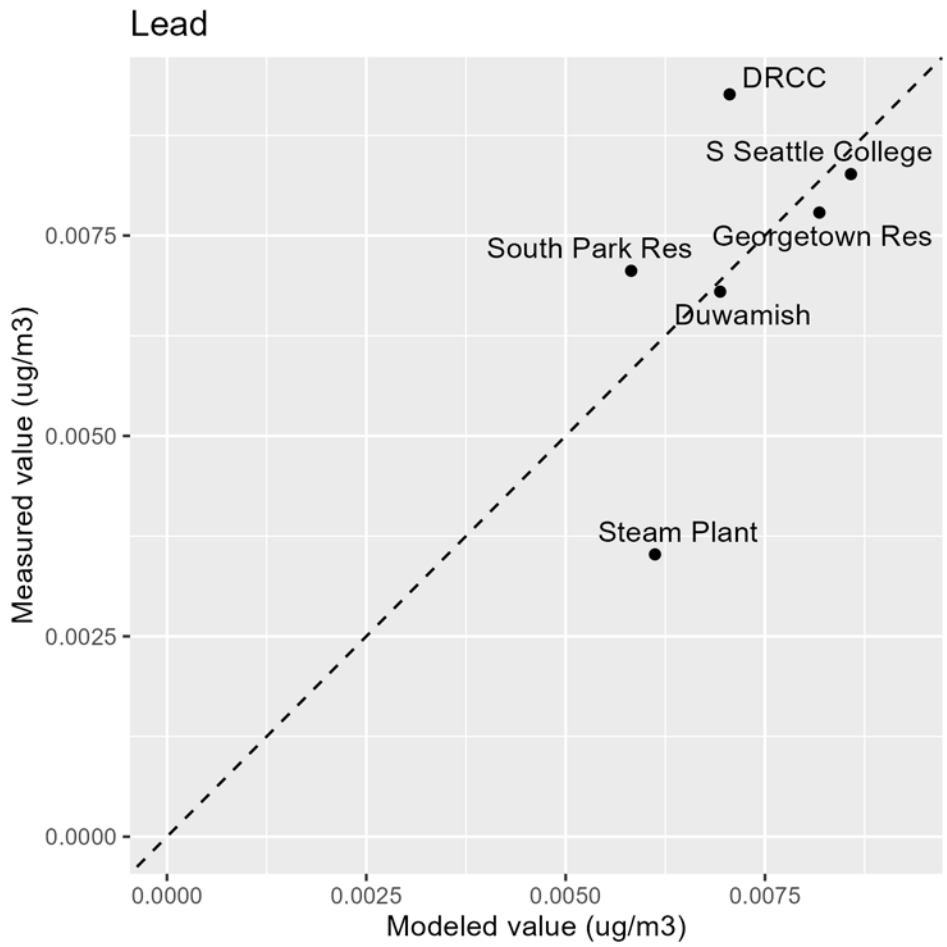
Summary statistics: R^2 = 0.27, adjusted R^2 = 0.09, RMSE = 0.87 ng/m^3, sample mean = 3.55 ng/m^3

Figure H-7. Moss Model Performance - Cobalt



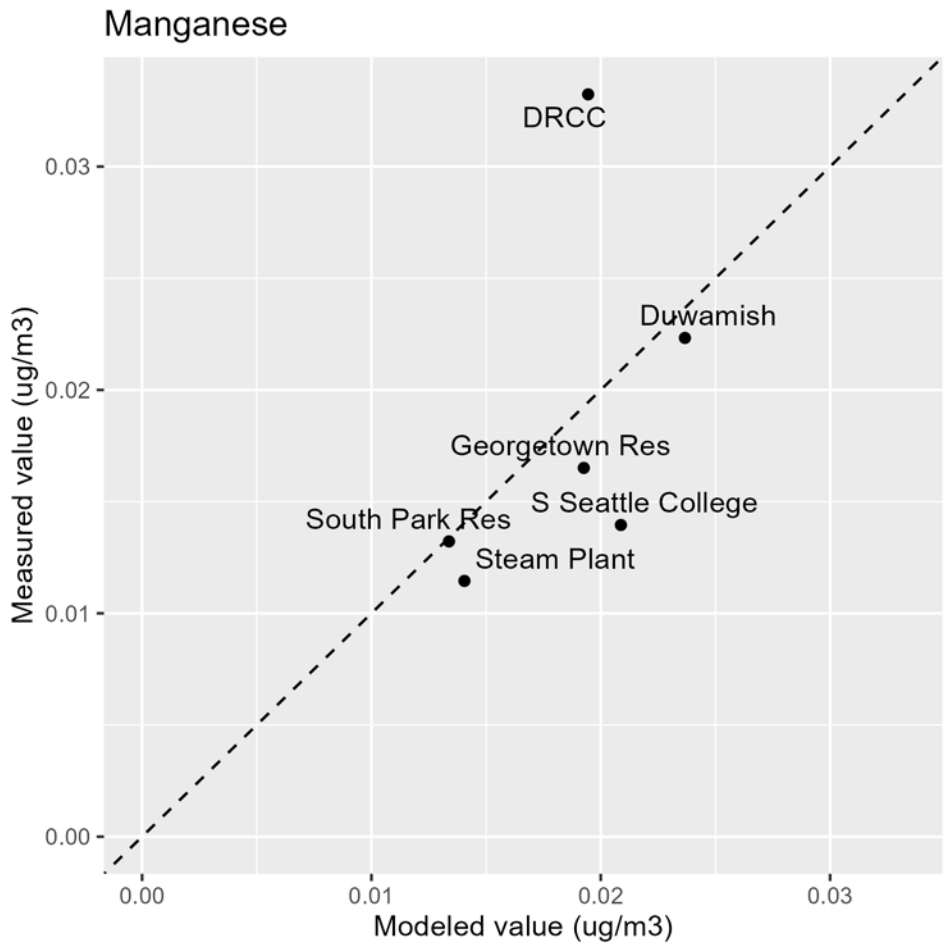
Summary statistics: R^2 = 0.91, adjusted R^2 = 0.89, RMSE = 0.02 ng/m^3, sample mean = 0.23 ng/m^3

Figure H-8. Moss Model Performance - Lead



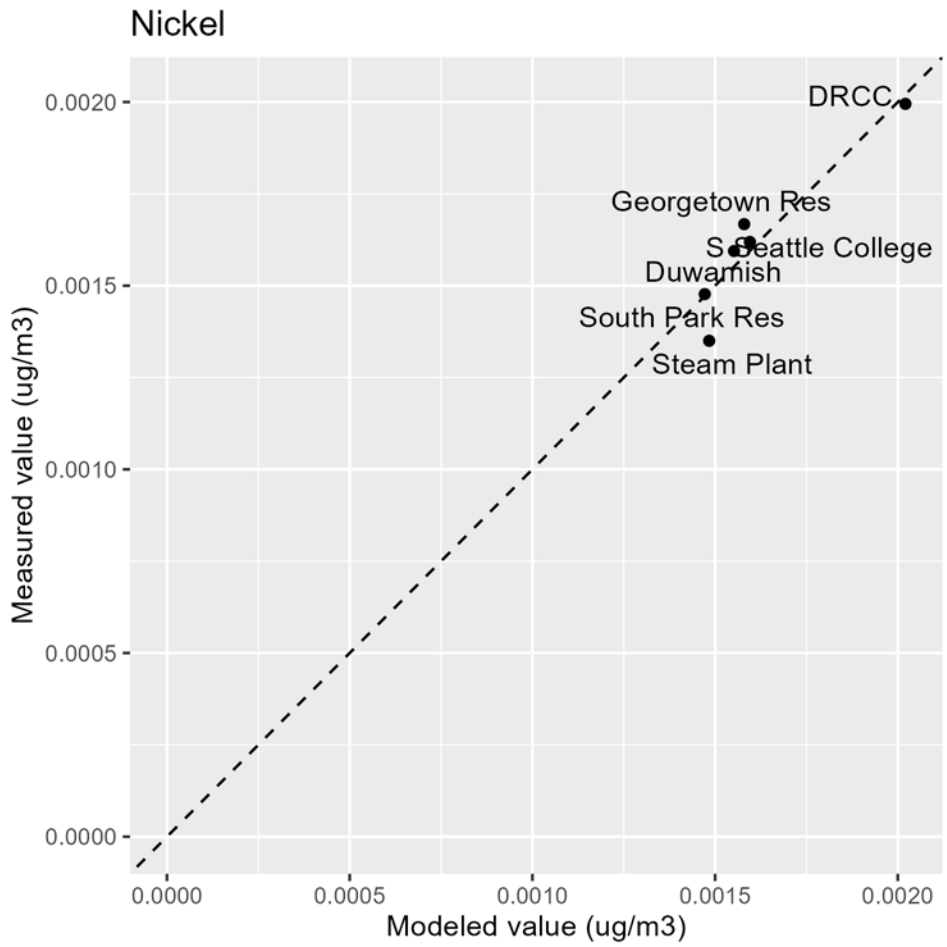
Summary statistics: R^2 = 0.31, adjusted R^2 = 0.14, RMSE = 1.5 ng/m^3, sample mean = 7.12 ng/m^3

Figure H-9. Moss Model Performance - Manganese



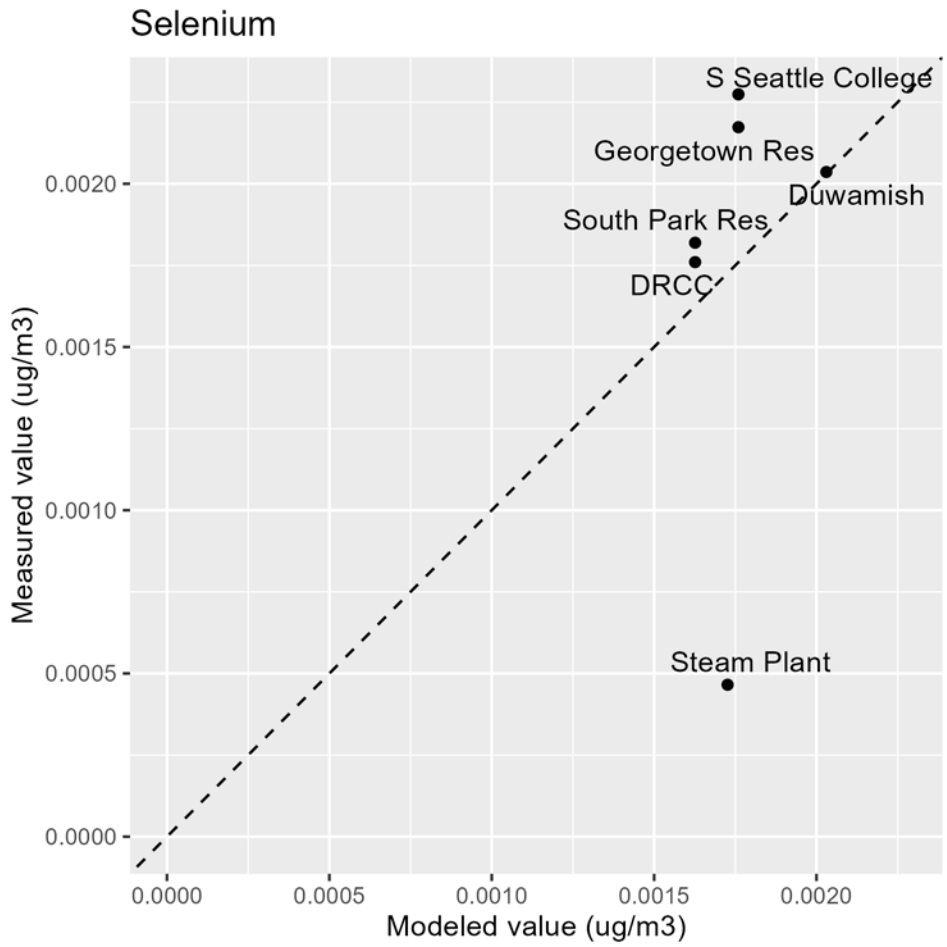
Summary statistics: R^2 = 0.24, adjusted R^2 = 0.05, RMSE = 6.51 ng/m^3, sample mean = 18.45 ng/m^3

Figure H-10. Moss Model Performance - Nickel



Summary statistics: R^2 = 0.88, adjusted R^2 = 0.85, RMSE = 0.07 ng/m^3, sample mean = 1.62 ng/m^3

Figure H-11. Moss Model Performance - Selenium



Summary statistics: R^2 = 0.05, adjusted R^2 = -0.19, RMSE = 0.59 ng/m^3, sample mean = 1.75 ng/m^3

Appendix I. Community interest: Attempt to map pollutant-specific and zoning maps for moss comparison

Despite the many limitations with this approach, including low correlations to the chromium value (0.27) which drives most of the risks herein, we proceeded to display the maps below for reference for transparency. Appendix H above describes the approach in more detail.

Figure I-1. Estimated cancer risk from metals including zone definitions.

Note: There is an area west of the playfield that has some residential lots, which were allowed to keep their designation when the area was re-zoned as industrial. When these lots are sold, they will become industrial.

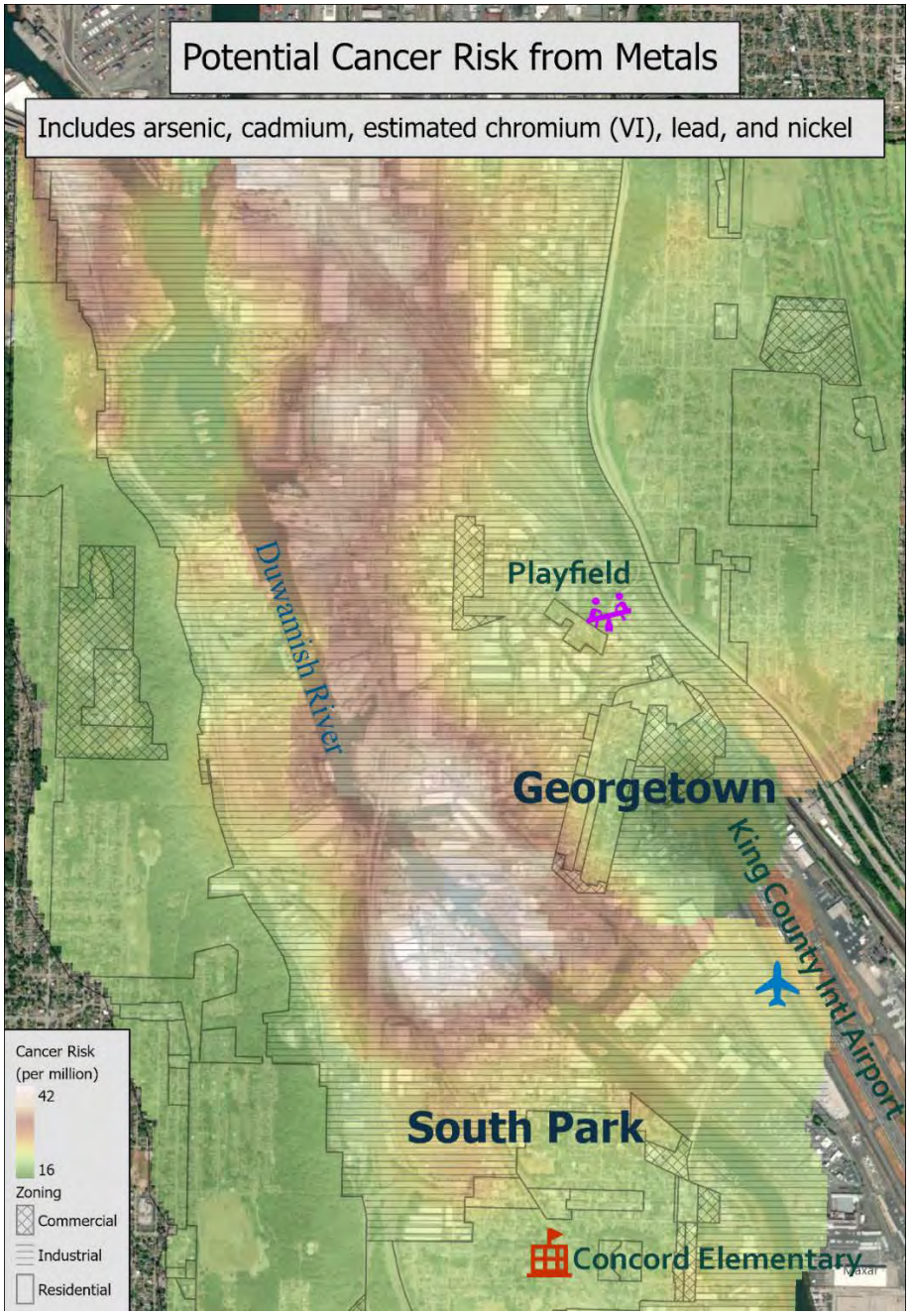
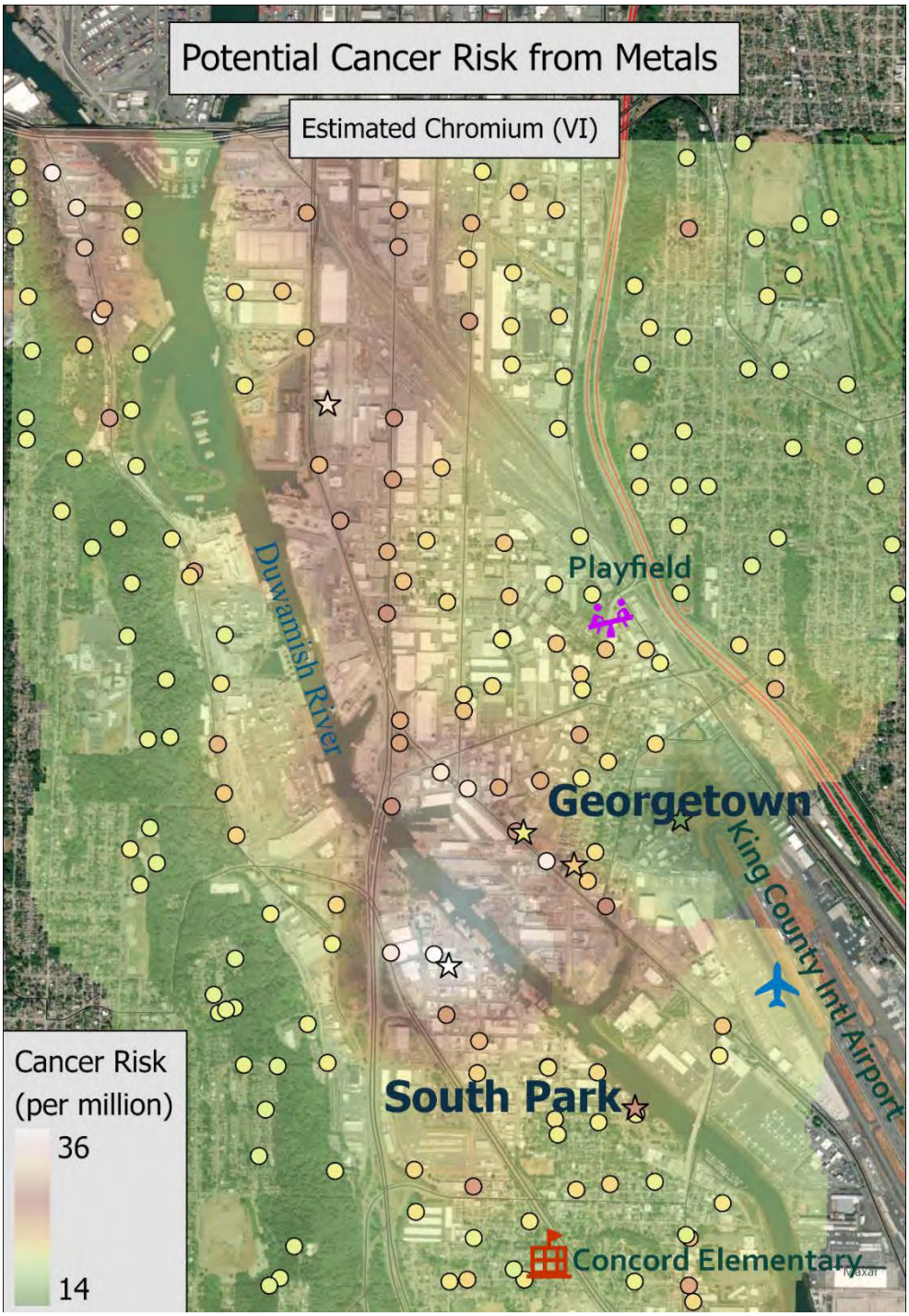


Figure I-2. Estimated cancer risk from arsenic.

Across all moss and air sampling sites, arsenic accounted for about 10% of cancer risk from metals.

Figure I-3. Estimated cancer risk from hexavalent chromium.



Across all moss and air sampling sites, estimated hexavalent chromium accounted for about 87% of cancer risk from metals.

Figure I-4. Estimated arsenic concentrations in ng/m³.

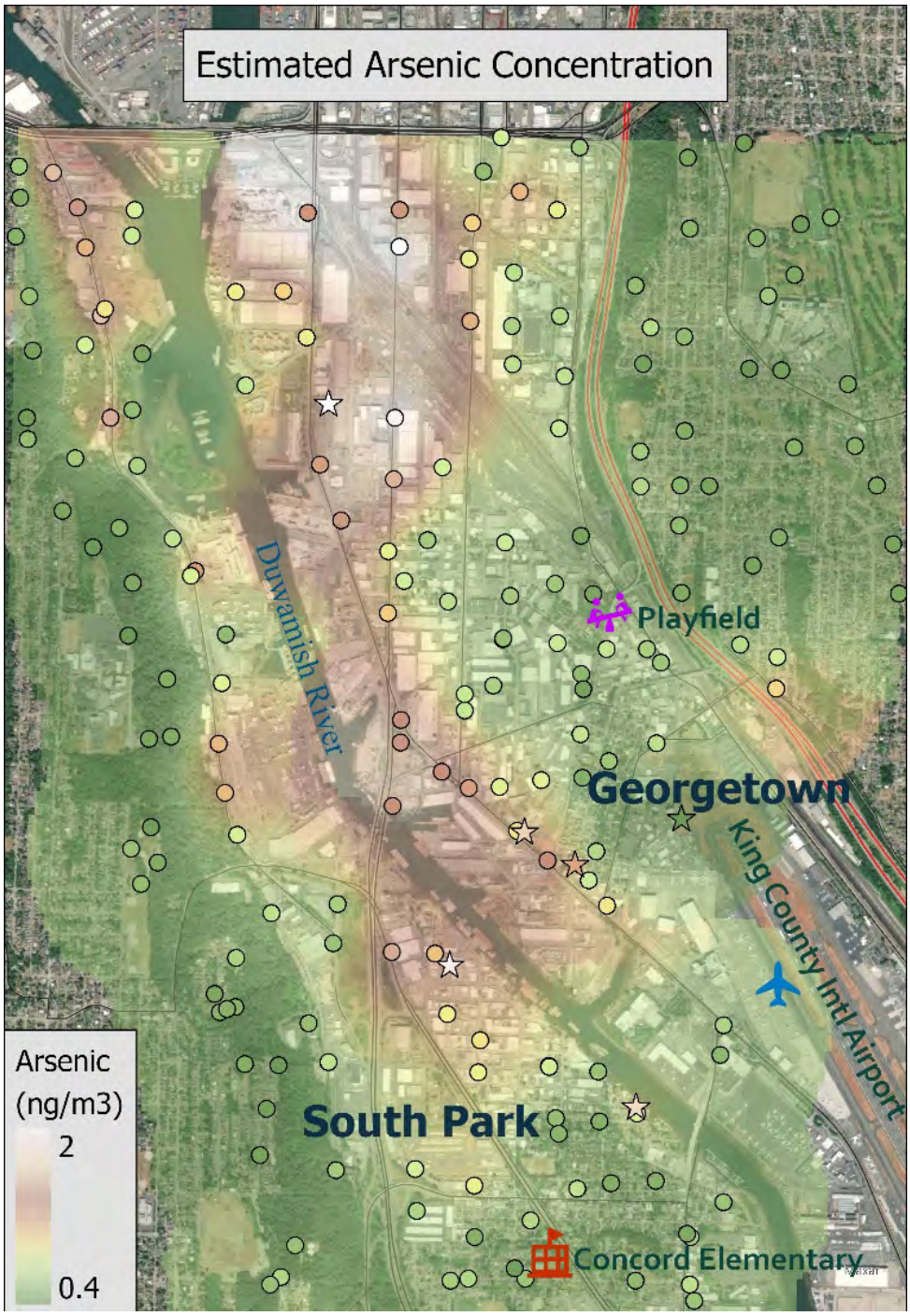


Figure I-5. Estimated cadmium concentrations in ng/m³.

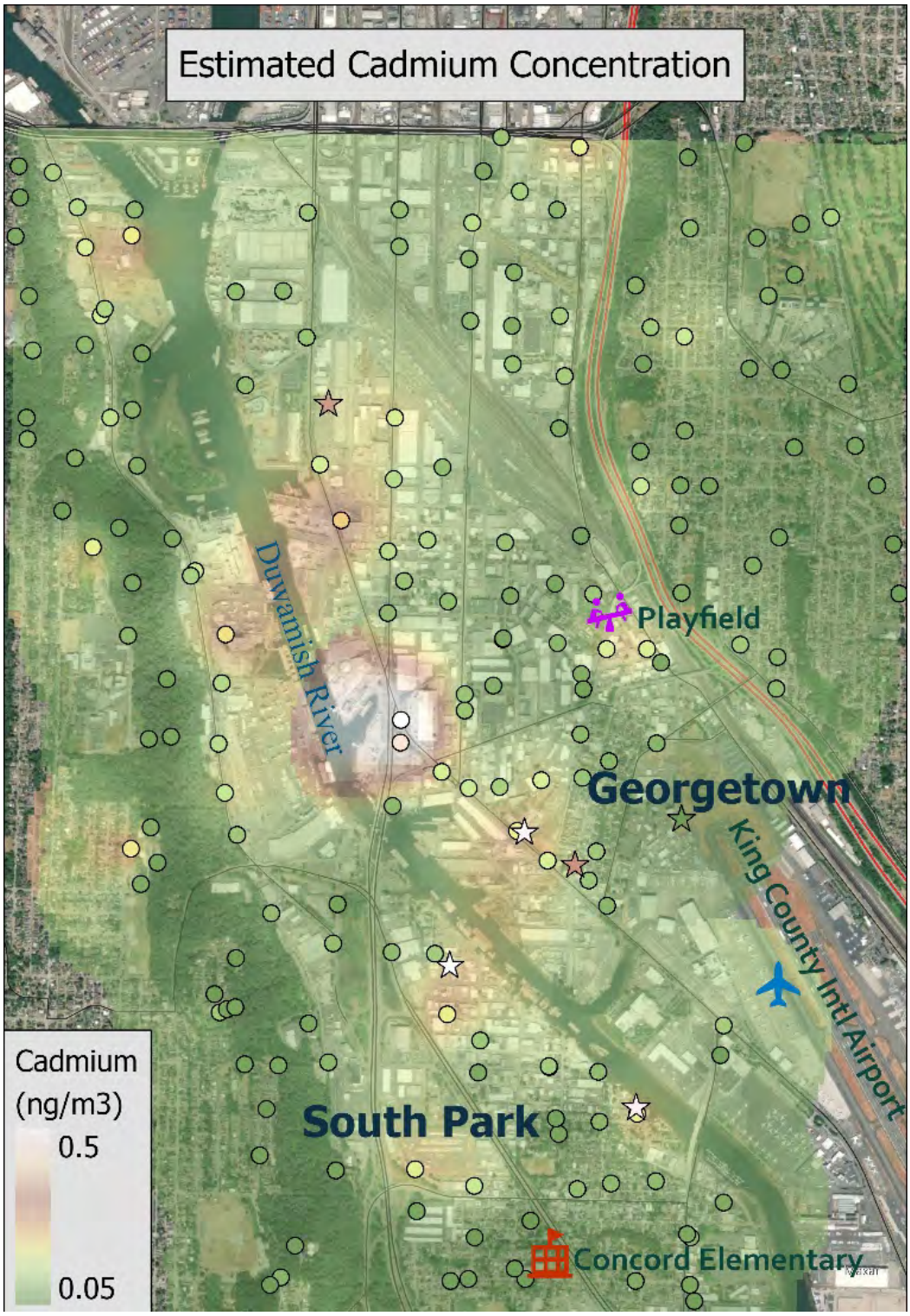


Figure I-6. Estimated total chromium concentrations in ng/m³.

Figure I-7. Estimated cobalt concentrations in ng/m³.

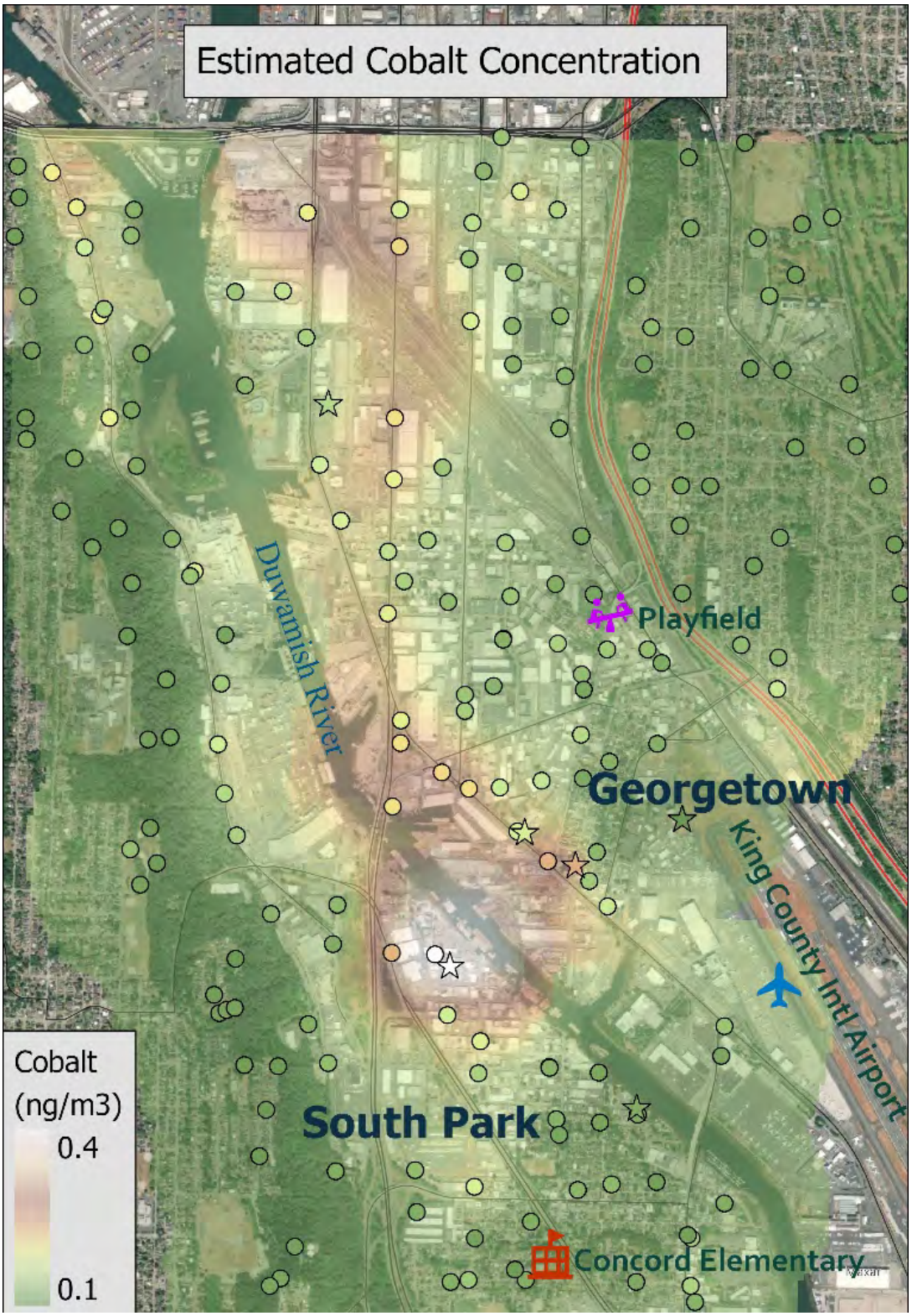


Figure I-8. Estimated lead concentrations in ng/m³.

Figure I-9. Estimated manganese concentrations in ng/m³.

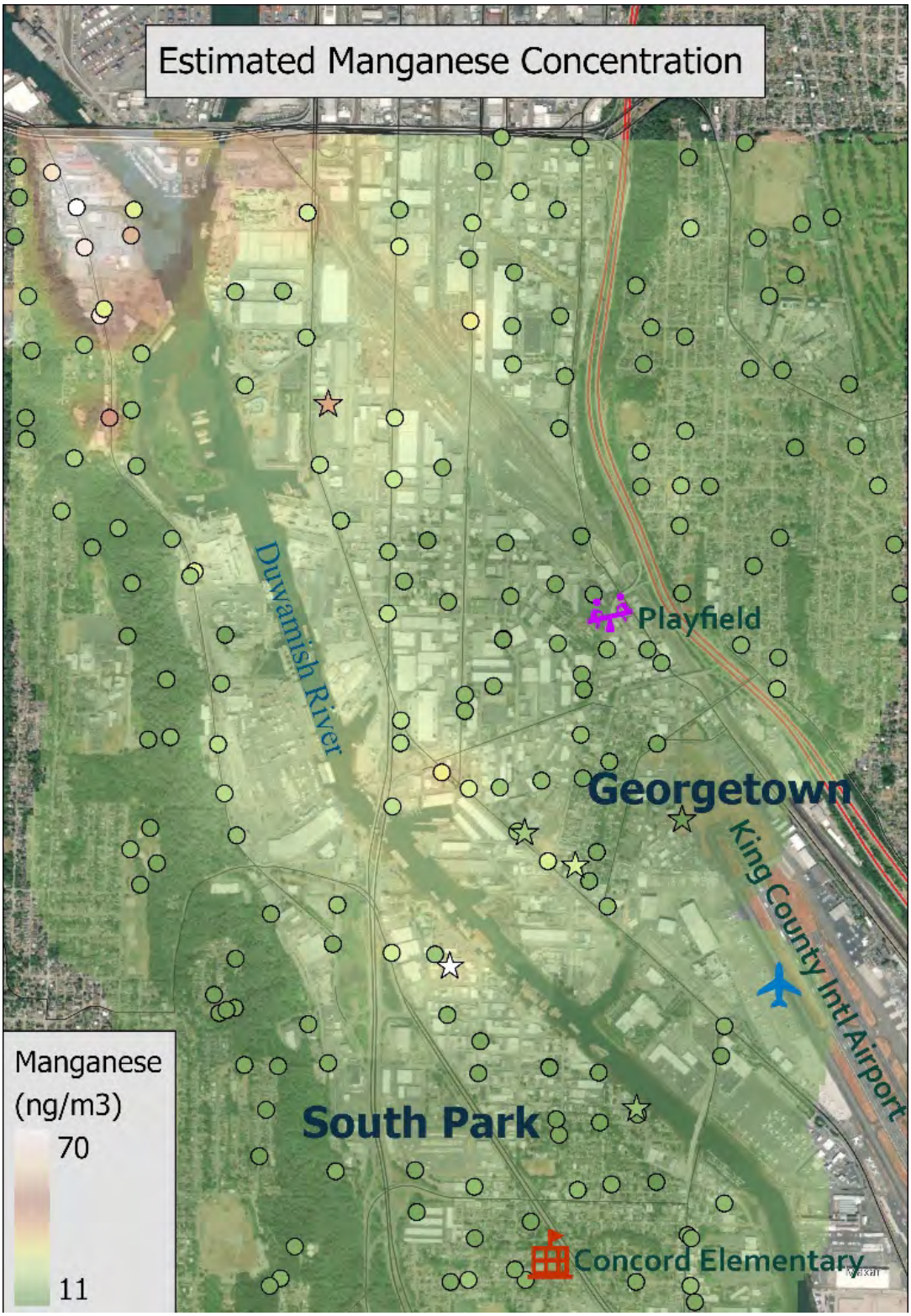


Figure I-10. Estimated nickel concentrations in ng/m³.

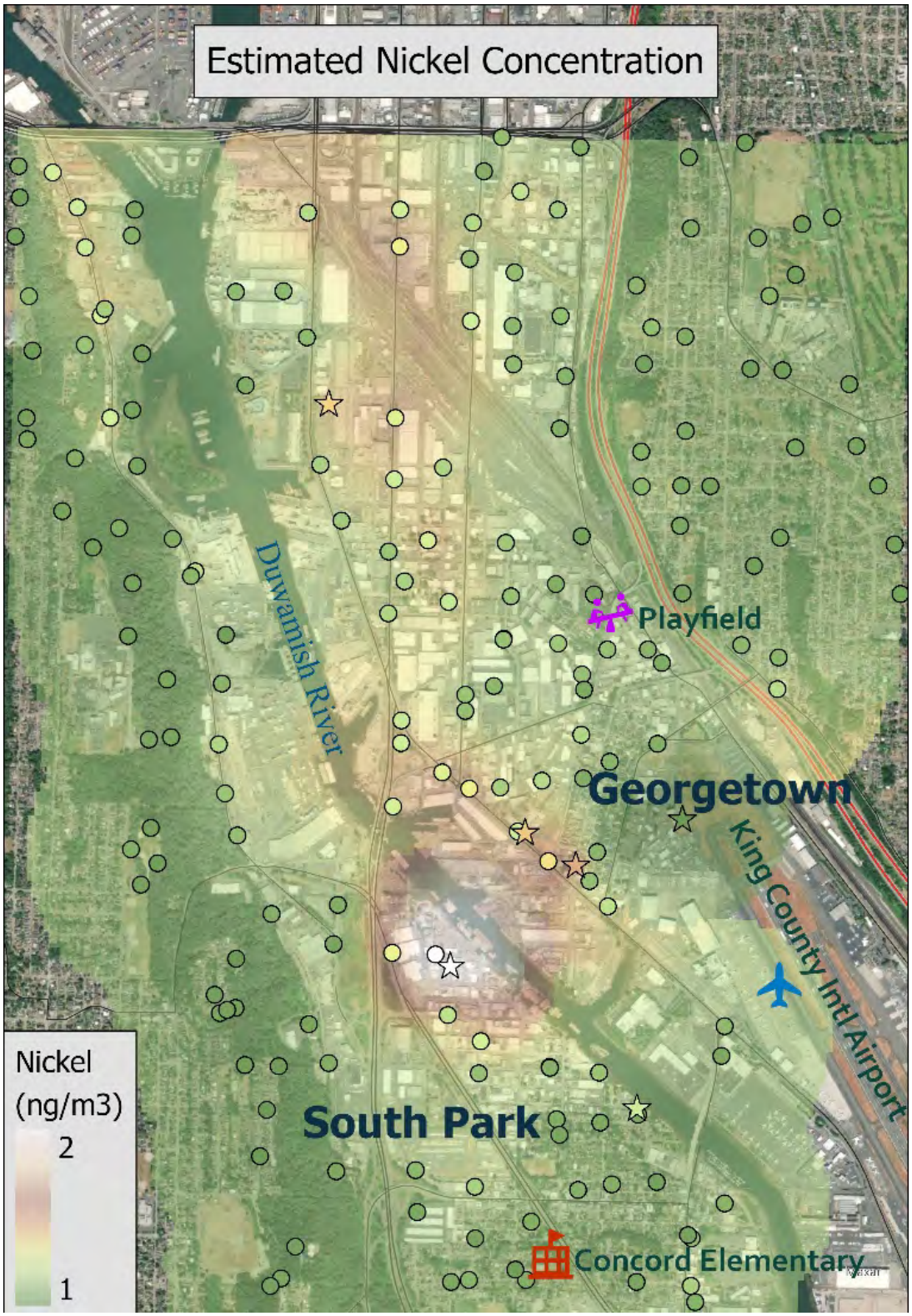


Figure I-11. Estimated selenium concentrations in ng/m³.

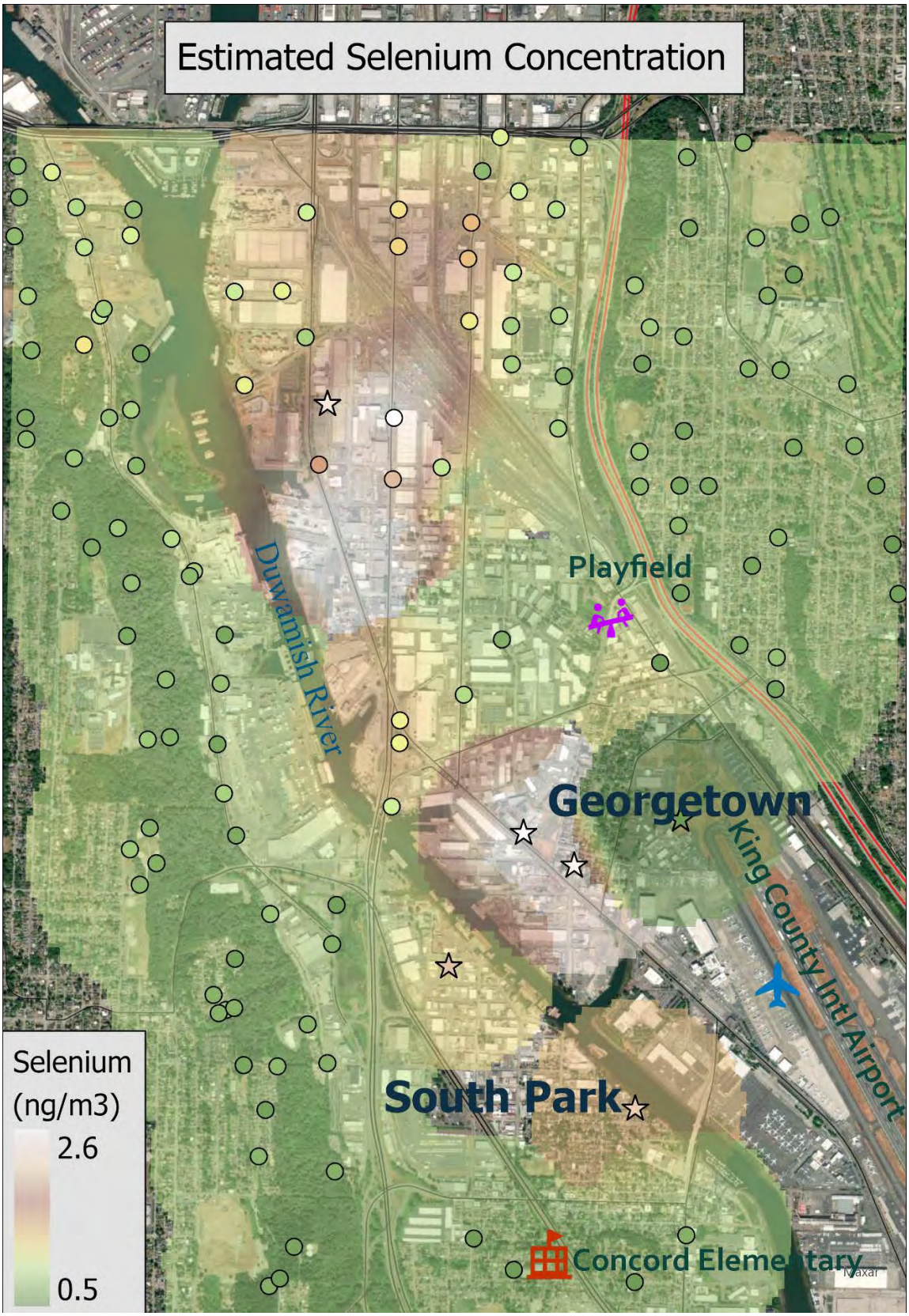


Figure I-12. Map with potential cancer risk from metals in the Duwamish Valley extrapolated from moss samples calibrated to adjacent air quality samples.

Appendix J. Community interest: Comparison to Portland moss study

Overall

In the Portland moss study, elevated cadmium and arsenic levels were found in moss near a stained-glass manufacturer (denoted as stained glass #1 in the report).[2] Oregon DEQ followed up with air sampling near the facility. That air sampling campaign recorded a maximum cadmium concentration of nearly 200 ng/m^3 and an average of 29 ng/m^3. The air monitoring performed in our study had a maximum cadmium concentration of 1.9 ng/m^3 and site-averages of 0.1-0.2 ng/m^3. The maximum concentration of arsenic in the air in the Portland study was approximately 100 ng/m^3 with an average of 32 ng/m^3. In this study, we found a maximum of 8.5 ng/m^3 arsenic and a site-averages of 0.4 - 1.3 ng/m^3. **The levels of arsenic and cadmium seen in our study were much lower than the Portland study** and don't indicate a specific extreme source as in Portland.

It is important to note that, at least with current sampling and quantification protocols, moss has not been established to be a reliable quantitative method for assessing ambient concentrations of pollution in the air between regions or studies (while regulatory methods explicitly have been). Moss inherently introduces additional variables and measurement uncertainty (confounders) due to the complexity of the collection media (a living, biological material) and its variability in the sampling environment, both of which are factors that have been deliberately designed out of the regulatory methods (e.g. PM_{10} and deposition methods) because of the uncertainty they bring. An incomplete list of potential confounders that could easily make the Seattle and Portland samples not directly comparable include: the type of moss, the sampling duration, weather conditions during sampling including temperature, sunlight, rain, relative humidity, wind direction, all of which could affect growth, surface uptake of particles, and ion exchange activity on the surfaces. Current research has shown that the basic mechanisms of metal uptake by moss

[2] Donovan G., Jovan S., Gatziolis D., Burstyn I., Michael Y., Amacher M., and Monleon V. (2016). "Using an epiphytic moss to identify previously unknown sources of atmospheric cadmium pollution". 2016. Sci of the Total Env 559:84-93.

are not well understood, much less well controlled in current sampling methods and thus semi-quantitative/not-comparable results are common.[3,4]

Arsenic and cadmium ratios

One way to assess the transferability of moss results is to calculate the air to moss ratio. This is simply the concentration of the metal in the air (ng/m^3) divided by the concentration of that metal in moss (mg/dry kg). For the Portland study, the cadmium ratio was 29.4 ng/m^3 (the average air concentration) divided by 4 mg/kg (the average of the highest quintile of nearby moss samples), which equals 7.4. In our study the cadmium ratio was 0.1 ng/m^3 (the average of all our sites) divided by 0.9 mg/kg (the average of the kriging predictions closest to our sites), which equals 0.14. The arsenic ratio was 31.7 ng/m^3 divided by 0.5 mg/kg, which equals 63. In our study, the arsenic ratio was 1 ng/m^3 divided by 1.7 mg/kg, which equals 0.6.

The ratios found in our study were not similar to the ratios found in the Portland study from the air sampling performed near the stained-glass manufacturer. So, applying the Portland ratio to the moss samples from Seattle would not result in accurate estimates of the air concentration.

[3] Int J Environ Res Public Health. 2022 Apr; 19(8): 4706, doi: 10.3390/ijerph19084706, Is Active Moss Biomonitoring Comparable to Air Filter Standard Sampling?, P. Świsłowski, A. Nowak, S. Wacławek, Z. Ziembik, and M. Rajfur.

[4] Orthotrichum Lyellii as an Active Moss Biomonitor: Examining the Interplay Between Ambient PM10, Bulk Deposition and Heavy Metals in an Urban Environment, Kiel, Scott Bradley. Portland State University, ProQuest Dissertations Publishing, 2022. 29319498.

Appendix K. PMF site pie charts and factor profiles

General descriptions:

Sources were identified from the PMF analysis based on their composition, seasonality, and correlation to other measured parameters. At all five sites, nine factors were found to be the most reasonable. Eight of these factors were found at all sites: Ammonium sulfate/nitrate, Sea Salt, Nitrate-rich, Sulfate-rich, Crustal/Diesel, Motor Vehicles – Gasoline, Fresh Wood Smoke, and OP-rich/Aged Wood Smoke. In addition, each site had a unique factor. Seattle 10th and Weller had a Motor Vehicles – Diesel factor; Seattle Beacon Hill had an Unidentified Urban factor; Tacoma Tideflats a K rich factor; Tacoma South L an Aged Sea Salt factor; and Seattle Duwamish a Ca rich factor.

Below are pie charts of several the most important chemicals or pollutants/measures. In the figures below, the stripped factors indicate those that are regarded as being primarily diesel or having a large contribution from diesel.

Site descriptions:

Below are pie charts of the PMF factor components as fraction of $PM_{2.5}$ mass, pollution rose plots for the PMF factors using daily wind speeds, and seasonal trends for the PMF factors for each site.

Figure K-1. Seattle Duwamish PMF Factor Pie Chart

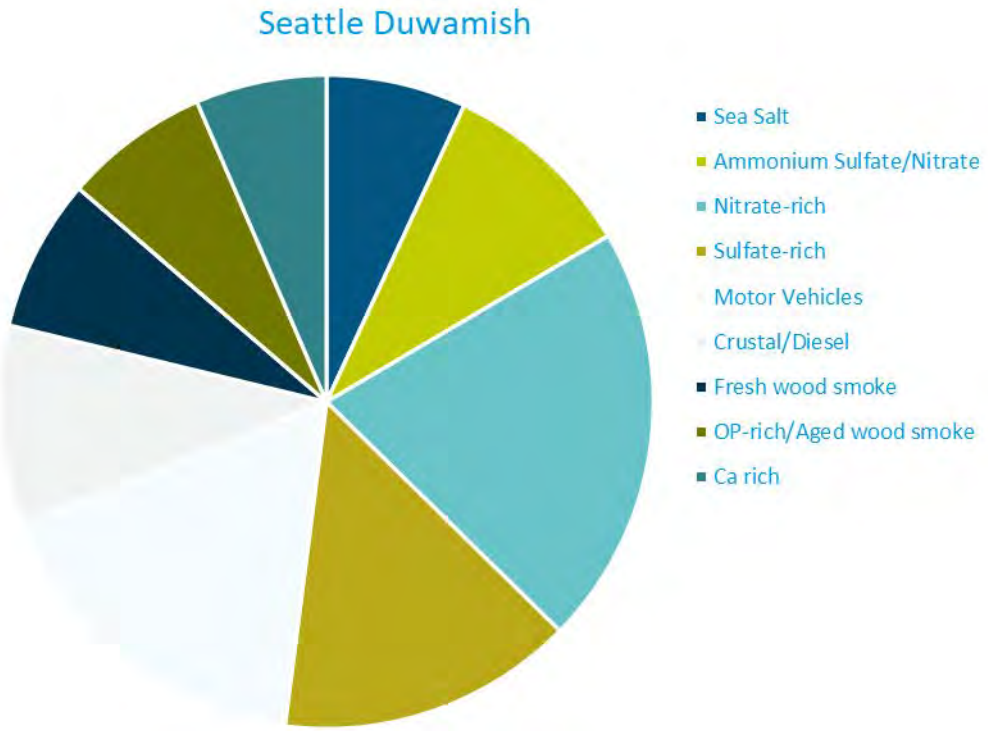


Figure K-2. Seattle Duwamish daily pollution roses for PMF factors

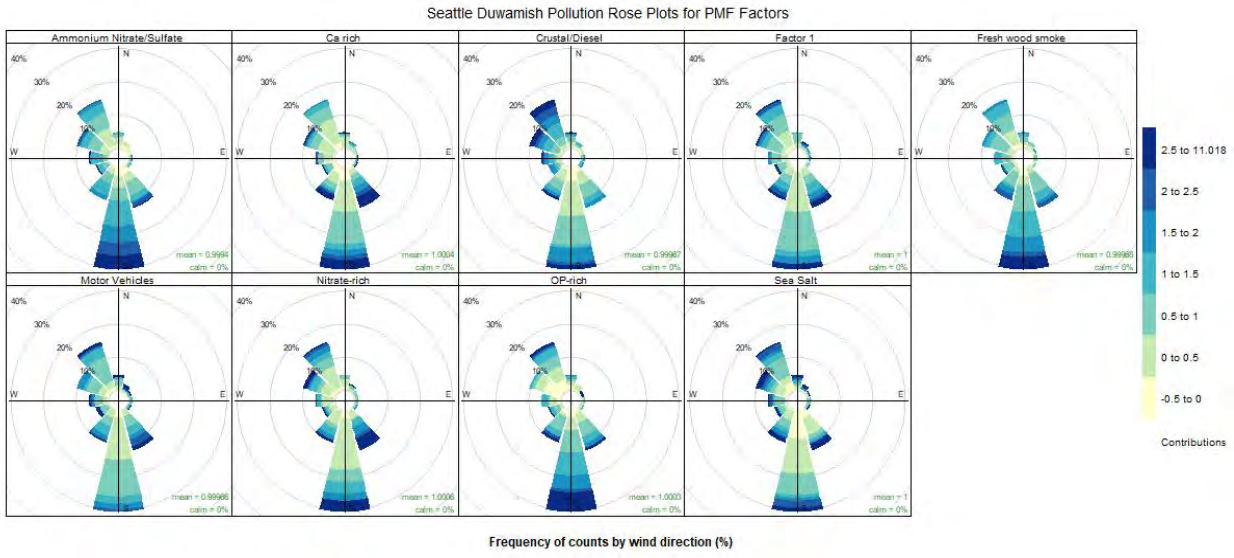


Figure K-3. Seattle Duwamish seasonal trend for PMF factors

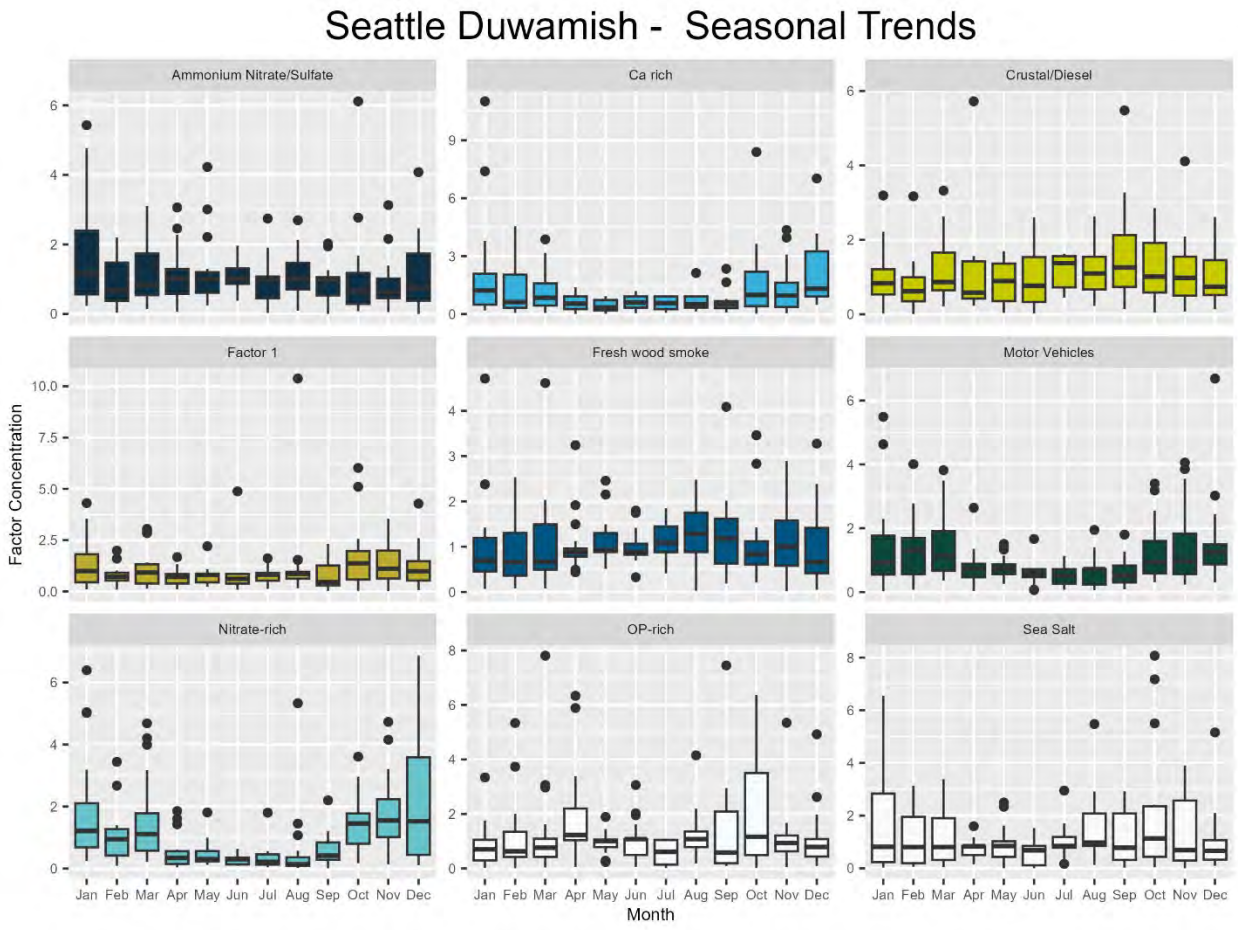


Figure K-4. Seattle 10th & Weller PMF Factor Pie Chart

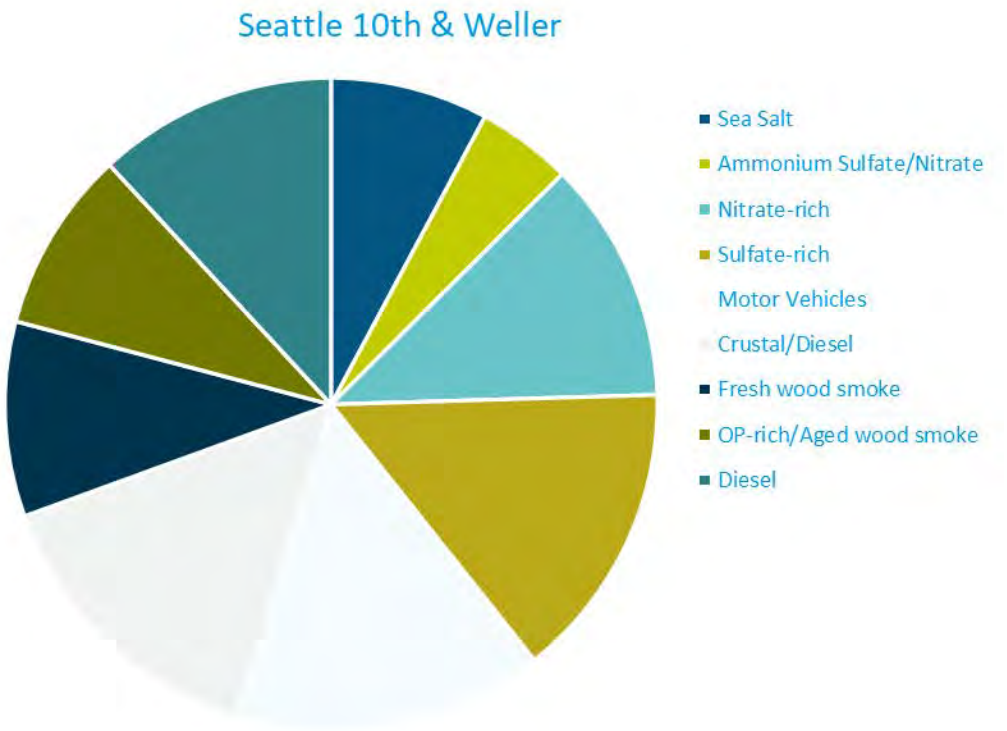


Figure K-5. Seattle 10th & Weller daily pollution roses for PMF factors

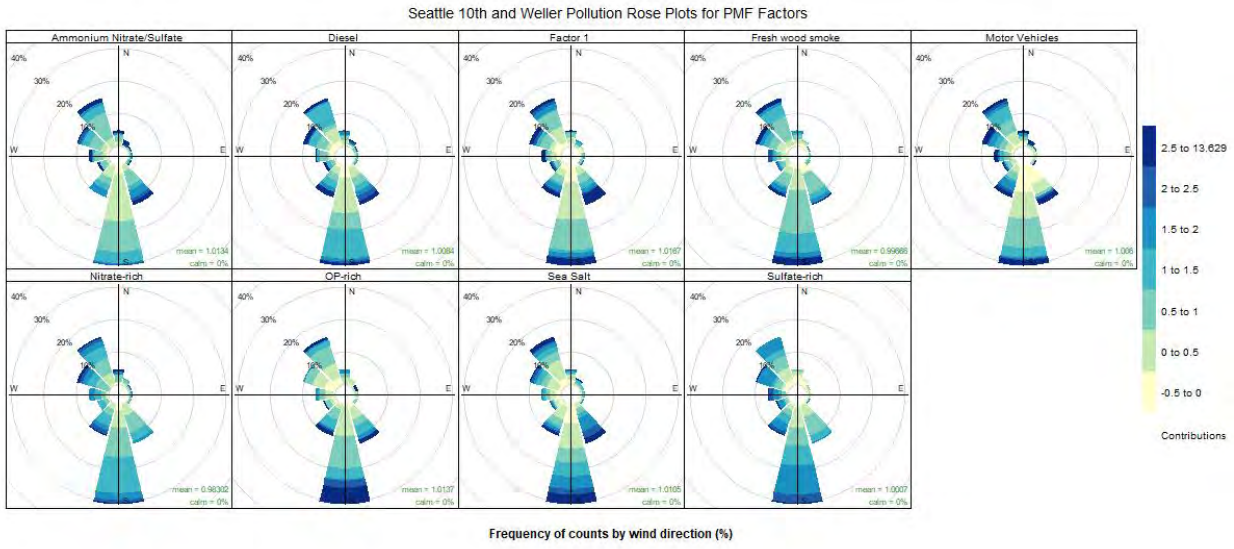


Figure K- 6. Seattle 10th & Weller seasonal trend for PMF factors

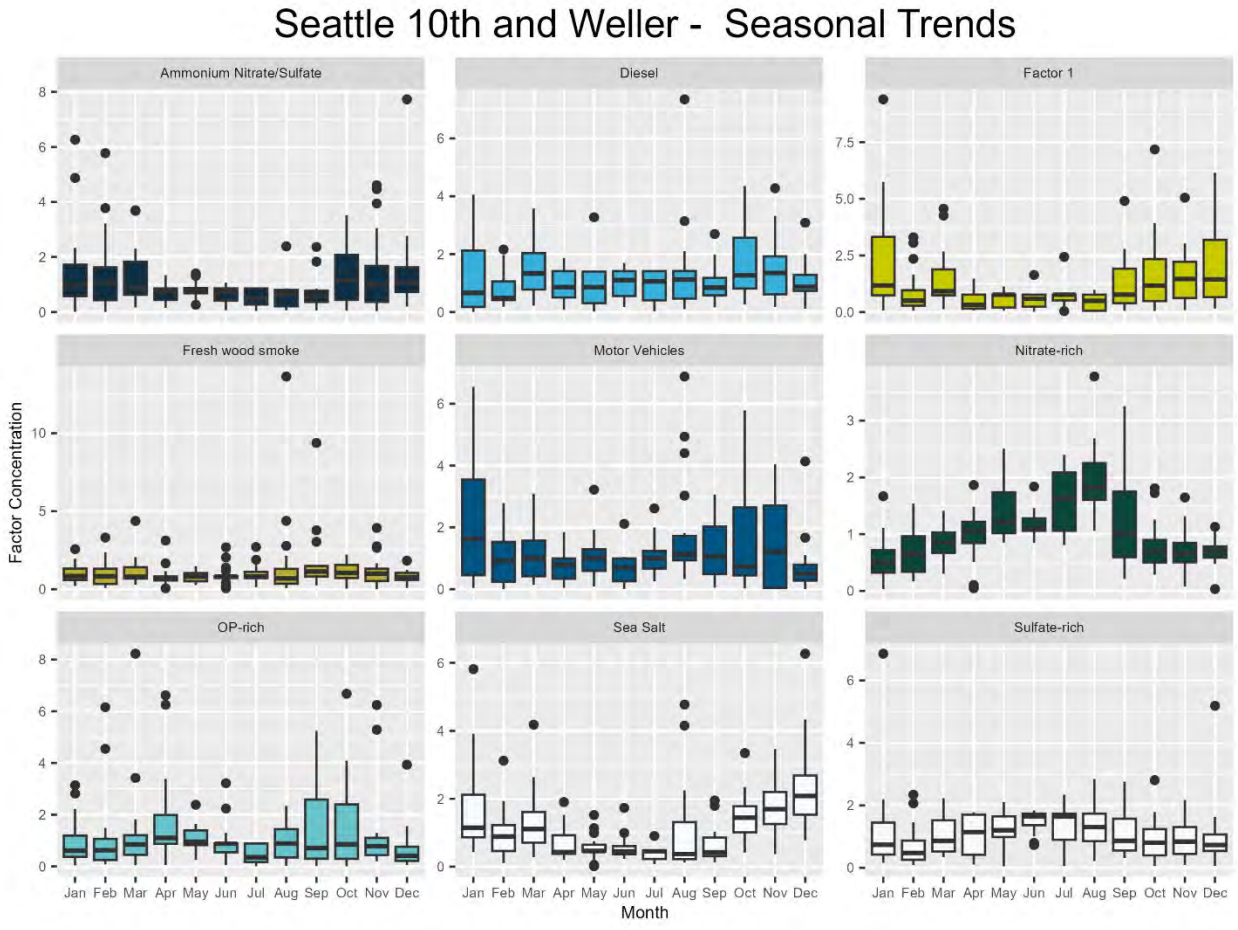


Figure K-7. Seattle Beacon Hill PMF Factor Pie Chart

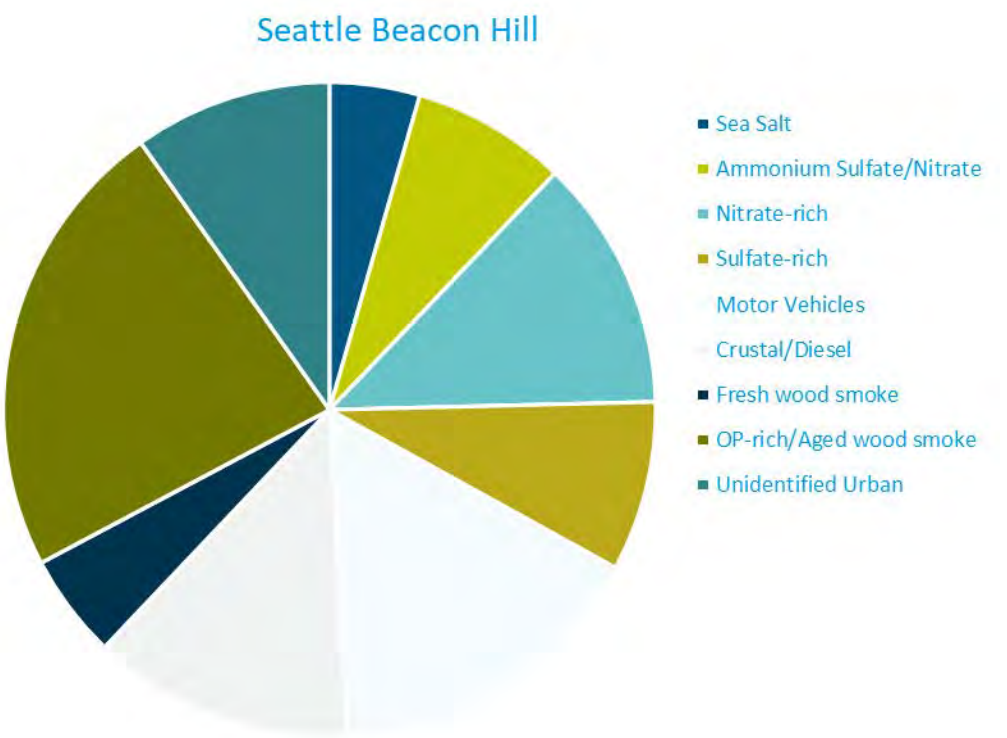


Figure K-8. Seattle Beacon Hill daily pollution roses for PMF factors

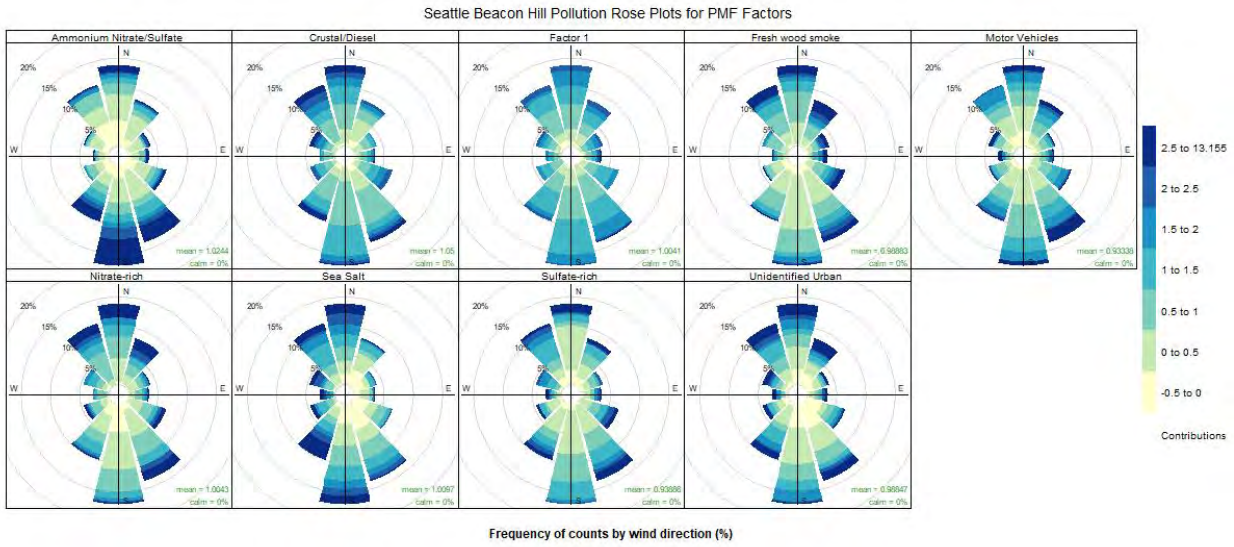


Figure K-9. Seattle Beacon Hill seasonal trend for PMF factors

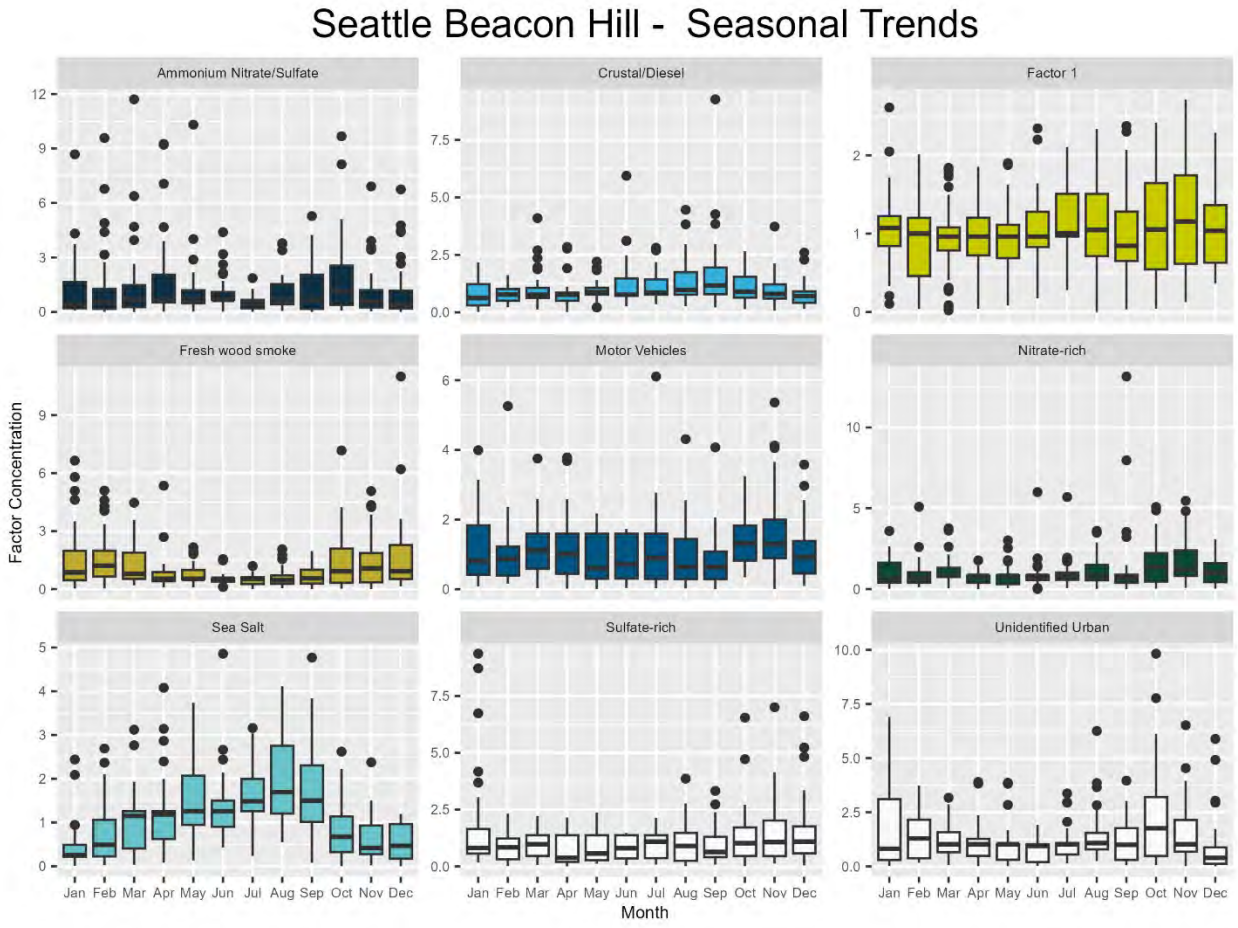


Figure K-10. Tacoma South L PMF Factor Pie Chart

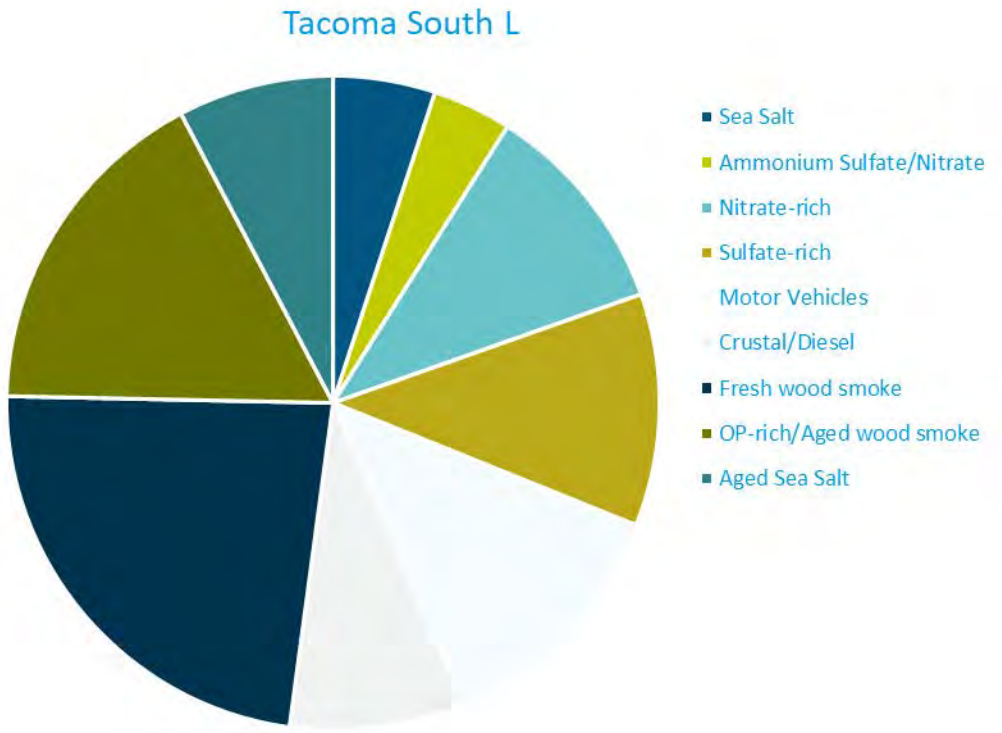


Figure K-11. Tacoma South L daily pollution roses for PMF factors

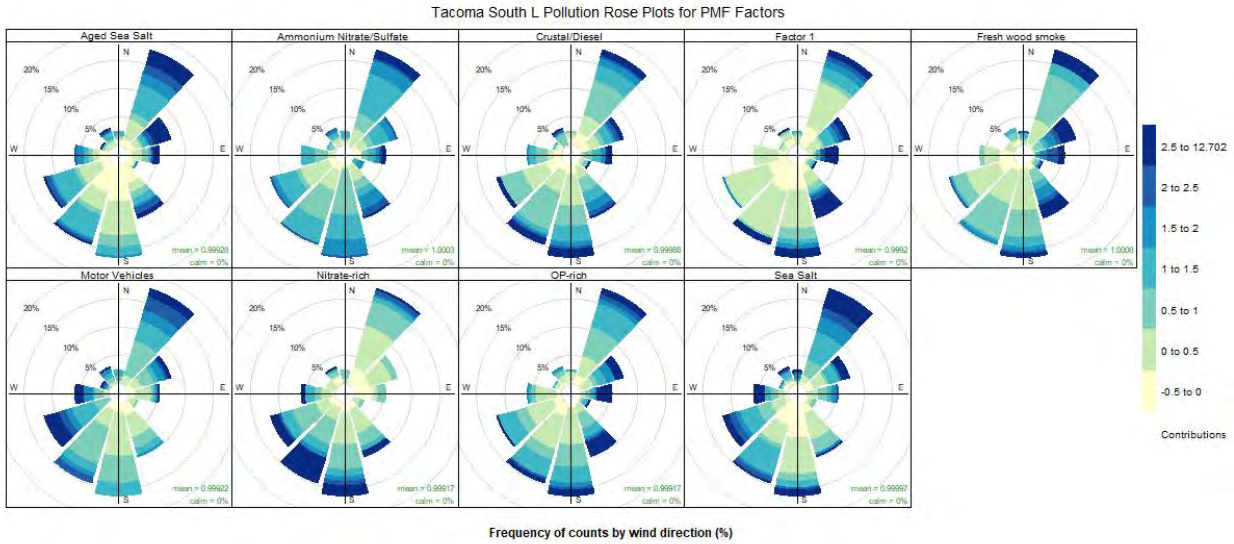


Figure K-12. Tacoma South L seasonal trend for PMF factors

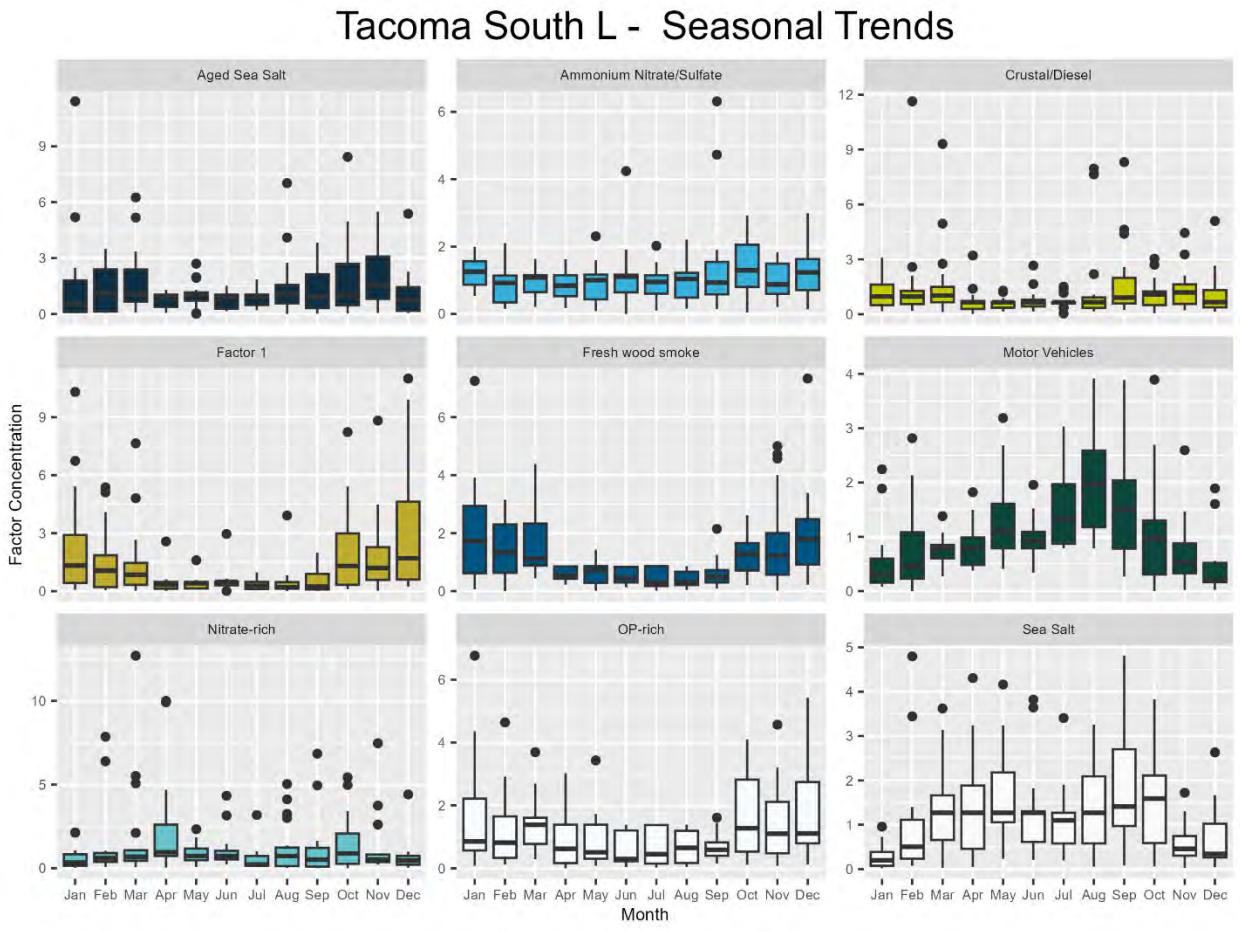


Figure K-13. Tacoma Tideflats PMF Factor Pie Chart

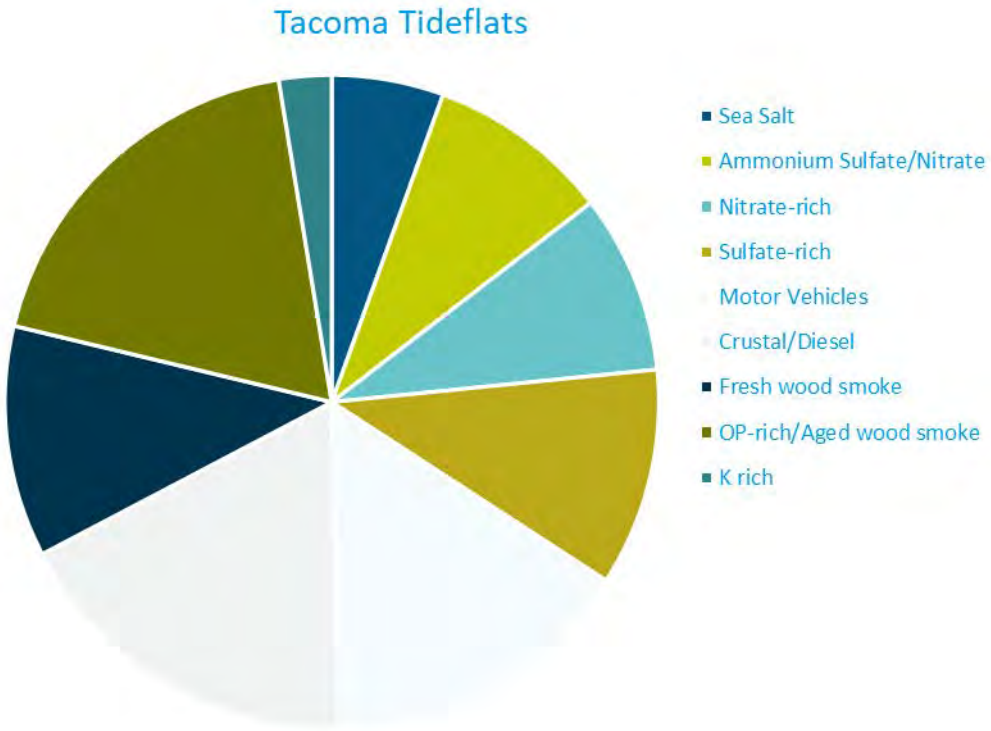


Figure K-14. Tacoma Tideflats daily pollution roses for PMF factors

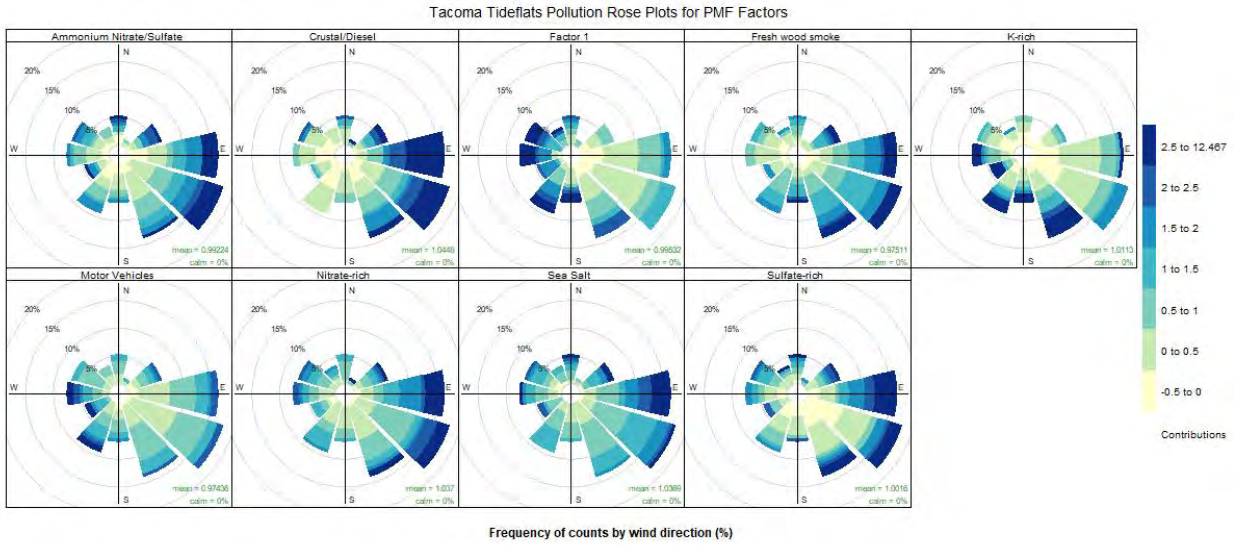
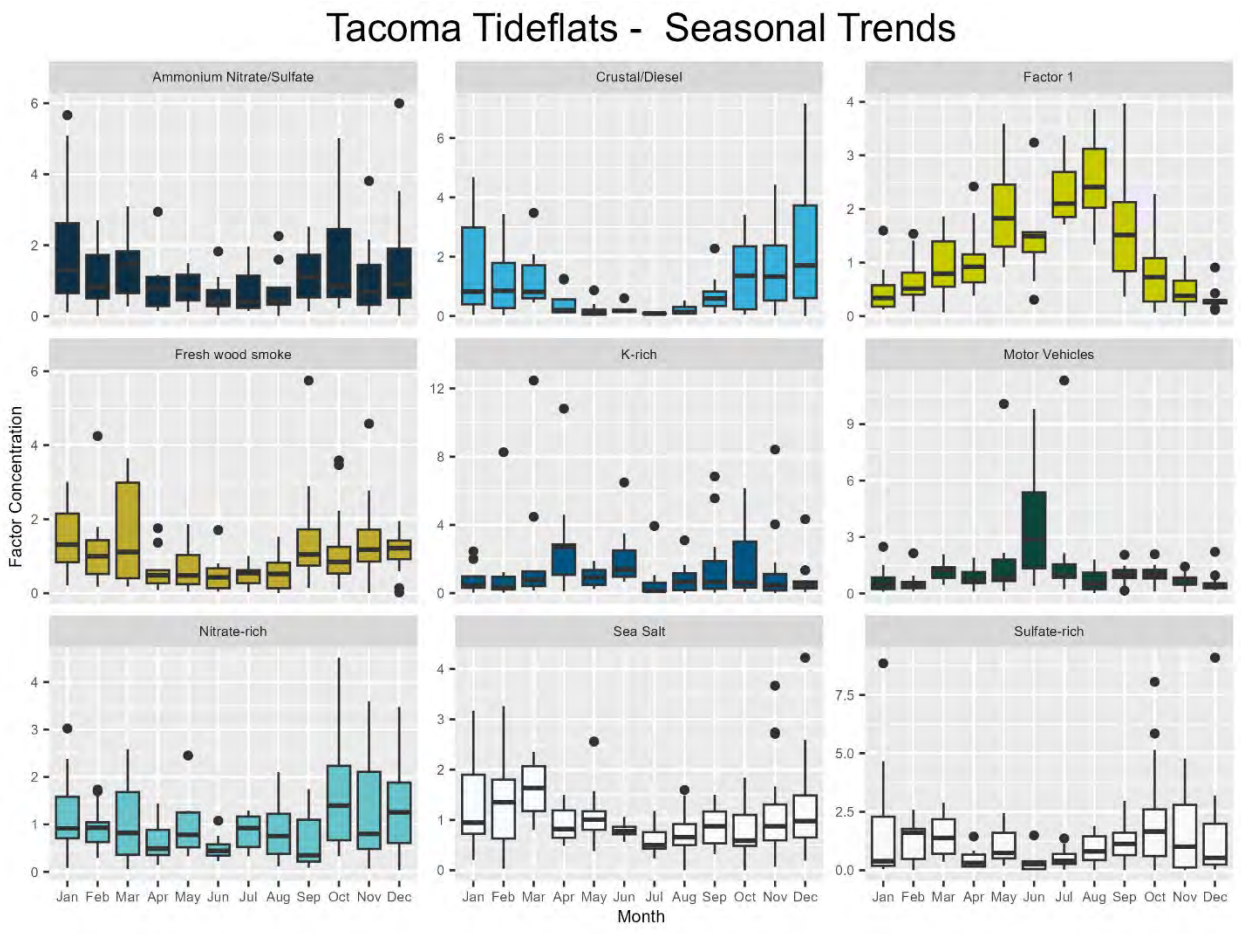


Figure K-15. Tacoma Tideflats seasonal trend for PMF factors

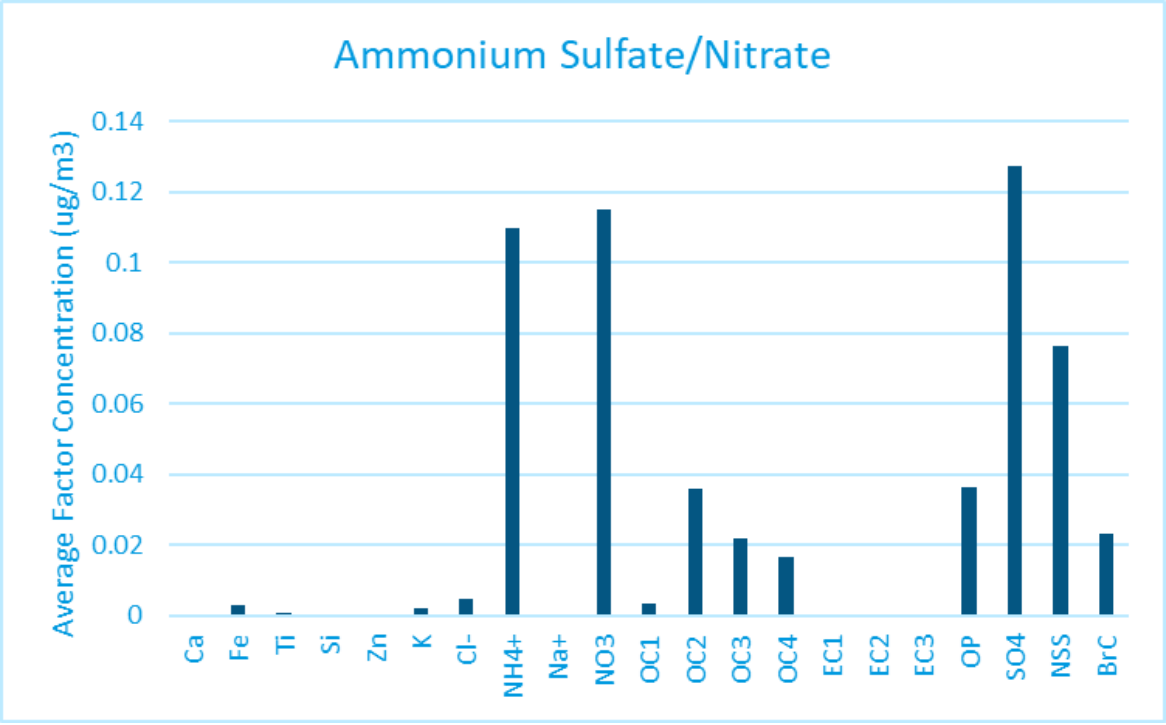


Factor descriptions:

Ammonium sulfate/nitrate:

The primary constituents in these factors were NH_4^+, NO_3^-, SO_4^{2-} and NSS. There were also contributions from higher-temperature OC components, pyrolyzed organic carbon (OP), and brown carbon (BrC). These factors represent 4-10% of $PM_{2.5}$ mass at the five sites, the highest concentrations being at Seattle Duwamish and Tacoma Tideflats, and lowest at Tacoma South L. The likely sources for these factors are oil refinery operations, wood combustion, and residual fuel oil. We were not able to verify any further because Nickel and Vanadium were not included in this analysis. Nickel and Vanadium have been used to confirm the identity of the residual fuel oil factor but could not be used in this analysis because they both did not meet the <MDL requirement. When increasing the number of factors in the PMF solution to 10 and 11, this factor did not split.

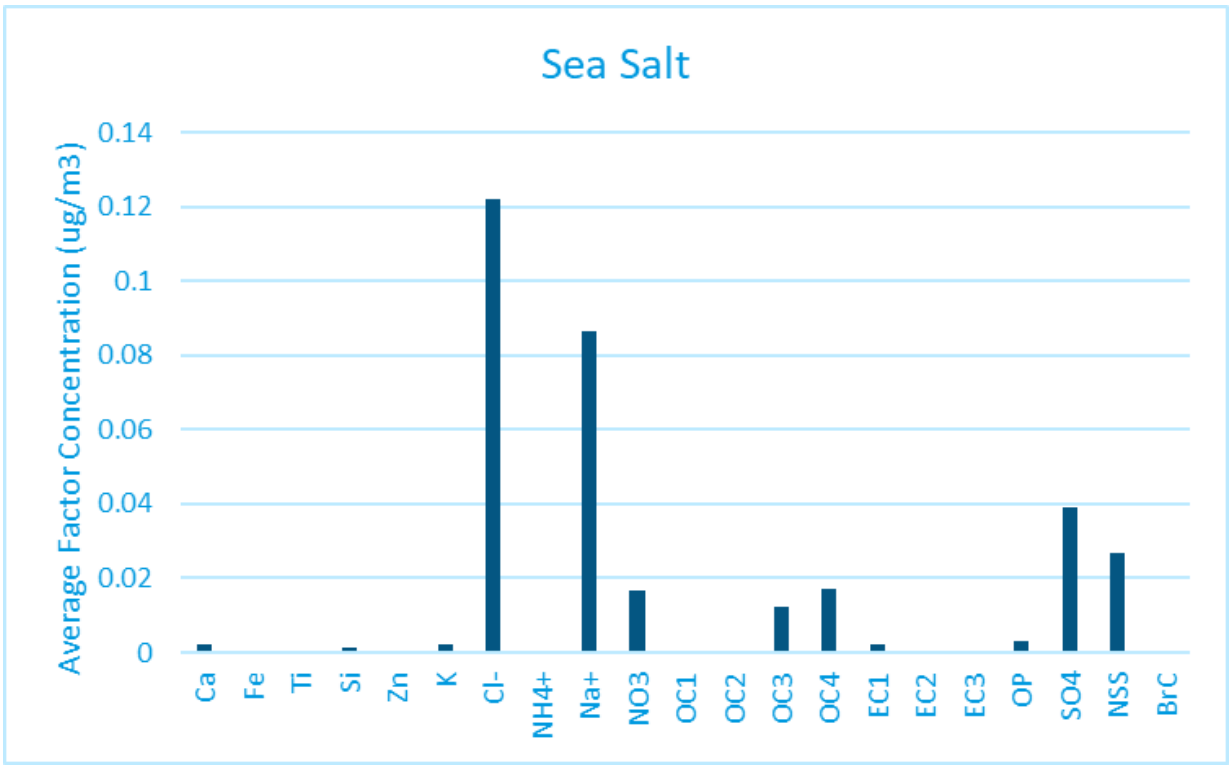
Figure K-16. Ammonium Sulfate/Nitrate Factor Profile



Sea Salt:

The sea salt factors were associated with the majority of Na^+ and Cl^-. These factors represent 4-8% of $PM_{2.5}$ mass at all sites, the highest concentrations being at Seattle 10th and Weller and Seattle Duwamish, and lowest at Seattle Beacon Hill.

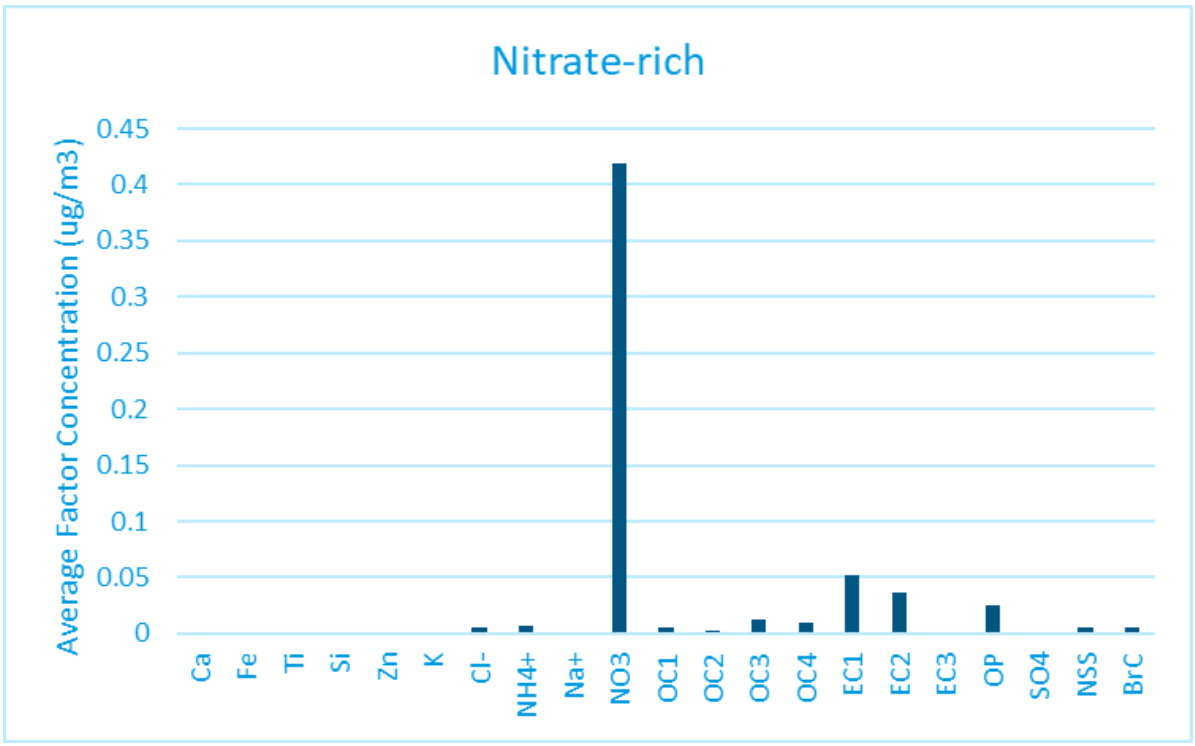
Figure K-17. Sea Salt Factor Profile



Nitrate-rich:

This factor was associated with high concentrations of NO_3^-, comprising between 9-21% of total $PM_{2.5}$ mass at the five sites. The highest proportion of $PM_{2.5}$ mass was at Seattle Duwamish at 21% and the other sites being between 9–12%. These factors are higher in winter for all sites, which is consistent with secondary nitrate. The presence of EC1, EC2 and OP also potentially suggests the presence of wood smoke.

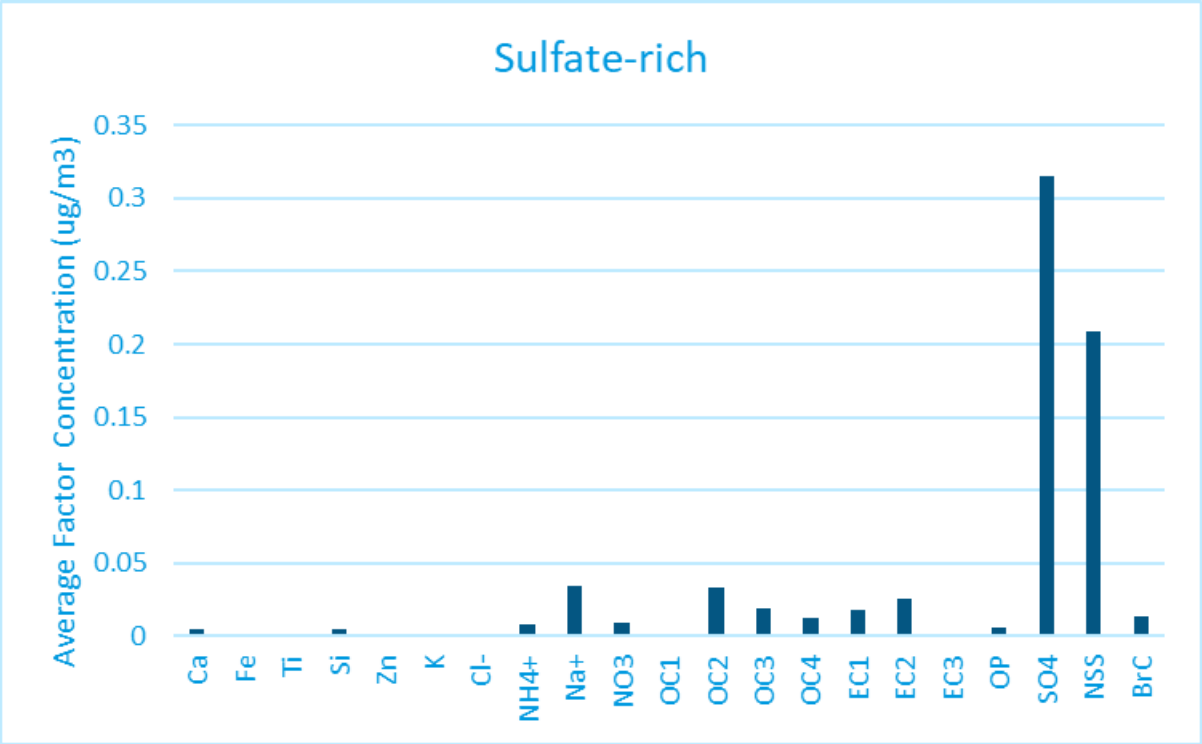
Figure K-18. Nitrate-rich Factor Profile



Sulfate-rich:

The sulfate-rich factors were associated with high concentrations of non-sulfate sulfur (NSS) and SO_4^{2-}. These factors comprised 8-15% of total $PM_{2.5}$ mass at the five sites, the highest being at Seattle Duwamish and Seattle 10th and Weller, and lowest Seattle Beacon Hill. The factors had higher concentrations during the summer for all sites. This seasonality is due to increased photochemical activity which forms secondary sulfate. There were also amounts of EC1 and EC2, likely due to maritime-related sources and fuel combustion. Past PMFs in the region have shown similar seasonality for factors assigned to maritime shipping.

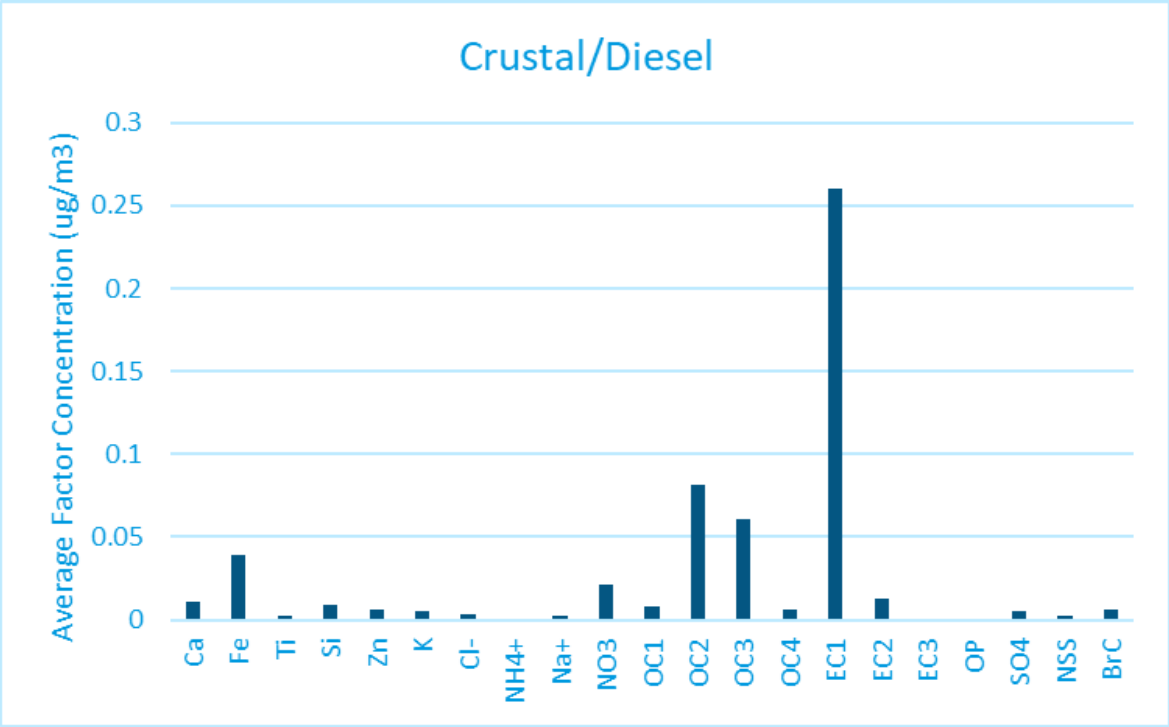
Figure K-19. Sulfate-rich Factor Profile



Crustal/Diesel:

These factors were a combination of diesel and crustal factors. It is characterized by high concentrations of EC1, some OC2 and OC3, and a majority of crustal elements Ca, Fe, Ti, Si, and Zn. These factors comprised 9-18% of total $PM_{2.5}$ mass at the five sites. The highest concentrations were at Tacoma Tideflats, likely due to increased truck traffic adjacent to our site during this study. During the study, there was an active dirt moving operation in which large dump trucks continuously passed within 20 feet of the site on a dirt road. The second highest concentration was at Seattle 10th and Weller, which is right next to I-5. When attempting to split this factor by running PMF with 10 or 11 factors, the factor did not split. Black carbon (BC) and nitrogen oxides (NO and NO_x/NO_y) are both markers of diesel emissions. BC and NO/NO_x/NO_y were well correlated with these factors (R^2 > 0.60) at sites where they were measured. In addition, these factors were higher on the weekday compared to weekend, peaking Tuesday through Thursday. This weekday/weekend difference was least pronounced at the more residential sites, Seattle Beacon Hill and Tacoma South L, and most pronounced at Tacoma Tideflats.

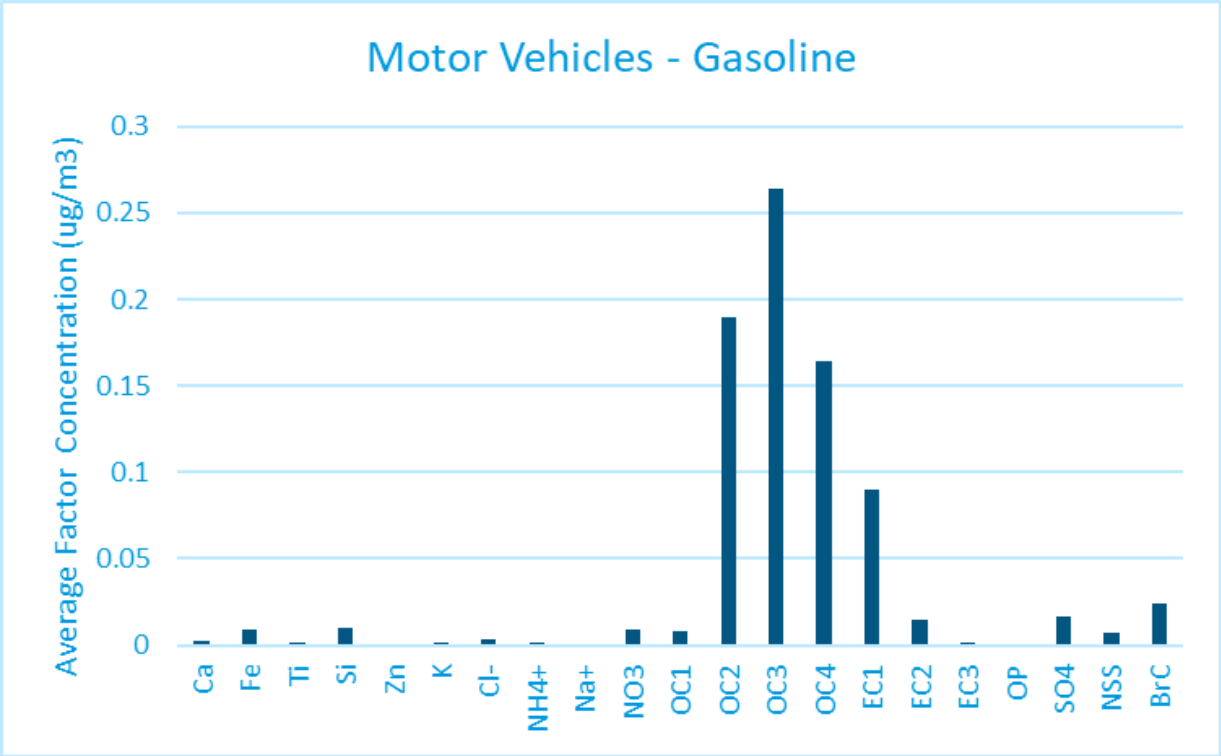
Figure K-20. Crustal/Diesel Factor Profile



Motor Vehicles - Gasoline:

The primary constituents in these factors were OC2, OC3, OC4, and EC1, and represented 12-17% of total $PM_{2.5}$ mass at the five sites. Highest concentrations for this factor were from Seattle Duwamish, Seattle 10th and Weller, and Tacoma Tideflats, with lower concentrations at the more residential sites Seattle Beacon Hill and Tacoma South L. The ratio between OC2, OC3, and OC4 in the factor profile is close to 1:2:1, which is characteristic of gasoline emissions. The factor also includes Fe which can come from tires and brakes, and Si which can come from re-entrained road dust.

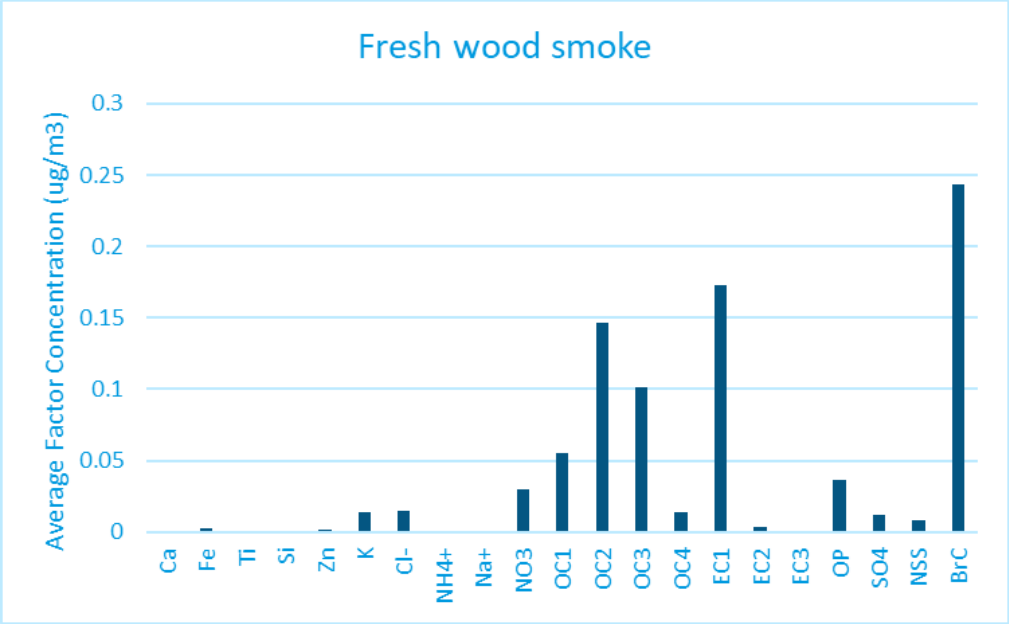
Figure K-21. Motor Vehicles - Gasoline Factor Profile



Fresh Wood Smoke:

The PMF factors associated with fresh wood smoke is characterized by high concentrations of lower temperature OC and EC fractions, significant portion of K, and brown carbon (BrC) at sites where BC/UV was measured. Concentrations peaked in the winter for most sites, consistent with the winter heating season. Average K/OC ratio was 0.043, similar to previous studies.[5,6] These factors comprise between 5-23% of total $PM_{2.5}$ mass at the five sites. The highest concentration by far was at Tacoma South L, with an annual $PM_{2.5}$ concentration of 1.42 $\mu g/m^3$. The fresh wood smoke factor is at Tacoma South L is significantly reduced compared to previous studies. Kotchenruther (2020) found wood smoke to contribute 3.53 $\mu g/m^3$ from 2015-2017 and 5.73 $\mu g/m^3$ from 2007-2009.[7] This continued reduction in fresh wood smoke $PM_{2.5}$ concentrations can be attributed to measures taken at the state and local level to reduce residential wood smoke PM emissions.

Figure K-22. Fresh Wood Smoke Factor Profile

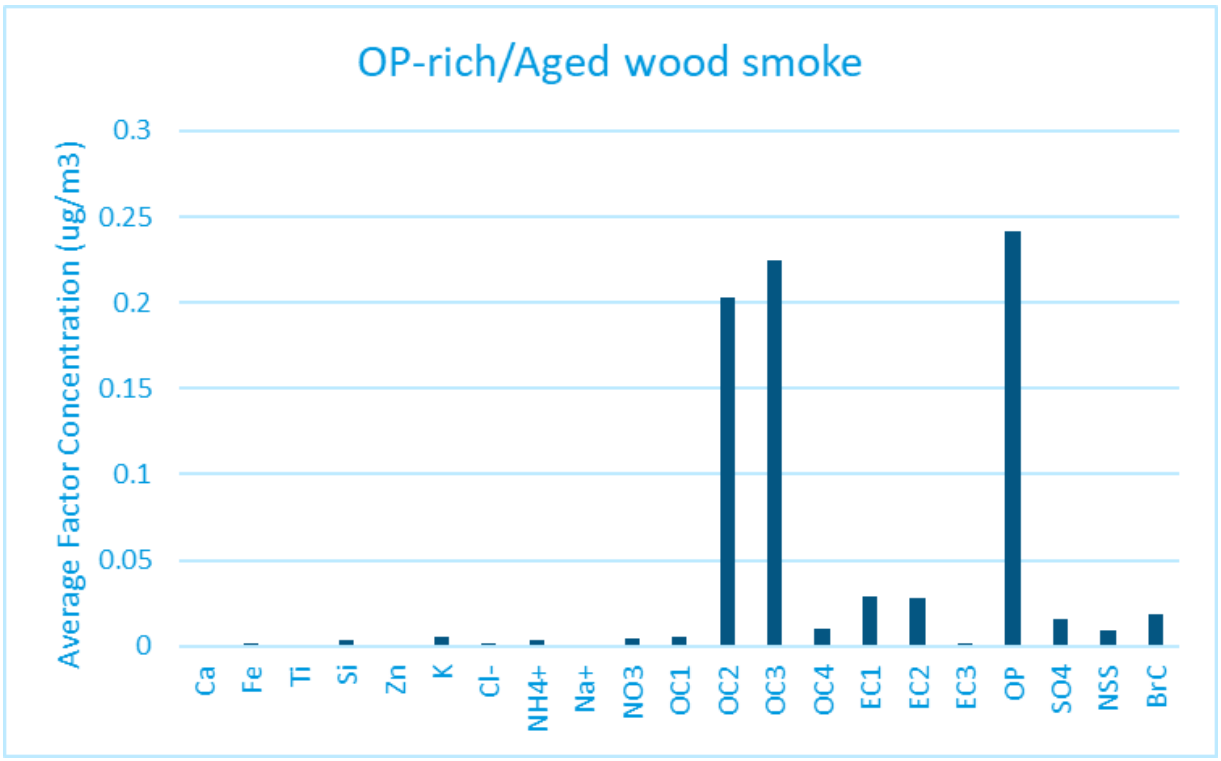


[5] Kotchenruther R. (2016). "Source apportionment of $PM_{2.5}$ at multiple Northwest U.S. sites: Assessing regional winter wood smoke impacts from residential wood Combustion". Amos Env 142:210-219.
[6] Friedman B. (2020). "Source apportionment of $PM_{2.5}$ at two Seattle chemical speciation sites". J Air Waste Manag Assoc, 70:7, 687-699.
[7] Kotchenruther R. (2020). "Recent changes in winter $PM_{2.5}$ contributions from wood smoke, motor vehicles, and other sources in the Northwest U.S." Atmos Env 237:117724.

OP-rich/Aged Wood Smoke:

Thess factors were dominated by OC2, OC3, and OP, with some contributions from EC1, EC2, and BrC. They comprise between 7-23% of total $PM_{2.5}$ mass at the five sites. The highest concentrations are Seattle Beacon Hill, Tacoma South L, and Tacoma Tideflats. The lowest concentrations were Seattle 10th and Weller and Seattle Duwamish. Seasonal concentrations show a slight maximum in the winter. The factor is a mixture of aged wood smoke from winter wood home heating and wildfire smoke, and secondary organic aerosol formation. At most sites (expect Tacoma South L) the OP-rich factors correlated well with the fresh wood smoke factors (R^2 > 0.5).

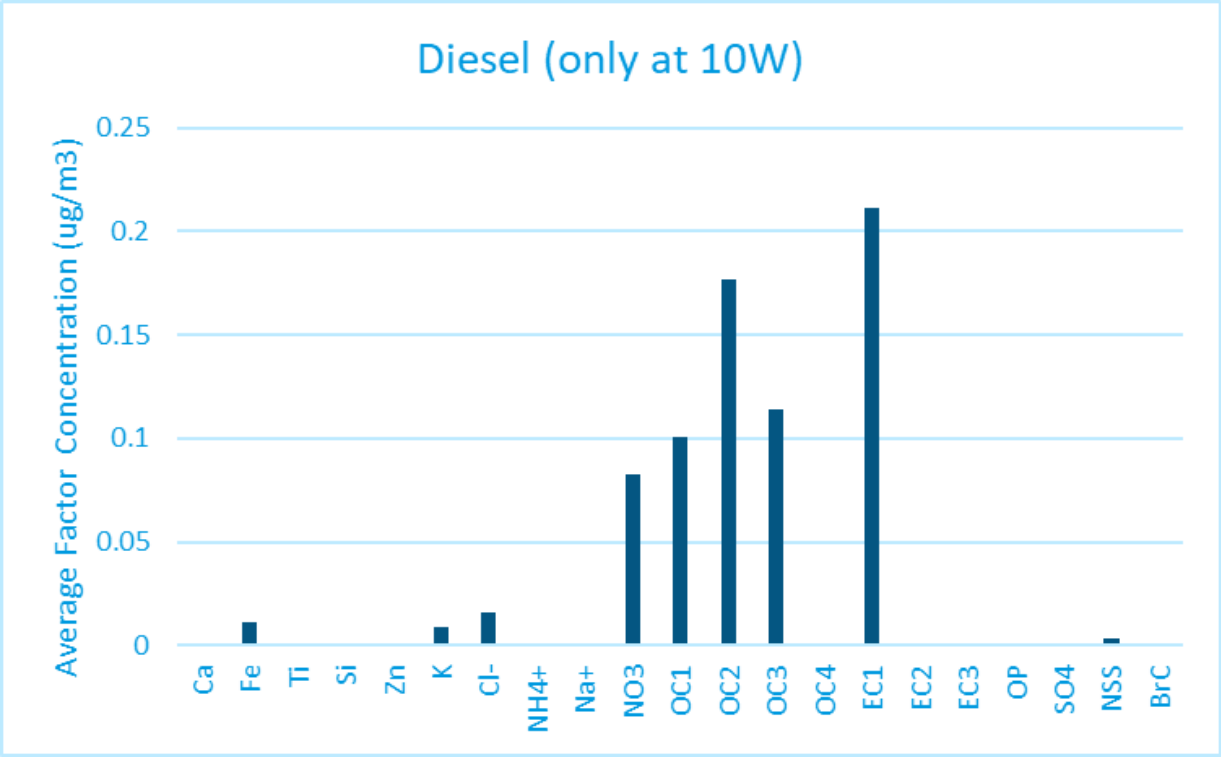
Figure K-23. OP-rich/Aged Wood Smoke Factor Profile



Motor Vehicles - Diesel:

This factor was found only at Seattle 10th and Weller. It comprised 11.9% of total $PM_{2.5}$ mass at Seattle 10th and Weller and was dominated by EC1, OC1, OC2, OC3, and NO_3, with contributions from Cl^-, Fe, and K. This factor was well correlated with BC (R^2 = 0.61), NO (R^2 = 0.66), and NO_2 (R^2 = 0.52), which are markers of diesel exhaust.

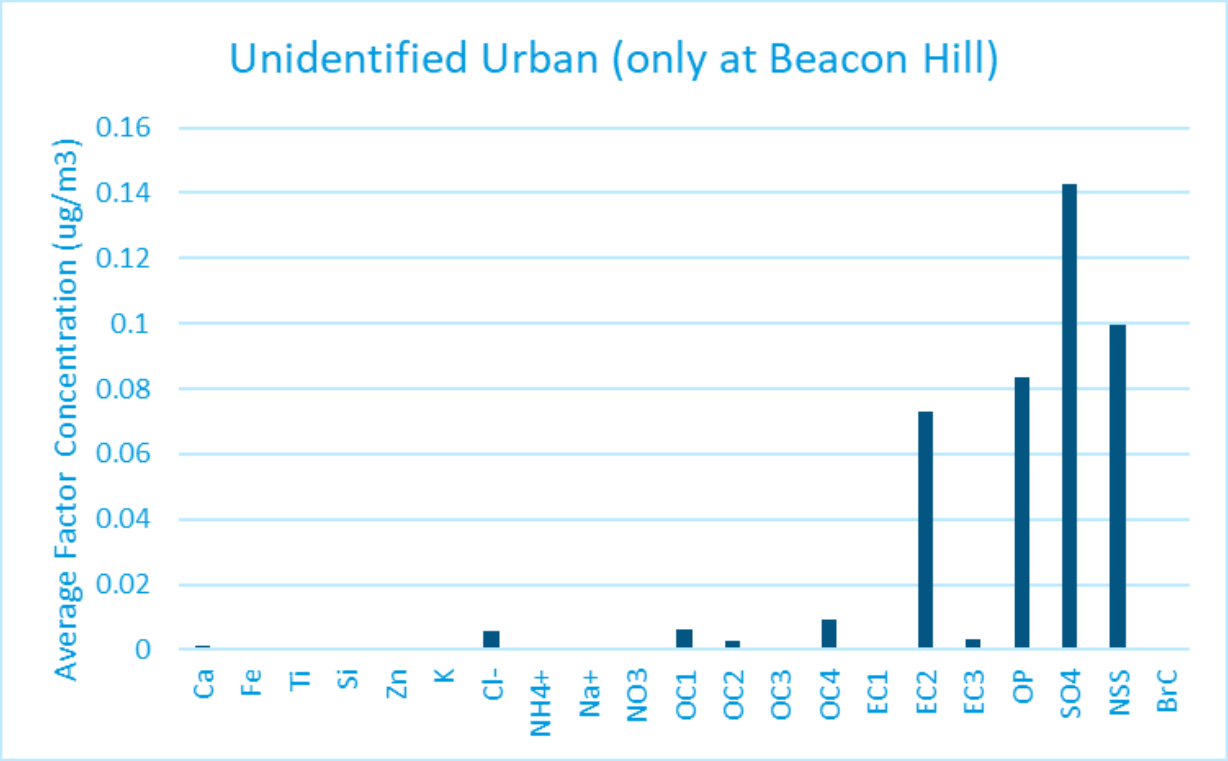
Figure K-24. Motor Vehicles - Diesel Factor Profile



Unidentified Urban:

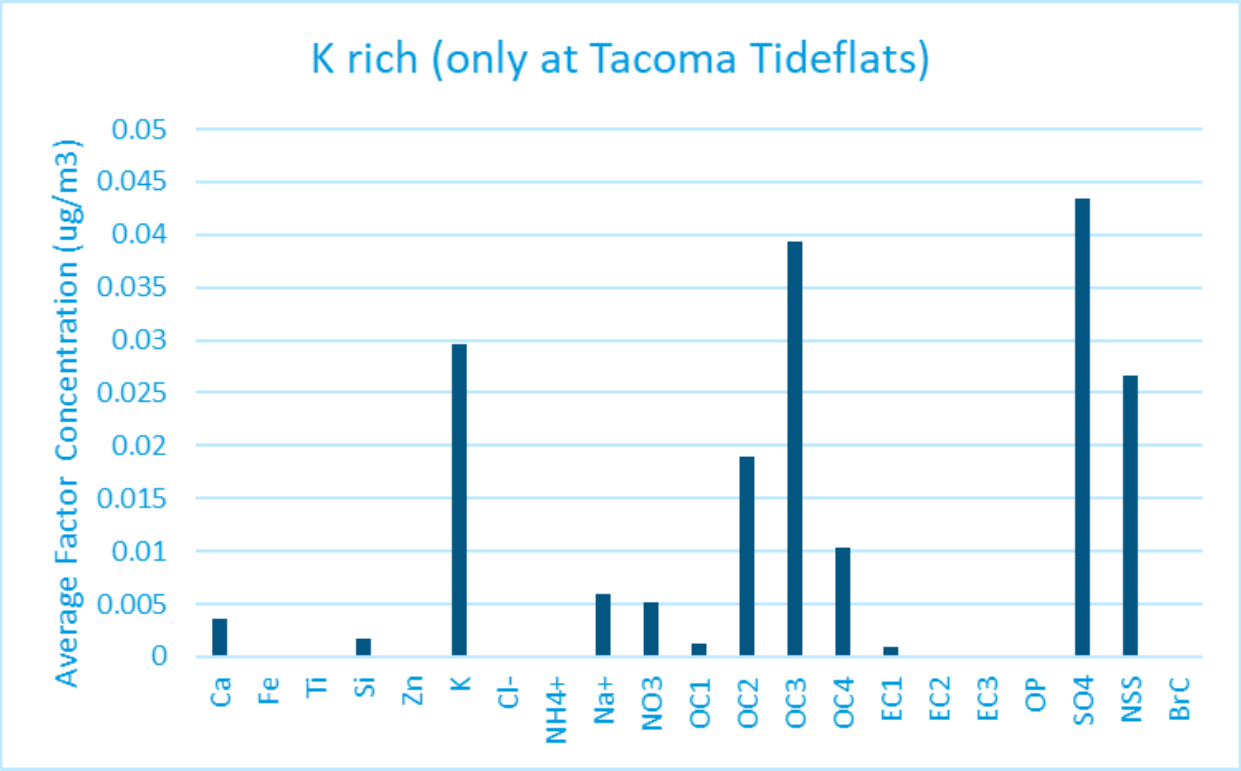
The Unidentified Urban factor was found only at Seattle Beacon Hill. It was dominated by EC2, OP, SO_4^{2-}, and NSS, and comprised 9.8% of total $PM_{2.5}$ mass. The source of this factor is unclear, but it is likely secondary organic aerosol from a variety of sources related to fuel combustion. There were no seasonal trends are observed.

Figure K-25. Unidentified Urban Factor Profile



K rich: The K rich factor was found only at Tacoma Tideflats. It is characterized by a majority of K, with contributions of higher temperature OC's, SO_4, and NSS. This factor only contributed 2.6% of $PM_{2.5}$ mass and the time-series were dominated by spikes in concentration during summer days. During these summer spikes no significant increase were observed in other PMF factors, BC, or $PM_{2.5}$, suggesting local firework activity. This factor was also found at Tacoma Tideflats by Friedman (2023).[8]

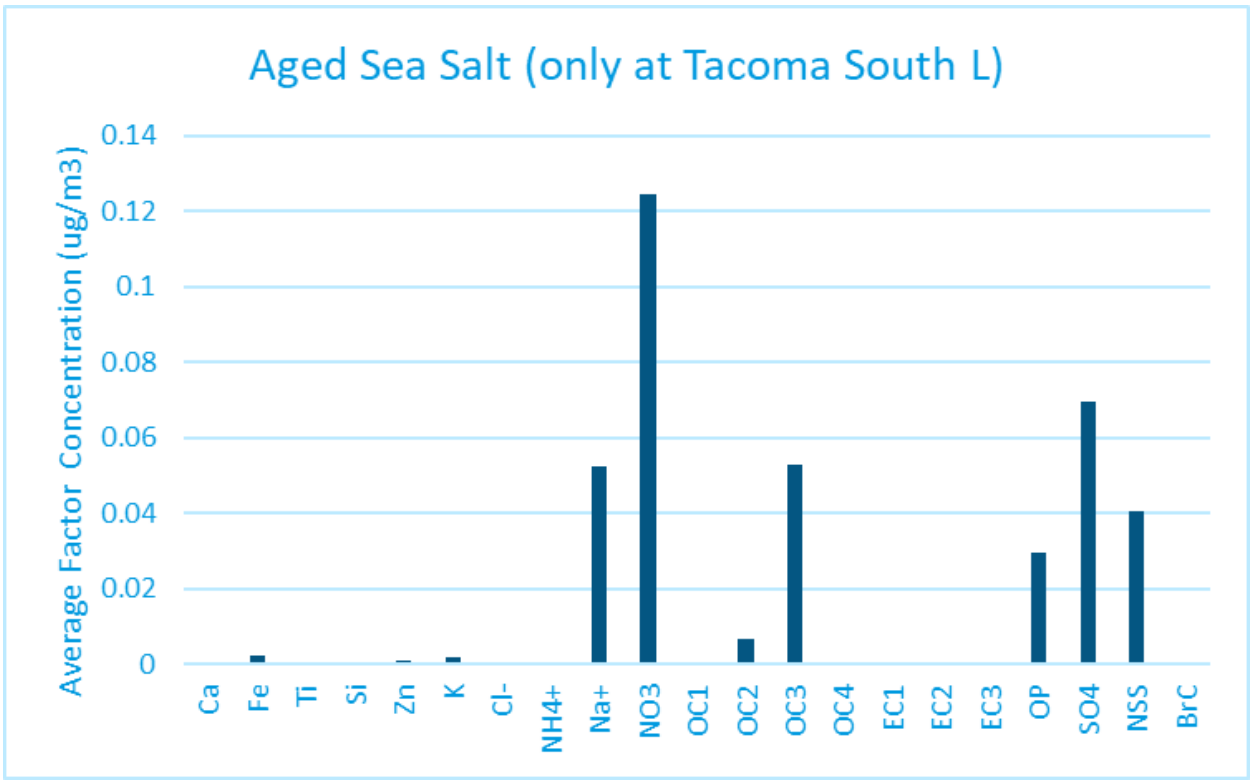
Figure K-26. K-rich Factor Profile



[8] Friedman, B. (2023). "Technical Report: Port of Tacoma Source Apportionment Study". WA Ecology, Publication 23-02-075.

Aged Sea Salt: This factor was only found only at Tacoma South L. It is nearly the same as the sea salt factor, except all of the Cl^- has been replaced with nitrate.

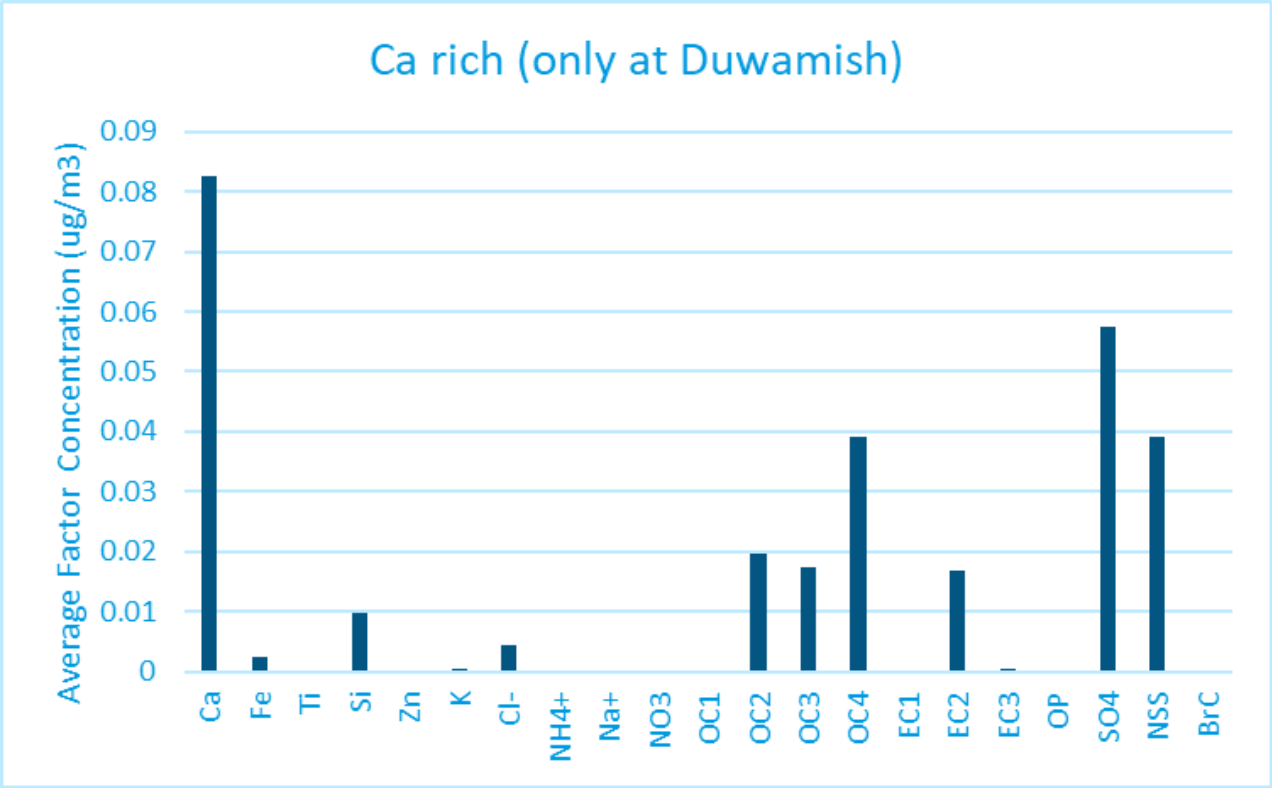
Figure K-27. Aged Sea Salt Factor Profile



Ca rich:

The Ca rich factor was only found at Seattle Duwamish and has the majority of Ca, as well as contributions from OCs, SO4 and NSS. This factor could be linked to cement production or other calcium rich operations and made up 6.5% of $PM_{2.5}$ at Duwamish. This factor has been found in previous studies at the Duwamish site.[9,10] Annual $PM_{2.5}$ concentration associated with this factor is similar to that in the 2013 study (0.40 $\mu g/m^3$ compared to 0.42 $\mu g/m^3$ in this study). In the 2008 study the factor annual average was 0.57 $\mu g/m^3$.

Figure K-28. Ca-rich Factor Profile



[9] Kotchenruther R. (2013). "A regional assessment of marine vessel $PM_{2.5}$ impacts in the U.S. Pacific Northwest using a receptor-based source apportionment method". Atmos Env 68: 103-111.

[10] Hopke P., Kim E. (2008). "Source characterization of ambient fine particles at multiple sites in the Seattle area". Atmos Env 42:6047-6056.

Appendix L. Additional PMF analysis including air toxics

Additional source contributions were conducted using PMF by including air toxics data along with the speciation data for each site. There were some common sources and trends observed at the sites. For instance, motor vehicles and wood smoke were the biggest contributors at each site. During summer months, we observed higher production of secondary pollutants like ammonium sulfate, ammonium nitrate, formaldehyde, and acetaldehyde. There were some factors which were observed at only a few sites like acenaphthylene-rich factor and manganese-rich factor were observed only at Seattle Duwamish and Seattle Beacon Hill sites due to potential outliers. Below are the results from all the sites:

Seattle Duwamish: We used air toxics (carbonyls, VOCs, SVOCs, and PM_{10} metals) along with the speciation data at the Duwamish site for the additional PMF analysis. The ten factors were identified at the site out of which motor vehicles, wood smoke and secondary sulfate were the biggest contributors. Additionally, diesel and gasoline sources were identified based on the organic species. The SVOCs like benzo(a)anthracene, benzo(a)pyrene, Indeno(1,2,3-c,d)pyrene, benzo(b)fluoranthene are characteristic of gasoline emissions and SVOCs like anthracene, fluoranthene, fluorene, phenanthrene, pyrene are characteristic of diesel emissions. There were additional factors like Manganese rich factor and acenaphthylene rich factor, which were observed only at this site as mentioned earlier. Below is a pie-chart of the contributing factors.

Figure L-1. Seattle Duwamish additional PMF Factor Pie Chart

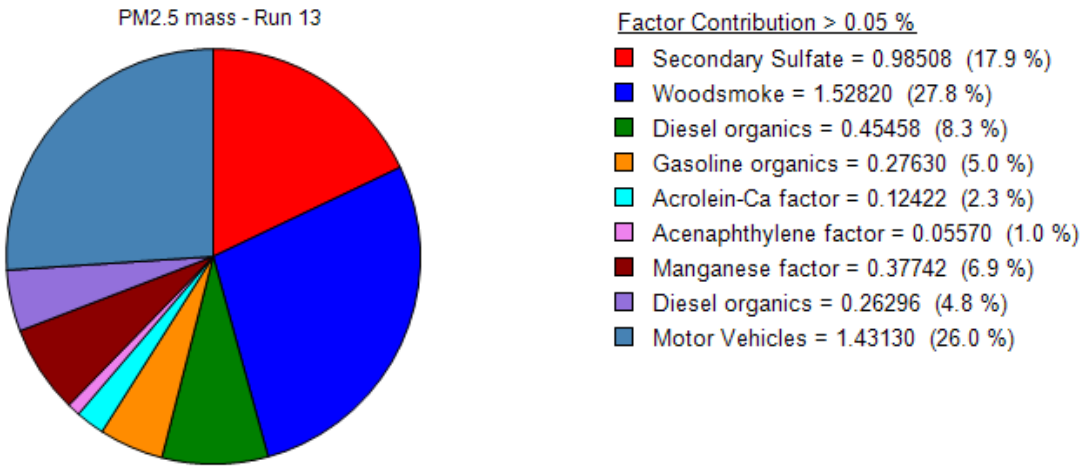


Figure L-2. Seattle Duwamish seasonal trend for PMF factors.

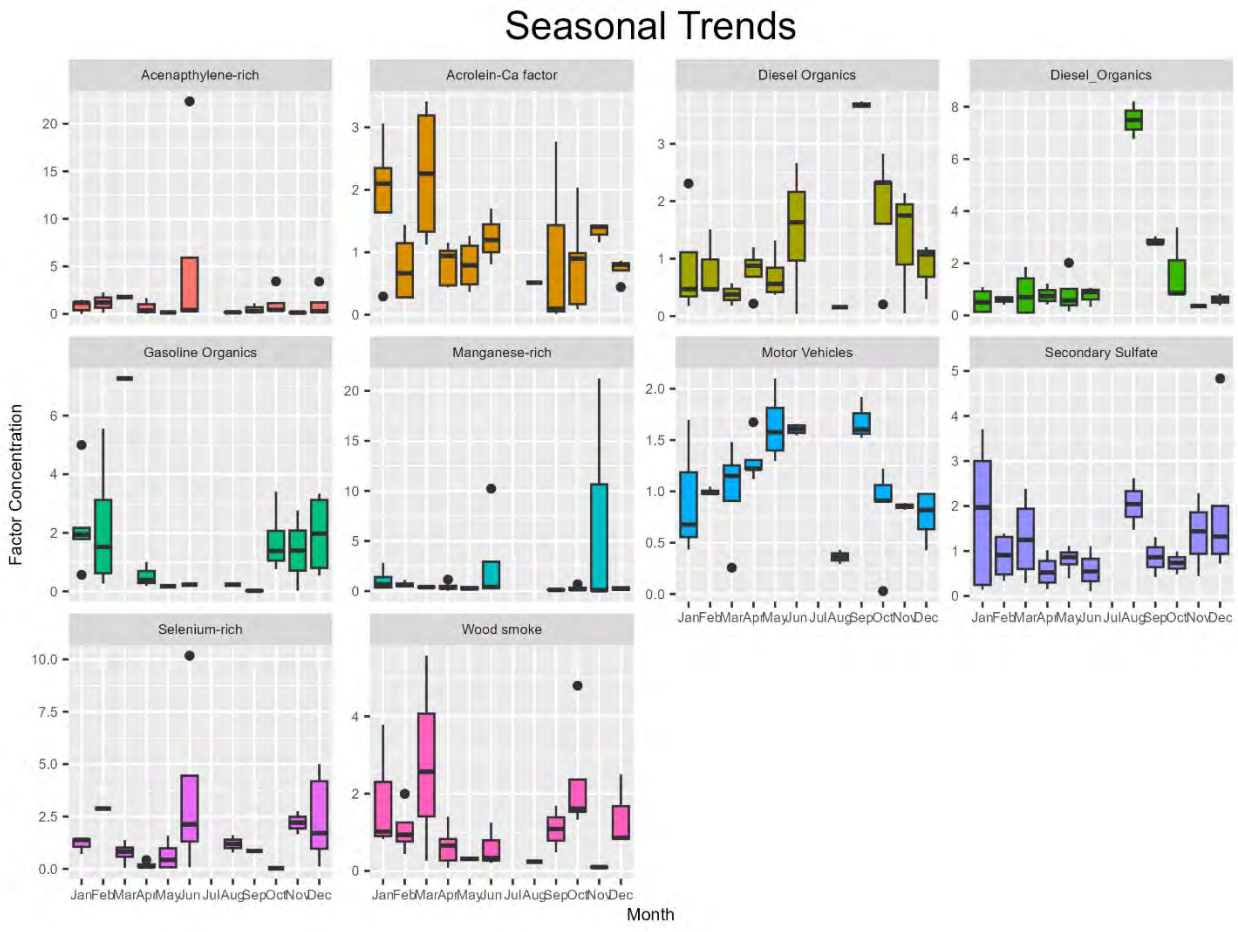


Figure L-3. Seattle Duwamish factor fingerprints PMF factors.

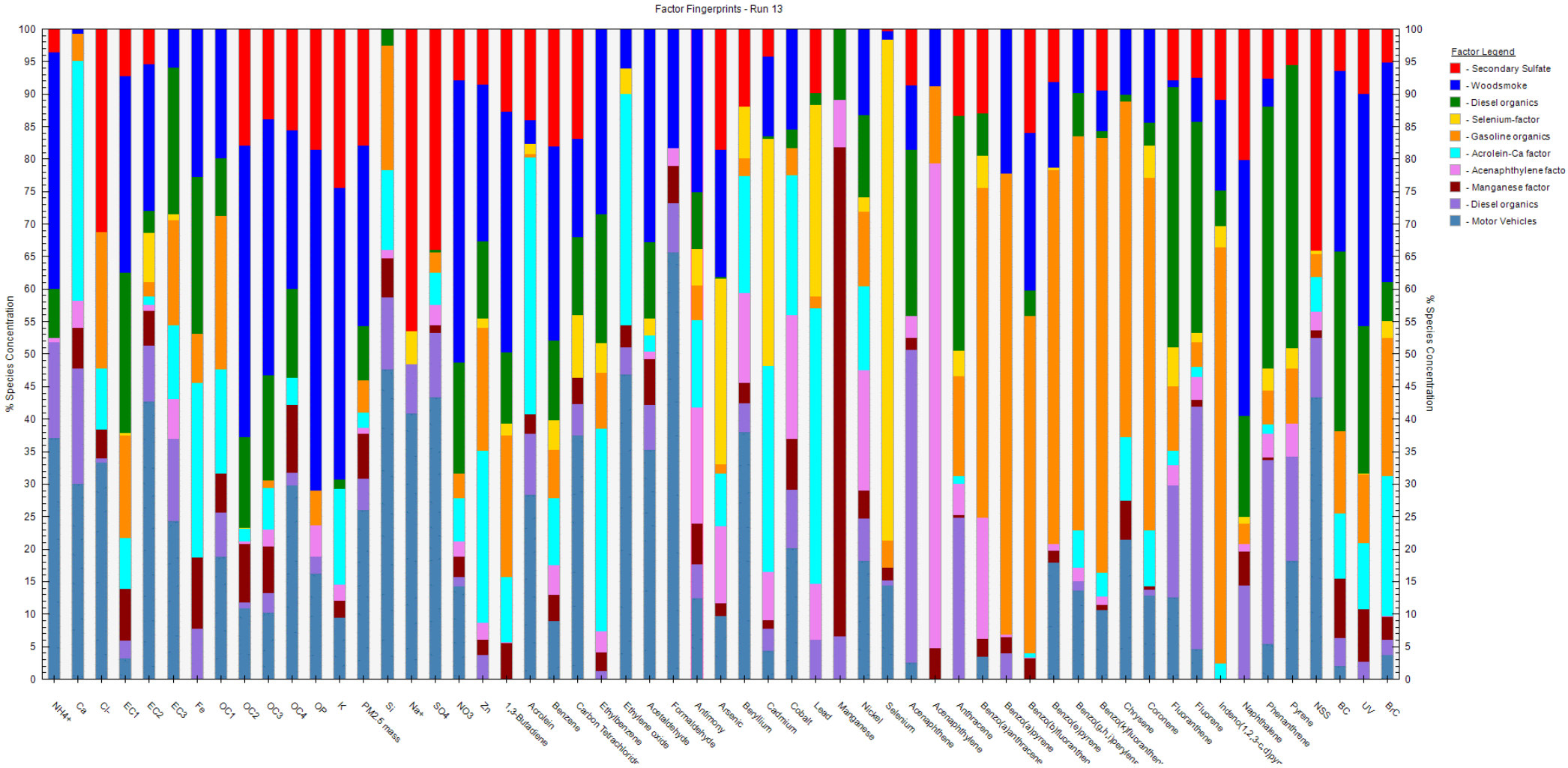
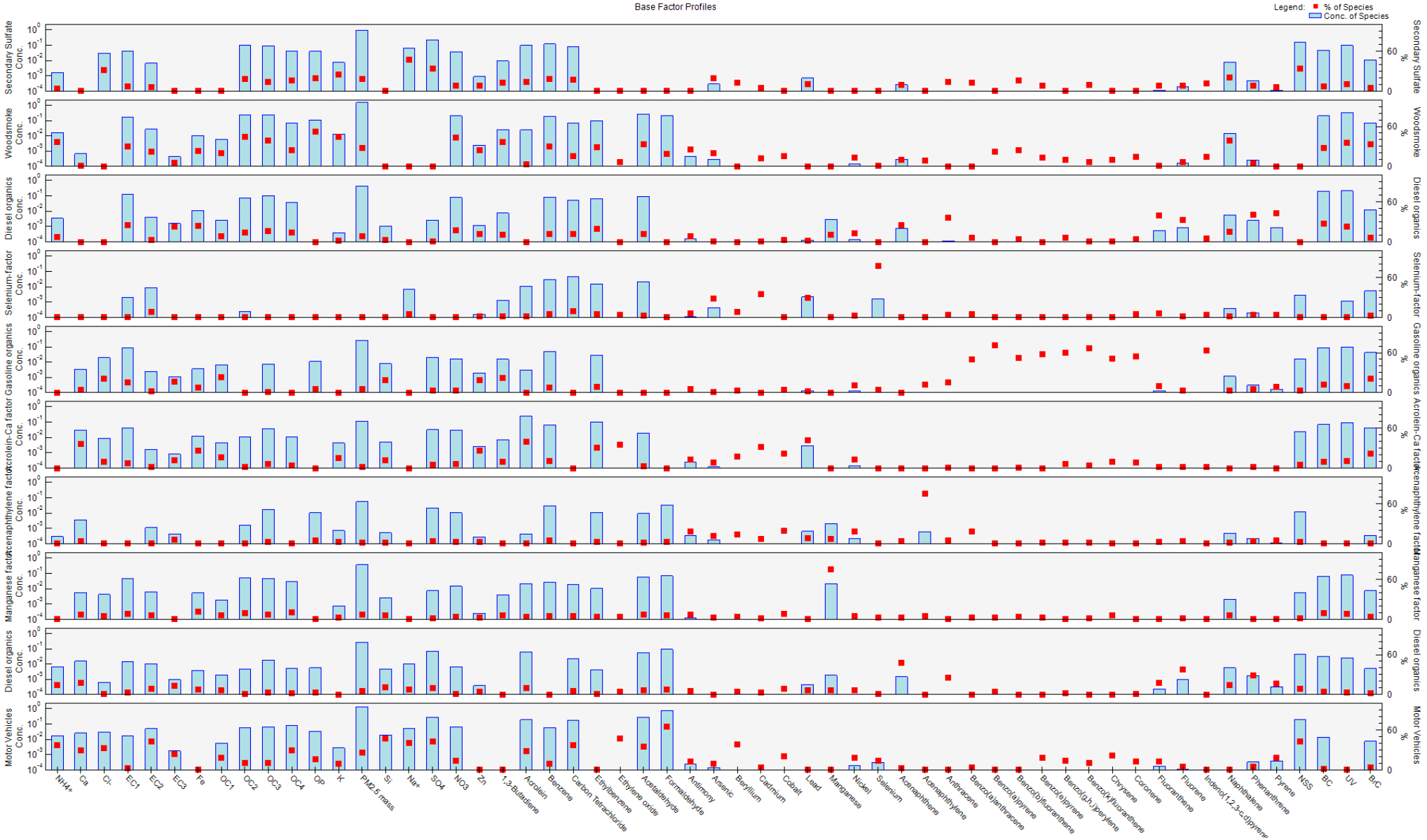


Figure L-4. Seattle Duwamish profiles and contributions for PMF factors.



Seattle 10th and Weller: We used air toxics (carbonyls, and VOCs) along with the speciation data at the 10th and Weller site for the additional PMF analysis. The nine factors were identified at the site out of which motor vehicles, wood smoke, ammonium nitrate and crustal/urban and were the biggest contributors. The site is a curbside location next to the I-5 and thus is heavily impacted by motor vehicles and the resuspension of dust which is reflected as crustal/urban source. Acrolein is also emitted from vehicle exhaust, tobacco smoke, and living near oil refineries, or pulp and paper mills. The acrolein-rich factor was highly correlated with the VOCs in the samples. Additionally, secondary sulfates, industrial solvents and sea salt were also identified based on the species signatures. Below is a pie-chart of the contributing factors.

Figure L-5. Seattle 10th and Weller additional PMF Factor Pie Chart

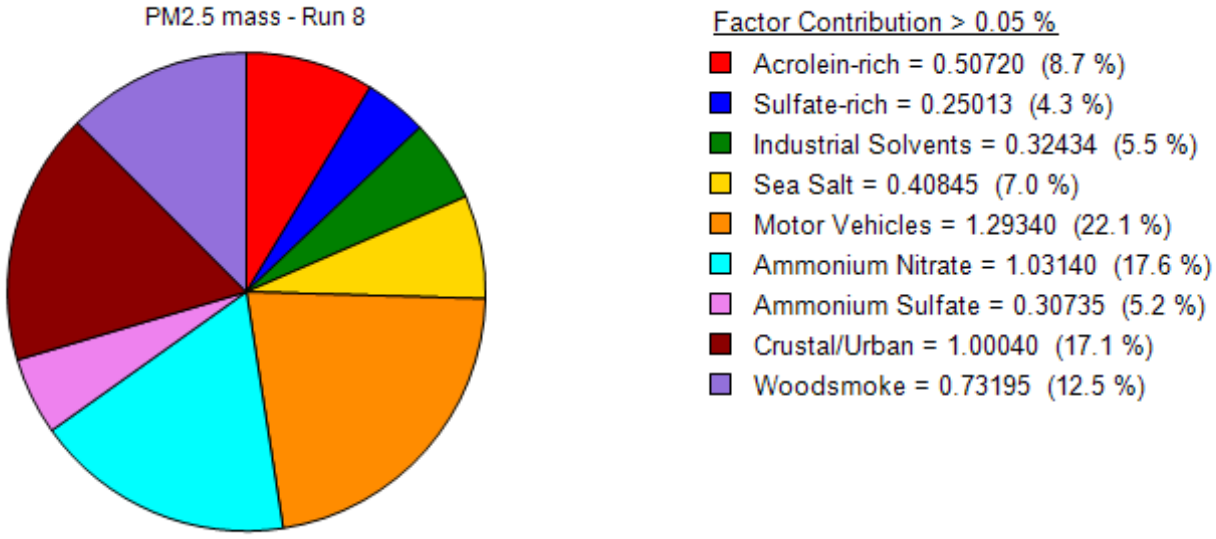


Figure L-6. Seattle 10th and Weller seasonal trend for PMF factors

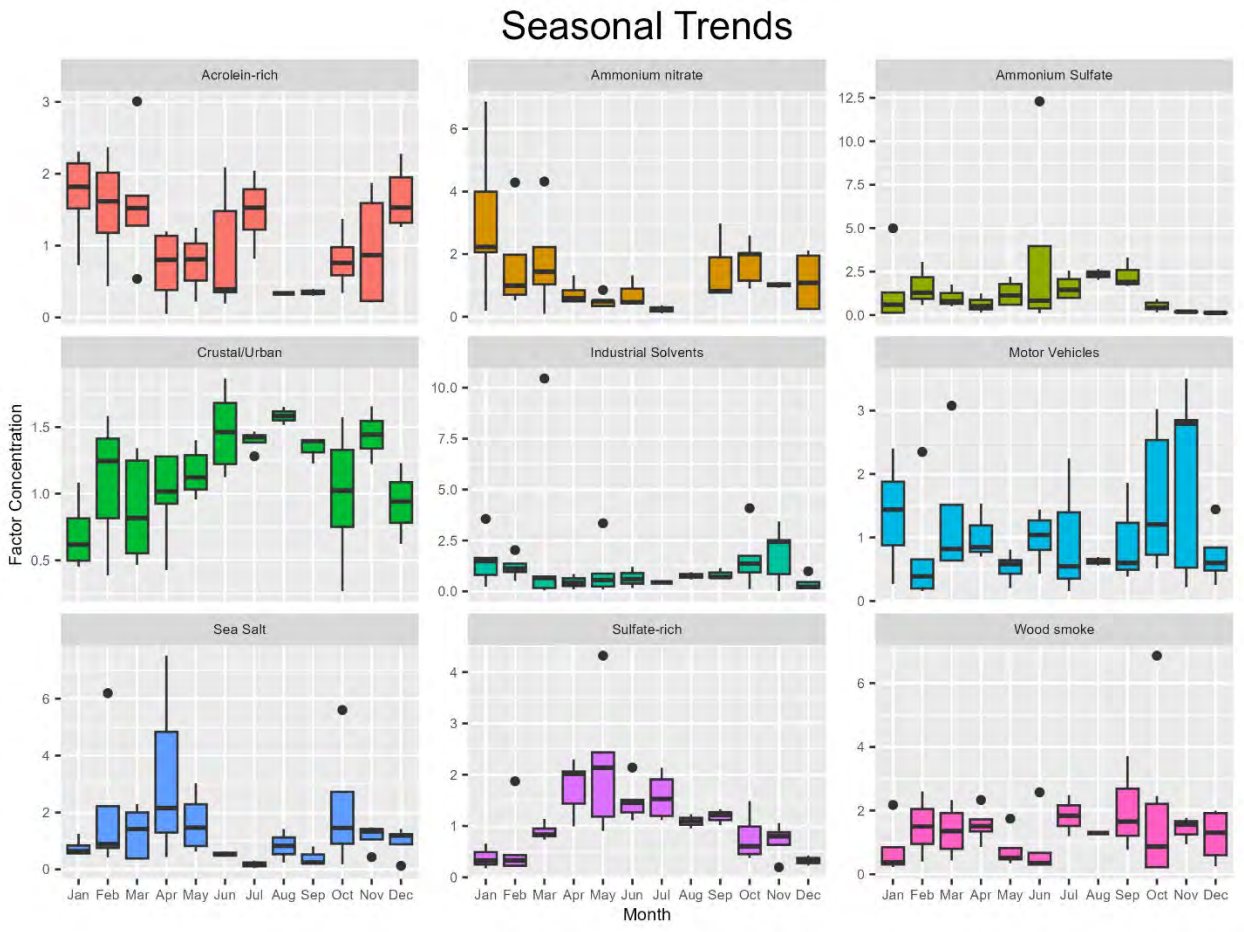


Figure L-7. Seattle 10th and Weller factor fingerprints PMF factors

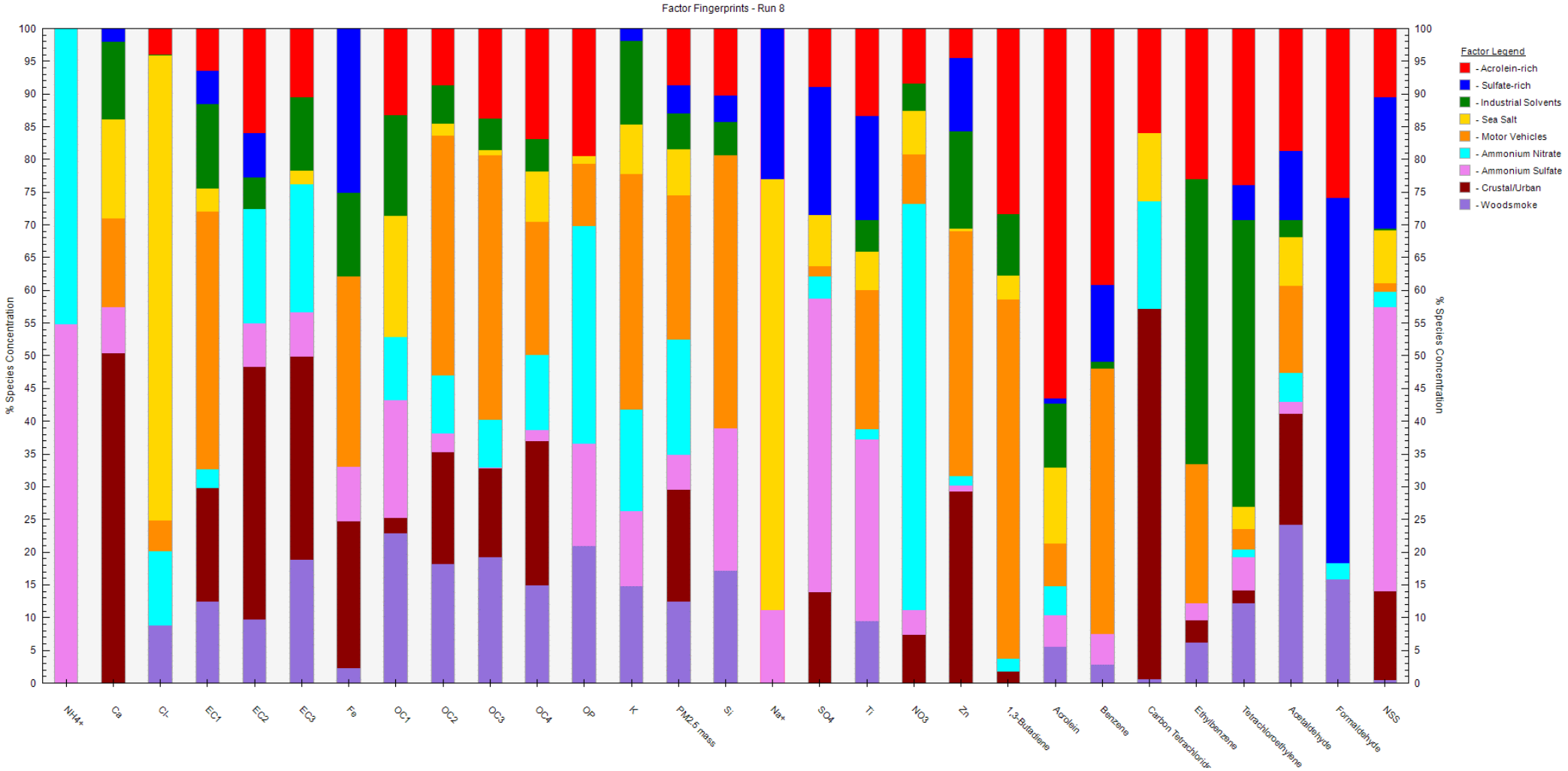
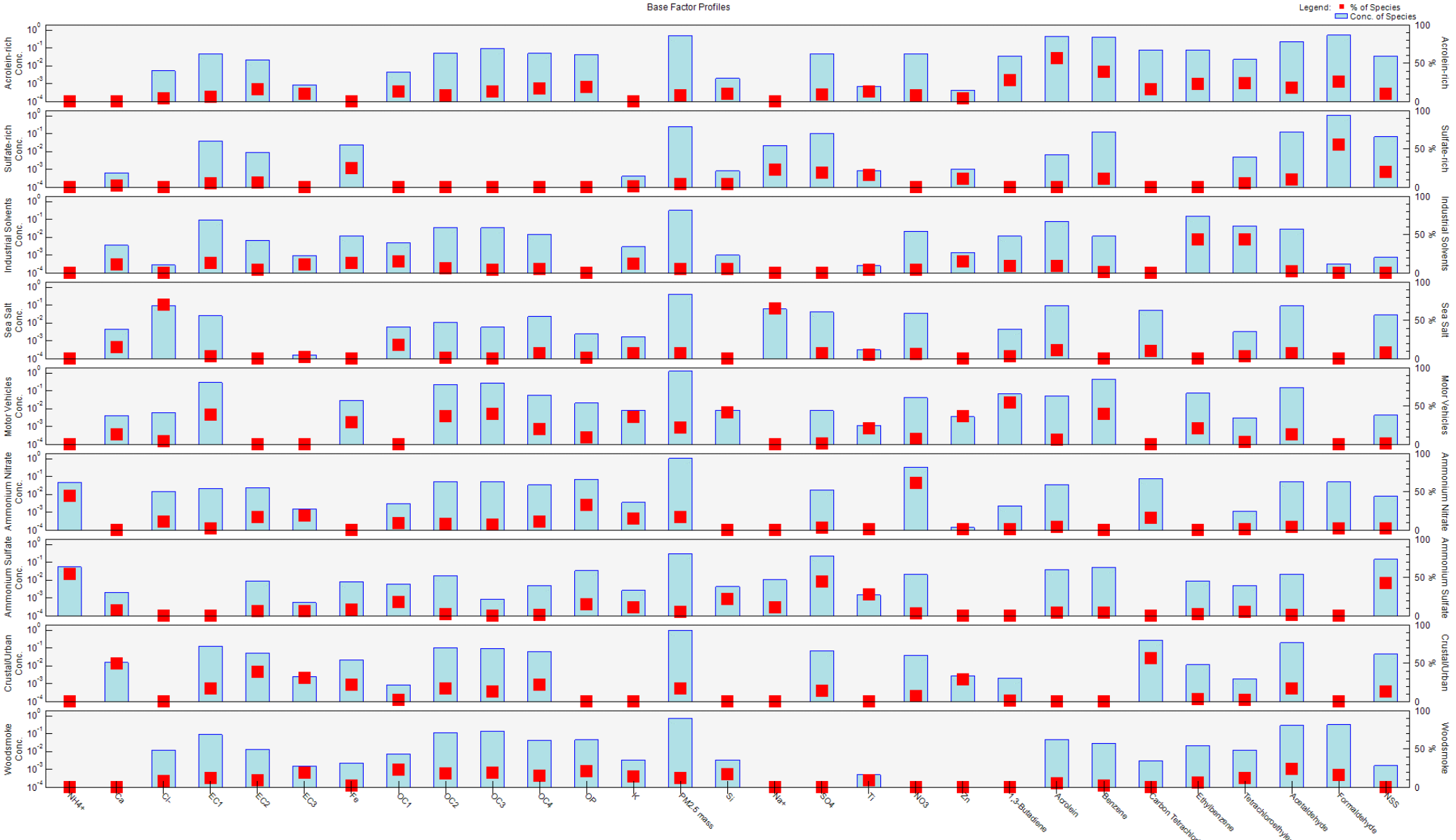


Figure L-8. Seattle 10th and Weller profiles for PMF factors



Tacoma South L: We used air toxics (carbonyls and VOCs) along with the speciation data at the Tacoma South L site for the additional PMF analysis. The nine factors were identified at the site out of which motor vehicles, wood smoke and secondary sulfate were the biggest contributors. This site is located in a residential area and is heavily influenced by wood smoke. There were additional factors like acrolein-rich factor which had high contributions of organics like carbon tetrachloride and benzene. Carbonyls acetaldehyde and formaldehyde were identified as a separate factor which showed high concentrations in summer as their production increase in high temperatures. Below is a pie-chart of the contributing factors.

Figure L-9. Tacoma South L additional PMF Factor Pie Chart

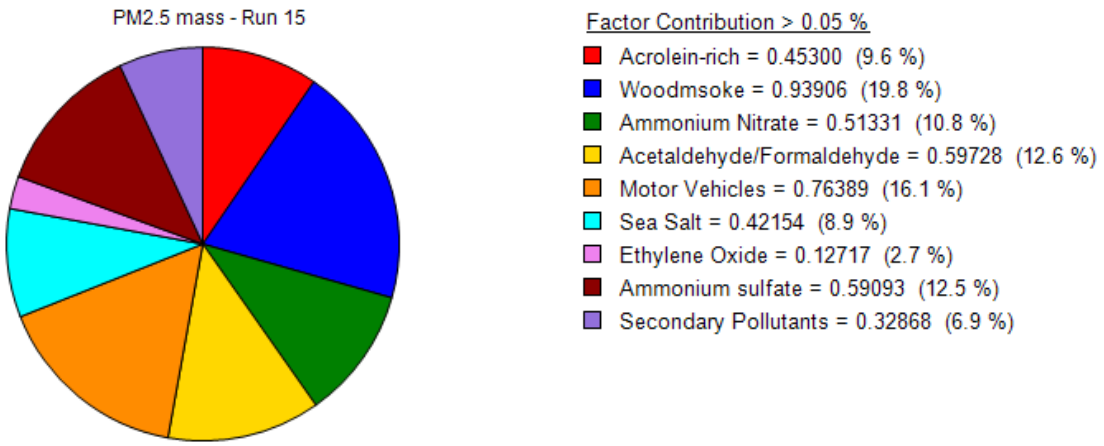


Figure L-10. Tacoma South L seasonal trend for PMF factors

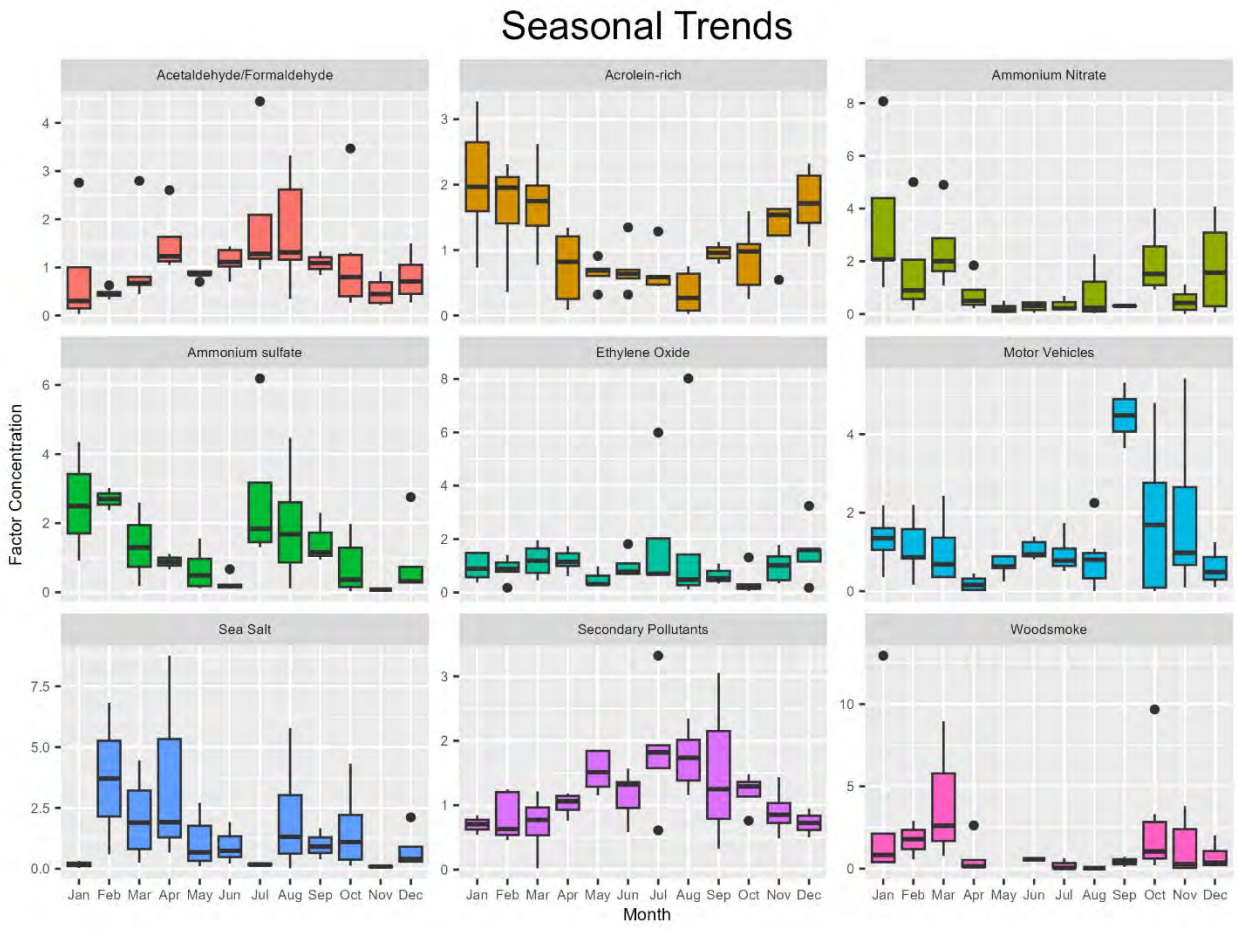


Figure L-11. Tacoma South L factor fingerprints PMF factors

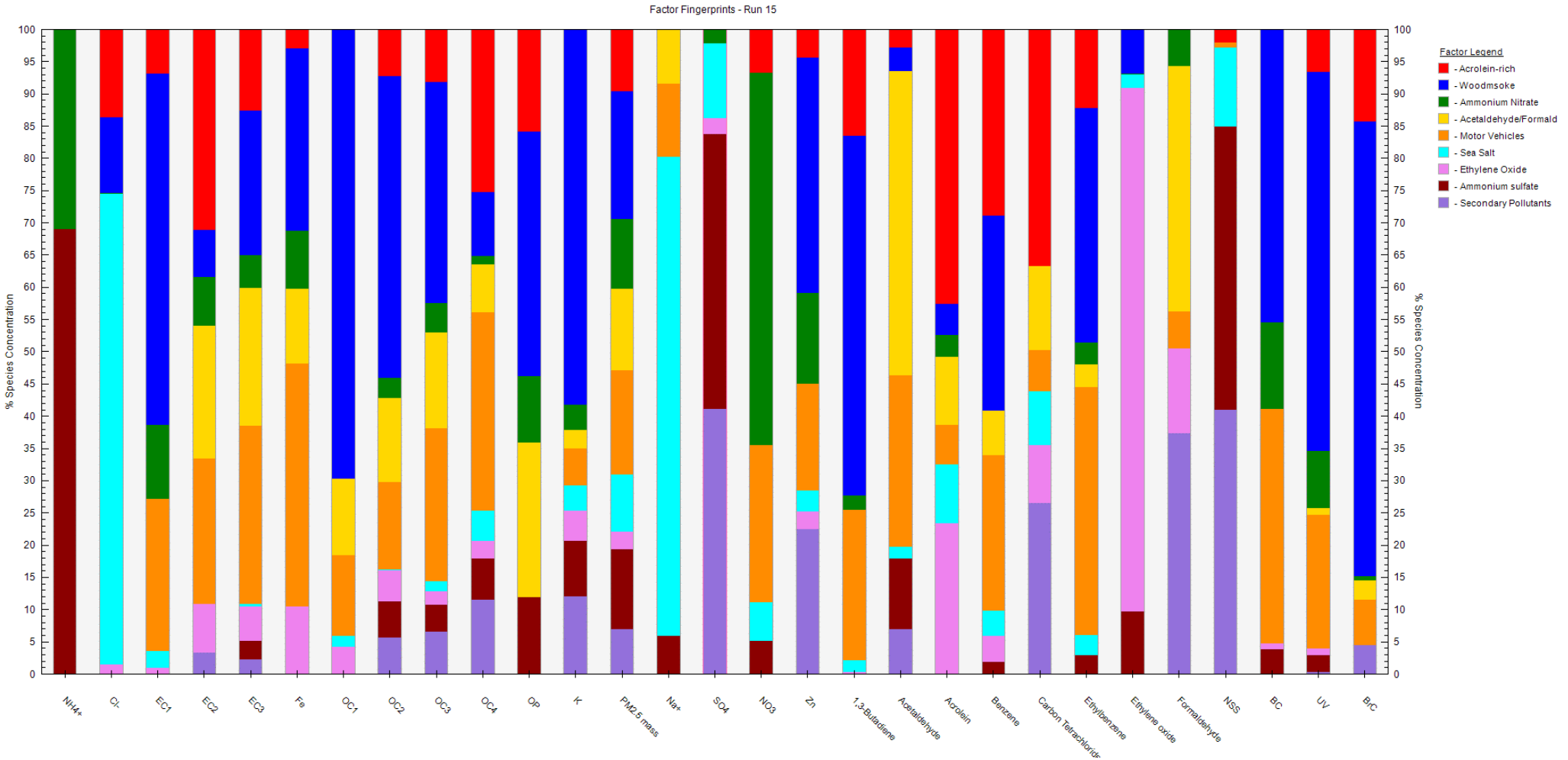
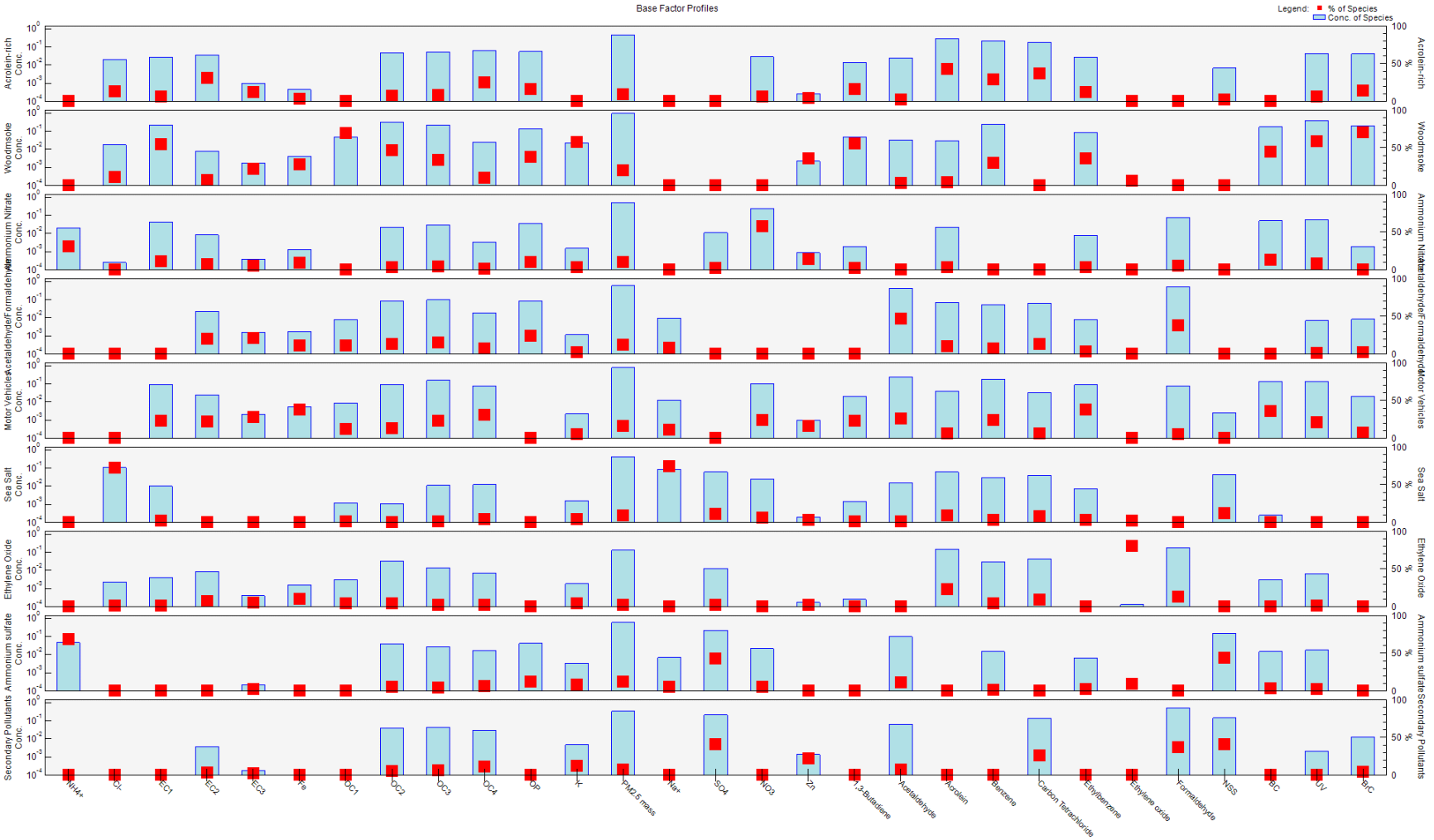


Figure L-12. Tacoma South L profiles and contributions for PMF factors



Seattle Beacon Hill: We used air toxics (carbonyls, VOCs, SVOCs, and PM_{10} metals) along with the speciation data at the Beacon Hill site for the additional PMF analysis. The ten factors were identified at the site out of which motor vehicles, wood smoke, Diesel and sea salt were the biggest contributors. With the help of VOCs and SVOCs, diesel and gasoline sources were identified. The SVOCs like benzo(a)anthracene, benzo(a)pyrene, Indeno(1,2,3-c,d)pyrene, benzo(b)fluoranthene are characteristic of gasoline emissions and SVOCs like anthracene, fluoranthene, fluorene, phenanthrene, pyrene are characteristic of diesel emissions. There were additional factors like Manganese rich factor and acenaphthylene rich factor, which were observed only at this site and at Seattle Duwamish sites. Below is a pie-chart of the contributing factors.

Figure L-133. Seattle Beacon Hill additional PMF Factor Pie Chart

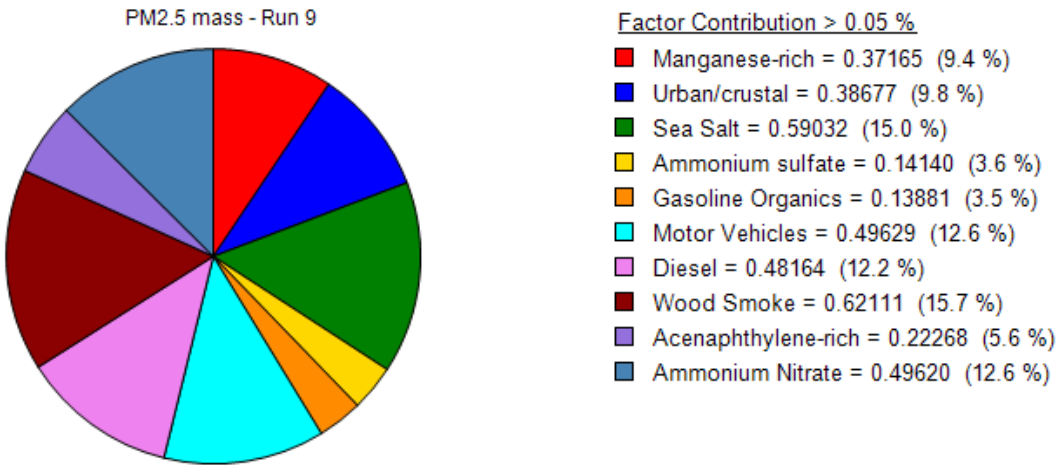


Figure L-14. Seattle Beacon Hill seasonal trend for PMF factors.

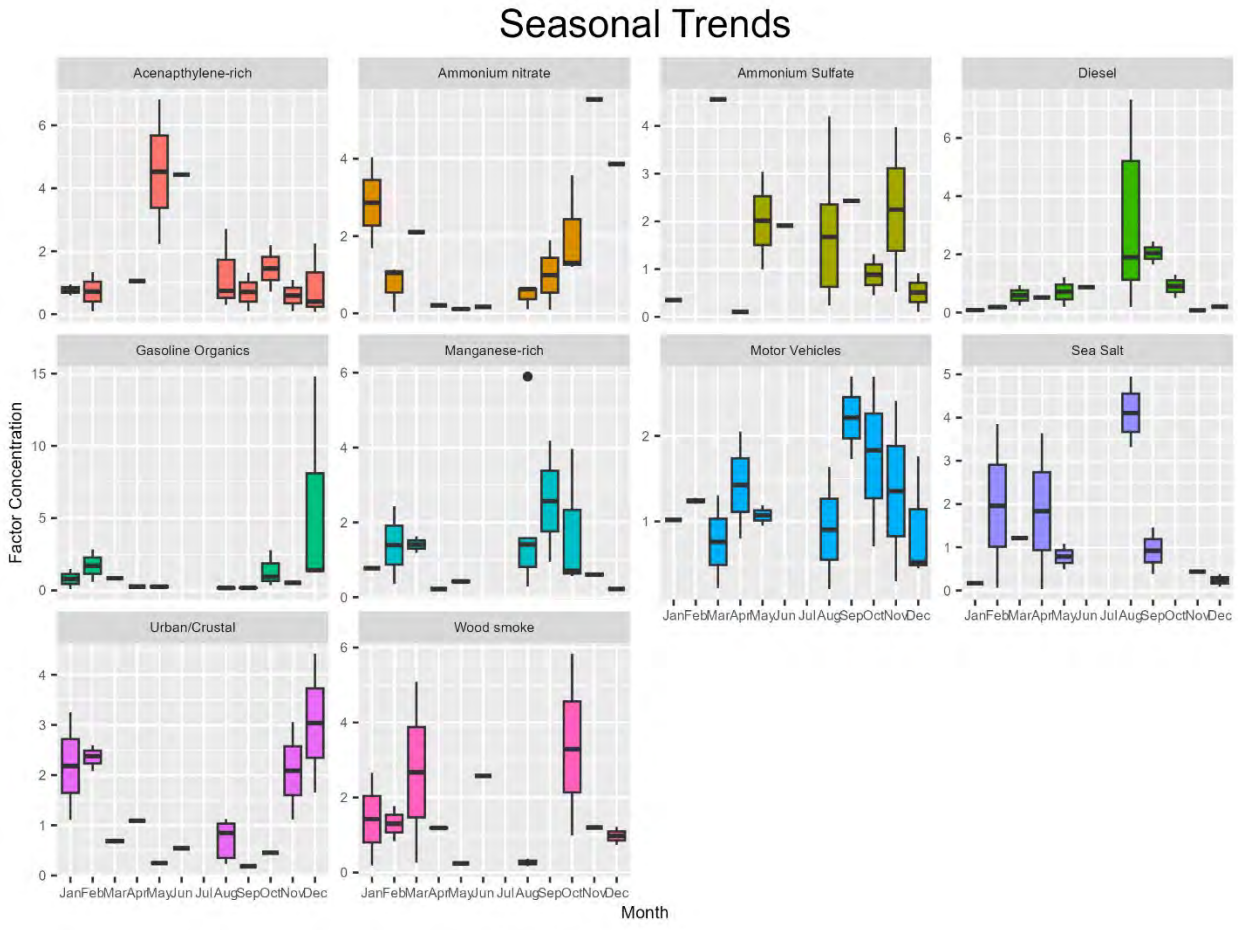


Figure L-15. Seattle Beacon Hill factor fingerprints PMF factors.

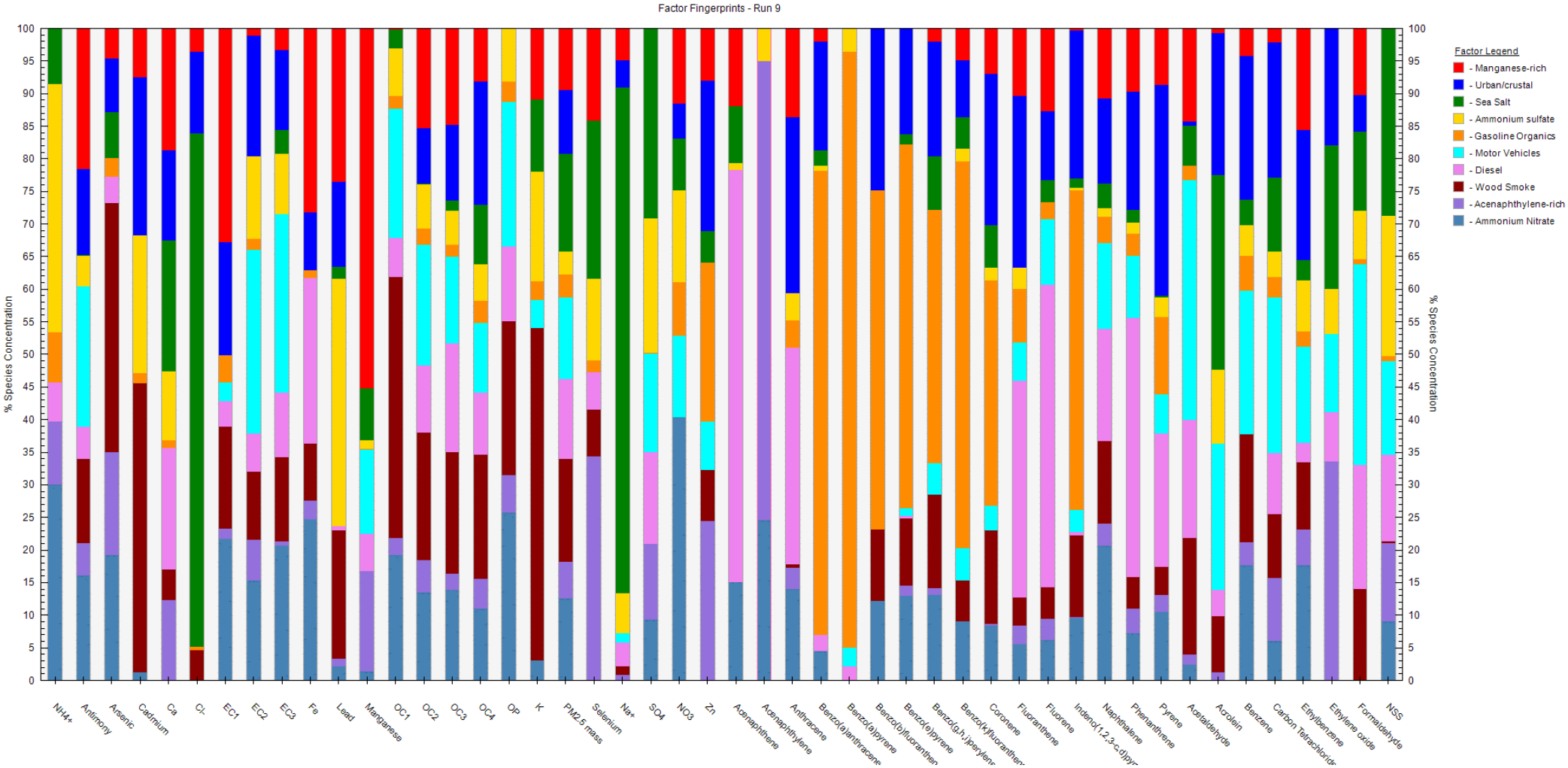
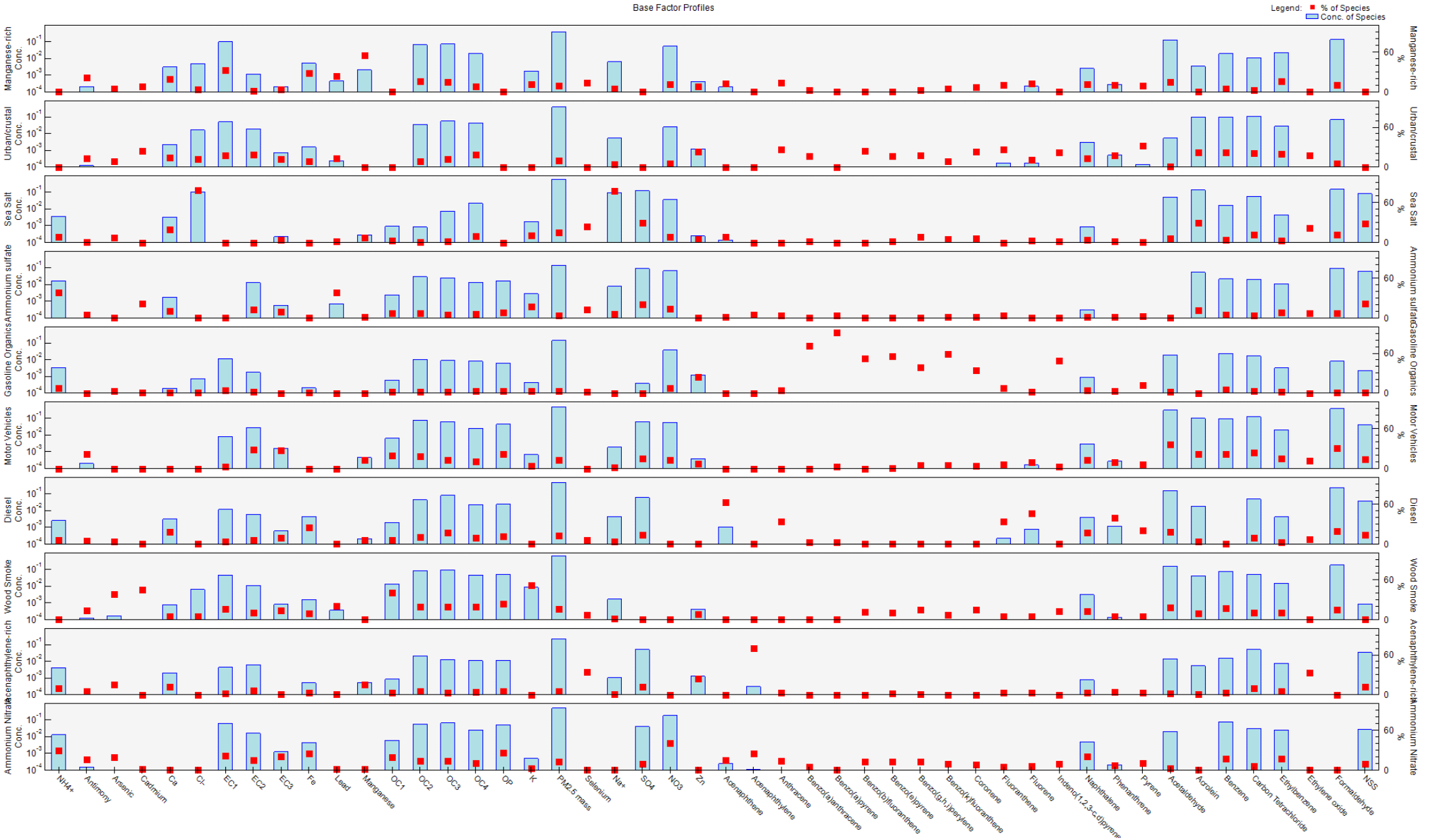


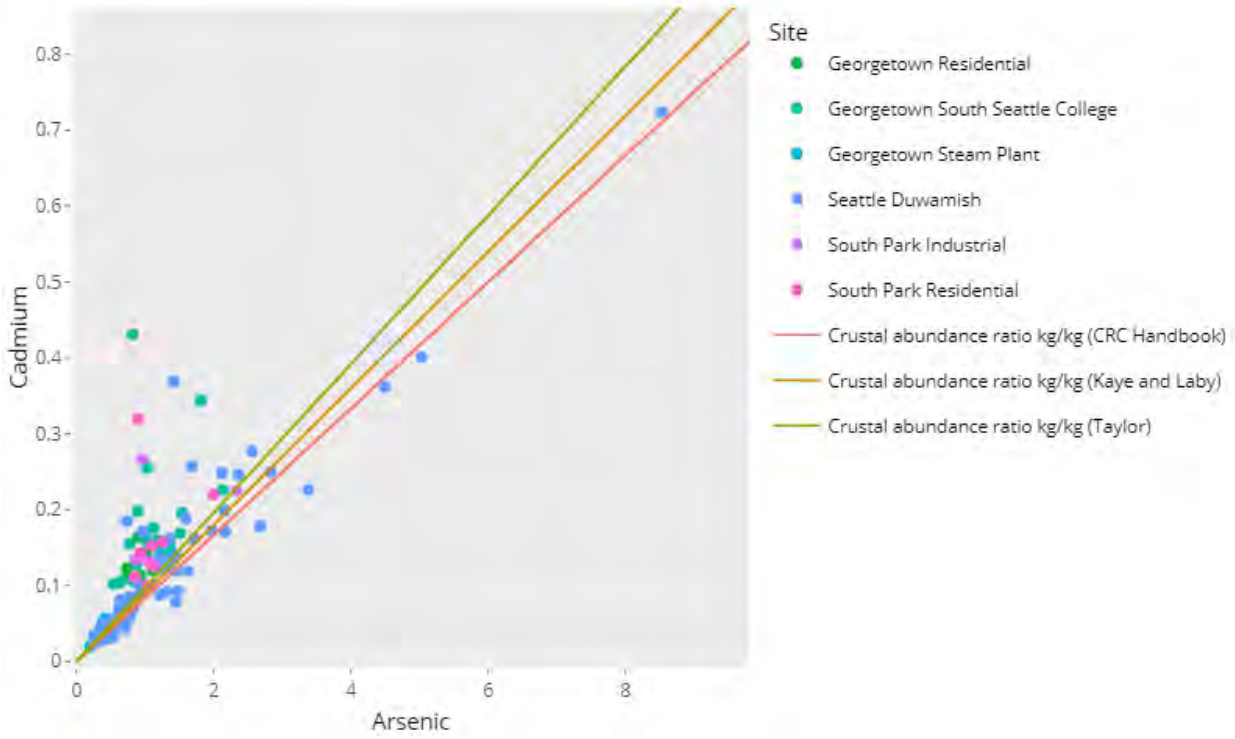
Figure L-16. Seattle Beacon Hill profiles and contributions for PMF factors.



Appendix M. Metal ratios compared to crustal abundance ratios

Figure M-1 below showed some correlation at the Seattle Duwamish monitoring site. The other locations had more limited number of samples covering a shorter time period but showed slightly higher cadmium to arsenic ratios. This may be seasonal in nature (those samples were collected in the summer), but we didn't investigate if this was related to seasonality.

Figure M-1. Arsenic vs cadmium concentrations for monitoring sites in the Duwamish Valley. The lines represent example crustal abundance ratios.



In Figures M-2 and M-3, arsenic vs lead and cadmium vs lead, showed somewhat stronger correlations to each other, as seen in the following figures.

Figure M-2. Lead vs Arsenic concentrations for monitoring sites in the Duwamish Valley. The lines represent example crustal abundance ratios.

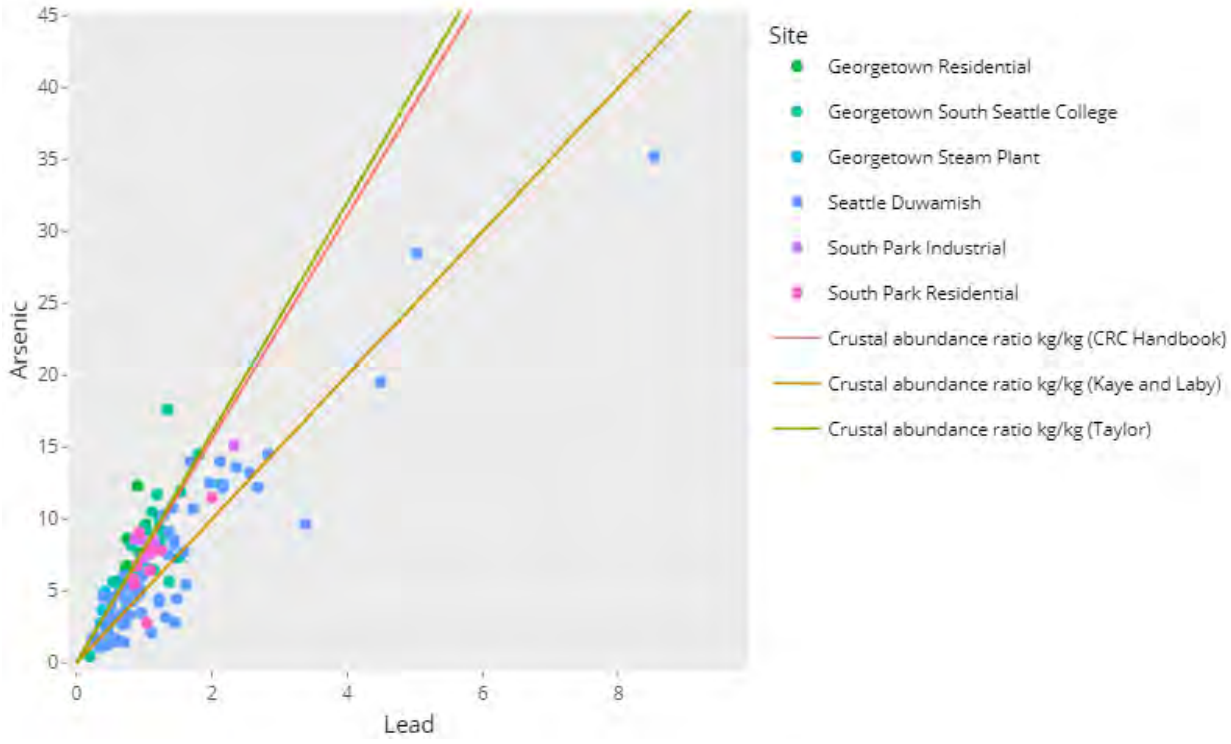
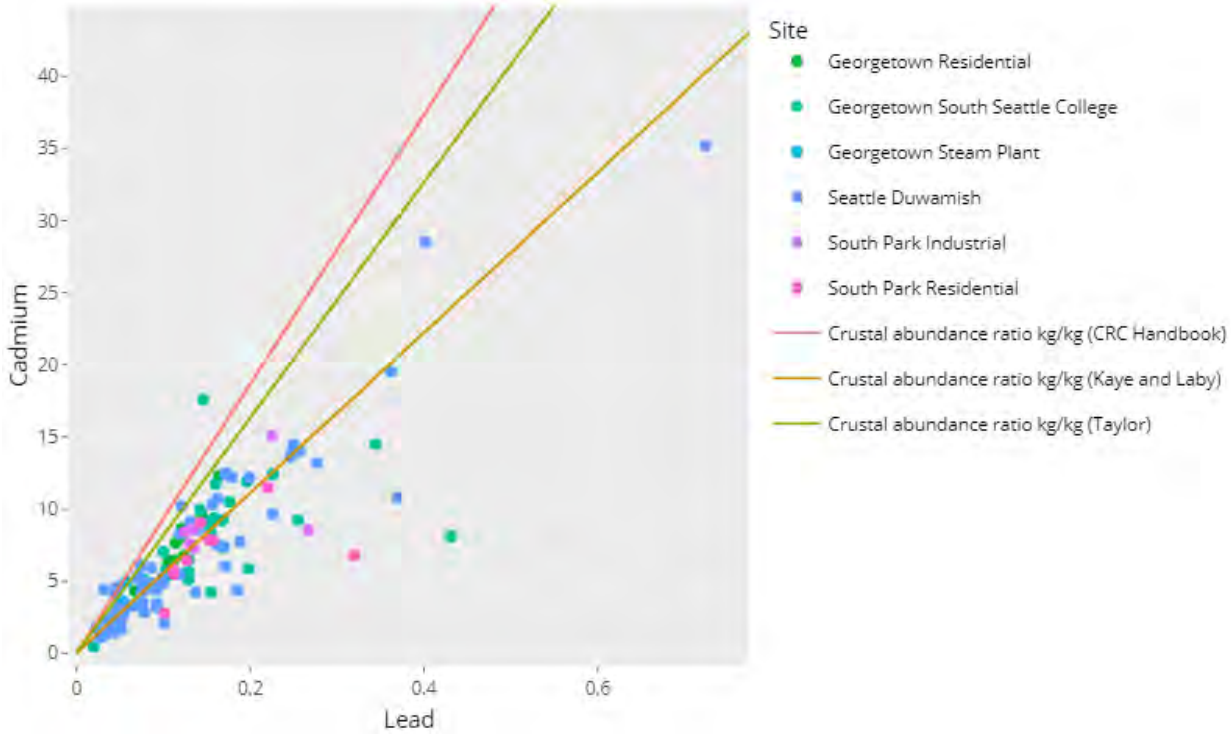


Figure M-3. Lead vs Cadmium concentrations for monitoring sites in the Duwamish Valley. The lines represent example crustal abundance ratios.



Appendix N. Single race graphs for average potential cancer risk from on-road diesel particulate matter

Figure N-11. Estimated average potential cancer risk from on-road diesel particulate matter by race – American Indian/Alaska Native.

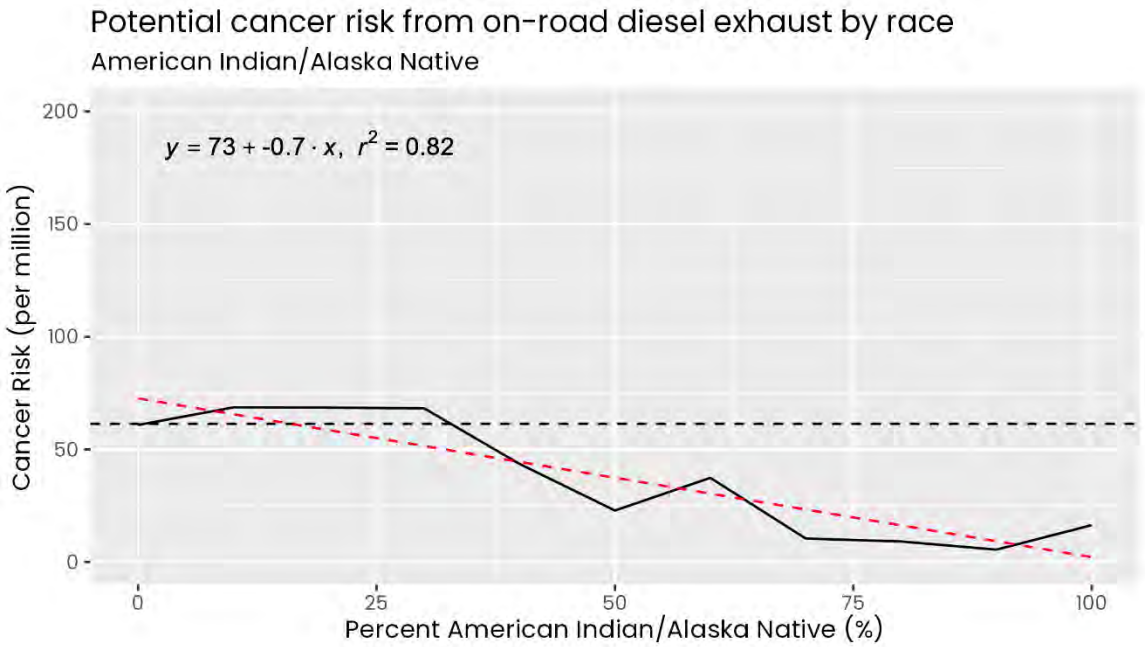


Figure N-22. Estimated average potential cancer risk from on-road diesel particulate matter by race – Asian.

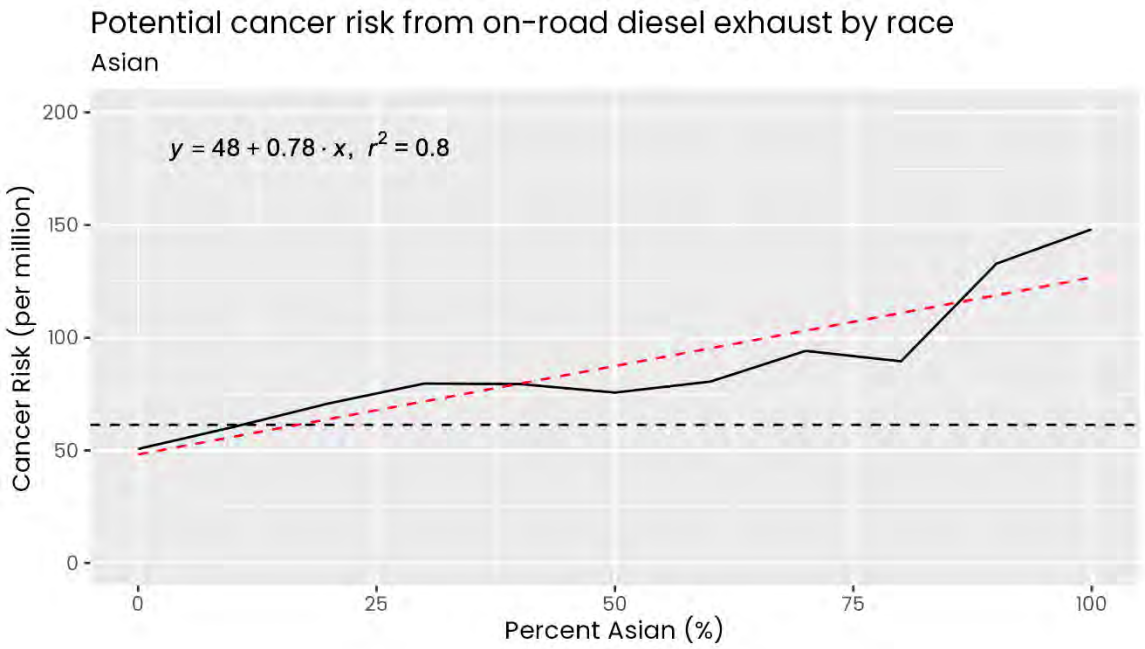


Figure N-33. Estimated average potential cancer risk from on-road diesel particulate matter by race – Black/African American.

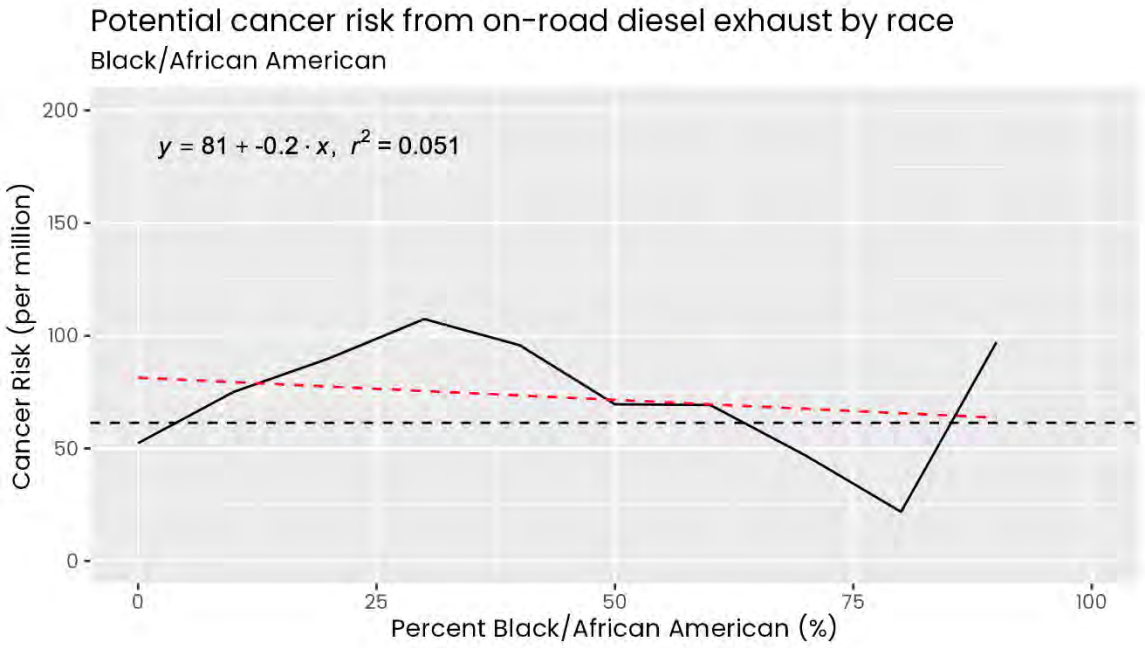


Figure N-44. Estimated average potential cancer risk from on-road diesel particulate matter by race – Multiple Races.

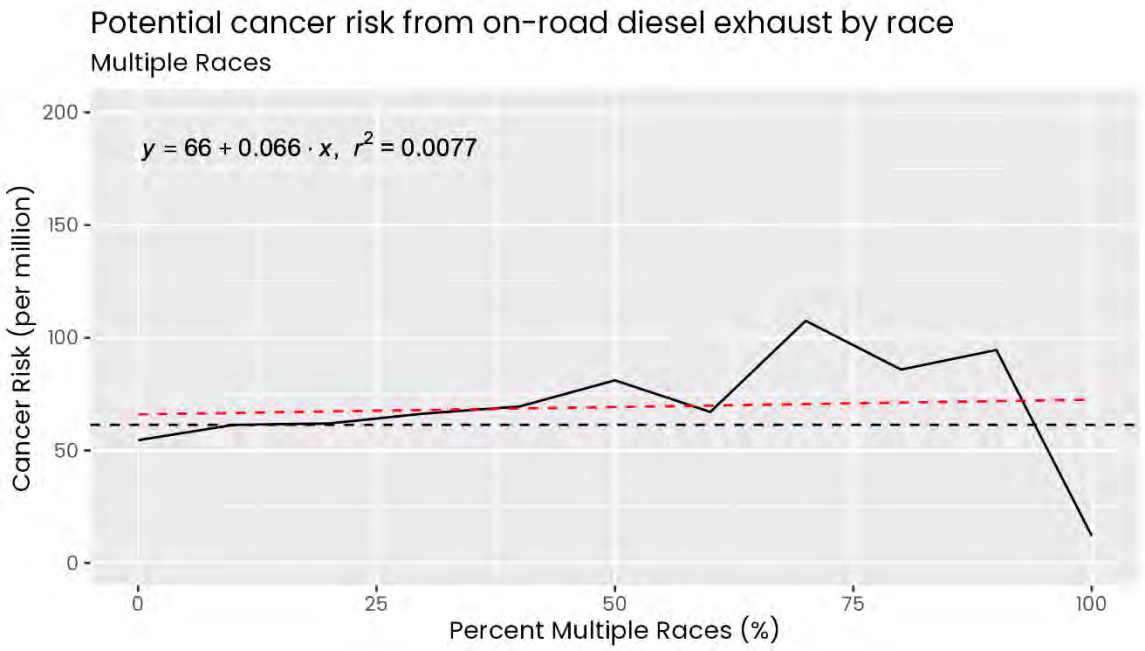


Figure N-55. Estimated average potential cancer risk from on-road diesel particulate matter by race – Native Hawaiian/Pacific Islander.

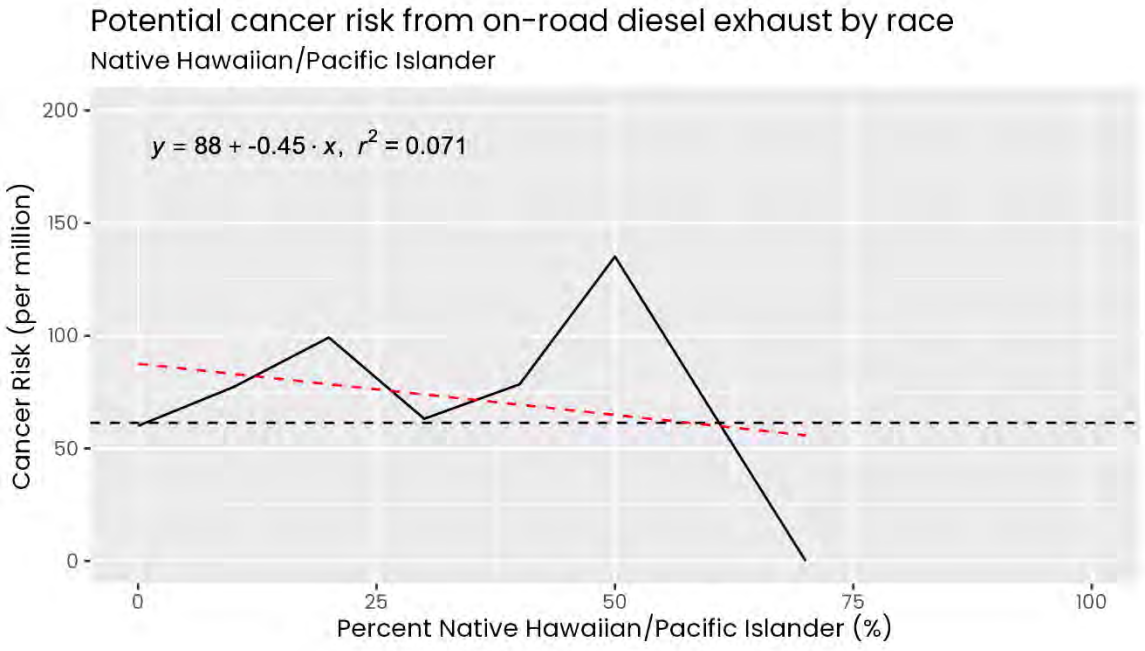
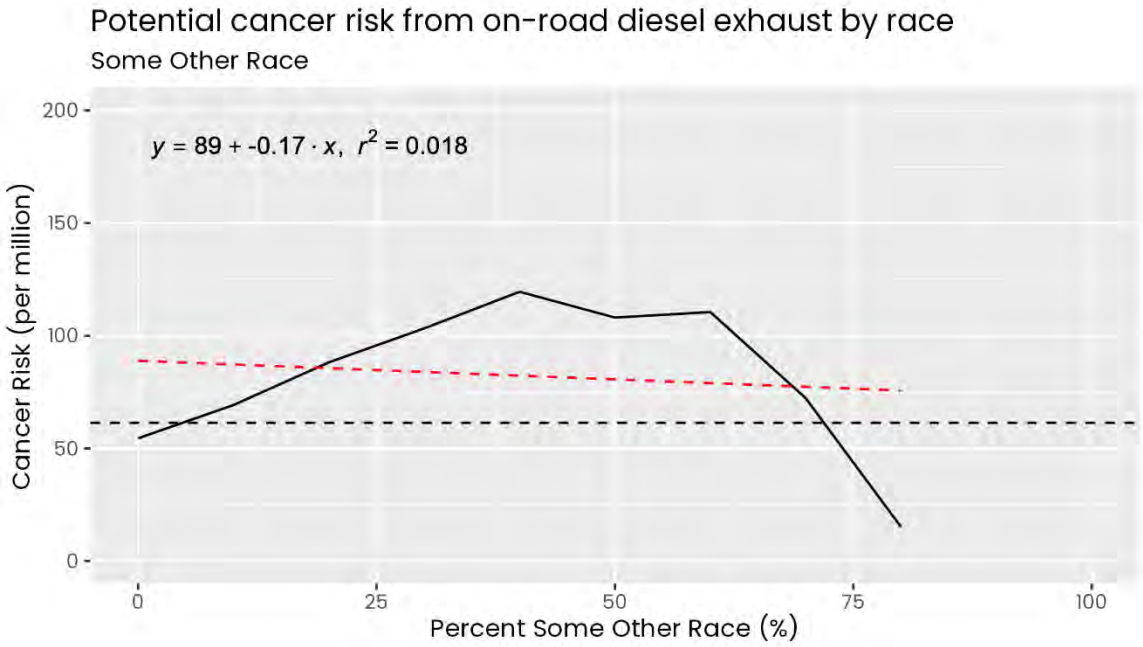


Figure N-66. Estimated average potential cancer risk from on-road diesel particulate matter by race – Some Other Race.



Appendix O. Box plots for PAHs

This section shows the box plots for PAHs. The dashed black line is the MDL. None of our sites had any PAH values above the MDL.

Figure O-17. Acenaphthene box plot.

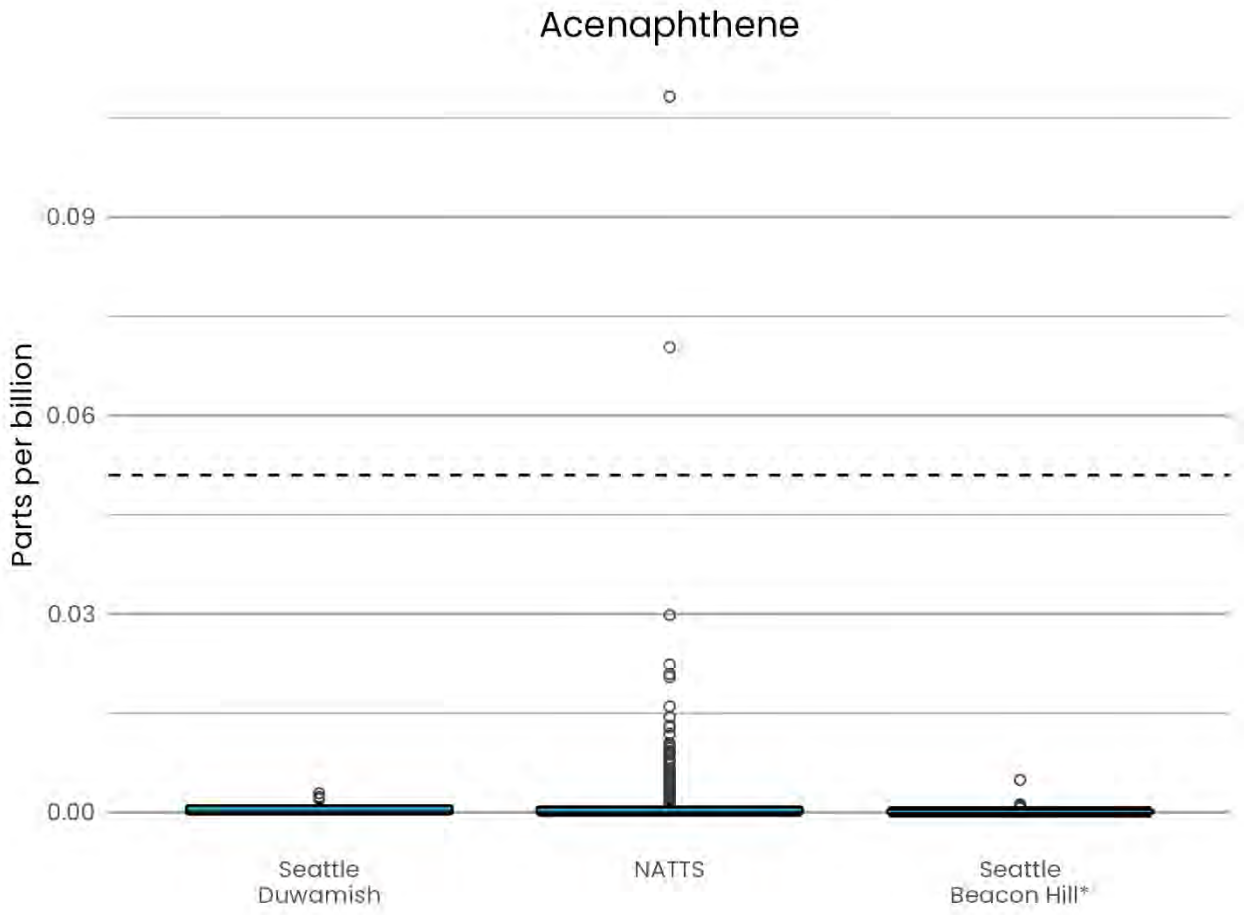


Figure O-28. Acenaphthylene box plot.

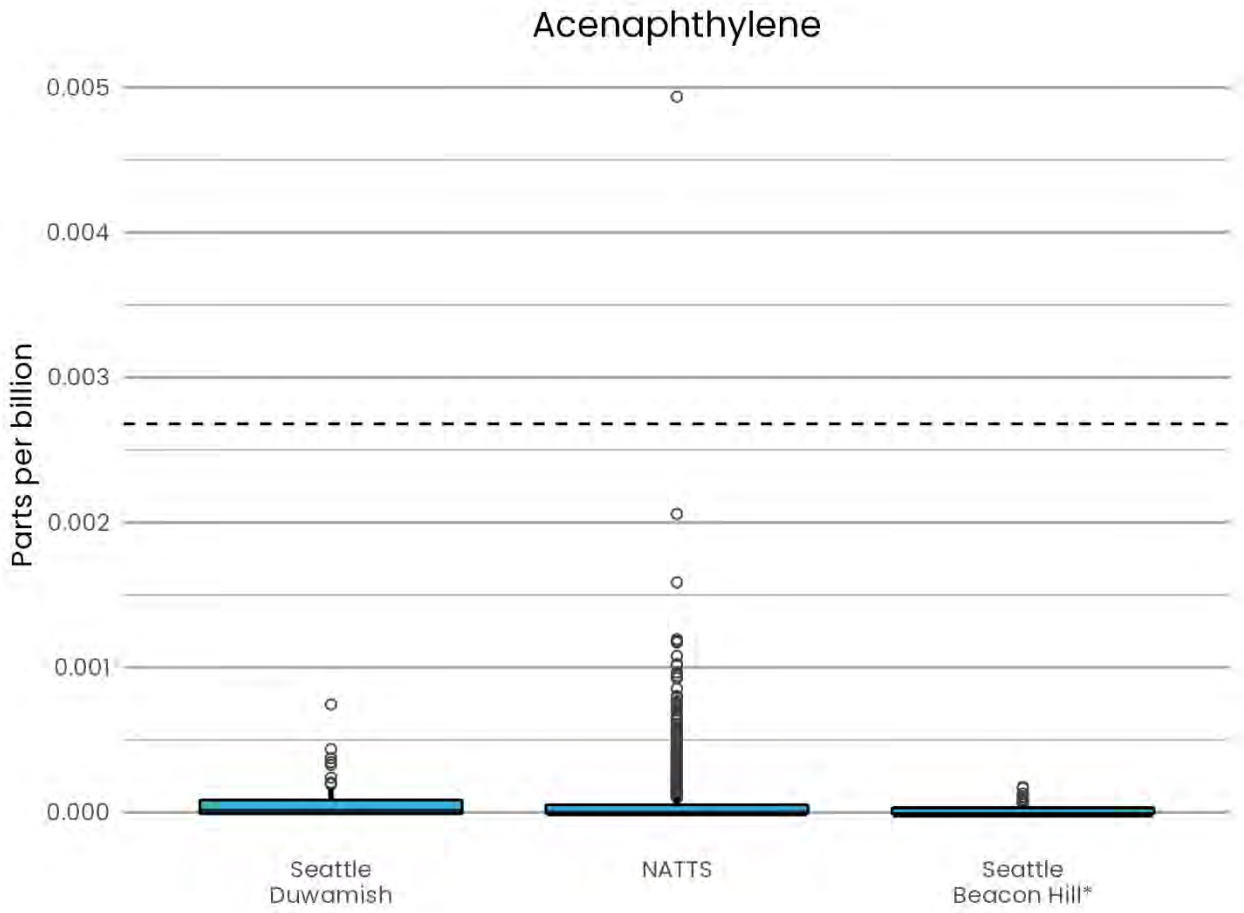


Figure O-39. Anthracene box plot.

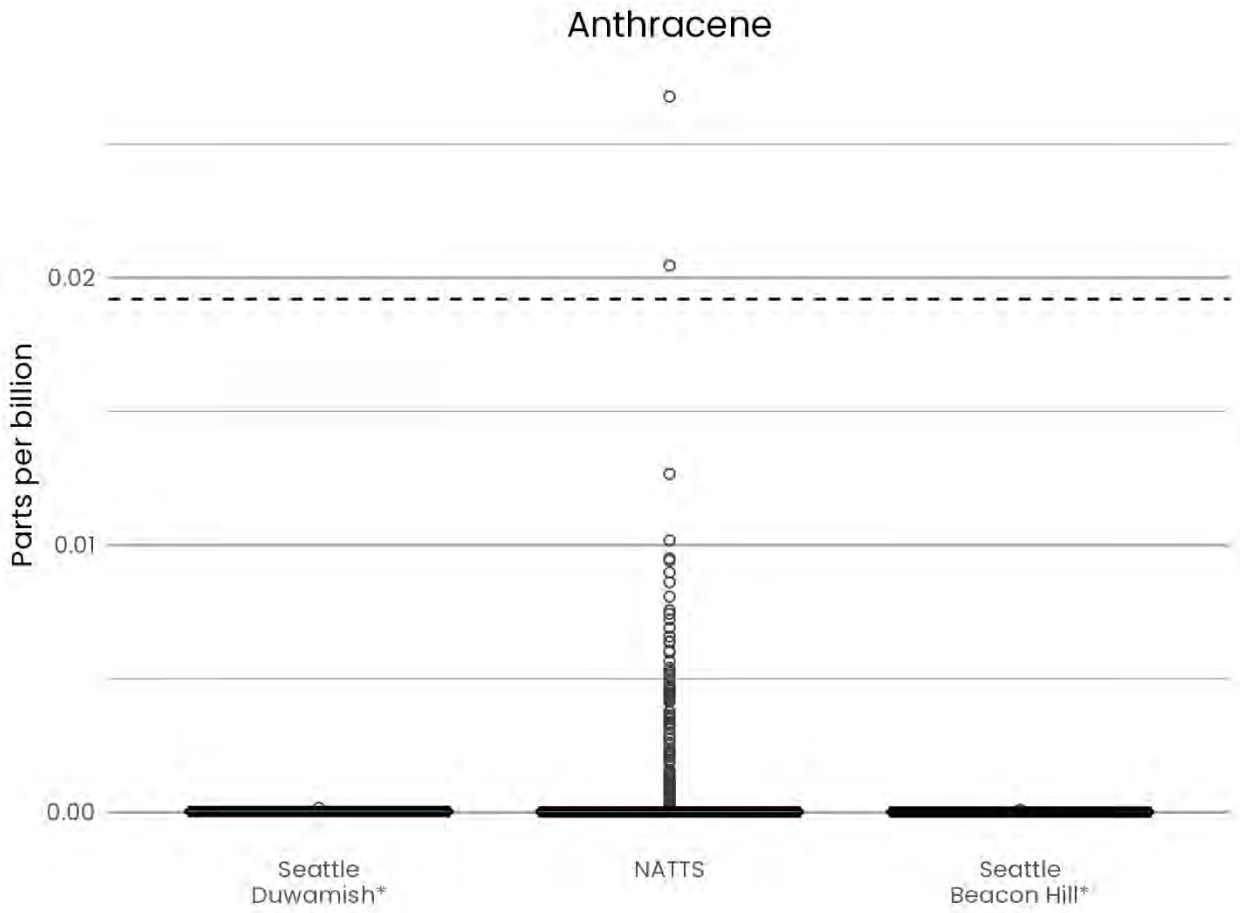


Figure O-410. Benzo[a]anthracene box plot.

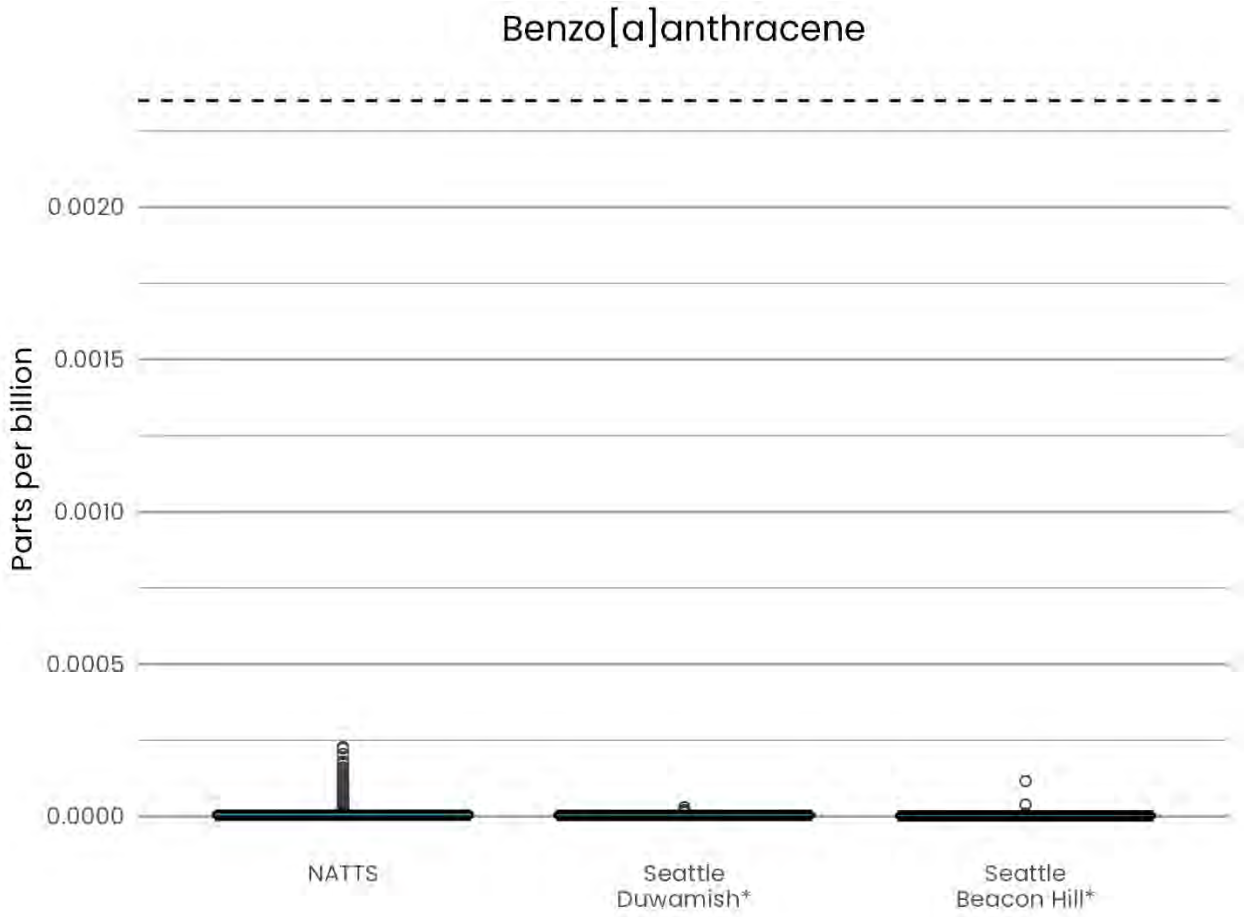


Figure O-511. Benzo[a]pyrene box plot.

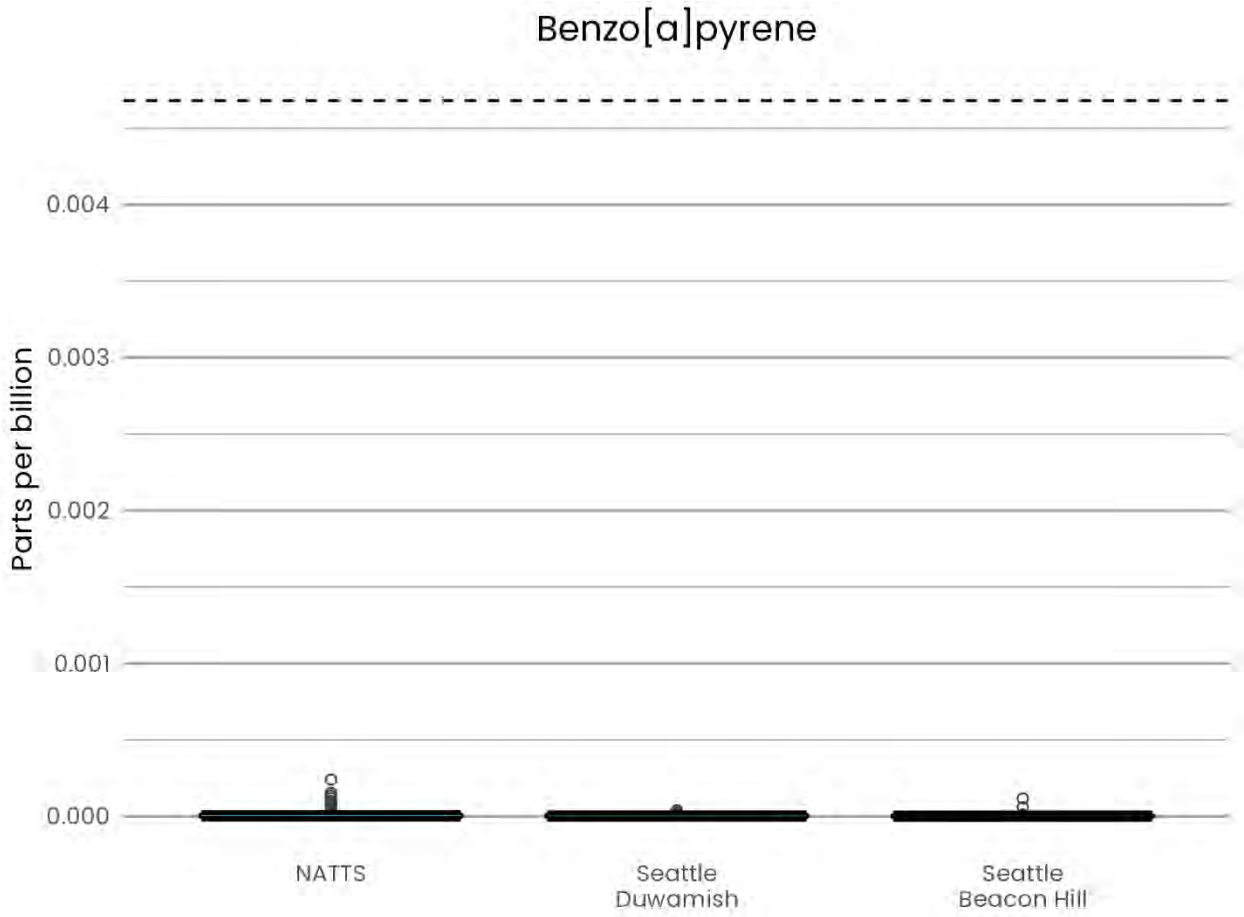


Figure O-612. Benzo[b]fluoranthene box plot.

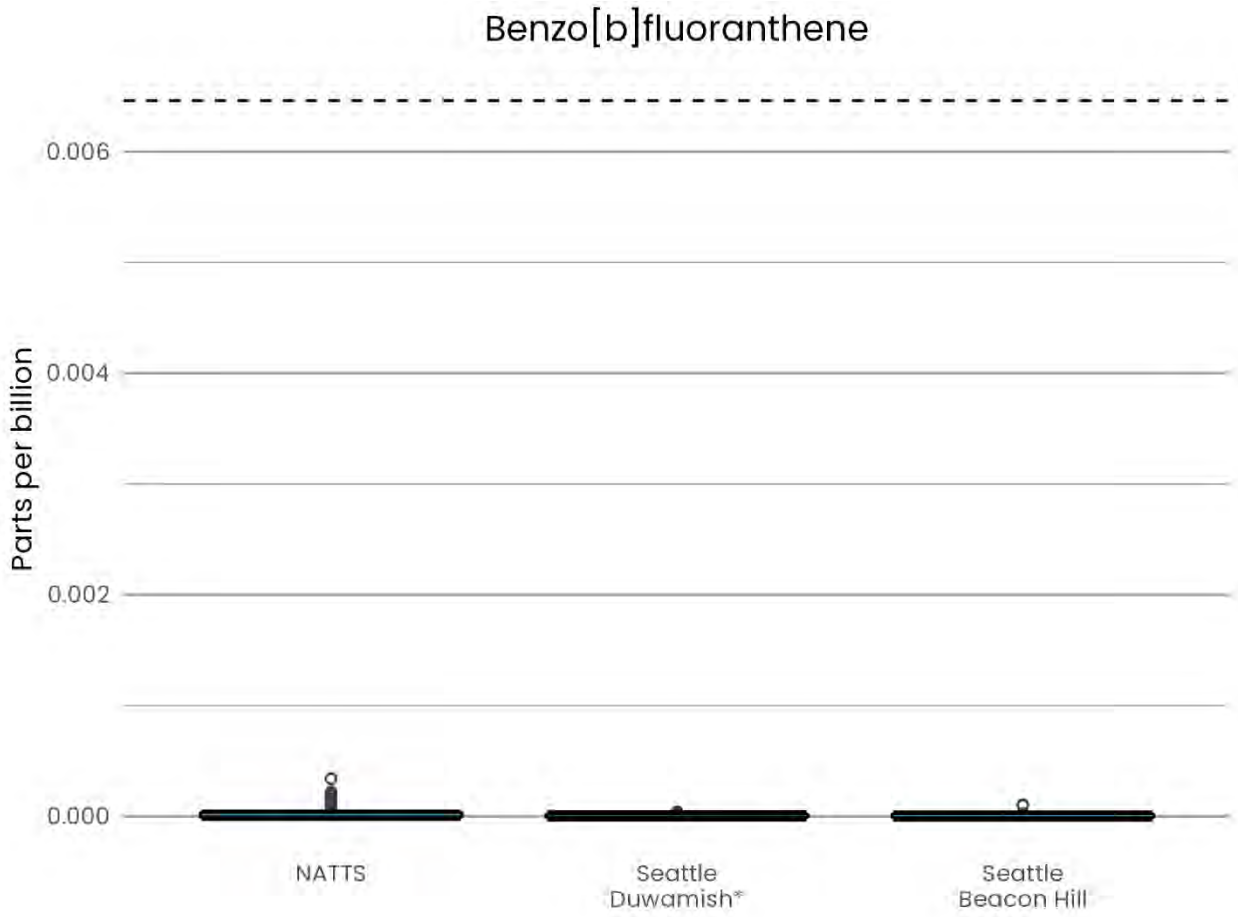


Figure O-713. Benzo[e]pyrene box plot.

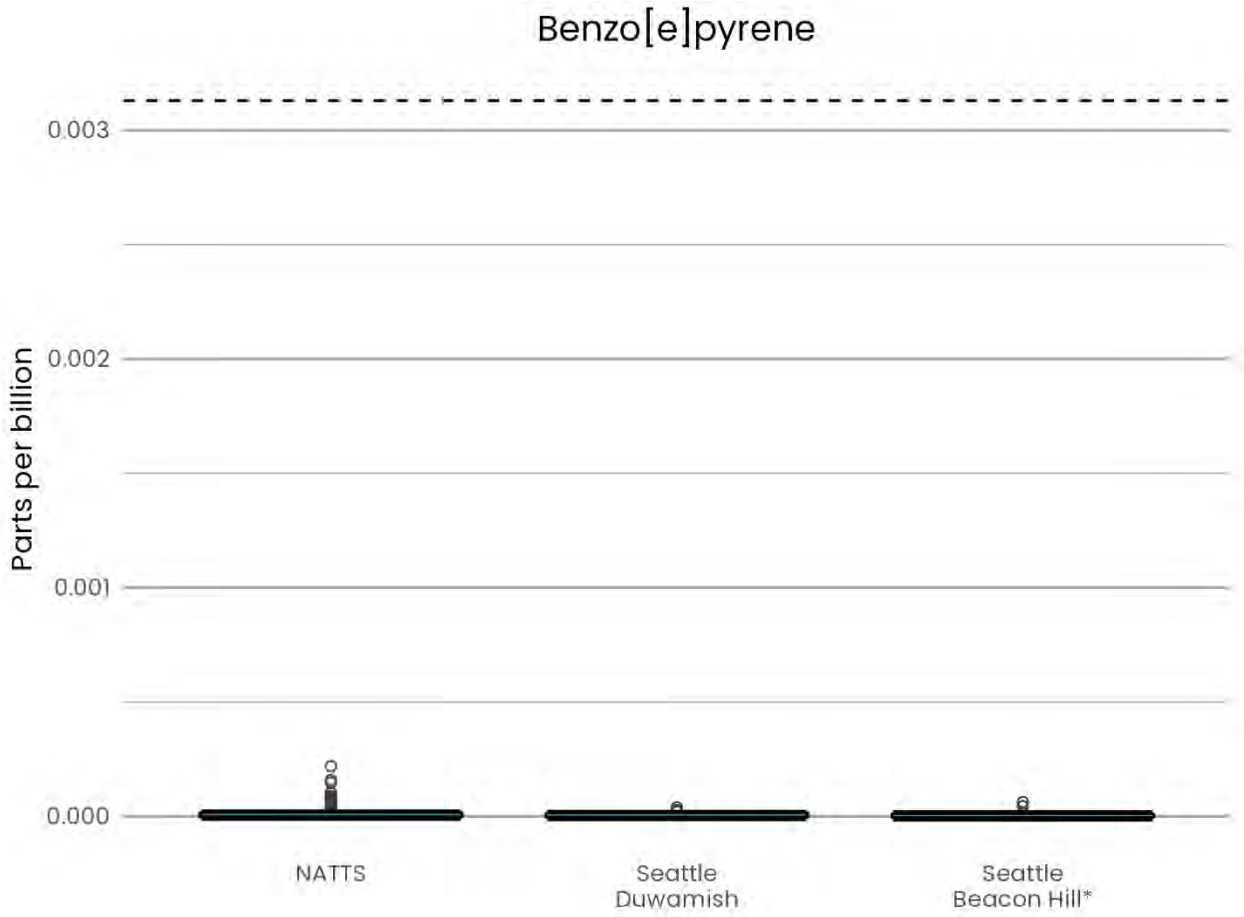


Figure O-814. Benzo[g,h,i]perylene box plot.

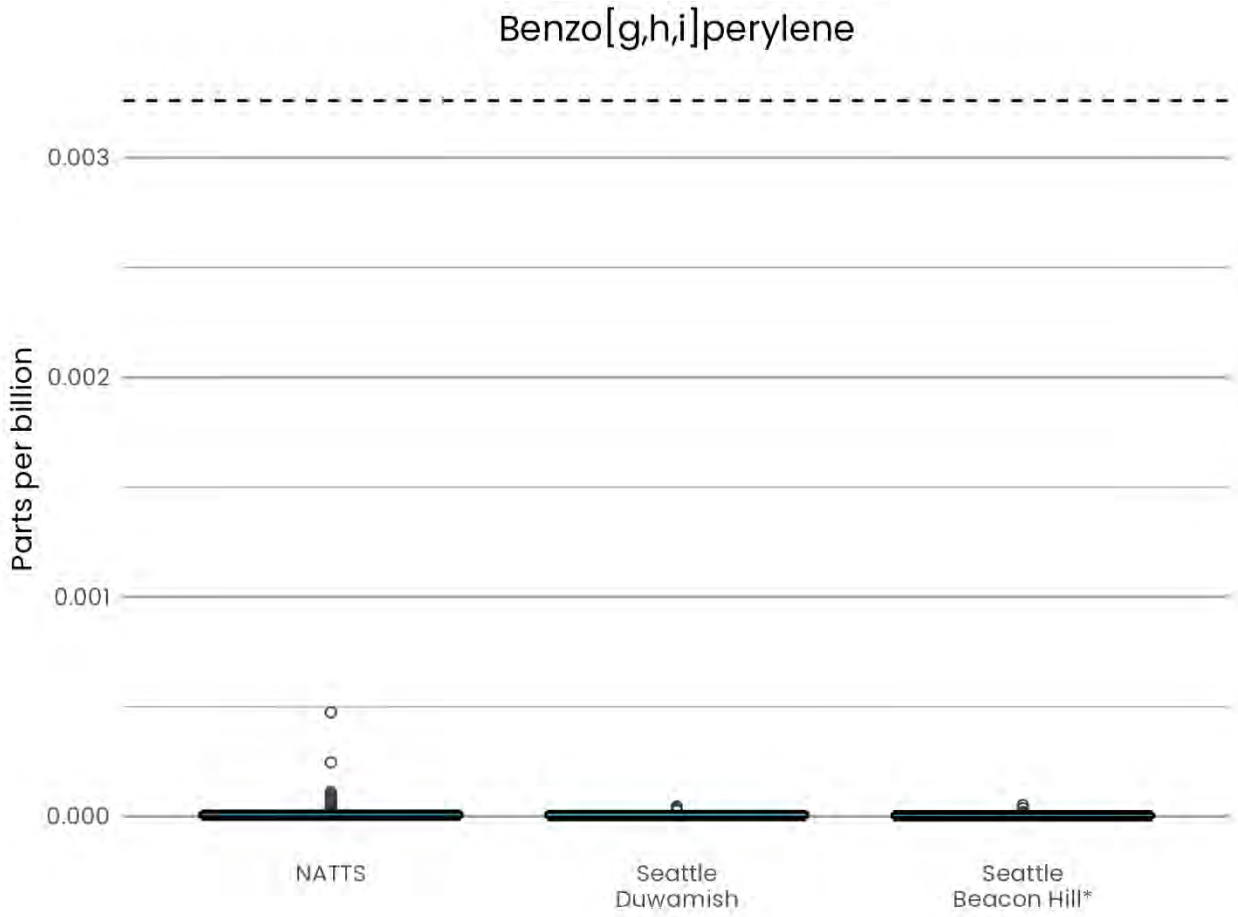


Figure O-915. Benzo[k]fluoranthene box plot.

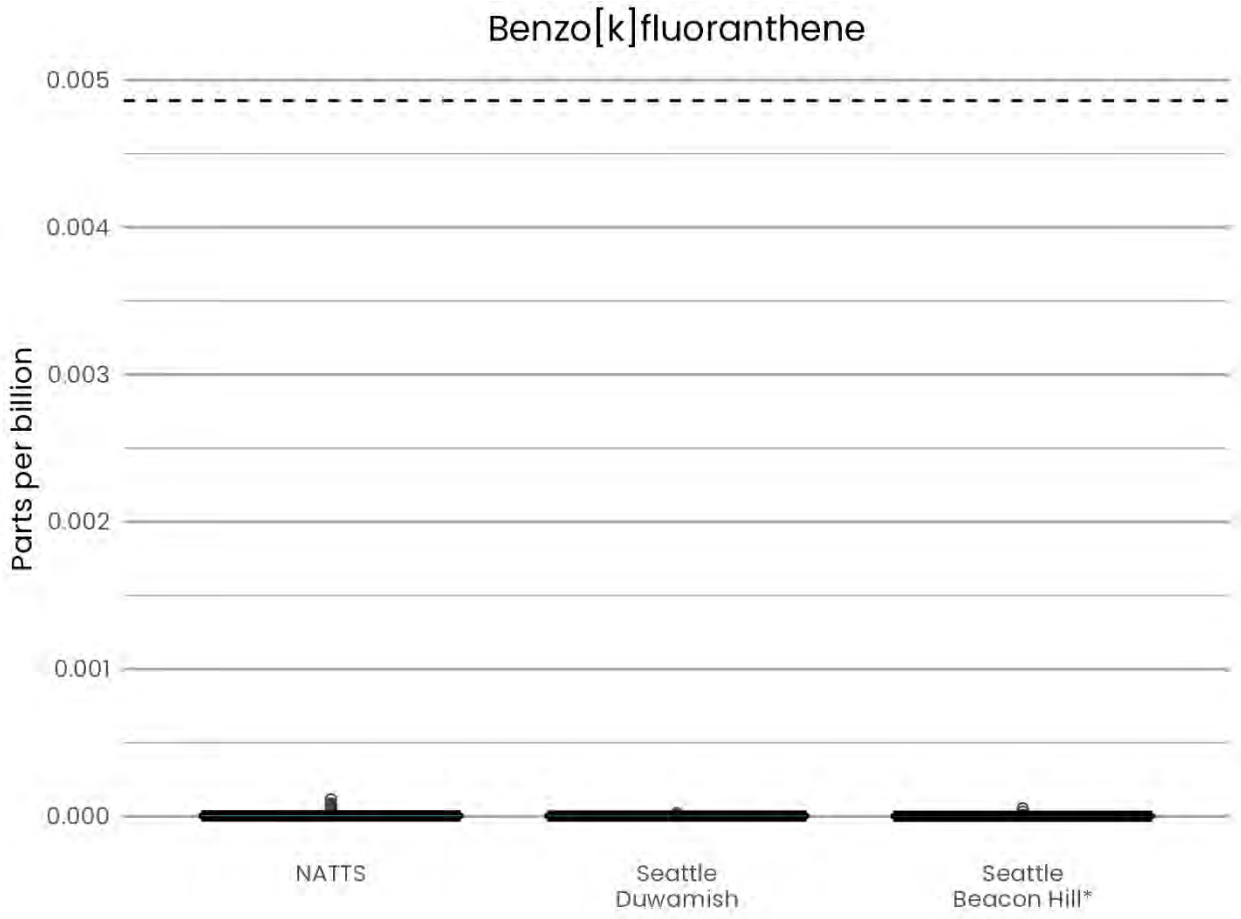


Figure O-1016. Chrysene box plot.

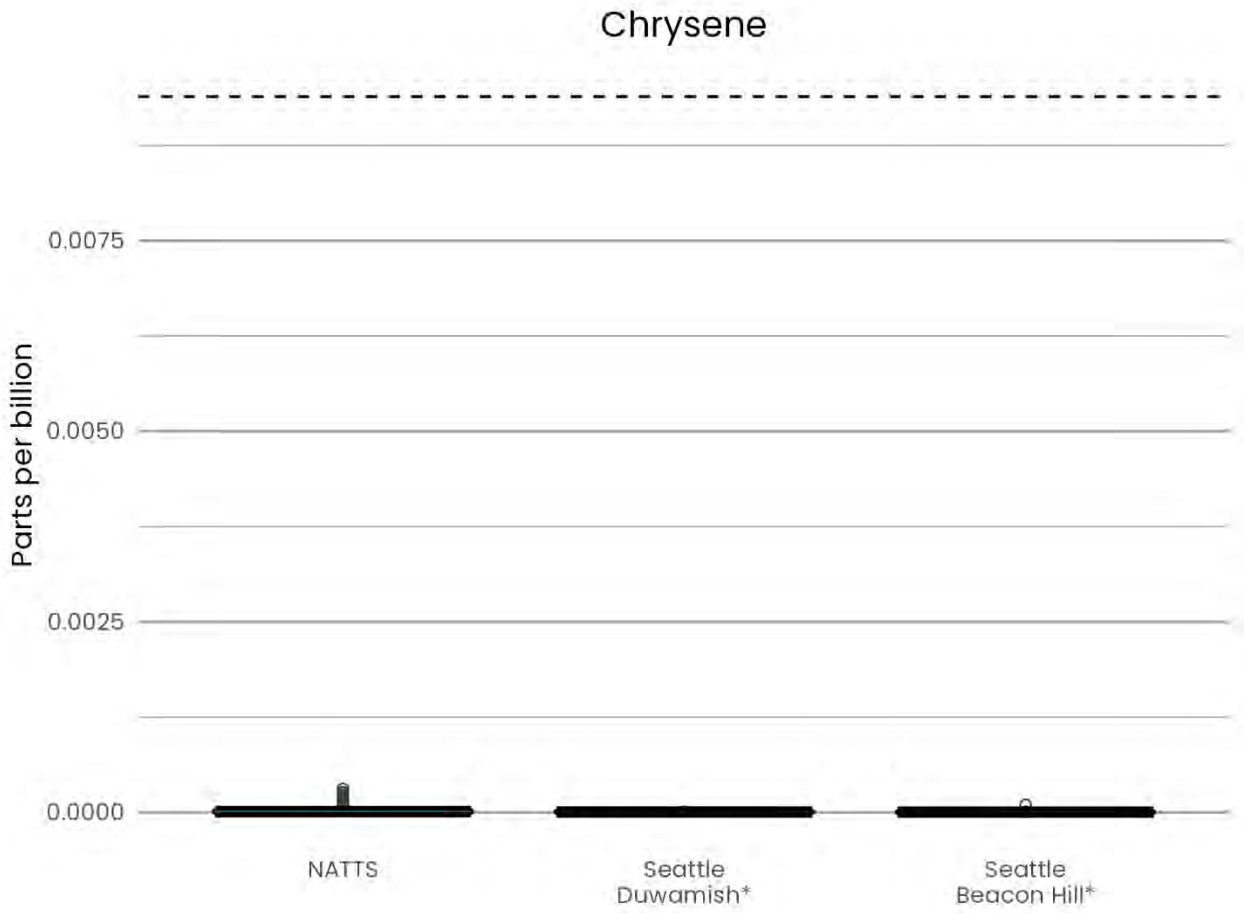


Figure O-1117. Coronene box plot.

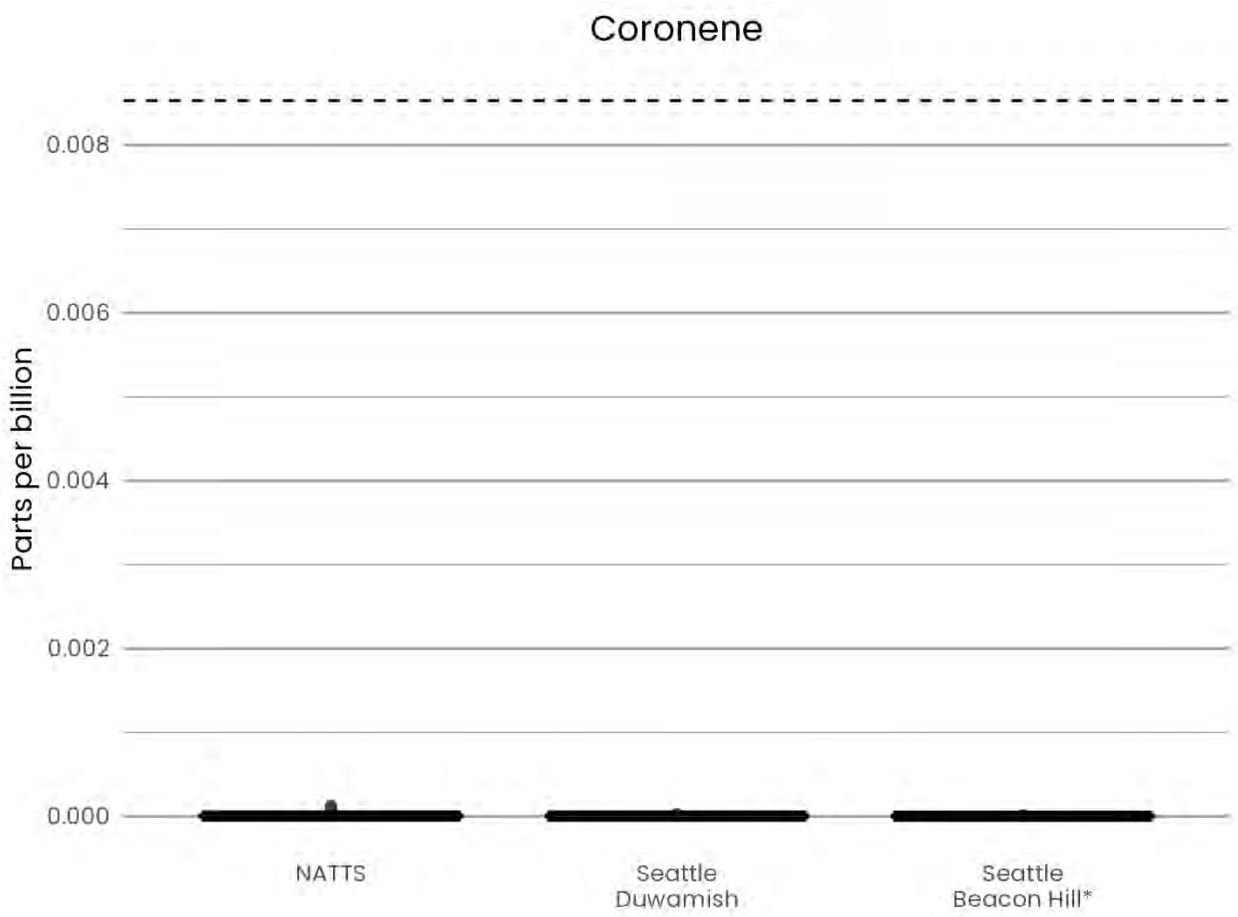


Figure O-1218. Dibenzo[a,h]anthracene box plot.

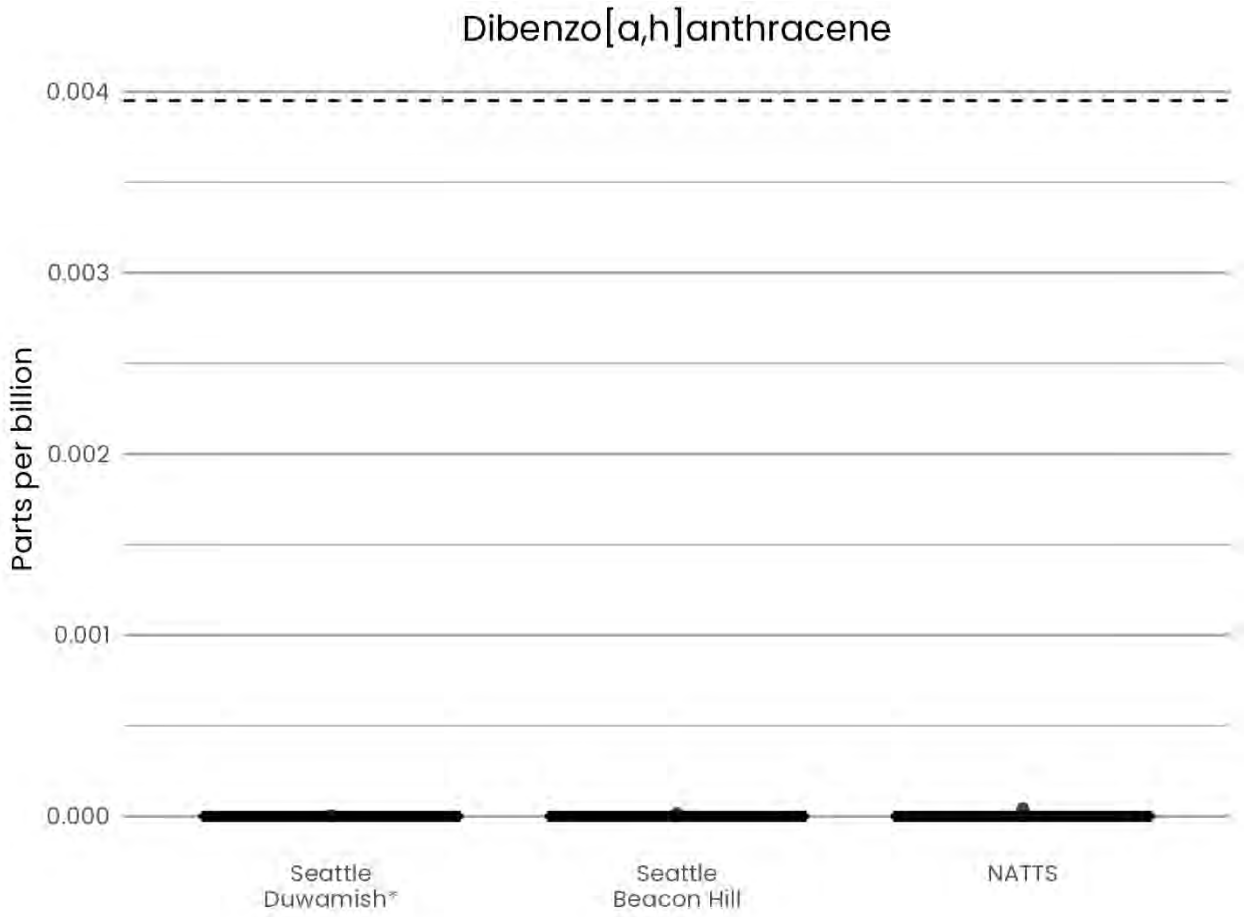


Figure O-1319. Fluoranthene box plot.

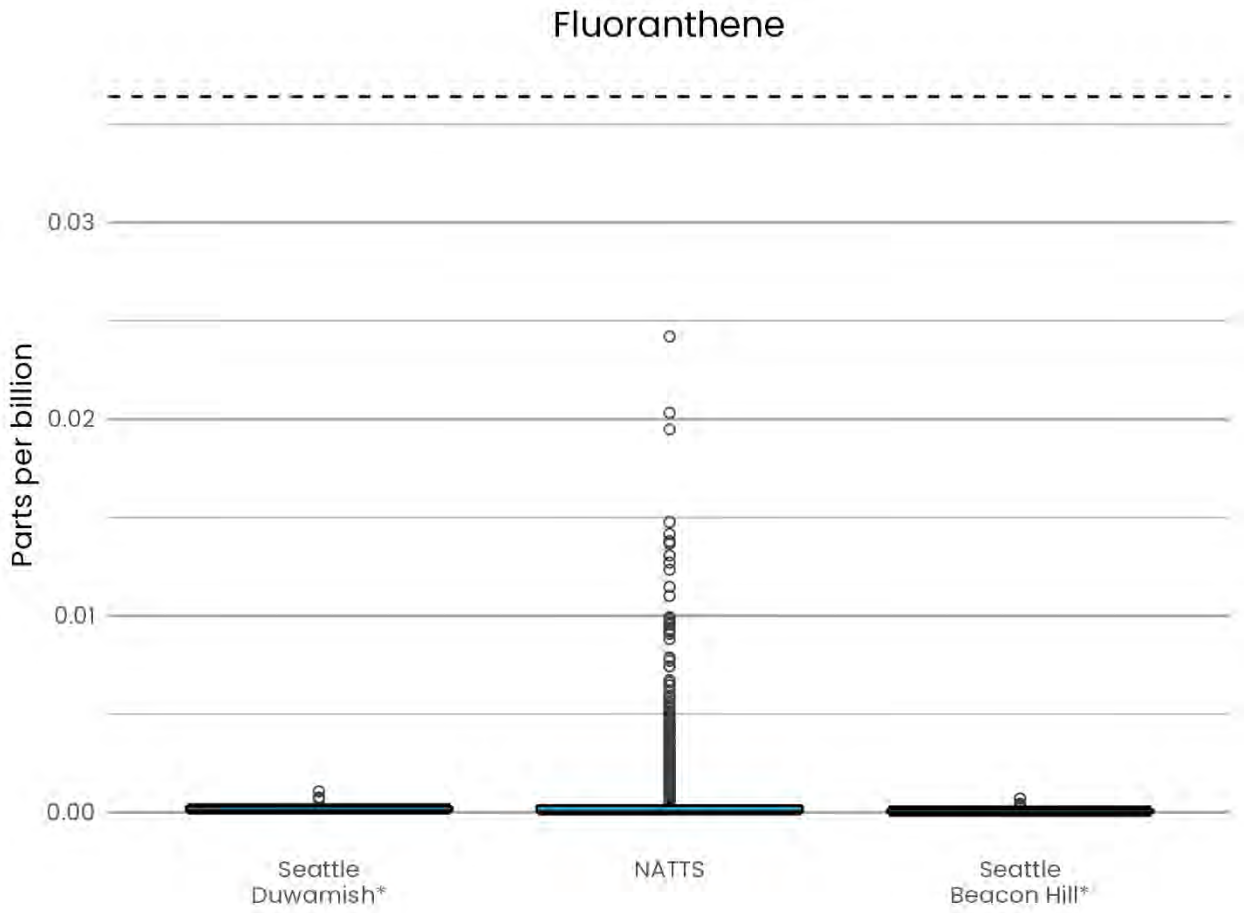


Figure O-1420. Fluorene box plot.

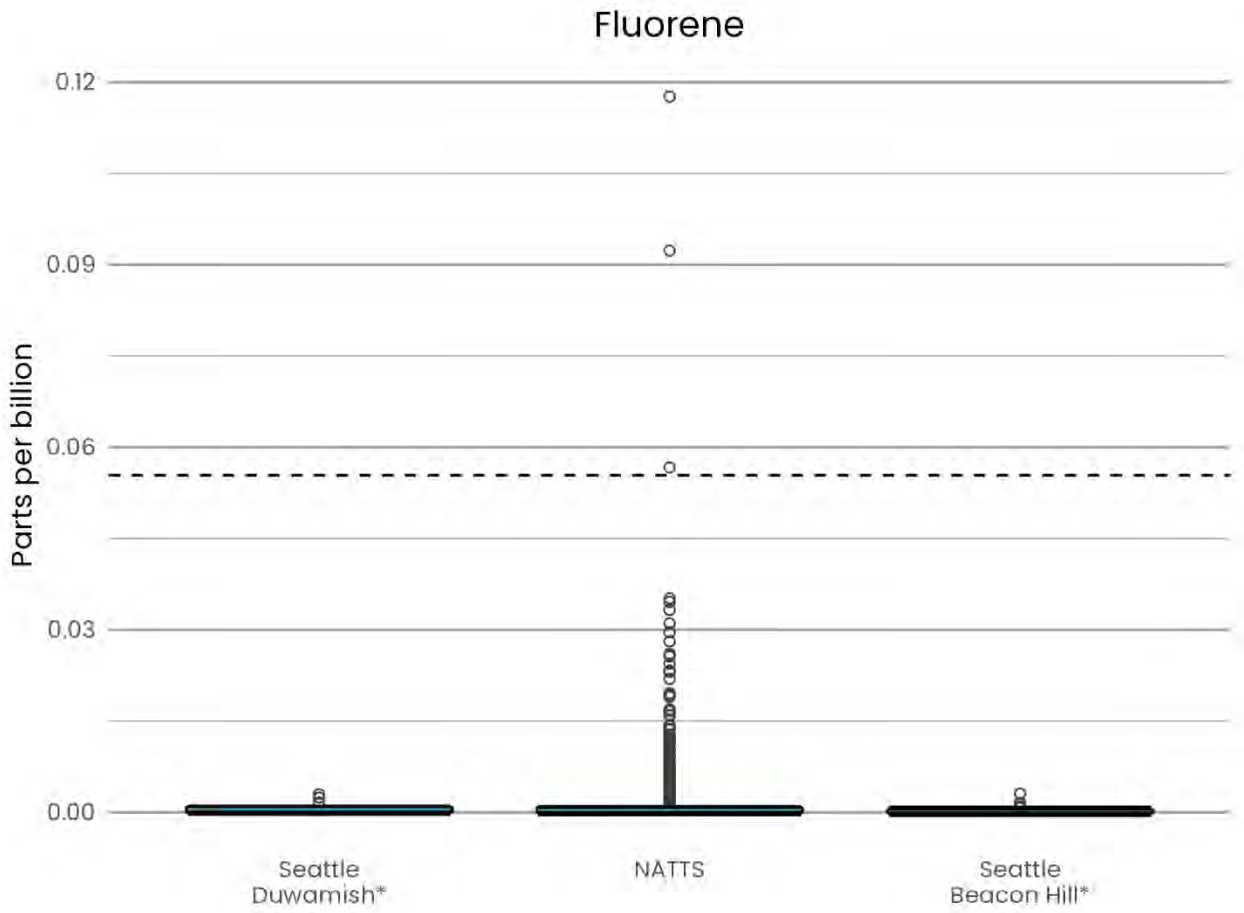


Figure O-1521. box plot.

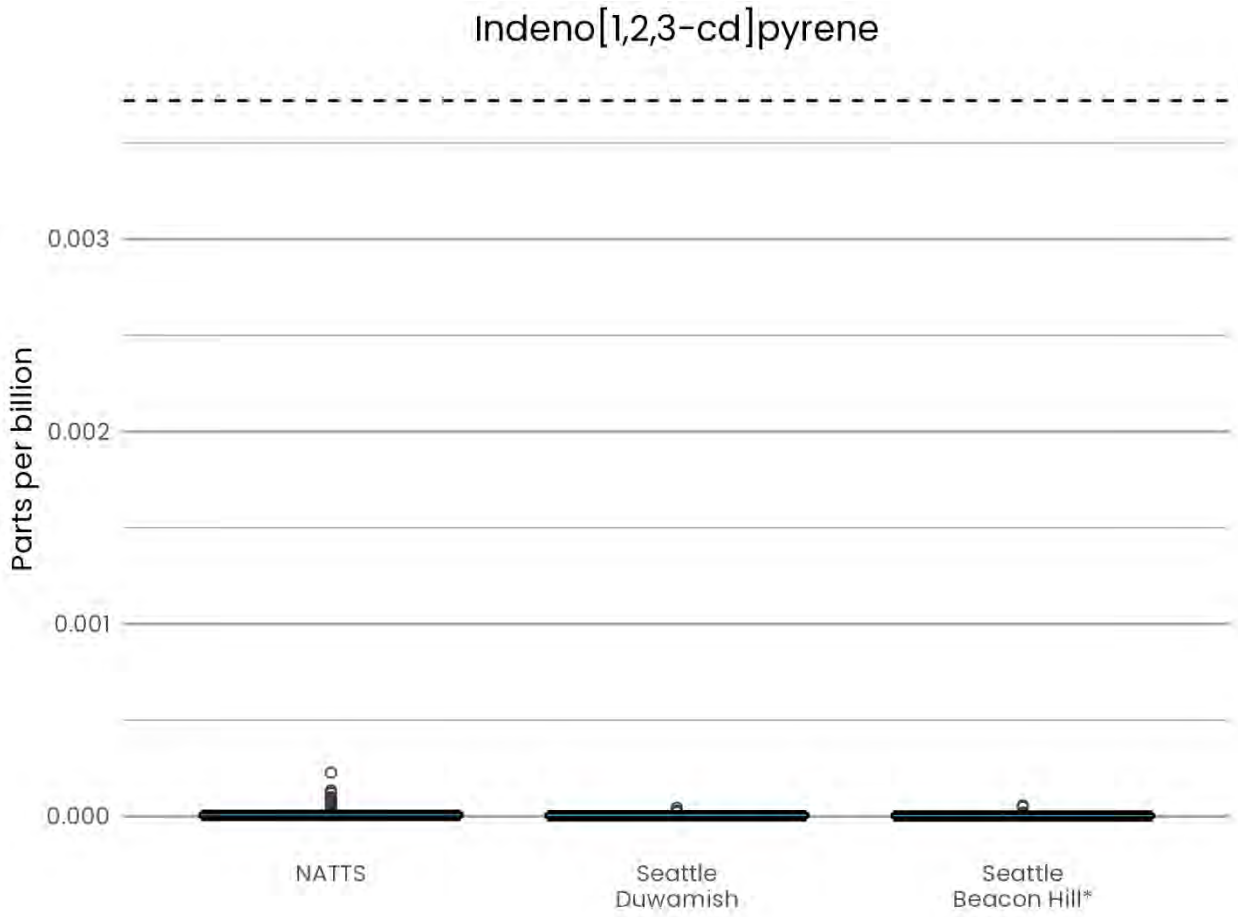


Figure O-1622. Naphthalene box plot.

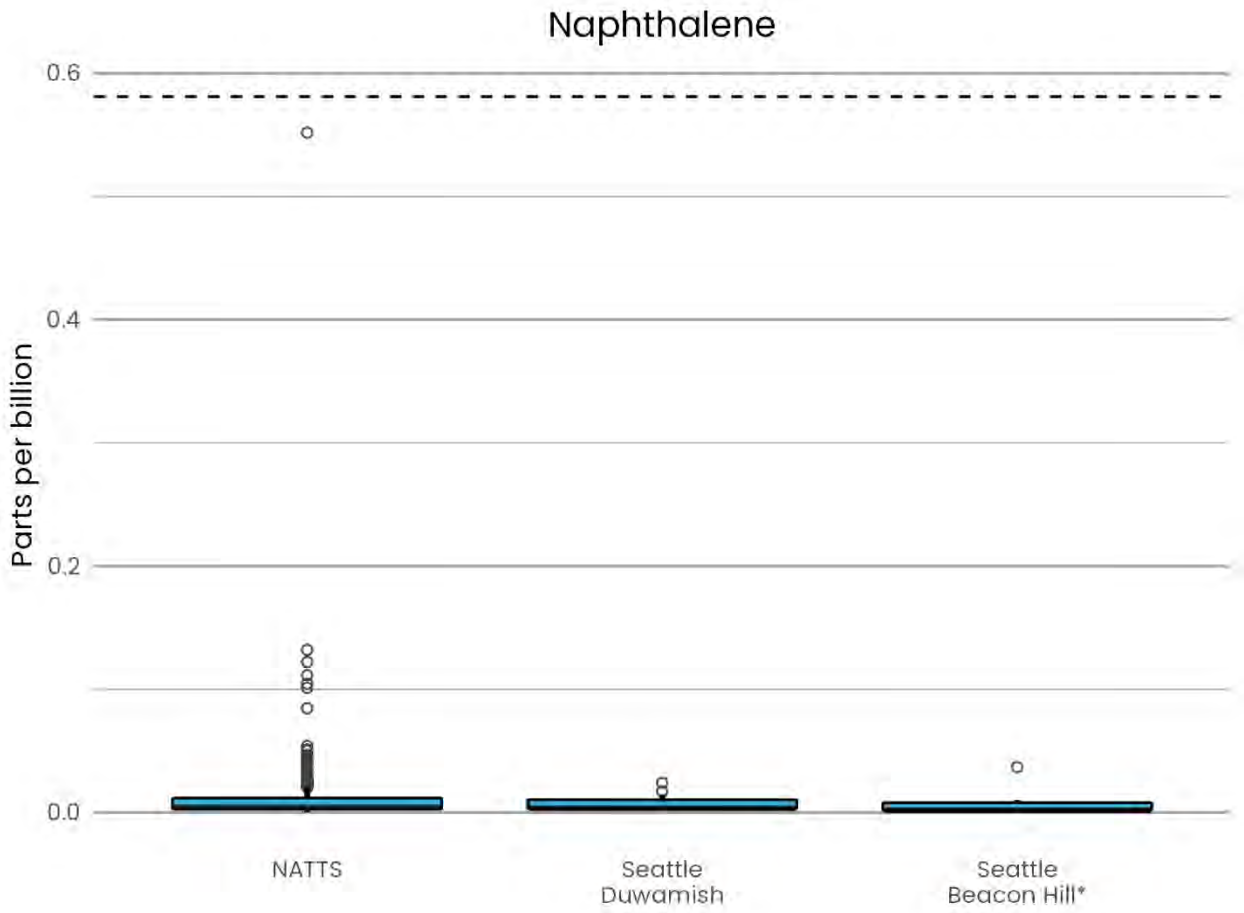


Figure O-1723. Perylene box plot.

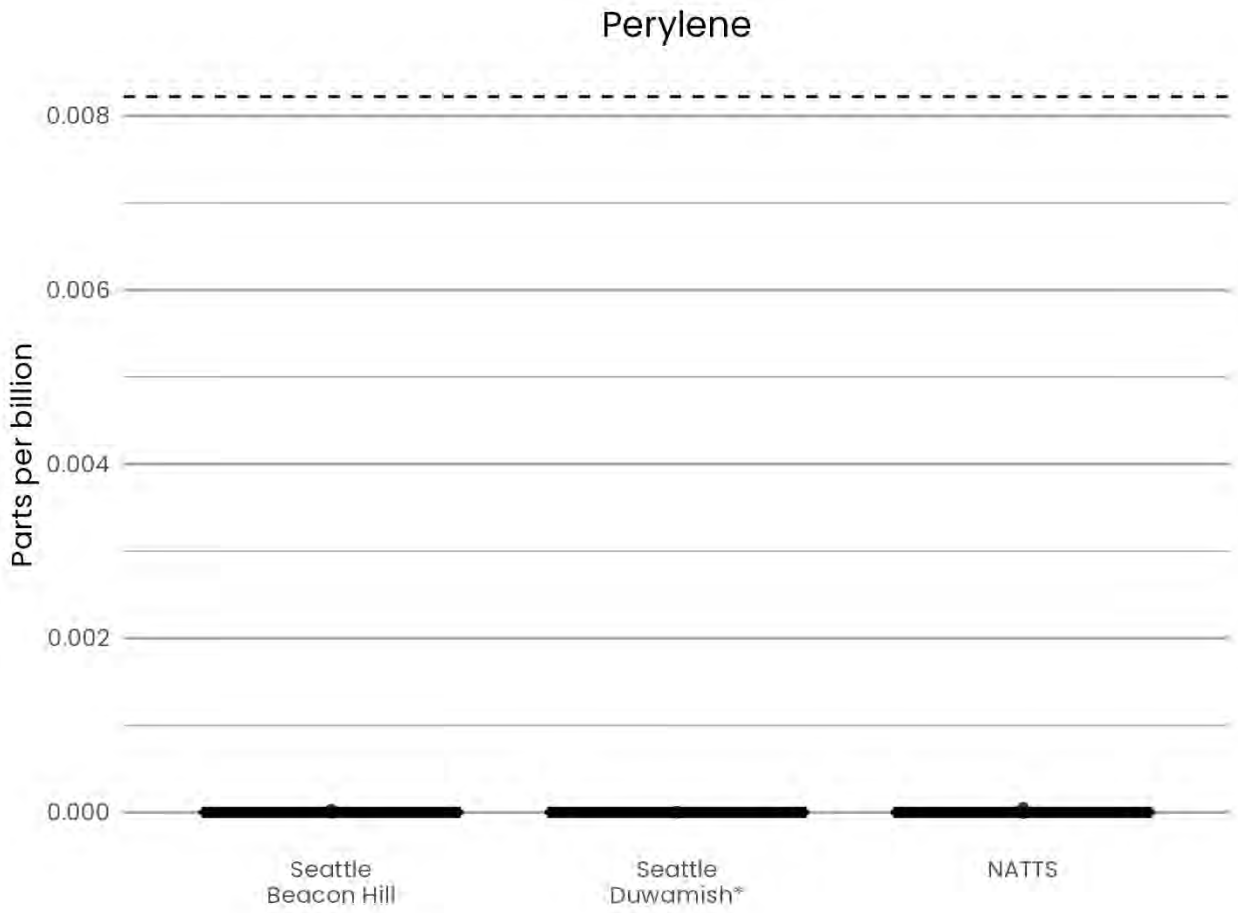


Figure O-1824. Phenanthrene box plot.

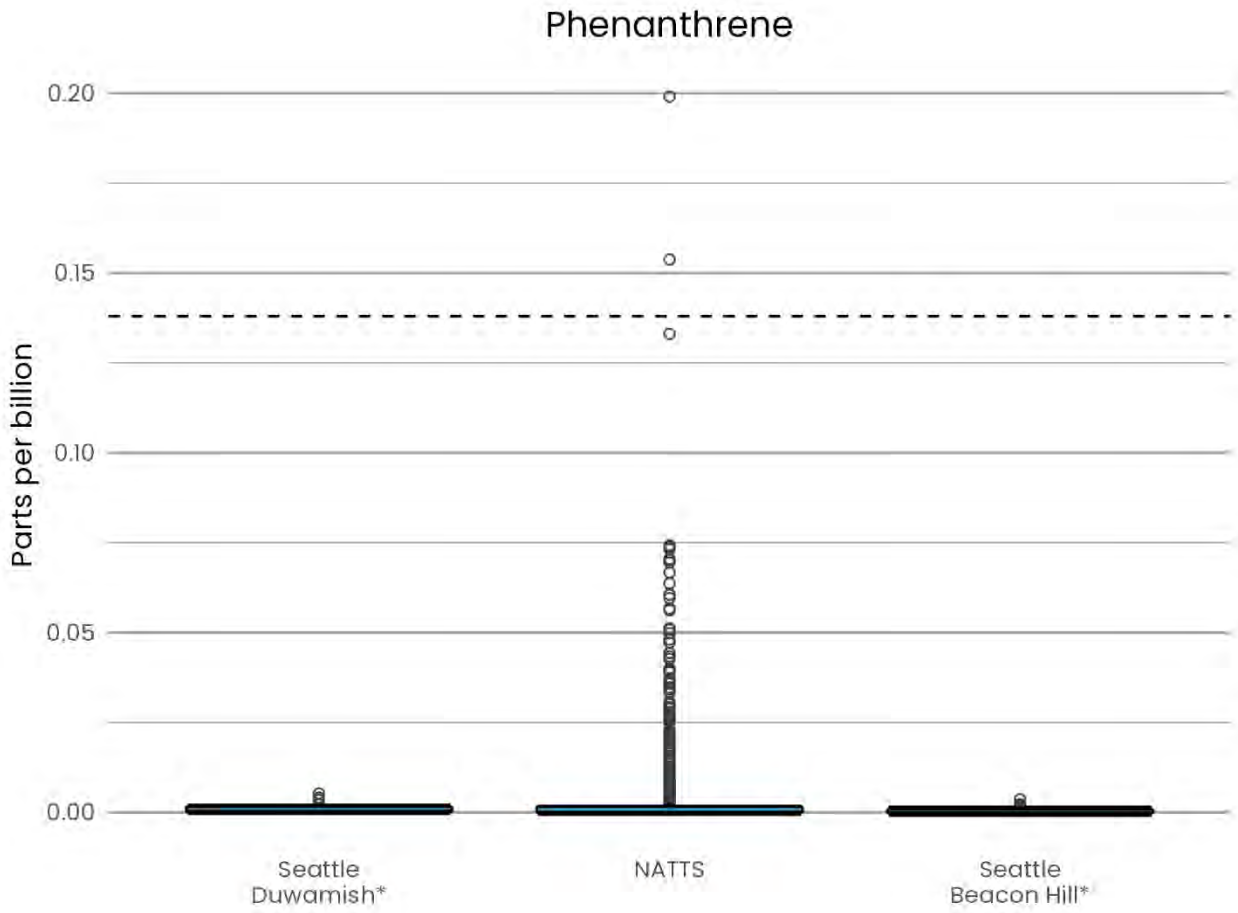
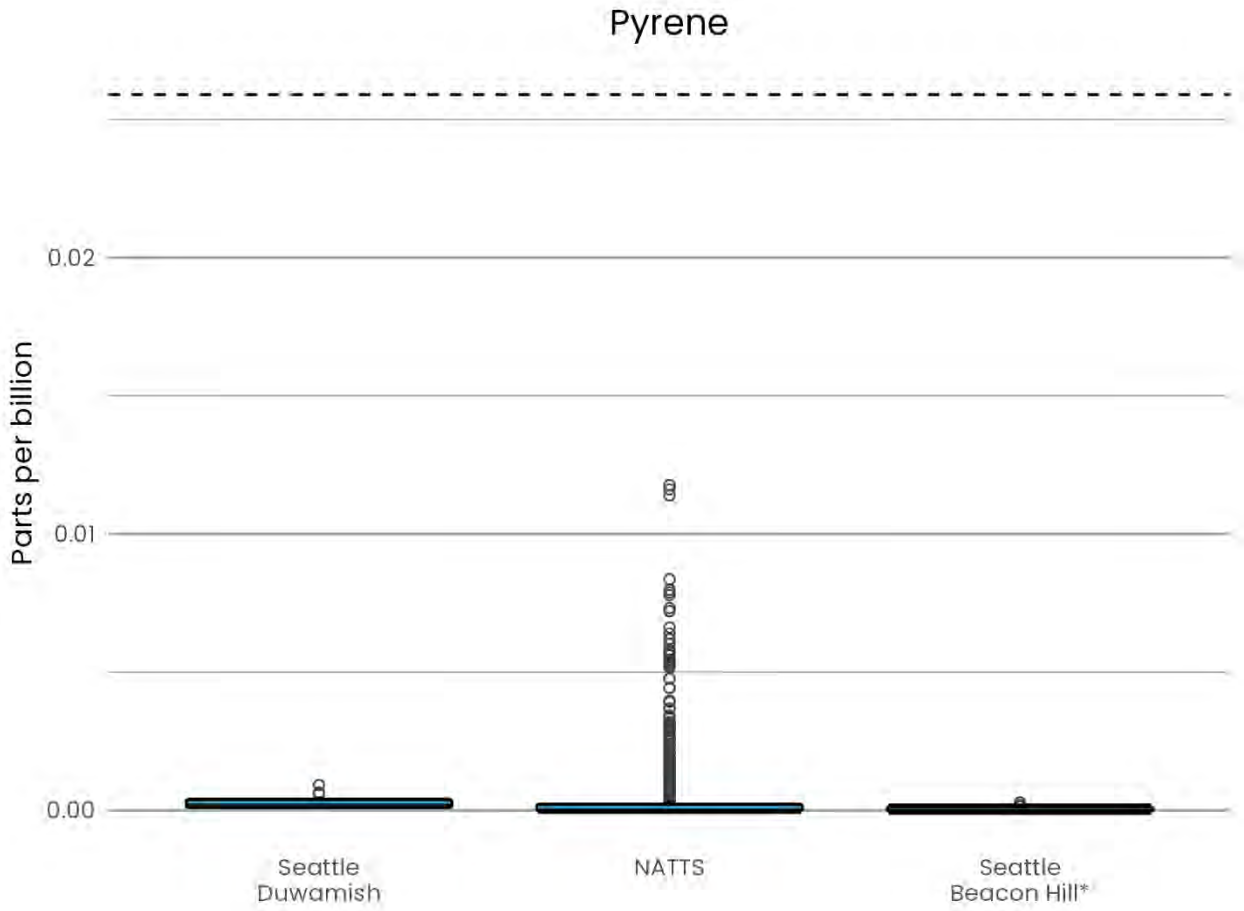


Figure O-1925. Pyrene box plot.



Appendix P. Summary statistics for fixed sites

This section contains summary statistics for the fixed sites. 5th is the 5th percentile, 25th is the 25th percentile and so on; 50th is the median; n is the number of samples.

Table P-126. Summary statistics for fixed sites.

Parameter	Site	5th	25th	Mean	50th	75th	95th	n	Units
1,3-Butadiene	10th & Weller	0.014	0.031	0.050	0.045	0.053	0.122	61	ppb
1,3-Butadiene	Beacon Hill	0.000	0.009	0.016	0.014	0.020	0.040	62	ppb
1,3-Butadiene	Duwamish	0.003	0.009	0.029	0.018	0.036	0.085	61	ppb
1,3-Butadiene	L St	0.005	0.009	0.038	0.015	0.047	0.126	63	ppb
1,3-Butadiene	S 36th St	0.004	0.022	0.039	0.029	0.050	0.098	62	ppb
1,3-Butadiene	Tideflats	0.004	0.009	0.029	0.016	0.031	0.106	65	ppb
Acenaphthene	Beacon Hill	0.00E+00	0.00E+00	2.71E-04	7.00E-05	2.45E-04	1.09E-03	59	ppb
Acenaphthene	Duwamish	0.00E+00	0.00E+00	5.72E-04	3.63E-04	7.98E-04	1.78E-03	56	ppb
Acenaphthylene	Beacon Hill	0.00E+00	0.00E+00	2.25E-05	3.11E-06	2.11E-05	1.10E-04	64	ppb
Acenaphthylene	Duwamish	0.00E+00	0.00E+00	7.80E-05	2.51E-05	7.54E-05	3.51E-04	57	ppb
Acetaldehyde	10th & Weller	0.463	0.555	0.690	0.630	0.774	1.070	60	ppb
Acetaldehyde	Beacon Hill	0.220	0.310	0.524	0.436	0.672	1.082	66	ppb
Acetaldehyde	Duwamish	0.238	0.329	0.507	0.413	0.603	0.985	59	ppb
Acetaldehyde	L St	0.253	0.323	0.536	0.427	0.552	1.108	62	ppb
Acetaldehyde	S 36th St	0.240	0.328	0.471	0.410	0.519	0.962	60	ppb
Acetaldehyde	Tideflats	0.273	0.365	0.564	0.475	0.705	1.041	60	ppb
Acrolein	10th & Weller	0.120	0.180	0.323	0.292	0.446	0.647	60	ppb
Acrolein	Beacon Hill	0.082	0.119	0.195	0.165	0.230	0.326	62	ppb
Acrolein	Duwamish	0.112	0.148	0.275	0.254	0.352	0.559	61	ppb
Acrolein	L St	0.095	0.156	0.276	0.250	0.345	0.596	62	ppb
Acrolein	S 36th St	0.116	0.189	0.298	0.257	0.417	0.578	60	ppb
Acrolein	Tideflats	0.090	0.162	0.350	0.302	0.464	0.794	65	ppb
Anthracene	Beacon Hill	3.91E-06	5.76E-06	1.76E-05	1.17E-05	1.73E-05	6.36E-05	63	ppb
Anthracene	Duwamish	0.00E+00	1.71E-05	4.09E-05	3.23E-05	6.04E-05	9.84E-05	56	ppb

Antimony	Beacon Hill	0.250	0.497	0.951	0.752	1.160	2.158	65	ng/m3
Antimony	Duwamish	0.628	0.927	1.793	1.325	2.185	4.428	66	ng/m3
Antimony	Tideflats	0.239	0.515	1.864	0.812	1.925	4.026	65	ng/m3
Arsenic	Beacon Hill	0.148	0.222	0.502	0.325	0.610	1.086	65	ng/m3
Arsenic	Duwamish	0.312	0.553	1.314	0.936	1.473	3.243	66	ng/m3
Arsenic	Tideflats	0.134	0.283	1.051	0.626	1.320	3.426	65	ng/m3
Benzene	10th & Weller	0.179	0.242	0.326	0.322	0.375	0.561	60	ppb
Benzene	Beacon Hill	0.060	0.090	0.135	0.127	0.167	0.247	62	ppb
Benzene	Duwamish	0.090	0.111	0.197	0.170	0.235	0.414	61	ppb
Benzene	L St	0.076	0.106	0.234	0.162	0.299	0.547	63	ppb
Benzene	S 36th St	0.116	0.138	0.229	0.188	0.267	0.432	62	ppb
Benzene	Tideflats	0.077	0.114	0.197	0.158	0.243	0.456	65	ppb
Benzo[a]anthracene	Beacon Hill	0.00E+00	9.25E-07	4.65E-06	1.51E-06	3.18E-06	7.95E-06	65	ppb
Benzo[a]anthracene	Duwamish	0.00E+00	1.80E-06	5.49E-06	3.18E-06	6.38E-06	1.83E-05	56	ppb
Benzo[a]pyrene	Beacon Hill	0.00E+00	4.28E-07	4.54E-06	1.01E-06	1.98E-06	1.10E-05	65	ppb
Benzo[a]pyrene	Duwamish	0.00E+00	1.04E-06	4.89E-06	1.80E-06	5.29E-06	2.10E-05	54	ppb
Benzo[b]fluoranthene	Beacon Hill	1.48E-06	1.89E-06	1.22E-05	2.57E-06	9.89E-06	5.58E-05	33	ppb
Benzo[b]fluoranthene	Duwamish	1.73E-06	2.43E-06	8.75E-06	4.03E-06	7.79E-06	3.51E-05	33	ppb
Benzo[e]pyrene	Beacon Hill	0.00E+00	1.39E-06	5.31E-06	2.11E-06	5.52E-06	1.32E-05	63	ppb
Benzo[e]pyrene	Duwamish	0.00E+00	2.38E-06	7.10E-06	3.70E-06	9.21E-06	2.38E-05	53	ppb
Benzo[g,h,i]perylene	Beacon Hill	0.00E+00	1.38E-06	5.37E-06	2.51E-06	6.08E-06	1.47E-05	61	ppb
Benzo[g,h,i]perylene	Duwamish	0.00E+00	2.09E-06	8.67E-06	3.62E-06	1.20E-05	3.20E-05	55	ppb
Benzo[k]fluoranthene	Beacon Hill	0.00E+00	0.00E+00	3.11E-06	8.85E-07	2.67E-06	9.19E-06	66	ppb
Benzo[k]fluoranthene	Duwamish	0.00E+00	7.61E-07	4.01E-06	1.56E-06	5.31E-06	1.49E-05	55	ppb
Beryllium	Beacon Hill	0.000	0.000	0.001	0.001	0.002	0.003	61	ng/m3
Beryllium	Duwamish	0.000	0.003	0.007	0.006	0.010	0.017	49	ng/m3

Beryllium	Tideflats	0.000	0.001	0.008	0.003	0.007	0.031	53	ng/m3
Cadmium	Beacon Hill	0.015	0.023	0.049	0.035	0.064	0.114	64	ng/m3
Cadmium	Duwamish	0.032	0.050	0.126	0.087	0.171	0.341	66	ng/m3
Cadmium	Tideflats	0.010	0.026	0.105	0.046	0.093	0.204	65	ng/m3
Carbon tetrachloride	10th & Weller	0.051	0.074	0.078	0.079	0.088	0.099	60	ppb
Carbon tetrachloride	Beacon Hill	0.074	0.078	0.084	0.082	0.089	0.099	62	ppb
Carbon tetrachloride	Duwamish	0.067	0.075	0.080	0.080	0.085	0.102	61	ppb
Carbon tetrachloride	L St	0.049	0.075	0.078	0.079	0.084	0.098	63	ppb
Carbon tetrachloride	S 36th St	0.066	0.077	0.080	0.079	0.085	0.098	62	ppb
Carbon tetrachloride	Tideflats	0.067	0.074	0.079	0.079	0.085	0.095	65	ppb
Chromium	Beacon Hill	4.412	5.210	6.004	6.090	6.870	7.556	65	ng/m3
Chromium	Duwamish	2.315	3.238	4.440	4.370	5.288	7.003	66	ng/m3
Chromium	Tideflats	1.694	2.210	2.986	2.540	3.555	5.912	65	ng/m3
Chrysene	Beacon Hill	0.000	0.000	0.000	0.000	0.000	0.000	22	ppb
Chrysene	Duwamish	0.000	0.000	0.000	0.000	0.000	0.000	19	ppb
Cobalt	Beacon Hill	0.030	0.050	0.079	0.073	0.100	0.162	65	ng/m3
Cobalt	Duwamish	0.050	0.095	0.192	0.154	0.237	0.458	66	ng/m3
Cobalt	Tideflats	0.027	0.057	0.207	0.105	0.256	0.530	65	ng/m3
Coronene	Beacon Hill	0.00E+00	1.06E-06	2.46E-06	1.49E-06	3.03E-06	6.82E-06	64	ppb
Coronene	Duwamish	0.00E+00	1.30E-06	4.75E-06	2.07E-06	5.78E-06	1.63E-05	55	ppb
Dibenzo[a,h]anthracene	Beacon Hill	0.00E+00	0.00E+00	6.36E-07	0.00E+00	0.00E+00	2.28E-06	66	ppb
Dibenzo[a,h]anthracene	Duwamish	0.00E+00	0.00E+00	3.47E-07	0.00E+00	0.00E+00	2.15E-06	57	ppb
Ethylbenzene	10th & Weller	0.034	0.046	0.079	0.062	0.089	0.179	61	ppb
Ethylbenzene	Beacon Hill	0.016	0.023	0.036	0.033	0.046	0.076	62	ppb
Ethylbenzene	Duwamish	0.020	0.040	0.098	0.063	0.120	0.220	61	ppb
Ethylbenzene	L St	0.012	0.020	0.059	0.033	0.076	0.200	63	ppb
Ethylbenzene	S 36th St	0.026	0.031	0.062	0.046	0.071	0.142	62	ppb

Ethylbenzene	Tideflats	0.016	0.026	0.061	0.043	0.083	0.158	64	ppb
Ethylene oxide	10th & Weller	0.000	0.055	0.112	0.088	0.116	0.282	29	ppb
Ethylene oxide	Beacon Hill	0.041	0.046	0.076	0.073	0.106	0.133	21	ppb
Ethylene oxide	Duwamish	0.041	0.061	0.106	0.075	0.154	0.217	27	ppb
Ethylene oxide	L St	0.039	0.054	0.140	0.078	0.117	0.462	32	ppb
Ethylene oxide	S 36th St	0.041	0.064	0.112	0.095	0.126	0.244	26	ppb
Ethylene oxide	Tideflats	0.030	0.050	0.127	0.090	0.132	0.395	31	ppb
Fluoranthene	Beacon Hill	2.55E-05	4.69E-05	1.04E-04	6.88E-05	9.22E-05	3.40E-04	64	ppb
Fluoranthene	Duwamish	8.21E-05	1.13E-04	2.15E-04	1.78E-04	2.40E-04	4.86E-04	56	ppb
Fluorene	Beacon Hill	7.43E-05	1.33E-04	3.27E-04	1.84E-04	2.86E-04	9.71E-04	64	ppb
Fluorene	Duwamish	1.77E-04	2.10E-04	5.33E-04	3.50E-04	6.91E-04	1.31E-03	56	ppb
Formaldehyde	10th & Weller	0.888	1.145	1.643	1.617	2.123	2.422	56	ppb
Formaldehyde	Beacon Hill	0.485	0.795	1.095	0.937	1.304	2.039	57	ppb
Formaldehyde	Duwamish	0.559	0.896	1.122	1.080	1.277	1.841	56	ppb
Formaldehyde	L St	0.565	0.744	1.142	1.027	1.324	2.200	59	ppb
Formaldehyde	S 36th St	0.447	0.672	1.029	1.002	1.222	1.892	57	ppb
Formaldehyde	Tideflats	0.613	0.939	1.245	1.214	1.530	2.121	56	ppb
Indeno[1,2,3-cd]pyrene	Beacon Hill	0.00E+00	9.39E-07	5.40E-06	1.92E-06	6.21E-06	1.55E-05	64	ppb
Indeno[1,2,3-cd]pyrene	Duwamish	0.00E+00	1.24E-06	6.91E-06	2.79E-06	9.43E-06	2.47E-05	56	ppb
Lead	Beacon Hill	0.490	0.965	1.747	1.270	2.270	4.336	65	ng/m3
Lead	Duwamish	1.428	2.843	6.770	4.575	9.370	14.375	66	ng/m3
Lead	Tideflats	0.493	0.962	4.000	2.025	5.735	14.600	65	ng/m3
Manganese	Beacon Hill	0.784	1.480	3.573	2.630	3.880	9.162	65	ng/m3
Manganese	Duwamish	2.903	5.133	23.224	10.900	16.825	31.475	66	ng/m3
Manganese	Tideflats	1.072	2.960	9.597	6.710	11.700	23.260	65	ng/m3
Mercury	Beacon Hill	0.002	0.003	0.006	0.005	0.008	0.013	65	ng/m3
Mercury	Duwamish	0.001	0.005	0.034	0.007	0.012	0.019	64	ng/m3
Mercury	Tideflats	0.000	0.005	0.009	0.008	0.012	0.018	64	ng/m3
Naphthalene	Beacon Hill	0.002	0.003	0.005	0.004	0.007	0.009	57	ppb

Naphthalene	Duwamish	0.003	0.004	0.007	0.006	0.009	0.015	47	ppb
Nickel	Beacon Hill	0.273	0.443	0.641	0.572	0.736	1.502	65	ng/m3
Nickel	Duwamish	0.457	0.776	1.604	1.305	1.933	3.828	66	ng/m3
Nickel	Tideflats	0.751	1.086	1.860	1.435	1.990	4.790	64	ng/m3
Perylene	Beacon Hill	0.00E+00	0.00E+00	6.15E-07	0.00E+00	0.00E+00	5.92E-07	66	ppb
Perylene	Duwamish	0.00E+00	0.00E+00	1.60E-07	0.00E+00	0.00E+00	9.45E-07	58	ppb
Phenanthrene	Beacon Hill	1.39E-04	2.44E-04	5.22E-04	3.32E-04	4.75E-04	1.85E-03	62	ppb
Phenanthrene	Duwamish	3.98E-04	5.00E-04	1.12E-03	8.47E-04	1.18E-03	2.78E-03	53	ppb
Pyrene	Beacon Hill	1.69E-05	3.12E-05	6.20E-05	4.95E-05	7.22E-05	1.71E-04	63	ppb
Pyrene	Duwamish	9.67E-05	1.57E-04	2.72E-04	2.58E-04	3.28E-04	5.39E-04	53	ppb
Selenium	Beacon Hill	0.026	0.092	0.228	0.170	0.267	0.651	65	ng/m3
Selenium	Duwamish	0.180	0.480	2.039	0.834	2.783	6.915	66	ng/m3
Selenium	Tideflats	0.020	0.066	0.147	0.124	0.216	0.312	64	ng/m3
Tetrachloroethylene	10th & Weller	0.005	0.007	0.017	0.010	0.015	0.028	61	ppb
Tetrachloroethylene	Beacon Hill	0.003	0.005	0.008	0.007	0.011	0.015	62	ppb
Tetrachloroethylene	Duwamish	0.005	0.010	0.020	0.017	0.024	0.044	61	ppb
Tetrachloroethylene	L St	0.004	0.006	0.013	0.009	0.016	0.034	63	ppb
Tetrachloroethylene	S 36th St	0.003	0.005	0.012	0.008	0.015	0.025	62	ppb
Tetrachloroethylene	Tideflats	0.005	0.007	0.016	0.011	0.021	0.038	65	ppb

Appendix Q. Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) model estimates

EPA's Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) software can be used to estimate the daily lead exposure for children from different sources[11]. It is typically used for risk analysis near Superfund sites. However, by adjusting the air lead concentration to the level found at the highest site in our study (0.009 µg/m^3 at the South Park Industrial site), we can estimate the impact of lead exposure from air compared to other media. The other sources of lead that are modeled by IEUBK are diet, water, and ingestion of outdoor soil and indoor dust. The model then combines all of these inputs and calculates an estimated blood lead level. IEUBK comes with default parameters for each type of source. In the analysis presented below only the air concentration of lead was changed. IEUBK can output values for a number of different age ranges, from 6-12 months up to 6-7 years. In the analysis we performed, the 6-12 month age group had the highest estimated blood lead and will be the only group presented. The 6-7 year age group, which had the lowest estimated blood lead, had levels that were about 60%, or 1.2 µg/dL lower than the 6-12 month group.

Figure Q-127. Estimated daily lead intake for children 6-12 months.

[11] Lead at Superfund Sites: Software and Users' Manuals, EPA, 2023. https://www.epa.gov/superfund/lead-superfund-sites-software-and-users-manuals.

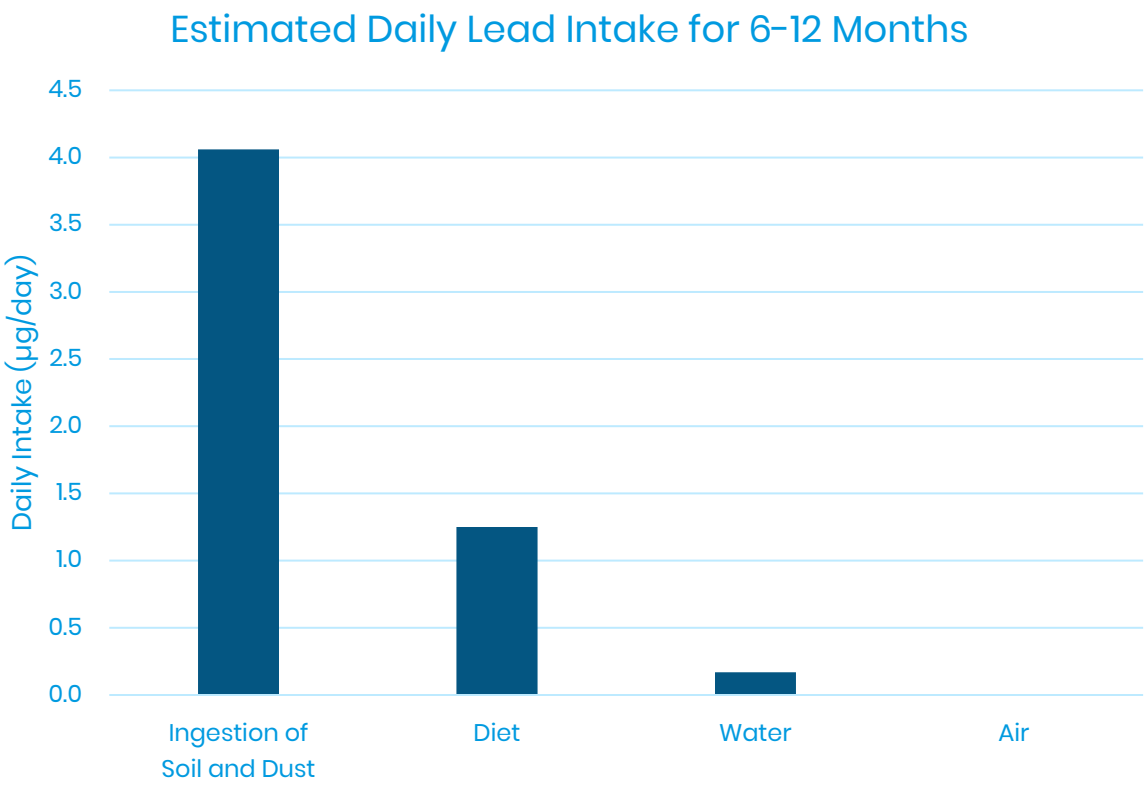


Figure Q-1 shows the estimated daily lead intake for children 6-12 months for different sources. Ingestion of outdoor soil or indoor dust was estimated at 4.1 µg/day. Diet was estimated at 1.2 µg/day. Water was estimated at 0.17 µg/day. And air was estimated at 0.003 µg/day. Smaller children breath in less air than larger children; and the 6-7 years group had an air intake of 0.011 µg/day. In this model, the amount of lead from air did not significantly contribute to the overall lead intake.