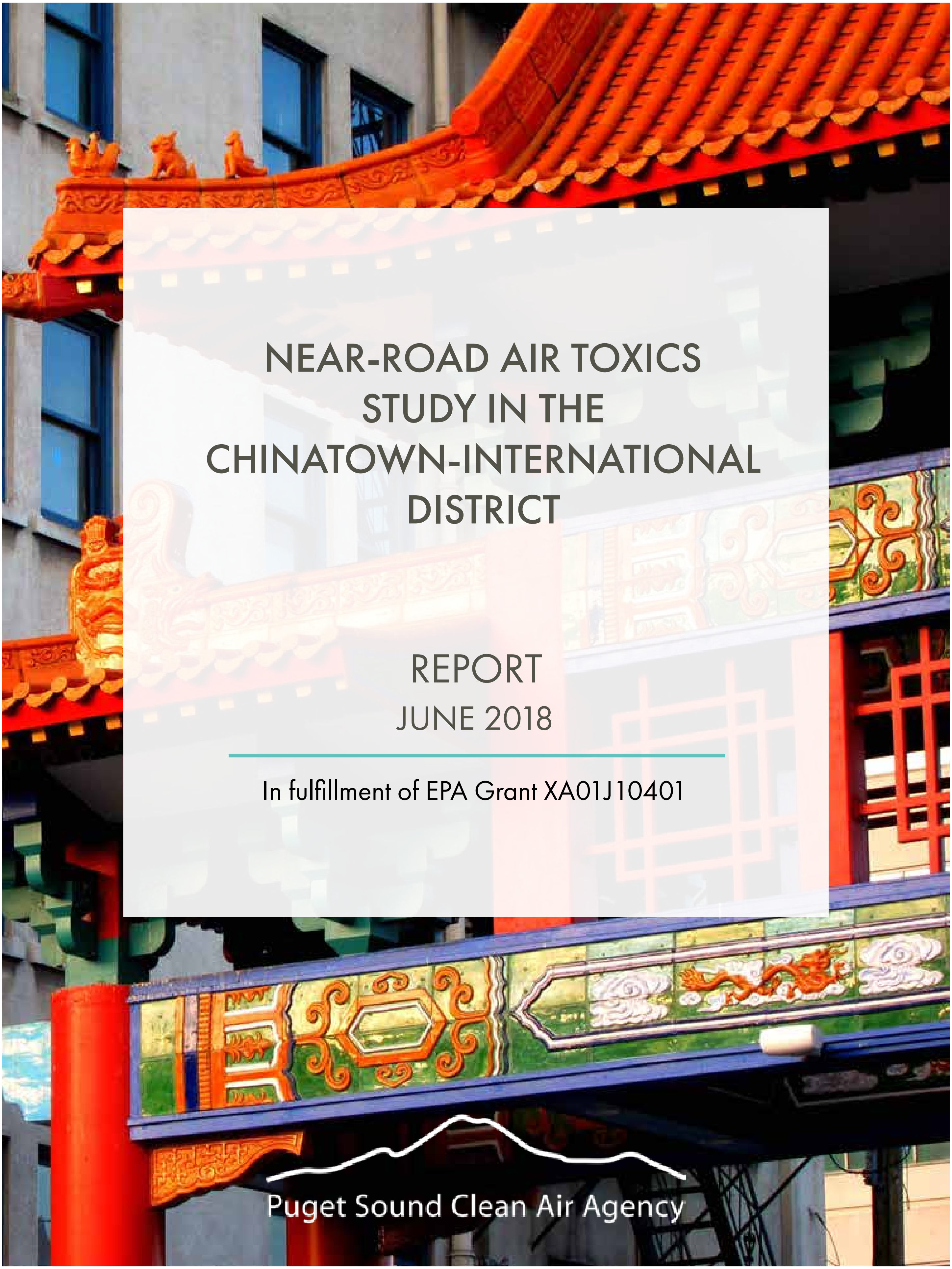

NEAR-ROAD AIR TOXICS STUDY IN THE CHINATOWN-INTERNATIONAL DISTRICT

REPORT
JUNE 2018

In fulfillment of EPA Grant XA01J10401

Puget Sound Clean Air Agency

Acknowledgements and Contact Information

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For more information about this report, please contact Matt Harper at (206) 689-4009.

Executive Summary

The Agency previously identified Seattle's Chinatown–International District (CID) as a "highly impacted community" in a screening exercise, based on a combination of air pollution sources, health impacts, and demographics of those that face economic or historic barriers to participation in clean air decisions and solutions.[1] The presumed largest air quality issue for the CID was I-5, which bisects the community, and I-90, which is at the southern edge.

In order to help the CID to better understand air pollution sources and risks, we continued our ongoing outreach work in the CID, and we conducted a year-long toxics sampling campaign. The sampling included more than 100 known air toxics, including those previously identified as having the highest potential health risk. The primary sampling site was the permanent near-road monitor at 10th & Weller, which is adjacent to I-5. We established two ancillary fixed sites at 6th & Jackson, and at Bailey Gatzert Elementary School, about 200 m and 500 m, respectively, from I-5. We selected five additional sampling sites based on community input on areas of greatest concern. We supplemented the fixed-site monitoring with walking-based mobile monitoring to help screen for potential missing hotspots.

In order to foster community involvement, we actively worked with a number of community groups and local leaders before and during the sampling period. We participated in multiple outreach events and established relationships with a local newspaper, a community development association, a community health group, a youth leadership and education program, and various additional community groups. Through these interactions and a web survey, we solicited feedback on what concerns the community had and where they would like supplementary sampling to occur. Our outreach also included a range of education about air quality basics and the conditions in the CID. An additional major component of our outreach was assembling fan-filters and distributing them to residents. We provided materials to construct a basic (but effective) filter for indoor air and instructed a youth group on how to assemble them. The youth then distributed the fans, at no cost, to elders and other community members.

Of the more than 100 air toxics that we measured, we found 14 that were over our health screening value (one-in-a-million potential cancer risk). These toxics and their concentrations were similar to other sites across the country, and are consistent with levels we observed in previous air toxics studies in Seattle and Tacoma. The greatest air toxics risk remains that from diesel particles, consistent with previous studies. At the near-road site, more than 75% of the potential cancer risk is attributable to this diesel particulate matter. The concentrations of all pollutants that have National Ambient Air Quality Standards (NAAQS) were below their respective standards.

The fixed site data show a clear, strong diurnal pattern that reflects significant influence from I-5. The dominant contributor from the highway is diesel vehicles, which are the biggest emitters of fine particles, black carbon, nitrogen oxides, and a range of toxics. The diurnal pollution pattern from vehicles was also clear in the ancillary fixed site data, although the magnitude of the pattern was

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[1] Puget Sound Clean Air Agency, "Highly Impacted Communities", 2014, www.pscleanair.org/documentcenter/view/2323.

weaker, likely reflecting a greater distance from the major source, I-5/I-90. From the diurnal pattern, the average annual contribution to $PM_{2.5}$ (fine particles) from highway vehicles at 10th & Weller is about 1.2 micrograms per cubic meter ($\mu g/m^3$), with about 80% of that being from diesel vehicles.

We used an air quality dispersion model (AERMOD) to examine the expected contribution from highway vehicles on I-5 and I-90, and from restaurants, within the study area. Emissions from the highway vehicles were substantially greater than the restaurants, with the restaurants contributing less than 0.05 $\mu g/m^3$ of $PM_{2.5}$ on an annual average, while highway vehicles contributed 0.5 to 1.0 $\mu g/m^3$ of $PM_{2.5}$ to a substantial portion of the study area. The majority of the $PM_{2.5}$ in the AERMOD modeling was due to diesel vehicles. The magnitude and spatial pattern of the I-5/I-90 emissions are consistent with the monitoring data, including the fixed sites, temporary sites, and mobile monitoring.

We also used a positive matrix factorization (PMF) model to assess potential source factors for the 10th & Weller pollutants. Due to having a relatively small data set, we could reliably resolve only six factors. The first three factors had temporal components, and were: winter wood smoke, a summer diesel (possibly due to different wind directions and upwind sources), and a factor representing a small number of short spikes (episodes). The remaining three factors were diesel, industrial, and background pollution and were more uniform in time. The PMF modeling suggests an annual average diesel PM concentration at 10th & Weller of 1.4 to 1.7 $\mu g/m^3$. The lower end of this range (just “diesel” and “summer diesel” factors) is similar to the AERMOD modeling and the monitoring data. Based on the magnitude of the diurnal pattern in the monitoring data, the AERMOD results for just I-5/I-90 vehicles, and the PMF solution, there may be an additional portion of daily diesel pollution (in addition the “diesel” and “summer diesel” factors) from nearby commercial, industrial, or highways that is impacting the study area. We would consider this portion to be a polluted urban/industrial background. We estimate it could be about 0.4-0.8 $\mu g/m^3$, which would bring the total diesel PM as high as 2.3 $\mu g/m^3$ (at 10th & Weller). The Washington State Department of Ecology is currently conducting a PMF study that will refine the diesel PM estimate based on a larger dataset than we had available for this study.

Analysis of the toxics data collected at the community directed sites and fixed sites shows an expected spatial gradient from I-5/I-90. Most of the toxics associated with vehicles decreased with distance from I-5. The toxics risk was dominated by diesel PM, with the next greatest risk coming from carbon tetrachloride, benzene, and 1,3 butadiene. The total diesel PM has two parts, a local/daily component (greater near I-5/I-90), and a background component (more uniform). At the 10th & Weller site, the total potential cancer risk from diesel PM was about 500 per million (roughly 300 per million from local/daily, and 200 per million from background), and from the remaining toxics about 100 per million, for a total of about 600 per million. We estimate that the local/daily diesel PM risk drops to about 100 per million at the ancillary fixed sites (6th & Jackson and Bailey Gatzert), while the background remains the same at roughly 200 per million. We used a 1/r (distance from the road) gradient based on the observed gradient to estimate and map risk for our entire jurisdiction.

When compared to Washington Ecology’s Beacon Hill National Air Toxics Trends Station (NATTS), and to previous 2001 and 2009 regional air toxics studies, results from this study confirm that most air toxics levels continue to improve.

We noted three anomalies (high values) in the toxics samples. We found that nearby, small sources were the likely causes, and the marginal (extra) risk was negligible compared to the overall diesel risk.

In response to the findings of this study, we will continue to work with the community to reduce emissions and limit exposure and impacts. The next steps for reducing emissions will be to reengage with the community, discuss potential actions and strategies, and develop a path forward. Individuals can immediately take actions to limit their exposure by:

- When possible, limit time spent near the highways when traffic volumes are highest
- Recirculate the air in your car when on busy roads
- Continue to open windows regularly to prevent mold, etc.
- Review air quality forecasts before outdoor strenuous activities
    - Continue to exercise outdoors if the air quality is not unhealthy, especially in the evening when traffic levels are typically lower
- Support clean transportation initiatives including cleaner vehicles and transportation systems
- Limit their own contributions to pollution including: using the cleanest transportation method (e.g. walking, biking, bus, carpool, clean vehicles), limiting burning
- Reduce overall impacts from air pollution by reducing exposure:
    - Limit exposure to second-hand smoke, and to other sources of smoke (incense, candles, idling trucks or buses, etc.)
    - Ensure that home indoor air is also clean
    - Consider purchasing or making an indoor air filter, and replace filters as needed

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List of Abbreviations

ASIL	Acceptable Source Impact Level
BC	Black carbon
CID	Chinatown-International District
CO	Carbon monoxide
GPS	Global positioning system
m^3	Cubic meter
NAAQS	National Ambient Air Quality Standard
NATA	National Air Toxics Assessment
NATTS	National Air Toxics Trends Stations
ng	nanogram (10^{-9} grams)
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides (NO + NO_2)
NOy	Total reactive nitrogen. The sum of NOx, nitric acid, and organic nitrates.
PAH(s)	Polycyclic aromatic hydrocarbon(s)
$PM_{2.5}$	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
PUF	Poly-urethane foam
UFPC(s)	Ultrafine particle count(s)
VOC(s)	Volatile organic compound(s)
μg	microgram (10^{-6} grams)
WILD	Wilderness Inner-city Leadership Development

Introduction

The aim of this project was to identify and more accurately define air toxics risks in the Chinatown-International District of Seattle, and to engage the community throughout the process. It investigated the major air pollutants and toxics in the study area, examined the impact of the nearby major highways, worked to involve and educate community members about these risks, and generate information about risks that may be helpful in other near-road communities.

Background

Seattle's Chinatown-International District and Yesler Terrace neighborhoods are unique and diverse communities facing language and other socio-economic barriers. An on-going air-pollution concern has been that Interstate-5 (I-5) runs through the center of the neighborhood, and happens to have the highest traffic volume in the Pacific Norwest. The 2005 National-Scale Air Toxics Assessment (NATA) estimated that this area has the highest risk census tract for cancer from air toxics in Washington State.

This project included significant community engagement. The project team integrated community members and groups into decision-making processes throughout the grant. Although one of the project's goals was to reach out to community members regarding highway air toxics risks, the project team maintained an ongoing dialogue with the community about the environment and improvements that can ultimately lead to cleaner air. We also hope that this study may be able to provide information about risks for other near-roadway communities across the Northwest.

Previous studies have highlighted that traffic pollution is a significant source of air toxics risk in general, and in our region.[2,3] In 2001, we (the Agency) and Washington State Department of Ecology (Ecology) completed a toxics study in the Seattle area. This study found that the most important air toxics risk was from diesel particulate matter and wood smoke, with significant contributions form formaldehyde, hexavalent chromium, and benzene. This study, however, did not include a near-road monitoring site.

In 2009, in partnership with the University of Washington, we completed another monitoring campaign that extended the air toxics evaluation to three sites in the Tacoma area and the industrial valley in Seattle. This study identified vehicles, and specifically diesel exhaust, as the main source of air toxics risk in the region.

In 2014, the Agency conducted a four-week pilot study in the Chinatown – International District area to capitalize on the newly established near-road monitor at 10th & Weller. This pilot study used data from the near-road monitor along with portable monitors temporarily installed at intermediate distances to I-5, along with Ogawa badges, and mobile monitoring runs. This pilot study found a clear, strong impact at

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[2] Karner et al, "Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data", Environ Sci Technol, 2010, 44, 5334–5344.

[3] Brugge et al, "Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks", Environmental Health, 2007, 6, 23.

the near-road monitor from the highway traffic, and was consistent with other studies showing a significant decrease in the impact by about 300 meters from the road. The pilot study, however, did not measure toxics concentrations, nor assess risks, and only sampled for small portion of a full year.

Study Objectives

Building from the findings of the pilot study, as well as the prior study of socioeconomic barriers and health risk,[1] the Agency identified the Chinatown-International District as a priority area for further work as a part of our Environmental Justice strategic goal. More specific questions included: how do air toxics vary from near the highway out into the neighborhood? What pollutants drive the air toxics risk for most of the neighborhood? What is the gradient of pollutants that drive local air toxics risk? After initial engagements with community members about the pilot study, many wanted to know more about air pollution risk, and how it varied through the neighborhood. Further questions included: What health effects are associated with these risks? And, what can be done to reduce these risks?

The project team developed the following broad data objectives:

1. Estimate the potential cancer and non-cancer risks for three fixed monitoring sites in the area.
2. Estimate air toxics concentration gradients with proximity to the highway.
3. Compare air toxics concentrations and risks to the national NATTS network.
4. Compare air toxics concentrations to nearby 2011 NATA census tract estimates.
5. Identify & quantify air toxics sources through factor analysis and other analyses.
6. Extrapolate risks from the gradient study to quantify potentially exposed populations and their potential risk.

In light of the data objectives, it is important to acknowledge that measuring air toxics is challenging and expensive because ambient levels of toxic chemicals are often very low compared to their detection limit, and the potential for contamination exists for many chemicals. In a similar 2009 study, many of the air toxics fell below detection limits.

Both of the previous air toxics studies were valuable in helping the agency and the communities better understand their air quality issues. We designed this study to produce community centered, scientifically defensible data to help them address their questions about air toxics risks, and to help inform what they might be able to do.

This project has three major components: 1) community engagement, starting before sampling and continuing through and after sampling, 2) the air toxics sampling, and 3) analysis and reporting.

We sought out our community partners' input to our study design, especially for the "community-directed" canister samples. Our community collaboration and outreach provided, and will continue to provide, avenues for residents to learn about air toxics and their potential health risks. This report represents an extensive evaluation of the air toxics sampling results from the study period. We will provide this report, along with other outreach materials, to the community using appropriate forums, venues, and languages.

We hope this project will foster continued work with our community partners as we work toward our goal of clean air for everyone.

Sampling Design & Methods

Air Monitoring Methodology

This project used three sampling approaches: a) fixed-site air toxics sampling, b) community-directed sampling and c) mobile monitoring.

The fixed-site air toxics sampling ran for a full year. At our near-road monitor (10th & Weller) it included the full suite of VOCs, aldehydes, PAHs, and PM_{10} metals. We also monitored at two additional sites for the toxics identified as most important in the respective census tracts by the 2005 NATA. These toxics are: benzene, 1,3-butadiene, formaldehyde, and acetaldehyde. Our monitoring leveraged existing instruments including speciation sampling, and gaseous and particle monitors in both fixed and mobile sampling. This combination of monitoring significantly strengthens the data analysis, and specifically benefits the source apportionment modeling.

For the community-directed sampling, the agency asked the community where they would like to locate additional sampling canisters. These canisters were analyzed by Eastern Research Group (ERG) for volatile organic compounds (VOCs) which provide a direct measure of the air toxics concentrations, and a comparison to the three fixed sites. We collected community input on canister locations through a series of surveys and outreach events. The agency processed the survey results and worked with a number of our community contacts to find specific locations to place the canisters. This community-directed sampling provided a venue for meaningful community input and generated additional data to improve the spatial maps and analysis.

For the mobile monitoring, the agency used hand-held and backpack sized air pollution sensors to collect data on several walks through the neighborhood. The purpose of these mobile samplers was to assess spatial variability and screen for unknown hotspots between our fixed site monitoring.

Fixed station descriptions:

Table 1 lists the names of all the sites used in the current study. Below are brief descriptions of the three main fixed sites. All sites are in King county, have a location setting that is classified as Urban, and were operated from 9/27/16 – 10/1/17, or earlier for Beacon Hill and 10th & Weller. Table 2 lists further details on the three fixed sites.

Seattle-10th & Weller: This station is Washington State's Primary near-road monitoring site. Washington State Dept. of Ecology installed the site in April of 2014. It has since routinely collected CO, NO_2, NOx, $PM_{2.5}$, and black carbon data. The station has been used in several studies, and is a common location for additional monitoring (e.g. $PM_{2.5}$ speciation). For the purposes of this highway air toxics study, instruments used at the site included Magee Scientific Aethalometer model 633, Xontec VOC canister model 910, Xontec carbonyl tube model 925, and a MOB multipollutant box - described in the section below. Additionally, we collected semi-volatile VOCs with a PUF sampler (poly-urethane foam), as well as PM_{10} filters for toxic metal analysis.

Table 1. Site names, short names, and role in plan.

Official Site Name	Short Name	Fixed Sites	Community Directed
Seattle-10th & Weller	10th & Weller	X	
Seattle-6th & Jackson	6th & Jackson	X	
Seattle-Yesler Way	Bailey Gatzert	X	
Nisei Veteran's Center	Nisei Vet Hall		X
Denise Louie Education Center	Denise Louie Ed Cntr		X
8th & Yesler	8th & Yesler		X
Seattle Beacon Hill	Beacon Hill	X	
8th & Jackson	8th & Jackson		X
Danny Woo Garden	Danny Woo Garden		X
Union Station	Union Station		X

Table 2. Fixed site information

Site Name	**10th & Weller**	**6th & Jackson**	**Bailey Gatzert**	**Beacon Hill**
AQS Code	530330030	530330035	530330034	530330080
Operator (study)	PSCAA	PSCAA	PSCAA	WA Ecology
Purpose	Near Road	Community study	Community study	Neighborhood
Environment	Urban	Urban	Urban	Suburban
Longitude	-122.319722	-122.326111	-122.314444	122.308619
Latitude	47.597222	47.599444	47.600833	47.568195
Site Elevation (meters)	42	26	58	104

Seattle-6th & Jackson: This site was in a temporary shelter on the roof of a 2-story building located at the intersection of South Jackson Street and 6th Avenue. The probe was near the shelter initially, but after seeing higher formaldehyde and acetaldehyde results, we moved the probe right before the 1/1/2017 sample. The probe was then located near the parapet near 6th Avenue. As discussed later in this report, the probe move didn't seem to lead to any obvious change in the aldehyde concentrations. Instruments used at the site included a Magee Scientific Aethalometer model 633, Xontec VOC canister, Xontec carbonyl tube samplers, and a MOB multipollutant box.

Seattle-Yesler Way: This site was located on the campus of the Bailey Gatzert Elementary School, which is part of the Seattle School District. The monitoring shelter was a Plastifab shelter, which housed several of the same instruments as the Seattle 6th & Jackson site. The probe was located near the east border of the campus, between the parking lot and the grass field. Instruments used at the site included a Magee Scientific Aethalometer model 633, Xontec VOC canister, Xontec carbonyl tube samplers, and a MOB multipollutant box.

Seattle-Beacon Hill: This site 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, NOy, $PM_{2.5}$, along with $PM_{2.5}$ speciation.

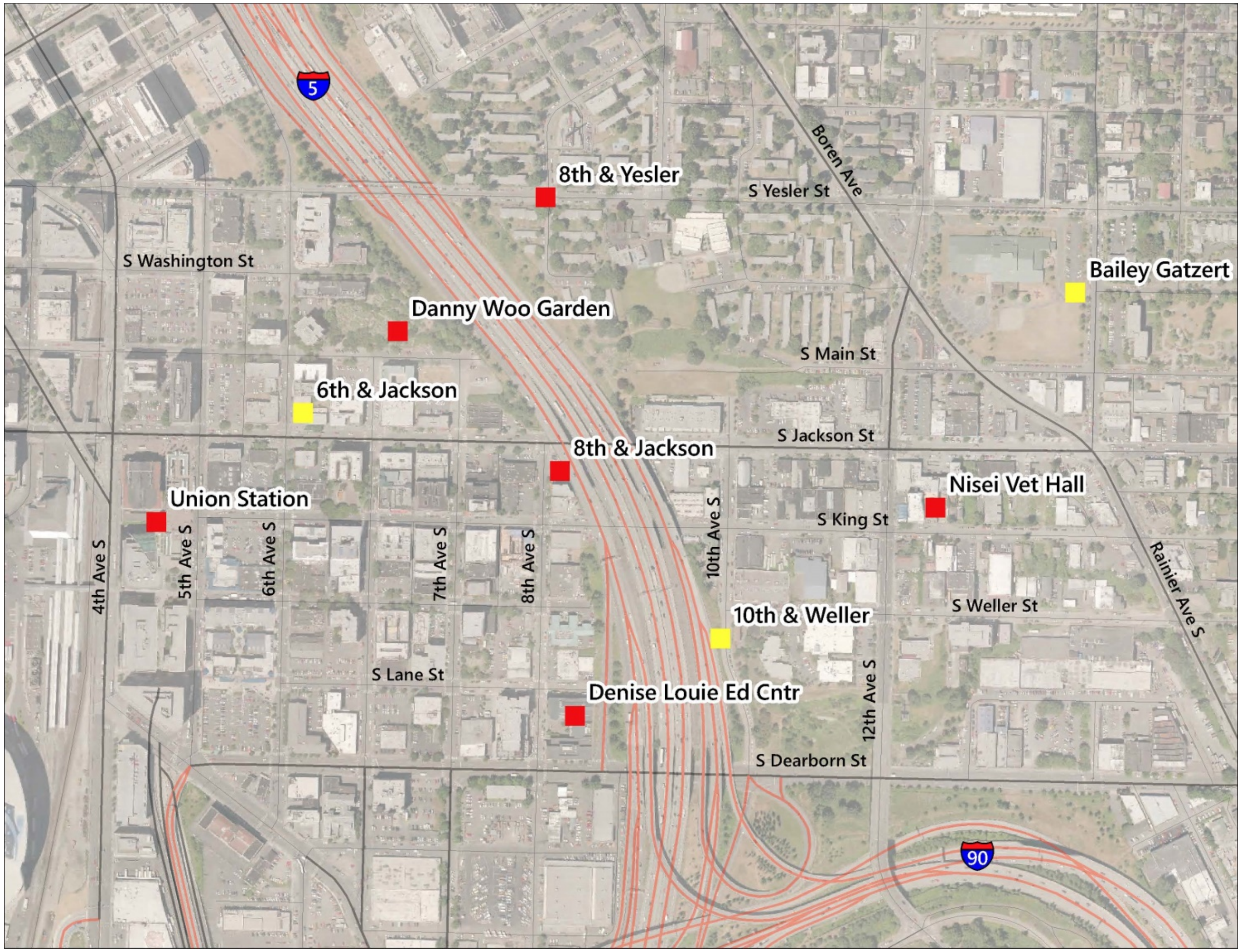
Community directed site descriptions

The agency outreach team solicited feedback from community members regarding where the community wanted additional monitoring. The community identified six areas. Within those areas, Agency staff identified and work with the community to select the following specific locations:

- *Union Station* – The canister was located on the roof of a 1-story building near the bus stop on 5th Avenue south of S King St.
- *Danny Woo Garden* – The canister was located in the middle of the garden on top of a wooden trellis.
- *8th & Jackson* – The canister was secured to a chain-link fence at a parking lot just underneath the I-5 bridge on Jackson near 8th.
- *Denise Louie Education Center* – The canister was located on the balcony of the day care adjacent to the playground.
- *8th & Yesler* – The canister was secured to a chain-link fence on the intersection of 8th & Yesler, which is on the property of the low-income housing units.
- *Nisei Veteran's Center* – The canister was located on the front porch of the veteran's center.

Figure 1. Map of the Chinatown – International District study area

Community directed monitoring locations are indicated as red squares. The community chose the general locations as described previously, and the Agency determined the specific location based on space availability and security. The yellow squares indicate the fixed sites, as well as the Seattle 10th & Weller near-road site. The Beacon Hill monitor is not shown and is about 3 km to the south of the CID.



MOB box description

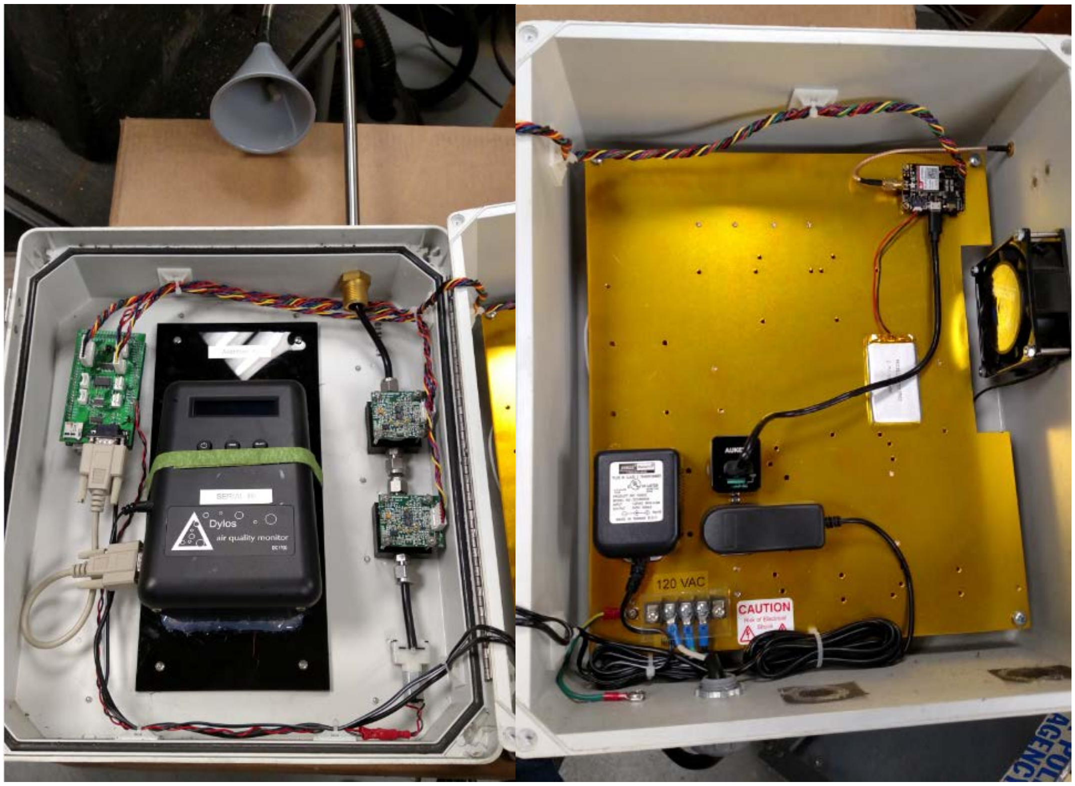
The Agency has an ongoing effort to develop and integrate new tools to measure air pollutants, including the use of micro-sensors. The MOB box is a custom-built box designed to measure some of the key pollutants (CO, NO_2, and $PM_{2.5}$) at a lower cost, and with easier and faster installation.

Figure 2. MOB box installed at the 6th & Jackson site.

The MOB box consists of an enclosure that allows air to flow into and out of several spaces. On the top of the box, the shepherd's hook with rain protection funnel is the gaseous sampling train air intake. Both CO and NO_2 are measured using electrochemical gas sensors that are manufactured by Adafruit Industries. The voltages sensed by these micro-sensors roughly correlate to ambient concentrations of CO and NO_2, after calibration.

The top and bottom vents on the front of the door are the air intakes and outlets for the particle counting system. This MOB box version uses a particle counter made from a modified Dylos model 1700, which outputs small and large particle counts. Small particle count nominally means particles between 0.5 and 2.5 microns in diameter. Large particle count means particles greater than 2.5 microns in diameter. These roughly estimate $PM_{2.5}$ and PM_{10} mass, although significant bias can occur. Each box also has an Arduino microcontroller that acts as an onboard data logger, a small cell-phone modem that transmits data packets, and an onboard microSD card that records the data.

Figure 3. Inside of a MOB box.



Mobile monitoring description

There is a wide range of potential instruments, platforms, sampling strategies, and objectives for mobile monitoring. Our goal was to sample with backpack mounted equipment while walking around the neighborhood on at least 5 days. Additional objectives and instruments would be explored on a case-by-case basis. Monitoring with a backpack platform brought several major limitations. We found two instruments that would fit the constraints of the backpack monitoring and help us meet our data objectives. We also clarified two main purposes for our mobile monitoring, which extended beyond backpack monitoring. Within each purpose, there were several uses for these monitors that are summarized below in Table 3.

Table 3. Summary of various mobile & temporary monitoring tools used.

System Name	Measures	Quantitative?	Usable by Community?
AE-51 microAeth	Black Carbon	Yes	No
Enmont Ultrafine particle counter	UFP, GPS	Yes	No
AirBeam monitor with Android Cell Phone	Particle count to $PM_{2.5}$ estimate, T, RH, GPS	Semi	Yes
Holux GPS monitor	GPS	Yes	No
Aeroqual series 500 sensor	Total VOC	No	No
Dylos Model 1700	Particle count (large and small)	Semi	Yes
MOB box	NO, CO, $PM_{2.5}$ estimated, T, RH	Semi	No

In this table, "Quantitative?" indicates the appropriate use of the data with regards to its accuracy and precision. "Yes" means that the measurements have minimal errors or biases, and proportionally greater values indicate proportionally greater pollutants. "No" means that the stated measurement has biases, errors, or otherwise may not respond proportionally to pollutant levels, but nonetheless can be useful to indicate relatively higher or lower pollution levels. "Semi" indicates that under some circumstances, or with calibration, the data can be considered quantitative (like a "Yes"). But, the measurements are likely to be less precise and the proportionality can be poor. "Usable by Community?" refers to how difficult it is use the device and obtain good quality data. "Yes" indicates simple operation and minimal care while in use. "No" indicates that the device requires more extensive training and improper use could result in bad data or damage to the instrumentation.

Monitoring for Education and Outreach:

We identified education and outreach as a primary opportunity and objective for our mobile monitoring. Handheld, user-friendly devices can provide invaluable spatial data, and engage the community. Community members can get first-hand experience with the challenges of study design, operating instrumentation, data processing, and also seeing how pollutant concentrations change in time and space. We found several opportunities with the INTERIM Community Development Association (CDA) Wilderness Inner-city Leadership Development (WILD) program, including student run sampling, and a study/demonstration of air filtering.

As a part of our outreach activities with the WILD organization, we developed a walking monitoring activity that fit into their lesson plans. We found the AirBeam hand held monitor with an Android cell phone to be a useful tool to show high school age students one approach for collecting air quality information in their community. In the first session, we introduced the sensor and helped them make a Bluetooth connection to their phones so they could record their data. We briefly discussed pollution sources and characteristics of the neighborhood, and then divided the students into teams of 3 or 4. We prompted each team to use the scientific method and to find an experimental question that they wanted to explore with the monitors. Each group designed their experiment, and then collected data by walking around the neighborhood with a WILD or Agency mentor. When the groups came back together, they discussed what they learned by collecting the data, and talked about future actions and strategies that can be used to improve community air quality.

During another outreach activity with the WILD organization, we found the Dylos model 1700 (also used in the MOB boxes) to be a useful tool. The WILD organization had just assembled custom-made fan-filters, and then distributed them to elders in the community. (These fan-filters are comprised of a furnace filter (with a MERV-13 or higher) mounted to a basic box fan, with a total cost of about $35 each. The Agency provided the materials and training.) After this project, several students asked how effective the fan-filters are in reducing pollutants. The WILD group leader and PSCAA monitoring personnel worked with the students to conduct an experiment. They first selected three small rooms, ranging from 100 to 300 ft^2. The students used a Dylos to establish a baseline small particle count for a few minutes, and then started running the fan-filter. The students collected data (at 30 second intervals) and observed the small particle counts drop in all three rooms after about 6 or 7 minutes. The small particle count reduction ranged from 40 to 60% depending on size of the room, or whether the room was closed, or had any door or window openings. While we don't consider this test to be conclusive evidence, it did provide good initial evidence and confidence that the fan-filters have a good potential to reduce fine particles in the indoor air of community residents.

Characterization and identification of the neighborhood:

The second primary objective of mobile monitoring was to augment our data on the spatial distribution of pollutants in the study area. There is not, however, a standard instrument package or set of devices that are established for this sort of mobile monitoring. So, this task begins with evaluating several instruments/devices.

There were two important constraints for backpack-based mobile monitoring: 1) sensitivity at the time resolution of a typical walking pace and 2) suitability for carrying on a backpack. The sensitivity/time resolution constraint is different for the various pollutants. Pollutants with sources that are weak compared to the background will be difficult to detect and require greater sensitivity and precision. The portability constraint eliminates most regulatory grade instruments because they are large, heavy, need A/C power, and need stable room temperatures.

We initially explored using an Aeroqual total VOC (volatile organic compound) sensor. But, challenges with the detection limit and the measurement recording systems caused us to abandon this instrument.

The first of the two instruments we did select was the Enmont ultrafine particle counter. Ultrafine particles (UFPs) are generally defined as being less than 0.1 microns in diameter. For the Enmont, the small size limit (minimum size) is 0.005 microns. UFPs are a good candidate for mobile monitoring because cars and trucks are major sources of UFPs, and the levels near the major roads are generally much higher than background. It is important to note that while the ultrafine particle counts often have a strong signal compared to background, the count doesn't necessarily relate to total fine particle mass, which is what the health research is based on. While it is very likely that UFPs will contribute to health risk at least to the extent that they contribute to fine particle mass, there is currently not robust research that addresses health impacts due to UFPs above and beyond their mass[4], although there is some preliminary evidence.[5]

The second instrument we selected was the AE-51 micro aethalometer (microAeth) because it is small, provides a measure of pollution that is better related to particle mass than is ultrafine particle count, and measures a key toxic (black carbon, aka BC) which is a marker of diesel pollution. Black carbon is also important because it is a short-lived climate forcing agent. The microAeths were configured to have the maximum sample flow rate, and a 60 second averaging time in order to maximize the sensitivity for low BC concentrations.

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[4] Amy Heinzerling, Joy Hsu, and Fuyuen Yip, Respiratory Health Effects of Ultrafine Particles in Children: A Literature Review, Water Air Soil Pollut. 2016 Jan; 227: 32. doi: 10.1007/s11270-015-2726-6

[5] E.g. Habre R, Zhou H, Eckel SP, Enebish T, Fruin S, Bastain T, Rappaport E, Gilliland F, Short-term effects of airport-associated ultrafine particle exposure on lung function and inflammation in adults with asthma., Environ Int. 2018 Sep; 118:48-59. doi: 10.1016/j.envint.2018.05.031.

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Table 4. Sites, parameters measured, and sampling schedule

Sites	Measured parameters (from this grant and *leveraged*)	Monitoring duration or frequency
10th & Weller (current near-road NO$_2$ site)	• Full suite of VOCs, PAHs, aldehydes, PM$_{10}$ metals, *PM$_{2.5}$ speciation*	• Daily samples every six days for one year
	• *NO$_2$, NO$_x$, NO, CO, BC, PM$_{2.5}$, temperature, winds, traffic counts*	• *Continuous hourly for at least the duration of the study*
Beacon Hill (current NATTS site)	• *Full suite of VOCs, PAHs, aldehydes, PM$_{10}$ metals, PM$_{2.5}$ speciation*	• Daily samples every six days for one year
	• *NO$_2$, NO$_x$, NO, SO$_2$, CO, BC, PM$_{2.5}$, temperature, winds*	• *Continuous hourly for at least the duration of the study*
6th & Jackson (on east-side of I-5)	• Benzene, 1,3-butadiene, formaldehyde, acetaldehyde,	• Daily samples every six days for one year
	• NO, CO, BC, PM$_{2.5}$	• *Continuous hourly for the duration of the study*
Yesler Way/ Bailey Gatzert (west of I-5)	• Benzene, 1,3-butadiene, formaldehyde, acetaldehyde,	• Daily samples every six days for one year
	• NO, CO, BC, PM$_{2.5}$	• *Continuous hourly for the duration of the study*
6 other Community Directed locations	Benzene, 1,3-butadiene, formaldehyde, acetaldehyde	• sampled 3 to 5 days, in-sync with the other one-in-six day schedule
Mobile monitoring	BC, ultra-fine particle counts	• 5-10 days out of the one-in-six day sampling schedule

Monitoring Results

Our data come from monitoring we conducted, and from a nearby site, Beacon Hill, which was operated by the Washington State Department of Ecology (Ecology). The monitoring results and analysis focus on the data we collected at the fixed sites and through mobile monitoring, including toxics, meteorology, and criteria pollutants.

Other air toxics data inclusion

In the Beacon Hill neighborhood of Seattle, Ecology maintains an air monitoring station that is one of 30 EPA-sponsored National Air Toxic Trends Stations (NATTS). This site measures many different pollutants, including fine particles, nitrogen dioxide, carbon monoxide, sulfur dioxide, speciated fine particles ($PM_{2.5}$), PM_{10} metals, and air toxics. This site provides helpful air toxics trend information going back to 2000. For most of the highest risk air toxics, we included historical trends at Beacon Hill in Appendix G. As the site is on top of a hill and about 1km away from Interstate 5, it also provides an "urban background" for comparison to sites nearer the highways.

For comparisons with the rest of the U.S., we also compiled data from other NATTS. We included data with three full years (2014-2016) to account for year-to-year variable in meteorology. We selected data from only NATTS that had 3 years of complete data for each priority pollutant spanning 2014-2016. At the time of our analysis, we did not have the complete 2017 year of data to include in this report.

To assess how air toxics risk modeling (EPA's 2011 National Air Toxics Assessment, NATA) held in our region, we also compared this study's results against the EPA model. The results are in the Analysis section of this report.

Data review, invalidation, blanks

Prior to all analyses, we screened the data through several QA steps, including identifying potential outliers by reviewing typical patterns, reviewing collocated (duplicate) sample precision, reviewing lab QA spikes, and ensuring that all QA criteria were met according to the Quality Assurance Project Plan (Appendix H), including data completeness. The data used in this analysis passed all QA criteria for blanks, precision, and recoveries.

Lists of all the air toxics measured during this study are in Table A-1 (VOCs), Table A-2 (aldehydes), Table A-3 (PAHs), and Table A-4 (PM_{10} metals) of Appendix A.

Overall, our air toxics samples passed 75% completeness criteria over the study period. Table A-5 in Appendix A gives a full list of all the null (lost) samples during the study period, including the dates, instrument, reason, and analytes lost.

From the QA review, we fully invalidated the acetonitrile results from the canister samples, as there were obvious interferences from the cartridges used for sampling aldehydes, which use acetonitrile as a solvent. Although the concentrations were artificially elevated, the levels were still below the

Washington State Acceptable Source Impact Levels (more details on this review in the next section below).

The contract lab (ERG) blank corrected results for the following analytes due to a blank issue over the time period of 9/27/16-3/2/17: vinyl chloride, dichlorodifluoromethane, chloromethane, dichlorotetrafluoroethane, chloroethane, trichlorofluoromethane, propylene, and bromochloromethane.

The blank corrections, at both the Beacon Hill and the 10th & Weller sites, seemed to artificially increase the results on those dates when compared to the Beacon Hill historical data (which is all non-detect). The differences between the blanks and the sample values were larger than historical un-blank corrected results, resulting in an artificial bias. Since vinyl chloride typically has a cancer unit risk factor near or below the detection limit, the blank correction resulted in elevating the risk (and creating likely false detects when typically there aren't any). Nonetheless, we conservatively include the blank-corrected results in our risk summaries with a footnote that they are likely elevated due to the bias in the blank correction.

From our data review, we discovered formaldehyde and acetaldehyde levels at the 6th & Jackson site to be unexpectedly high. See the Analysis Chapter for more detail.

Summaries for priority air toxics

This section provides details for the priority air toxics. We define priority air toxics as having a potential risk over one-in-a-million or a non-cancer hazard risk ratio of over 1. The screening for cancer and non-cancer risk is covered in the next section.

Below, we also provide box plots showing the data distributions. The middle of these boxes indicates the median (at the line where the color goes from a lighter to dark shade). The top and bottom of the boxes represent the 75th and 25th percentiles, respectively, also known as the interquartile range (IQR). The whiskers represent 1.5 times the IQR. That is, all data within 1.5 times the width of the adjoining box. The remaining data points are all the values that are higher than or below that range.

With each box plot, we make comparisons across the fixed sites and national air monitor sites from the National Air Toxics Trends Stations (NATTS). The NATTS data span 3 years (2014-2016) across multiple sites and so includes a few thousand samples, while our study had only one year of data (and about 60 samples per site). As a result, you will see a larger number of data above the whiskers for the NATTS data since the sample count is so much larger. This also typically meant that averages for the NATTS were generally higher than medians, with high outliers bringing up the average significantly.

In addition, we did not show sites with air toxics results which had potential cancer risks below one-in-a-million. Therefore, some plots have only the 10th & Weller site and NATTS that had levels above the detection limit, or above the one-in-a-million potential cancer risk threshold, or both.

In order to get a full distribution, we did not include any data in the box plots that had less than the one full year of data, except for the community directed sites. These box plots are in the Analysis section and Appendix F.

In this section, we also describe some of the trends in air toxics over time at the Beacon Hill site, which goes back to the year 2000, for most air toxics. These trends are in Appendix G.

Lastly, statistical summaries for each the air toxics, for each site are in Appendix A in Table A-11.

Carbon Tetrachloride

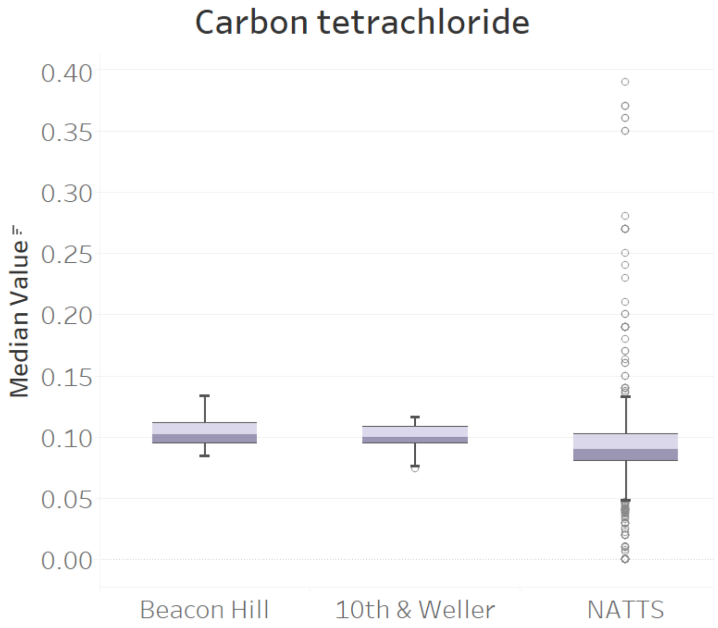
Carbon tetrachloride had the highest risks among all the directly measurable air toxics (the risk from diesel exhaust is higher, but not directly measurable).

The EPA lists carbon tetrachloride as a probable human carcinogen. Carbon tetrachloride inhalation is also associated with liver and kidney damage.[6] 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 Beacon Hill site, we did not find a statistically significant trend in carbon tetrachloride levels over time (see Appendix G).

Figure 4 below shows the box plot for carbon tetrachloride. The data show no significant differences across the sites in Seattle or nationally, but the results are still marginally higher in Seattle. Prior Agency analysis showed that there is a latitudinal gradient across the country. That is, areas further north had higher levels of carbon tetrachloride. This trend (higher concentrations with increasing latitude) matches observed surface concentrations in prior studies, however, this is the inverse trend of what the bulk atmospheric distribution is. At higher altitudes, the gradient is highest towards the equator.[7]

Figure 4. Carbon tetrachloride box plot (in ppb)



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

[7] Allen NDC, Bernath, PF, Boone, CD, et al. "Global carbon tetrachloride distributions obtained from the Atmospheric Chemistry Experiment (ACE)", *Atmos Chem Phys*, **2009**, 9, 7449-7549.

Benzene

Benzene has the next highest potential cancer risk of all measurable air toxics.

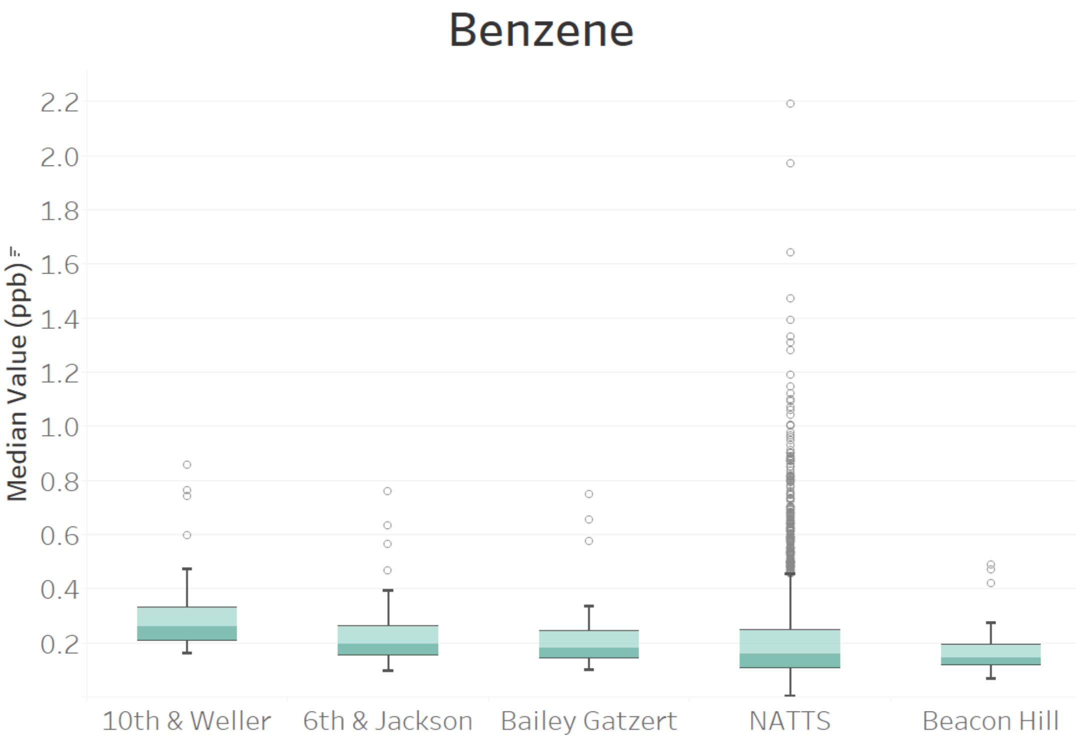
The EPA lists benzene as a known human carcinogen. Benzene inhalation is also linked with blood, immune and nervous system disorders. [8] This air toxic comes from a variety of sources, including car and truck exhaust, cigarette smoking, wood burning, evaporation of industrial solvents, and other combustion.

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 Beacon Hill site, we found a statistically significant drop in risk from benzene at a rate of about two-per-million per year since 2000 (see Appendix G).

Figure 5 below shows the box plot for benzene. The median benzene was highest at the near-road site, 10th & Weller. All the sites had higher medians than the NATTS, with the exception of Beacon Hill.

Also, Figure 66 shows how benzene levels decrease with distance to I-5 in the community-directed sampling results.

Figure 5. Benzene box plot (in ppb)



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

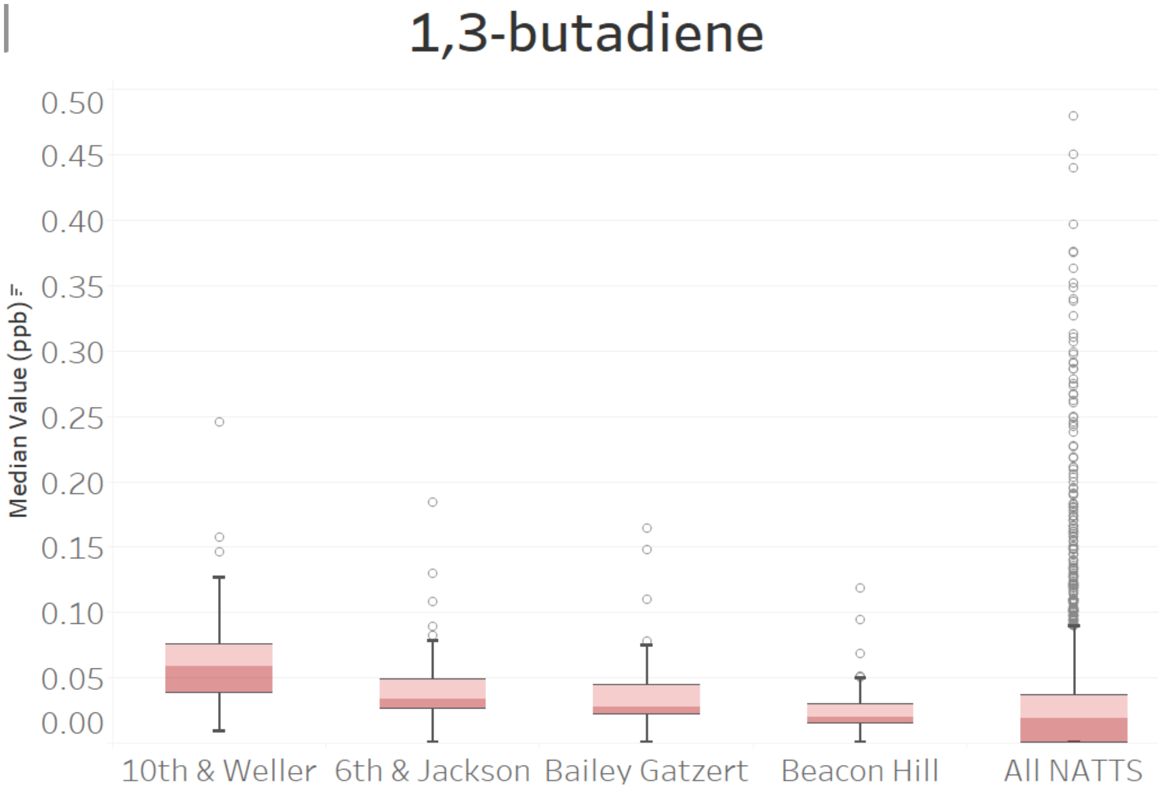
1,3-butadiene

The EPA lists 1,3-butadiene as a known human carcinogen, and inhalation is also associated with neurological effects.[9] Primary sources include cars, trucks, buses, and wood burning. So, any Agency efforts that reduce vehicle exhaust and wood stove emission also reduce 1,3-butadiene emissions. Since 2000, we found a statistically significant drop in risk from 1,3-butadiene at the Beacon Hill site at a rate of about one-per-million per year (see Appendix G).

For this study, most of our 1,3-butadiene concentrations were higher than the median of the rest of the NATTS. Since our three fixed sites are in proximity of a major highway, while many of the NATTS aren't, we can expect to have higher levels than most other NATTS. 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 (e.g. benzene). As expected, the IQR of the Beacon Hill data falls within the IQR of the NATTS, but the bottom end (25%ile) is still elevated compared to the NATTS. There may be another significant source of 1,3-butadiene in our region, but we do not have any good candidates at this point.

Figure 65 (in the community-directed sampling section) shows the 1,3-butadiene gradient where the concentration increases with proximity to I-5.

Figure 6. 1,3-butadiene box plot (in ppb)



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

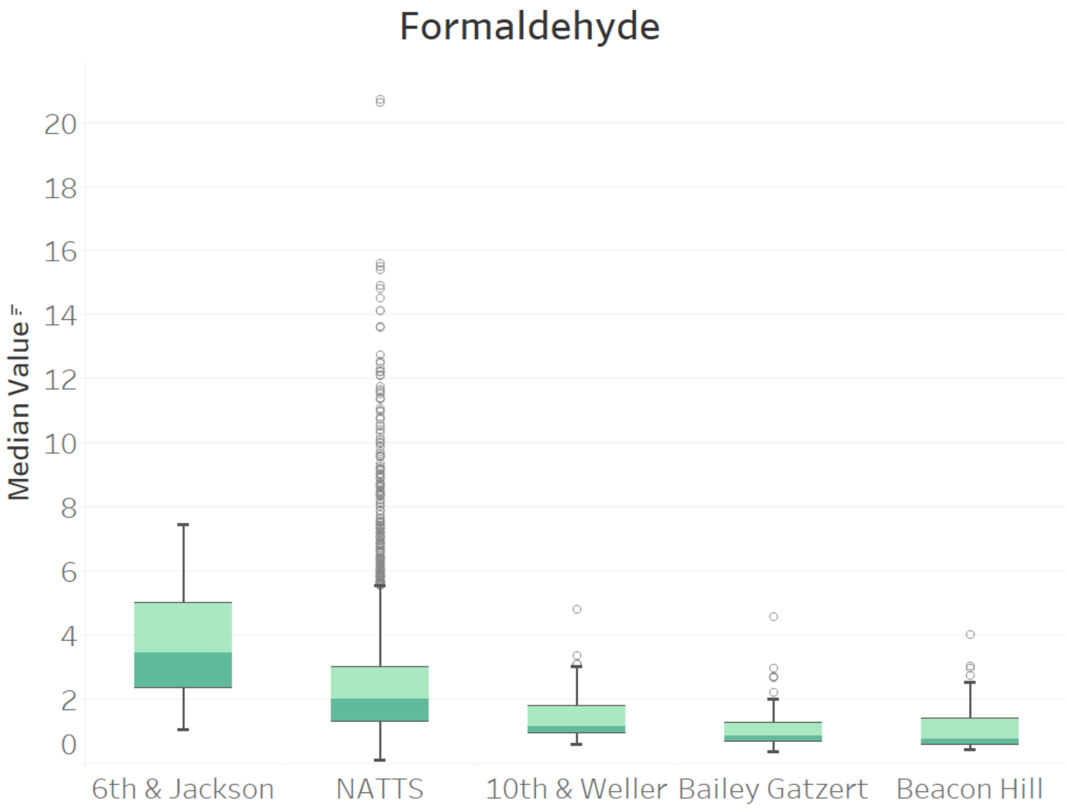
Formaldehyde

The EPA lists formaldehyde as a probable human carcinogen. Inhalation is also associated with eye, nose, throat, and lung irritation.[10] Ambient formaldehyde can both be emitted directly from a source, and 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, we found a statistically significant drop in risk from formaldehyde at a rate of about one per million per year (see Appendix G).

Figure 7 below shows the formaldehyde data as a box plot. The 6th & Jackson site is significantly higher than the other sites. We this issue further in the analysis section. In summary, we believe that the elevated formaldehyde at 6th & Jackson is likely due to a very-near source of material off-gassing.

Besides 6th & Jackson, our fixed sites are much lower than the median of the NATTS . This is likely due to our region being mostly ventilated by cleaner marine air with fewer pollution sources than the rest of the country. Our airshed typically ventilates out daily, especially in the summer months. This incoming (background) air has less direct emissions and less atmospheric formation than other parts of the country.

Figure 7. Formaldehyde box plot (in ppb)



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

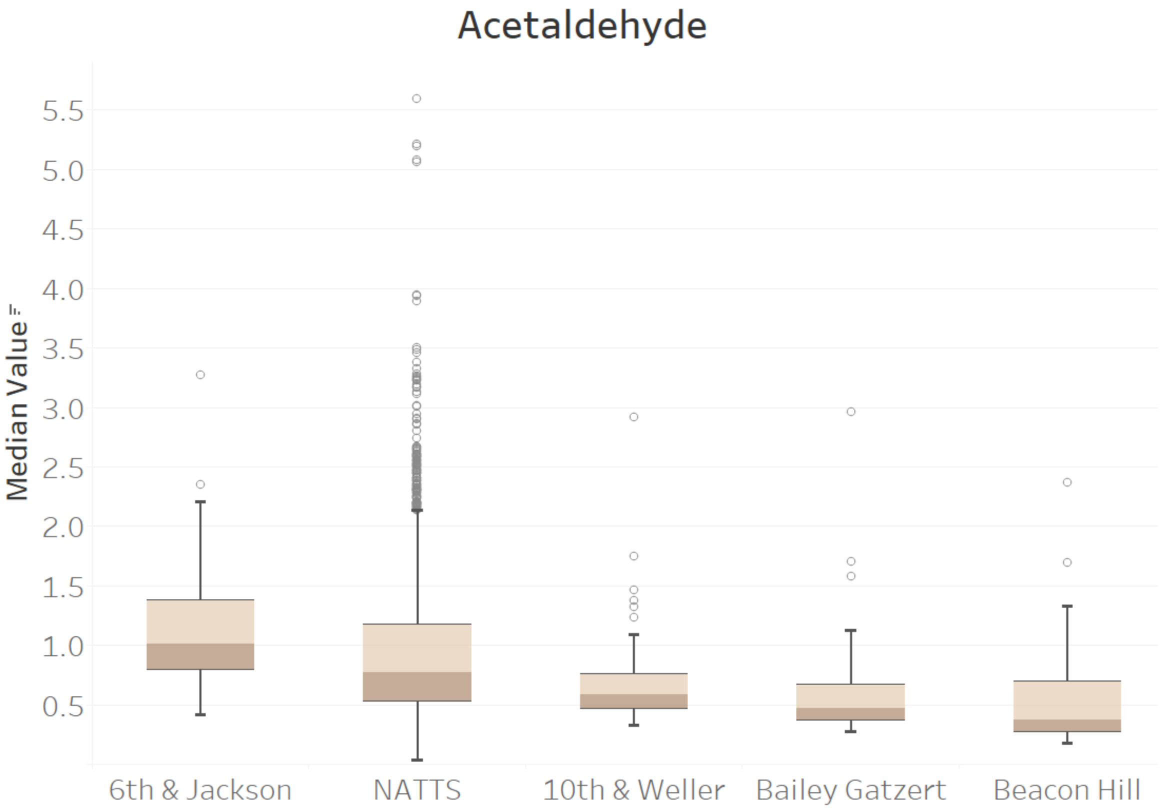
Acetaldehyde

The EPA lists acetaldehyde as a probable human carcinogen. Acetaldehyde inhalation is also associated with irritation of eyes, throat and lungs, and effects similar to alcoholism.[11] 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 0.2 per million per year (see Appendix G).

The box plot in Figure 8 shows a similar result to the formaldehyde results above (with 6th & Jackson having a similar very-near source of material off-gassing). For more information, see the analysis section of this report.

The box plot also shows that our fixed sites, except for 6th & Jackson, 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.

Figure 8. Acetaldehyde box plot (in ppb)



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

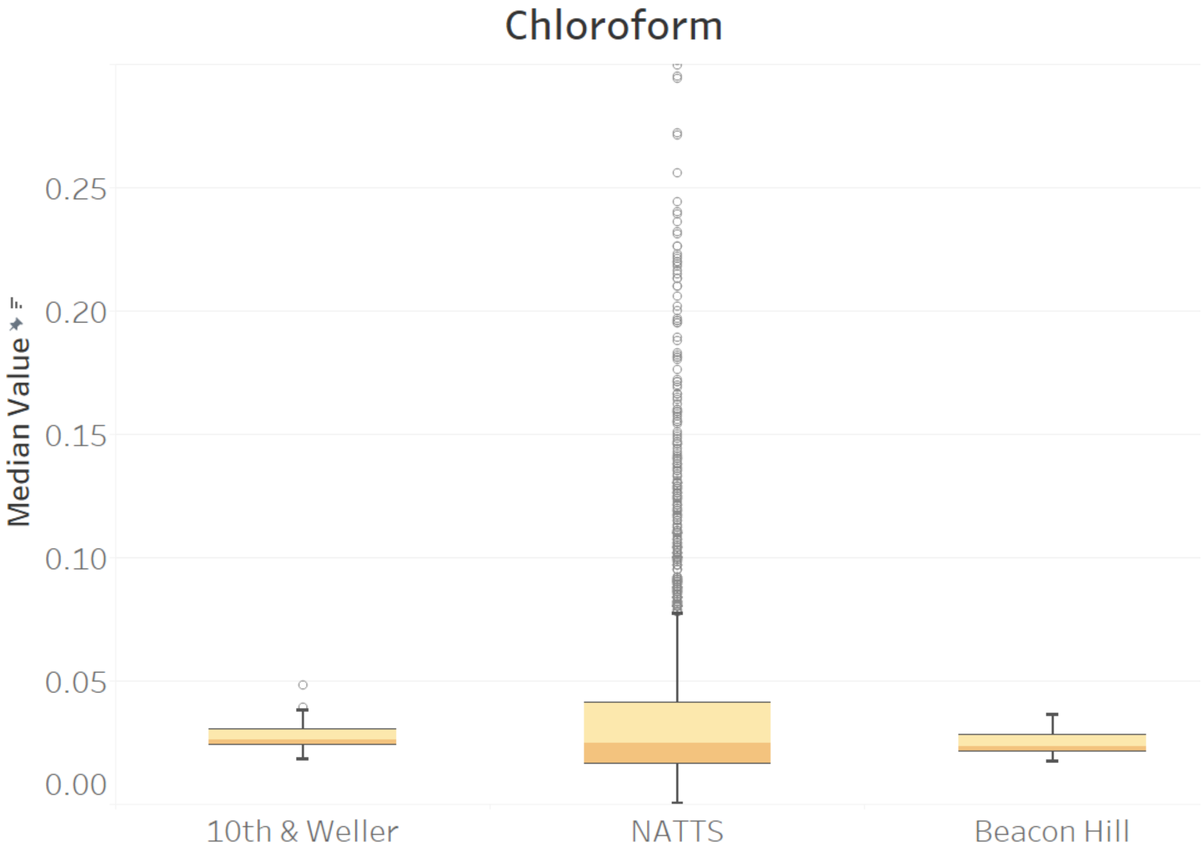
Chloroform

The EPA lists chloroform as a probable human carcinogen. Chloroform inhalation is associated with central nervous system effects and liver damage.[12] Main sources of chloroform are water treatment plants and reservoirs. Since the Beacon Hill monitoring site is located at the Beacon Hill reservoir, the chloroform data may be biased high. Nonetheless, it is still useful to calculate and assess the long-term trend and potential risks.

The Agency does not prioritize efforts to reduce chloroform emissions, as it does not likely present risk in areas other than those directly adjacent to reservoirs. Since 2000, we found a statistically significant drop in risk from chloroform at a rate of about 0.2 per million per year (see Appendix G).

Figure 9 below shows the chloroform box plot. The medians are very similar across Beacon Hill, 10th & Weller, and the NATTS.

Figure 9 Chloroform box plot (in ppb)



Note: the maximum y-axis was forced to a lower value in this figure, as a specific NATTS site resulted in many outliers that would make it virtually impossible to distinguish the boxes visually.

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

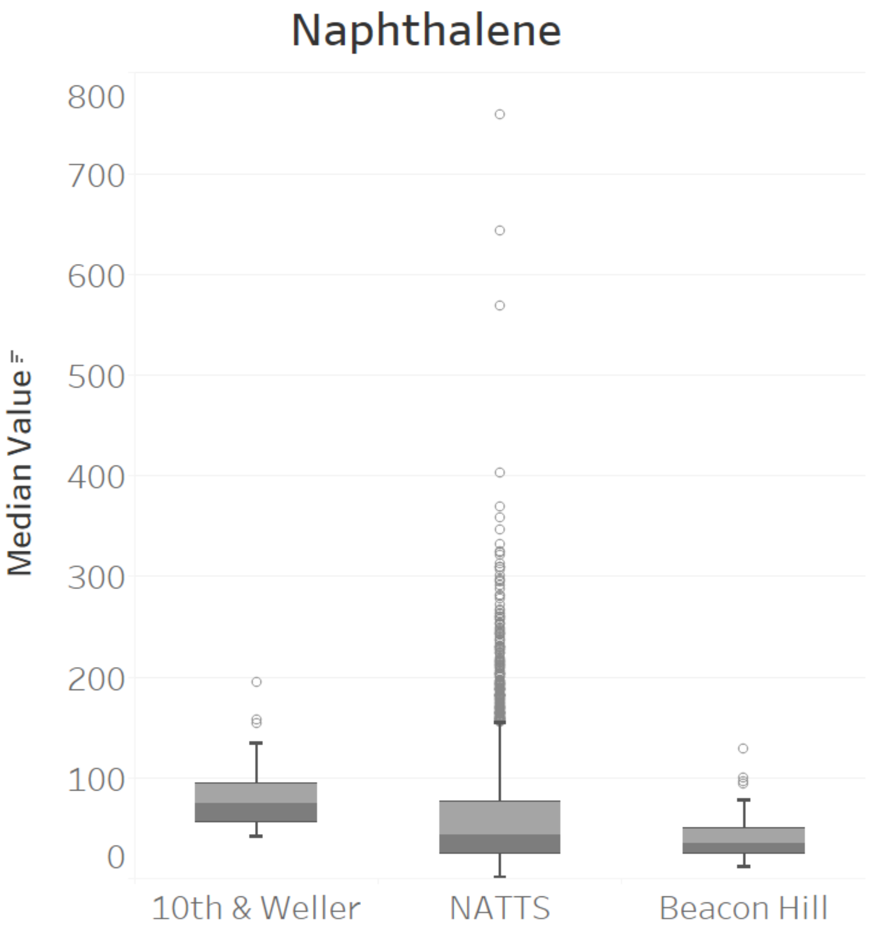
Naphthalene

EPA lists naphthalene as a possible human carcinogen. Naphthalene is similarly associated with respiratory effects and retina damage.[13] Local sources of naphthalene include combustion of wood and heavy fuels.

The Agency works to reduce wood burning emissions (which would include naphthalene) through regulations, burn bans, and wood stove replacement programs. The Agency also has worked to reduce diesel exhaust through a multitude of engine replacement projects over the years. Since 2000, we found a statistically significant drop in risk from naphthalene at Beacon Hill at a rate of about 0.1 per million per year (see Appendix G). Monitoring for naphthalene and other polycyclic aromatic hydrocarbons started at Beacon Hill in 2008.

Figure 10 shows the naphthalene results. The median was highest at the near-road site (10th & Weller), followed by the NATTS median, and lastly Beacon Hill.

Figure 10. Naphthalene box plot (in nanograms per cubic meter)



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

Arsenic

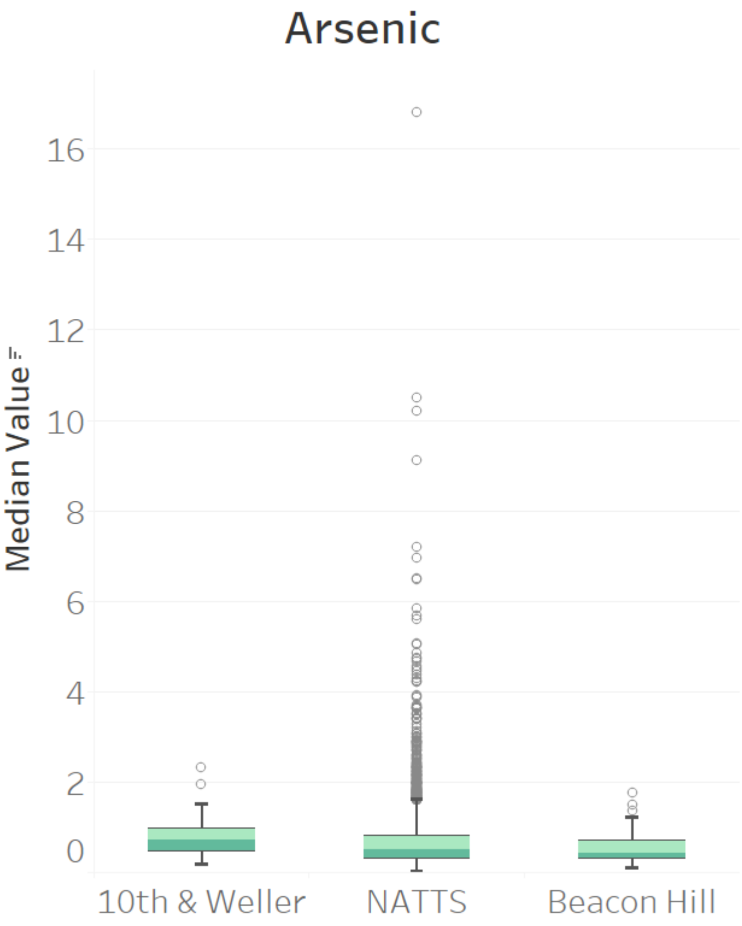
EPA lists arsenic as a known carcinogen. Exposure to arsenic is also associated with skin irritation and liver and kidney damage.[14] Arsenic is used to treat wood and was historically used in glass coloring, was a byproduct of zinc smelting. Combustion of distillate oil is also a source of arsenic in the Puget Sound area. Since 2000, we found a statistically significant drop in risk from arsenic at a rate of about 0.1 per million per year at the Beacon Hill site (see Appendix G).

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 11 shows that arsenic is generally higher at 10th & Weller when compared to the NATTS (0.71 and 0.49 ppb, respectively). Beacon Hill has a similar median as the NATTS (0.41 ppb).

For more details on potential sources, see the Positive Matrix Factorization (PMF) section, which includes a good portion of the arsenic within a metals/industrial factor.

Figure 11. Arsenic box plot (in nanograms per cubic meter)



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

Ethylene Dichloride

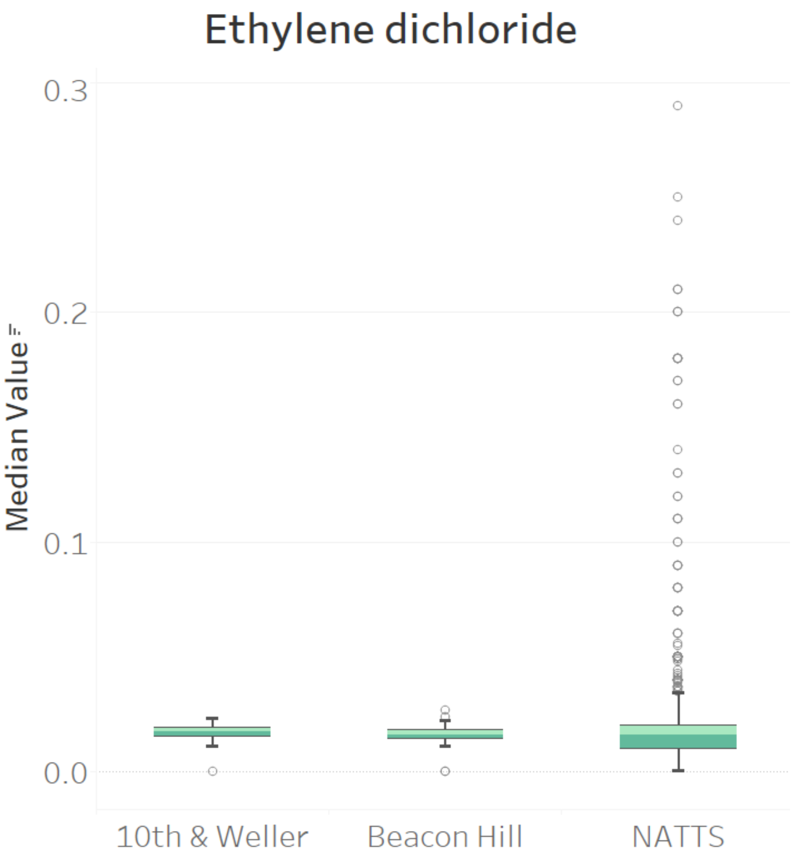
EPA lists ethylene dichloride as a probable human carcinogen. It is primarily used as a solvent in the production of other chemicals like vinyl chloride. It is also added to leaded gas.[15]

There is no useful trend information at Beacon Hill for this air toxic since many of the samples are near the practical quantitation limit of the measurement method. That is, most of the samples are below twice the method detection limit. For context, the detection limits have historically been near the one-in-a-million potential cancer risk level.

The Agency's permitting program works with and regulates industrial producers of ethylene dichloride to reduce emissions.

Below, Figure 12 shows box plots for 10th & Weller, Beacon Hill, and the NATTS. All have very similar medians.

Figure 12. Ethylene dichloride box plot (in ppb)



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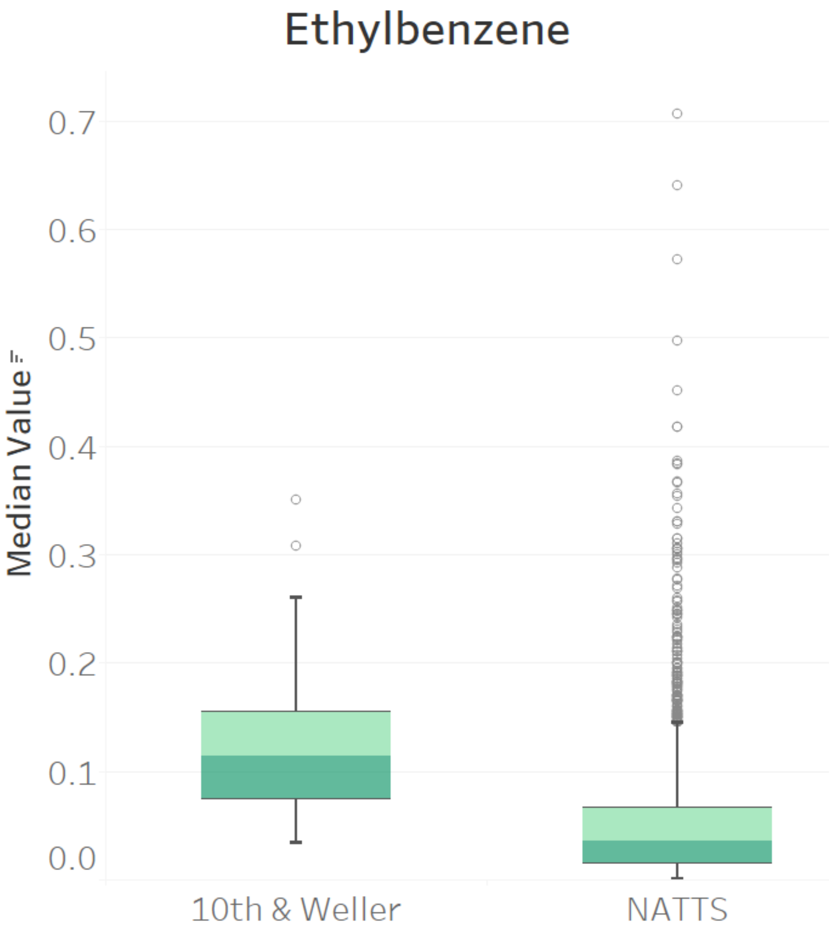
[15] EPA Hazard Summary, https://www.epa.gov/sites/production/files/2016-09/documents/ethylene-dichloride.pdf.

Ethyl benzene

EPA lists ethylbenzene as a Group D pollutant, which is not classifiable as to human carcinogenicity due to limited data.[16] Chronic exposure to ethylbenzene may affect the blood, liver, and kidneys. Local sources of ethylbenzene are volatilization from fuels, asphalt, and naphtha, and other solvents. It is also used in styrene production. At Beacon Hill, we did not find a statistically significant trend in ethylbenzene levels over the time frame that we had data (see Appendix G). The Agency works with and regulates solvent-using businesses to reduce ethylbenzene emissions.

Figure 13 shows much higher ethylbenzene at 10th & Weller when compared with the IQR of the NATTS. Although the levels are appreciably higher, the potential cancer risk is still near the one-per-million threshold at 10th & Weller (and mostly below that for the NATTS). The levels at Beacon Hill were below the screening threshold and therefore were not included in this figure.

Figure 13. Ethylbenzene box plot (in ppb)



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

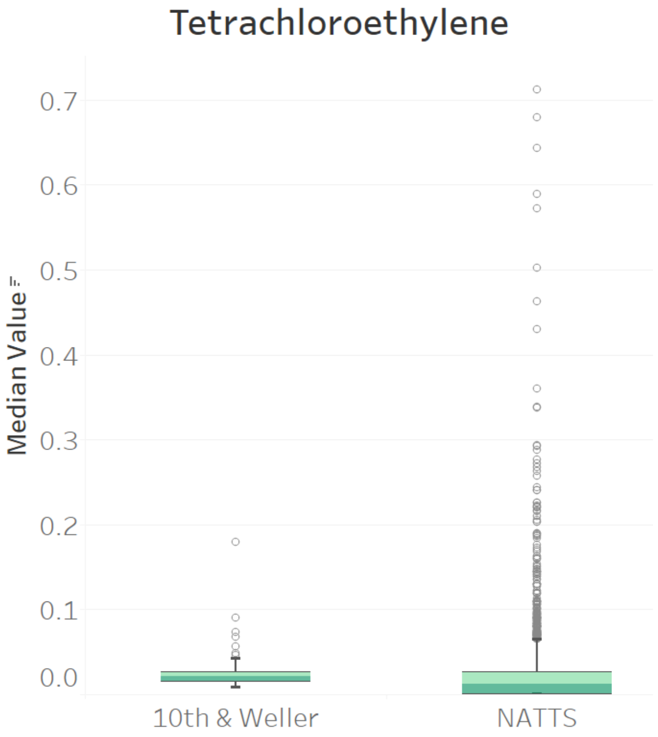
Tetrachloroethylene

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.[17] 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 0.1 per million per year (see Appendix G).

Figure 14 shows the box plot for 10th & Weller versus the NATTS. The median is higher at 10th & Weller, but it is not substantially higher, and the IQR of 10th & Weller is within the IQR of the NATTS.

Figure 14. Tetrachloroethylene box plot (in ppb)



See the community-directed sampling section for more information on higher concentrations identified in that portion of our sampling. The higher levels are likely due to a local dry cleaner located a few blocks from the Denise Louise Education Center monitoring location. Figure 67 shows the results of the few samples at the Denise Louise Ed Center versus individual NATTS and our other monitors from this study.

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

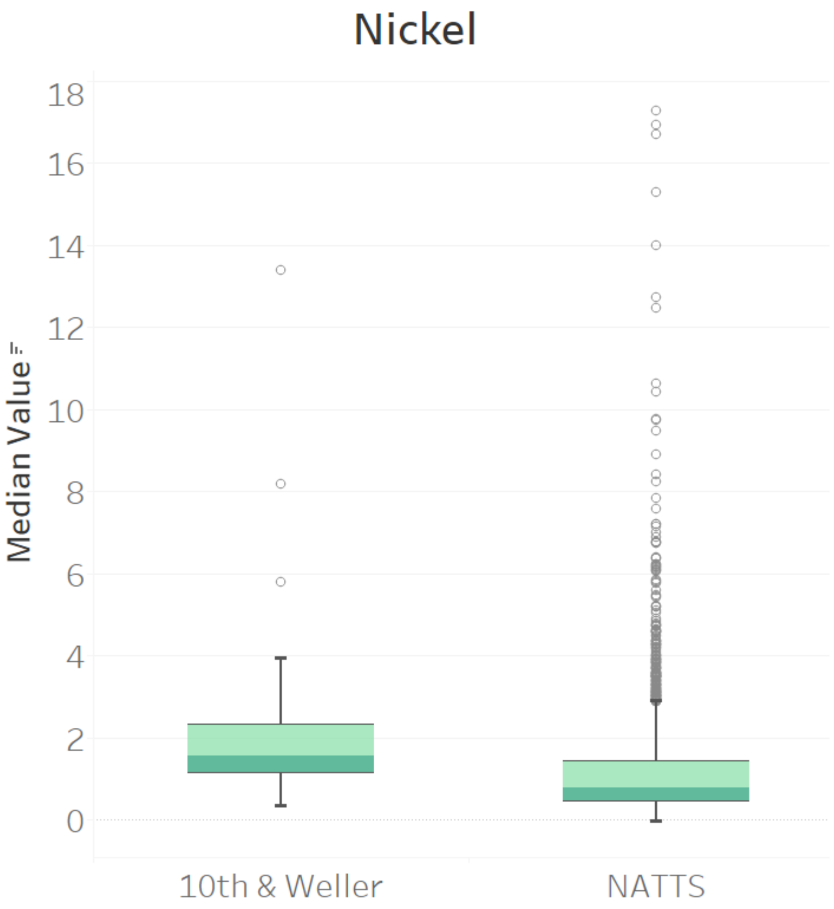
Nickel

EPA lists nickel as a known human carcinogen. Nickel is also associated with dermatitis and respiratory effects.[18] Combustion of gasoline and diesel fuels (car, truck, and bus exhaust) is a main source of nickel in the Puget Sound area. Since 2000, we found a statistically significant drop in risk from nickel at a rate of about 0.1 per million per year (see Appendix G) at Beacon Hill. Agency efforts that target reducing vehicle exhaust also reduce nickel emissions.

Figure 15 shows the nickel results for 10th & Weller versus the NATTS. The median is higher at 10th & Weller, but the average is more similar due to some NATTS that have much higher nickel concentrations.

Levels at Beacon Hill were below one-in-a-million, and as a result was excluded from this box plot.

Figure 15. Nickel box plot (in nanograms per cubic meter)



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

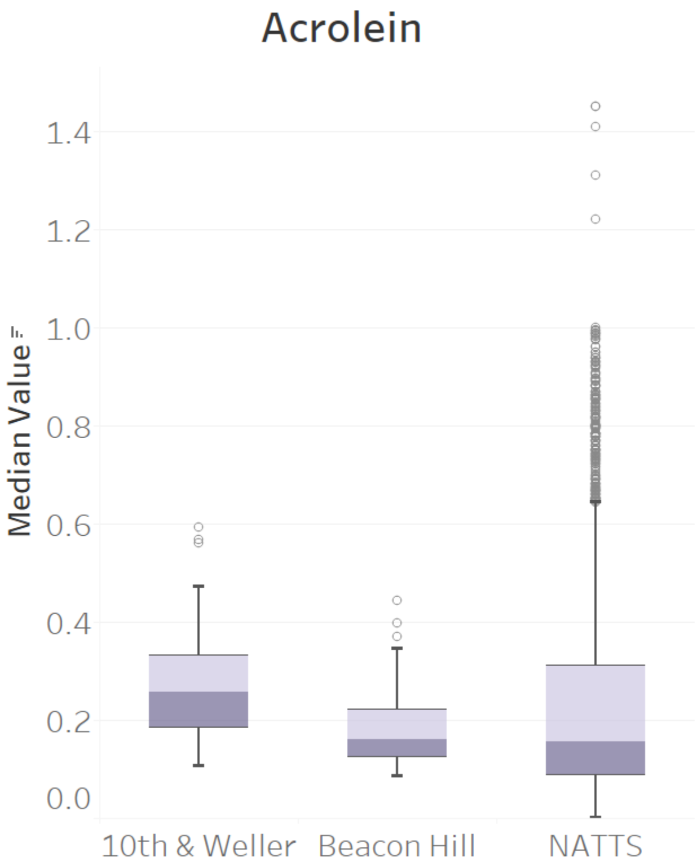
Acrolein

Only one air toxic, acrolein, failed the screen for non-cancer health effects, with measured concentrations consistently exceeding the reference concentration. Acrolein is a byproduct of high-temperature cooking of some foods, and is also emitted from cigarette smoking and the combustion of common fuels. It irritates the lungs, eyes, and nose.[19]

Unfortunately, acrolein has historically been one of the most difficult pollutants to monitor, and its measurements have had large uncertainty.[20] Therefore, for acrolein, we did not perform a trend analysis at Beacon Hill as the results are likely all within the uncertainty of the measurement.

The box plot in Figure 16 below shows a significantly higher median at 10th & Weller, while the Beacon Hill and NATTS acrolein medians are similar.

Figure 16. Acrolein box plot (in ppb)



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[19] EPA, Acrolein Hazard Summary; https://www.epa.gov/sites/production/files/2016-08/documents/acrolein.pdf.
[20] EPA, Schools Monitoring Acrolein Update, https://www3.epa.gov/air/sat/pdfs/acroleinupdate.pdf.

The community-directed sampling did not show an acrolein gradient with distances from I-5. Also, the 10th & Weller site wasn't the highest among the community-directed samples. These results may, however, support that cigarette smoking was a potential factor in some of the samples, particularly the Nisei Veteran's Hall. For more detail about these results, see the community-directed sampling section of this report.

Air toxics health risk screening

Cancer-risk screening

We compiled all valid data and screened them against Washington State established screening levels (ASIL)[21] for ambient air toxics concentrations. For carcinogens, the Washington State screening levels are set at concentrations that pose additional potential cancer risk of one in a million (for a 70-year lifetime exposure). For air toxics above the screening level, we estimated potential cancer risks using the associated unit risk factors.

We present carcinogenic health effects as an incremental probability or risk of developing cancer over a lifetime. This can also be interpreted as potential cancer cases over a population of potentially exposed individuals. For example, a one in a million potential cancer risk can be viewed as one additional cancer case for every million people equally exposed to that concentration for 70 years. This is in addition to those cancer cases that would normally occur in an unexposed population of one million people over a lifetime.

Potential cancer risk (for an individual) is estimated by multiplying a pollutant's concentration by its unit risk factor (a.k.a. inhalation unit risk (IUR), or unit risk estimate (URE)):

$$\text{Potential Cancer Risk (risk)} = \text{Pollutant Concentration } (\mu g/m^3) * \text{Unit Risk Estimate } (\text{risk} / (\mu g/m^3))$$

The URE (or unit risk factor or IUR) represents the potency of each pollutant, and is defined as "The upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air."[22] UREs are typically derived from animal laboratory studies. Human data from epidemiological or clinical studies can also provide similar dose-response information. UREs are designed to be protective of health; therefore, risks derived from UREs are upper-bound estimates. Actual risks may be lower, and possibly as low as zero. Upper-bound estimates are used to ensure that risks are not underestimated. See Appendix A for further description of the screening methodology, the unit risk factors, and the Washington State screening levels.

A number of air toxics have UREs and concentrations below their respective detection limits. That is, these air toxics may have a potential cancer risk above our screening threshold (one-per-million), but the concentrations aren't high enough for us to quantify them (because of limitations of the measurement method). We only know the upper-bound of that risk. Therefore, the risk is uncertain and cannot be reported definitively except as an upper limit. These air toxics and their respective upper-bound risks are reported in Appendix A Table A-9.

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[21] Washington State Acceptable Source Impact Levels (ASILs) as found in the Washington State Administrative Code (WAC). (2009). WAC 173-460-150. http://apps.leg.wa.gov/wac/default.aspx?cite=173-460-150.

[22] US EPA. National Air Toxics Assessment. NATA: Glossary of Terms. https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms#cancer-risk

For other air toxics that didn't have an ASIL, we found other appropriate cancer and non-cancer screening levels for other similar air toxics. See Appendix A, Table A-7. This table includes the screening value, exposure duration for comparison, and the screening level rationale.

Some of the other air toxics that we measured do not have an applicable unit risk factor or equivalent. These air toxics are listed in Appendix A, Table A-8.

Some samples were below the detection limit, but still present risk over the screening threshold. For these data sets, we included the results and used Kaplan-Meier estimations to better estimate the value. The summary statistics for the air toxics that had risks over one-in-a-million are in Table A-11 of Appendix A.

In Appendix A, Table A-10, we also list the air toxics that had risks that were below levels of concern (the ASIL, one-per-million potential cancer risk) across all the sites.

For the air toxics portion of this study, we sampled for 108 chemicals on a one-every-six-days schedule. The chemical types included VOCs, aldehydes, PAHs, and PM_{10} metal samples. Table 5 lists the toxics that had mean potential cancer risks above one-in-a-million, along with the national sites for comparison.

Table 5. Air toxics with a mean potential cancer risk over one-in-a-million and comparison with the mean National Air Toxics Trends Stations (NATTS).

	Potential cancer risk per million				
Pollutant	**10th & Weller**	**Beacon Hill**	**6th & Jackson**	**Bailey Gatzert**	**National Air Toxics Trends Stations mean**
Carbon Tetrachloride	26.5	27.4	-	-	24.8
Benzene	27.3	15.2	20.8	19.8	20.4
1,3-Butadiene	23.7	9.0	15.4	13.8	15.0
Formaldehyde	10.5	7.9	_26.9_*	8.1	19.5
Acetaldehyde	3.3	2.6	_5.5_*	2.9	5.2
Chloroform	3.1	2.8	-	-	9.1
Naphthalene	2.8	1.3	-	-	2.4
Arsenic PM_{10}	2.5	1.8	-	-	2.4
Vinyl Chloride	_2.0_**, ***	-	-	-	_NA_****
Ethylene Dichloride	_1.8_***	_1.7_***	-	-	1.9
Ethylbenzene	1.2	-	-	-	0.6
Tetrachloroethylene	_1.1_***	-	-	-	11.6
Nickel PM_{10}	1.0	-	-	-	0.7
Total	**105**	**69.6**	-	-	**126**

* = Likely biased high due to a local source of formaldehyde and acetaldehyde.

** = Artificially biased high due to blank correction technique used by the lab in analysis. This was not included in the total for risk estimate.

*** = More than half the samples were below the method detection limit.

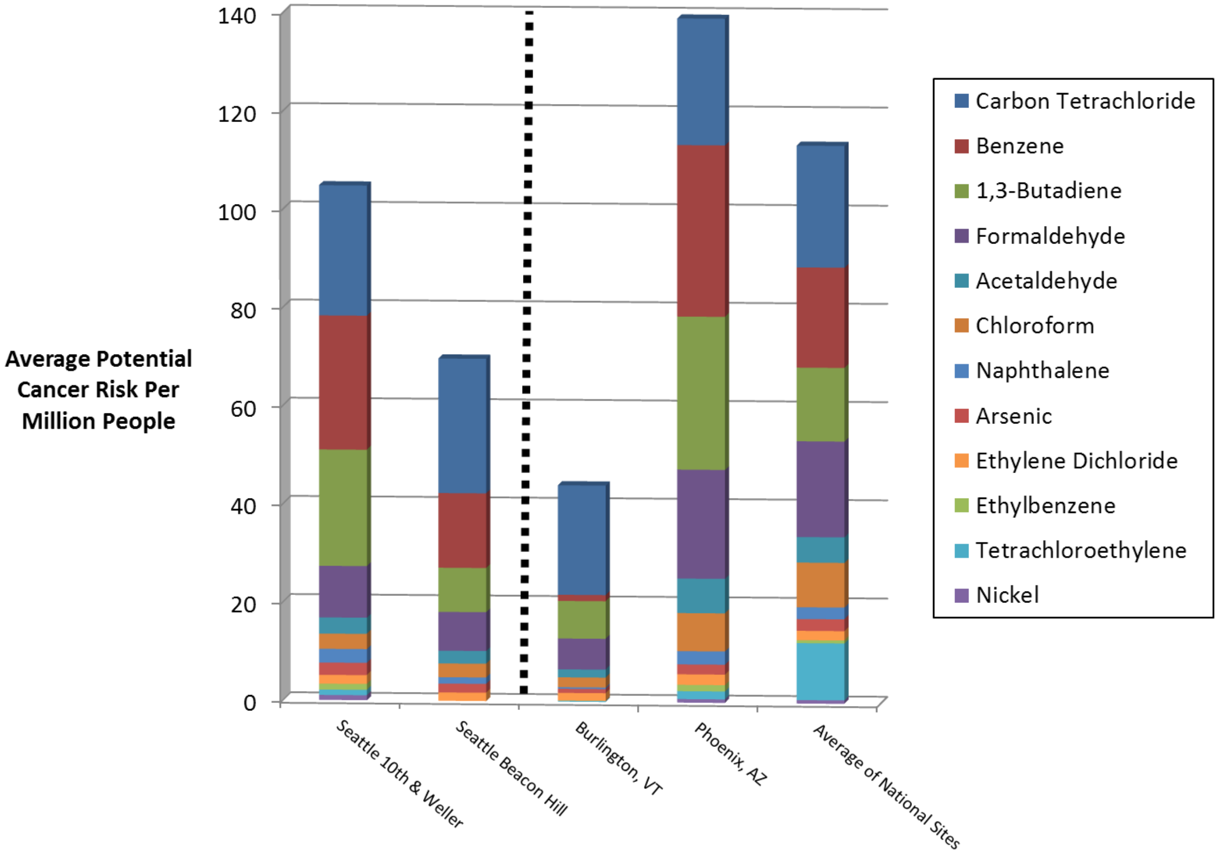
****= With known potential bias in our own data set due to vinyl chloride, we did not download this air toxic for the NATTS.

\- = Not measured at site.

For the air toxics with risks over one-in-a-million, we listed the summary statistics in the original concentration units in Table A-11 in Appendix A.

In Figure 17 below, we show the potential cancer risks at the two relevant Seattle sites (10th & Weller and Beacon Hill) for the air toxics with a potential cancer risk over one-in-a-million, along with two sites in other parts of the country for context. The national average consists of the NATTS site data that passed data completeness criteria for the years 2014-2016. Of these sites, the highest and lowest cumulative sites for these air toxics are also displayed in the figure (Burlington, VT, lowest and Phoenix, AZ, highest). Please note that many of the sites didn't pass data completeness and were excluded (including locations like Houston, TX).

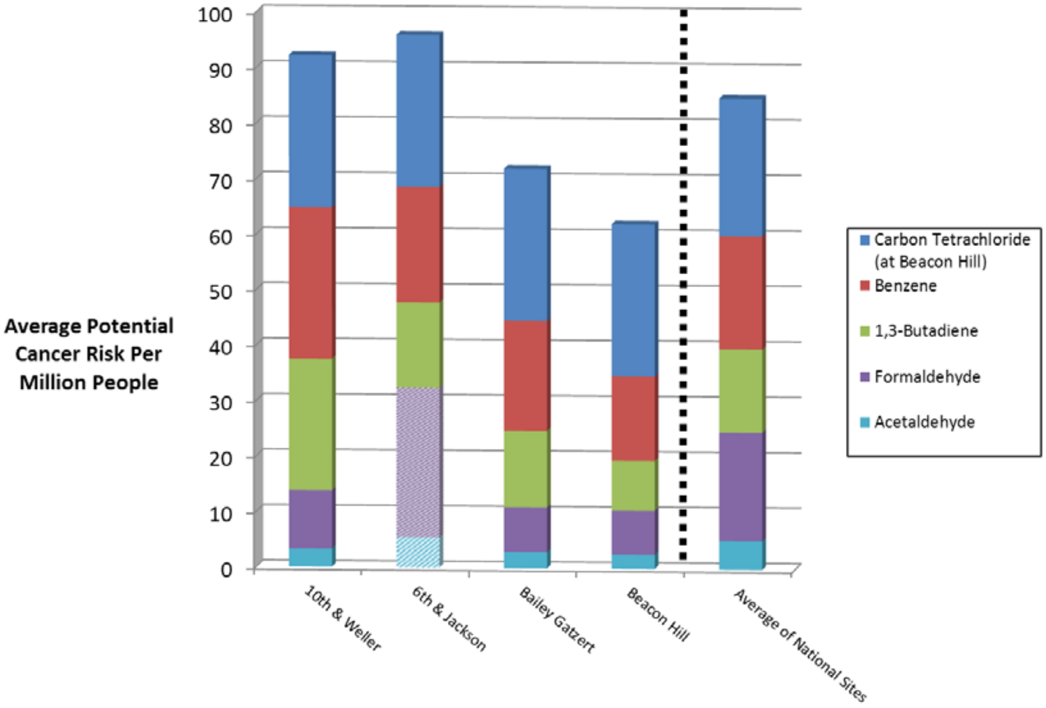
Figure 17. Air toxics with a mean potential cancer risk over one-in-a-million and comparison with other cities.



In order to save resources so that we could sample more toxics at 10th & Weller, we monitored for only the top four combustion-related air toxics in our region (benzene, 1,3-butadiene, formaldehyde, and acetaldehyde) at two additional sites (6th & Jackson and Bailey Gatzert). Since carbon tetrachloride is a "background" air toxic and is historically ubiquitous in our region, we did not monitor for carbon tetrachloride at the additional sites.

Figure 18 below summarizes the risk across the sites by looking only at these four top risk drivers. In this figure, since carbon tetrachloride is relatively uniform, we used the Beacon Hill potential cancer risk estimate for all of the Puget Sound sites (but not for the national average). With this assumption, and based on historical air toxics monitoring, this methodology covers roughly 80-90% of the non-diesel potential risk from air toxics at our sites, and presumably our region.

Figure 18. Risks from top non-diesel air toxics in the Puget Sound region compared to national averages.



Note: Formaldehyde and acetaldehyde at 6th & Jackson is likely biased high due to a local source.

For these four air toxics, the 10th & Weller site is higher than the rest, with the exception of the 6th & Jackson formaldehyde and acetaldehyde levels. Because of the anomalous aldehyde levels at 6th & Jackson, this site is only slightly higher than 10th & Weller. For more information, we investigated the aldehyde anomaly in the analysis section of this report. In summary, our investigation found that the formaldehyde and acetaldehyde at 6th & Jackson is likely due to a very-near source and isn't representative of the area. Nonetheless, we include this (likely unrepresentative) extra risk in the figure so that it can be put into context of the total and national risks.

Non-cancer risk health screening

The Agency did not evaluate pollutants for short-term/acute health effects, because data collected (24 hour samples) do not allow for this type of evaluation.

Non-carcinogenic effects are evaluated as exceeding (or not exceeding) a particular health guideline, referred to as a reference concentration. This non-carcinogen evaluation does not calculate a probability but instead determines whether a particular exposure is below the threshold at which there could be an adverse effect.

Reference concentrations (RfCs), like unit risk factors, are based on animal or human studies. RfCs are derived from toxicity studies that report the lowest concentration of inhalation exposure at which adverse (but non-cancer) health effects occur, or the highest concentration at which no such adverse effects are observed, or both. This concentration is then divided by factors to account for uncertainties and variability such as extrapolating from animals to humans, from healthy adult individuals to sensitive individuals, or from sub-chronic to chronic exposures.

A hazard quotient is a ratio of the estimated exposure concentration, divided by a reference concentration (RfC) deemed to have no adverse effect from a lifetime exposure to that level.

Hazard Quotient (HQ) = Pollutant Concentration (µg/m^3)/ Reference Concentration (µg/m^3)

A hazard quotient of less than 1 is typically considered to not present health risk, per pollutant. The Agency factored in an additional safety factor, and considered hazard indices less than 0.1 to not present health risk. This is to account for the fact that people are exposed to multiple air toxics simultaneously, and to be protective.

Acrolein was the only air toxic with a hazard quotient greater than 1. Formaldehyde and manganese had a hazard quotient greater than 0.1 and less than 1.0. Their reference concentrations as established by EPA IRIS or OEHHA and adopted by the Washington State Department of Ecology are shown in Table 6 below. All other air toxics hazard quotients were well below 0.1, as shown in Table 7.

Table 6. Reference Concentrations (RfC) for Air Toxics with Average Hazard Quotient >0.1

Chemical	**RfC (mg/m^3)**	**Target Organ for Critical Effect**	**Source**
Acrolein	2.5E-05	Nasal epithelium	IRIS
Formaldehyde	9.0E-03	Respiratory system, eyes	OEHHA
Manganese	9.0E-05	Nervous system	OEHHA

Table 7. Average Hazard Quotients for all Pollutants over the Non-cancer Screening Level

Site	Acrolein	Acetaldehyde	Arsenic PM$_{10}$	Benzene	Carbon Tetrachloride	Formaldehyde	Manganese PM$_{10}$	Nickel PM$_{10}$
10th & Weller	1.8	<0.01	0.05	0.02	0.02	0.20	0.13	0.04
Beacon Hill	1.2	<0.01	0.04	<0.01	0.02	0.15	0.05	0.02
6th & Jackson	NA	0.01	NA	0.01	NA	0.50*	NA	NA
Bailey Gatzert	NA	<0.01	NA	0.01	NA	0.15	NA	NA

* = Likely biased high due to local source of formaldehyde treated products.

NA = not sampled.

Wildfire impacts

During the year of sampling we had significant wildfire smoke events in our region. In Table 8 below, we list the wildfire impacted days that overlapped our sampling schedule, with a qualitative impact on pollution levels that we expect. The wildfire smoke increased the fine particle concentrations and appeared to influence ozone concentrations, both increasing and decreasing ozone from expected values. It is also reasonable to expect that the wildfire plume would impact NOx, black carbon, and a range of PM elements, VOCs, SVOCs, aldehydes, and PAHs.

Table 8. Wildfire smoke impacts

Scheduled sample date	Expected level of wildfire impact based on regional fine particle levels
8/5/17	Minor
8/11/17	Significant
8/29/17	Significant
9/4/17	Minor
9/16/17	Significant

We conducted a sensitivity analysis comparing annual averages with and without these potentially impacted days. For most air toxics, we found annual levels to be about 4% higher with these days included compared to without these days. To be conservative, we have chosen to include these days in the analysis and summaries.

Fixed site monitoring results

Basic averages and patterns

Meteorology

In general, weather conditions (meteorology) have a strong influence on pollution concentrations and patterns. The study area is no exception. The study area is located in the saddle point (valley) between a ridge in the southeast portion of Seattle proper (often referred to as Yesler Terrace) and the north end of the ridge of Beacon Hill. In general, winds come from the south-southwest and west or the northeast. In the winter, southerlies (from the south) and easterlies are more common, while in the summer, westerlies are more common. Winds are seldom observed from the north to northwest, nor from the southeast to south due to the blocking effect of the terrain. See Figure 19 through Figure 21 for the wind roses at the 10th & Weller fixed site monitor. In these figures, the distance from the center indicates the percent of total hours that the wind was from that direction and the shade corresponds to the speed, with darker shades being stronger.

From November through about March, most of the region has low stratus clouds, with frequent light rain, and temperatures in the 30s to low 50s, with a few days of freezing temperatures and snow. During the summer (roughly June-Sept) temperatures range from the 60s to low 80s, with few clouds and low humidity. The only unusual meteorological event during the campaign was the substantial impact from regional wildfires in August and September, which was mentioned previously.

Figure 19. Wind rose at 10th & Weller for the full campaign duration.

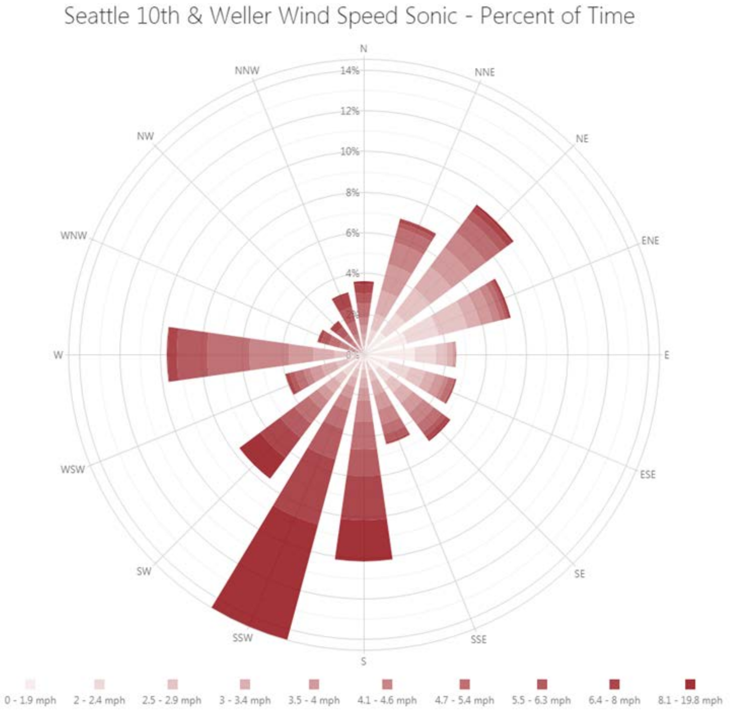


Figure 20. Wind rose for winter (Nov-March).

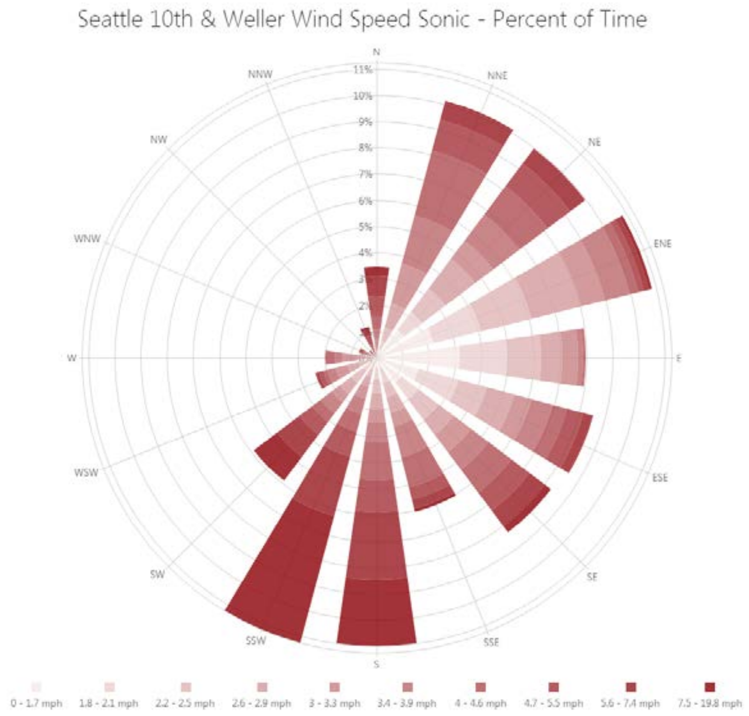
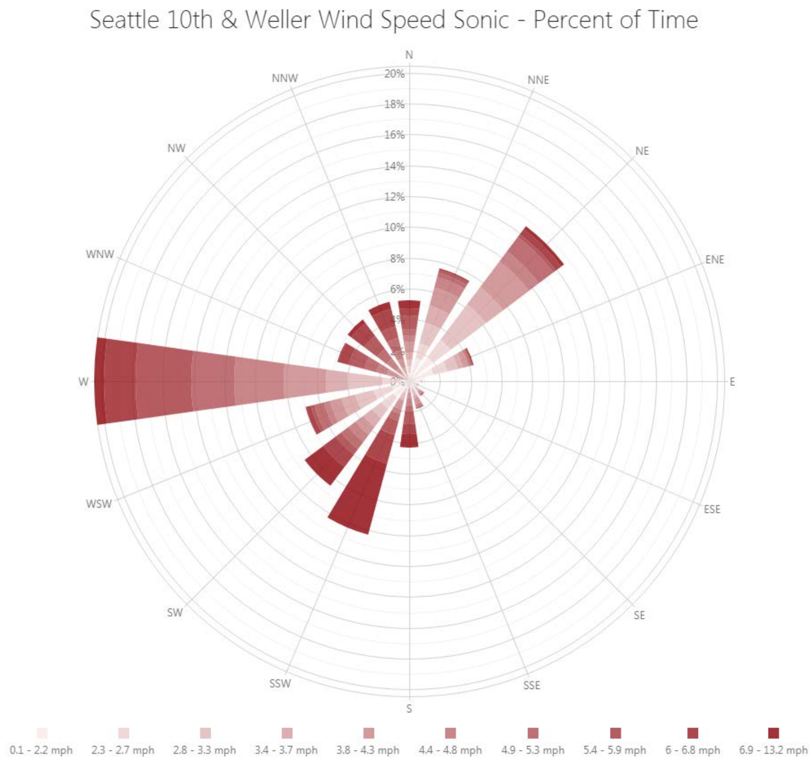


Figure 21. Wind rose for summer (June – Sept 15)

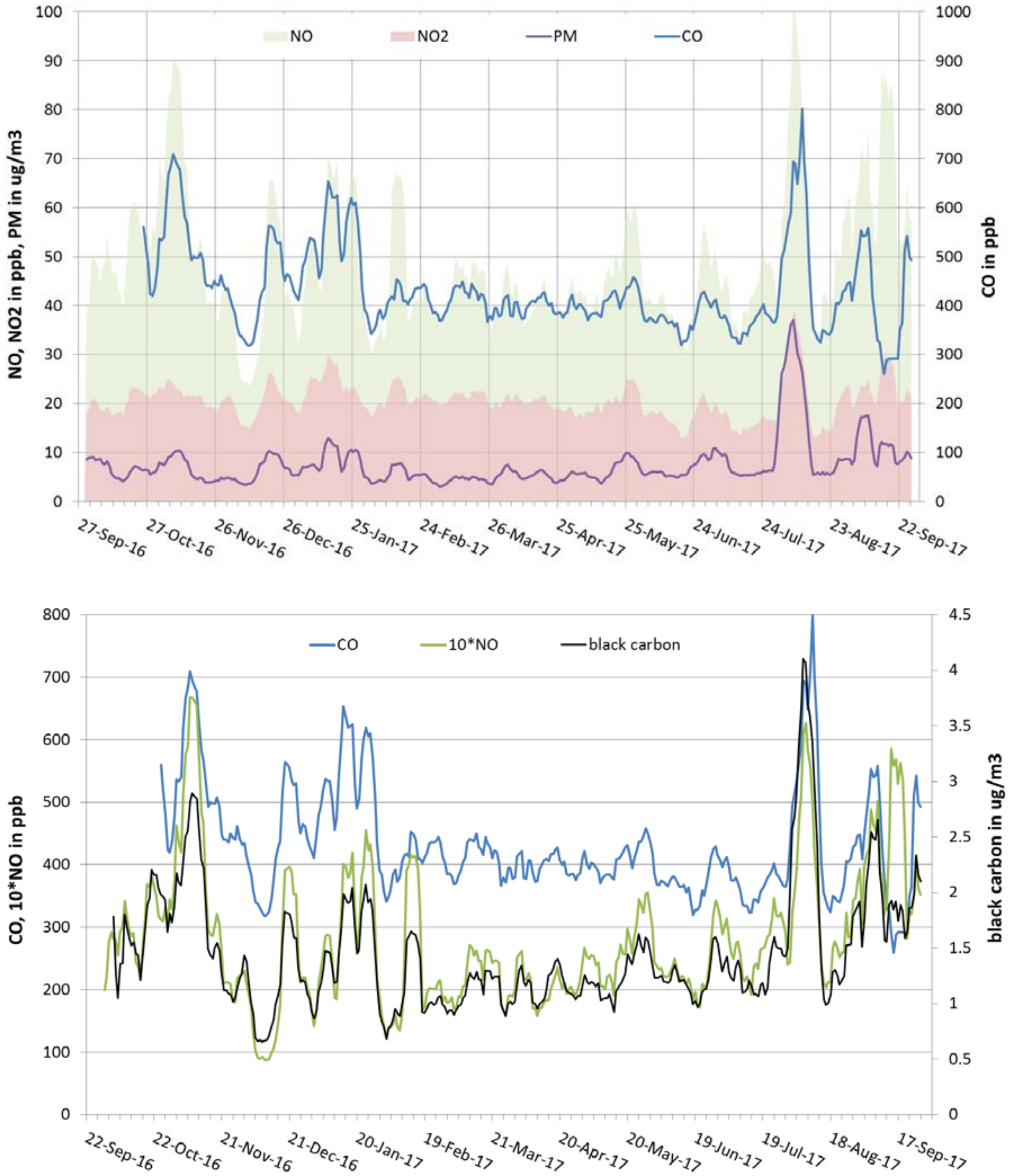


Stagnation events are common in both the winter and the summer. In the winter, many of the coldest days will be accompanied by (and actually made even colder by) clear skies and light to stagnant winds. A similar pattern occurs in the summer, although the temperatures are higher. At nighttime under these conditions, there is very little wind and very poor mixing, and pollutant concentrations can rise rapidly. The stagnation is usually relieved as sunlight warms the surface, typically within an hour or two of sunrise. During the campaign, about 3.5% (~300 hours) had average winds speeds less than 1.5 mph.

Campaign time series and basic statistics for pollutants

The campaign measured more than 100 air toxics, pollutants, or pollutant fractions at three fixed sites and five temporary sampling locations. Some additional statistics and plots are included in Appendix A, while only the most important and revealing parameters are shown here. Figure 22 shows a full time series at 10th & Weller of NO, NO_2, $PM_{2.5}$ fine particulate matter, and CO. In this figure, the plotted values are 7-day running averages because the variability in the daily values was great enough that they would be too visually cluttered to read. Also, note that NO and NO_2 are stacked so that that the top of the NO line would be the value of NOx. (NO_x is defined as NO + NO_2).

Figure 22a and b. Time series of 7-day running averages for the full campaign at 10^{th} & Weller.



Additionally, the campaign conducted continuous measurements with less expensive, portable instruments (MOB boxes) at the 10th & Weller site and two temporary fixed sites, 6th & Jackson, and Baily Gatzert. Figure 23 shows similar time series for the MOB measurements of $PM_{2.5}$ fine particles, CO, and NO.

Figure 23. Time series of 7-day running averages for MOB box data at 10th & Weller (10W), 6th & Jackson (6J), and Bailey Gatzert (BG).

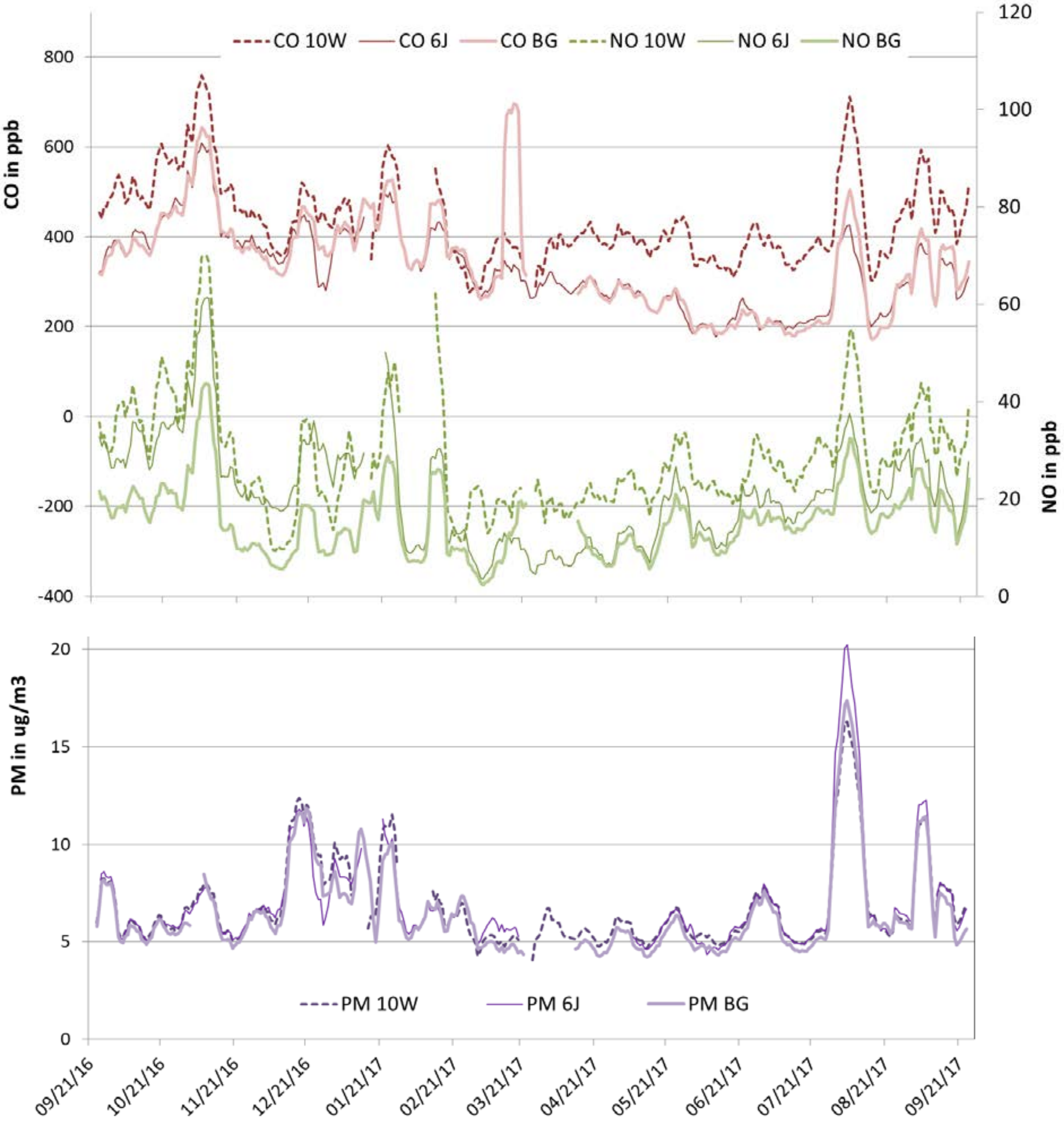


Table 9 summarizes the statistics for the air pollutants at the 10th & Weller site for which there are NAAQS (the criteria pollutants $PM_{2.5}$, CO, NO_2), along with two characterizations of the particulate matter ($PM_{2.5}$): black carbon (BC), and UV absorption (UV). These $PM_{2.5}$, CO, and NO, NO_2, NOx measurements were made with regulatory compliant instruments.

Table 9. 10th & Weller criteria pollutant results for daily averages.

	$PM_{2.5}$ µg/m^3	CO ppb	NO_2 ppb	NO ppb	NOx ppb	BC (PM) µg/m^3	UV (PM) µg/m^3	Temp F	WS mph
count	366	322	366	366	366	357	357	369	369
min	1.56	128	6.0	0.79	10.1	0.27	0.26	28.9	1.8
25%ile	4.30	345	15.7	14.4	30.7	0.83	1.03	45.6	3.4
median	5.76	405	20.3	22.6	43	1.2	1.45	53.1	4.1
75%ile	7.82	470	24.4	35.5	59.6	1.79	2.12	62.3	5.2
max	56.0	1053	55.4	124	168	5.92	7.75	78.3	10.7
average	7.5	433	20.7	28.2	48.9	1.45	1.78	53.1	4.5

Table 10 summarizes the statistics for the MOB instruments for the campaign.

Table 10. MOB instrument results for daily averages.

	10th & Weller			6th & Jackson			Baily Gatzert		
	$PM_{2.5}$ µg/m^3	CO ppb	NO ppb	$PM_{2.5}$ µg/m^3	CO ppb	NO ppb	$PM_{2.5}$ µg/m^3	CO ppb	NO ppb
count	372	372	372	372	372	372	372	372	372
min	2.7	75	4.1	2.7	74.5	3.1	2.7	75	1.2
25%ile	4.8	329	18.1	4.5	262	12.6	4.5	210	8.1
median	5.5	387	26.0	5.5	331	21.0	5.2	303	15.0
75%ile	6.8	465	40.0	6.7	411	28.6	6.5	387	23.1
max	21.3	1006	119	21.4	879	103	21.4	2321	84.4
average	6.1	402	30.6	5.9	345	23.7	5.8	323	19.8

Daily patterns for pollutants

For pollutants that were measured with a frequency of hourly or greater, we can average the values by time of day and examine diurnal patterns. Figure 24 shows the diurnal pattern of key pollutants at the 10th & Weller site for the winter and the summer. In this analysis we define summer as May 1 – Aug 31, and winter as Nov 1 – Feb 28. The overall diurnal pattern of the full campaign is between the winter and summer patterns, but is not shown here.

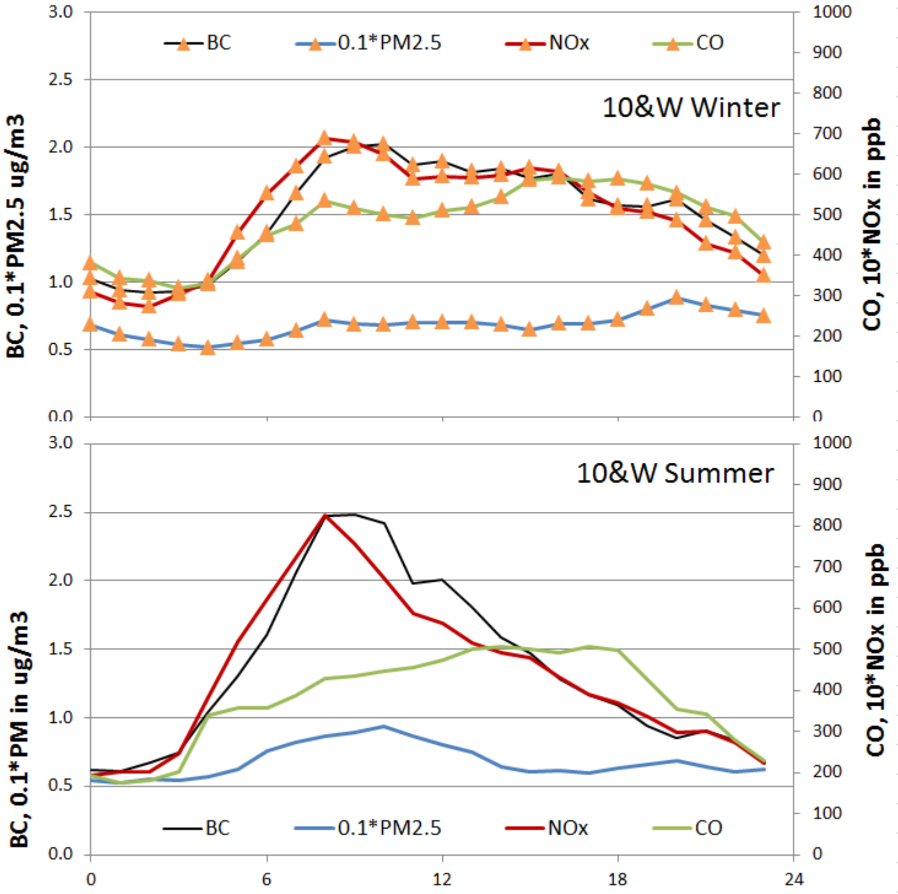
The second plot of diurnal patterns, Figure 25, compares NO across the three fixed sites. In all of these figures, a diurnal pattern is clear for most pollutants. The pollutant levels begin to rise in the early morning, peak during the day, and then drop off in the evening. The relative size of the daytime peak is small for $PM_{2.5}$, and the daytime peak is also generally somewhat lower at the temporary sites, 6th & Jackson, and Bailey Gatzert for NO. Note that the NOx and the black carbon are strongly correlated at 10th & Weller. This agrees with our expectation of mobile source on I-5, particularly diesel vehicles, being the dominant pollution source in the near-road environment. CO is not well correlated to both NO and black carbon, suggesting a different source or source type. The diurnal pattern of NO at 6th &

Jackson and Bailey Gatzert suggests a similar source as 10th & Weller, but with a weaker or more diluted impact.

The third figure of diurnal patterns, Figure 26, shows a portion of the black carbon (BC) that can be attributed to the burning of biomass, in contrast to a diesel internal combustion engine. This measure could also be sensitive to other emissions in which the combustion is poor or there is smoldering or smoking, such as cooking. In the winter, a diurnal pattern of biomass burning black carbon (BB BC) is clear, with levels that rise in the late afternoon and peak in the late evening. This pattern is consistent with residential wood burning activity and emissions profiles in other areas.

Figure 24 shows the diurnal patterns for pollutants using the regulatory CO, NOx, and $PM_{2.5}$ instrumentation. The top set of lines with triangle markers indicate winter values and the bottom set are summer values. BC indicates black carbon, measured by a 7-channel aethalometer.

Figure 24. Diurnal patterns at the 10th & Weller site.



In Figure 25, below, “10&W Ref” refers to the reference (regulatory) instrument at the 10th & Weller site. The other NO observations are from the MOBs. The top set of lines with triangle markers indicate winter values and the bottom set are summer values.

Figure 25. Diurnal pattern of NO at the three fixed sites.

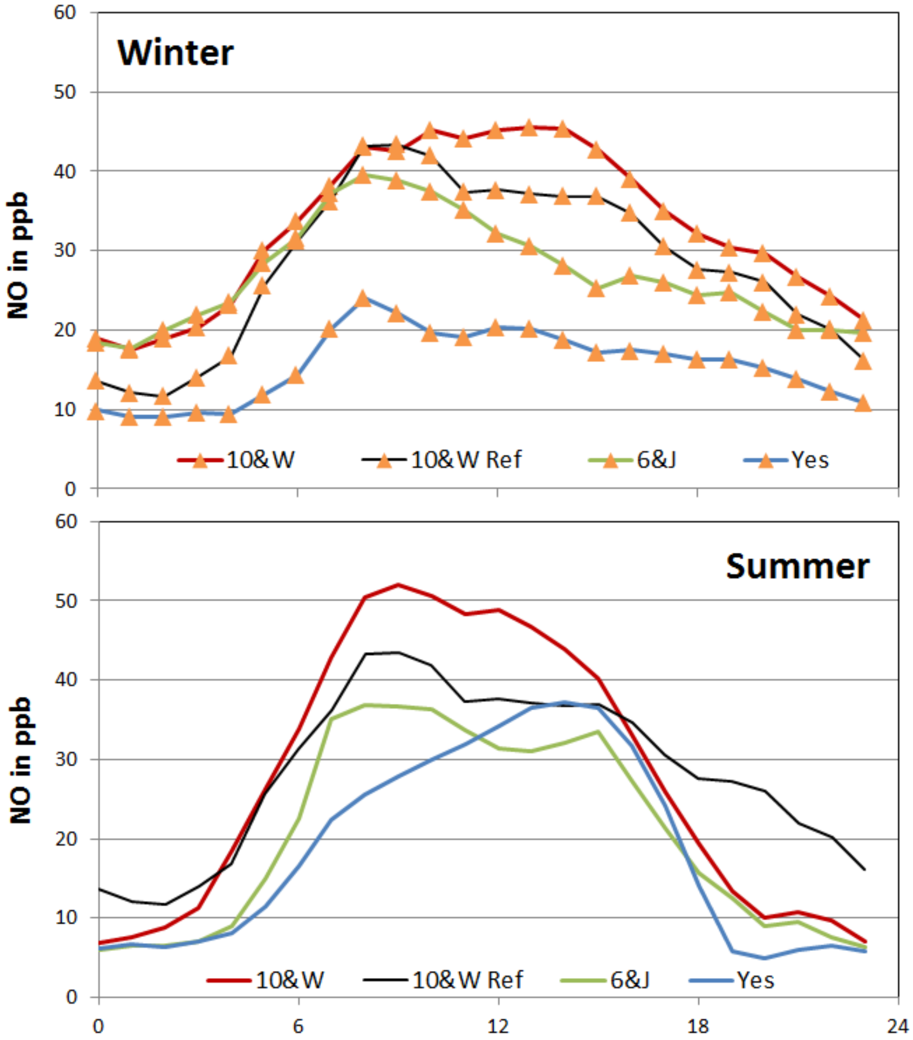
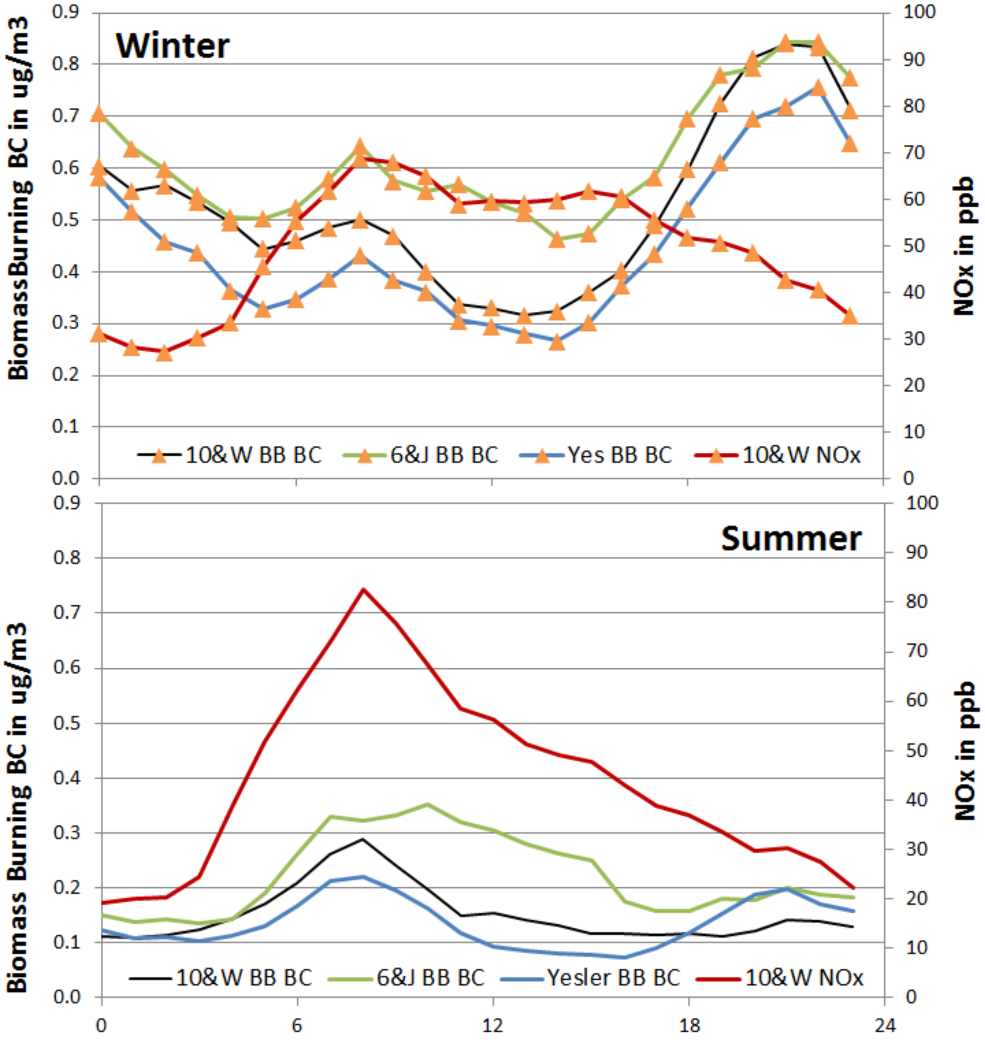


Figure 26 shows diurnal patterns of a portion of the black carbon (BC) that can be attributed to burning of biomass (BB BC). This value is obtained by subtracting the BC signal from the UV signal. This is often used to indicate wood burning in fireplaces or stoves, but, it may also be sensitive to particles from other. The top set of lines with triangle markers indicate winter values and the bottom set are summer values.

Figure 26. Diurnal pattern of biomass burning black carbon.



Directional patterns for pollutants

Pollutant concentration can also be averaged as a function of wind direction (aka pollution rose). For pollutants with sampling frequencies of hourly or greater, this can be done by grouping and averaging by wind direction bin as reported by the wind direction sensor. For pollutants that are sampled as a daily composite, which includes the toxics and speciation, daily average pollutant concentration must be binned by a vector average wind direction for the day. Also, wind direction and speed were only measured at the 10th & Weller site, so the wind direction and speed at the other sites (6th & Jackson, Yesler, and the community directed canister locations) may not be accurate, but are likely in the same general range. In the pollution rose figures, the distance from the center indicates the relative amount of pollution when the wind was from the respective direction, scaled to the maximum.

Figure 27 shows the core regulatory observations ($PM_{2.5}$, NOx, CO) along with the black carbon, at the 10th & Weller site. The direction patterns all show a maximum from the west-southwest, with much lower levels coming from the north through the east, and to the south-southeast. Black carbon and NO are directionally well correlated. While the CO and $PM_{2.5}$ do have maxima from the west-southwest, the CO peak is broader, and the $PM_{2.5}$ has a modest local maxima (peak) to the east-northeast.

The second pollution rose (Figure 28) shows the wintertime biomass burning black carbon (BB BC) burning signal (also described in the previous section) along with the 10th & Weller NOx. The biomass BC signal at all three sites has a distinct peak to the east-northeast, while the 10th & Weller NOx, by contrast, still shows the maximum to the west.

The third pollution rose (Figure 29) is the summer version of Figure 28. Here, the majority of the biomass burning BC, and the NOx, come from the west-southwest. And, there is no longer a local maxima to the east-northeast, but there is one to the east-southeast.

Figure 27. Pollution rose for 10th & Weller $PM_{2.5}$, NO, black carbon, and CO.

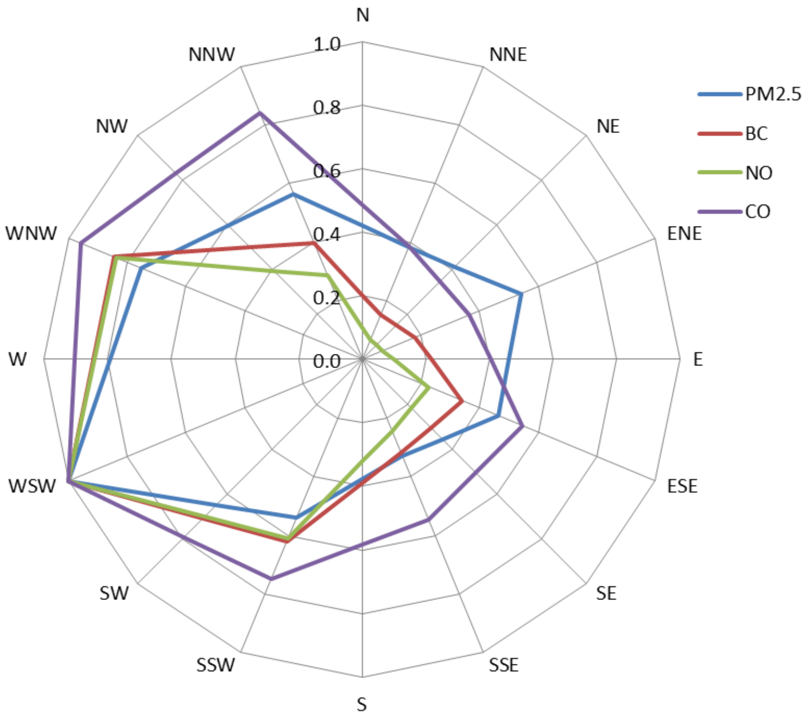


Figure 28. Winter biomass burning black carbon (BB BC) at the fixed sites.

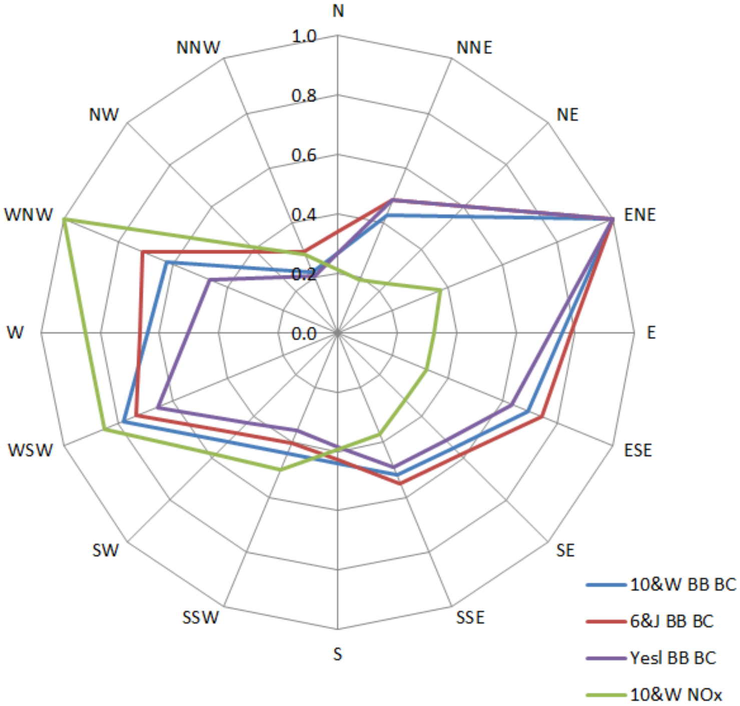
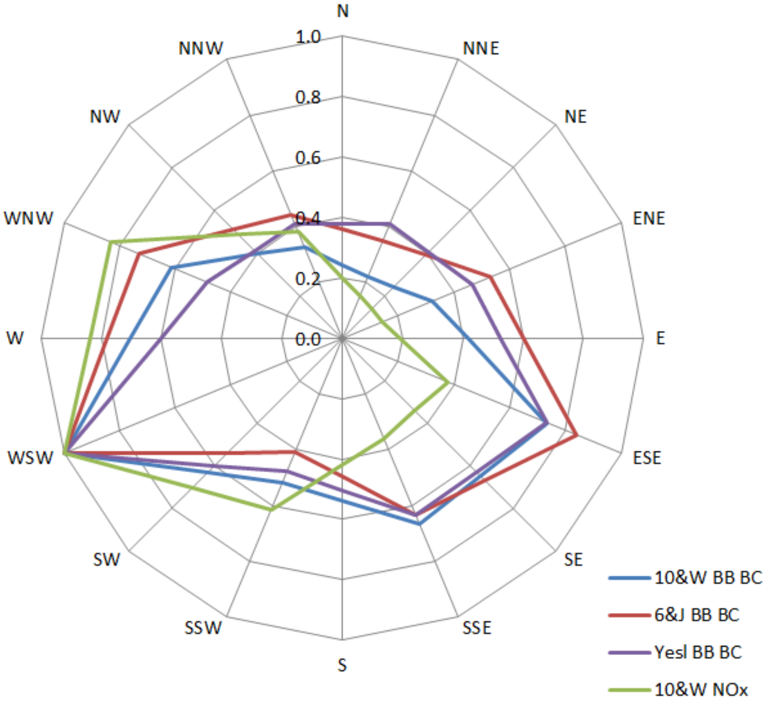


Figure 29. Summer biomass burning black carbon (BB BC) at the fixed sites.



Sidewalk mobile monitoring

Description of mobile runs

In order to look at how pollution changed across the neighborhood we walked around the area with two different air sensors. We measured ultrafine particles with an Enmont PUFP C100 and black carbon with an AE51 MicroAeth. Both ultrafine particles and black carbon are markers for diesel particulate matter. We limited our walking speed to approximately one block a minute since the MicroAeth only records one data point a minute. The Enmont records data once a second. We conducted seven walks around the neighborhood. Walks took one hour, on average, and occurred in the morning. The weather on the days of the walks was either sunny or partly cloudy. We summarize the results in a map of the median value of all data collected within each grid. This allows us to see whether there were any hotspots and whether pollution levels were elevated near I-5.

Figure 30 shows a gridded map of the median ultrafine particle counts. Ultrafine particle counts (UPC) were elevated (purple) near I-5 and were lower further away from I-5 (yellow to white). The area east of I-5 had fewer ultrafine particles than the area west of I-5.

Figure 31 shows a similar map for the black carbon measurements. The black carbon concentrations were distributed similarly to UPC, with the highest levels near I-5, lowest levels to the east and northeast, and somewhat higher values to the west of I-5 compared to east of I-5. This is consistent with our expectation as both ultrafine particles and black carbon are markers for diesel particulate matter, of which, vehicles on I-5 are a major source. We did not find any unexpected hotspots, which suggests that our fixed-site monitors provided sufficient coverage of the neighborhood.

Figure 30. Map of median ultrafine particle counts.

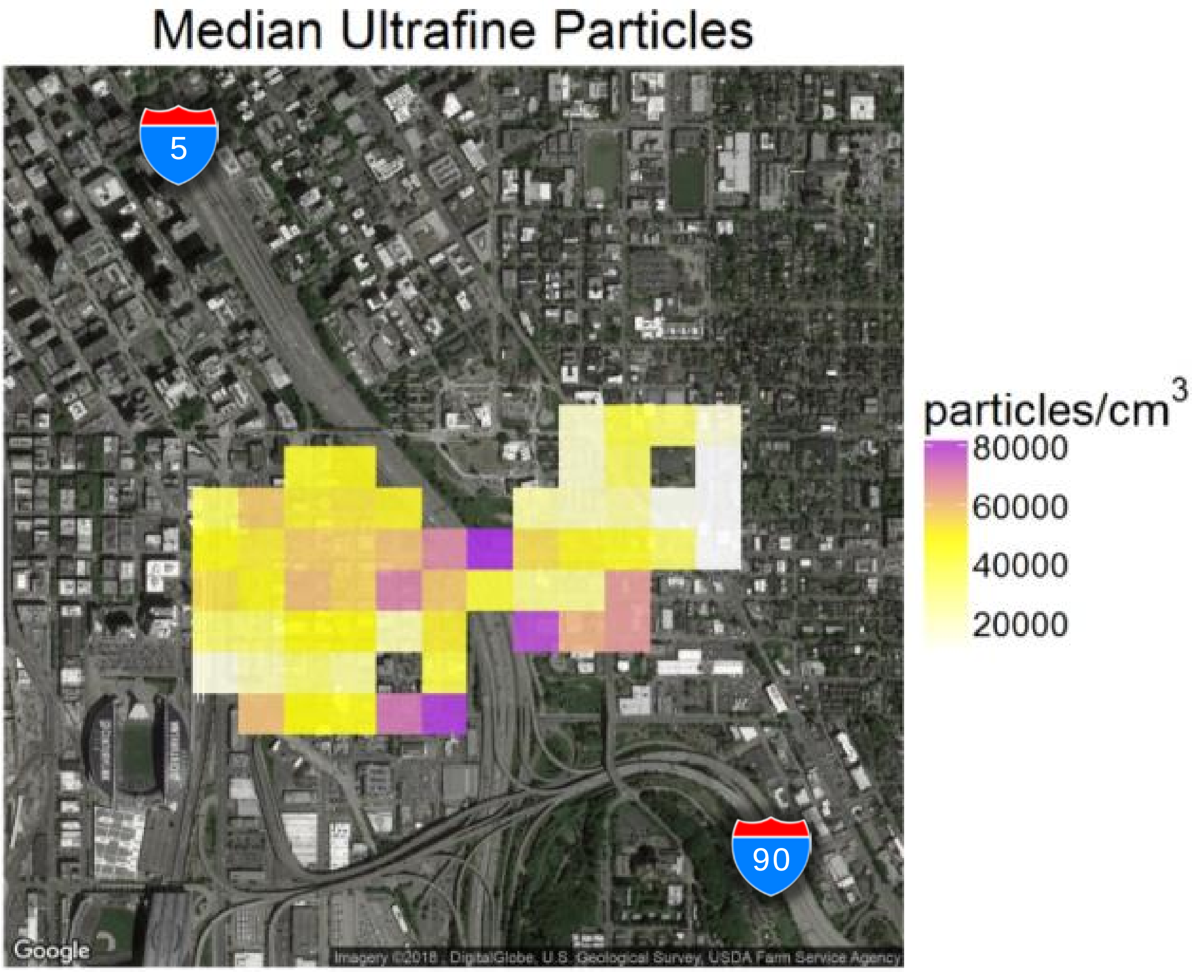
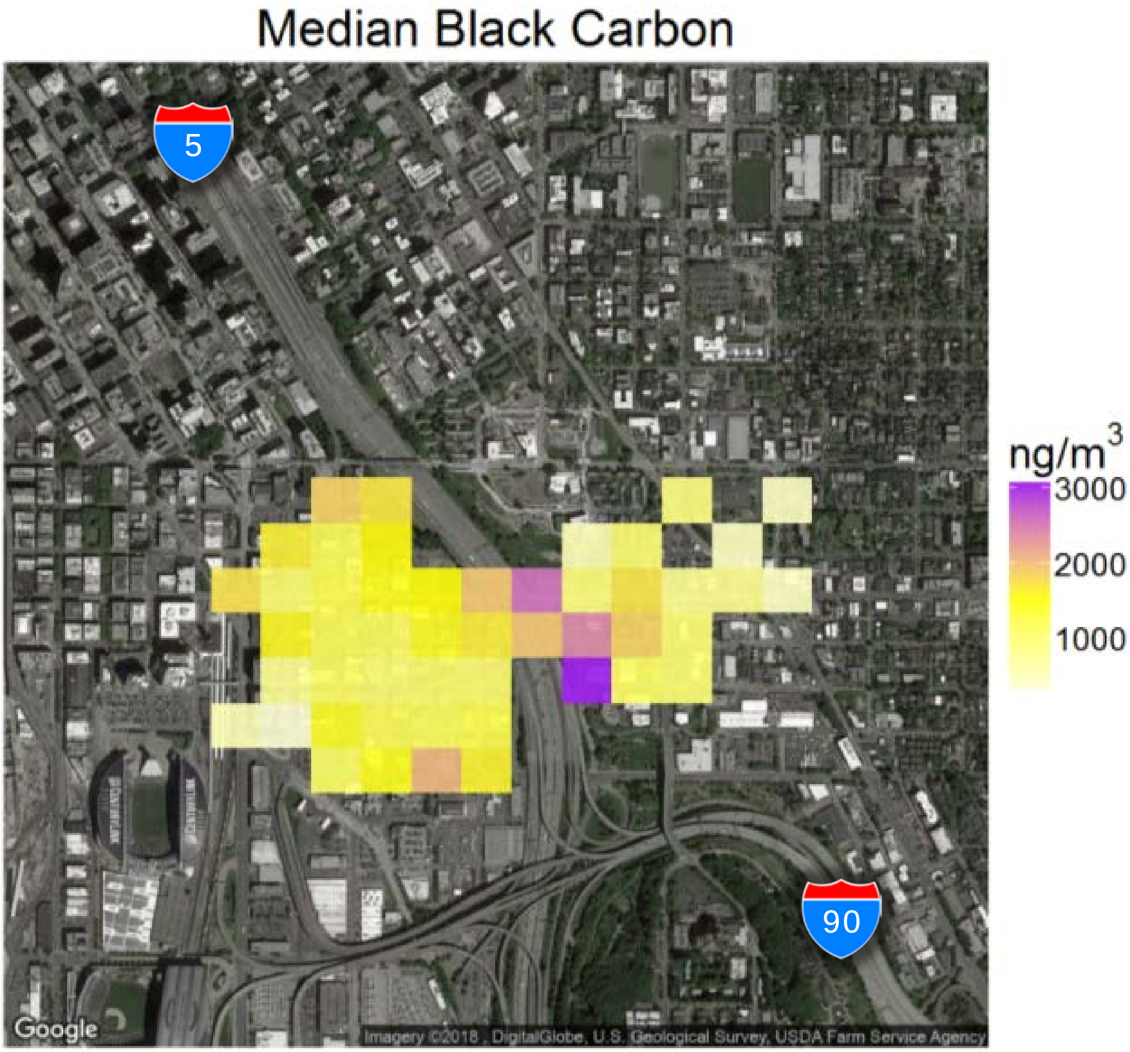


Figure 31. Map of median black carbon concentration.



Modeling Results

We implemented two modeling tools to help our analysis of potential sources, and to test our assumptions of the major sources and influences on the study area. The first modeling tool is the receptor modeling technique called positive matrix factorization (PMF). 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. Further details are below and in Appendix B.

The second modeling tool we used was the regulatory dispersion model AERMOD. AERMOD is the EPA preferred model for assessing if sources comply with air quality standards and regulations. The model simulates the dispersion of emissions in actual meteorological conditions. It predicts the steady state and long-term average concentration across the modeled domain. For the Chinatown – International District study area, we explicitly modeled the biggest $PM_{2.5}$, CO, NOx, and black carbon sources that we could identify. This included I-90 and I-5, and local restaurants. The roads were modeled as area sources (which is the accepted conventional approach) rather than individual vehicles. The restaurants were modeled individually with average emission profiles, emission factors, and activity levels applied from limited online data sources. Further details are below and in Appendix C.

Positive Matrix Factorization

We explored PMF solutions for data collected at the 10th & Weller site. The data set included criteria pollutants, PM_{10} metals, $PM_{2.5}$ speciation, PAHs, VOCs, and aldehydes. All of data were from 61 dates corresponding to the speciation 1-in-6 schedule. The full list of species measured (>100) was reduced for this analysis because a number of species had high fractions of values below their detection limits. In addition, several sampling days were missing one or more species, and the carbon fractionation data (OC1-4, EC1,2) from Sept 2017 were not yet available at the time of analysis. For missing values, the median of the remaining data was substituted and the uncertainty was set at four times the uncertainty of the median.

We explored solutions that included 5-11 factors. Ideal PMF applications use at least 150-200 sample dates with 20 or more species. Due to the shorter duration of this project, we had only 61 sample dates, although with 81 species/analytes. So, it is expected that the power or sensitivity of the data set will be reduced from previous analyses that found 8-11 factors in this part of Seattle [23,24,25,26] .

For our dataset, we found that PMF solutions with more than seven factors were not robust or stable. Ultimately, six factors was greatest number that we could resolve with error/uncertainty that was within modeling guidelines. While the default 6-factor solution was fairly robust, not all of the factors seemed unique or distinct and they did have some uncertainty (called rotational ambiguity). Two constraints were applied to force the factors to be more similar to known emissions, and we found that these did not degrade the robustness. See Appendix B for further details.

Figure 32 below shows the fingerprint of the 6-factor PMF solution. In this figure, each species/analyte/chemical is shown as a "stacked bar." The relative contribution (out of 100%) of each factor to the total is indicated by the color. Note that not all factors are present in each species.

Figure 33 and Figure 34 show time series of the strength of each factor. For these plots, the contribution of each factor has been scaled so that the average equals one. The two factors with seasonal patterns (fresh wood smoke and summer) and the very episodic factor (smoldering episodes) are shown in Figure 33 and the remaining three factors that don't have seasonal trends are in Figure 34.

For PMF analysis, we labeled the factors based on 1) the chemicals or species that dominated the factor, 2) the pattern, trend, or behavior over time, or 3) a combination of the two. We identified the first factor, fresh wooksmoke, because of the strong UV-BC component, its presence during the heating season, the organic carbon (OC), the suite of benzo-PAHs, and several additional PAHs. The seasonality of the wood smoke factor can be seen in the time series of the strength of each factor in Figure 33.

The second factor, smoldering episodes, was dominated by four specific dates in which all pollution levels were high, but there was a great deal of organic carbon (OC1) that did not fit into another factor. The high OC1 content (the lightest, most volatile fraction) suggests emissions from sources when or where the combustion quality was very poor, or smoldering. This could include especially poor quality biomass burning (wood burning), smokey startup of cooking stoves, cigarette smoking, or smoldering wildfires.

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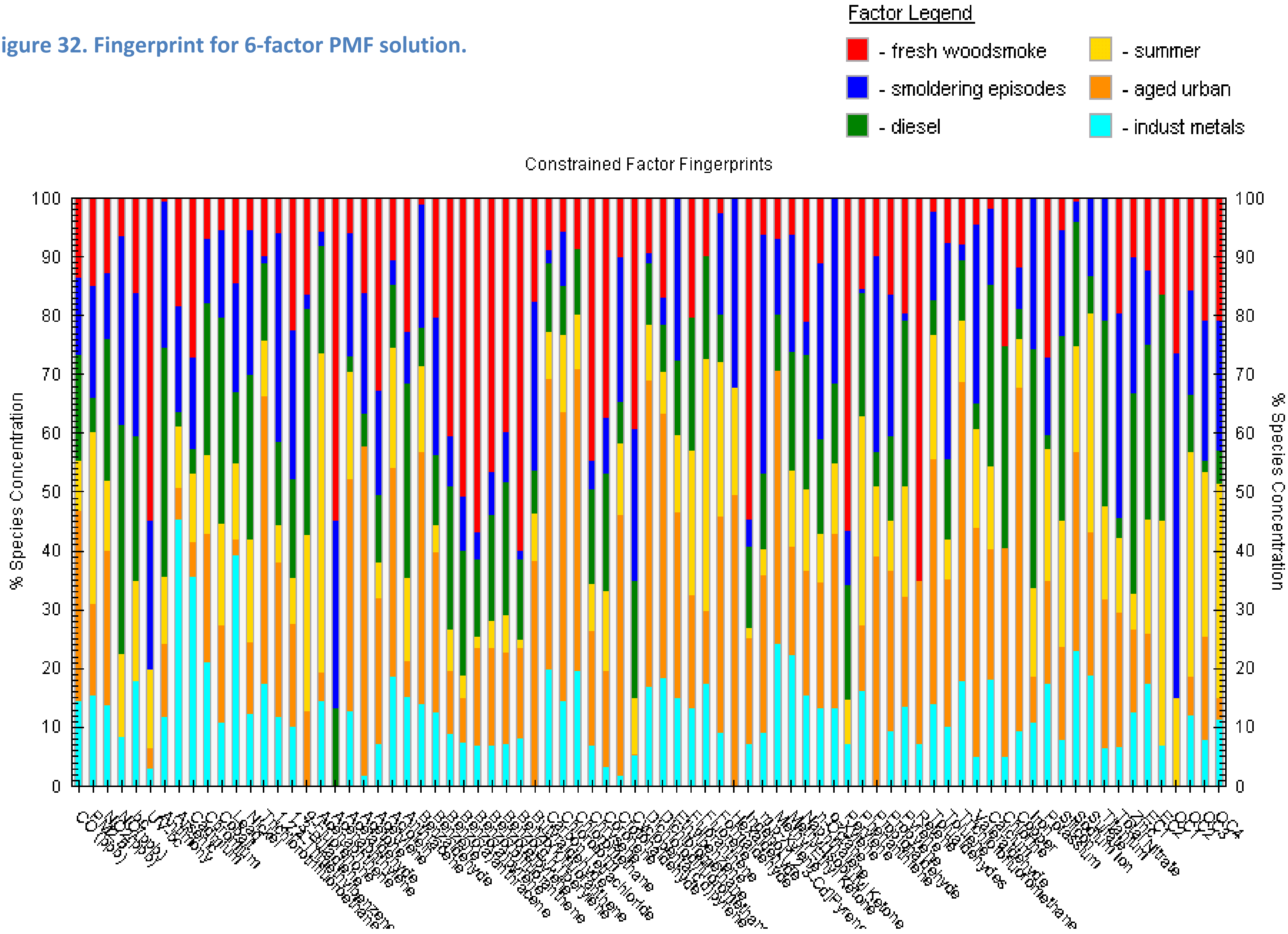
[23] Kotchenruther, R., (2013) A regional assessment of marine vessel $PM_{2.5}$ impacts in the U.S. Pacific Northwest using a receptor-based source apportionment, Atmospheric Environment 68, 103-111.
method

[24] Kotchenruther, R., (2017). The effects of marine vessel fuel sulfur regulations on ambient $PM_{2.5}$ at coastal and near coastal monitoring sites in the U.S., Atmospheric Environment 151, 52-61.

[25] Kim, E., and P.K. Hopke, (2008). Source characterization of ambient fine particles at multiple sites in the Seattle area, Atmospheric Environment 42, 6047– 6056.

[26] Wu, C., T.V. Larson, S. Wu, J. Williamson, H. H. Westberg, L.J. Sally Liu, (2007), Source apportionment of $PM_{2.5}$ and selected hazardous air pollutants in Seattle, Science of the Total Environment 386, 42–52.

Figure 32. Fingerprint for 6-factor PMF solution.



The third factor, “summer” is strongest in the summer and early fall, weak in the winter, and includes carbon fractions that are not explained by the other year-around factors. This factor could reflect sources that are upwind in the summer (further to west) when westerlies are more prevalent and stronger. This factor has a strong sulfate component and could be similar to the “Secondary sulfate” factor identified by Kotchenruther (2015).[27]

The remaining factors have a fair amount of overlap in their content of carbon fractions, aldehydes, and criteria pollutants and are present throughout the whole study period. Nonetheless, there are distinguishing characteristics that correspond to realistic potential sources or source categories. See Appendix B for pie charts of contributions to several key species. The “indust metals” factor is dominant for arsenic, cadmium, and lead. The “aged urban” factor does not have any NO, BC, OC1, and EC2, but does have CO and OC2-4, and some EC1, and so resembles gasoline vehicles. But, this factor has additional strong signal from copper, sodium, chlorine, and halogenated background chemicals, so is likely a mixture of the two (or the “unidentified urban” factor reported by Kotchenruther. It is also interesting to note that aged urban and industrial metals factors are inversely correlated (slope ~ -1.4, r^2=0.48).

The remaining factor, “diesel”, has strong signals from NO, BC, EC1, and EC2, which are good markers for diesel highway vehicles. Also, the “aged urban” and “indust metals” factors are mostly complimentary (orthogonal), which suggests there may be another factor, or there may be systematic discrepancies in similar measurements of the same species, e.g. BC vs EC1, and EC2.

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[27] Kotchenruther, R.A. (2015). The effects of marine vessel fuel sulfur regulations on ambient $PM_{2.5}$ along the west coast of the U.S., Atmospheric Environment 103 (2015) 121-128.

Figure 33. PMF factors 1-3 time series

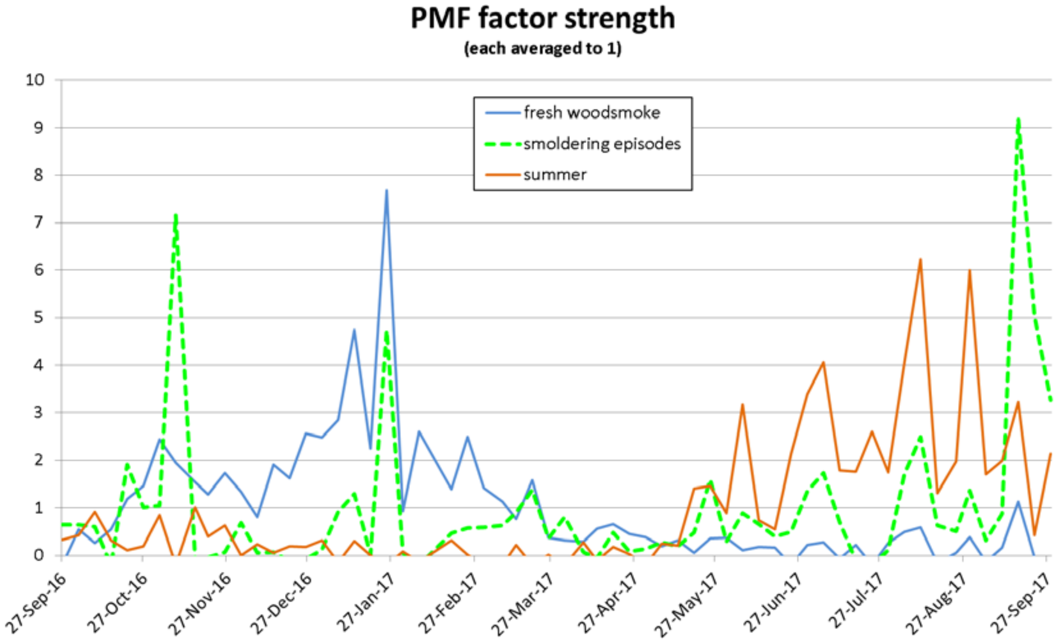
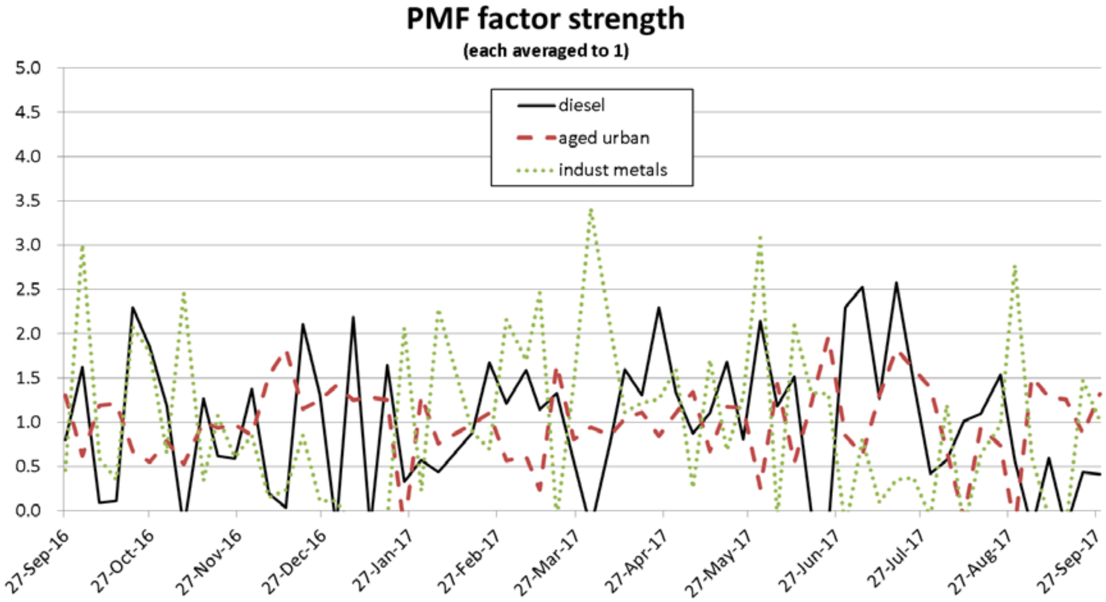


Figure 34. PMF factors 4-6 time series



Dispersion modeling

Restaurants

Figure 35 below shows the annual mean $PM_{2.5}$ from 87 restaurants modeled within the domain. The peak concentration is about 0.18 $\mu g/m^3$ and is isolated to a small area in the west central portion. There is a wider area of concentrations in the range of 0.05-0.07 $\mu g/m^3$ surrounding the maximum. Apart from this area, and therefore most of the study area, modeled concentrations of $PM_{2.5}$ from restaurants are less than 0.02 $\mu g/m^3$. Figure 36, below, shows the same data but plotted with a logarithmic scale so that values at the lower end, and thus more of the study area, have color. In this figure, most of the domain is in the range of 0.002-0.011 $\mu g/m^3$ with a few relatively higher spots appearing to the east of I-5.

Figure 35. Modeled annual mean $PM_{2.5}$ from restaurants.

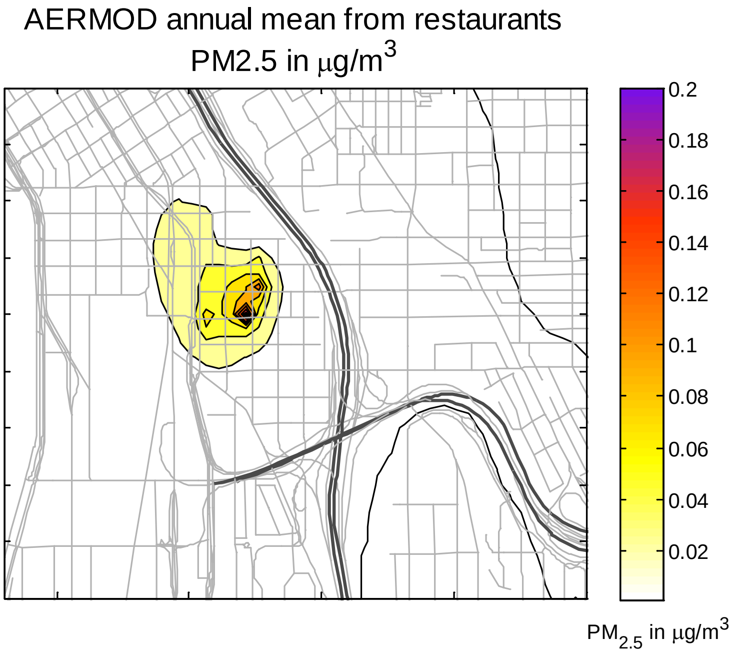
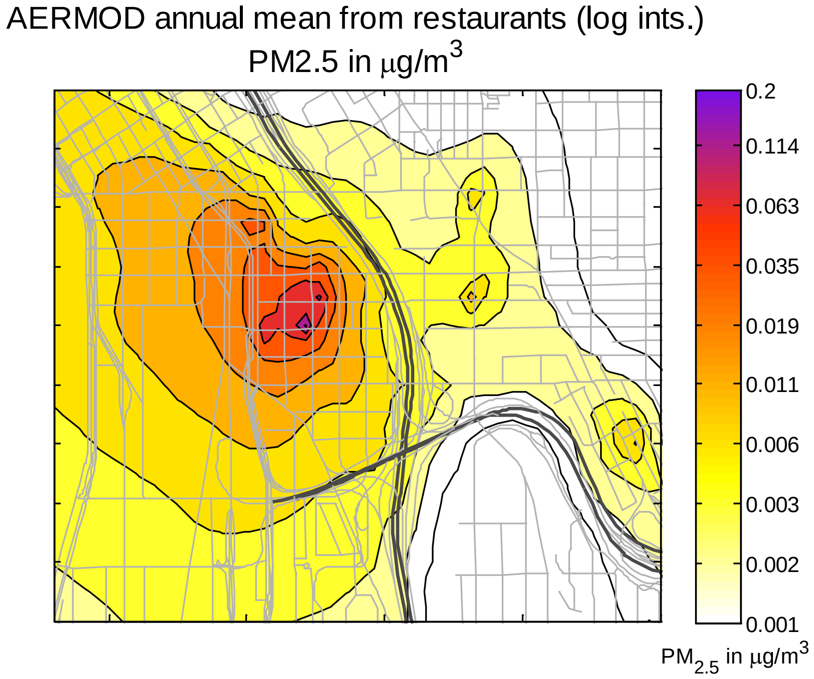


Figure 36. Modeled annual mean $PM_{2.5}$ from restaurant using a logarithmic scale.



Vehicles on I-5 and I-90

Figure 37 through Figure 40 show the mean annual concentration of $PM_{2.5}$, NOx, black carbon, and CO from vehicles (cars and trucks) on I-5 and I-90. (Note that in these figures, values for CO and NOx in $\mu g/m^3$ can be converted to ppb by multiplying by 0.8 and 0.75, respectively.)

Note that all pollutants from a single source type/grouping (e.g. cars, or trucks, or cars & trucks) have the same spatial pattern. The only difference is that the magnitude (value) of the pollutants varies with the emissions strength. Most of the observable differences in the figures are due to the contour lines being drawn at different points relative to the maximum, even though the underlying pattern is identical. There may, however, be some difference between the spatial patterns of car and truck emissions because these have differing temporal activity patterns and so could be disbursed somewhat differently depending on diurnal wind patterns and dispersion conditions.

For all four of these pollutants (PM2.5, NOx, black carbon, and CO), the highest annual mean is on and near I-5, to the south of the interchange with I-90. Apart from this maximum, there are local maxima along I-5 and I-90 which drop off within a few hundred meters of the road. And, there are elevated concentrations (at about 20% of the maximum) to the west of I-5 in the central portion of the domain. The on-road emissions have minimal impact on the higher elevations of Beacon Hill in the southeast portion of the domain, and in Yesler Terrace in the north central area. The annual $PM_{2.5}$ contribution is < 1 $\mu g/m^3$ for most of the study area (more than 200-300 meters from the roads). This is well below the annual NAAQS for $PM_{2.5}$ which is 12 $\mu g/m^3$. The spatial patterns for NOx, black carbon, and CO appear similar, and their maxima are all well below the NAAQS for NO_2 (there is no NAAQS for NOx) and CO (black carbon doesn't have a NAAQS). For most of the study area, the annual concentrations from the I-5 and I-90 on-road sources is less than 40 ppb (NOx), 0.5 $\mu g/m^3$ (black carbon), and 150 ppb (CO).

Figure 41 shows the $PM_{2.5}$ from both categories: cars & trucks, and restaurants. In this figure, the restaurant emissions are overwhelmed by the car & truck emissions and so have minimal impact on the spatial pattern and overall maximum. The predicted annual average $PM_{2.5}$ concentration at the 10th & Weller monitor is 0.81 $\mu g/m^3$.

Figure 42 shows the black carbon (BC) contribution from cars and trucks separately, but both are plotted on the same scale and color range. The BC from trucks peaks at about 1.0 $\mu g/m^3$, while the BC from cars peaks at about 0.1 $\mu g/m^3$. The maximum for both occurs on I-5 just south of I-90.

Figure 37. Modeled annual mean $PM_{2.5}$ from cars and trucks on I-5 and I-90.

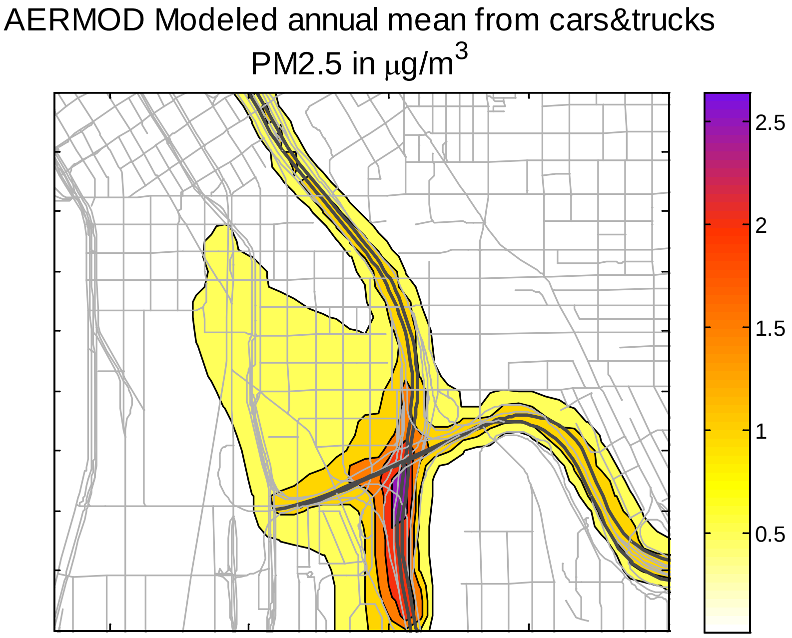


Figure 38. Modeled annual mean NOx from cars and trucks on I-5 and I-90.

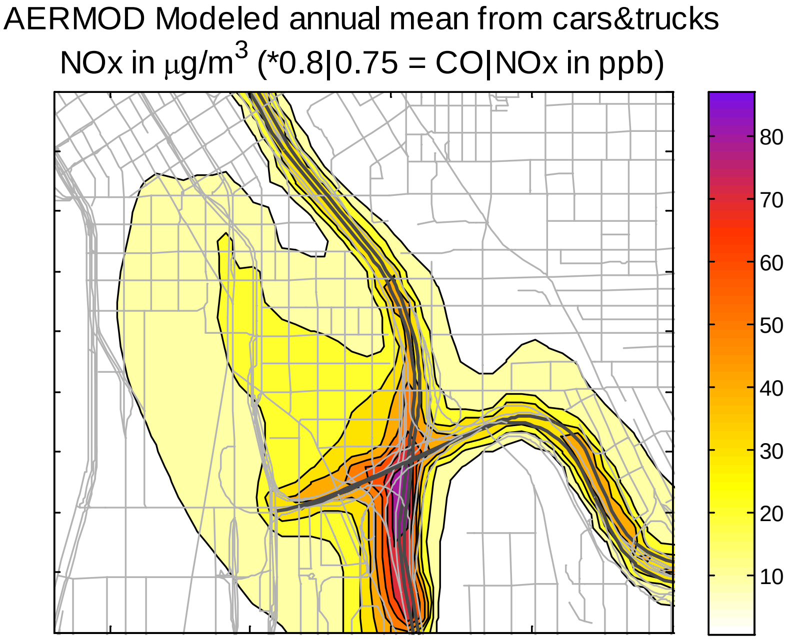


Figure 39. Modeled annual mean black carbon (BC) from cars and trucks on I-5 and I-90.

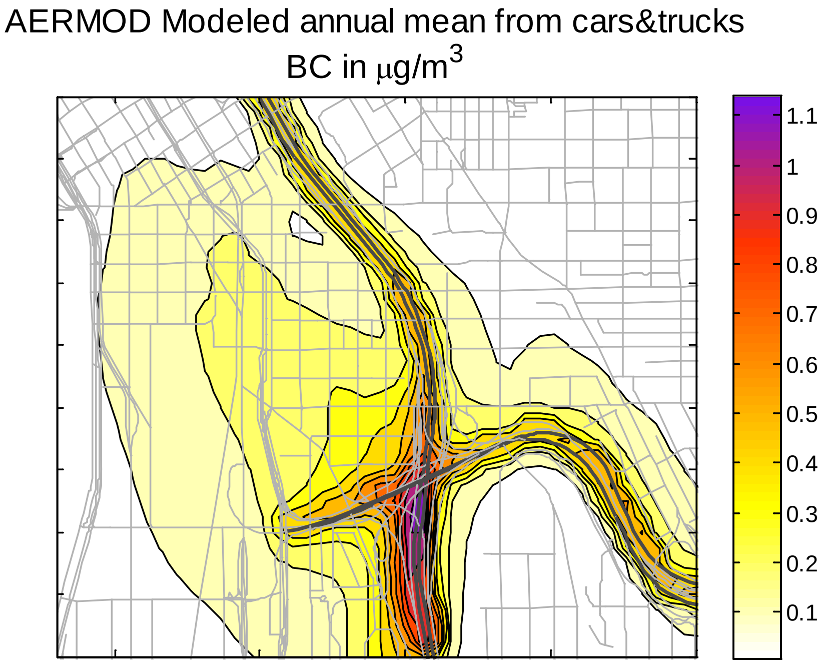


Figure 40. Modeled annual mean CO from cars and trucks on I-5 and I-90.

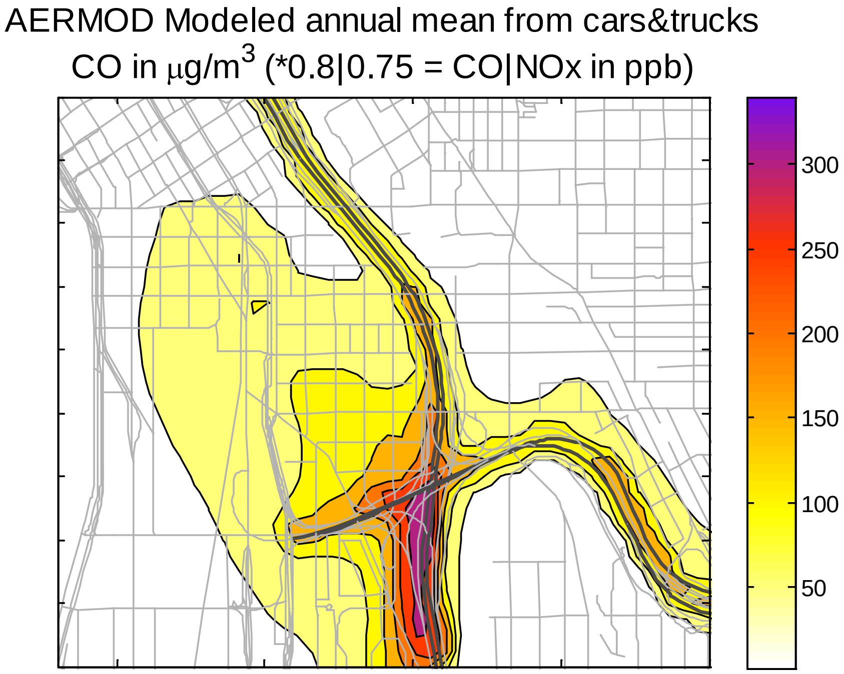


Figure 41. Modeled annual mean $PM_{2.5}$ from cars, trucks, and restaurants.

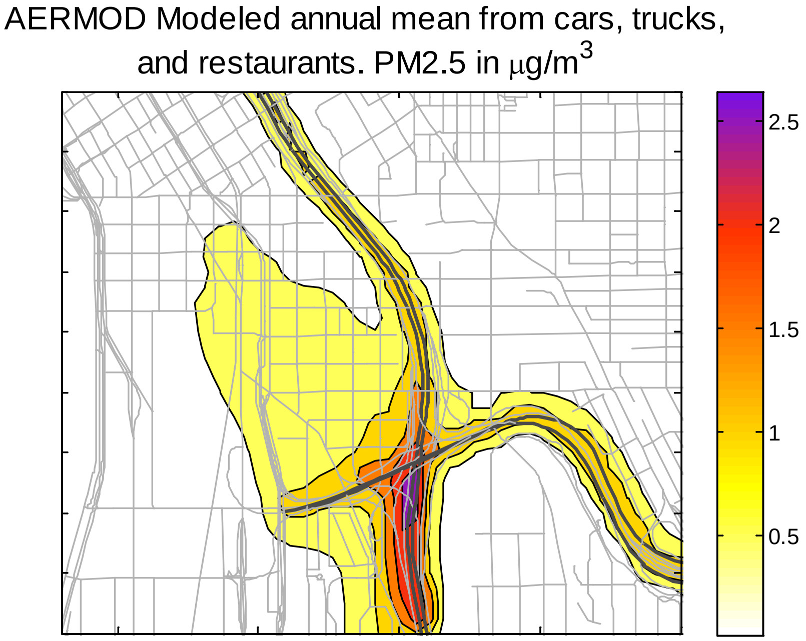
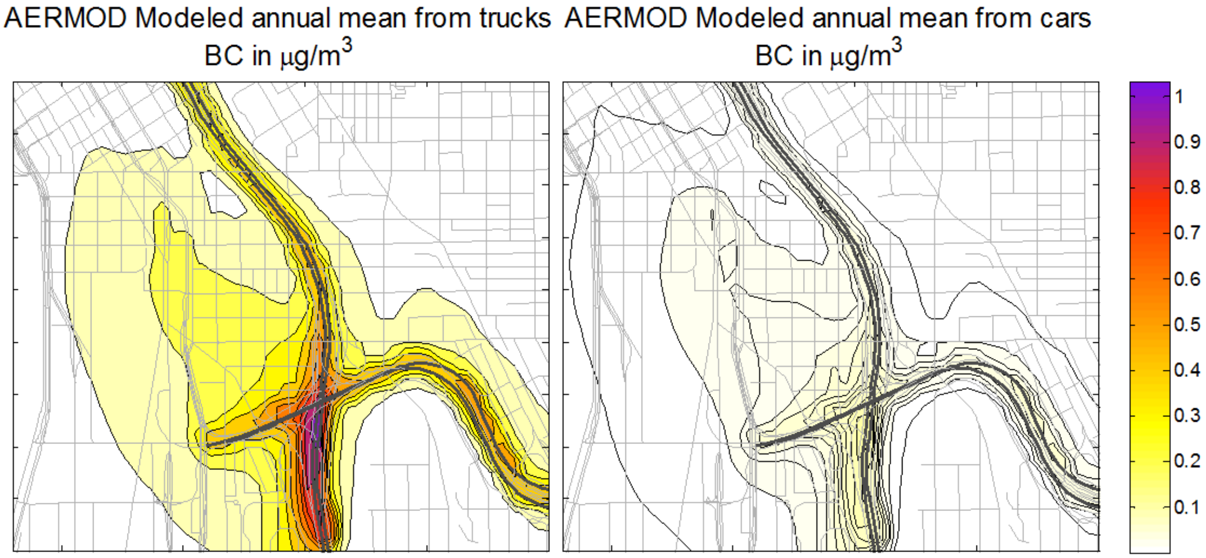


Figure 42. Modeled annual mean black carbon separately for cars and trucks.



Analysis

Air Toxics Risks Analysis

On-road Diesel Exhaust Risk Gradient Map

To assess the toxic risk further from the road (the 10th & Weller site is only about 30 feet from the edge of the closest lane) we extrapolated the on-road diesel particulate matter (DPM) concentrations (and potential cancer risk) from 10th & Weller away from the highway with an assumed gradient.

For diesel $PM_{2.5}$, we used 1/distance for the gradient, as we didn't have an adequate measure like we did for benzene and 1,3-butadiene in the community-directed sampling study. Also, the AERMOD results predicted a mean gradient from the road that was roughly proportional to 1/distance, so we felt that this treatment would be appropriate.

This gradient analysis is a measure of direct diesel $PM_{2.5}$ from major roadways. In many ways this is not a conservative estimate of all the risk from diesel exhaust (that is, the risks are likely considerably higher). This estimate does not include background diesel emissions from upwind areas. Additionally, this is an on-road diesel exhaust estimate only, and does not include non-road diesel emissions, which 2014 National Emission Inventory estimates show can be over half the total diesel exhaust in the region. Air monitors (e.g. Beacon Hill) confirm that there are significant diesel exhaust impacts in areas not directly adjacent major roadways.

In our analysis, we used the Washington State Department of Transportation freight data for 2017.[28] We tiered the segments into 3 levels by estimated annual tonnage. We binned the data into annual tonnage: over 4 million tons, 4 million to 1 million tons, and less than 1 million tons. Binning the data helps to not miss potentially significant truck volumes that may be masked by a closer low volume roadway.

We then linked the data to census blocks (joined lines-to-polygon) for each of these bins and used the distance provided by ArcGIS 10. We selected "Join…" then selected "Join data from another layer based on spatial location" and chose the WSDOT freight shapefiles to join. This links the freight tonnage to the census blocks, which also provides a distance to the line segment (roadway) from the block centroid. Then, we divided the freight tonnage by the distance to census block centroid, for each of the three bins. The distances and tonnage volumes were then scaled to the road segments nearest the 10th & Weller site.

Lastly, we summed the impact on each block group by the three different bins. The final concentrations were then multiplied by their respective unit risk factor for diesel to estimate potential cancer risk (see next section for more detail).

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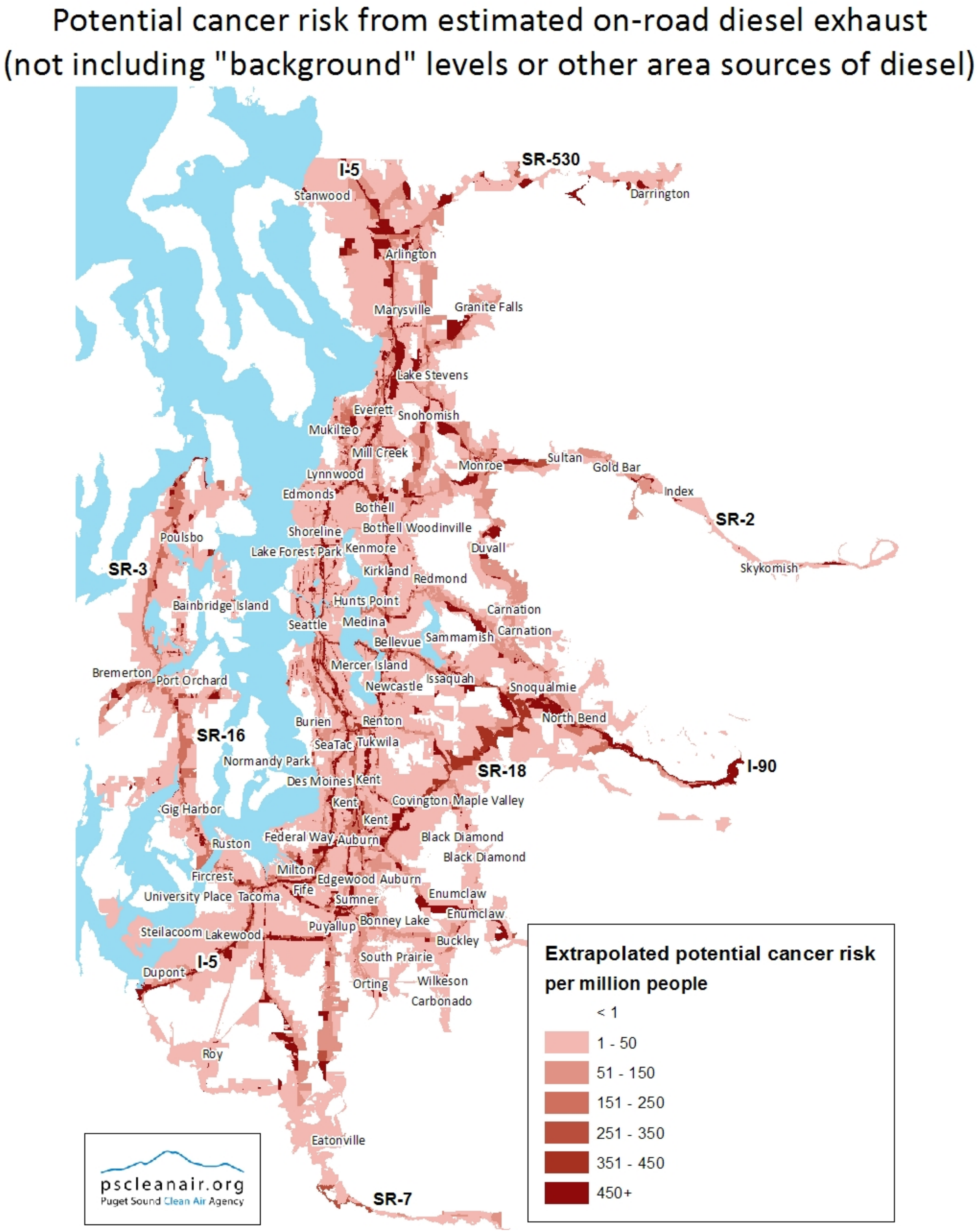
[28] Washington State Department of Transportation, 2017 Freight and Goods Transportation System of Washington shapefile, http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm

For the analysis, we treated all census blocks within 10 meters of a roadway as 10 meters since many blocks are adjacent the road and are given a distance of “0”. Additionally, the blocks aren’t consistently drawn and will have some uncertainty at close proximity.

We excluded large blocks (areas greater than 10 square miles) in rural areas that may share a boundary with a major roadway. For large blocks, dispersion of highway pollution would happen over much smaller distances than the size of the census block. So, the concentrations would change greatly for populations in the blocks that are furthest from the roadway. This is a slightly less conservative approach, but we believe it is reasonable for many of these rural blocks that would otherwise visually overestimate the risks for most people in the block.

Figure 43 below shows the map of the extrapolated potential cancer risk due to on-road diesel by census block.

Figure 43. Extrapolated potential cancer risk due to direct diesel exhaust from on-road vehicles at census block level.



Estimated local on-road diesel $PM_{2.5}$ at 6th& Jackson and Bailey Gatzert fixed sites

Diesel PM estimates further from I-5/I-90 are valuable for assessing spatial gradients and risk over the greater study area. The two fixed sites, 6th & Jackson and Bailey Gatzert, don't have the extensive data that was available at 10th & Weller (PM_{10} metals, PAHs, VOC, aldehydes, $PM_{2.5}$ speciation) and so a similar PMF approach is unlikely to be useful. The two other methods for estimating diesel $PM_{2.5}$, AERMOD modeling and pollutant ratios, are viable and yield fairly consistent results. The AERMOD modeling predicts an annual $PM_{2.5}$ concentration from trucks of 0.27 $\mu g/m^3$ at 6th & Jackson, and 0.078 $\mu g/m^3$ at Bailey Gatzert. The pollutant ratio method yields annual truck $PM_{2.5}$ estimates of 0.34 $\mu g/m^3$ at 6th & Jackson, and 0.24 $\mu g/m^3$ at Bailey Gatzert. There is modest agreement at 6th & Jackson, but AERMOD substantially under-predicts the calculated value at Bailey Gatzert. Likely explanations for the discrepancy include sources other than the vehicles on I-5/I-90 which aren't captured in the AERMOD modeling (e.g. vehicles on local streets or outside the domain, cooking, etc.), and errors in the pollutant ratio method for calculating on-road diesel $PM_{2.5}$. It should also be noted that the pollutant ratio method is only sensitive to $PM_{2.5}$ levels that have a diurnal pattern similar to traffic on I-5/I-90. Any "background" pollution from previous days or outside the domain would not be included.

These on-road diesel $PM_{2.5}$ estimates are within the range of previous PMF studies, and expected values, although it is difficult to find a good, direct comparison due to the difficulty of identifying diesel PM. Previous PMF studies [29] have looked for diesel PM factors at sites both near, and further from the highway. As discussed in further detail in Appendix A, one study reported a diesel factor with an average PM of 0.45 $\mu g/m^3$ at Beacon Hill, and 0.18 $\mu g/m^3$ at Georgetown. A second study found a factor that included diesel PM (and possibly other PM as well) with an average of 0.9 $\mu g/m^3$ at Beacon Hill for 2007-2012.

Summary of all diesel $PM_{2.5}$ estimates

Diesel PM (and other pollutants) can both be emitted within the study domain and observed soon after emissions (a.k.a. "fresh"), or it can accumulate from previous days or be transported into the study area from sources outside the study area and can be considered "background".

We can obtain values for fresh emissions directly from modeling such as AERMOD. But, since diesel PM does not have a precise chemical or operational definition, we cannot directly measure it. To obtain values from observational data, we must make additional assumptions and calculations based on the pollutants that we did measure. In the 10th & Weller data, nitric oxide (NO) and black carbon appear to

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

Kim, E., and P.K. Hopke (2008) Source characterization of ambient fine particles at multiple sites in the Seattle area. Atmospheric Environment 42 (2008) 6047– 6056.

Wu, Cf., T.V. Larson, Sy. Wu, J. Williamson, H.H. Westberg, L.J. S. Liu (2007) Source apportionment of $PM_{2.5}$ and selected hazardous air pollutants in Seattle. Science of the Total Environment 386 (2007) 42–52.

be good tracers for fresh diesel emissions. Their diurnal pattern is consistent with traffic data and their ratio is consistent with emissions profiles. So, we can scale the net daily black carbon to diesel $PM_{2.5}$ using ratios from our emissions profiles. We can do a similar calculation for the 6th& Jackson and Bailey Gatzert data, and then compare them to the truck emissions from I-5/I-90 was as modeled with AERMOD.

The "background" or non-fresh diesel PM is harder to identify and quantify in observational data. To obtain a background PM value, we assume that black carbon is the best available tracer because $NO/NO_2/NO_x$ are reactive on the time scale of minutes to hours, CO emissions are weaker compared to other sources such as gasoline cars, $PM_{2.5}$ has too many other sources, and fine or ultra-fine particle counts have multiple sources and aren't consistently well correlated to PM mass. So, for a background diesel PM, we can estimate a value from the summer average minimum black carbon at the three fixed sites. (This, of course, assumes that background BC is mostly diesel.) Winter data was excluded because it has a substantial contribution from wood burning, which has significant uncertainty and couldn't be subtracted with reasonable certainty. The daily average minimum, which generally occurs in the early morning before traffic starts, is assumed to be a background signal because it is not due to that day's traffic. For the purposes of obtaining a background diesel PM estimate, we assume that the black carbon and $PM_{2.5}$ in the background is similar to the fresh emissions, where 80% is due to diesel trucks and the rest is gasoline vehicles or other non-diesel sources. Almost certainly there are other sources in the background, such as ships, trains, off-road vehicles, generators, or stationary sources, but more accurately quantifying these is beyond the scope of this study.

The PMF modeling would be able to identify both local diesel PM and background diesel PM if they were completely associated with a specific factor, or uniquely formed their own factors. But, it is not reasonable to assume this will occur and most likely diesel PM will be distributed into more than one factor. In the present analysis, the most diesel–like factor had high black carbon and high EC1, but the $PM_{2.5}$ was lower than would be expected given the $BC:PM_{2.5}$ ratio (0.49) of the on-road diesel emissions profile. The industrial metals/diesel factor also had BC and EC1, but there was substantially more PM2.5 than would be expected from the on-road diesel emissions profile. So, the diesel PM2.5 reported for the industrial metals/diesel factor (see Table 11) was obtained by scaling its BC by the $BC:PM_{2.5}$ on-road diesel emissions profile.

The estimated background value from observation data is 0.78 $\mu g/m^3$, and 0.43 to 1.3 $\mu g/m^3$ based on the PMF factors industrial metals/diesel and summer diesel plus industrial metals/diesel, respectively.

Table 11 summarizes the diesel $PM_{2.5}$ estimates and the sources of the data. "Local on-road" or "Background" indicates whether the value represents fresh emissions from a relatively local source and has a daily pattern, such as the I-5/I-90 traffic, or background/previous emissions which don't have a daily pattern.

Table 11. Summary of Diesel $PM_{2.5}$ estimates and data source.

Source	Source/Description	Diesel $PM_{2.5}$ ($\mu g/m^3$)	Local on-road or Background
AERMOD	Grid point further from road than10&W	0.30	Local on-road
	Grid point closest to 10&W monitor	0.63	Local on-road
	Grid point closer to road from 10&W	1.0	Local on-road
	Grid point closest to 6th & Jackson	0.27	Local on-road
	Grid point closest to Bailey Gatzert	0.078	Local on-road
PMF (10&W)	Diesel factor	0.39	Local on-road
	Summer diesel/industrial	0.91	mix
	Industrial metals/diesel (scaled by BC)	0.43	Background
10&W monitor	Diurnal peak of BC, scaled to diesel $PM_{2.5}$:BC ratio from on-road fleets	0.86	Local on-road
6th & Jackson monitor	Diurnal peak of BC, scaled to diesel $PM_{2.5}$:BC ratio from on-road fleets	0.34	Local on-road
Bailey Gatzert monitor	Diurnal peak of BC, scaled to diesel $PM_{2.5}$:BC ratio from on-road fleets	0.24	Local on-road
average of all three fixed sites	Daily minimum BC, scaled to diesel $PM_{2.5}$:BC ratio from on-road fleets	0.78	Background

Combined risk from modeled diesel exhaust with other monitored air toxics

To better estimate the potential cancer risks with diesel exhaust included, we applied some of the diesel exhaust estimates from the table above to quantify the risks. This analysis differs from the estimated risks found in Figure 17 and Figure 18 since we can't monitor for diesel exhaust directly. Therefore, we have to rely on our modeled approaches for estimated diesel exhaust concentrations from this Analysis section of the report.

For this estimate, we used the California EPA's Office of Environmental Health and Hazard Assessment (OEHHA) unit risk factor.[30,31] Similarly, from the PMF analysis, we also have a wood smoke estimate that we applied to estimate the potential cancer risk (for 1.0 $\mu g/m^3$ of wood smoke). For wood smoke, we used a unit risk factor developed by Lewtas,[32] et al. from a series of bioassay mutagenicity tests. More details on these unit risk factor and how they are applied are in Appendix A.

We then added the estimated potential cancer risk from diesel exhaust to the monitored air toxics we quantified in the air toxics health screening section earlier in this report.

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[30] US EPA. "Integrated Risk Information System". http://www.epa.gov/iris/.

[31] California Environmental Protection Agency, Office of Environmental Health and Hazard Assessment. http://www.arb.ca.gov/toxics/healthval/healthval.htm.

[32] 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.

To estimate potential cancer risk, we used two approaches for 10th & Weller. One approach used the PMF analysis results. Another approach used the monitored diurnal peak estimates.

For the PMF estimates for diesel exhaust at this site, we included the factors that were most associated with having diesel exhaust in them (as found in Table 11). That is, we used the range of 0.9 $\mu g/m^3$ (the "summer/diesel industrial" factor alone), with 1.3 $\mu g/m^3$ as the middle estimate ("summer/diesel industrial" plus "diesel"), and 1.7 $\mu g/m^3$ as the high estimate ("summer/diesel industrial" plus "diesel" plus "industrial metals").

From the monitored diurnal peak estimates for diesel exhaust, we applied the estimated "background" diesel exhaust of 0.8 $\mu g/m^3$ (also found in Table 11). We also used the "local on-road" estimates for each site (0.8, 0.3 and 0.2 $\mu g/m^3$ for 10th & Weller, 6th & Jackson, and Bailey Gatzert, respectively).

Figure 44 below shows the potential cancer risks from the different diesel exhaust estimates (from PMF and the monitored diurnal patterns), and wood smoke, stacked on top of the other potential cancer risks we estimated earlier in this report for the other measurable air toxics.

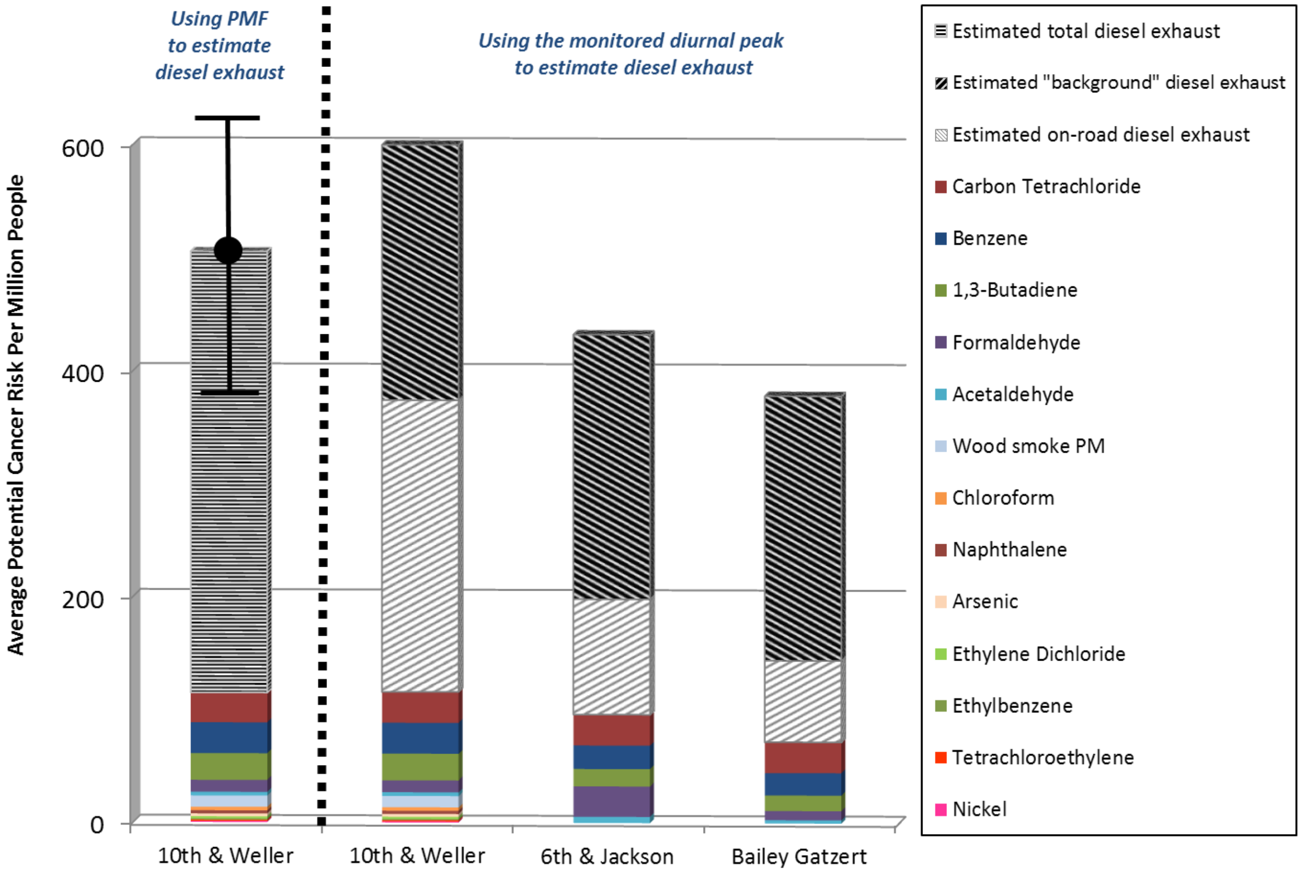
Combing these approaches, the total risk right on I-5 (at 10th & Weller) is roughly 400-600 per million potential cancers per million people. The other two sites (6th & Jackson and Bailey Gatzert) are lower (both near 400 per million, with Bailey Gatzert the lowest) due to the drop in the estimated local on-road contribution to the diesel risk. However, we estimated that the "background" risk from other area diesel sources is still significantly higher than the other air toxics we monitored for in this study (benzene, etc.).

Limitations

There is a lot of uncertainty in these approaches, with many of the aforementioned concerns, including the uncertainty on the black carbon proportion coming from diesel vehicles in the area, the proportions of diesel exhaust within each of the PMF factors, and the sharp gradient differences from the road that can vary the local on-road impacts particularly at 10th & Weller, where a few meter difference can result in a concentration of half the value.

In this analysis, we may also be double counting some of the risk from the other air toxics (benzene, 1,3-butadiene, etc.). But as the PMF results showed, not all of the risk from these air toxics are attributed to on-road diesel vehicles specifically, and is only a fraction of the total. Considering the uncertainty of our ranging diesel exhaust estimates, the potential double counting that is occurring may only be in the order of 5% or less when looking at the total risk and is well within our uncertainties.

Figure 44. The average potential cancer risk per million people at the three main fixed sites with estimated diesel exhaust and wood smoke included (using different methods)

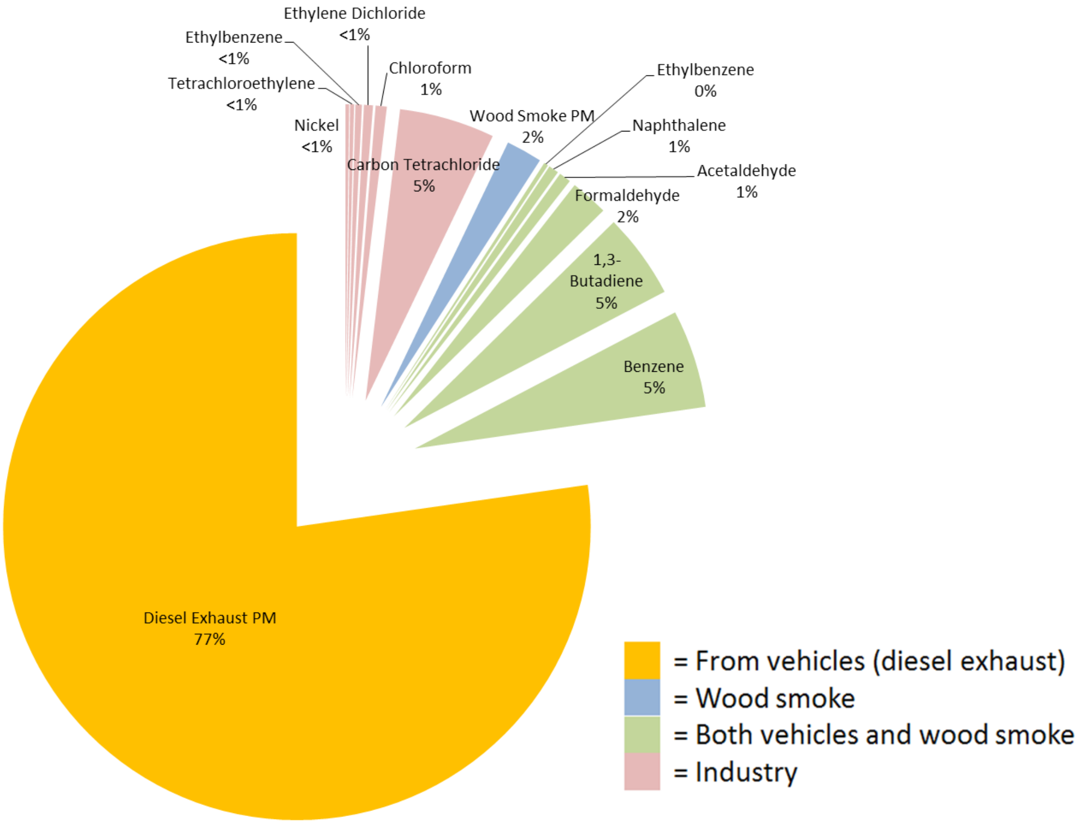


Key points from the combined potential cancer risk estimates

As a result, these estimates are not intended to be quantified as exact values. Yet, the figure demonstrates a few key points. The main finding is that diesel exhaust still is the main concern for potential cancer risk in the area. Another finding is that there is still substantial risk further away from the road due to the estimated "background" diesel exhaust sources (non-road engines, port/industrial areas, other distant roadways, etc.). However, this figure also highlights that the highway also still carries substantial additional risk, where more distant sources don't share the same diesel exhaust burden.

In Figure 45 below, we attribute the risk from the PMF estimate for 10th & Weller (from the prior figure) as a pie chart and color code the results based on general source types. Diesel exhaust is yellow, and blue is wood smoke. Green includes sources from diesel and wood smoke. Lastly, pink is sources from industrial processes.

Figure 45. Pie chart attributing potential cancer risk at 10th & Weller to types of air pollution and color coded by type of source



This figure demonstrates that less than 10% of the risk is associated with industrial or commercial processes, with combustion related air toxics (from cars and trucks and winter wood smoke) contribute to an estimated 90% of the potential cancer risk.

Analysis on higher levels of formaldehyde and acetaldehyde at 6th & Jackson

We found consistently higher formaldehyde and acetaldehyde at the 6th & Jackson site throughout the study period. Figure 46 and Figure 47 below show the levels over the one year of sampling at the four sites that we did have annual data, including 6th & Jackson.

As shown in Table 5 in the Monitoring Results section above, we see that the average formaldehyde levels are not too much higher than the national average. Nonetheless, it was significantly higher than the rest of our Seattle air monitoring data past or present, so we pursued the following analysis to see if we could determine a specific source or cause.

After the results of the first month of samples arrived (typically several months lag time), we saw the bias and moved the probe away from the shelter before the sample taken on 1/1/17. We thought that the shelter could have been a potential source of contamination. As we later saw, while moving the probe inlet may have reduced the initial discrepancy (in Sept and October) with the other sites, both pollutants remained significantly elevated for the remainder of the study.

Figure 46. Formaldehyde levels over the study period at four sites.

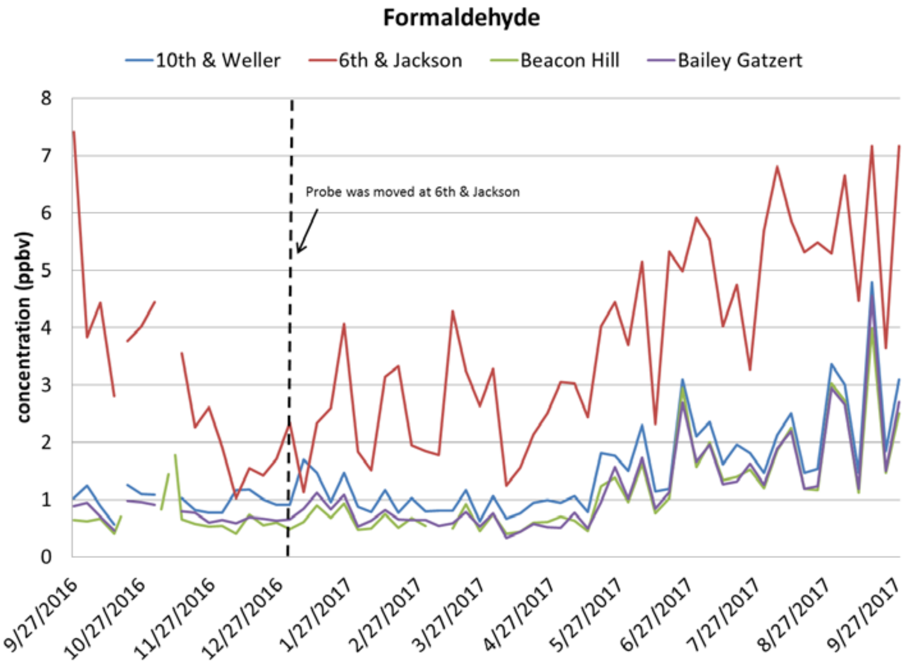
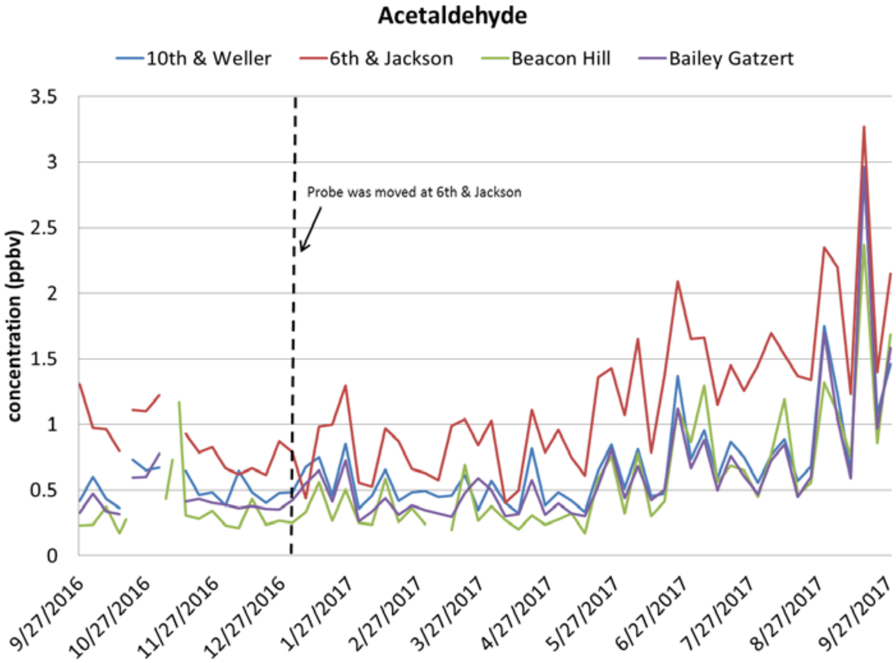


Figure 47. Acetaldehyde levels over the study period at four sites.



The formaldehyde pattern (in Figure 46) at 6th & Jackson doesn't strongly match that of the other sites. Figure 48 below shows correlations of 10th & Weller vs the other sites for formaldehyde. The different sites correlate well with each other ($R^2 > 0.9$), with the exception of 6th & Jackson which had a much lower correlation ($R^2 < 0.5$).

With acetaldehyde, the relationship is not as clear as with formaldehyde. Figure 49 shows the relationships among the sites for acetaldehyde. The correlations for 6th & Jackson and Beacon Hill are similar (both R^2 near 0.8).

Figure 48. Site formaldehyde correlations with 10th & Weller

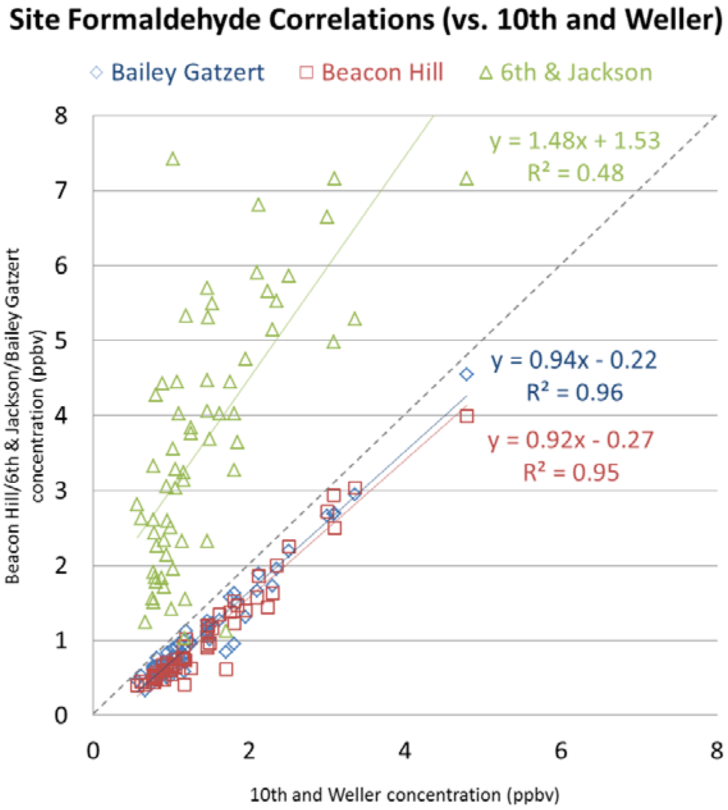
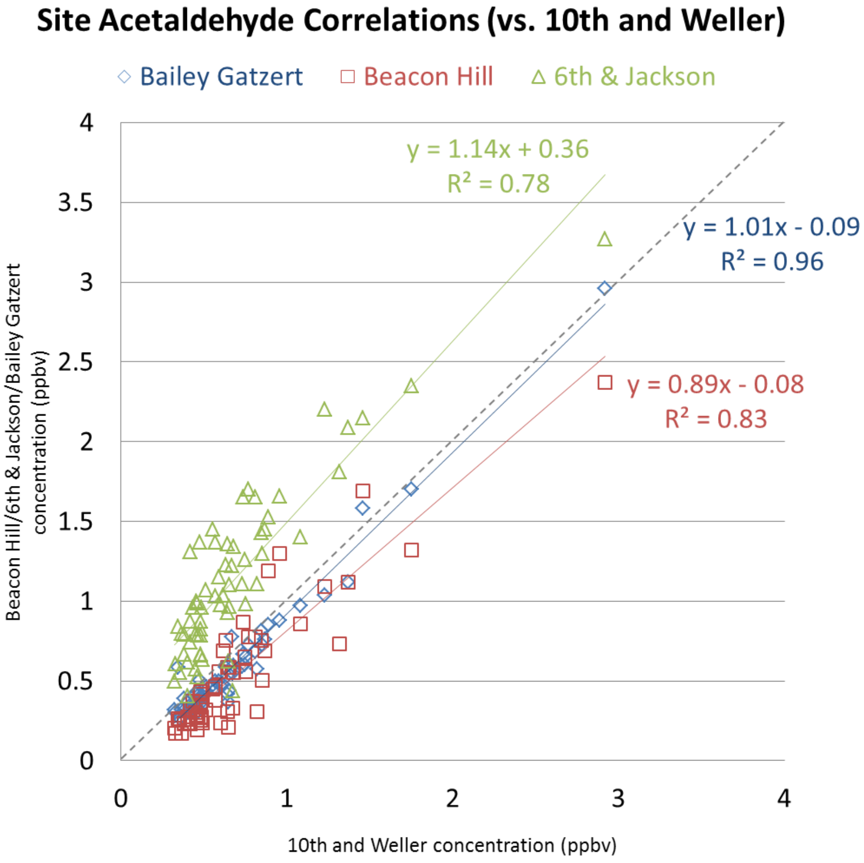


Figure 49. Site acetaldehyde correlations with 10th & Weller



The graphs (in Figure 46 and Figure 47) indicate that higher aldehyde levels occurred in the summer months. As ambient formaldehyde and acetaldehyde are mostly “secondary” pollutants (are formed when other pollutants in the atmosphere react with one another), we would expect these aldehydes to have some temperature dependence, especially at hotter temperatures.

Figure 50 and Figure 51 below show the formaldehyde and acetaldehyde temperature relationships across the fixed monitoring sites. The patterns is more linear at the 6th & Jackson site, which could suggest that there is a direct off-gassing of some kind rather than secondary chemistry behavior as seen by the other pollutants. The acetaldehyde temperature relationships are similar, but much weaker, suggesting that any nearby off-gassing is less significant for acetaldehyde than for formaldehyde, but still present in both.

Figure 50. Formaldehyde concentrations versus temperature at the fixed study sites

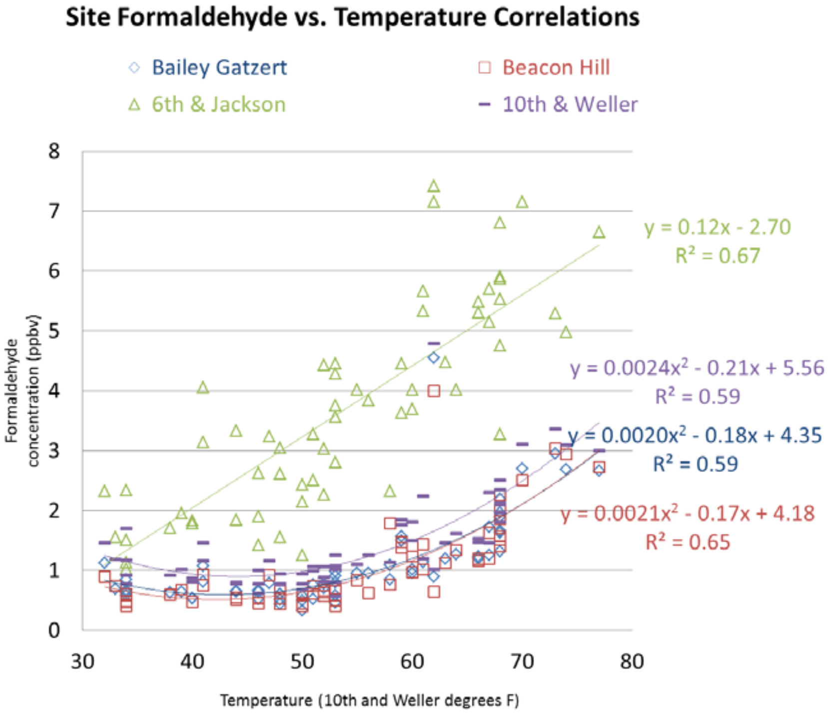
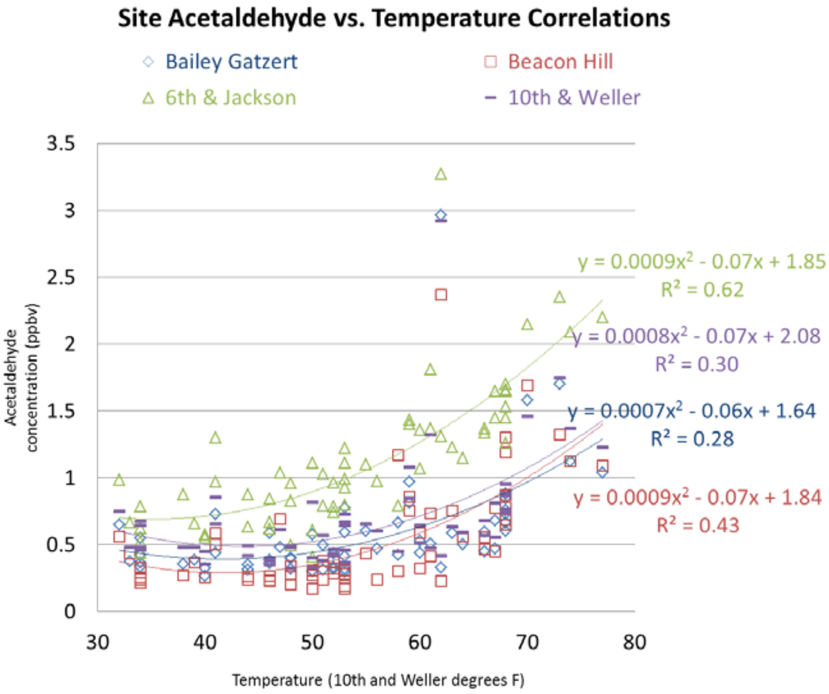
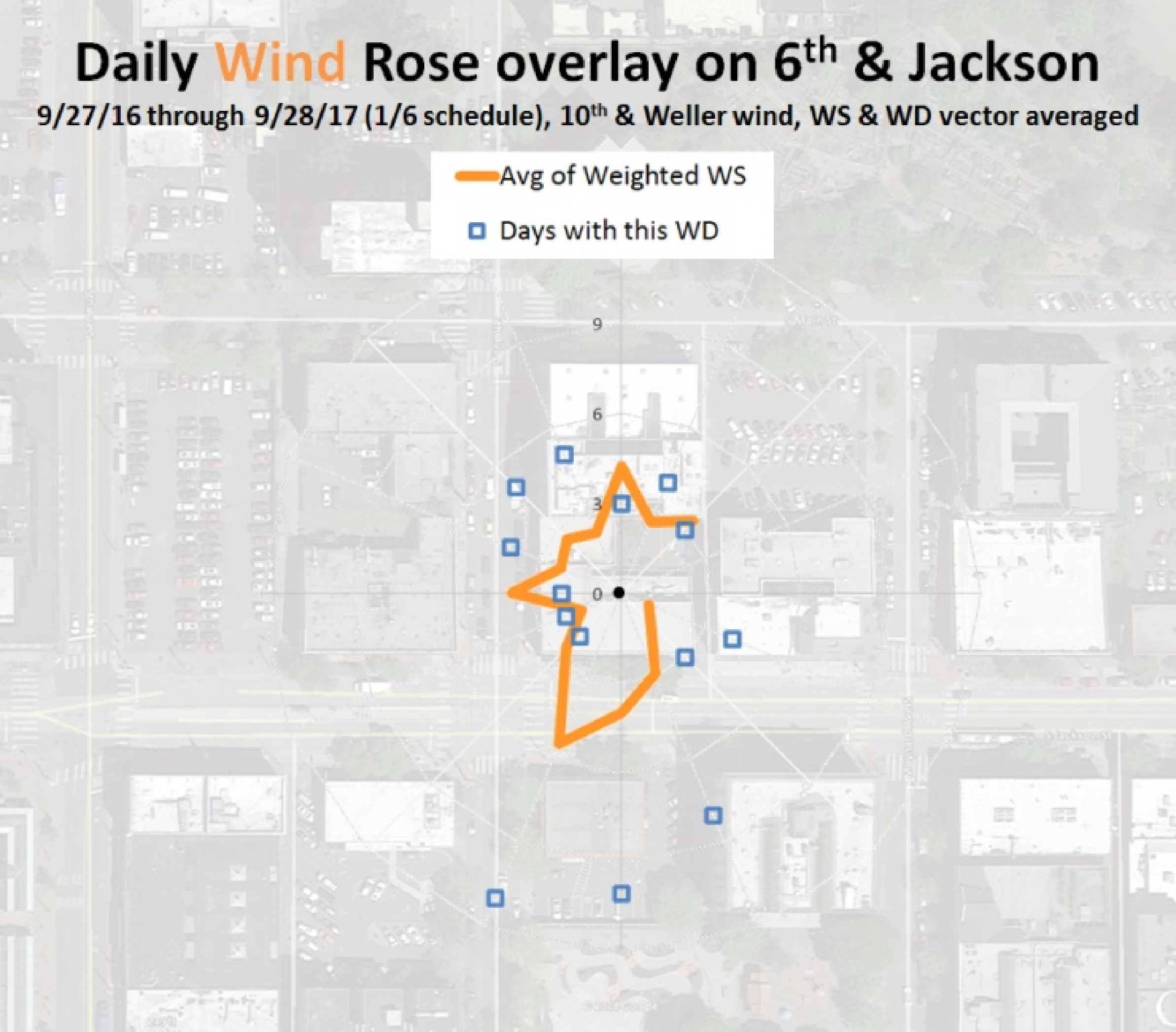


Figure 51. Acetaldehyde concentrations versus temperature at the fixed study sites



Pollution roses for formaldehyde and acetaldehyde did not display any obvious directionality. As a baseline for comparison to the pollution roses, we include the wind rose over the study period at the 10th & Weller site below in Figure 52. The blue squares show that the daily vector averaged winds were mostly from the south, including zero days from the east. The averaged winds in orange show strongest winds are mostly north-south.

Figure 52. Daily Wind Rose at 6th & Jackson



In Figure 53 below, we include the average formaldehyde by wind direction. The red outline doesn't fit the wind rose pattern nor does it show any particular wind direction. To see if there were high formaldehyde days that could suggest a significant source directionality, we also looked at the maximum formaldehyde level by wind direction, and also saw no specific directionality (Figure 54). Similarly, acetaldehyde results showed no obvious directionality.

Figure 53. 6th and Jackson average formaldehyde rose plot.

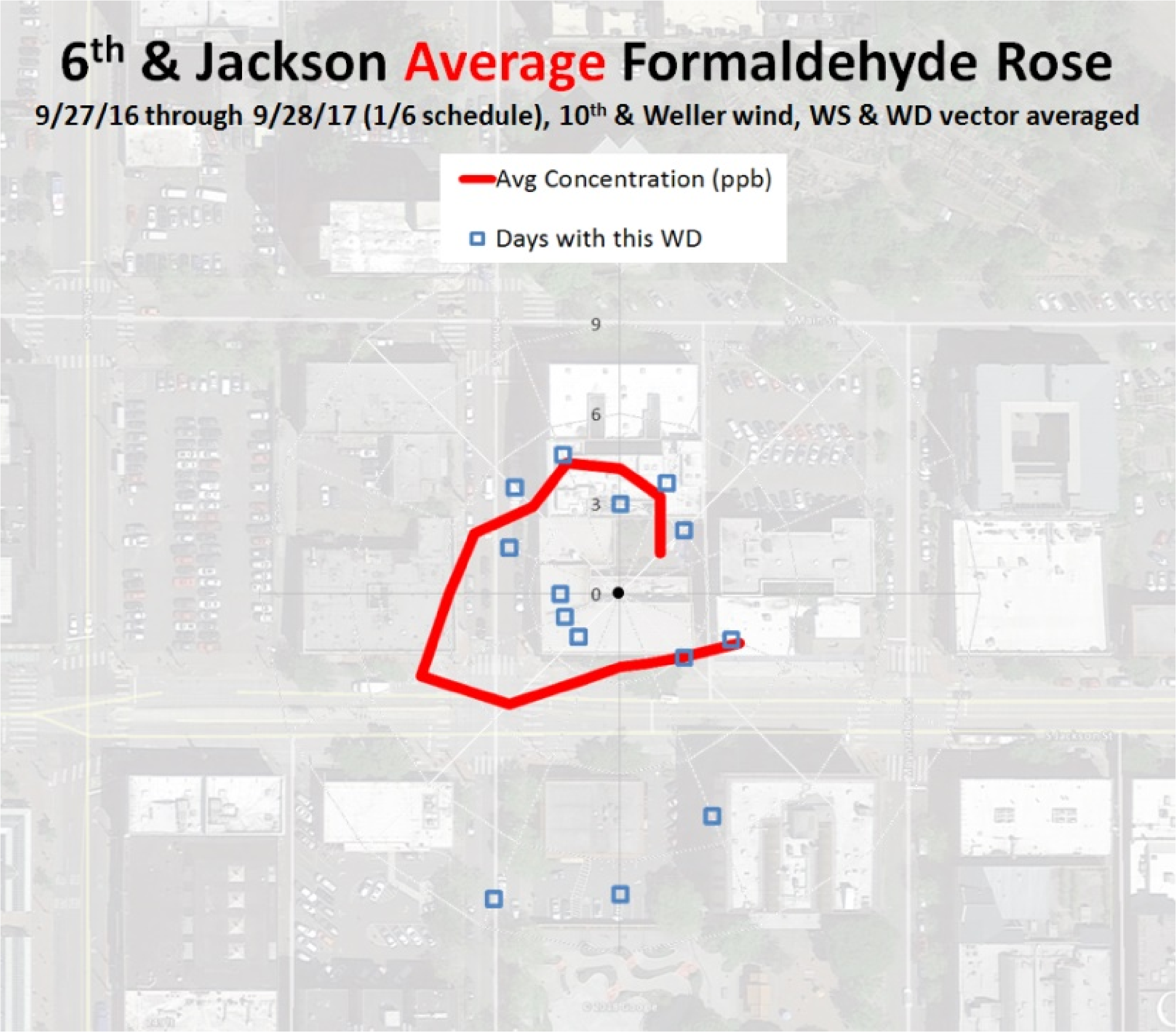
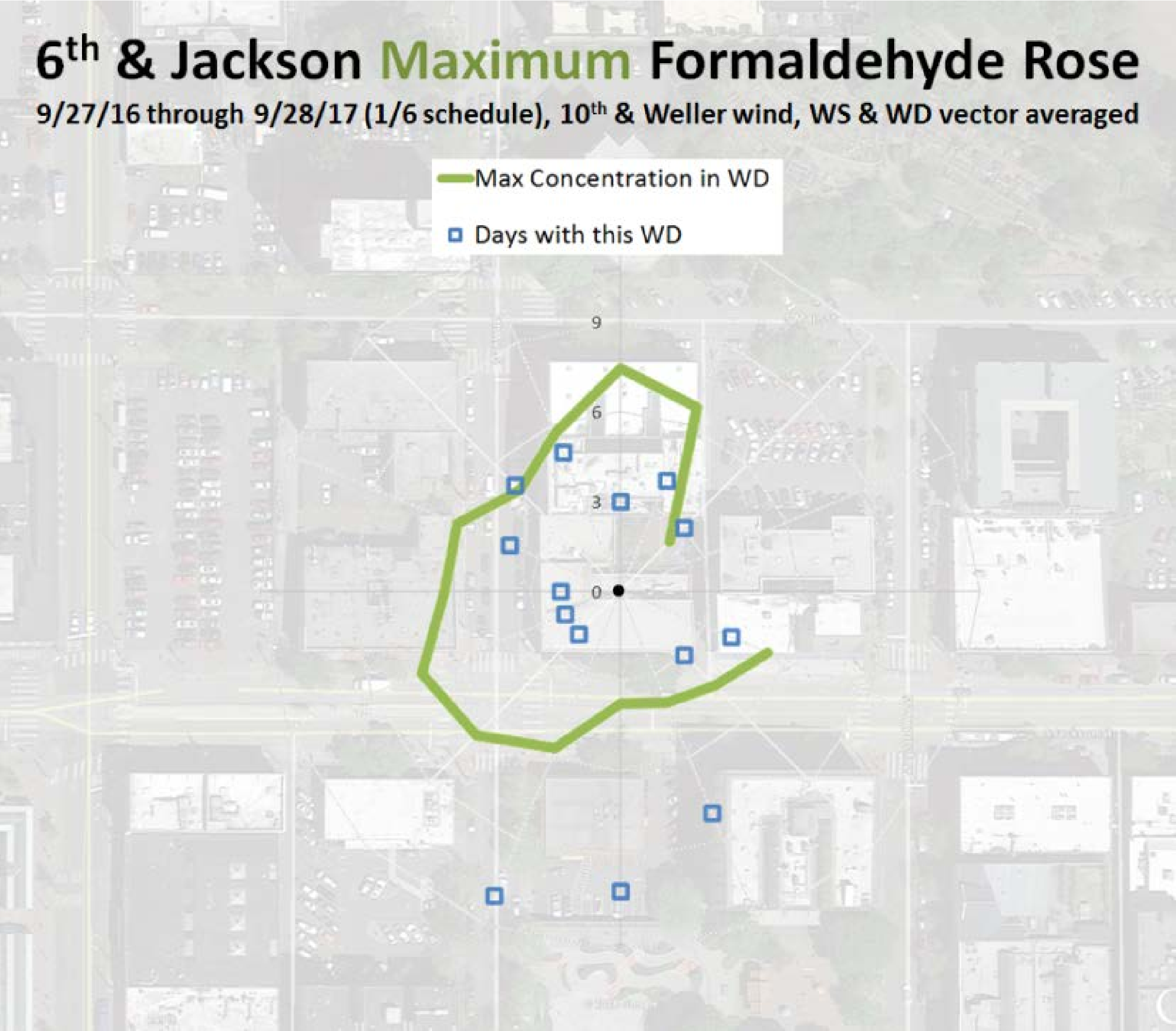


Figure 54. 6th & Jackson maximum formaldehyde rose plot.



In summary, the linear temperature dependence could indicate a direct off-gassing of a nearby source that is proportional to temperature. Moving the probe also did not result in any significant change, which could suggest a source that is fairly uniform on the roof or somewhat more distant. Also, the results show no obvious wind dependence, which could suggest a source that could be found fairly uniformly on the roof.

In regard to further investigation: Finding the source with micro-scale air monitoring of ambient levels of pollutants can be difficult as it would potentially require a large number of samples over multiple time periods. And, even with this level of investment, the end result could still remain inconclusive.

Formaldehyde (and acetaldehyde) most commonly off-gasses from a number of products like composite woods (plywood, particle board), building materials and urea-formaldehyde insulation, e-cigarette or cigarette smoke, glues, fabrics, paints, and solvents.[33]

Other less likely activities (but are ongoing in the building operations as of the writing of this report) could result in some formaldehyde loss including dental work (Sargenti paste), barber shops (hair straighteners), or art work (solvents, paints). However, some of these sources seem unlikely considering the lack of directionality in the winds.

Air toxics risk comparison to the EPA's 2011 National Air Toxics Assessment Model

The National-Scale Air Toxics Assessment (NATA) is EPA's ongoing modeling of air toxics levels and potential cancer risk across the United States. The intent of the NATA is to serve only a screening tool, and is not intended to be a completely accurate depiction of the air quality and air quality risk at high resolution.

EPA describes how the NATA is to be used, which includes prioritizing pollutants and emission sources, identifying locations of interest for further investigation, providing a starting point for local-scale assessments, or focusing community efforts.[34]

Table 12 shows a comparison of EPA's 2011 NATA model to our monitored fixed air toxics site monitoring data. For the comparison, we used modeled ambient concentrations for specific census tracts that contained our monitors, and compared them with observed concentrations in this study.

We colored the numbers of the model/monitor data ratios as below:

- > 2.0 in red = model is biased **high** (over predicting)
- < 0.5 in blue = model is biased **low** (not capturing enough emissions)

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[33] https://www.epa.gov/formaldehyde/facts-about-formaldehyde

[34] https://www.epa.gov/national-air-toxics-assessment/nata-overview#how-to-use-nata

Table 12. Model to monitor ratios comparing the EPA NATA model to our fixed site data

Analyte	10th and Weller	Beacon Hill	6th & Jackson	Bailey Gatzert
1,3-Butadiene	3.4	6.3	5.5	5.0
Acetaldehyde	2.9	3.2	_1.8*_	3.1
Arsenic	1.0	0.6		
Benzene	4.4	5.3	6.1	5.1
Carbon Tetrachloride	0.9	0.8		
Chloroform	0.01	0.01		
Ethylbenzene	1.7	1.5		
Ethylene Dichloride	_0.05**_	_0.04**_		
Formaldehyde	2.0	2.3	_0.8*_	2.4
Naphthalene	2.7	4.4		
Nickel Compounds	8.1	4.3		
Tetrachloroethylene	_3.3**_	_2.7**_		
Vinyl Chloride	_0.003**,***_	_0.03**,***_		

* = These monitored results are biased high likely from off-gassing materials at the monitoring site.
** = Over 50% of the samples are below the method detection limit.
***= Likely has a high bias due to a blank correction that was applied by the lab.

As we expected, concentrations from the 2011 NATA model are substantially higher than our monitored results for a number of toxics. In a 2015 Agency analysis, we demonstrated that the 2011 NATA model was artificially high in our region.[35]

The 2015 analysis pointed to inherent flaws in modeling with CMAQ in the Puget Sound region. Our region has complex terrain that was represented in a 12 by 12 km grid. In this large of a grid, the Puget Sound area has large bodies of water (like Lake Washington and Puget Sound) that are associated as land in the model, and mountains and mountain passes become barely identified features (e.g. Mount Rainier at 14,400 feet fits a grid cell). As a result, typical wind speeds and directions are completely mischaracterized across the region.

At the time of this report, the draft 2014 NATA was available, but not yet ready for public release. We conducted a similar analysis using this draft and can generally conclude that it under-predicts the observed values from our air toxics study.

Interestingly, the 2011 NATA didn't seem to capture the chloroform. The 2002 NATA, however, did have more chloroform, based on our analysis from our Tacoma/Seattle air toxics study. The NATTS comparison above didn't appear to show that the chloroform in Puget Sound is significantly higher than the rest of the nation. This would indicate another potential bias in the model.

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[35] Correspondence between Erik Saganic at PSCAA and Madeleine Strum at EPA titled, "Comments from the Puget Sound Clean Air Agency on the Draft 2011 NATA, 8/28/15."

Lastly, reviewing the NATA data in the comparison was also helpful for the QA process. We saw how acetonitrile model-to-monitor performance was 0.1 at 10th & Weller for example, where at Beacon Hill the ratio was 1.4. This was extra evidence to help us invalidate the acetonitrile results at 10th & Weller, as discussed above in the Monitoring Results section of this report. From our inspection, no other analytes had such an apparent difference vs other sites.

PAH analysis

This section summarizes an analysis we performed on the PAH data from samples collected at the 10th & Weller monitoring site. In this PAH analysis, we looked at the seasonality, wind directionality, and comparisons of the 10th & Weller site with the Beacon Hill site.

We found a surprising pattern that the PAH quantities at our near-road site versus an urban background site were tied more to the reactivity of the species than to the directionality or seasonality overall. This analysis demonstrates the complexity of measuring air pollution concentrations at different gradients from a busy roadway. This is further evidence of why our PMF analysis has multiple factors with diesel included, and that, in general, PMF analyses shouldn't be simplified into a simple source, direction, or seasonal approach, as many other variables are often at play.

Seasonality and directionality

Some PAHs were clearly higher in the winter months, some were higher in the summer months, and others were relatively constant throughout. In Appendix D are figures for each PAH that include a graph over the study period and a pollution rose.

Interestingly, we also found the PAHs that were higher in the winter all had a clear directionality coming from the east (away from I-5). The summer PAHs all showed the highest levels coming from the west (from I-5). And the PAHs with no seasonality also showed no directionality.

The following table breaks out the different groups by season and general wind quadrant. It is sorted by the season with the highest levels at the top. The table also includes the wind quadrant, obtained from reviewing pollution roses.

Table 13. Table of PAHs with dominant season, and wind quadrant.

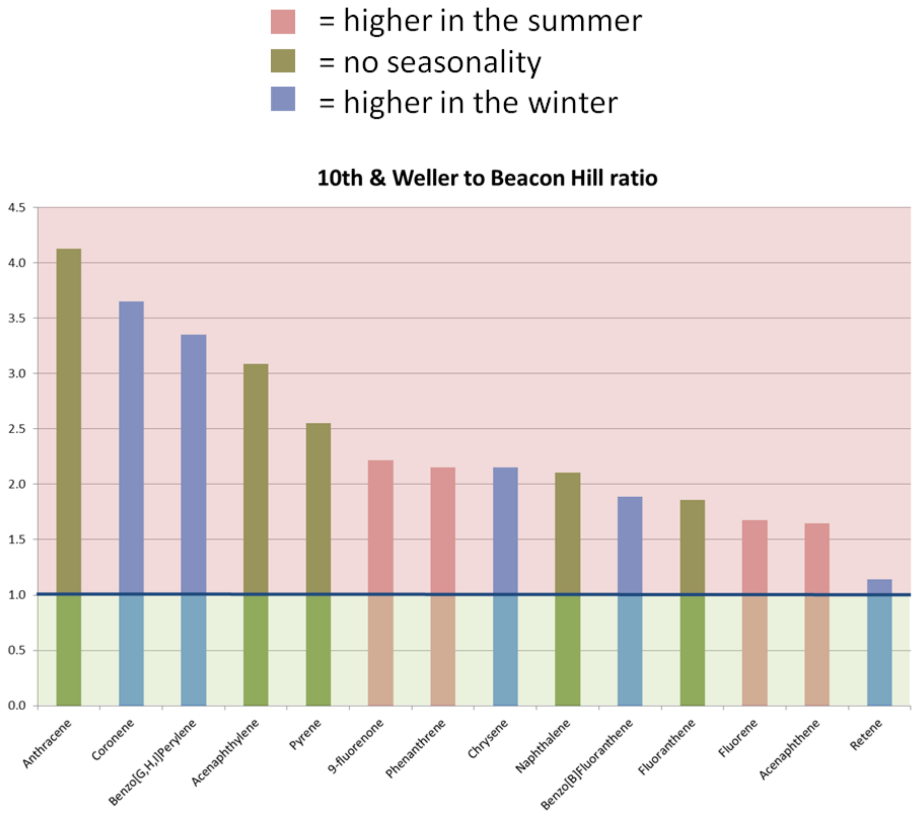
PAH	**Highest season**	**Directionality** (wind direction ***from***)
9-fluorenone	Summer	West
Acenaphthene	Summer	West
Fluorene	Summer	West
Phenanthrene	Summer	West
Benzo[A]Anthracene	Winter	East
Benzo[A]Pyrene	Winter	East
Benzo[B]Fluoranthene	Winter	East
Benzo[E]Pyrene	Winter	East
Benzo[G,H,I]Perylene	Winter	East
Benzo[K]Fluoranthene	Winter	East
Chrysene	Winter	East
Coronene	Winter	East
Indeno[1,2,3-Cd]Pyrene	Winter	East
Perylene	Winter	East
Retene	Winter	East
Acenaphthylene	No seasonality	East and West
Anthracene	No seasonality	No clear directionality
Cyclopenta[cd]pyrene	No seasonality	East and West
Fluoranthene	No seasonality	No clear directionality
Naphthalene	No seasonality	No clear directionality
Pyrene	No seasonality	No clear directionality

PAH comparisons between 10th & Weller and Beacon Hill

In our PAH analysis, we also compared PAHs at 10th & Weller (the near-road fixed site) to Beacon Hill (the NATTS site a few miles away that represents an urban background). We looked at the ratio of each median PAH concentration at the two sites.

We hypothesized these ratios could predict some of the seasonality and directionality (sources from the east would be I-5, and sources from the west would be residential wood smoke). However, when compared to the seasonality, directionality didn't fit as clearly. This could be due to a number of factors, but the most likely is that multiple PAH sources were not factored in (e.g. restaurant or BBQ emissions). Figure 55 below illustrates the lack of pattern in this comparison.

Figure 55. PAH ratios of 10th & Weller vs Beacon Hill.



In this figure, pink background shading (above the 1.0 line) denotes 10th & Weller being greater than Beacon Hill, and the light green background shading (below the 1.0 line) indicates 10th & Weller being less than Beacon Hill. The bars are colored by their season.

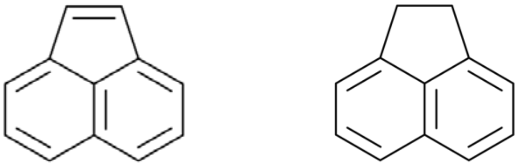
For the analysis in this section, we excluded PAHs with samples over 25 % below the MDLs, which occurred more frequently at Beacon Hill than at 10th & Weller. You can find the ratios for all the PAHs (including those with more than 25% of the samples below the MDLs) in Figure D-1 in Appendix D. We opted to not do further statistics with non-detect methods since these PAHs didn't have respective first-order rate constants (see the rate constant analysis in subsequent pages).

The figure above indicates that not all PAH ratios are the same between the two sites. This likely indicates that there are a variety of PAH sources. Since PAHs are larger molecules (relative to gaseous criteria pollutants CO, NO_2, SO_2, and a number of VOCs), the sources are generally not fully burned fuels, such as diesel, wood, or food (there are a number of restaurants and barbecues at the vicinity of the 10th & Weller site).

We also tested another hypothesis that PAHs are undergoing chemical reactions after they are emitted, but before sampling. Since Beacon Hill is farther away from most sources, the PAHs that are sampled there may be "aged" or more represent the urban background.

For example, acenaphthylene is the more conjugated (and less oxidized) sister compound of acenaphthene (see Figure 56 below).

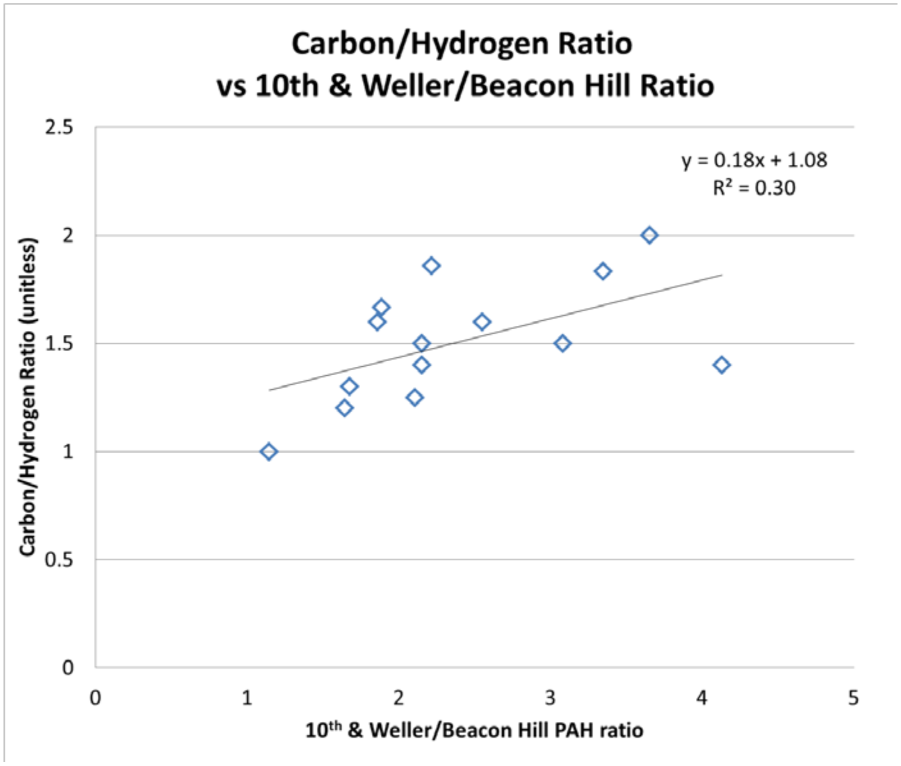
Figure 56. Acenaphthylene molecular structure (left) and the oxidized version acenaphthene (right).



Concentrations of the less oxidized acenaphthylene are higher at 10th & Weller than at Beacon Hill. But, for the more oxidized version (more "aged") acenaphthene, concentrations are similar.

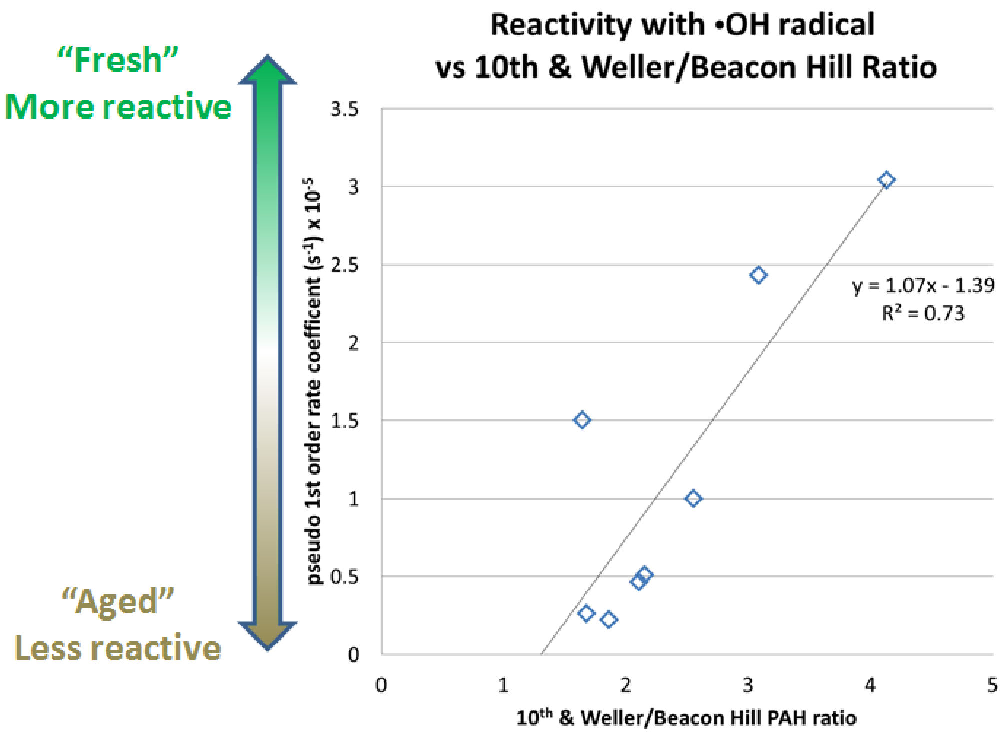
A simple measure of the amount of conjugation (and, in turn, is like an oxidation state) is the carbon to hydrogen ratio. Figure 57 shows the carbon-to-hydrogen ratio of the PAH species vs the 10th & Weller to Beacon Hill PAH ratio. Although somewhat weak, it appears to show a relationship.

Figure 57. Carbon/hydrogen ratio vs 10th & Weller/Beacon Hill ratio



To get a better estimate for this atmospheric reactivity, we looked at pseudo-first order reaction rate coefficients of these PAHs with hydroxyl radical.[36] Although the data set was limited to the number of species for which we could find rate coefficients, we found a statistically significant trend suggesting that this hypothesis could explain the non-uniform site differences we saw.

Figure 58. PAH ratio at 10th & Weller vs Beacon Hill compared to hydroxyl radical reactivity



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[36] Rate coefficient source: http://pubs.rsc.org/en/content/articlehtml/2013/cs/c3cs60147a
Keyte, IJ, Harrison, RM, Lammel, G, Chemical reactivity and long-range transport potential of polycyclic aromatic hydrocarbons – a review, *Chem Soc Rev*, 2013, 42, 9333-9391.
Data from Table 9, values were averaged where multiple coefficients existed.

Community-Directed Samples

Survey results and identification of sampling locations

To better identify areas and sources that the community was concerned about, we ran a series of surveys in a few different formats. We used three different forms of surveys and received 236 individual responses:

1. A large poster map at a few different public events where participants would place stickers on a map of areas of concern (111 votes)
2. Online, where participants selected regions of greatest concern to them (200 votes among 69 participants)
3. Cantonese-speaking survey results, completed on individual maps (138 votes).

For the poster map and the Cantonese-speaking survey results, we don't have the exact number of participants as in some cases individuals were allowed to pick one or more locations.

Below, we include a compilation of the results of the three surveys in Figure 59. Figure 60 includes the survey results with where the community-directed sampling occurred. This compilation includes the results of the three surveys weighted equally, and not by the frequency of votes. That is, for example, regardless of participation, the poster survey had the same level of importance as the online survey and as the Cantonese-speaking participants in the final result. In Appendix E, we show the results of these three surveys separately in Figure E-1, Figure E-2, and Figure E-3.

Figure 59. Percent of votes in each region from the three surveys, weighted equally

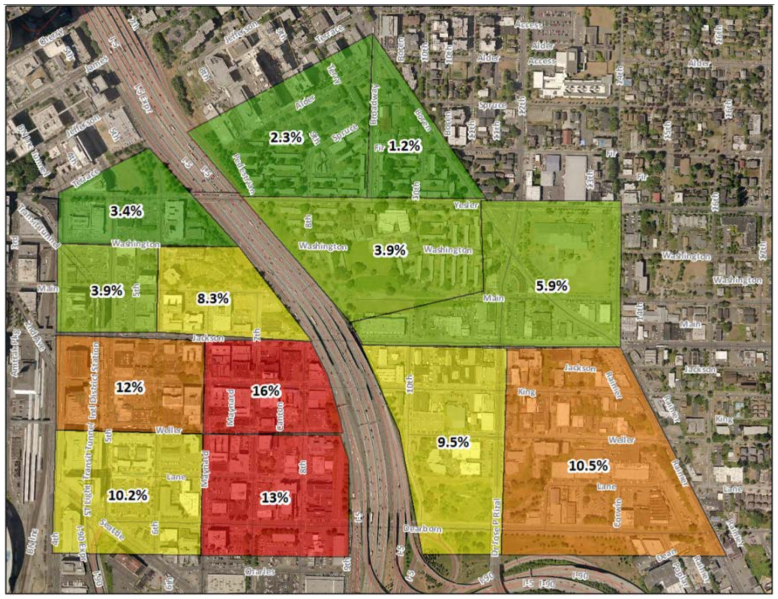
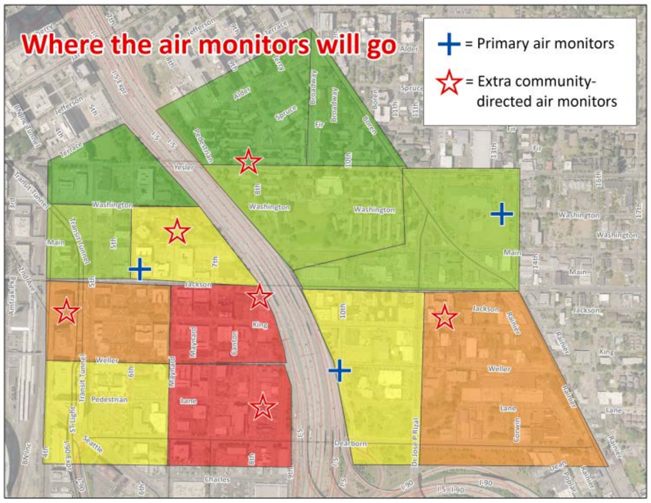
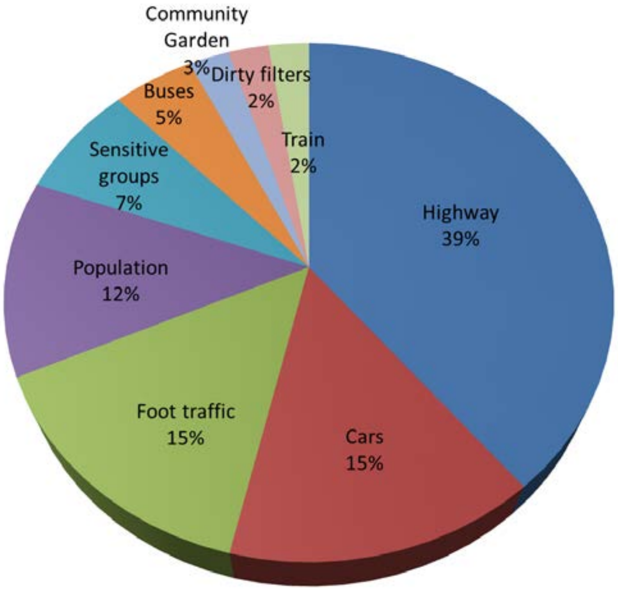


Figure 60. The community-directed sampling locations overlaid with the survey results



In Appendix E, we provide the remaining survey maps and analysis. The online survey had more questions and the option for comments. We mapped many of these results including comments that mentioned “sensitive groups”, “trains”, “buses”, etc. Figure 61 shows a pie chart of why the respondents selected the locations they did. These categories were captured from raw, free-form comments, interpreted and categorized into these bins.

Figure 61 Reasons for areas chosen from the comments (online survey only)



In Appendix E, Figure E-19 through Figure E-28, we also included results mapped by self-identified ethnic or cultural groups. This was done because there are different communities within the study area and this type of analysis has the potential to uncover differing interests of these groups.

Community-Directed Sampling Results

In this study, we monitored for the full suite of volatile organic compounds at the community-directed sites using EPA Method TO-15 (canisters) as described in the Sampling Design and Methodology Section earlier in this report.

For the community-directed sampling, one goal was to run as many of these samples on the same days as possible to maximize the ability to make comparisons. We also aimed to collect samples on five separate days during two of the seasons (in this case winter and summer). Due to work schedule constraints, we collected all the samples on weekdays. Also, some of the sites were unavailable for sampling or had sample failures, resulting in less than five samples collected on certain days. In Table 14 below, we summarize the sampling dates and locations.

Table 14. Community-directed sampling schedule and other study sites that included the full suite of volatile organic compounds

Sampling Date	Day of Week	Wind Speed[1]	Wind Direction[2]	10t & Weller	8th & Jackson	Beacon Hill	Danny Woo Garden**	Denise Louie Ed Cntr*	Nisei Vet Hall*	Union Station	8th & Yesler**
1/25/17	Wed	1.3	112	X	X	X	X	-	-	X	X
1/31/17	Tues	5.0	0	X	X	X	X	X	-	X	X
7/12/17	Wed	2.3	317	X	X	X	X	X	X	X	-
7/18/17	Tues	2.2	309	X	X	X	X	-	X	X	X
7/24/17	Mon	3.1	322	X	X	X	-	X	X	X	X

1- Vector averaged wind speed at 10th & Weller
2- Vector averaged wind direction at 10th & Weller
X = sampled day
* = Sampled on three days
** = Sampled on four days
– = Not sampled that day

We screened all the samples for any value over the one-per-million potential cancer risk screening level and found the same list of species as identified in the Air Toxics Health Risk Screening Section earlier in this report.

Since we did not measure for one year and only a sampled on a few days, our intent was to quickly screen for any unusually high levels of any air toxic, and also to make some comparisons across the study area. There are too few samples to report an annual potential cancer risk from these samples.

For the community-directed sampling analysis, we deemed an air toxic worth including if any concentrations were above Washington's ASIL for that air toxic, as we describe early in this report. Also, in this summary, we only included the relevant sample days at 10th & Weller and Beacon Hill and excluded the rest of the days of the year for better comparison against the other sites.

In Appendix F, we show a series of box plots for each of the significant air toxics during the study period, including maps with the relevant concentrations.

Air toxics ranked medians

In Table 15 below, we rank the sites for each air toxic. Then we average the ranks across all the different air toxics. (1 = highest risk, 8 or 10 = lowest risk) The table is also shaded from red to orange to yellow to green, with the highest ranked sites in red and the lowest ranked in green.

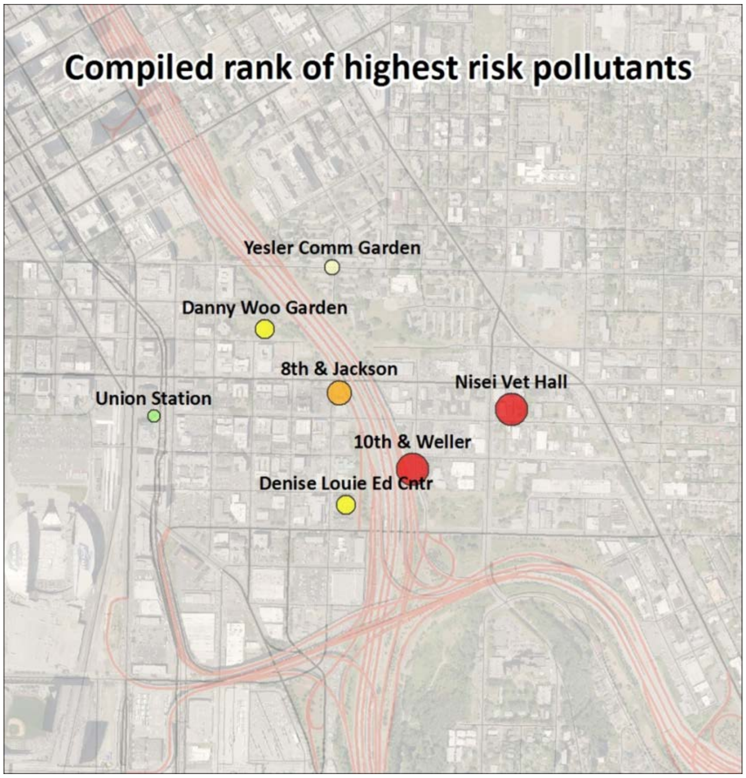
Table 15. Community-directed samples ranked by air toxic concern

Site	1,3-Butadiene	Acrolein	Benzene	Carbon Tetrachloride	Chloroform	Ethylbenzene	Tetrachloroethylene	Average Rank
Nisei Vet Hall*	1	1	1	2	1	1	2	**1.3**
10th & Weller	3	5	2	3	4	3	4	**3.4**
8th & Jackson	2	7	3	7	2	2	3	**3.7**
Denise Louie Ed Cntr*	6	2	8	8	3	7	1	**5.0**
Danny Woo Garden**	4	6	4	5	7	5	5	**5.1**
8th & Yesler**	5	4	6	6	8	4	7	**5.7**
Union Station	8	3	9	4	5	6	6	**5.9**
Beacon Hill	10	8	10	1	6	8	8	**7.3**
6th & Jackson	7		5					
Bailey Gatzert	9		7					

We included 6th & Jackson and Bailey Gatzert in the ranking only for benzene and 1,3 butadiene because the other toxics were not analyzed at these sites.

In Figure 62 below, we map the community-directed sites by the average rank found in Table 15 above. The more red and larger the size, the higher the air toxics levels we found. Interestingly, the Nisei Veteran's Hall had the highest air toxics medians in the comparisons across nearly all the air toxics. The other samples appear to be related more to their relative distance to I-5. (Beacon Hill not pictured.)

Figure 62. Map of the community-directed sampling sites with scaled markers.



As our box plots showed in Appendix F, although the medians are uniformly higher at the Nisei Veteran's Hall, we did not see a vastly higher median at this site across all the relevant air toxics. The only exception was acrolein, which with a median of about twice the next highest site. This air toxics is an acute irritant, but does not carry the potential cancer risk concerns that the other types of air toxics have.

At this time, we don't know with high confidence why the levels were uniformly higher at the Nisei Veteran's Hall, across the air toxics. It is located in a busy area of the neighborhood, with a series of forklifts, truck loading zones, and restaurants to the north. Additionally, another good candidate is cigarette smoke from any foot traffic or occupants of the Veteran's Hall during the sampling period (the sampler was located on a porch by the entrance to the Hall). Since cigarette smoke has a high emission factor for acrolein[37], this potential source could be an explanation for the increased acrolein (and the other species like benzene and 1,3-butadiene which also come from combustion).

Community-directed sampling gradients to I-5

With an apparent gradient to the roadway for these sites (other than the Nisei Veteran's Hall), we plotted the site ranks against their respective distances to I-5 in Figure 63 and Figure 64 (which

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[37] Stevens, JF, Maier, CS. Acrolein: Sources, metabolism, and biomolecular interactions relevant to human health and disease, *Mol Nutr Food Res*, 52, *1*, 2008, 7-25. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2423340/.

excluding Nisei Veteran's Hall). Although a fairly limited data set, we found a significant trend ($R^2 = 0.8$) when we remove Nisei Veteran's Hall from the plot. Note that for these two figures, risk is the average compiled air toxics median rank (1 = higher rank/risk, 8 = low rank/risk).

Figure 63. Air toxics risk rank of community-directed samples vs distance to I-5.

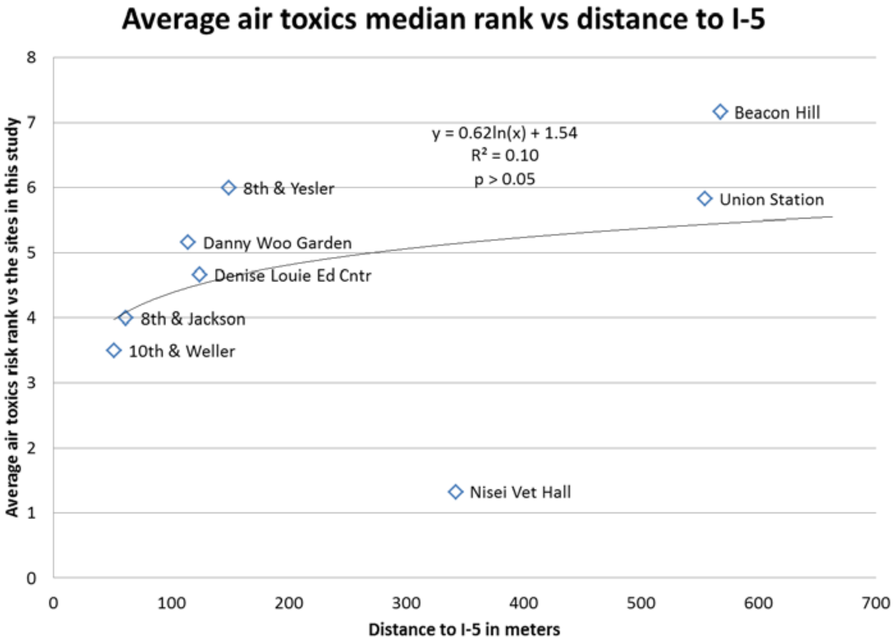
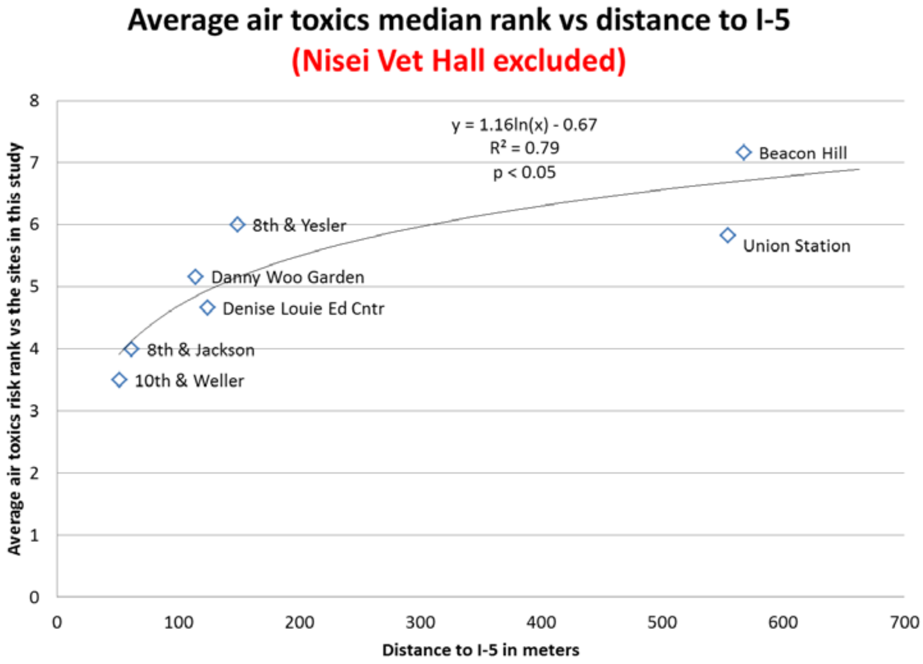


Figure 64. Same as Figure 63, but with Nisei Veteran's Hall excluded.



When we look at gradients from the roadway for individual air toxics, the only air toxics with statistically significant trends are benzene and 1,3-butadiene. These trends are shown in Figure 65 and Figure 66 below, both with and with the Nisei Vets Hall site. For reference, we included the gradients for the other pollutants in Appendix F.

Figure 65. 1,3-butadiene vs distance to I-5.

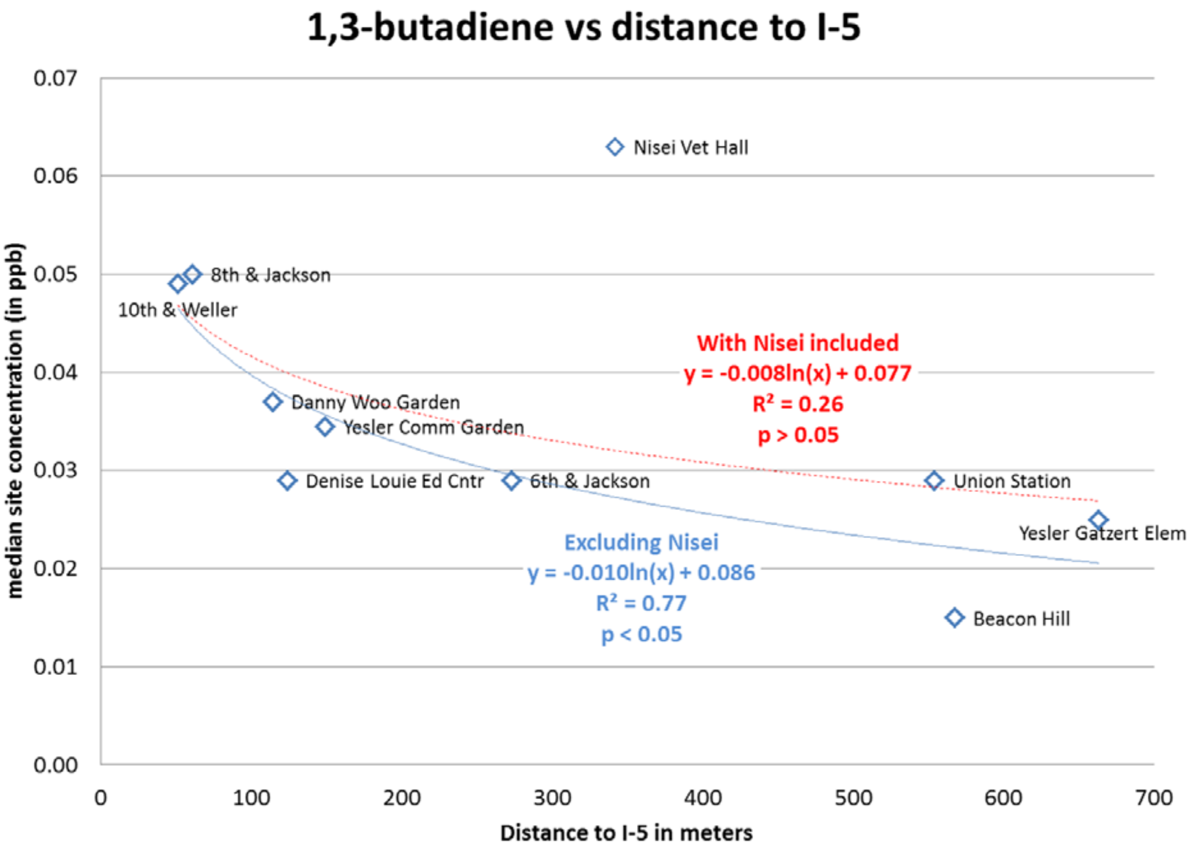
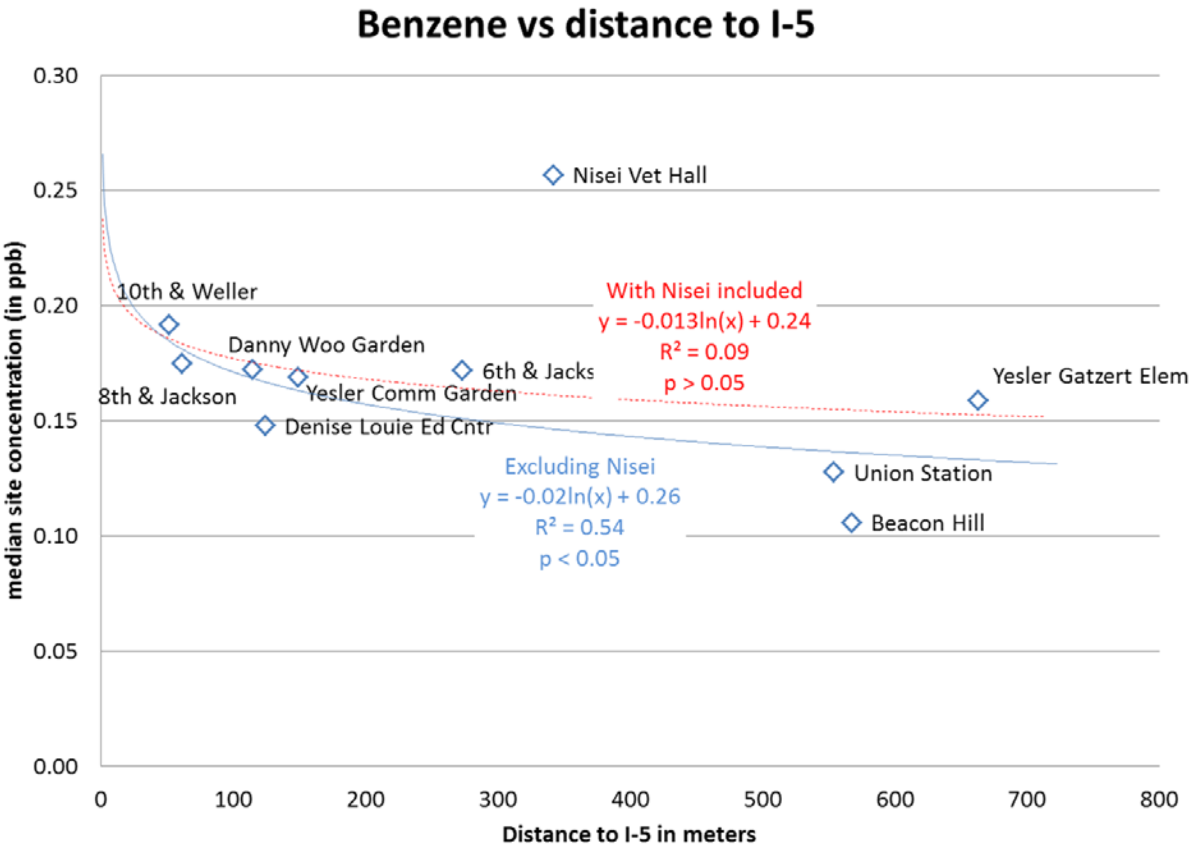


Figure 66. Benzene vs distance to I-5.

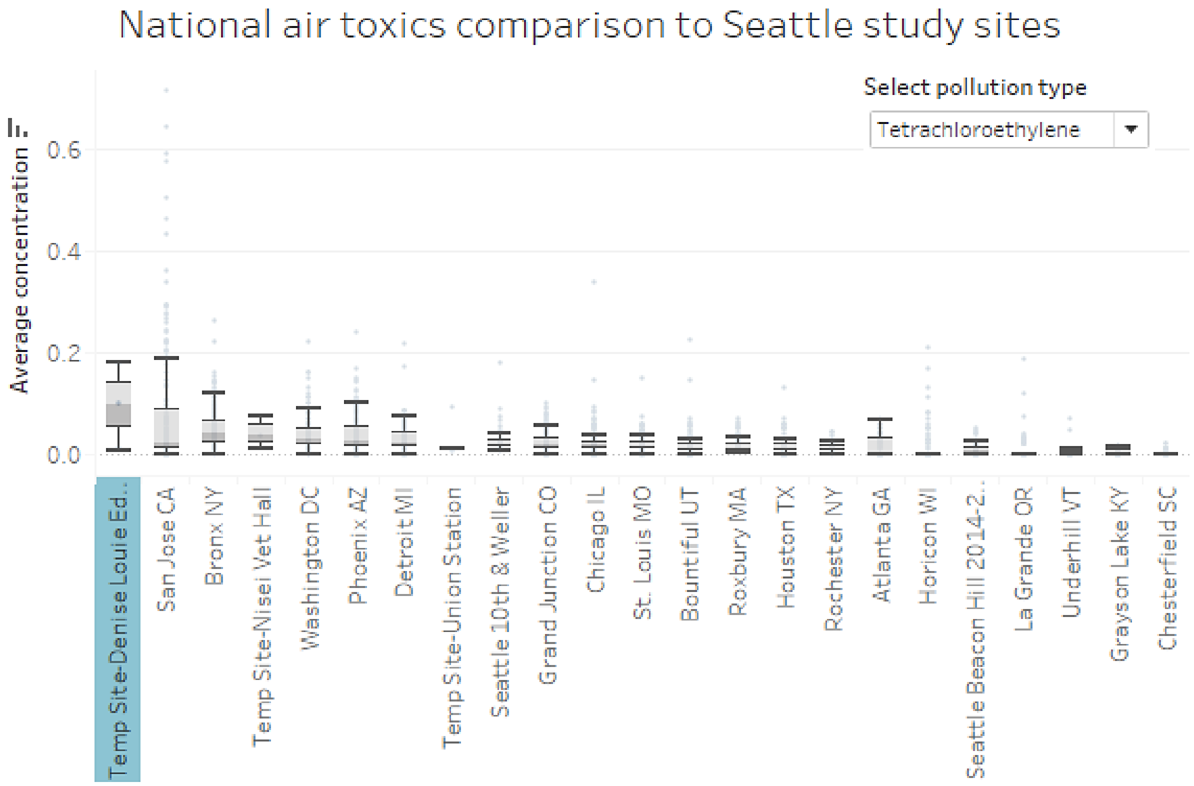


We used a simple logarithmic correlation in the above figures. We could have used other methods to better fit the curve, but using this technique also showed statistically significant correlations with the Nisei Vet Hall removed in all the plots. The exponential increase to the source (road) is an expected feature for many air pollutants.[2]

Tetrachloroethylene results at the Denise Louie Ed Cntr

In this study, we also found higher levels of tetrachloroethylene (PERC) at the Denise Louie Ed Cntr compared to the other community-directed samples. Figure 67 shows the National Air Toxics Trends Sites (NATTS) compared to the Seattle community-directed and fixed sites. When compared to the NATTS, we still see that this site is much higher than most of the national air monitoring sites with the exception of San Jose, CA at times.

Figure 67. Tetrachloroethylene box plots at the Denise Louie Ed Cntr site vs the rest of US.



Since the data set is limited (we only sampled for 3 days at this site), the data average would be unlikely to accurately represent the long-term (annual) average concentration. One of the three days was a clean day and the level was below the detection limit (on 1/31/17). However, we can make a conservative estimate based on the limited data we had by assuming the highest day would be the average throughout the entire year. With this assumption, the potential cancer risk for this air toxic would be 7 per million. Even with this conservative assumption, this result would only rank as the fifth highest air toxic of concern at the 10th & Weller site.

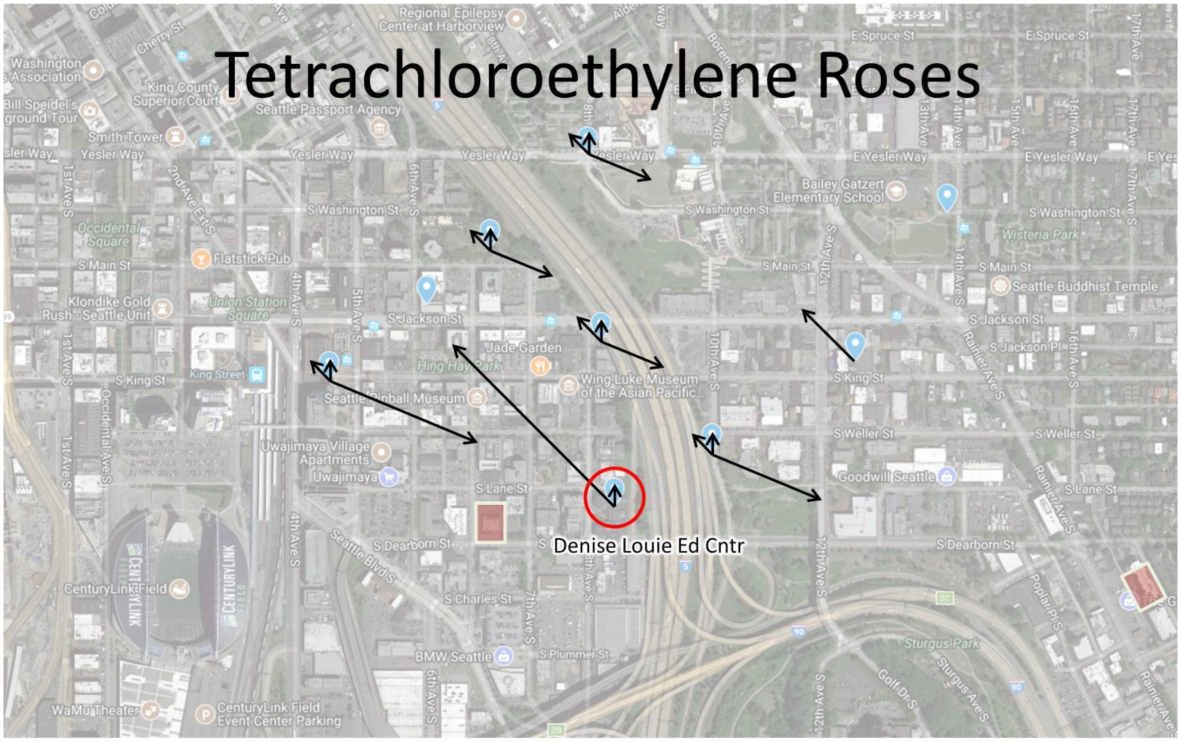
To better understand potential sources, we looked at the daily winds (vector averaged). Note that all sites use the same wind direction data from the 10th & Weller site because we did not collect site-specific met data. See Table 14 for the dates, wind directions, and sampling occurrence. Figure 68 below shows the pollution roses for tetrachloroethylene from all the community-directed samples.

There were five total sampling days. Four sites had samples on all five days and four other sites were missing one or two of the five days. Three of the sample dates (all summer) had vector-averaged wind directions from a narrow range to the northwest (309-322 degrees from north). So, for all sites, we averaged concentrations and wind directions for the two or three available summer days into a single vector. Each site then has three vectors, one represents the average of the summer days, one the northerly day (1/31/17) and one for the roughly easterly day (1/25/17).

In the figure, the arrows point to the direction the wind was coming from (not the direction the wind was blowing to). The length of the arrow represents the magnitude of the average concentration along that wind direction. All the vectors are scaled to each other.

Since the Denise Louie Ed Cntr had only three sample days, its pollution rose is limited compared most other sites. And, the sample on the northerly day (1/31/17) was below the detection limit, so that leaves only two sample days, with winds were both from the northwest. These two days, however, were clearly at higher concentrations compared to the other sites when winds were northwesterly (and in the summer).

Figure 68. Pollution roses for tetrachloroethylene at the community-directed samplers.



↑ = wind direction coming *from* 🟥 = dry cleaners

In general, these pollution roses show a similar pattern on these sampling days, except for the Denise Louie Ed Cntr and the Nisei Veteran's Hall, which shows the reverse (highest from the northwest).

The most common source of tetrachloroethylene is from dry cleaners. It can also be found in metal cleaning degreasers,[38] but the quantities from these sources (auto body or other metal working shops) are likely significantly less than from the dry cleaning industry, if the solvent is used at all. In Figure 68 above, we identified the location of the two dry cleaners in the area with red transparent boxes. On the

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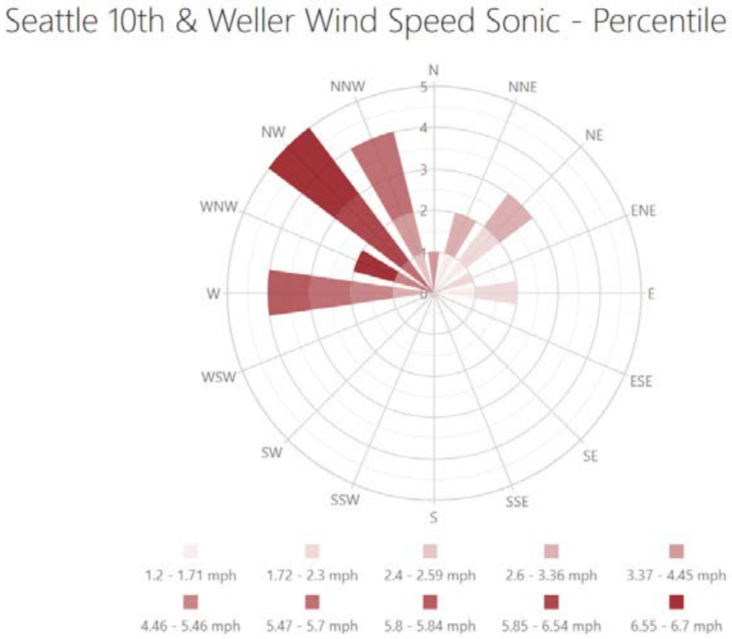
[38] https://www.epa.gov/sites/production/files/2016-09/documents/tetrachloroethylene.pdf

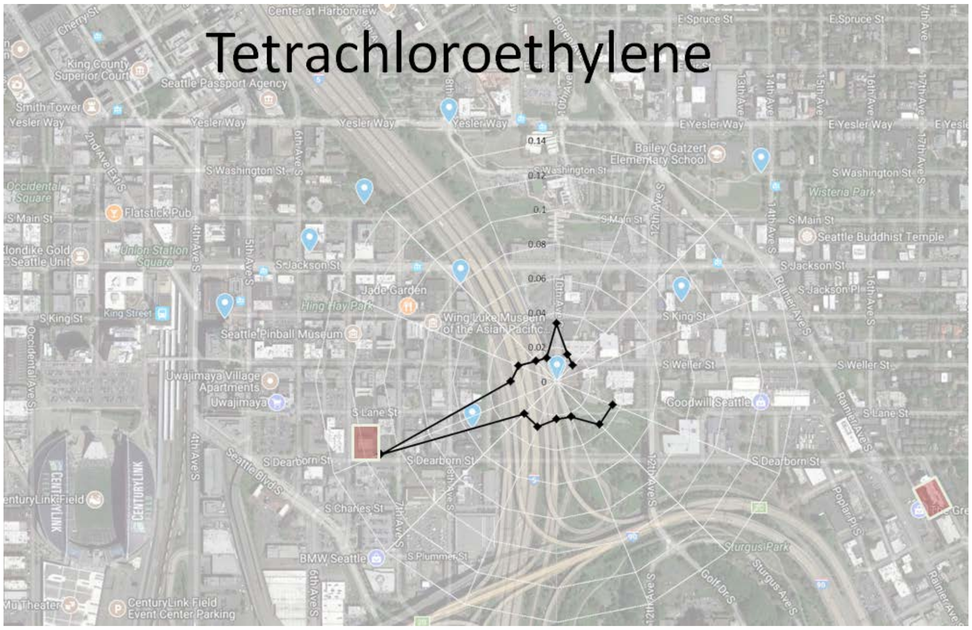
days with higher levels at the Denise Louie Ed Cntr, hourly wind directions show four hours in the westerly direction (as seen in Figure 69 below). Since the samples were collected on a 24-hour a basis, determining an exact location is difficult. However, the presence of westerlies during the sampling and the high concentrations does suggest that the dry cleaner two to three blocks could be a source.

Figure 69. Hourly wind speed and direction on 7/27/17 at the 10th & Weller site (on the maximum concentration day at the Denise Louise Ed Cntr)



At the 10th & Weller location, we have a full year of tetrachloroethylene data. In Figure 70 below, we show the pollution rose from a full year of monitoring. There were no vector-averaged winds from the east, so there is a gap in the pollution rose in this direction. This wind rose also supports that the nearby dry cleaner may be a source and may be impacting other locations downwind.

Figure 70. Pollution rose for tetrachloroethylene at the 10th & Weller site.



After this analysis, we communicated with the dry cleaner and they mentioned that since our sampling period, they upgraded their equipment, which should help mitigate tetrachloroethylene losses.

At this time, we don't have an explanation for why the Nisei Vet Hall also had higher northwesterly levels. These samples all occurred during the summer (we did not have this monitor location yet for our winter sampling campaign). As the Nisei Vet Hall does not appear to be downwind of any specific sources, with a limited data set of three samples, and without samples with additional wind directions, we cannot identify a specific reason or potential source.

Summary of Community Engagement

The air toxics study presented a new and exciting challenge for our Agency: collaborating with the community to determine how and where to study air pollutants. We engaged with the community through education and citizen science activities, and for input on sampling location (canisters for toxics).

Our education and citizen science activates were described in an earlier section, Monitoring for Education and Outreach:, and focused on youth in the WILD program and hands-on activities.

Ahead of deploying the air toxic canisters, we worked with community partners over several months 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.

In-person outreach

We attended seven different events or outreach opportunities in the neighborhood. A major component of these events was soliciting input about where they had concerns. Using a map of the neighborhood, community members used stickers to identify areas they thought had higher amounts of air pollution and should be studied further. Below is a list of the events.

- CIDBIA Night Market – September 10, 2016
    - Set up a table and map display at a local community event. Attendees had the opportunity to place stickers where they wanted us to measure air pollution.
    - Event attendees often mentioned garbage and other unwanted odors, in addition to traffic in the neighborhood.
    - Most attendees tended to be visitors to the neighborhood, rather than those who live or work in the CID.
- Keiro NW Residents' Meeting – September 28, 2016
    - Talked to approximately 25 Japanese-speaking residents about air pollution, environmental justice, and the upcoming study.
- Asian Pacific Director's Coalition Meeting – October 12, 2016
    - Presented at the monthly meeting of the Asian Pacific Director's Coalition (APDC), a group that consists of high-level directors and administrators who work in Seattle-based non-profits and civil rights organizations. The group primarily focuses on issues important to the Asian-Pacific Islander (API) community.
- Yesler Annual Survey Event – October 21, 2016
    - Neighborcare Health, a local health care provider with community ties to the Yesler Terrace neighborhood, invited us to host a table at one of their annual community events.
- Keiro NW Health Fair – October 22, 2016
    - Set-up a map display at Keiro NW's annual health fair for API residents.
- InterIm CDA Residents' Meeting – October 26, 2016
    - Talked to approximately 46 Cantonese-speaking residents of the neighborhood about air pollution and the upcoming study.
    - Residents placed stickers on handout maps to indicate where air toxic canisters should be located.
- Uwajimaya Outreach – November 16, 2016
    - Hosted a table outside the Uwajimaya Market (a local grocery store) entrance with students from InterIm CDA's after-school youth program (WILD).

Figure 71. Agency booth at two outreach events.

Online survey

With the help of our community partner, InterIm CDA, we also put together an online survey to collect input on where to place the additional samplers (air toxic canisters). The survey showed a map of the CID divided into 13 separate areas and asked respondents to pick their top three choices for where to measure air pollution. The survey – which required two minutes or less for respondents – also asked basic demographic information, including age, race, and relationship with the neighborhood (resident, worker, or visitor).

We sent the survey to multiple organizations' listservs, including the Business Improvement Area, Yesler Community Collaborative, InterIm CDA, Seattle Chinatown-International District Preservation Development Authority (SCIDpda), APDC, and more. The survey was also publicized by the neighborhood's local newspaper, the International Examiner. As discussed in the previous section, Figure 59 shows the results of the survey with the percent of the vote that each area received. Figure 60 shows where we placed the canister samples. And, the sectors are colored by ranking of the percentage of the votes.

Community engagement results

Overall, we received 236 individual responses through both online and in-person outreach. The survey results gave us an indication of where air toxic canisters should be located throughout the neighborhood.

Community collaboration was also key in placing a third air monitoring station, which ultimately was sited at 6th & Jackson. The three initial locations we investigated were found to not be suitable for several reasons. So, the Agency met with InterIm CDA to find neighborhood property owners that would be willing to host an air monitoring station that would fit the study's needs. Eventually one property owner agreed to help. Our ongoing partnership with InterIm CDA allowed us to make contact with the property owner and develop a collaboration – without these connections the site would have not been possible.

More generally, the study allowed the Agency to reach out to and talk with dozens of community organizations, residents, and individuals with ties to the neighborhood in order to build relationships, understand the community's needs, and explore potential partnerships.

Synthesis and Findings

Our core, fixed site (10th & Weller) shows a clear signature of highway pollution, dominated by diesel. This is evident in the strong relationship between nitric oxide (NO) and black carbon, the diurnal pattern, and the directionality. The summer shows a stronger diurnal pattern than winter (and the average), which is evidence of either 1) increased emissions in the summertime from the same sources (least likely), 2) increased activity in the same or similar upwind environment, or 3) a different airflow pattern and thus different upwind sources (more likely). Further away from I-5 and I-90 (further than the 10th & Weller site) at the two fixed sites (using MOBs), we see evidence of a similar diurnal pattern, but it is much weaker. The average impact of I-5 is almost certainly weaker further away, and these sites will reflect emissions from sources that are closer to them, such as cars and trucks on the streets and neighborhood restaurants and businesses.

There is also a clear sign of a wintertime wood smoke impact. The wood smoke is evident by the diurnal pattern, seasonality, and the chemical signature. The impact appears to be similar at 10th & Weller and Yesler, and somewhat smaller at 6th & Jackson. This lack of a strong gradient suggests the source is further away, or more diffuse, than I-5 and I-90. The wind direction during the wood smoke impacted times was fairly consistently from the ENE, which suggests upwind residential neighborhoods could be a significant source.

Despite the clear impact from the highways and the wood smoke, all criteria pollutants were below the NAAQS at 10th & Weller, suggesting that the study area is also below the NAAQS. The mobile monitoring was consistent with the evidence from the fixed sites that the highways are the dominant pollution source for the central study area (within a few hundred meters of 10th and Weller). And, it is also evidence there are no other sources of black carbon or particles within the study area that are similar in magnitude (of total emissions) to the highways.

AERMOD modeling of the restaurants and vehicles on I-5/I-90 predicts an annual average $PM_{2.5}$ elevation at the 10th & Weller site of 0.8 $\mu g/m^3$. Since the site is located close to the main source, the highway, it is in a strong spatial gradient. Small changes (or errors) in the receptor location (site location), source location (road center and edge, and activity within the source area), modeled environment (such as buildings, bridges, etc.), or errors due to simplified or incomplete model physics can produce large differences in concentration, even though the overall shape and pattern of the emissions is sufficiently accurate. To help assess the range of uncertainty on the model prediction, the next closest grid points along the gradient (straight east from the road) are 1.3, and 0.4 $\mu g/m^3$, respectively (50 m west and east of 10th & Weller). The diurnal average pattern from the hourly data at 10th & Weller suggest an annual average contribution of 0.6-1.2 $\mu g/m^3$ (range is winter average to summer average) from daily emissions during traffic and business hours (roughly 5AM-8PM). Since the

AERMOD data includes only the roads and restaurants, we would expect that the observations would be higher due to additional sources that weren't included in the model. Overall, the AERMOD modeling and the observations show reasonable agreement and together support that I-5/I-90 traffic is the dominant source of $PM_{2.5}$ in the study area, but there may be an additional 0.5-1.0 $\mu g/m^3$ of background anthropogenic $PM_{2.5}$ that we haven't identified.

The PMF modeling consistently identified a wood smoke factor (wintertime dominant), and several fossil fuel combustion factors that had varying amounts of black carbon, $PM_{2.5}$, and elemental/organic carbon (which are tracers of diesel and industrial activities). For estimating the overall impact of diesel emissions, the PMF factor "diesel" is the most direct measure based on the strong contribution from nitric oxide, black carbon, and EC1 and EC2. The "summer industrial" factor appears to capture diesel impact, too, because of its strong sulfate and EC2 components. While there are components in other factors that also found in diesel emissions, they are not exclusive to diesel and so could easily be gasoline vehicles or other industrial combustion processes. The "summer industrial" and "diesel" PMF factors have annual $PM_{2.5}$ contributions of 0.9 and 0.4 $\mu g/m^3$, respectively. The "summer industrial" factor alone compares reasonably well to the AERMOD simulations. But, the ratios of BC to $PM_{2.5}$ in these two factors are different from emissions profiles, which implies these PMF factors aren't exclusively or completely capturing all diesel emissions.

A recent study comparing near-road monitors to more distant monitors[39] suggested the 10th & Weller site has a 1.3-2.6 $\mu g/m^3$ elevation compared to background. This agrees reasonably well with the PMF factors "diesel" plus "summer industrial" at the low end (1.3 $\mu g/m^3$), and "diesel", "summer", and "industrial metals" factors (which sum to 1.7 $\mu g/m^3$) at the higher end. It should be noted that when doing a comparison with more distant monitors (25 km, 50 km, and 100 km), sources within a few km of the near-road monitor (10th & Weller in our case) will be captured by this difference method identically to sources much closer to the monitor, e.g. the highway. The means that the difference method (and therefore the 1.3 – 2.6 $\mu g/m^3$ value) will likely reflect more than just the adjacent highway (I-5/ & I-90) and will include other sources within a few km, such as other roads and in our case, activities outside the Chinatown-International District study area. Therefore, it would be more appropriate to compare the difference method values to a set of PMF factors including more than just the near-road "diesel" factor.

Our calculation of toxic risk from the gradient map suggests that the major roads contribute a potential cancer risk of 1-50 per million from on-road diesel exhaust, to most of the Puget Sound area. This is probably an underestimate since it is not considering the aggregate airshed and background emissions from other roads downwind. Areas adjacent to the busiest freeways are in the range of 400-600 per million and higher. A comparison of the PAH levels to Beacon Hill suggests that the 10th & Weller site is significantly more impacted by fresh PAHs, including PAHs from wood combustion, and fossil fuel combustion, particularly incomplete combustion that is typical of diesel vehicles.

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[39] DeWinter, J.L., S.G. Brown, A. F. Seagram, K. Landsberg, D.S. Eisinger, (2018) A national-scale review of air pollutant concentrations measured in the U.S. near-road monitoring network during 2014 and 2015, Atmospheric Environment (2018), doi: 10.1016/j.atmosenv.2018.04.003.

There were anomalously high values for several pollutants at the 6th & Jackson site and the Nisei Veterans Hall (canister samples). These could be due to contamination, or more likely, some unique, very local sources such as a smoking, e-cigarettes (a.k.a. vaping), or small commercial/business processes. One canister site, Denise Louie Ed Cntr, detected modestly higher levels of tetrachloroethylene (PERC), which is used predominantly in dry cleaning. Our analysis suggests that it may have come from a nearby dry cleaner. With a conservative assumption about the average levels (highest observed is the average), the risk was < 10 in million for potential cancer.

Emissions inventories of known pollution sources in King County and near the study area suggest that on-road diesel should dominate in the near-road environment. Further from the road, we expect to see background pollution that reflects an average mix of the nearby sources. The largest sources near to the CID are several industries (cement, glass, steel) in the Duwamish Valley, ships and cargo handling equipment of the port (mostly diesel), and diesel vehicles from nearby roads and highways. In the winter there can also be substantial emissions from residential wood burning. The nearest residential neighborhoods with potential for wood burning emissions would be immediately to the northeast, east, and southeast of the CID. There are no large electricity generation utilities within King County.

Overall, the data present a clear picture that the core of the study area is primarily impacted by the vehicle emissions from I-5 and I-90. This impact, however, decreases with distance from the highway so that by 300-500 meters, there is minimal impact compared to background levels. There appears to be a relatively minimal impact from restaurants. Emissions further upwind, or outside of the study area, also appear to contribute, although they likely do so more uniformly. The clearest other signals we could discern were wood smoke in the wintertime and a summer increase in industrial/diesel possibly from the west of the study area. But, it is difficult to distinguish or identify more precisely.

The toxics data are consistent with this analysis, and suggest that the dominant toxics risk is from the vehicle emissions on I-5/I-90, although a similar level of background pollution (from outside the study area) could also be an import contributor.

Appendices

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Appendix A. Air Toxics Data and Analysis

Table A-1. All volatile organic compounds measured using canisters (EPA method TO-15).

1,1,1-Trichloroethane	cis-1,3-Dichloropropene
1,1,2,2-Tetrachloroethane	Dibromochloromethane
1,1,2-Trichloroethane	Dichlorodifluoromethane
1,1-Dichloroethane	Dichloromethane
1,1-Dichloroethene	Dichlorotetrafluoroethane
1,2,4-Trichlorobenzene	Ethyl Acrylate
1,2,4-Trimethylbenzene	Ethyl tert-Butyl Ether
1,2-Dibromoethane	Ethylbenzene
1,2-Dichloroethane	Hexachloro-1,3-butadiene
1,2-Dichloropropane	m,p-Xylene
1,3,5-Trimethylbenzene	m-Dichlorobenzene
1,3-Butadiene	Methyl Isobutyl Ketone
Acetonitrile	Methyl Methacrylate
Acetylene	Methyl tert-Butyl Ether
Acrolein	n-Octane
Acrylonitrile	o-Dichlorobenzene
Benzene	o-Xylene
Bromochloromethane	p-Dichlorobenzene
Bromodichloromethane	Propylene
Bromoform	Styrene
Bromomethane	tert-Amyl Methyl Ether
Carbon Disulfide	Tetrachloroethylene
Carbon Tetrachloride	Toluene
Chlorobenzene	trans-1,2-Dichloroethylene
Chloroethane	trans-1,3-Dichloropropene
Chloroform	Trichloroethylene
Chloromethane	Trichlorofluoromethane
Chloroprene	Trichlorotrifluoroethane
cis-1,2-Dichloroethylene	Vinyl chloride

Table A-2. All aldehyde (or carbonyl) compounds measured using cartridges (EPA method TO-11a).

2,5-Dimethylbenzaldehyde
2-Butanone
Acetaldehyde
Acetone
Benzaldehyde
Butyraldehyde
Crotonaldehyde
Formaldehyde
Hexaldehyde
Isovaleraldehyde
Propionaldehyde
Tolualdehydes
Valeraldehyde

Table A-3. All polycyclic aromatic hydrocarbons (PAHs or semi-volatile compounds) measured using cartridges (EPA method TO-13a).

9-Fluorenone
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
Cyclopenta(c,d)pyrene
Dibenz(a,h)anthracene
Fluoranthene
Fluorene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Perylene
Phenanthrene
Pyrene
Retene

Table A-4. All PM_{10} metals measured using cartridges (with EPA method IO-2.1).

Antimony
Arsenic
Cadmium
Chromium
Cobalt
Lead
Manganese
Mercury
Nickel
Selenium

Table A-5. All of the null (lost) samples, including the dates, instrument, reason, and analytes lost.

Site	Date	Instrument	AQS Null Reason	Notes
10th and Weller	11/8/2016	PAH	Machine Malfunction	Impacted all PAHs
	3/20/2017	PAH	Power Failure	Impacted all PAHs
	9/27/2016	Aldehyde	Interference/co-elution/misidentification	Only impacted Crotonaldehyde
	11/20/2016	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	12/20/2016	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	1/1/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde
	3/26/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	4/7/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	5/7/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde
	7/18/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	7/24/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	8/11/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde

Beacon Hill	3/8/2017	Aldehyde	Machine Malfunction	Impacted all aldehydes
	10/18/2016	Aldehyde	Interference/co-elution/misidentification	Only impacted Crotonaldehyde
	1/19/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes And Valderaldehyde
	2/6/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes and Valderaldehyde
	2/12/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	3/2/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes and Valderaldehyde
	3/14/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Hexanaldehyde
	3/26/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Valeraldehyde
	4/25/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	5/1/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde
	5/31/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde
	7/30/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde and Methyl Ethyl Ketone
	9/16/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Methyl Ethyl Ketone and Tolualdehydes
	9/22/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Tolualdehydes
	9/28/2017	Aldehyde	Interference/co-elution/misidentification	Only impacted Butyraldehyde and Hexanaldehyde
	5/19/2017	PM_{10} metals	Voided by Operator	Impacted all PM_{10} metals
	5/22/2017	PM_{10} metals	Voided by Operator	Impacted all PM_{10} metals
	5/25/2017	PM_{10} metals	Voided by Operator	Impacted all PM_{10} metals
	5/28/2017	PM_{10} metals	Voided by Operator	Impacted all PM_{10} metals
	5/31/2017	PM_{10} metals	Voided by Operator	Impacted all PM_{10} metals

Yesler Gatzert Elem	11/20/2016	VOC	Operator Error	Impacted all VOC (but just 1,3-Butadiene and Benzene)
	7/6/2017	VOC	Sample Flow Rate or CV out of Limits	Impacted all VOC (but just 1,3-Butadiene and Benzene)

In this section, we describe how health risks were evaluated and how air toxics were ranked based on monitored concentrations and available health information.

First, we reviewed pollutants to determine whether we found data that was complete and valid, and consistently above the method's minimum level of detection (MDL). Then, we compared valid datasets to the Washington State Department of Ecology's (Ecology's) Acceptable Source Impact Levels (ASIL), using them as screening values.[40] If a pollutant's mean was greater than the ASIL, then it was of potential health concern and highlighted in this report. We grouped air toxics monitoring parameters into four screening categories through this process:

- Air toxics with detection limits above the ASIL, with concentrations below the MDL. These air toxics levels and risks are indeterminate. These air toxics are shown in Table A-9 in this appendix.
- Air toxics without ASILs for comparison. Table A-8 in this appendix shows air toxics that do not have a corresponding ASIL. Several air toxics also had invalid datasets, below detection limits or with few detects. While some air toxics have valid datasets, potential health risks are indeterminate because there's no screening level for comparison.
- Air toxics with valid datasets with concentrations below ASILs. Table A-10 in this appendix shows air toxics that were not detected and the MDL is below the ASIL, and air toxics that were detected and found to be consistently below the WA 460 ASIL. Although the table lists mean concentrations, it is noteworthy that in many instances maximum concentrations were below the ASIL. Because these air toxics have known levels below health screening values, they do not likely present health risk, and were not further explored in this study.
- Air toxics with valid datasets above ASILs. These air toxics are listed in Table 5 in the main body of the report. With concentrations greater than health screening levels, these air toxics present potential health risk and are the focus of this study. In the following sections, the Agency evaluates and ranks these air toxics based on chronic cancer and non-cancer health effects.

The Agency did not evaluate pollutants for short-term/acute health effects, because data collected (24 hour samples) do not allow for this type of evaluation.

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[40] Washington State Administrative Code (WAC). (2009). WAC 173-460-150. http://apps.leg.wa.gov/wac/default.aspx?cite=173-460-150.

Carcinogenic Health Screening: Unit Risk Factors

Carcinogenic health effects are presented as a probability or risk of developing cancer over a lifetime. Typically, this is interpreted as potential cancer cases over the population of potentially exposed individuals. For example, a one in a million potential cancer risk can be viewed as one additional cancer case for every million people equally exposed to that concentration. This is in addition to those cancer cases that would normally occur in an unexposed population of one million people over a lifetime.

Potential cancer risk is estimated by multiplying a pollutant's concentration by its unit risk factor:

$$\textit{Potential Cancer Risk (risk)} = \textit{Pollutant Concentration } (\mu g/m^3) * \textit{Unit Risk Factor } (risk / (\mu g/m^3))$$

A unit risk factor (URF) represents the potency of each pollutant, and is defined as "a measure of the potential cancer risk of exposure to 1 microgram chemical per cubic meter of air over a 70-year period."[41] URFs are typically derived from animal laboratory studies, and human data from epidemiological or clinical studies can also provide dose-response information. URFs are designed to be protective of health; therefore, risks derived from URFs are upper bound estimates. Actual risks may be lower, and possibly as low as zero. Upper bound estimates are used to ensure that risks are not underestimated.

Table A-6 shows the URFs that were used for pollutants in this study whose annual average concentrations exceeded a screening threshold of 1 in a million potential cancer risk. The threshold of 1 in a million potential cancer risk is used as the starting point for defining a risk level of concern by most environmental agencies, including the Agency, Washington State Department of Ecology, and EPA. Those pollutants whose ambient concentrations present risk below 1 in a million potential cancer risk are shown in Table A-10 of this appendix.

The URFs shown in Table A-6 are consistent with those used by the Washington State Department of Ecology in their rulemaking for acceptable source impact levels (ASILs) for air toxics.[40] The source for the URF is also listed in the table. Most of the URFs were obtained from the US EPA IRIS (Integrated Risk

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[41] US EPA. "2002 National Air Toxics Assessment. Glossary of Terms – Unit Risk Factor and Cancer Risk". http://www.epa.gov/ttn/atw/nata2002/gloss1.html.

Information System) database and from California EPA's Office of Environmental Health and Hazard Assessment (OEHHA).[42,43] Both are credible, extensively peer-reviewed sources. Cancer confidence ratings are also included. US EPA IRIS assigns the weight of evidence rating, with Group A being associated with the greatest certainty of evidence for causing cancer in humans and Group E having evidence that the chemical does not cause cancer in humans.[44] Where IRIS gave no assignment, IARC's (International Agency for Research on Cancer's) rating was used. Weight of evidence ratings are shown in Table C-6 in Appendix C. While diesel particulate matter and wood smoke particles were not measured explicitly in this study, we use their estimates from other studies because these are key air toxics. Thus, their unit risk factors are included in Table A-6 and are discussed below.

Table A-6. Unit risk factors and cancer ratings for air toxics with average potential cancer risk greater than 1-in-a-million.

Air Toxic	URF (risk/$\mu g/m^3$)	Weight of Evidence	Source
1,3-Butadiene	1.7E-04	A	CA EPA/OEHHA
Acetaldehyde	2.7E-06	B2	CA EPA/OEHHA
Arsenic**	3.3E-03	A	CA EPA/OEHHA
Benzene	2.9E-05	A	CA EPA/OEHHA
Carbon tetrachloride	4.2E-05	B2	CA EPA/OEHHA
Chloroform	2.3E-05	B2	US EPA/IRIS
Diesel particulate matter	3.0E-04	B2	CA EPA/OEHHA
Ethylbenzene	2.5E-06	D	CA EPA/OEHHA
Ethylene Dichloride	2.6E-05	B2	CA EPA/OEHHA
Formaldehyde	6.0E-06	B1	CA EPA/OEHHA
Naphthalene	3.4E-05	C	CA EPA/OEHHA
Nickel**	4.8E-04***	A***	US EPA/IRIS
Tetrachloroethylene	5.9E-06	IARC 2A ~ B1	CA EPA/OEHHA
Wood smoke particles*	1.0E-05	IARC 2A ~ B1	Lewtas, 1988

** Measured in this study as PM_{10} metals.
*** As nickel subsulfide from refinery dust.

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[42] US EPA. "Integrated Risk Information System". http://www.epa.gov/iris/.

[43] California Environmental Protection Agency, Office of Environmental Health and Hazard Assessment. http://www.arb.ca.gov/toxics/healthval/healthval.htm.

[44] US EPA. (1992). "EPA's Approach for Assessing the Risks Associated with Chronic Exposure to Carcinogens. Background Document 2". http://www.epa.gov/iris/carcino.htm.

Wood smoke unit risk factor

Wood smoke is comprised of a variety of constituents, including but not limited to: particulate matter, nitrogen oxides, carbon monoxide, sulfur oxides, volatile organic compounds, and polycyclic aromatic hydrocarbons (PAHs). Many of the chemicals listed as constituents in wood smoke have been identified as probable or likely human carcinogens.

The unit risk factor for wood smoke was developed through a comparative potency method where the mutagenicity and tumor initiating potency from particles emitted from several sources (e.g., diesels, wood smoke and gasoline-powered automobiles) are systematically evaluated. Lewtas uses bioassay-directed fractionation, a combination of several chemical separation and bioassay techniques, to identify the more toxic elements of several complex mixtures. In the Lewtas study, mutagenicity tests are conducted on different segments of the total mixtures. Segments showing higher mutagenic potencies are further divided into groups and tested until the components or segments with the highest potencies are identified.[32]

We recognize the Lewtas wood smoke URF has not undergone the same rigorous evaluation as the other URFs used in our analysis. Nonetheless, it is developed through a method recommended by the National Academy of Sciences and is published in a respected peer-reviewed journal.[45]

Further, the International Agency for Research in Cancer (IARC) evaluated wood smoke, and determined it to be a Group 2A carcinogen – probably carcinogenic to humans. In reaching this evaluation, IARC considered mechanistic and other relevant data. These data included the presence of polycyclic aromatic hydrocarbons and other carcinogenic compounds in wood smoke; evidence of mutagenicity of wood smoke; and multiple studies that show cytogenetic damage in humans who are exposed to wood smoke.[46]

Diesel particulate matter unit risk factor

Diesel particulate matter (DPM) is a component of diesel exhaust. DPM contains elemental carbon, organic carbon, and small amounts of nitrate, metals, and unidentified compounds. We focus on the particulate component of diesel exhaust because it is thought to contain the majority of the toxicity associated with the mixture. Some experiments have shown the tumorigenicity of diesel exhaust is from the particulate components, not the vapor components. The vast majority of animal and human exposure studies use DPM as a measure of diesel engine exhaust. These particles and their adsorbed toxics penetrate deep into the lung during inhalation.

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[45] National Academy of Sciences (1988). "Complex Mixtures: Methods for In Vivo Toxicity Testing". National Academy Press. Washington DC.

[46] International Agency for Research on Cancer. (2006) "IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Volume 95: Indoor Air Pollution from Heating and Cooking: Some Solid Fuels and Cooking Oil Fumes". Lyon, France.

While specific knowledge of the role of the adsorbed chemicals is not known, it is hypothesized that the presence of such substances may influence particle toxicity. However, relatively little is known about the cumulative toxicity of the multiple toxics present in certain combustion mixtures. For example, it is possible that antagonism or synergism occurs among the chemicals and/or particles. In addition, there may be a variety of carcinogenic or toxic chemicals present in the mixture that have not yet been identified.[45] Therefore, we use unit risk factors for the whole mixture to estimate potential risk for diesel particulate and wood smoke, rather than unit risk factors for individual carcinogens and summing the individual risks.

The carcinogenicity of diesel particulate matter is widely recognized by a number of health agencies including the US EPA,[47] California EPA,[48] the US Department of Health and Human Services,[49] and the International Agency for Research on Cancer (IARC).[50] The Washington State Department of Ecology conducted an extensive review of the literature on diesel exposures and health, and endorses the California EPA URF.[51]

The Clean Air Agency uses an appropriate approach based on the California OEHHA DPM unit risk factor, which has been widely cited and is the basis for the diesel retrofit program in place for several years in California. This approach evaluates 100% of the highly toxic diesel particulates as a complete and complex mixture. Risk assessment using the single DPM URF is likely to account for potential interactions (i.e., synergism and antagonism) among the hundreds and/or thousands of chemicals in DPM. To the extent that diesel exhaust contains priority air toxics like benzene, formaldehyde, and acetaldehyde, there is the possibility for ‘double counting’ some of the potential risk for these air toxics. However, the benefits of the complex mixture approach outlined above far outweigh any downside of potential double-counting. Also, these three air toxics have other known sources, so the potential for ‘double counting’ for them is small.

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[47] US EPA. (2009). “2002 National Air Toxics Assessment”. http://www.epa.gov/ttn/atw/nata2002/.

[48] California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (1988). “For the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Part B: Health Risk Assessment for Diesel Exhaust”.

[49] National Toxicology Program. (2001). Public Health Service, US Department of Health and Human Services. “9th Report on Carcinogens”. Revised January 2001.

[50] International Agency for Research on Cancer (IARC). (1989). “IARC Monograph on the Evaluation of Carcinogenic Risks to Humans. Vol 46: Diesel and Gasoline Engine Exhausts”.

[51] Washington State Department of Ecology. (2008). “Concerns About Adverse Health Effects of Diesel Engines White Paper”. http://www.ecy.wa.gov/pubs/0802032.pdf.

The following table lists the parameters we measured that do not have a respective unit risk factor for us to estimate the potential cancer risk with:

Table A-7. Air toxics without a respective Washington State Acceptable Source Impact Levels (ASIL), but with a screening level derived from other surrogate species.

Air toxic	**Non-ASIL screening measure**	**Time average for comparison**	**Source/rationale**
1,1,2-trichloro-1,2,2-trifluoroethane	50,000 µg/m^3	Annual	The chronic risk-based concentration published by US EPA for chlorodifluoromethane (https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=657).
1,2,4-trichlorobenzene	0.091 µg/m^3	Annual	The risk-based concentration for 1,4-dichlorobenzene published by OEHHA and the WA ASIL; 1,2,4-trichlorobenzene is an irritant. A dermal exposure study in mice was found inadequate for drawing conclusions as to carcinogenicity in humans.
1,2,4-trimethylbenzene	4,166 µg/m^3	Daily	24 hour, an adjusted occupational exposure limit, the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for trimethylbenzenes is 25 ppm as an 8 hour Total Weight Average (or 124,991 µg/m^3 per 8 hour at 20°C and 1 atm); Exposure-time-adjustment and inter-individual (or intraspecies) uncertainty factors were applied: 8/24 can be applied to adjust the partial day exposure (8-h workday expression of the TLV) to a full day of continuous exposure, as is expected in ambient conditions, and 0.1 can be applied to account for the healthy worker effect.
1,3,5-trimethylbenzene	4,166 µg/m^3	Daily	The adjusted ACGIH TLV for trimethylbenzenes as described above.
2,5-dimethylbenzaldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Acetone	26 ppm 13 ppm	Daily Annual	Acute and Chronic ATSDR Minimum Risk Levels respectively (https://www.atsdr.cdc.gov/mrls/mrllist.asp)
Benzaldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Benzo[E]Pyrene	0.4545 µg/m^3	Annual	From Bostrom et al (2002)[52] Toxic Equivalency Factor (TEF) (approximately 0.002 BAPeq) derived unit risk factor.
Benzo[G,H,I]Perylene	0.04545 µg/m^3	Annual	From Bostrom et al (2002) Toxic Equivalency Factor (approximately 0.02 BAPeq) derived unit risk factor
Butyraldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Crotonaldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Dichlorodifluoromethane	100 µg/m^3	Annual	EPA Provisional Peer-Reviewed Toxicity Value (PPRTV): https://cfpub.epa.gov/ncea/pprtv/documents/Dichlorodifluoromethane.pdf
Fluoranthene	0.0182 µg/m^3	Annual	Evidence for mutagenicity is equivocal. You could use the TEF (approximately 0.05 BAPeq) from Bostrom et al (2002) used to derive
Hexanaldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Isovaleraldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
N-Octane	700 µg/m^3	Annual	Reference concentration(RfC) published by US EPA for n-hexane
Phenanthrene	1.8182 µg/m^3	Annual	Some metabolites are weakly mutagenic; Some studies have considered it to have a "bay-region", however it does not clearly fall into this category. You could use Bostrom's TEF (approximately 0.0005 BAPeq) to derive
Propionaldehyde	8 µg/m^3	Annual	Propionaldehyde causes respiratory tract irritation and histopathology. IRIS RfC: https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=1011
Pyrene	0.9091 µg/m^3	Annual	The TEF (approximately 0.001 BAPeq (Bostrom et al 2002)) derived the cancer risk-based concentration
Tert-Butyl Ethyl Ether	3,000 µg/m^3 2.6E-7 µg/m^3	Annual Annual	A close analog (methyl tertiary butyl ether) EPA RfC and then OEHHA URF
Tolualdehydes	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.
Trichlorofluoromethane	50,000 µg/m^3	Annual	The chronic risk-based concentration published by US EPA for chlorodifluoromethane (https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=657).
Valeraldehyde	3.9 µg/m^3	Daily	Acute reference exposure level (REL) (1-h avg) published by OEHHA for formaldehyde (94 µg/m^3), but with only daily samples, we screened as though 1 hour is at the REL and then divided by 24 hours.

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[52] Bostrom, CC; Gerde, P; Hanberg, A; et al. (2002) Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. Environ Health Perspect 110 (Suppl 3):451–488.

Table A-8. Air toxics measured that do not have a respective unit risk factor in the list of Washington State Acceptable Source Impact Levels (ASIL) or other surrogate.

9-fluorenone
Acenaphthene
Acenaphthylene
Acetylene
Anthracene
Bromochloromethane
Chloroprene
(Total) Chromium PM_{10}
Cis-1,2-Dichloroethene
Cis-1,3-Dichloropropylene
Coronene
Cyclopenta[cd]pyrene
Dibenzo[A,H]Anthracene
Ethyl Acrylate
Fluorene
Freon 114
Perylene
Retene
Tert-Amyl Methyl Ether
Trans-1,2-Dichlororthylene

The following table lists the air toxics that have a unit risk factor below the method detection limit. The sampling method doesn't give us data resolved enough to state definitively that these air toxics don't present any risk in our region. In theory, these air toxics could have a maximum risk up to the value in the far right column (assuming that all the values were just under the detection limit).

Table A-9. Air toxics with Method Detection Limits above the Washington State Acceptable Source Impact Levels (ASIL).

Air toxic	Average Method Detection Limit ($\mu g/m^3$)	Unit Risk Factor ($\mu g/m^3$)	Potential Cancer Risk at the Detection Limit (per million)
1,1,2,2-Tetrachloroethane	0.271	0.017	15.7
1,1,2-Trichloroethane	0.186	0.063	3.0
1,2-Dichlorobenzene	0.266	0.091	2.9
1,2-Dichloropropane	0.142	0.100	1.4
1,3-Dichlorobenzene	0.248	0.091	2.7
1,4-Dichlorobenzene	0.228	0.091	2.5
Acrylonitrile	0.058	0.003	16.9
Bromodichloromethane	0.201	0.027	7.4
Dibromochloromethane	0.255	0.037	6.9
Hexachlorobutadiene	0.607	0.046	13.3
Trans-1,3-Dichloropropylene	0.147	0.063	2.4

For the air toxics with a Washington State Acceptable Source Impact Level (ASIL), this table lists the air toxics that were below levels of concern (one-in-a-million potential cancer risk) when compared to the ASILs.

Table A-10. Toxics with an ASIL that were below levels of concern (1-in-a-million potential cancer risk)

Carbon Disulfide	Dibenz(a,h)anthracene	cis-1,2-Dichloroethylene
2,5-Dimethylbenzaldehyde	Fluoranthene	cis-1,3-Dichloropropene
2-Butanone	Fluorene	Dichlorodifluoromethane
Acetone	Indeno(1,2,3-c,d)pyrene	Dichloromethane
Benzaldehyde	Perylene	Dichlorotetrafluoroethane
Butyraldehyde	Phenanthrene	Ethyl Acrylate
Crotonaldehyde	Pyrene	Ethyl tert-Butyl Ether
Hexaldehyde	Retene	m,p-Xylene
Isovaleraldehyde	1,1,1-Trichloroethane	m-Dichlorobenzene
Propionaldehyde	1,1-Dichloroethane	Methyl Isobutyl Ketone
Tolualdehydes	1,1-Dichloroethene	Methyl Methacrylate
Valeraldehyde	1,2,4-Trichlorobenzene	Methyl tert-Butyl Ether
9-Fluorenone	1,2,4-Trimethylbenzene	n-Octane
Acenaphthene	1,2-Dibromoethane	o-Dichlorobenzene
Acenaphthylene	1,3,5-Trimethylbenzene	o-Xylene
Anthracene	Acetonitrile	p-Dichlorobenzene
Benzo(a)anthracene	Acetylene	Propylene
Benzo(a)pyrene	Acrolein	Styrene
Benzo(b)fluoranthene	Bromochloromethane	tert-Amyl Methyl Ether
Benzo(e)pyrene	Bromoform	Toluene
Benzo(g,h,i)perylene	Bromomethane	Trichloroethylene
Benzo(k)fluoranthene	Chlorobenzene	Trichlorofluoromethane
Chrysene	Chloroethane	Trichlorotrifluoroethane
Coronene	Chloromethane	Vinyl chloride
Cyclopenta(c,d)pyrene	Chloroprene	

Table A-11. Summary statistics for all study sites for pollutants with potential cancer risk over one-in-a-million, in original concentration units.

Notes:

- ND = non-detects
- Median, Mean, 95%ile, Max are in their respective units
- MDL means method detection limit

8th & Jackson

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	5	0	ppb	0.05	0.0884	0.173	0.181	0	0%	0
Acrolein	5	0	ppb	0.205	0.268	0.386	0.4	0	0%	0
Benzene	5	0	ppb	0.175	0.314	0.614	0.672	0	0%	0
Carbon Tetrachloride	5	0	ppb	0.094	0.0952	0.109	0.111	0	0%	0
Chloroform	5	0	ppb	0.03	0.03	0.0356	0.036	0	0%	0
Ethylbenzene	5	0	ppb	0.155	0.152	0.188	0.196	0	0%	0
Ethylene Dichloride	5	0	ppb	0.02	0.0206	0.0258	0.027	4	80%	0
Tetrachloroethylene	5	0	ppb	0.018	0.021	0.0374	0.041	4	80%	0
Vinyl Chloride	5	3	ppb	0	0.0042	0.0126	0.014	5	100%	0

Danny Woo Garden

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	4	0	ppb	0.037	0.05	0.0919	0.1	0	0%	0
Acrolein	4	0	ppb	0.211	0.263	0.453	0.49	0	0%	0
Benzene	4	0	ppb	0.173	0.249	0.478	0.527	0	0%	0
Carbon Tetrachloride	4	0	ppb	0.095	0.0975	0.111	0.113	0	0%	0
Chloroform	4	0	ppb	0.028	0.029	0.0343	0.035	0	0%	0
Ethylbenzene	4	0	ppb	0.125	0.109	0.146	0.148	0	0%	0
Ethylene Dichloride	4	1	ppb	0.0175	0.0133	0.018	0.018	4	100%	0
Tetrachloroethylene	4	0	ppb	0.012	0.0185	0.0367	0.041	3	75%	0
Vinyl Chloride	4	2	ppb	0.0005	0.0025	0.0078	0.009	4	100%	0

Denise Louie Ed Cntr

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	3	0	ppb	0.029	0.0313	0.0398	0.041	0	0%	0
Acrolein	3	0	ppb	0.299	0.307	0.386	0.396	0	0%	0
Benzene	3	0	ppb	0.148	0.15	0.186	0.19	0	0%	0
Carbon Tetrachloride	3	0	ppb	0.092	0.094	0.102	0.103	0	0%	0
Chloroform	3	0	ppb	0.03	0.0317	0.0381	0.039	0	0%	0
Ethylbenzene	3	0	ppb	0.122	0.0973	0.129	0.13	0	0%	0
Ethylene Dichloride	3	0	ppb	0.018	0.018	0.018	0.018	3	100%	0
Tetrachloroethylene	3	0	ppb	0.099	0.0967	0.173	0.181	1	33%	0
Vinyl Chloride	3	2	ppb	0	0.00267	0.0072	0.008	3	100%	0

Nisei Vet Hall

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	3	0	ppb	0.063	0.0617	0.0684	0.069	0	0%	0
Acrolein	3	0	ppb	0.639	0.55	0.731	0.741	0	0%	0
Benzene	3	0	ppb	0.257	0.255	0.261	0.262	0	0%	0
Carbon Tetrachloride	3	0	ppb	0.1	0.101	0.114	0.116	0	0%	0
Chloroform	3	0	ppb	0.039	0.0377	0.0417	0.042	0	0%	0
Ethylbenzene	3	0	ppb	0.172	0.168	0.172	0.172	0	0%	0
Ethylene Dichloride	3	0	ppb	0.022	0.0227	0.0274	0.028	1	33%	0
Tetrachloroethylene	3	0	ppb	0.037	0.042	0.0721	0.076	1	33%	0
Vinyl Chloride	3	3	ppb	0	0	0	0	3	100%	0

10th & Weller

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	62	0	ppb	0.0585	0.0629	0.125	0.245	2	3%	0
Acetaldehyde	62	0	ppb	0.581	0.684	1.37	2.92	0	0%	0
Acetone	62	0	ppb	0.562	0.621	1.28	1.8	0	0%	0
Acrolein	62	0	ppb	0.258	0.271	0.471	0.594	1	2%	0
Arsenic PM_{10}	61	0	ng/m^3	0.708	0.766	1.5	2.31	0	0%	0
Benzene	62	0	ppb		0.295	0.590	0.856	0	0%	0
Carbon Tetrachloride	62	0	ppb	0.1	0.100	0.112	0.116	0	0%	0
Chloroform	62	0	ppb	0.026	0.0272	0.036	0.048	1	2%	0
Ethylbenzene	62	0	ppb	0.114	0.121	0.254	0.35	0	0%	0
Ethylene Dichloride	62	1	ppb	0.0175	0.0171	0.022	0.023	42	68%	0
Formaldehyde	62	0	ppb	1.16	1.43	3.09	4.79	0	0%	0
Naphthalene	62	0	ng/m^3	74.3	81.3	134	195	0	0%	2
Nickel PM_{10}	61	0	ng/m^3	1.54	2.09	3.92	13.4	0	0%	0
Tetrachloroethylene	62	0	ppb	0.021	0.0265	0.0675	0.179	42	68%	0
Vinyl Chloride	62	28	ppb	0.0085	0.0101	0.0365	0.06	49	79%	0

6th & Jackson

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	62	2	ppb	0.0335	0.0410	0.0887	0.184	7	11%	0
Acetaldehyde	62	0	ppb	1.01	1.14	2.15	3.27	0	0%	0
Benzene	62	0	ppb	0.194	0.225	0.462	0.758	0	0%	0
Formaldehyde	62	0	ppb	3.45	3.65	6.80	7.42	0	0%	0

Beacon Hill

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	62	8	ppb	0.02	0.0239	0.0509	0.118	31	50%	0
Acetaldehyde	61	0	ppb	0.371	0.540	1.3	2.37	0	0%	1
Acetone	61	0	ppb	0.855	1.09	1.9	3.71	0	0%	1
Acrolein	62	0	ppb	0.161	0.184	0.345	0.444	12	19%	0
Arsenic PM_{10}	63	0	ng/m^3	0.436	0.534	1.19	1.75	0	0%	5
Benzene	62	0	ppb	0.145	0.164	0.269	0.489	0	0%	0
Carbon Tetrachloride	62	0	ppb	0.103	0.104	0.125	0.133	0	0%	0
Chloroform	62	0	ppb	0.0235	0.0251	0.0359	0.036	3	5%	0
Ethylbenzene	62	0	ppb	0.0885	0.0827	0.1467	0.203	7	11%	0
Ethylene Dichloride	62	2	ppb	0.016	0.0159	0.021	0.027	46	74%	0
Formaldehyde	61	0	ppb	0.744	1.07	2.72	3.99	0	0%	1
Naphthalene	62	0	ng/m^3	35.3	39.4	93.3	129	0	0%	0
Nickel PM_{10}	63	0	ng/m^3	0.713	0.955	2.76	3.69	4	6%	5
Tetrachloroethylene	62	6	ppb	0.01	0.0124	0.0307	0.05	54	87%	0
Vinyl Chloride	62	46	ppb	0	0.00126	0.005	0.009	62	100%	0

Bailey Gatzert

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	59	4	ppb	0.028	0.0366	0.0812	0.164	13	22%	2
Acetaldehyde	62	0	ppb	0.471	0.590	1.12	2.96	0	0%	0
Benzene	59	0	ppb	0.18	0.214	0.356	0.749	0	0%	2
Formaldehyde	62	0	ppb	0.843	1.11	2.69	4.55	0	0%	0

Union Station

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	5	0	ppb	0.029	0.0502	0.121	0.144	0	0%	0
Acrolein	5	0	ppb	0.295	0.322	0.472	0.475	0	0%	0
Benzene	5	0	ppb	0.128	0.227	0.507	0.586	0	0%	0
Carbon Tetrachloride	5	0	ppb	0.096	0.0966	0.107	0.11	0	0%	0
Chloroform	5	0	ppb	0.03	0.03	0.0352	0.036	0	0%	0
Ethylbenzene	5	0	ppb	0.123	0.124	0.195	0.21	0	0%	0
Ethylene Dichloride	5	0	ppb	0.018	0.0186	0.0214	0.022	4	80%	0
Tetrachloroethylene	5	0	ppb	0.012	0.0276	0.0776	0.094	4	80%	0
Vinyl Chloride	5	4	ppb	0	0.0008	0.0032	0.004	5	100%	0

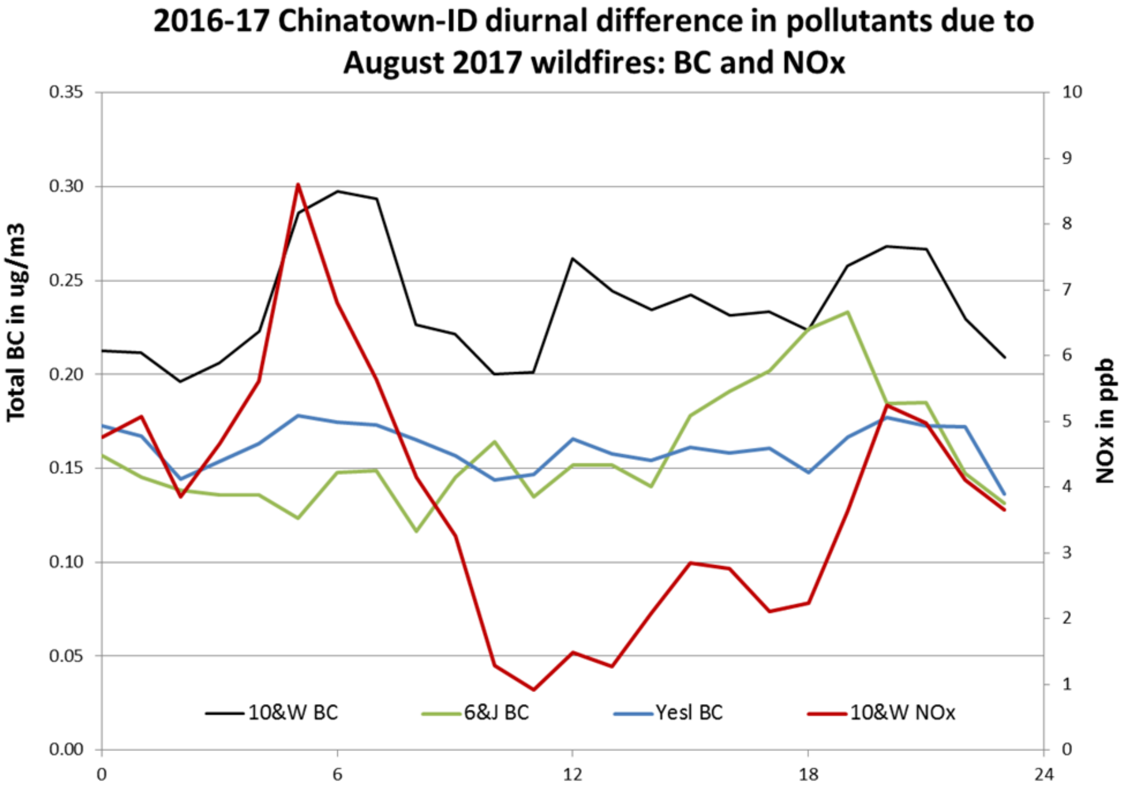
8th & Yesler

Pollutant	Sample Count	ND's	Units	Median	Mean	95th Percentile	Max	# Below MDL	% Below MDL	Nulls
1,3-Butadiene	4	0	ppb	0.0345	0.0573	0.116	0.13	0	0%	0
Acrolein	4	0	ppb	0.277	0.336	0.611	0.656	0	0%	0
Benzene	4	0	ppb	0.169	0.251	0.467	0.517	0	0%	0
Carbon Tetrachloride	4	0	ppb	0.0945	0.095	0.111	0.113	0	0%	0
Chloroform	4	0	ppb	0.0275	0.0298	0.0365	0.038	0	0%	0
Ethylbenzene	4	0	ppb	0.133	0.121	0.168	0.174	0	0%	0
Ethylene Dichloride	4	0	ppb	0.019	0.0193	0.0207	0.021	4	100%	0
Tetrachloroethylene	4	0	ppb	0.0115	0.0177	0.0343	0.038	3	75%	0
Vinyl Chloride	4	2	ppb	0.001	0.00275	0.00795	0.009	4	100%	0

Supplementary fixed site data, figures, and analysis

Figure A-1 below shows the difference in diurnal pollutant levels for black carbon at the three fixed sites, and in NOx at 10th & Weller, due wildfires on several August days. The plot shows the average excess for the summer months due to the wildfires (average with wildfires – average without wildfires). From these plots we can see that the black carbon impact is fairly uniform across the study area and stable throughout the day, which is what we would expect for a background, relatively unreactive pollutant. But, for NOx, we see a clear diurnal pattern in the difference, which is not surprising considering its reactivity and rapid photo-chemical processing.

Figure A-1. Black carbon diurnal pattern on the wildfire days at the three fixed sites, with NOx at 10th & Weller.



Diesel PM concentration and spatial pattern

There are no methods for directly measuring diesel fine particulate matter in a mix of particulate matter. A diesel $PM_{2.5}$ value can be estimated, however, from aethelometer measurements using the ratio of the UV channel and the BC channel. The contribution of diesel pollution to an pollution mixture can also be estimated with a receptor model, such as the PMF model we used. PMF modeling, however, may have a difficult time separating the diesel fraction if the diesel sources and activity levels closely match other sources, such as gasoline vehicles on the highway. Kotchenruther (2013)[53] identified an "iron rich" factor at Beacon Hill and Duwamish that was similar to factors in other studies that were labeled diesel, heavy-duty diesel, oil combustion or industrial activities, among others. For the period modeled, roughly 2007-2012, the "iron rich" factor had 0.9 and 0.8 $\mu g/m^3$ of $PM_{2.5}$ for Beacon Hill and Duwamish Valley, respectively. But, similar to our PMF, it is unclear if the $PM_{2.5}$ in this factor is purely "diesel $PM_{2.5}$" as is defined for calculations of toxic risk assessment, or this factor is the full amount of diesel $PM_{2.5}$, as some of the chemical tracers of diesel PM appear in other factors.

Two earlier factor analysis studies also identified diesel factors at Beacon Hill and other Seattle sites. The first by Kim and Hopke[54] (2008) identified a diesel factor at four Seattle sites: Olive Street, Beacon Hill, Duwamish, and Georgetown. The values ranged from 0.91 $\mu g/m^3$ at near-road site, Olive Street, to 0.65 $\mu g/m^3$ in the Duwamish Valley, 0.45 $\mu g/m^3$ at Beacon Hill, and 0.18 $\mu g/m^3$ at Georgetown. The second study by Wu et al, (2007)[55] identified a diesel factor at Beacon Hill of about 0.9-1.0 $\mu g/m^3$. Since diesel emissions have been steadily dropping since around 2008 due to lower emissions standard for new vehicles, it is not clear how comparable these older values are.

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

[54] Kim, E., and P.K. Hopke (2008) Source characterization of ambient fine particles at multiple sites in the Seattle area. Atmospheric Environment 42 (2008) 6047– 6056.

[55] Wu, Cf., T.V. Larson, Sy. Wu, J. Williamson, H.H. Westberg, L.J. S. Liu (2007) Source apportionment of $PM_{2.5}$ and selected hazardous air pollutants in Seattle. Science of the Total Environment 386 (2007) 42–52.

Appendix B. PMF model

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 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[56,57]. For our analysis, we used daily average (24-hour, midnight to midnight) values for the sample days when $PM_{2.5}$ speciation samples were collected at the 10th & Weller site. For these dates we used data from continuous monitors at 10th & Weller for 24-hour average CO, $PM_{2.5}$ (either by FEM TEOM, or BAM), NO, NO_2, black carbon, and UV absorption. We also included PM_{10} metals antimony, arsenic, cadmium, chromium, cobalt, lead, and nickel. PM_{10} metals sampled included beryllium, manganese, and mercury, but we excluded these from analysis because they had a large fraction of samples below their respective detection limits. The VOCs, aldehydes, and PAHs included are listed below in Table B-1. A few VOCs, aldehydes, and PAHs were not included due to the species having a large fraction of samples below the detection limit. The third major data set was the $PM_{2.5}$ speciation, which included several elements listed below in Table B-2, such as sodium ion, total nitrate, and elemental and organic carbon fractions (EC1, EC2, OC1-OC4).

The final data set had 61 days by 84 analytes, (total of 5124 possible), with 189 missing values, yielding 4935 data values.

We used the EPA PMF model version 5.0.14, and evaluated solution numbers ranging from 5-11. The uncertainty data was input on a per sample basis. The detection limit values were an average of values reported, specific to each analyte, for the speciation, aldehydes, VOCs, aldehydes, etc. The uncertainty

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[56] Norris, G., Duvall, R., Brown, S., Bai, S., 2014. EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide. U.S. Environmental Protection Agency. EPA/600/R-14/108.

[57] Paatero, P., Hopke, P.K., 2003. Discarding or downweighting high-noise variables in factor analytic models. Anal. Chim. Acta 490, 277-289.

for each sample above the detection limit was not known, but was generally assumed to be 20%. For criteria pollutants and continuous instruments, the uncertainty and method detection limit were taken from manufacturer's specifications or best professional estimates. For each sample, an overall uncertainty was calculated as:

$$overall\ uncertainty_{i,j} = \sqrt{\left(\frac{5}{6} * detection\ limit_i\right)^2 + \left(c_{i,j} * \ unc_{i,j}\right)^2}$$

Where

i - indicates the specific analyte or species

j - indicates the specific sample date

c – indicates the specific concentration or value, of the species *i,* on day *j*

unc - is the uncertainty of the method as a percent of the signal/value

The speciation and toxics samples were nominally on a 1-in-6 schedule, but on 4 days the VOCs, aldehydes, PAHs, and speciation were run one day later due to logistical constraints. For these days, the values were used, but additional uncertainty was added to the overall uncertainty for each sample to help account for day-to-day differences that were likely. For these days, the extra uncertainty was calculated as 3 x standard deviation of the uncertainty of the adjacent 15 samples (for each respective analyte).

In course of exploring the solutions, a factor was consistently identified that was comprised of almost solely and exclusively selenium. A similar, but somewhat less extreme version of this occurred with vanadium. While vanadium can be a good marker for heavy fuel combustion, too many of our samples were below the detection limit and this element consistently was solitary. So, both selenium and vanadium were flagged as "bad." Other analytes with signal to noise ratios < 1 were flagged as "weak."

In all cases, a wintertime wood smoke factor was identified, along with a factor that was stronger in the summer, a factor that was limited to a small number of extreme spikes, and a factor that contained a number of background analytes. We explored solutions with the number of factors ranging from 5-11. The "Q robust" metric increased with number of factors, as expected, but the other metrics of factor robustness began to degrade at around seven or eight factors. With six factors, the DISP metric produced no swaps with 50 runs, and the BS-DISPs had 4 total swaps (1, 1, and 2) in three factors (even with constraints). The base run with six factors resulted in the UV-BC being split more than expected and not as strong in the wood smoke factor, and the wood smoke factor not being as strong in the winter as expected. Also, the factor “aged urban”, which appeared to best capture regional background, was very high in EC2 (a marker for diesel), which wouldn’t match the expected properties of general background air. In order isolate a broader regional background and therefore nearby emissions, and optimize the wood smoke factor, constraints were applied to UV-BC and the EC2 in the wood smoke and aged urban factors, respectively. For both parameters, there was modest rotational ambiguity, so even with dQ max % set at 0.5, the constraints resulted in significant shifts in the parameter with little change in the Q robust, and more coherent factors.

Table B-1. VOCs, aldehydes, and PAHs included in the PMF analysis.

Trichlorotrifluoroethane	Benzo(e)pyrene	Hexaldehyde
1,2,4-Trimethylbenzene	Benzo(g,h,i)perylene	m,p-Xylene
1,3-Butadiene	Benzo(k)fluoranthene	Methyl Ethyl Ketone
9-Fluorenone	Butyraldehyde	Methyl Isobutyl Ketone
Acenaphthene	Carbon Tetrachloride	Naphthalene
Acenaphthylene	Chloroform	n-Octane
Acetaldehyde	Chloromethane	o-Xylene
Acetone	Chrysene	Perylene
Acetonitrile	Coronene	Phenanthrene
Acetylene	Crotonaldehyde	Propionaldehyde
Acrolein	Cyclopenta(c,d)pyrene	Propylene
Anthracene	Dichlorodifluoromethane	Pyrene
Benzaldehyde	Dichloromethane	Retene
Benzene	Ethylbenzene	Tolualdehydes
Benzo(a)anthracene	Fluoranthene	Toluene
Benzo(a)pyrene	Fluorene	Trichlorofluoromethane
Benzo(b)fluoranthene	Formaldehyde	Valeraldehyde

Table B-2. $PM_{2.5}$ components included in the PMF analysis, along with EC1, EC2, and OC1-4.

Calcium
Chlorine
Copper
Iron
Potassium
Silicon
Sodium Ion
Sulfate
Titanium
Total Nitrate
Vanadium
Zinc

Supplementary PMF figures

Below are pie charts of several the most important chemicals or pollutants/measures.

In Figures below, the stripped factors indicate those that are regarded as being primarily diesel, or having a large contribution from diesel.

Figure B-1. Contribution of PMF factors to total PM2.5.

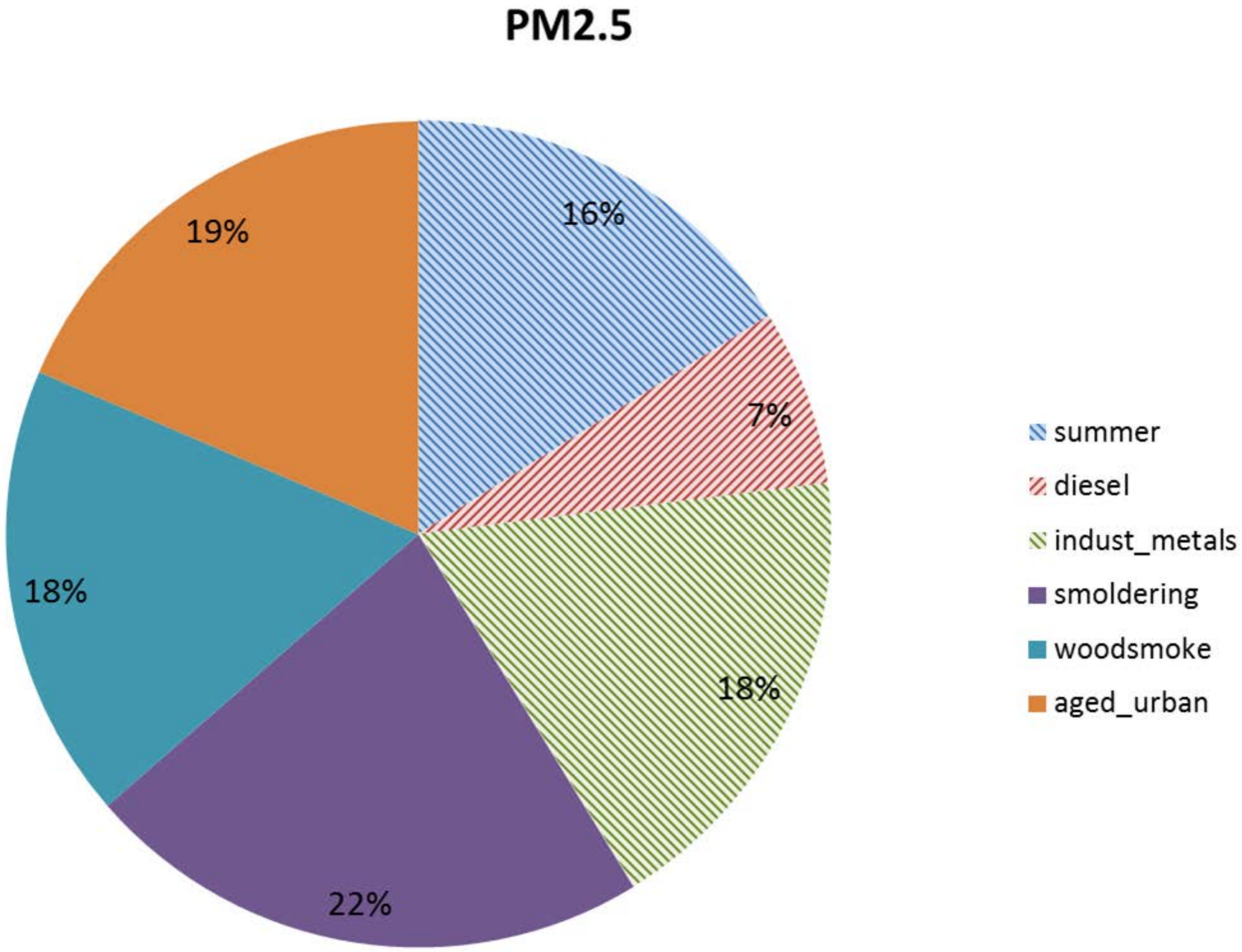


Figure B-2. Contribution of PMF factors to total BC.

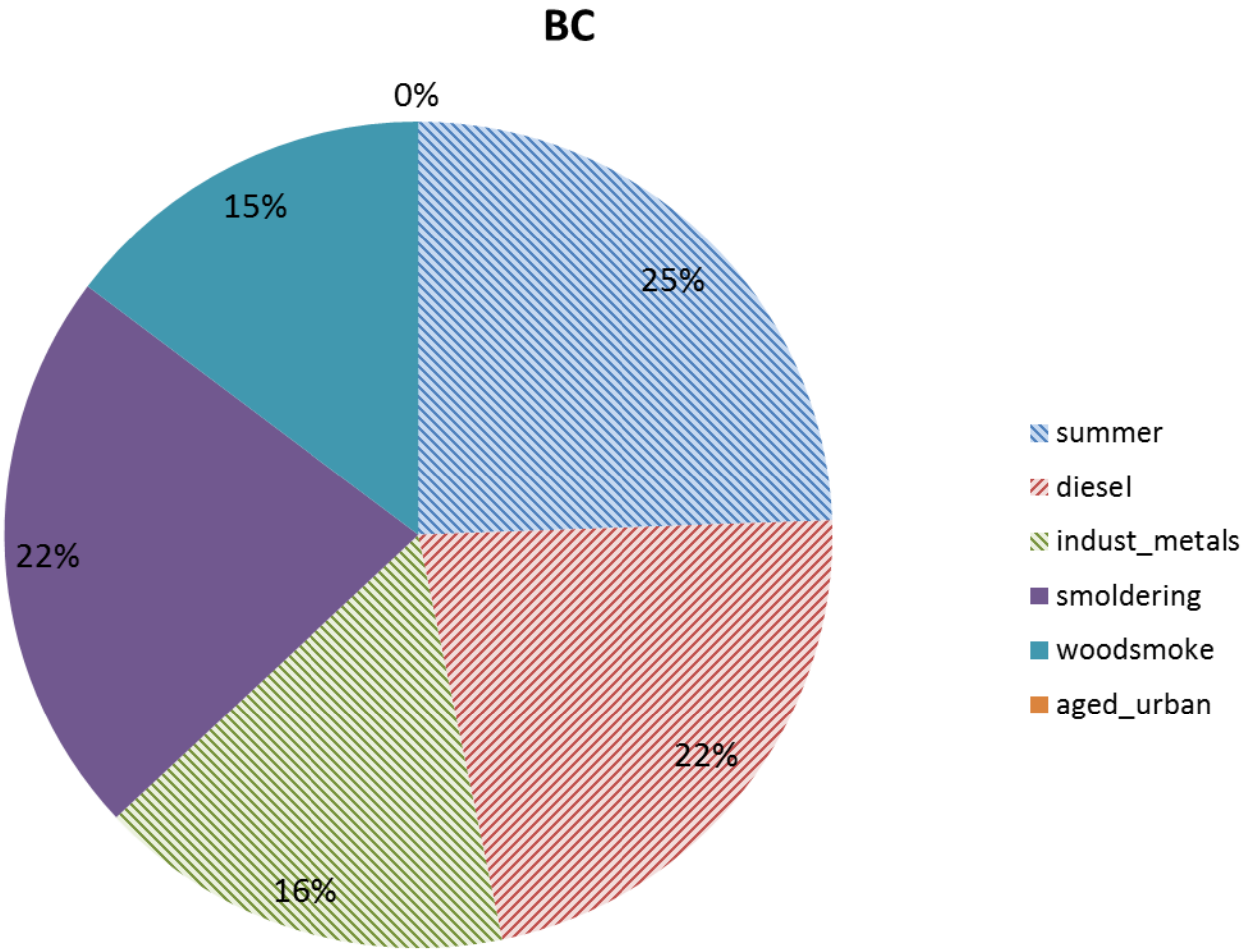


Figure B-3. Contribution of PMF factors total lead.

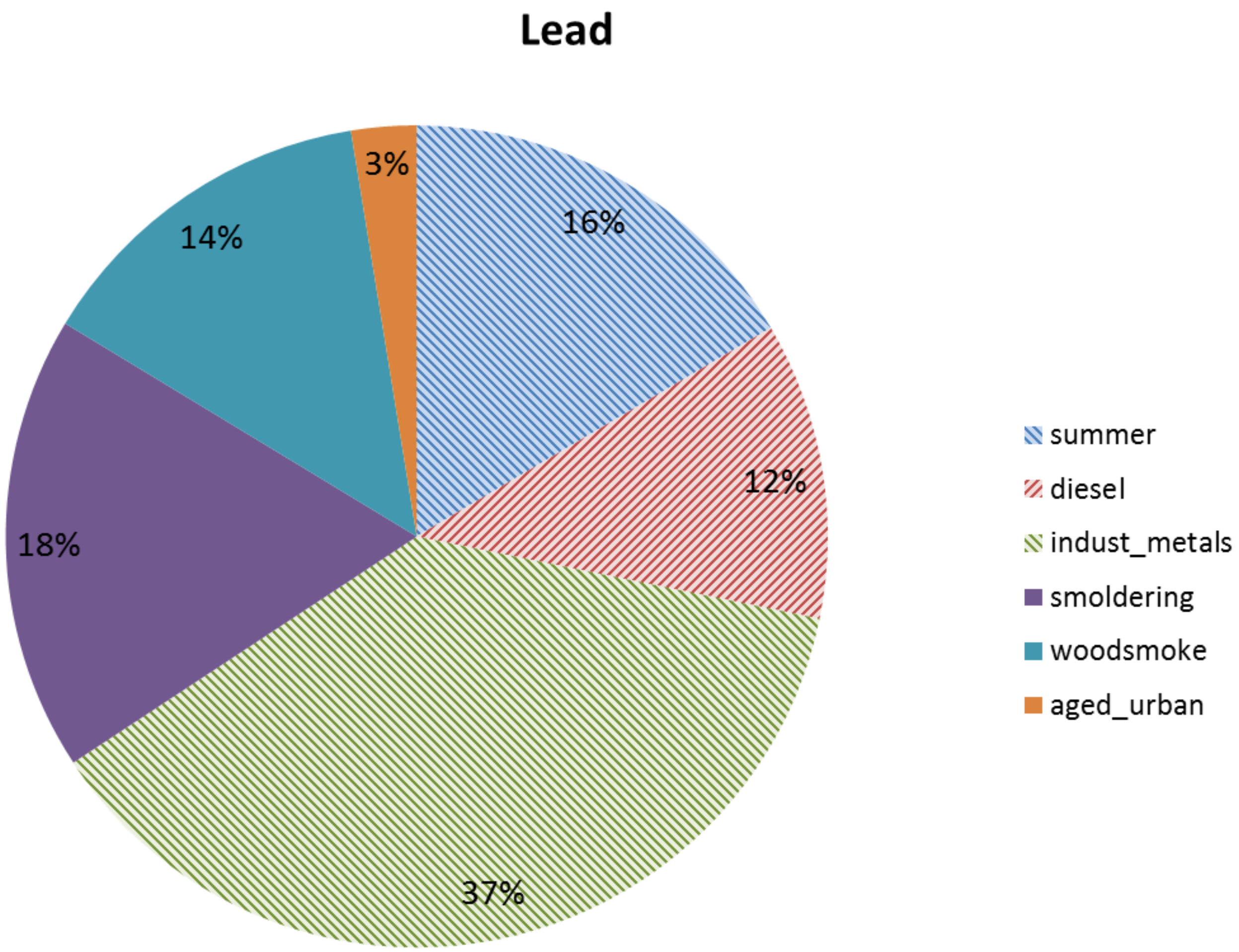


Figure B-4. Contribution of PMF factors to UV-BC.

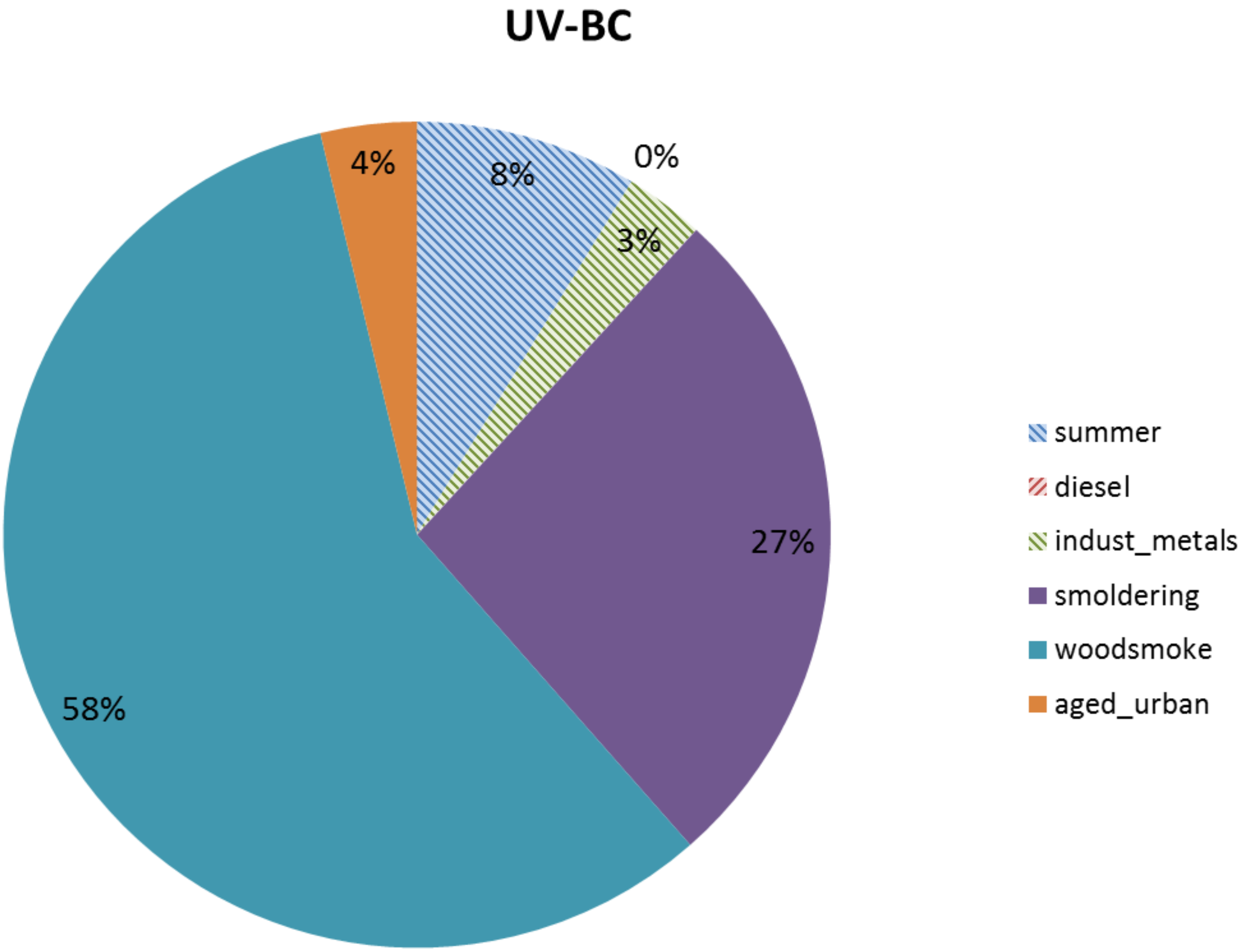


Figure B-5. Contributions from PMF factors to speciation carbon EC1.

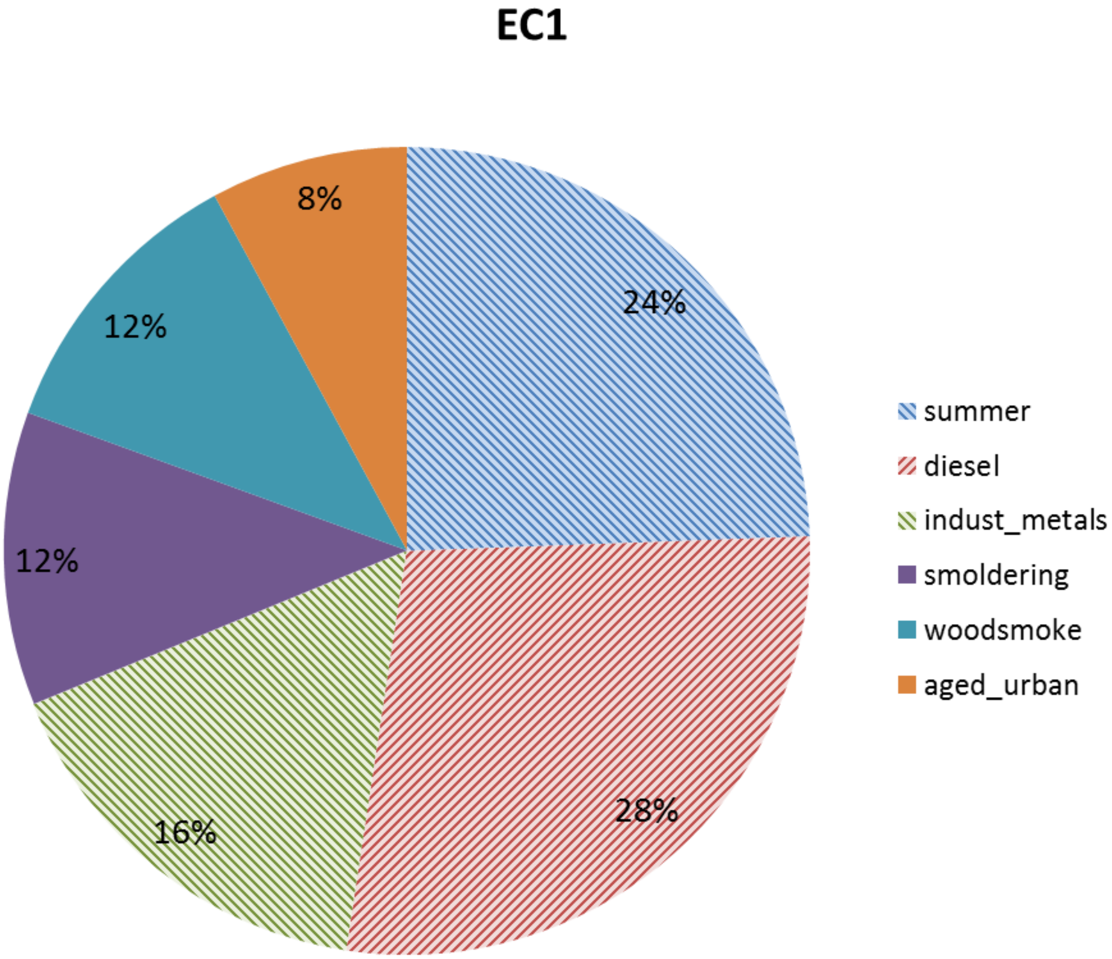
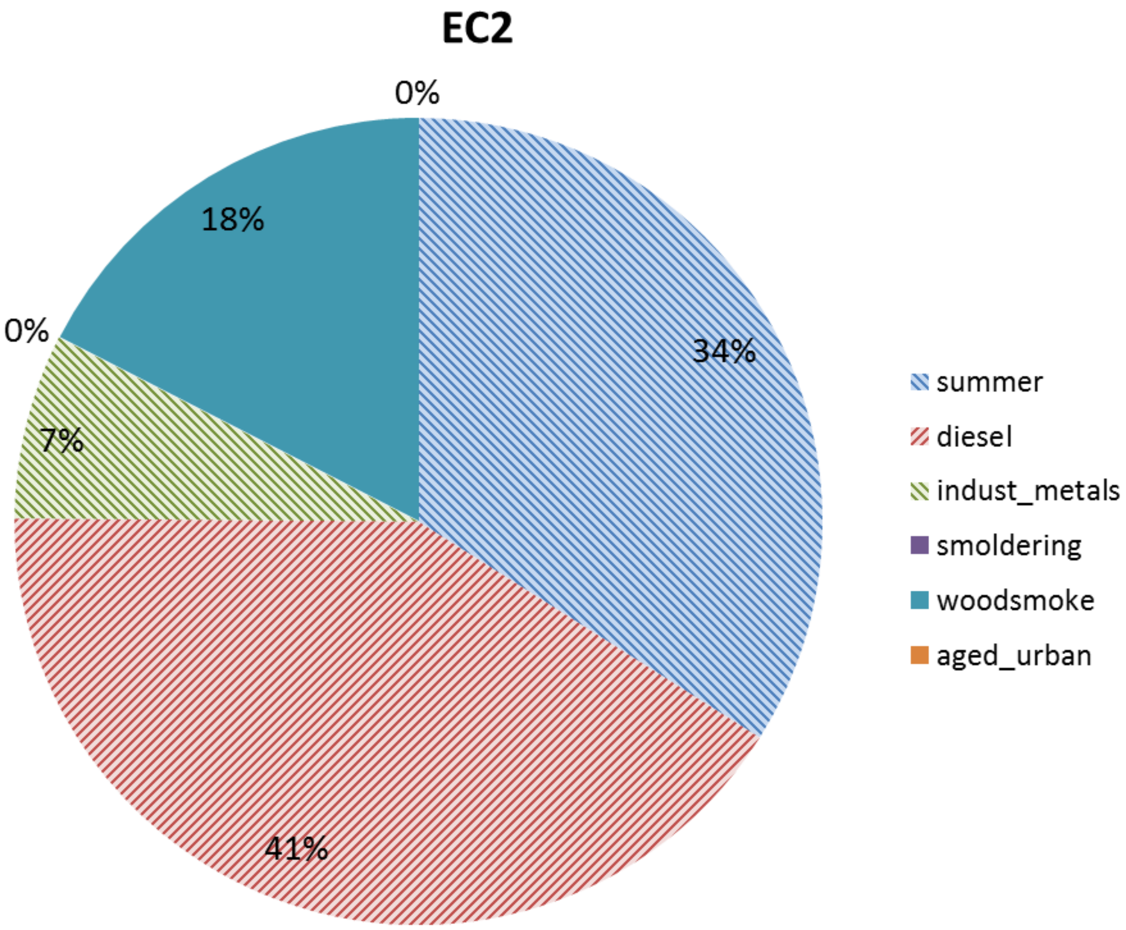


Figure B-6. Contributions of PMF factors to speciation carbon EC2.



Appendix C. AERMOD dispersion model

In order to test our hypothesis and assumption of vehicle pollution impacting the CID, we used a simplified, or ‘reduced form’ dispersion modeling approach for the major pollution sources in the study area. A ‘reduced form’ approach was used because of the number and complexity of potential sources compared to the available resources. For this work, we used the AERMOD dispersion model to predict steady state pollution levels resulting from restaurants, and from vehicles on I-5 and I-90. Additional details on the modeling are in the subsequent sections.

For both the restaurants and road sections, a single year (2015) was simulated using average daily emissions profiles. Since the study area has a modest amount of elevation and terrain features, we used a high resolution terrain map and site-specific meteorology to better reflect orographic influences on the dispersion. The site-specific meteorology (wind speed and direction, temperature, and relative humidity up to 500 meters) was obtained from a high-resolution WRF model simulation run by Vaisala, Inc. (formerly 3Tier) using a proprietary algorithm to downscale to 90 m resolution. The other meteorological input data were twice-daily soundings from Quillayute, WA, and local data from Sea-Tac Airport (all for 2015).

The road sections and restaurants were divided into zones, shown in Figure C-1. Each zone used meteorological data from a central, single point grid point within the zone (from the WRF simulation). The site-specific meteorology from the single, central point, and the Quillayute and Sea-Tac Airport data were processed with AERMET for input into the AERMOD runs. The locations of each restaurant were specified and each was simulated as an independent point source. The meteorology for the road zones was handled the same as for the restaurants, a central grid point was selected and used for the whole zone. But, the road sections were modeled as area sources. We also note that there are numerous large buildings and a range of emissions release heights (stack heights, road heights) that could significantly influence the results in specific locations. In some cases, buildings could reduce pollution levels at the ground by inducing faster winds and greater ventilation, and in other cases they could create dead zones or recirculation cavities that reduce dispersion. Simulating these details was beyond the resources for the current study. Further details on the activity and emissions factors are provide in the subsequent sections.

Restaurants

We identified around 100 restaurants in the study area from state health department inspection records and internet searching. We reconciled the two lists and eliminated duplicates, locations that were closed (permanently), or were not primarily for preparing and serving meals such as cafes and other beverage only businesses. Any named location that could not be verified with both current websites and reviews, and a visual confirmation from online photos, was individually verified from a site visit. Each restaurant was classified as either primarily frying, or charbroiling depending on the type of food served. We estimated the activity level (total servings prepared per day) from the state health department classification of size, and when not available, used the number of seats to cross reference to restaurants with a known size. Each restaurant was also classified as being primarily lunch, dinner, or mixed. The PM2.5 emissions from each restaurant was then calculated with the following equation:

$$hourly\ PM2.5_i = n * h_i * ef$$

Where:

- *i* is the hour of the day
- *n* is the total number of servings per day
- *ef* is the emission factor based on the food type being primarily frying or charbroiling
- h_i is the fraction of the daily servings in the hour *i*, with $\sum_i h_i = 1$, and a different h_i for lunch, dinner, and mixed profiles

So the daily total $PM_{2.5}$ emissions from each restaurant is:

$$daily\ PM2.5 = \sum_i n * h_i * ef$$

The diurnal activity profiles were estimated based on hourly activity charts posted online with restaurant reviews. We obtained 12 hourly profiles that appeared to capture the range of possibilities and then classified them as either primarily lunch, primarily dinner, or mixed. Each profile was scaled so the daily sum was 1, and then all profiles in the respective categories were averaged. The profiles are shown in Figure C-2.

The emission factors we used were the geometric mean of the values obtained from published literature. See Table C-1 for a list of the factors and sources used.

Figure C-1 map of AERMOD modeling domain with restaurant and road subdomains.

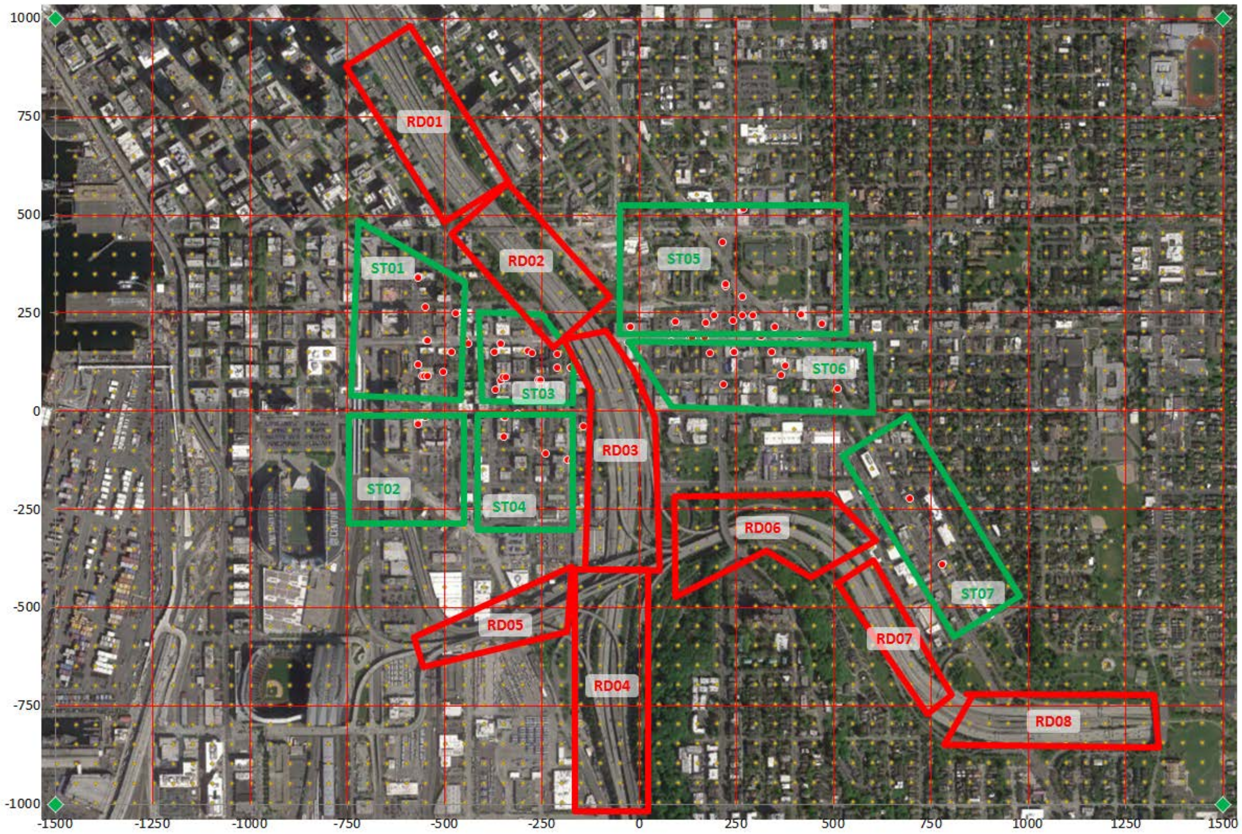


Figure C-2. Average diurnal activity pattern for the three types of restaurants.

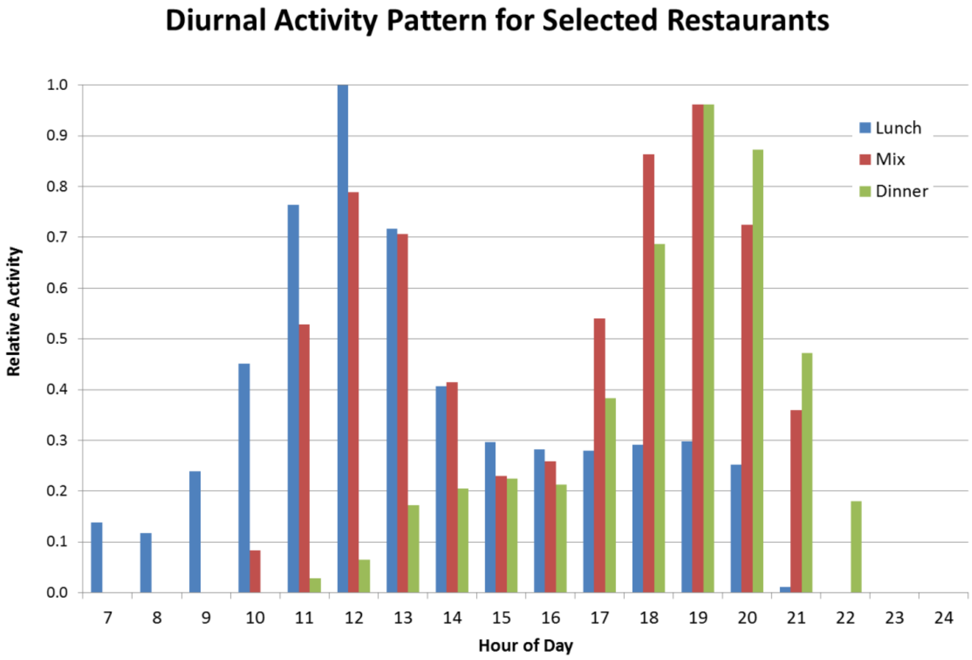

Diurnal Activity Pattern for Selected Restaurants

Table C-1. Restaurant emission factors obtained from literature

Value	Unit	Description	Author, year, Journal
6809	mg/portion	hamburger underfired charbroiler	EPA NEI, 2002
2299	mg/portion	charbroiled beef or chicken	McDonald, 2003, JAWMA
710	mg/portion	charbroiled beef or chicken	
80	mg/portion	high emission rate for grilling	Buonano, 2009, Atmos. Environ
7.2	mg/portion	low emission rate for grilling	
30.7	mg/portion	high emsssions, any food, fried or grilled	Hu, 2012, Law. Burk. Nat. Lab
16	mg/portion	low emission, any food, fried or grilled	
43.9	mg/portion	high emissions, any food, stir fried	CARB
20.7	mg/portion	low emissions, any food, stir fried	
41.3	mg/portion	high emissions, any food, stir fried	Wang, 2015, Aerosol and Air Quality Res.
20.7	mg/portion	low emissions, any food, stir fried	

		geometric mean
2232	mg/portion	charbroiling
26.2	mg/portion	frying or stir frying

Literature and References:

- EPA NEI, 2002 : San Joaquin Valley Unified Air Pollution Control District Emission Inventory Methodology, 690 Commercial Cooking Operations. https://www.arb.ca.gov/ei/areasrc/districtmeth/sjvalley/Mthd_Commercial_Cooking_EI_Area_Source_Methodology.pdf
- McDonald, 2003, JAWMA: McDonald, et. al., (2003). Journal of Air & Waste Management Association, 53:2, 185-194, DOI: 10.1080/10473289.2003.10466141
- Buonano, 2009, Atmos. Environ.: Buonanno, G. and Stabile, L. and Morawska, L. (2009) Particle emission factors during cooking activities. Atmospheric Environment, 43(20). pp. 3235-3242.
- Hu, 2012, Law. Burk. Nat. Lab: Hu, Tianchao, Brett C Singer, and Jennifer M Logue. Compilation of Published $PM_{2.5}$ Emission Rates for Cooking, Candles and Incense for Use in Modeling of Exposures in Residences. Berkeley: Lawrence Berkeley National Laboratory, 2012. LBNL-5890E
- CARB: www.arb.ca.gov/research/apr/past/97-330b.pdf and: https://www.arb.ca.gov/research/indoor/cooking/4-ARB-Section4.PDF
- Wang, 2015, Aerosol and Air Quality Res.: Wang et al., Aerosol and Air Quality Research, 15: 2357–2366, 2015.

Roads

Vehicle emissions from I-5 and I-90 within the study area were modeled as area sources composed of two categories, light-duty vehicles (e.g. gasoline cars and light trucks), and heavy-duty vehicles (large diesel engines, short and long haul with or without trailers). Each category has its own diurnal pattern and area (or activity) specific emission factor. The emissions for each unit area was calculated from the average annual daily traffic (AADT) obtained from the WA Dept. of Transportation (DOT) Traffic

GeoPortal for I-5 north and south of I-90, and I-90 east of the interchange with I-5. See Table C-2 for the traffic volume data. The diurnal patterns and relative light-duty/heavy-duty fractions were obtained from WS DOT traffic count location R117. R117 is on I-90 about 0.5 mile to the east of the I-5/I-90 interchange, and was the only traffic count location within the study area with hourly vehicle type data.

The hourly emissions for each square meter of simulated road ('patches') was calculated from the traffic counts passing through a given meter of road length multiplied by the fleet average emissions per meter, with the traffic counts varying throughout the hour of day. The emissions for the entire road, for each meter, were then divided by a generic width (100 m) to obtain an hourly emissions value per square meter. The width of I-5 and I-90 (from outside edge of paved surfaces perpendicular to the direction of travel) varies from about 60 meters to more than 150 meters near the interchange. Since the specific location of vehicles within that generic road width can vary considerably, won't be even, and can't be reasonably simulated, the specific road width is likely unimportant. The total emissions from each lineal meter of road were unaffected, but the specific distribution along the width of the road is only coarsely correct. This is not expected to have a significant impact on the pollutant concentrations beyond a hundred meters or so from the road edge. Comparisons of modeled concentrations to measurements in this region of sharp gradient (within 100 meters or so) should not be used to assess absolute accuracy of the model. Small changes in sampling location or modeled parameters could have large impacts in the location of the pollution plume which are different from, and could (but shouldn't) be confused with overall plume intensity.

The equation for the hourly emissions from road patches (square meter) is:

$$emissions\ per\ patch\ per\ category = T * c * h_i * ef * 1/width$$

Where:

T is the traffic counts passing the lineal meter per hour

c is the fraction of vehicles in the light-duty or heavy-duty category

h_i is the hourly fraction of total daily traffic of each category

ef is the average emissions factor per lineal meter for each category

$width$ is the assumed/generic road width

Table C-2. Annual average daily traffic (AADT) for the I-5 and I-90 modeled road segments.

road segment	AADT 2016
I-5 north of I-5/I-90 (both ways including express)	147,000
I-90 (both ways, including express)	146,000
I-5 south of I-5/I-90 (just south of intersection)	245,000
I-90 west of I-5/I-90	55,000

The emissions factors for $PM_{2.5}$, black carbon, NOx, and CO were obtained from the GREET model[58] for light duty vehicles and from the 2016 Puget Sound Maritime Inventory[59] for heavy-duty vehicles. For the both sectors, a fleet composite emission factor for each model year was scaled by the in-use model year fraction. The in-use model year fraction is different for heavy-duty compared to light-duty with heavy-duty vehicles generally having a longer lifetime before being replaced.

Based on the traffic count data, the fraction of diesel vehicles was expected to be about 4.8% of the total vehicles. Based on the observed hourly data at 10th & Weller, NO and black carbon were highly correlated, and CO and black carbon, and NOx were generally correlated. The slopes of the correlated pollutants can be used to compare with the mixture of assumed sources and source emissions ratios. The ratio method is effective for two non-reactive (for the duration of emissions to measurement) pollutants both coming from two sources (or source types) when their emissions ratios are different. Different observed ratios compared to emissions ratios imply that the source strengths or the source emission ratios are wrong. For our simplified model, we assumed a light-duty and a heavy-duty fleet, which have the starkest difference in their emission ratios of CO and black carbon (BC). Our light duty fleet has CO emissions about 30x that of the heavy duty fleet, while the heavy duty fleet (essentially diesel) has BC emissions about 7x that of the light duty fleet, producing a difference in CO:BC slopes of about 200x. For our data, the observed slope for the wintertime CO:BC in the diurnal average was about found to be about 255 $\mu g/\mu g$. (Winter was used because there was evidence that there may be sources from outside of the study area impact it more strongly in the summer, and there is also a greater potential for photochemical and temperature dependent reactions to occur in the summer.) This ratio is much lower than the theoretical value of 418 $\mu g/\mu g$ from the emissions data. The difference suggests that there is more influence from heavy-duty vehicles, either more vehicles, or more pollution per vehicle, or a more polluting fleet. So, the relative vehicle fraction was adjusted for the final AERMOD runs to reflect a greater source strength. It is unknown if the discrepancy is due to errors in the emissions profiles per vehicle (per vehicle year), the fleet makeup (age distribution), the total size of the fleet, or some combination thereof.

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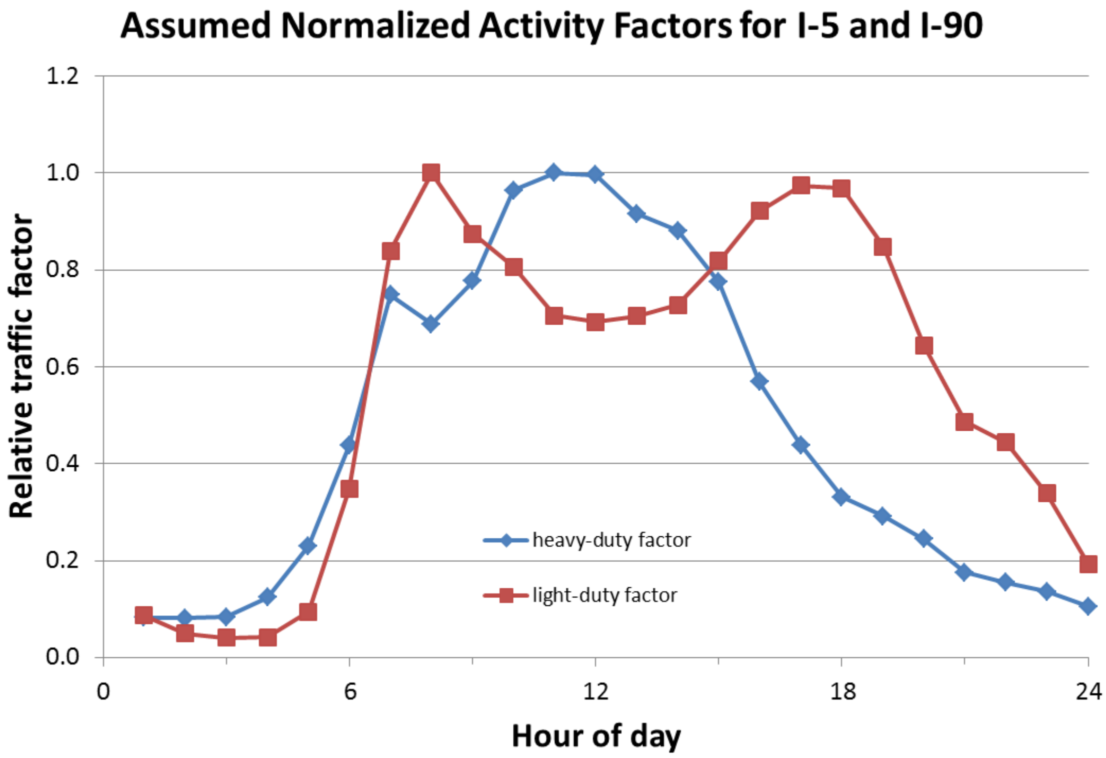
[58] Updated Emissions Factors of Air Pollutants from Vehicle Operations in GREET Using MOVES, Hao Cai, Andrew Burnham, Michael Wang, 2013. https://greet.es.anl.gov/files/vehicles-13

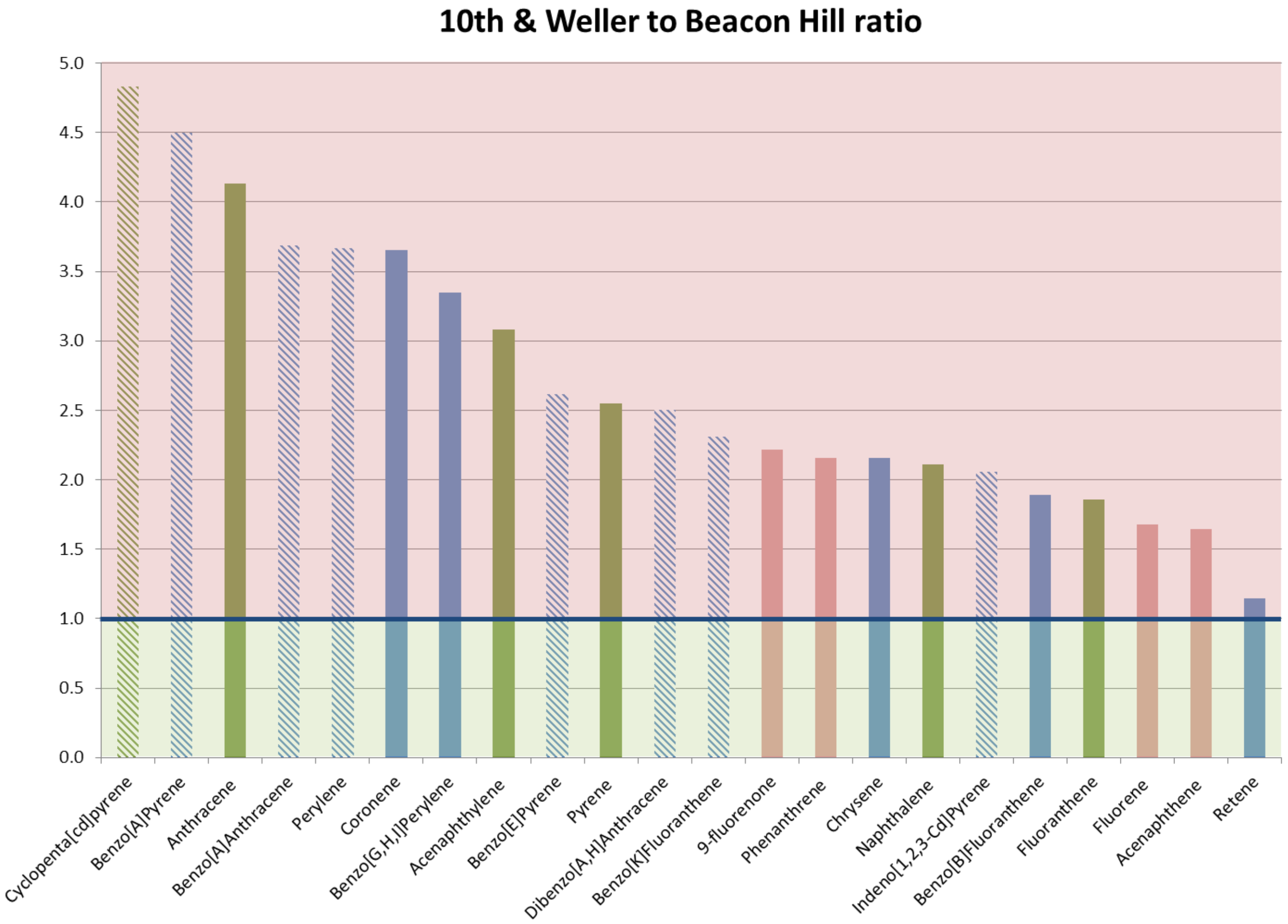
[59] https://pugetsoundmaritimeairforum.org/2016-puget-sound-maritime-air-emissions-inventory/

Figure C-3. Modeled temporal factor of vehicle activity for diesel and light duty.



Appendix D. PAH analysis

Figure D-1. PAH ratios of 10th & Weller vs Beacon Hill, with samples with > 25% below detection labeled with hashed lines.



Pollution rose for 10th & Weller PAHs that are higher in the summer.

Figure D-2. Fluorene chemical structure, pollution rose, and concentrations over study period

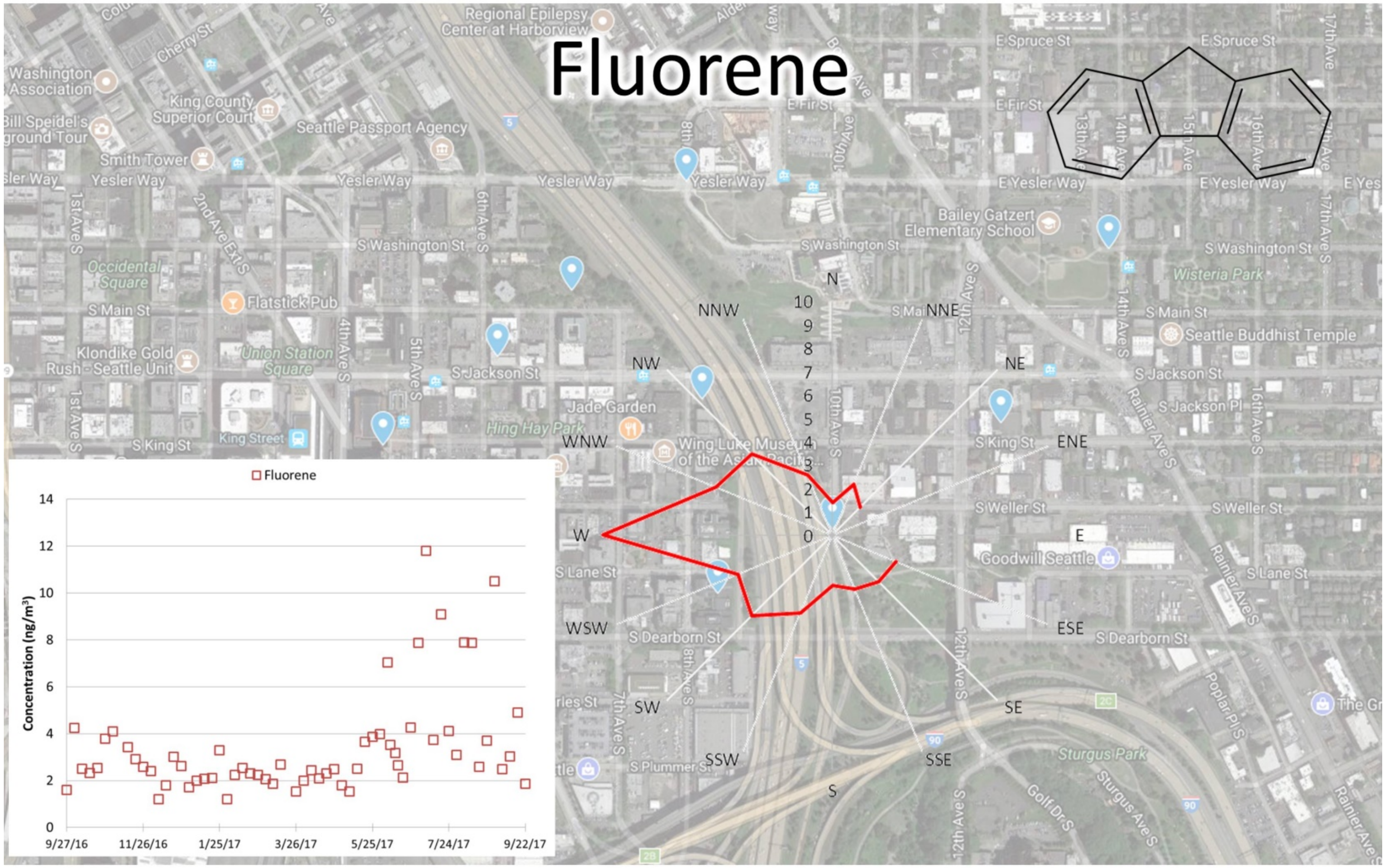


Figure D-3. Acenaphthene chemical structure, pollution rose, and concentrations over study period

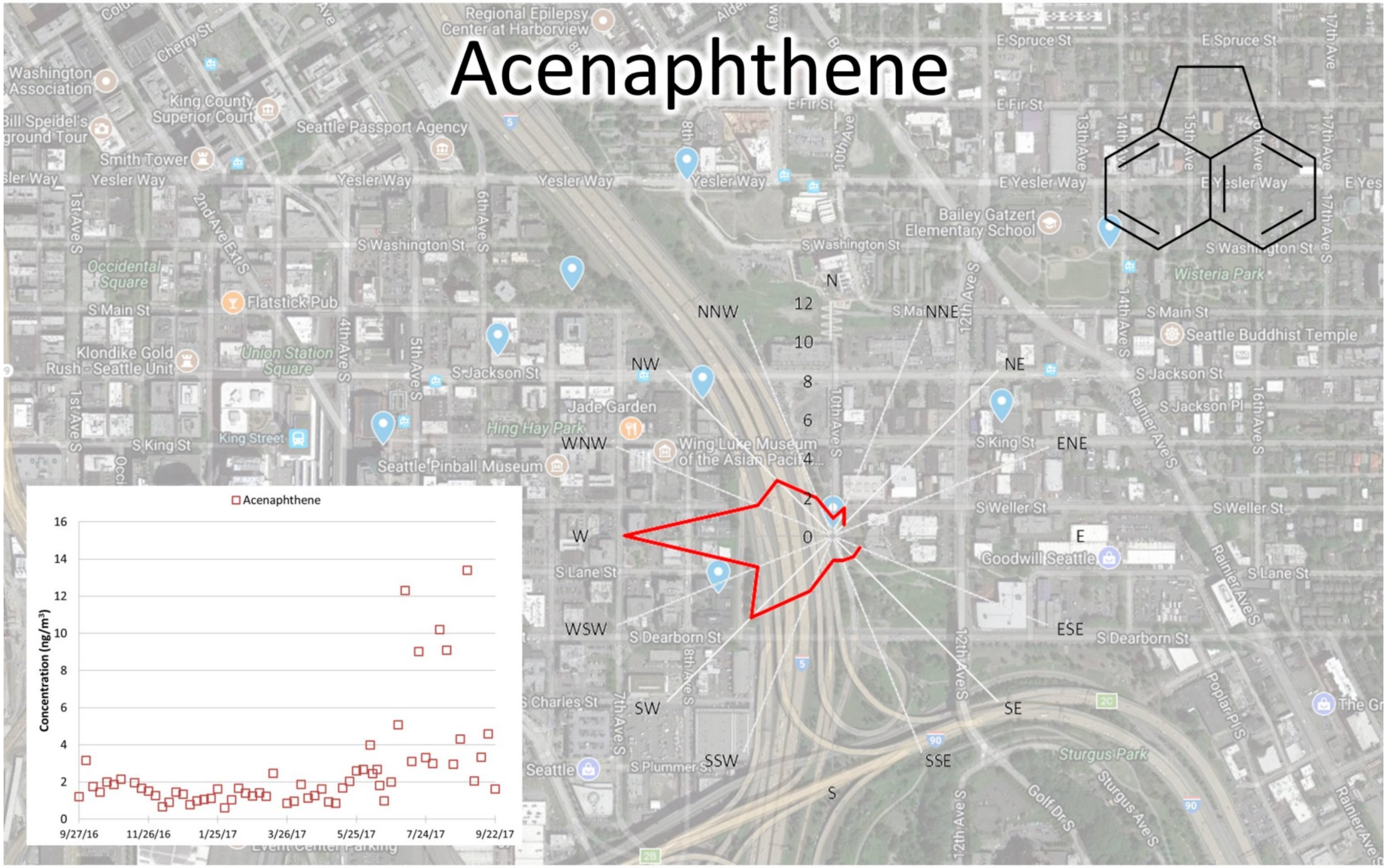


Figure D-4. Phenanthrene chemical structure, pollution rose, and concentrations over study period

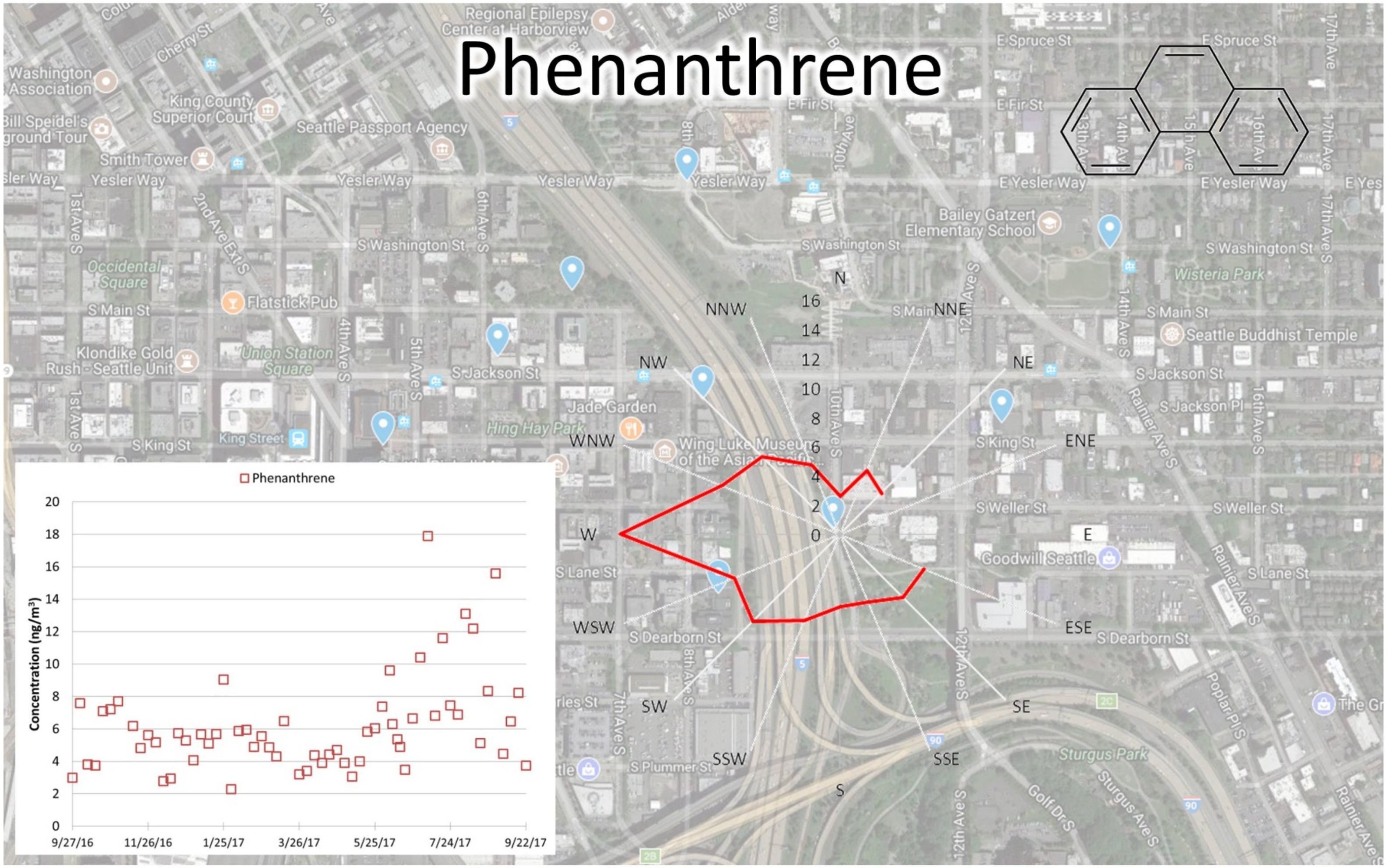
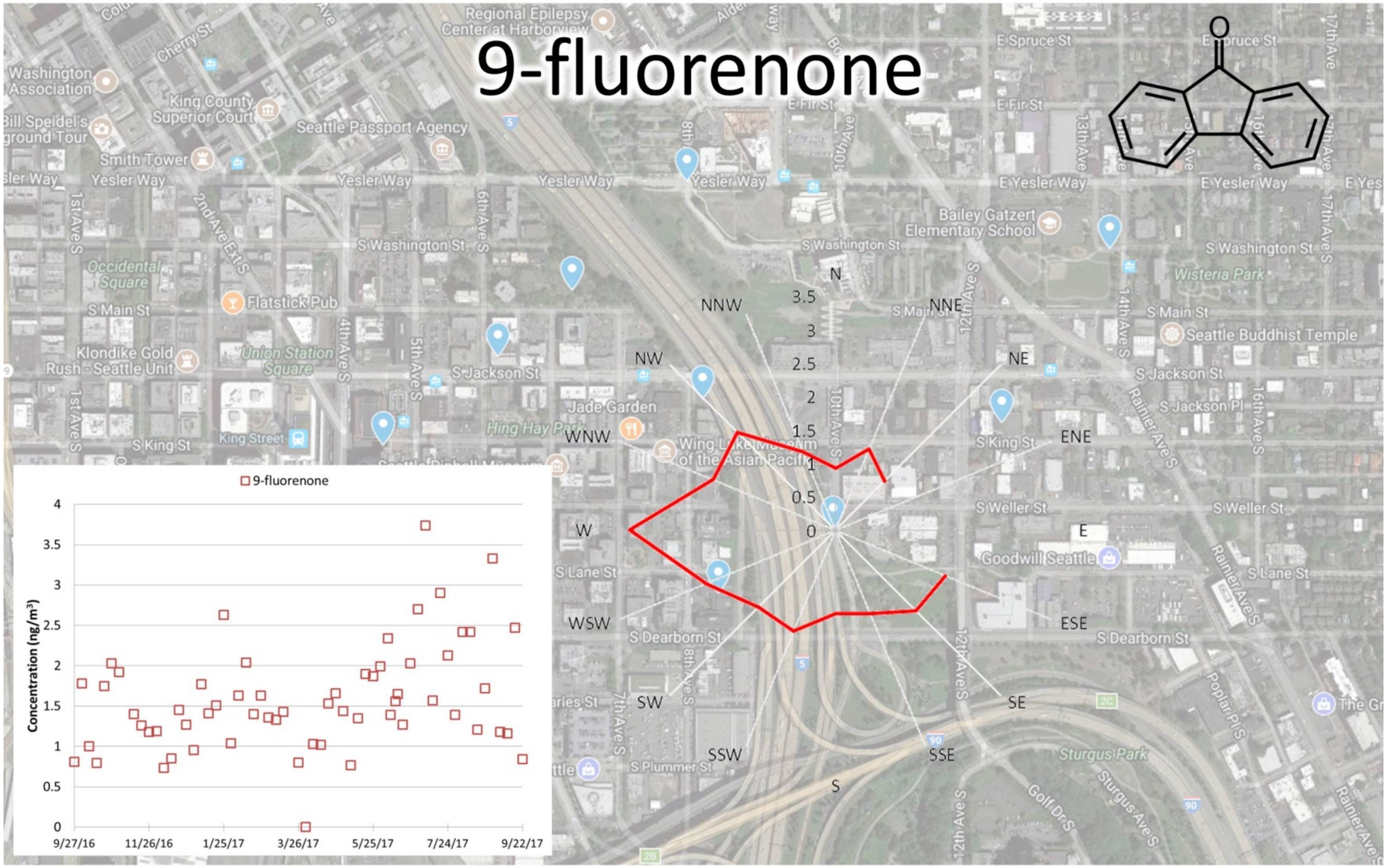
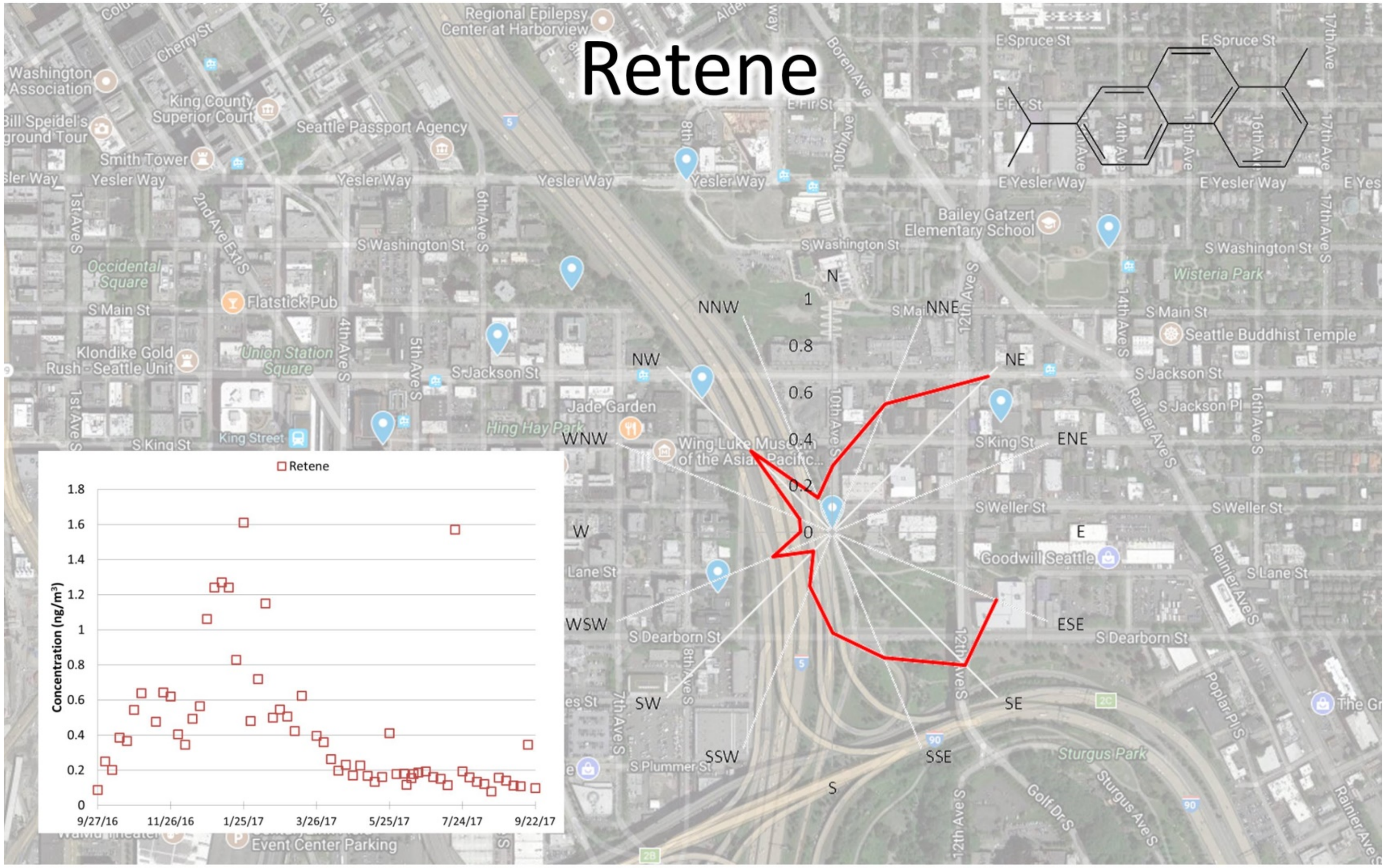


Figure D-5. 9-fluorenone chemical structure, pollution rose, and concentrations over study period



Pollution rose for 10th & Weller PAHs that are <u>higher in the winter</u>:

Figure D-6. Retene chemical structure, pollution rose, and concentrations over study period



Retene is the most abundant PAH in biomass burning: https://www.sciencedirect.com/science/article/pii/S0048969710013562
Alves CA, et al. Emission of trace gases and organic components in smoke particles from a wildfire in a mixed-evergreen forest in Portugal. *Sci Total Environ* 409(8):1466–1475. 2011. http://dx.doi.org/10.1016/j.scitotenv.2010.12.025

Figure D-7. Benzo[G,H,I]Perylene chemical structure, pollution rose, and concentrations over study period

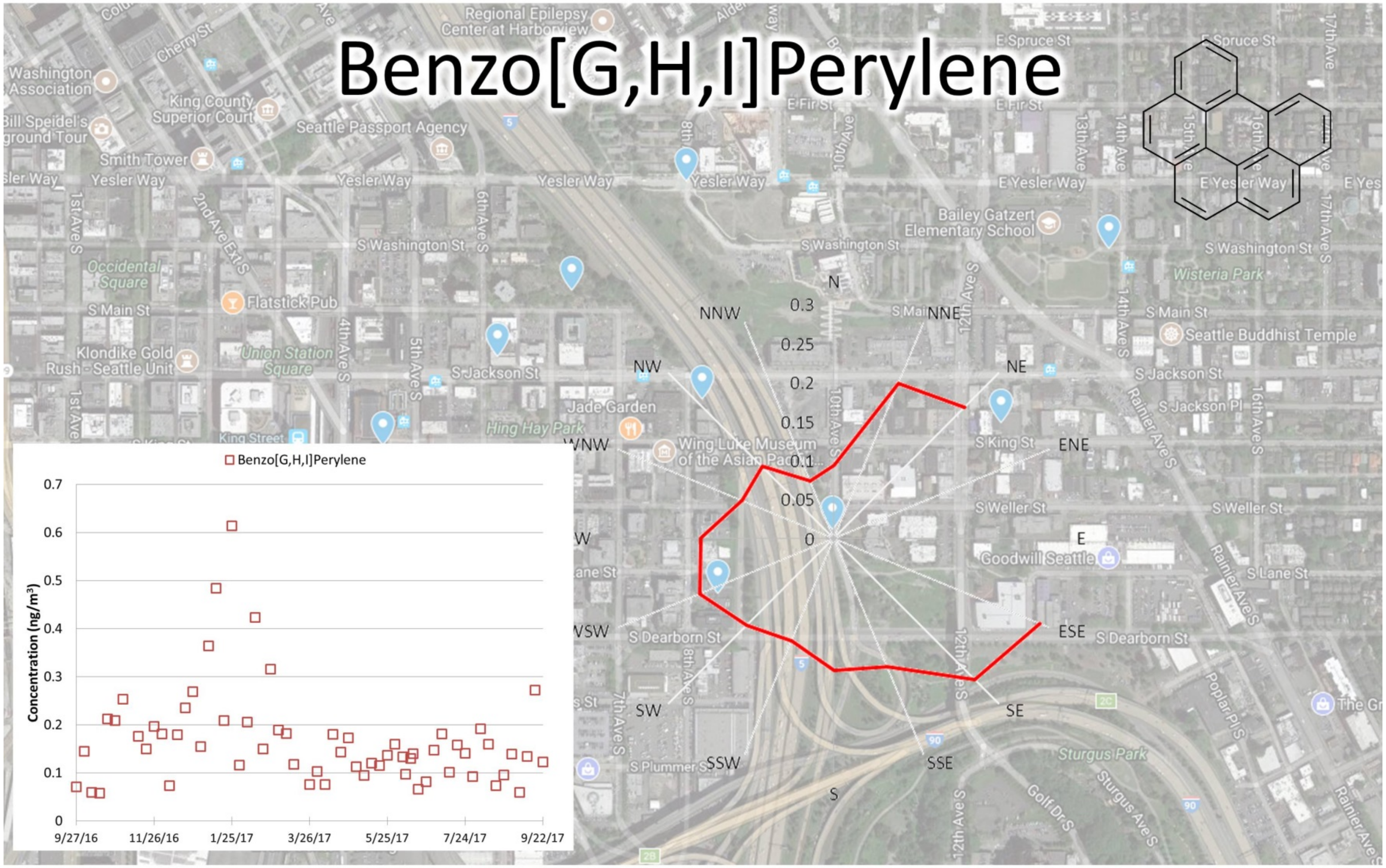


Figure D-8. Benzo[A]Pyrene chemical structure, pollution rose, and concentrations over study period

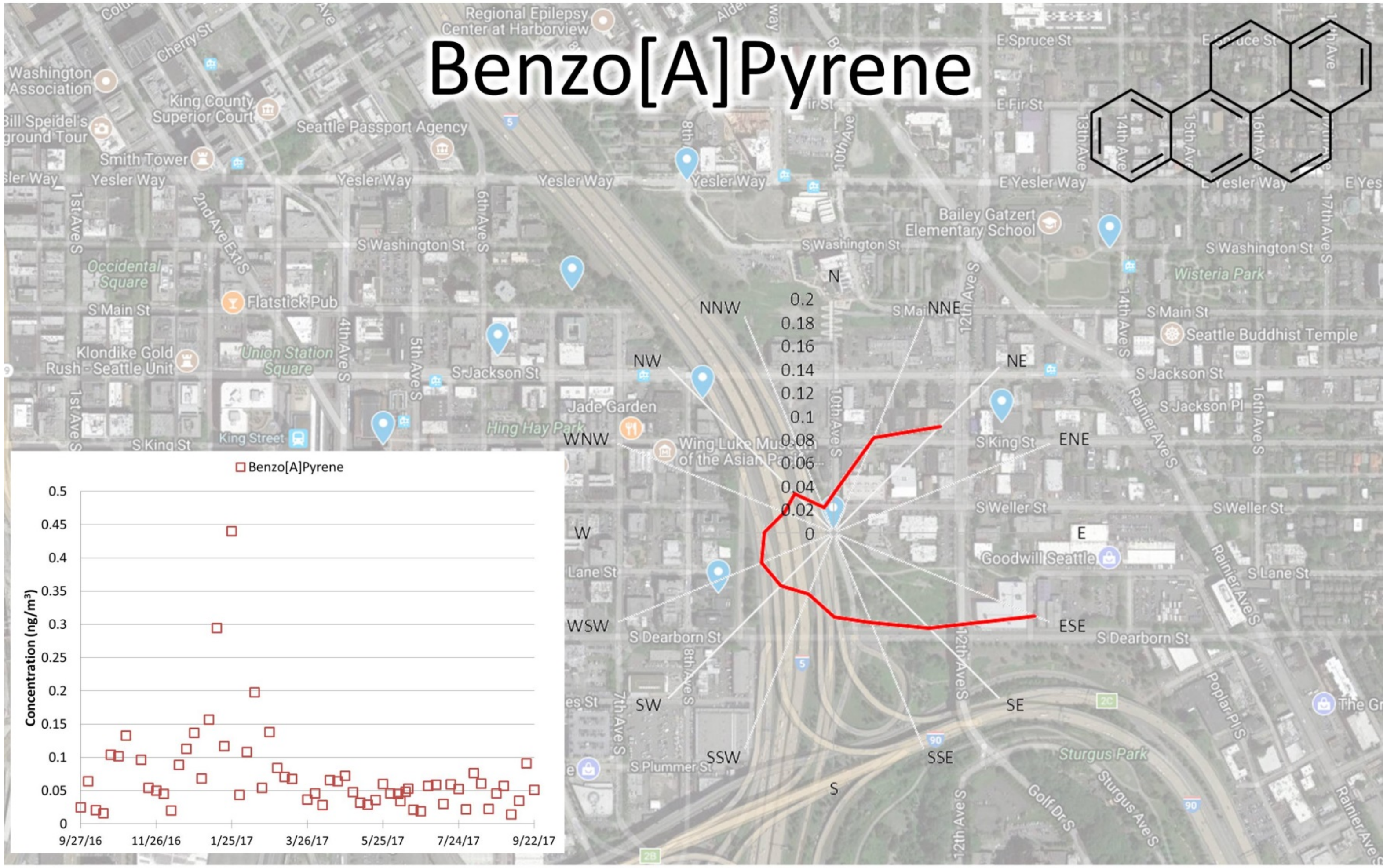


Figure D-9. Benzo[E]Pyrene chemical structure, pollution rose, and concentrations over study period

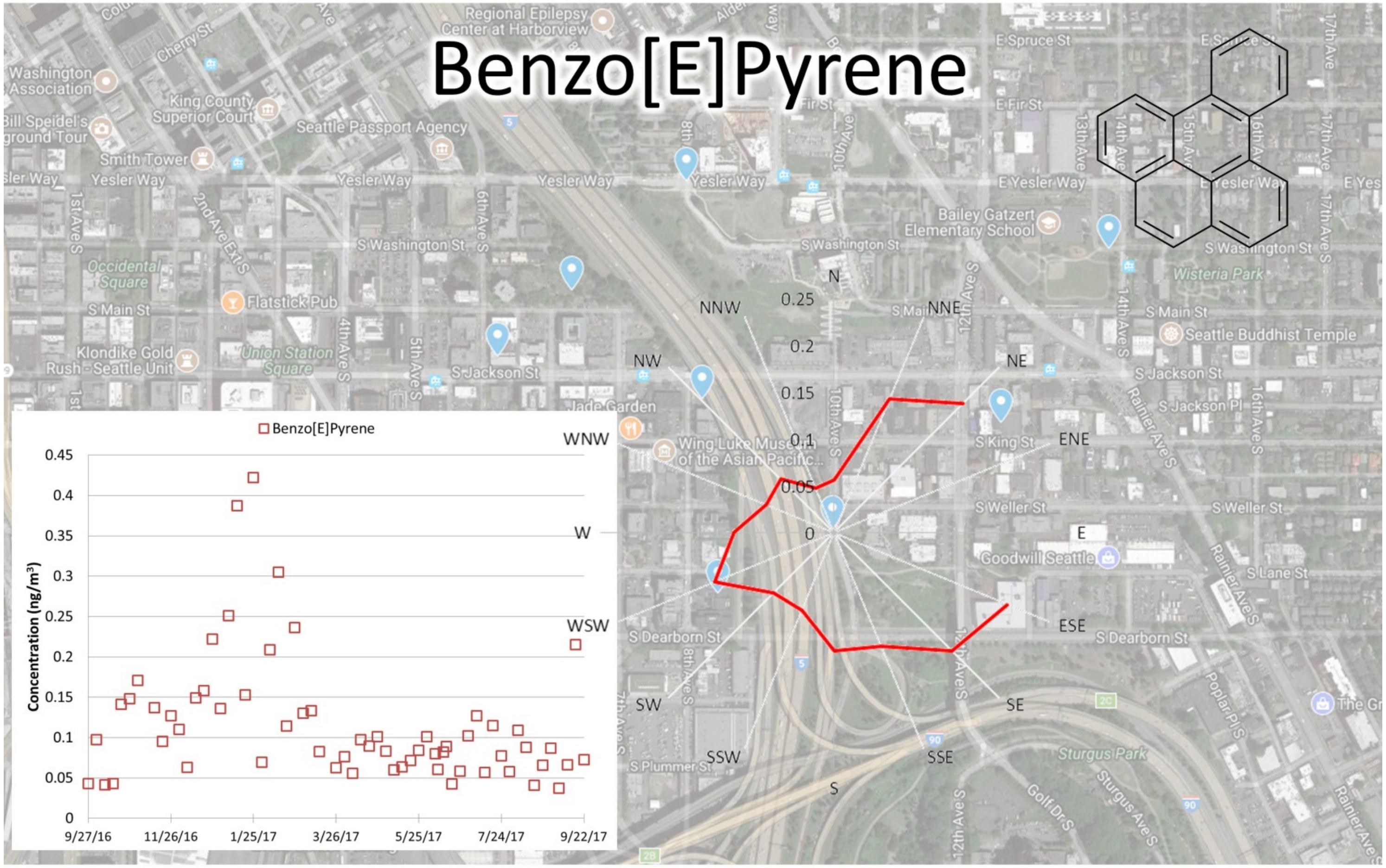


Figure D-10. Benzo[B]Fluoranthene chemical structure, pollution rose, and concentrations over study period

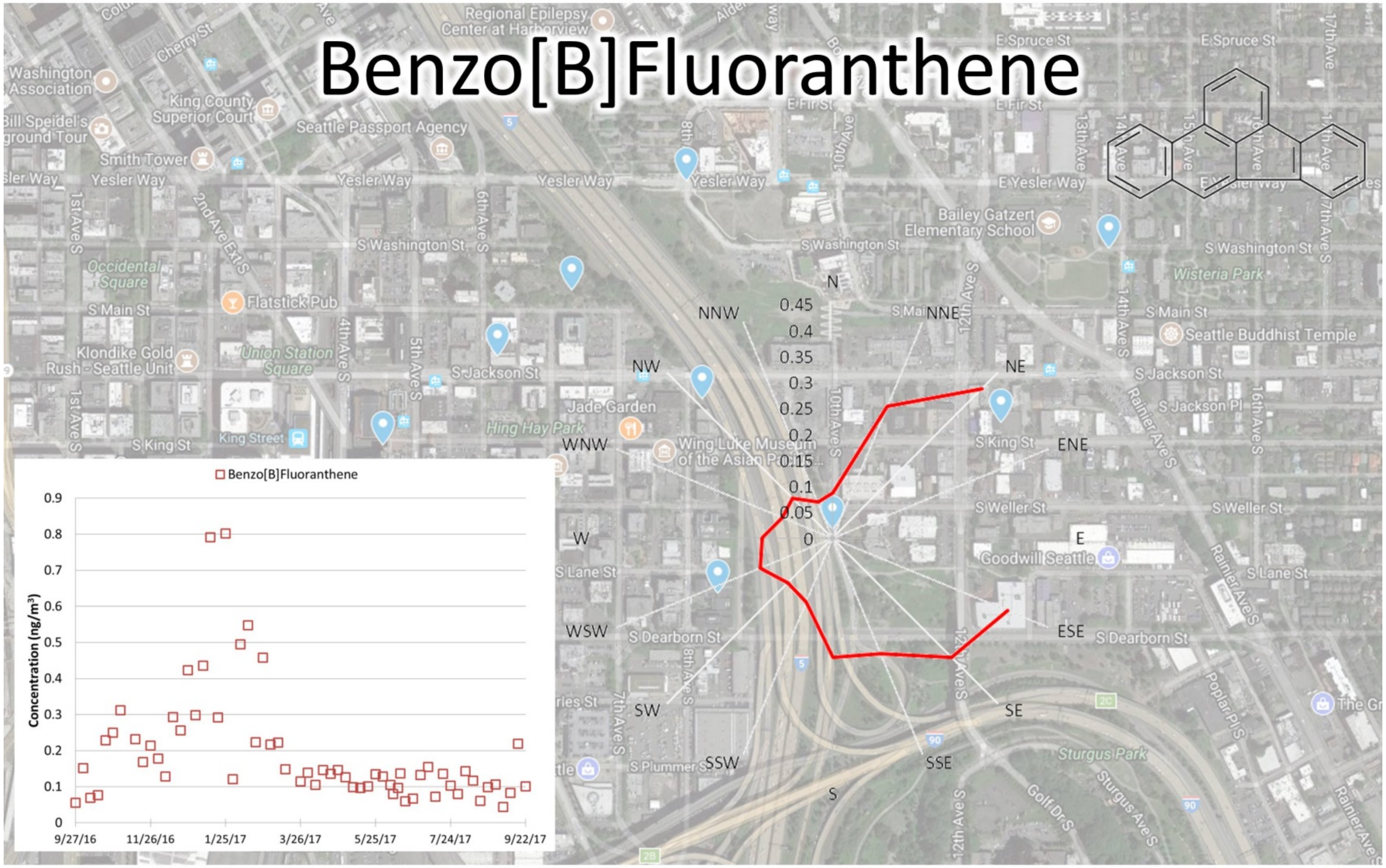
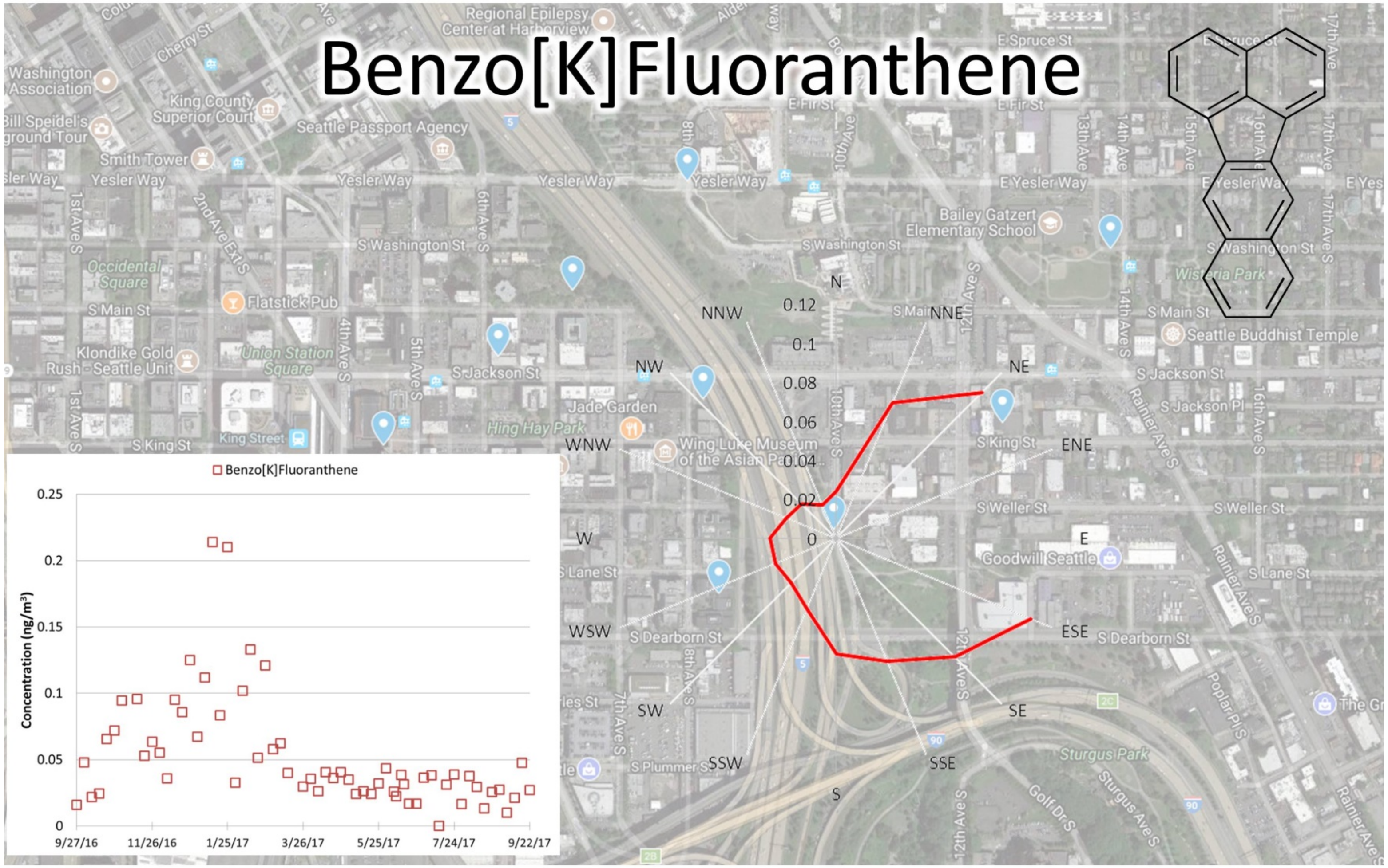


Figure D-11. Benzo[K]Fluoranthene chemical structure, pollution rose, and concentrations over study period



23% of samples were below the MDL

Figure D-12. Chrysene chemical structure, pollution rose, and concentrations over study period

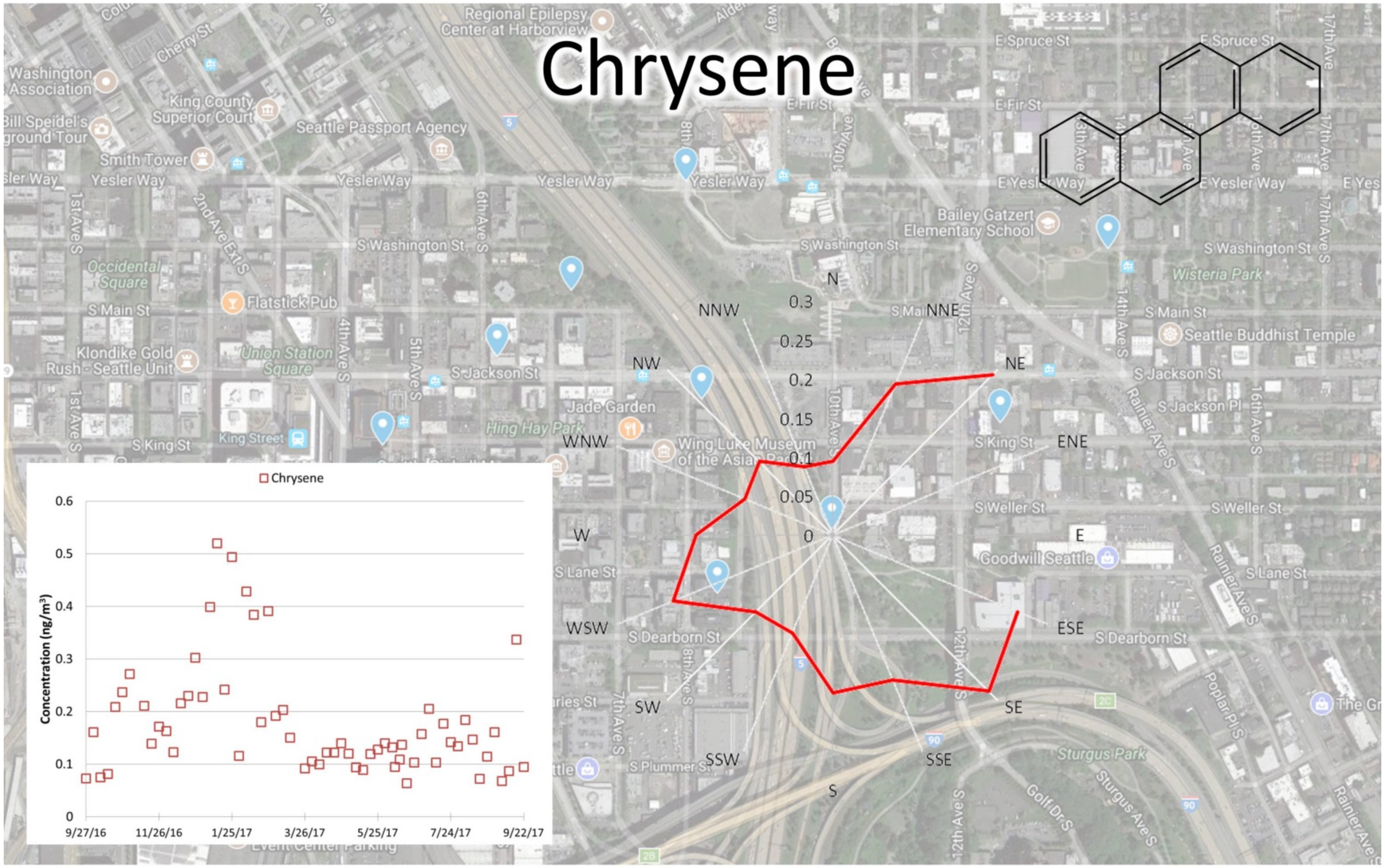


Figure D-13. Coronene chemical structure, pollution rose, and concentrations over study period

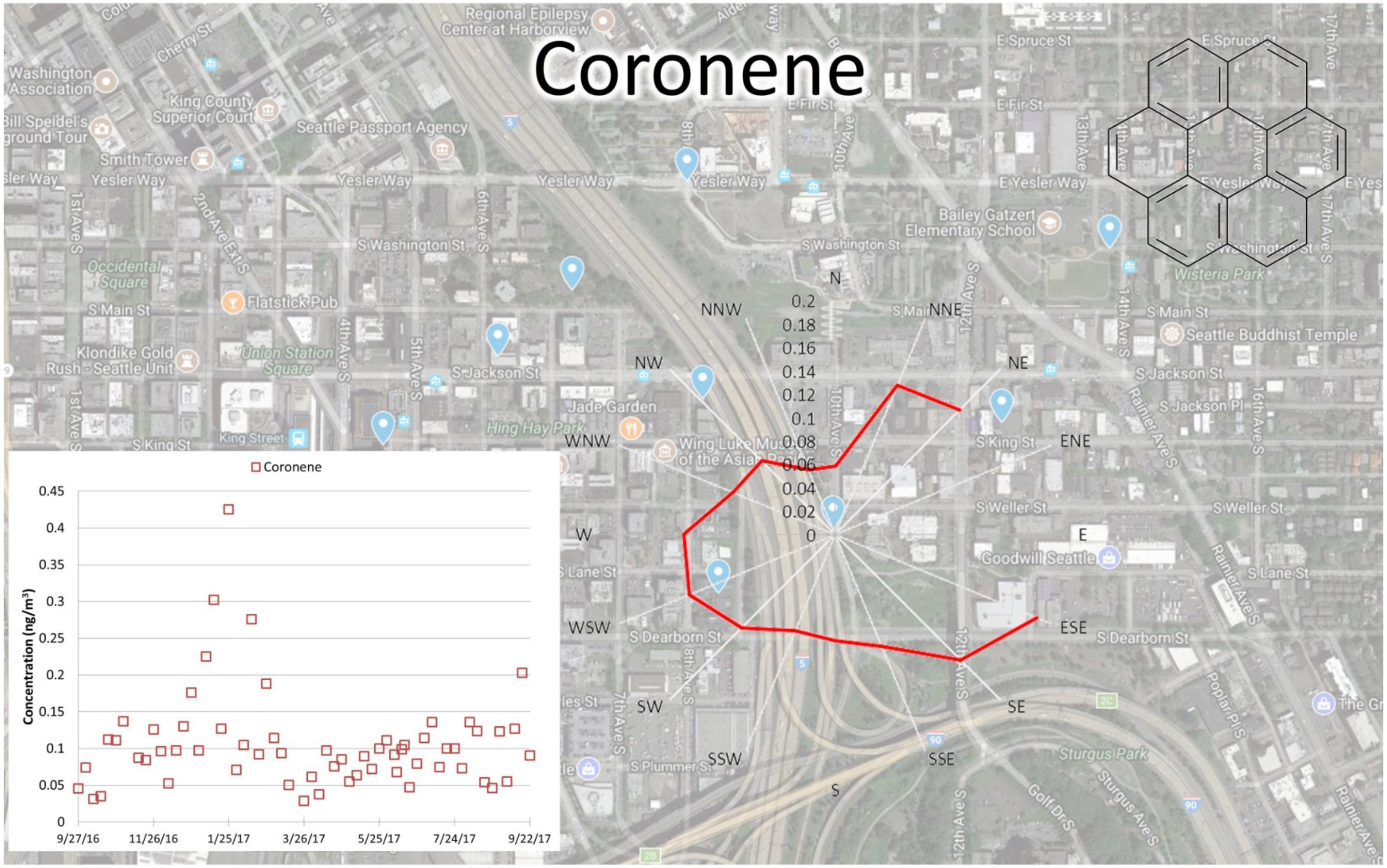


Figure D-14. Indeno[1,2,3-Cd]Pyrene

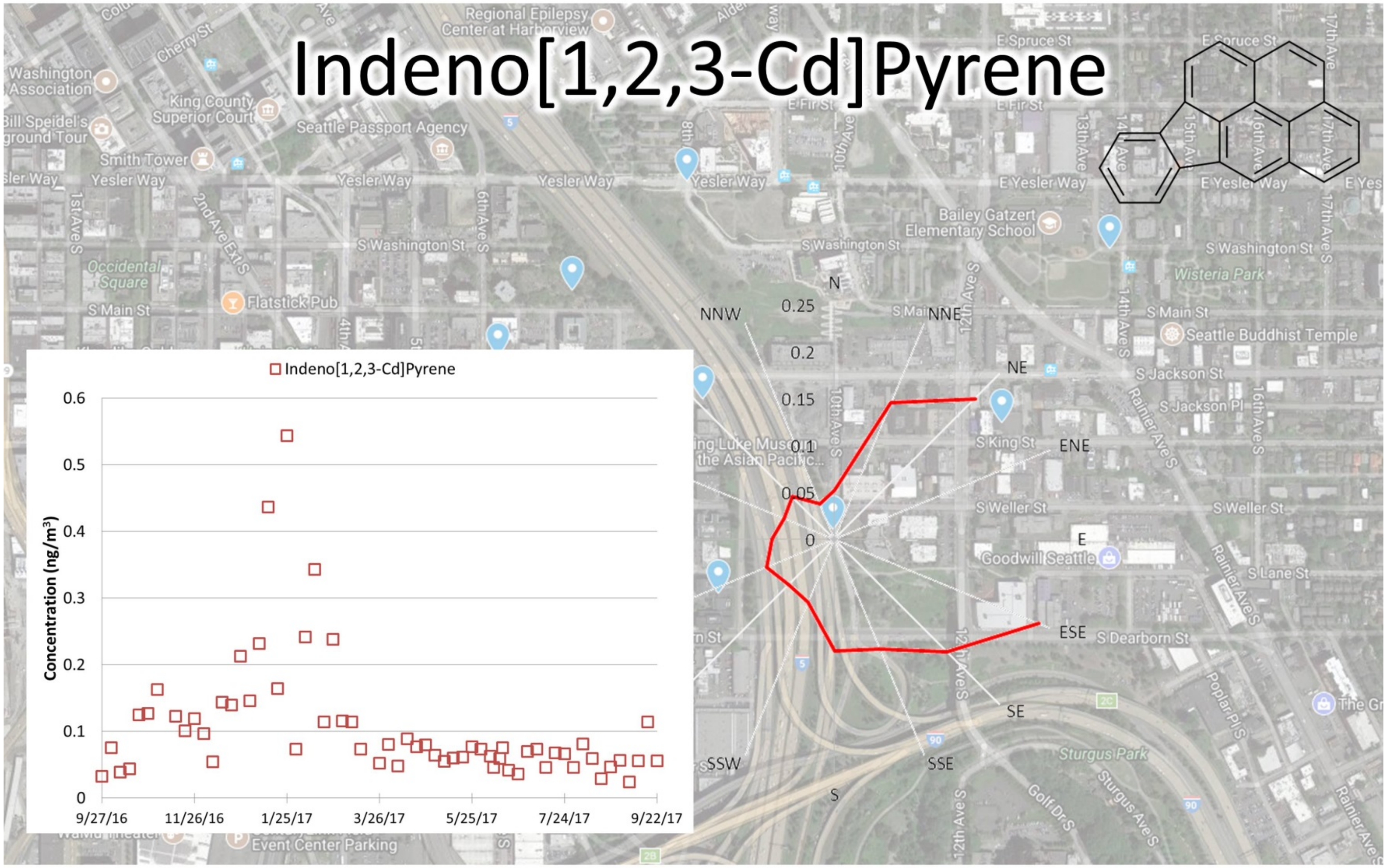
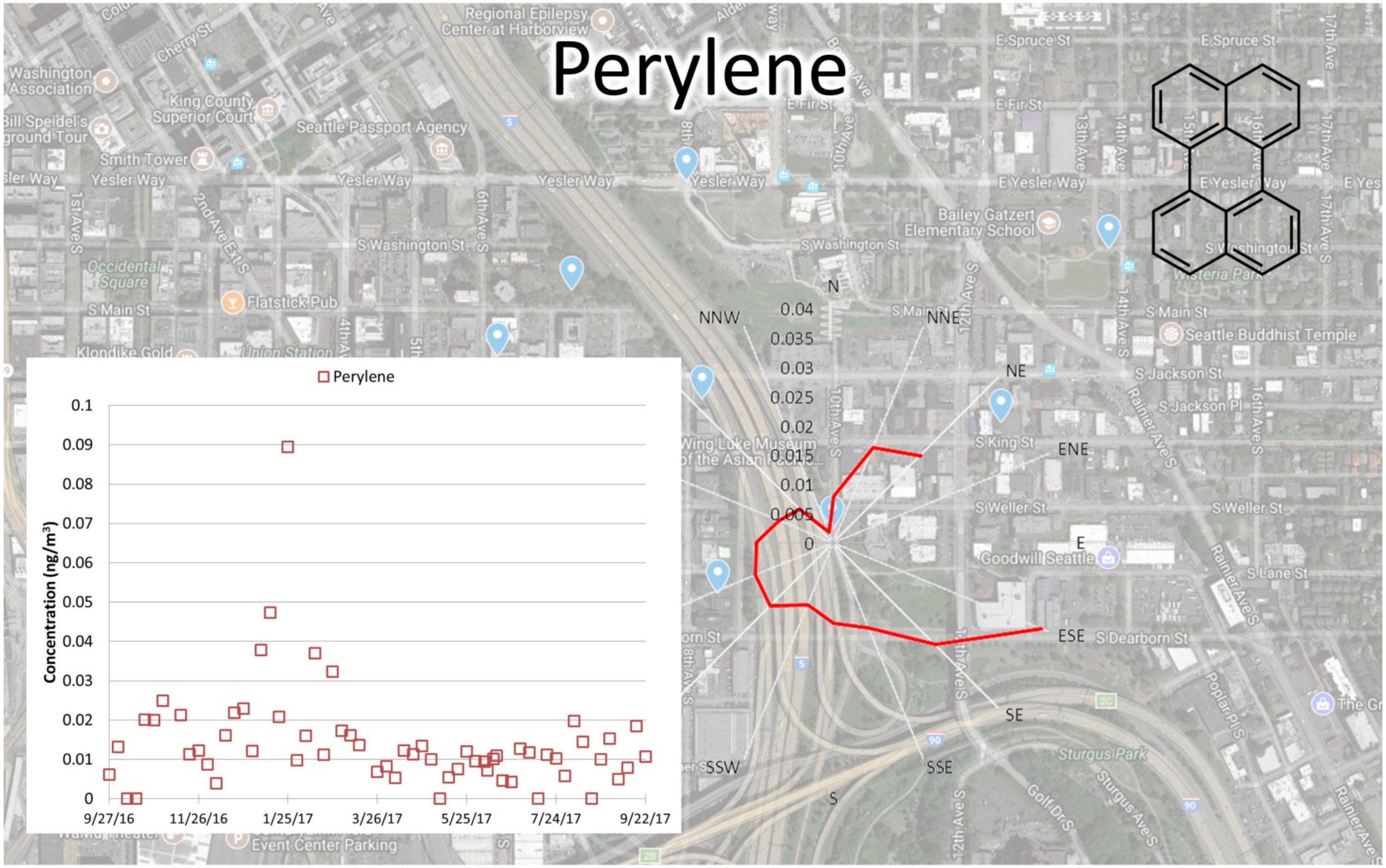
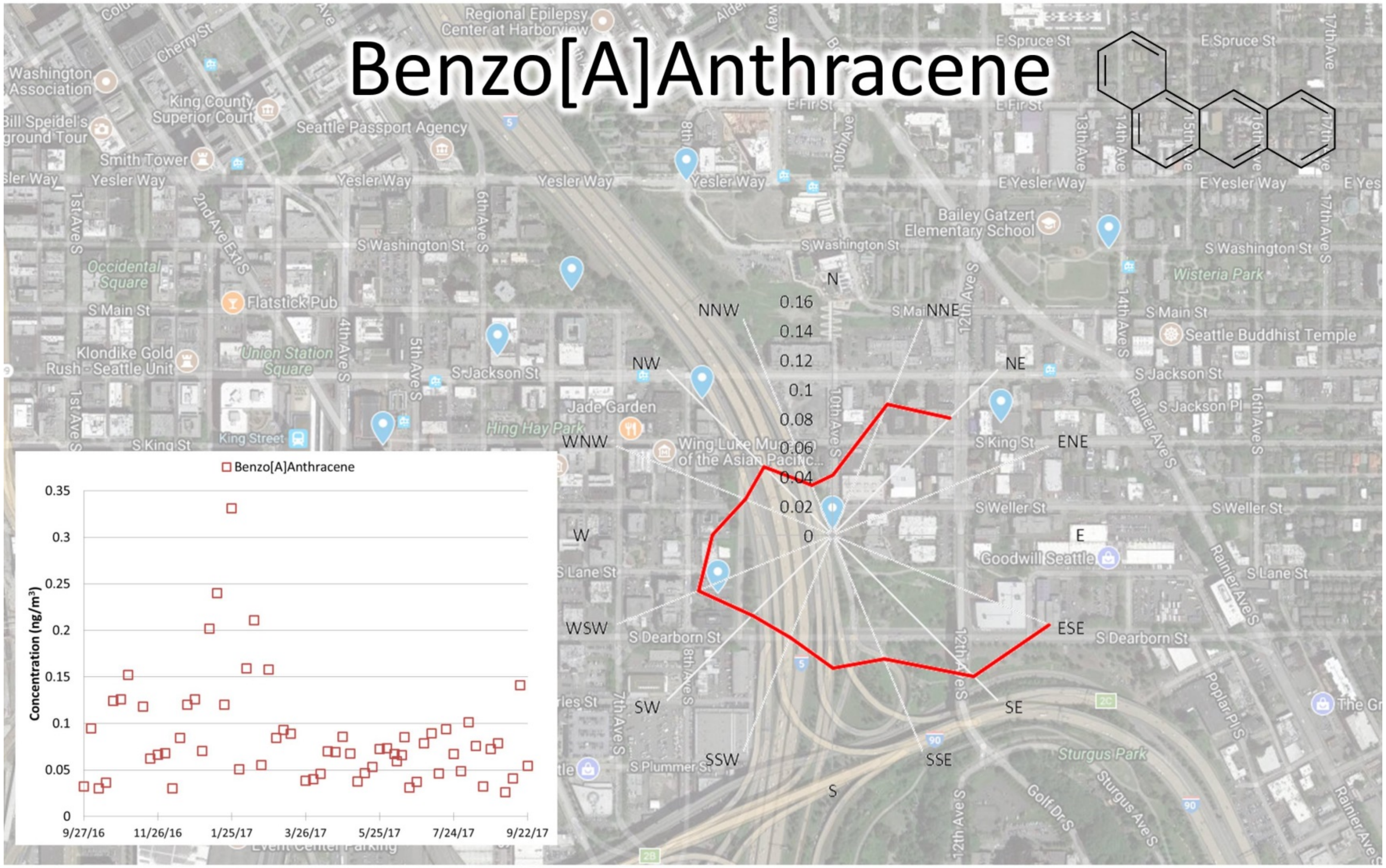


Figure D-15. Perylene chemical structure, pollution rose, and concentrations over study period



31% of samples were below the MDL

Figure D-16. Benzo[A]Anthracene chemical structure, pollution rose, and concentrations over study period



Pollution rose for 10th & Weller PAHs with no seasonality

Figure D-17. Pyrene chemical structure, pollution rose, and concentrations over study period

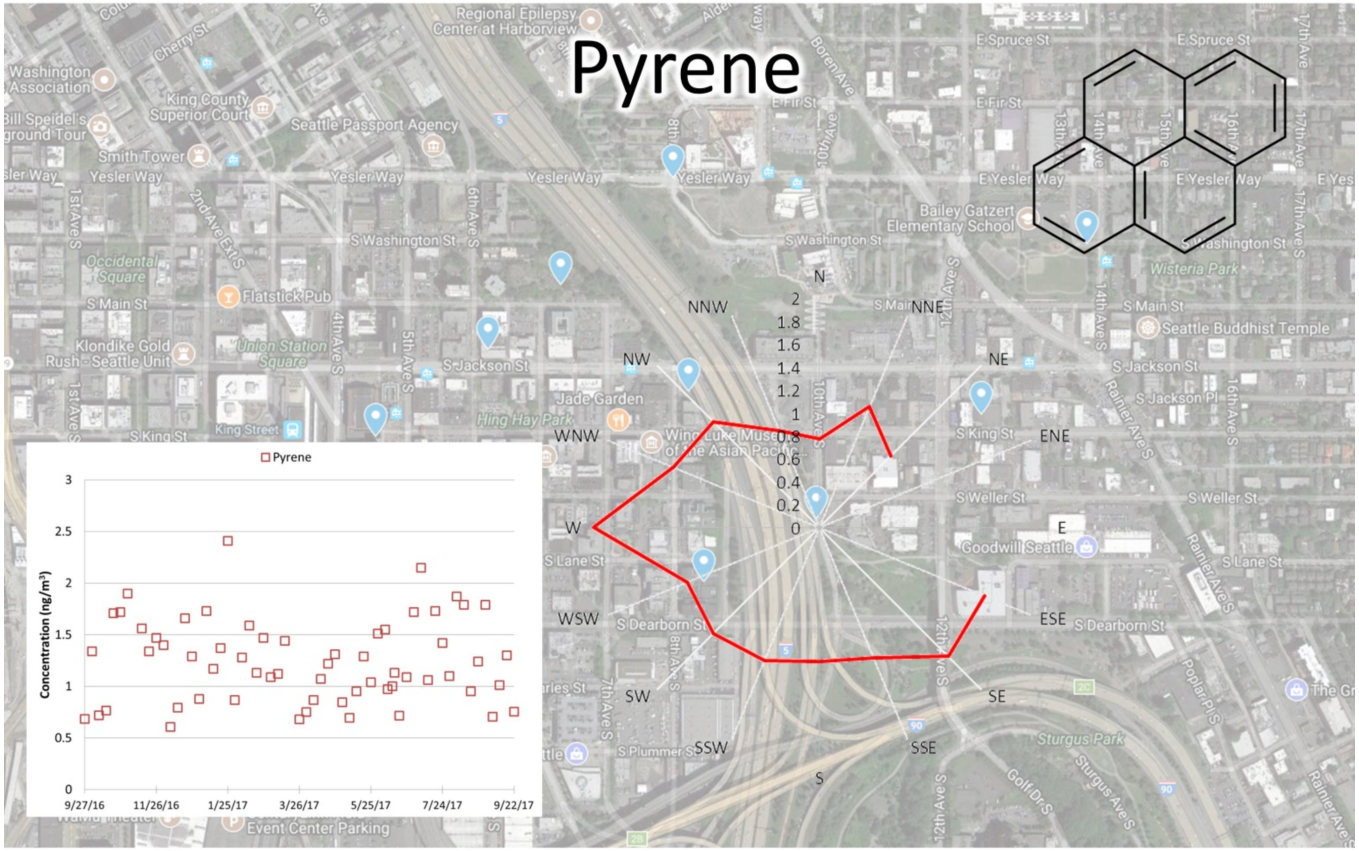


Figure D-18. Anthracene chemical structure, pollution rose, and concentrations over study period

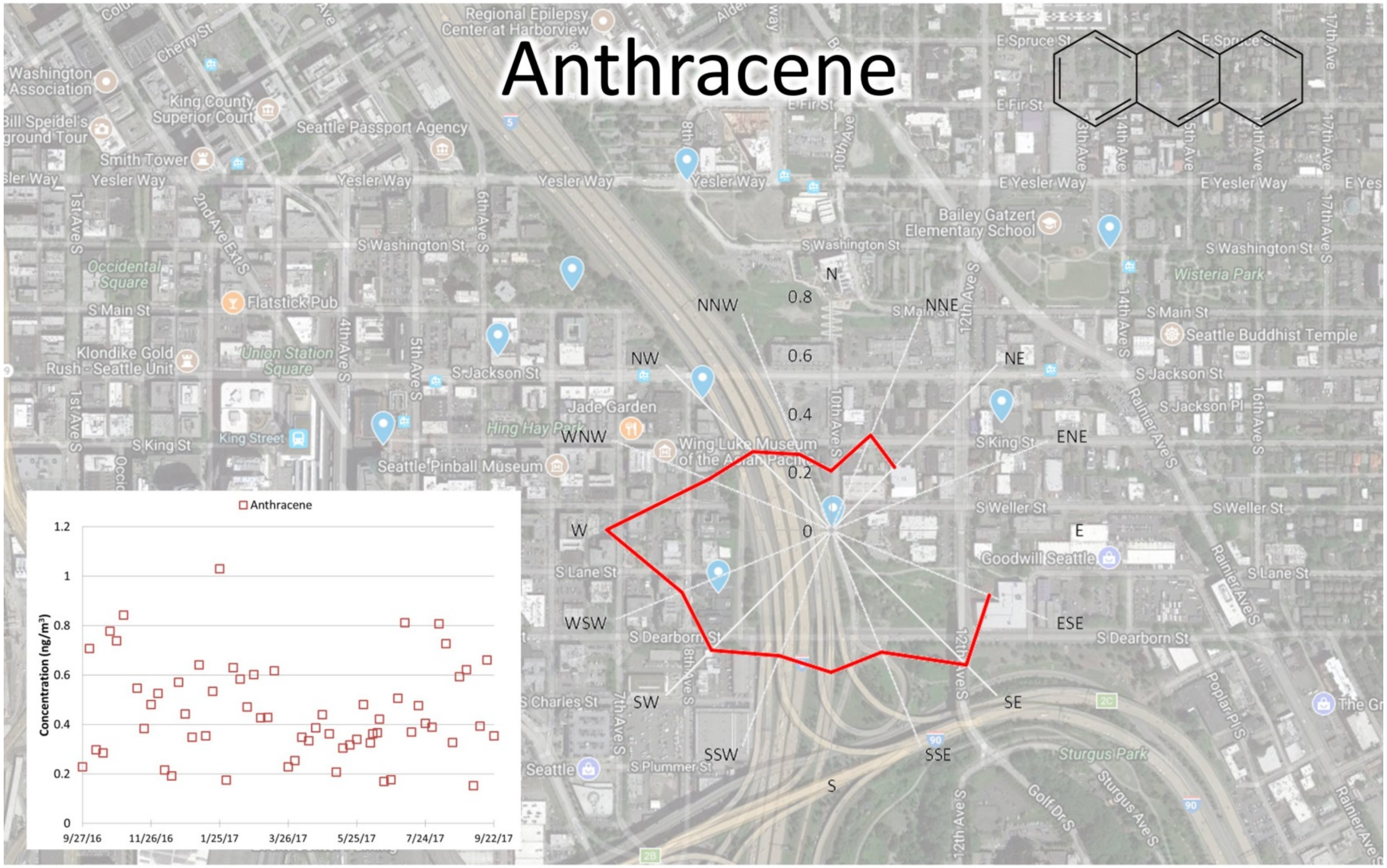


Figure D-19. Naphthalene chemical structure, pollution rose, and concentrations over study period

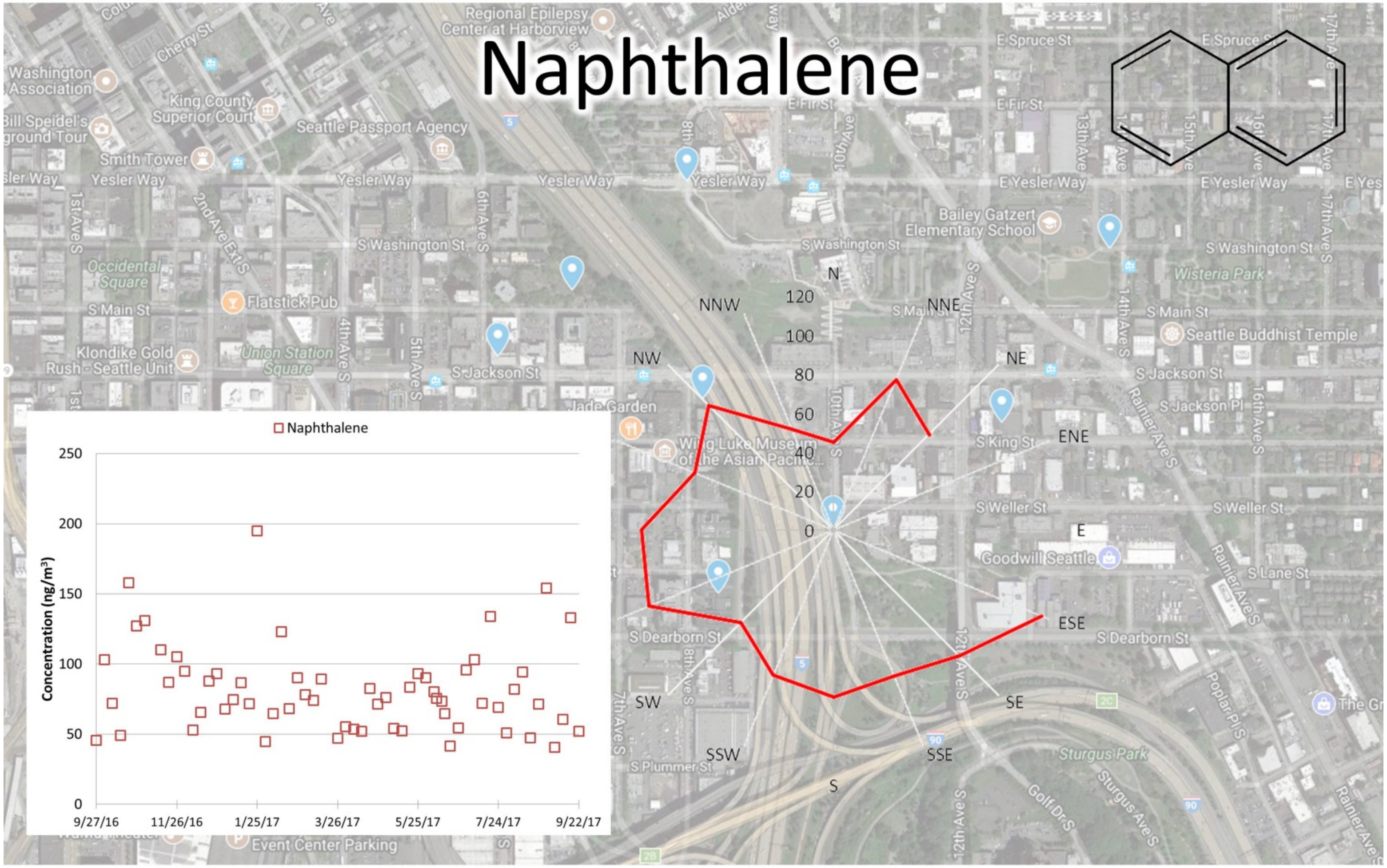


Figure D-20. Acenaphthene chemical structure, pollution rose, and concentrations over study period

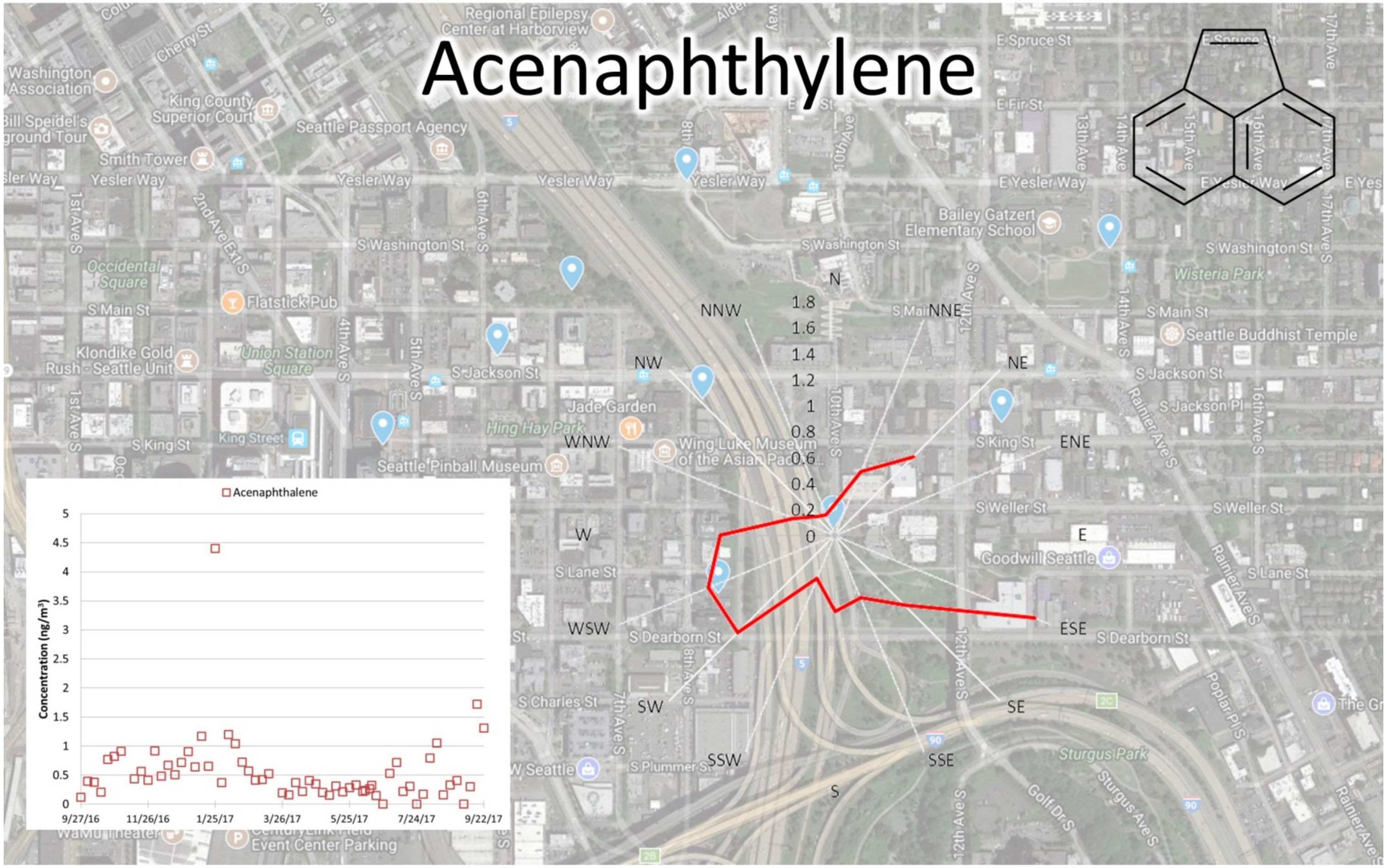


Figure D-21. Fluoranthene chemical structure, pollution rose, and concentrations over study period

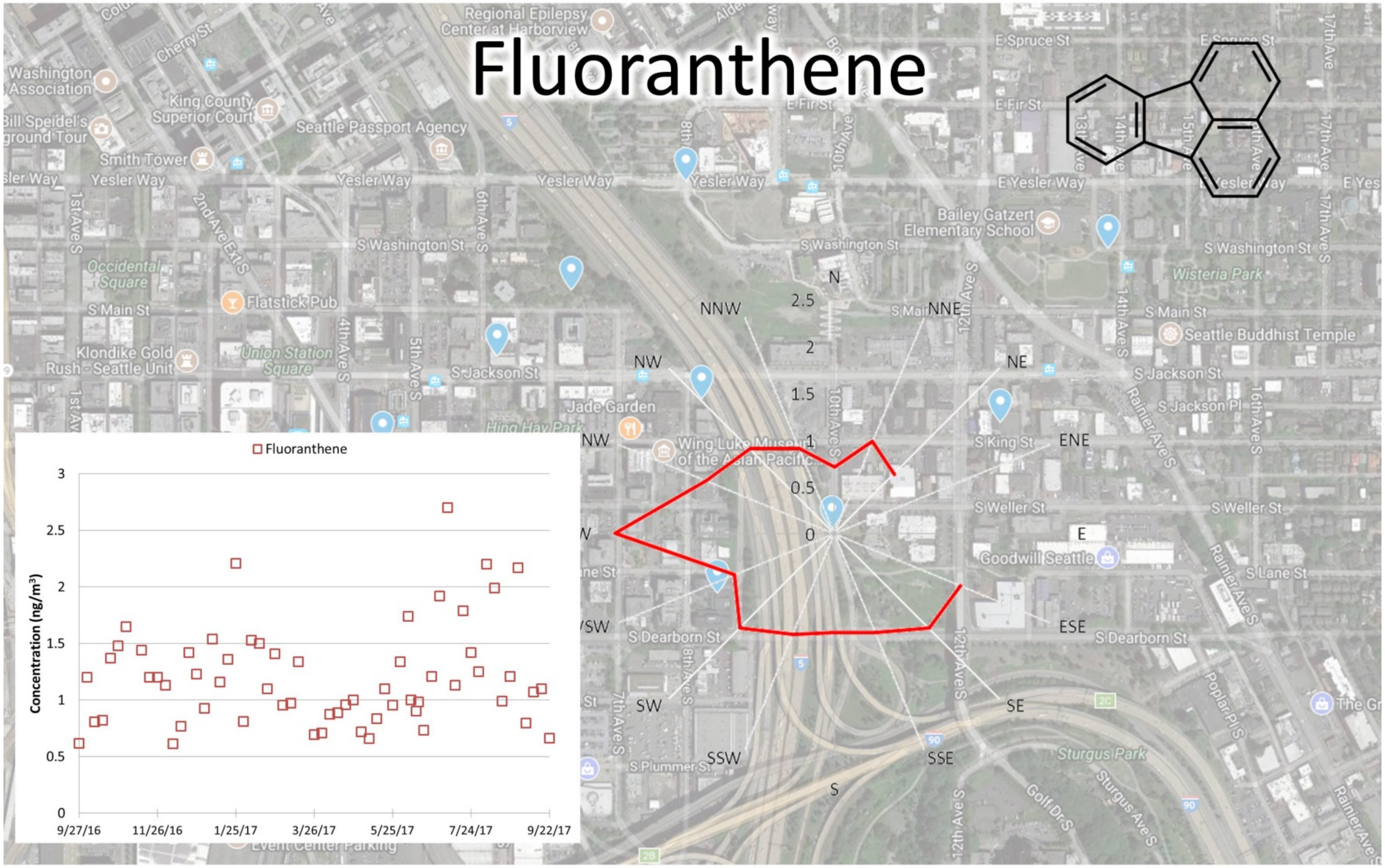
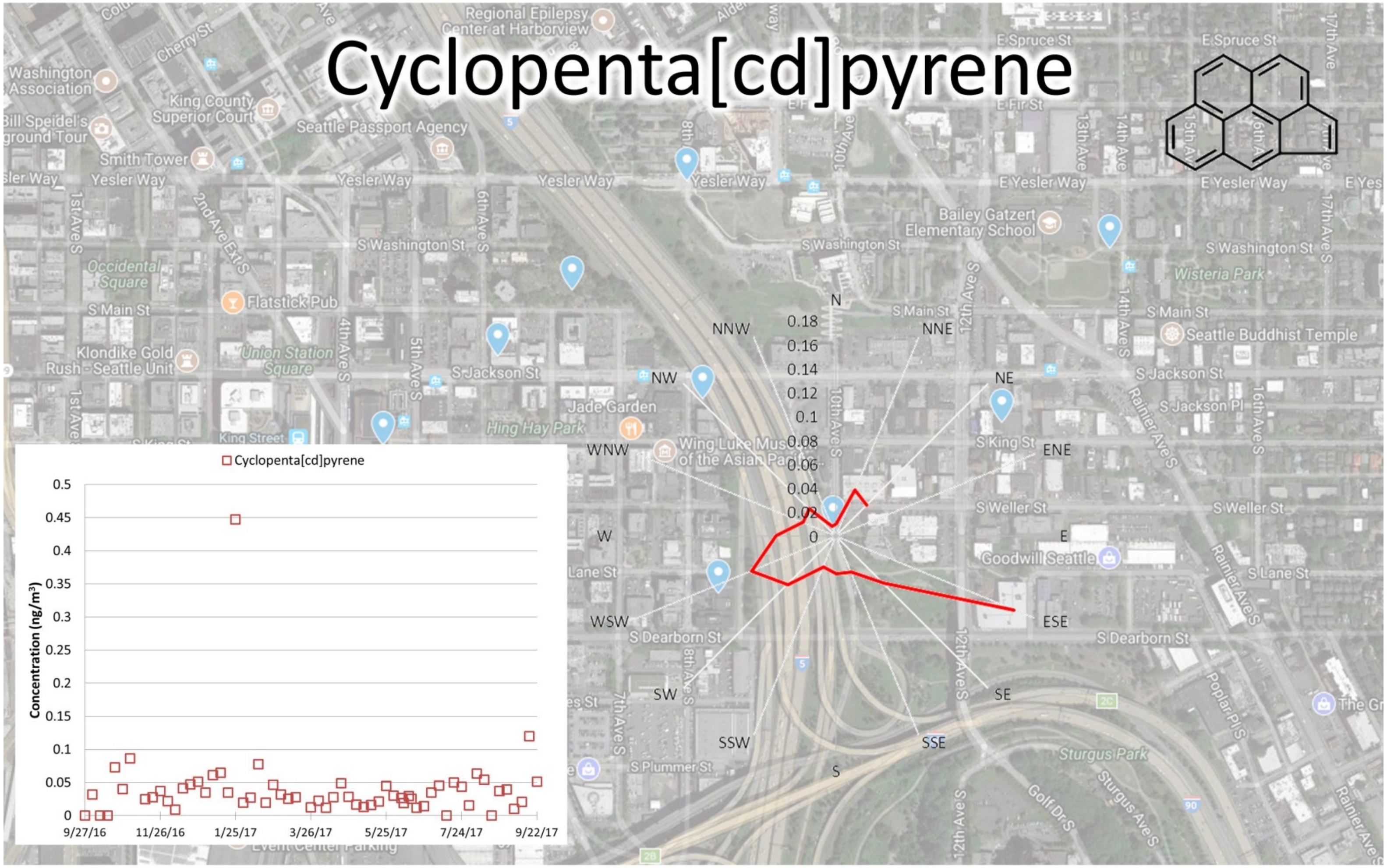


Figure D-22. Cyclopenta[cd]pyrene chemical structure, pollution rose, and concentrations over study period



26% of samples were below the MDL

Appendix E. Community-directed survey results

Figure E-1. Online survey results, percent of total votes by area

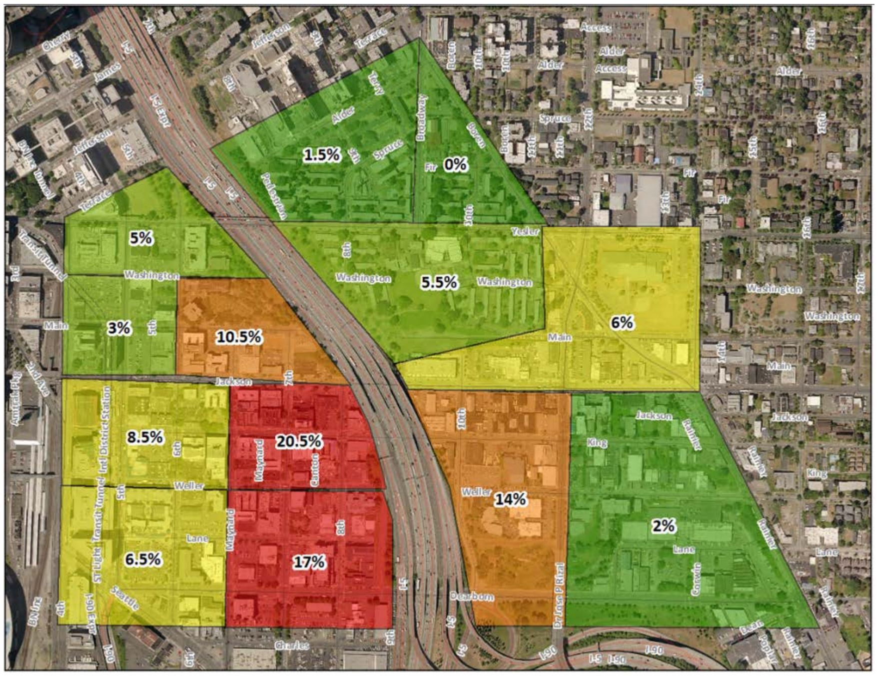


Figure E-2. Poster map survey results, percent of total votes by area.

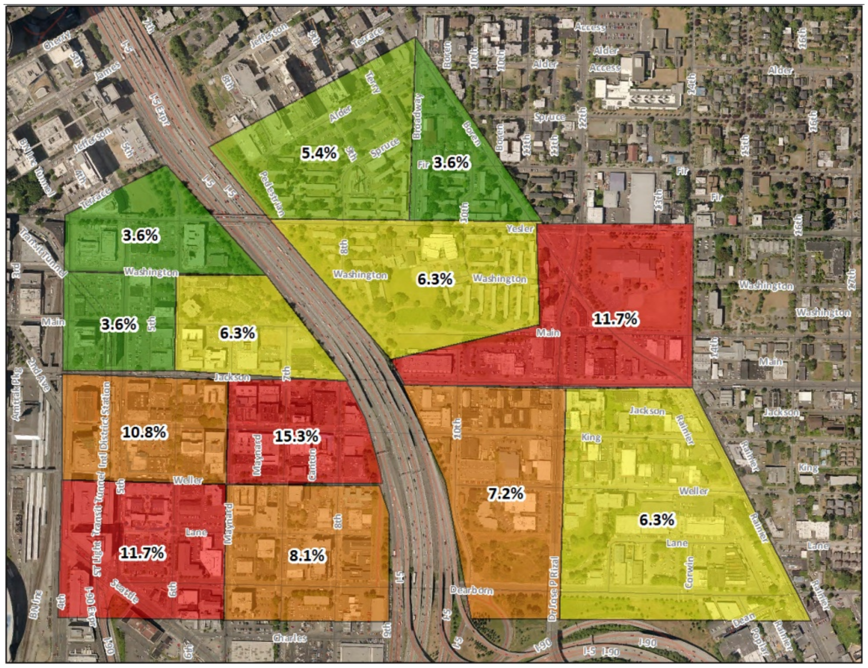


Figure E-3. Cantonese-speaking survey results, percent of total votes by area.

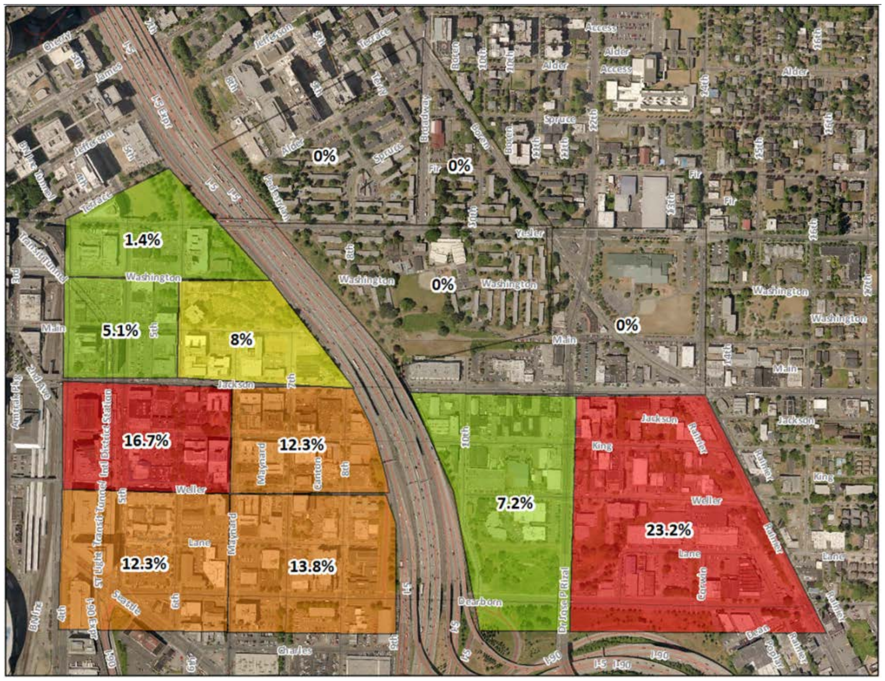


Figure E-4. Total votes by people that "live in the community" (from online survey and poster map)

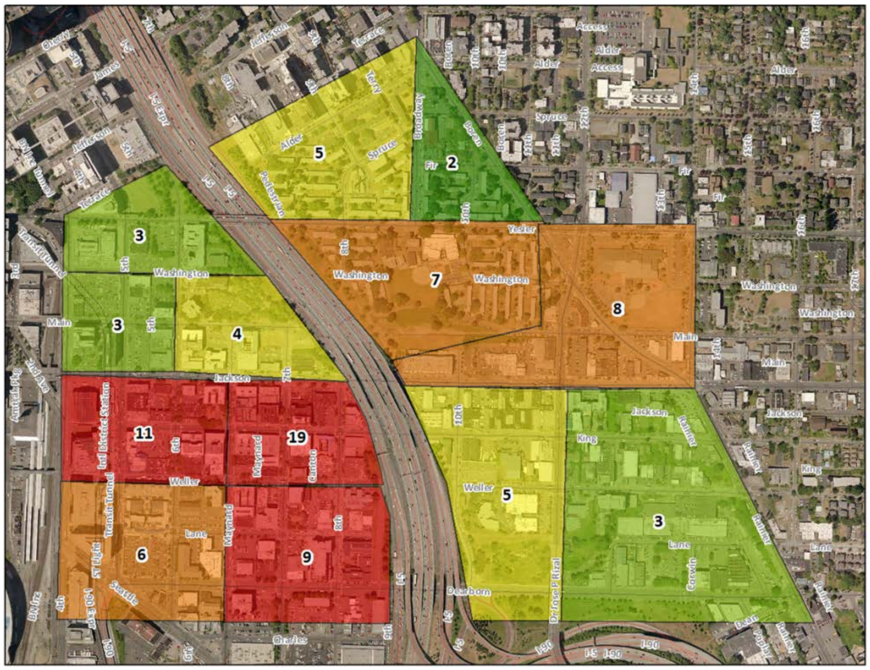


Figure E-5. Total votes by people that "work in the community" (from online survey and poster map)

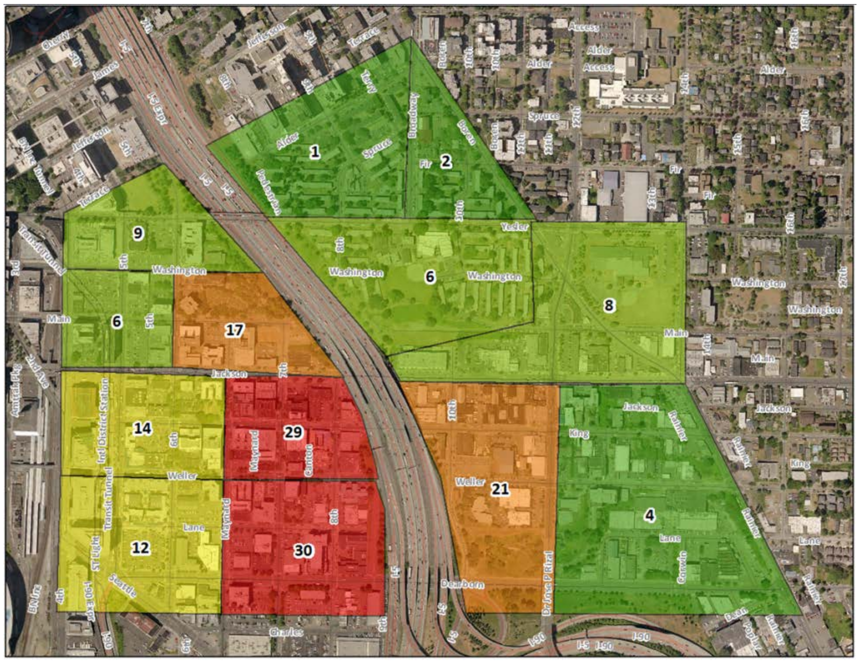


Figure E-6. Total votes by people that "visit the community" (from online survey and poster map)

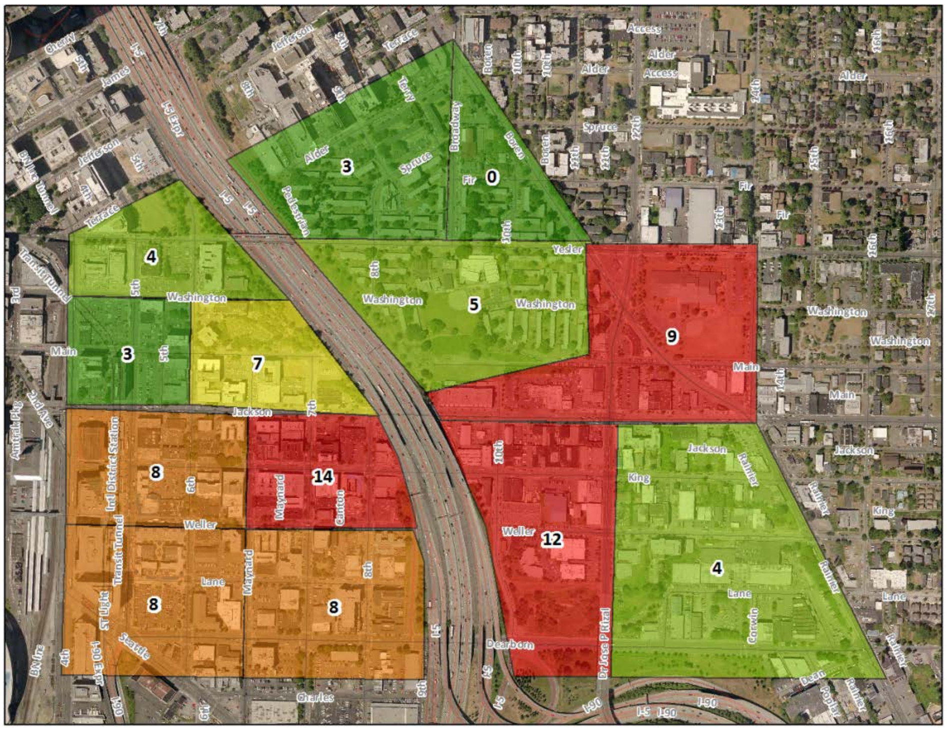


Figure E-7. Total votes that mentioned “sensitive groups” in the comments (online only).

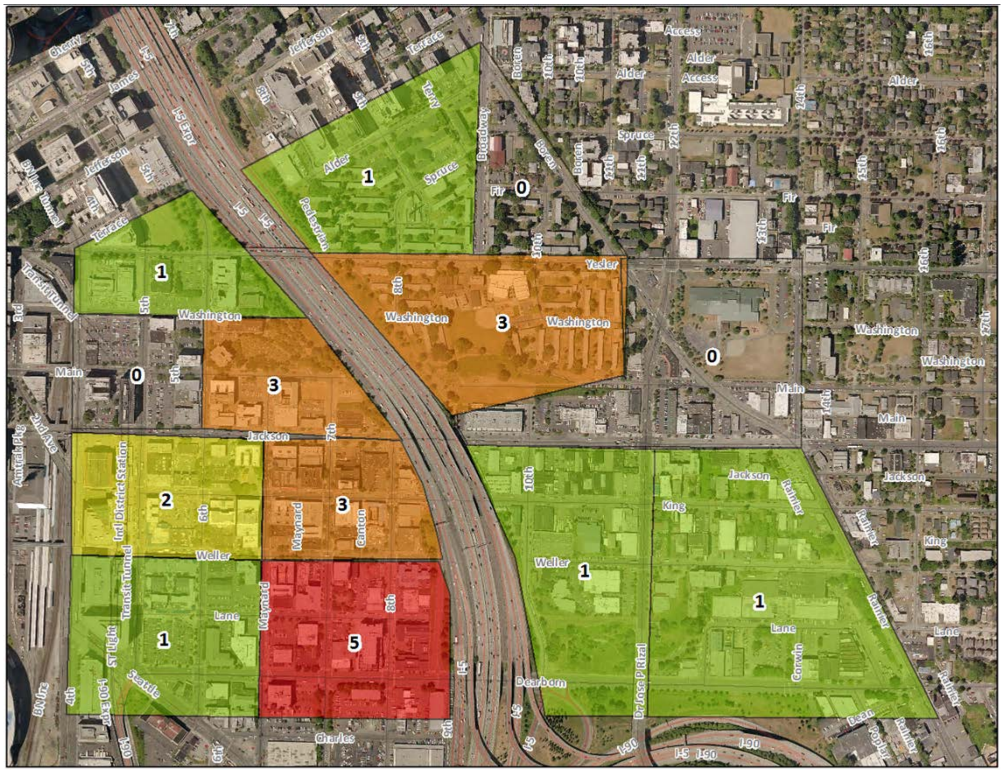


Figure E-8. Total votes that mentioned “population” in the comments (online only).

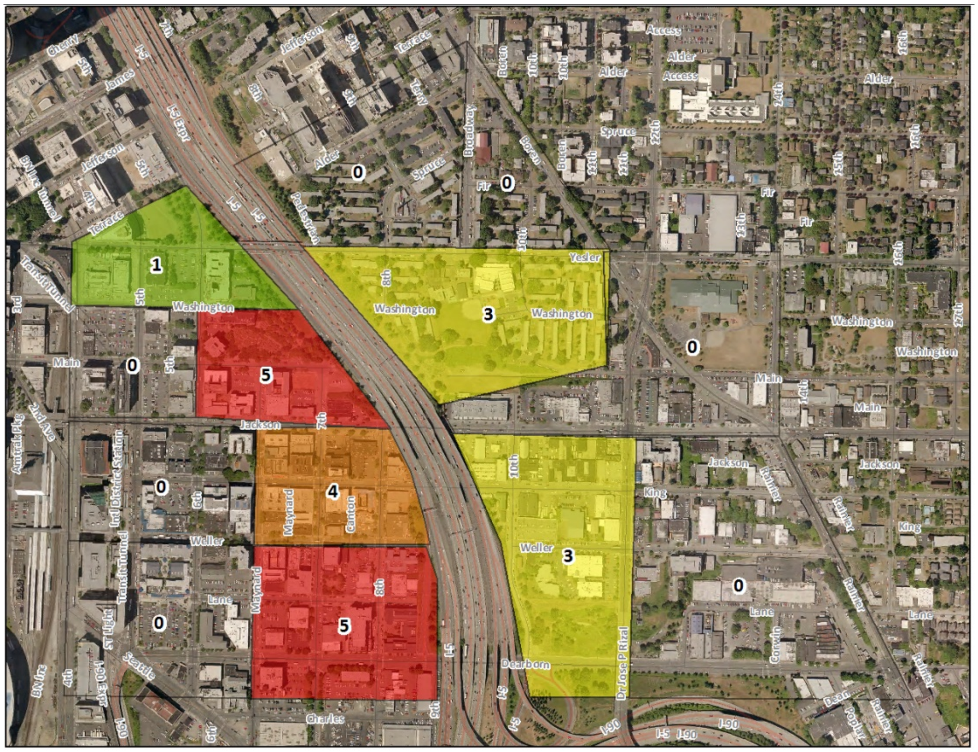


Figure E-9. Total votes that mentioned “foot traffic” in the comments (online only).

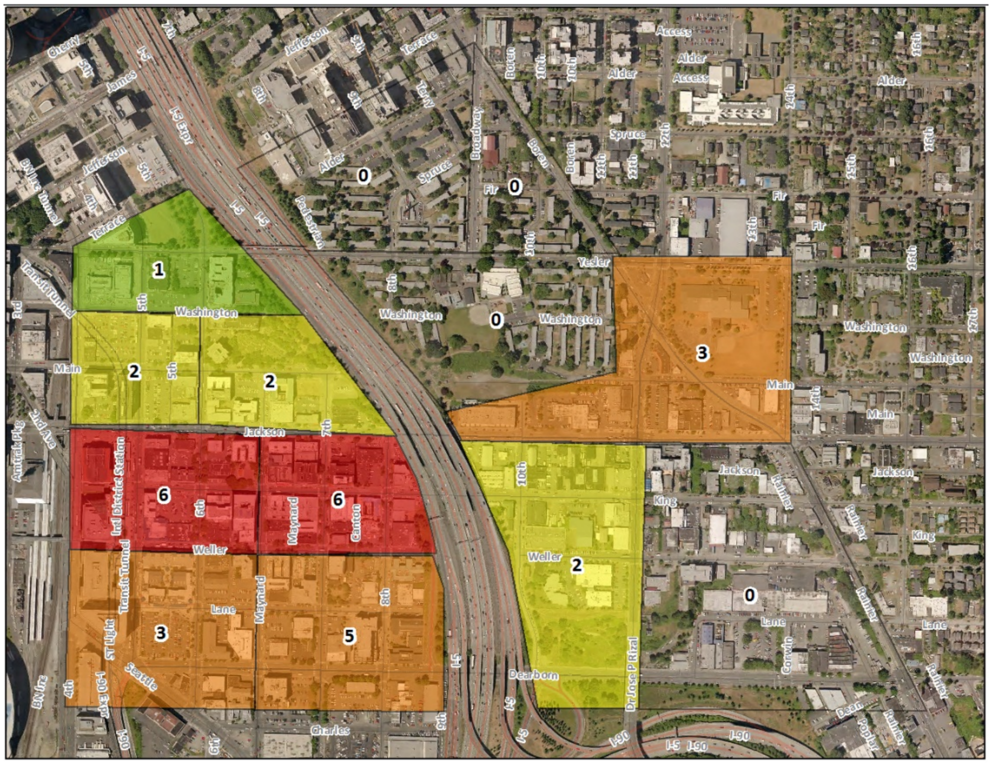


Figure E-10. Total votes that mentioned “highways” in the comments (online only).

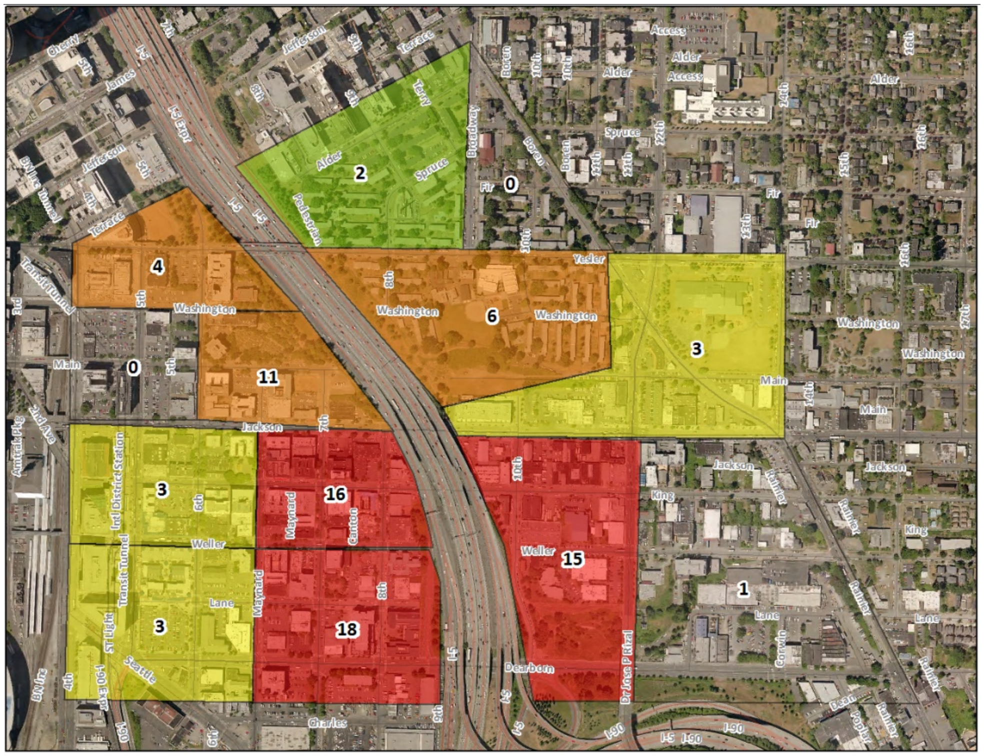


Figure E-11. Total votes that mentioned “cars” in the comments (online only).

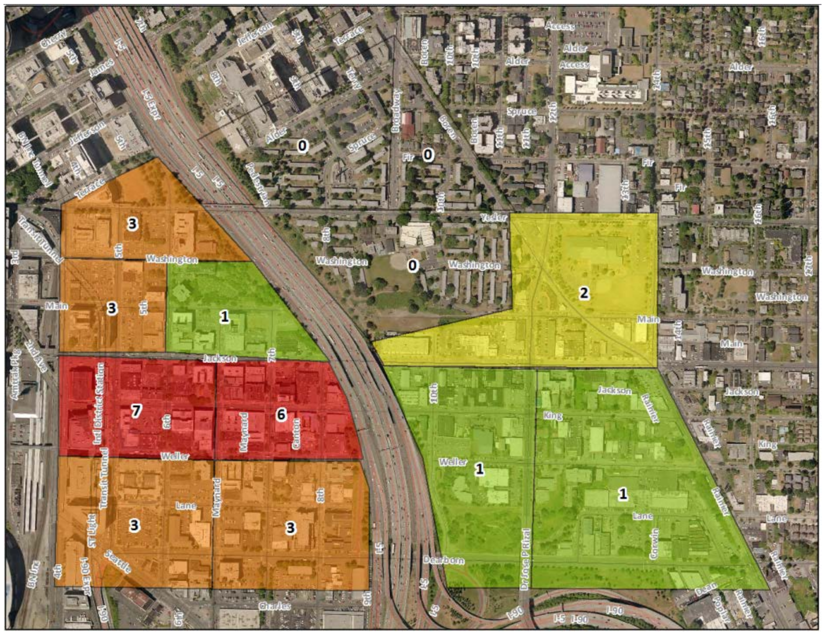


Figure E-12. Total votes that mentioned “trains” in the comments (online only).

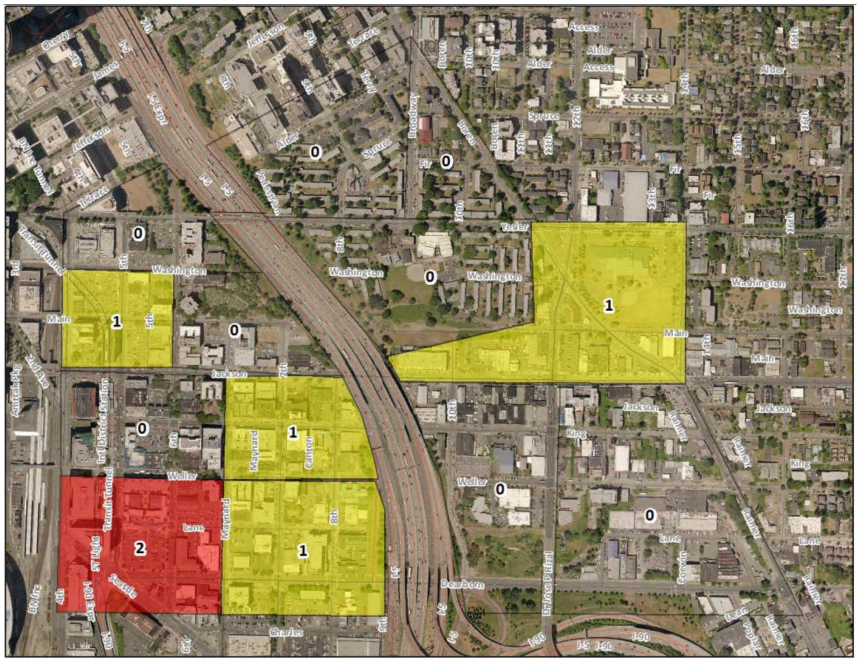


Figure E-13. Total votes that mentioned “buses” in the comments (online only).

Figure E- 14. Total votes that mentioned “community gardens” in the comments (online only).

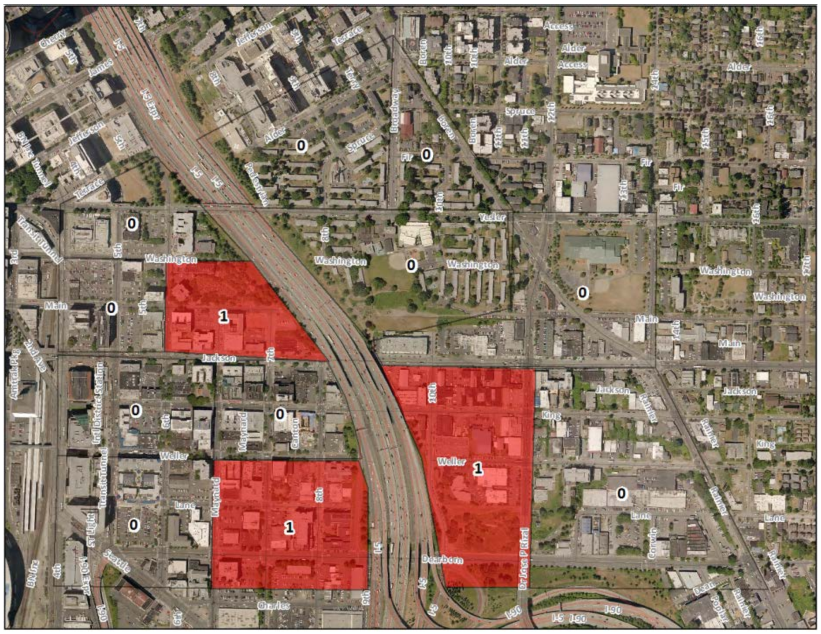


Figure E-15. Total votes from 18-29 year olds (online only).

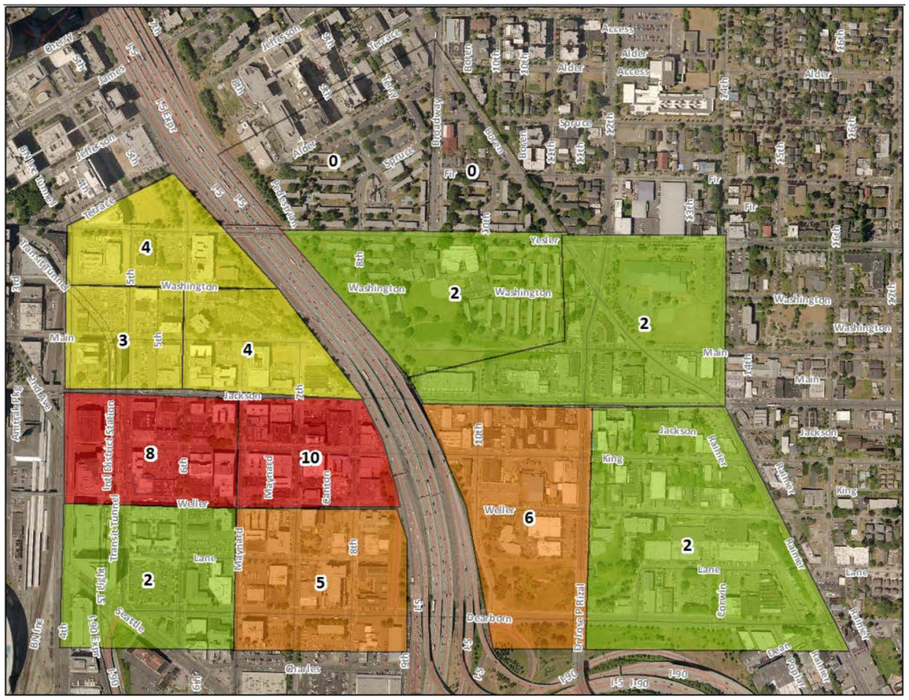


Figure E-16. Total votes from 30-49 year olds (online only).

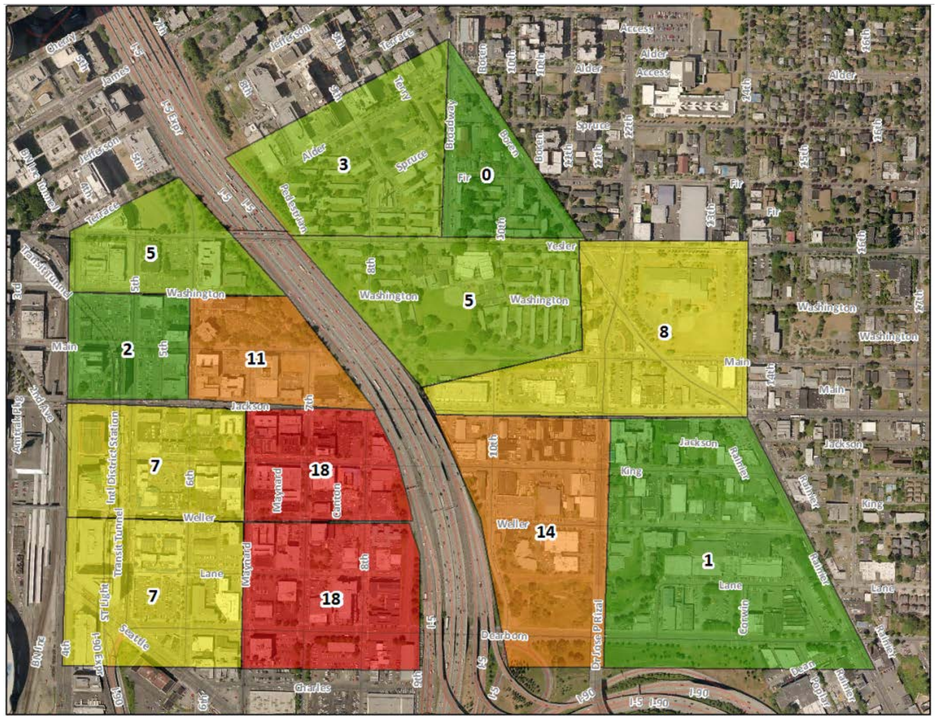


Figure E-17. Total votes from 50+ year olds (online only).

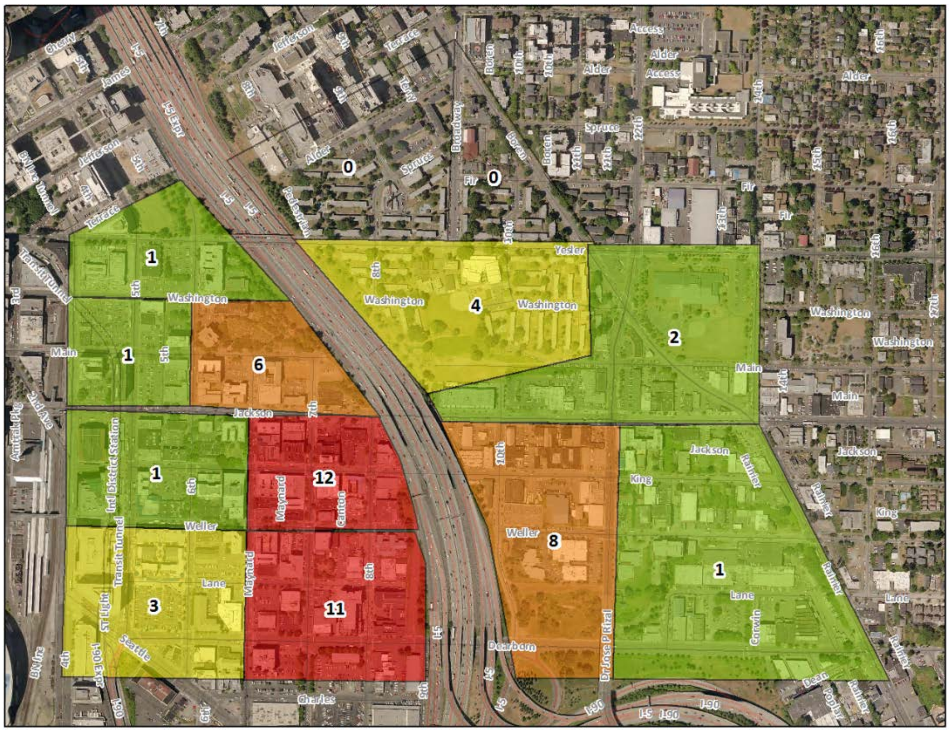


Figure E-18. Age of participants (online survey only)

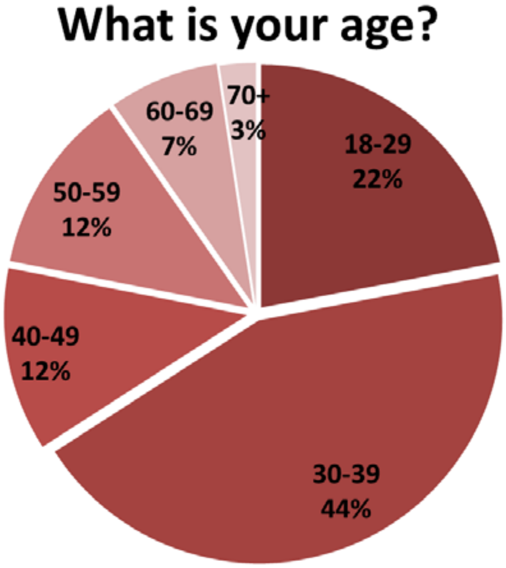


Figure E-19. Race or ethnic origins of survey participants (online survey only)

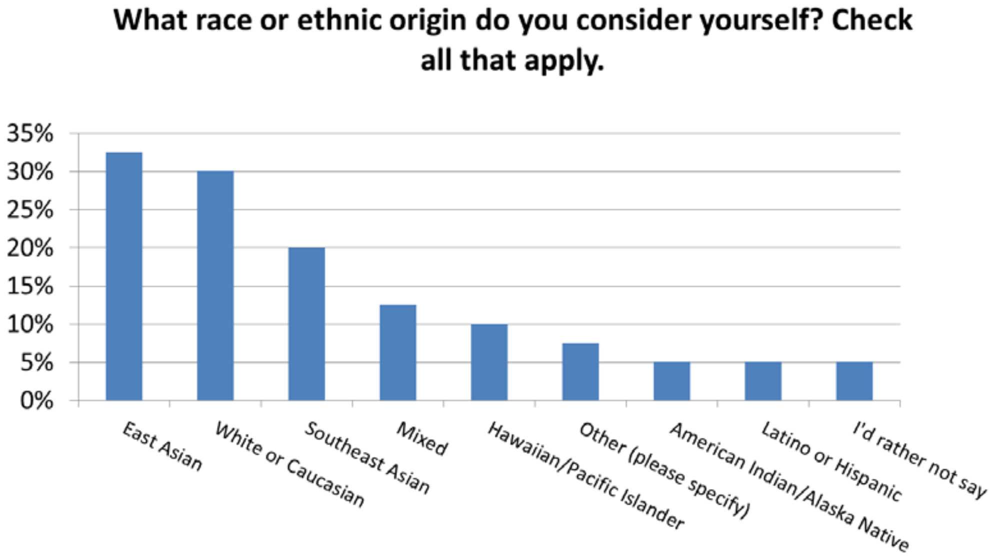


Figure E-20. Survey votes for self-identified as East Asian (online survey only)

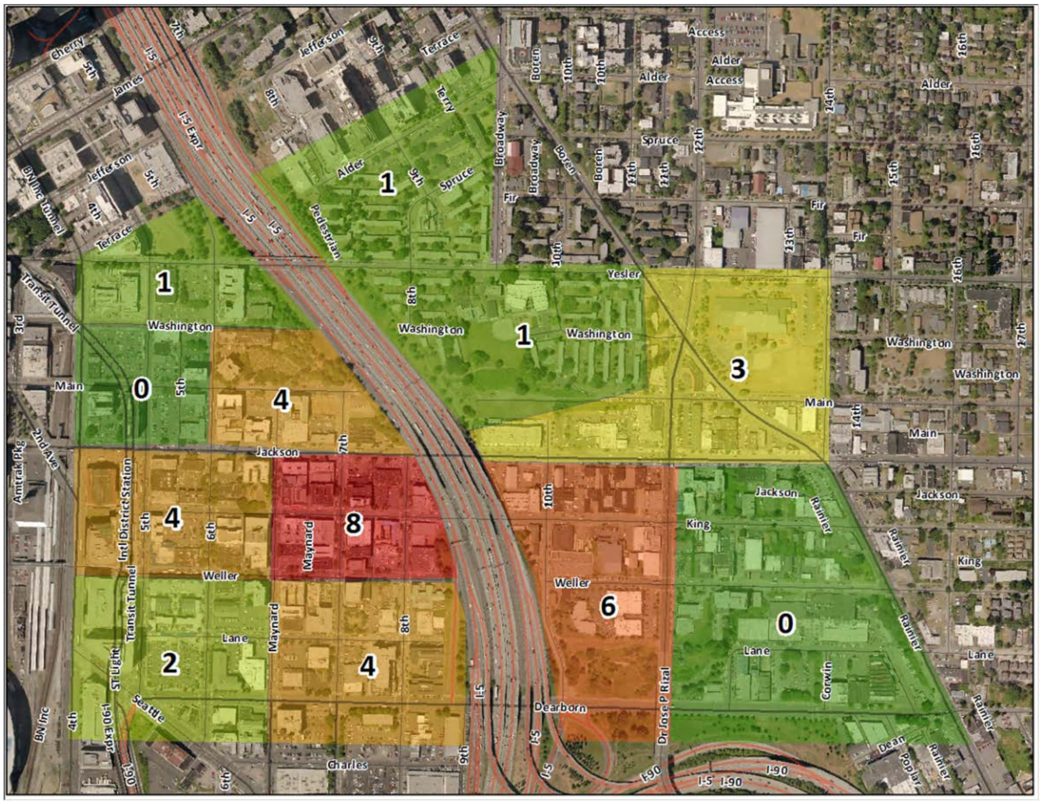


Figure E-21. Survey votes for self-identified as Southeast Asian (online survey only)

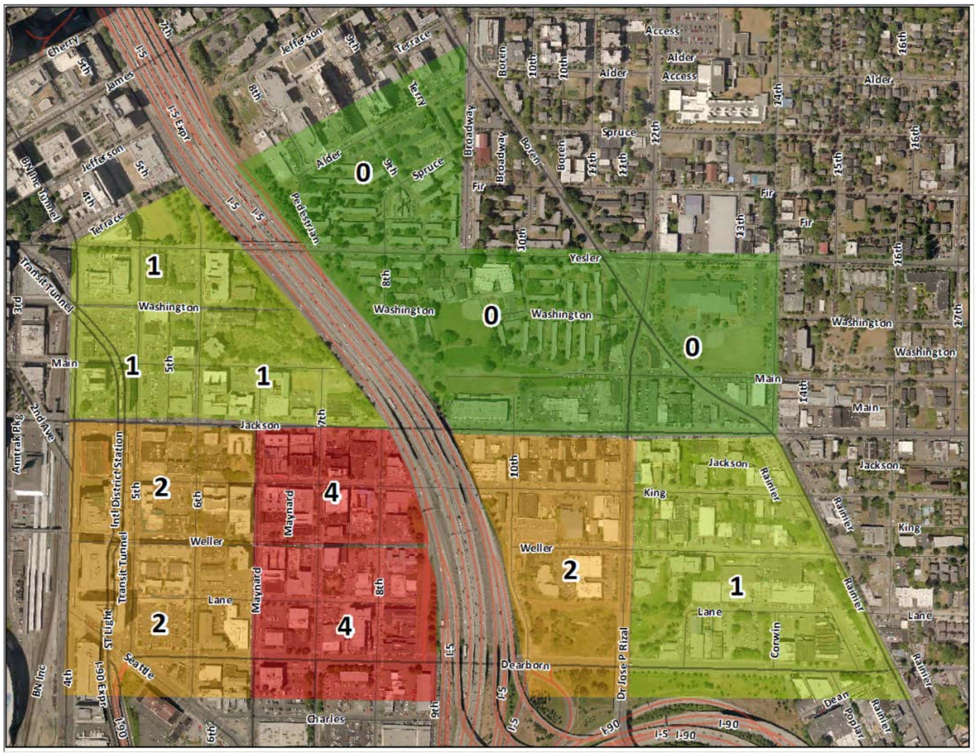


Figure E-22. Survey votes for self-identified as Native Hawaiian or Pacific Islander (online only)

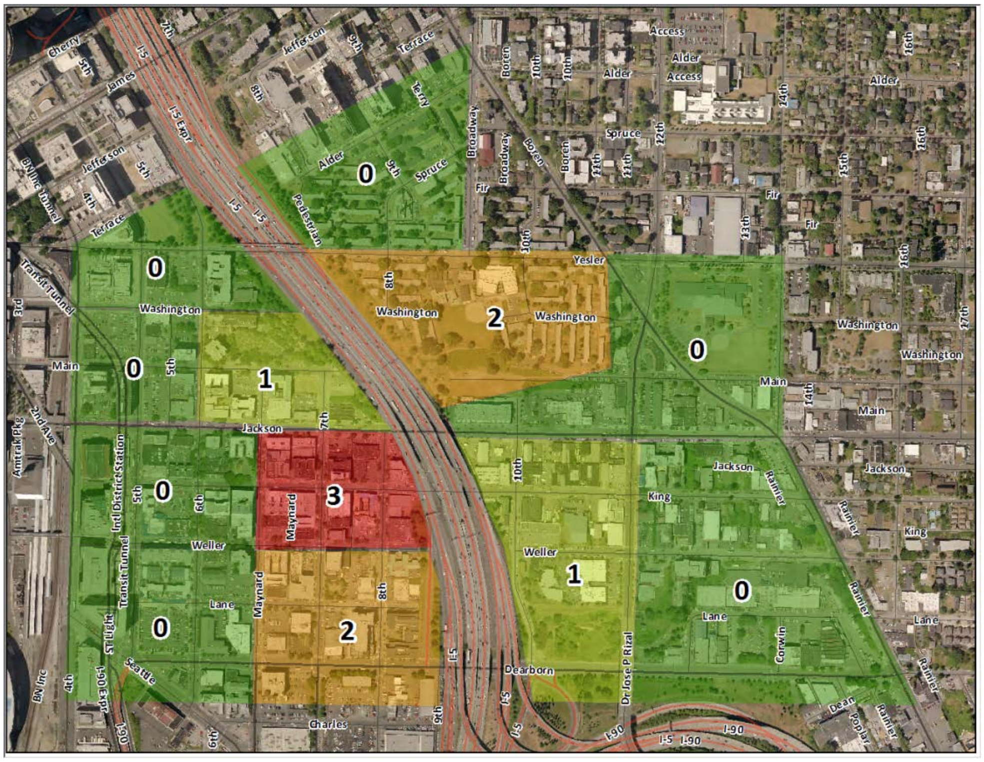


Figure E-23. Survey votes for self-identified as Chinese-American or Chinese (online only)

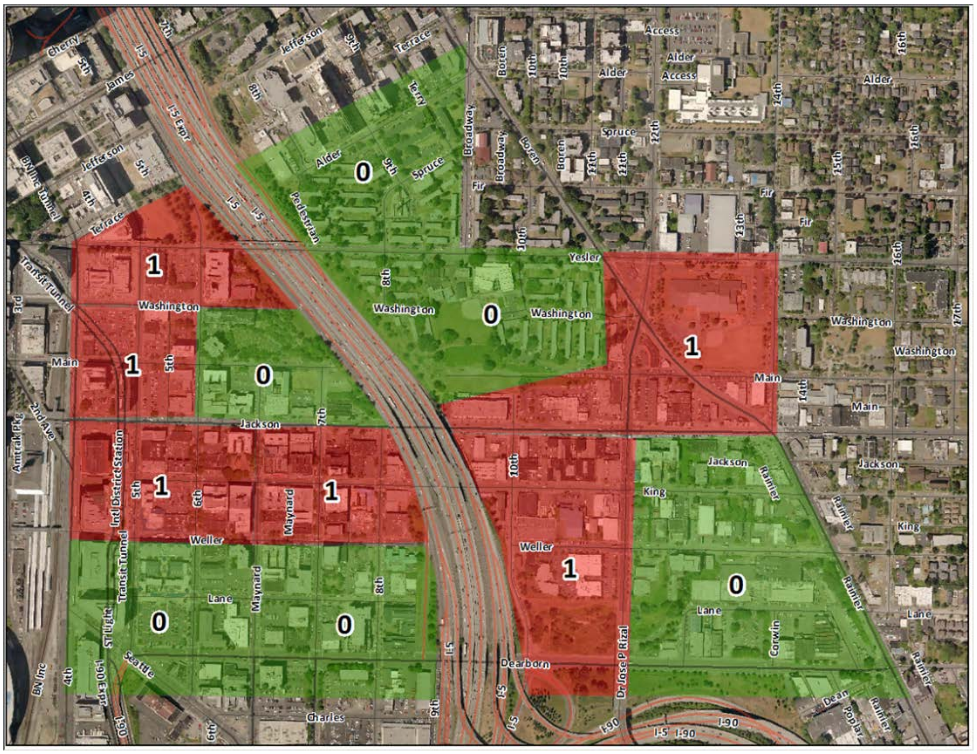


Figure E-24. Survey participant votes of self-identified as Filipino (online survey only)

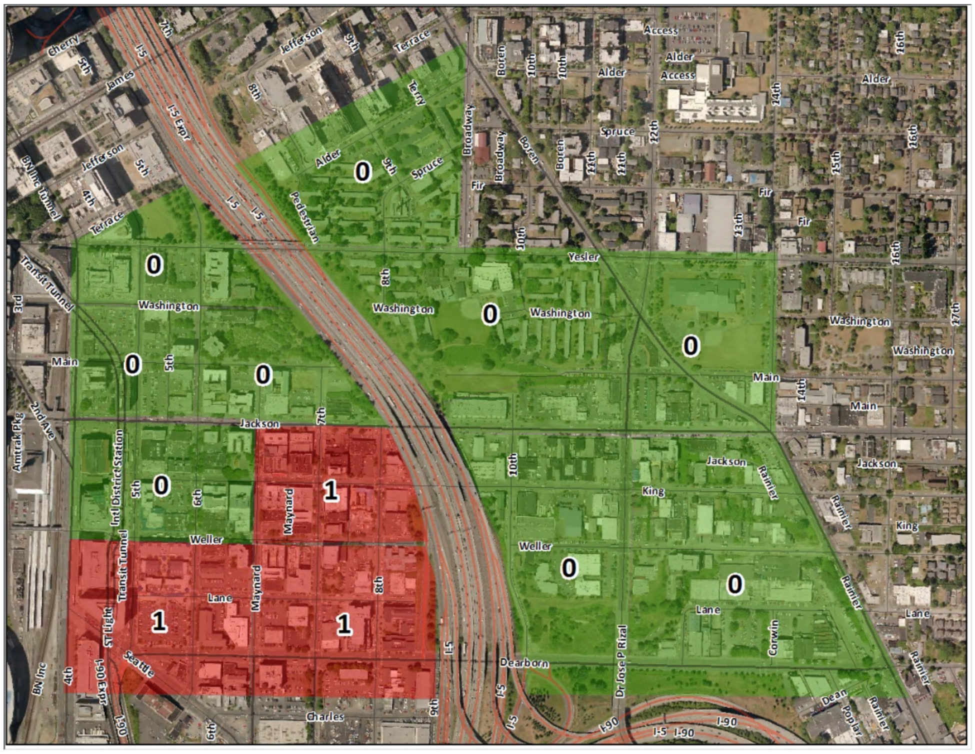


Figure E-25. Survey votes for self-identified as American Indian or Alaska Native (online only)

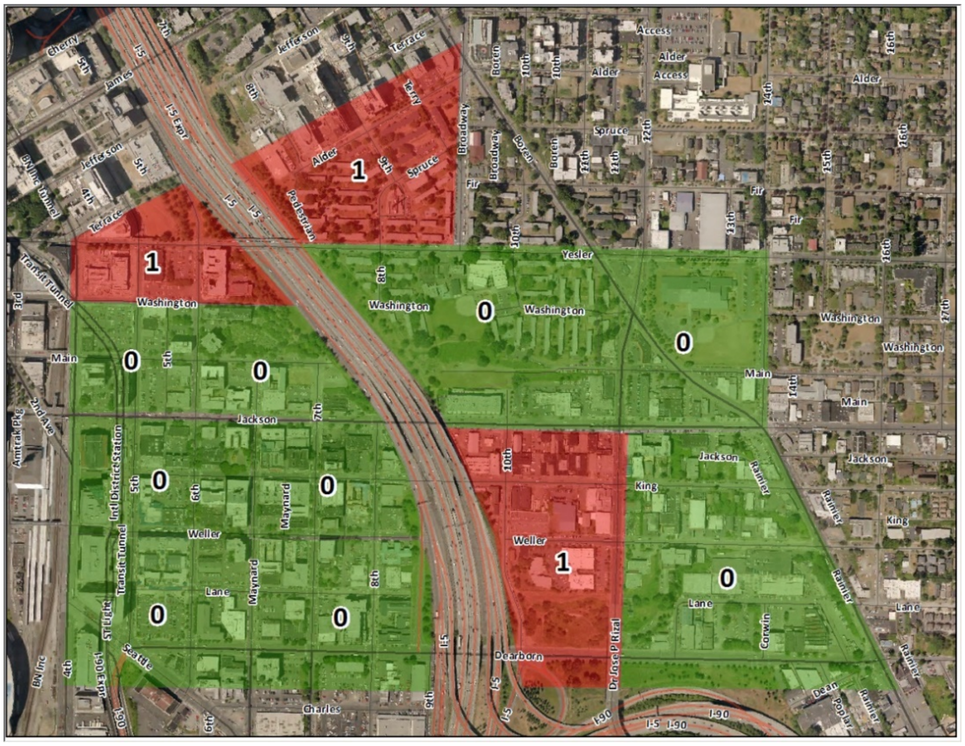


Figure E-26. Survey participant votes of self-identified as Latino or Hispanic (online survey only)

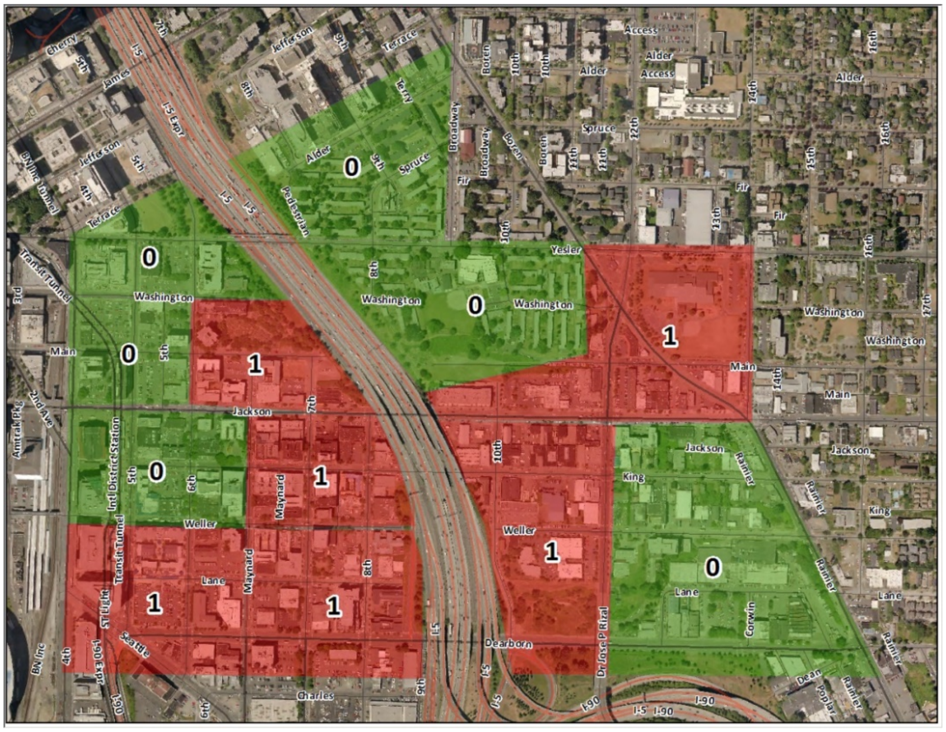


Figure E-27. Survey participant votes of self-identified as mixed (online survey only)

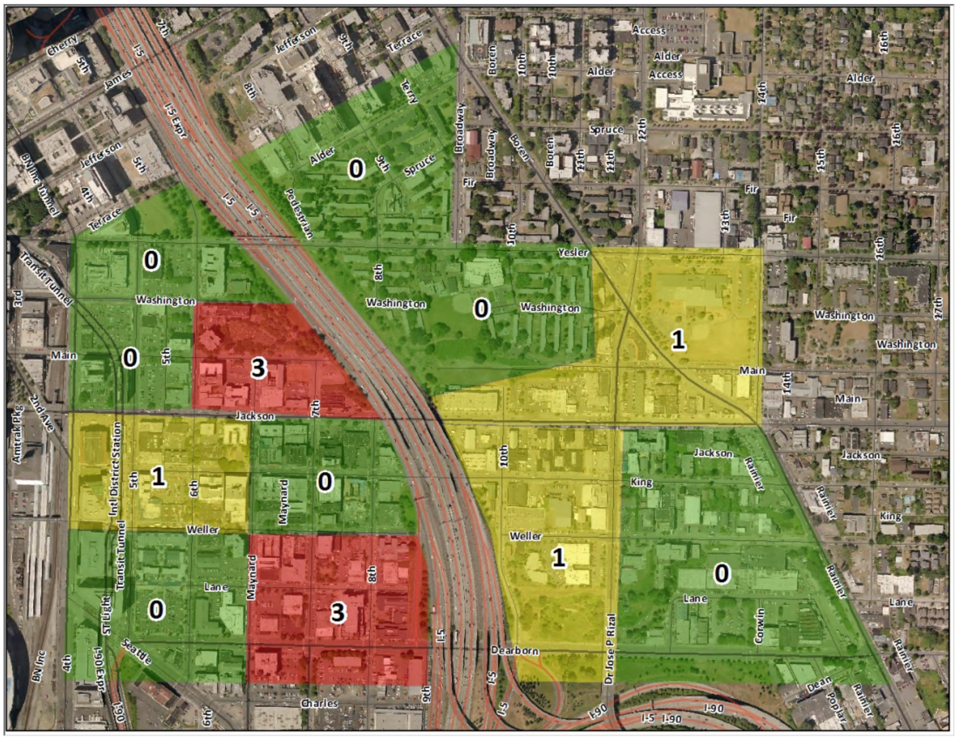
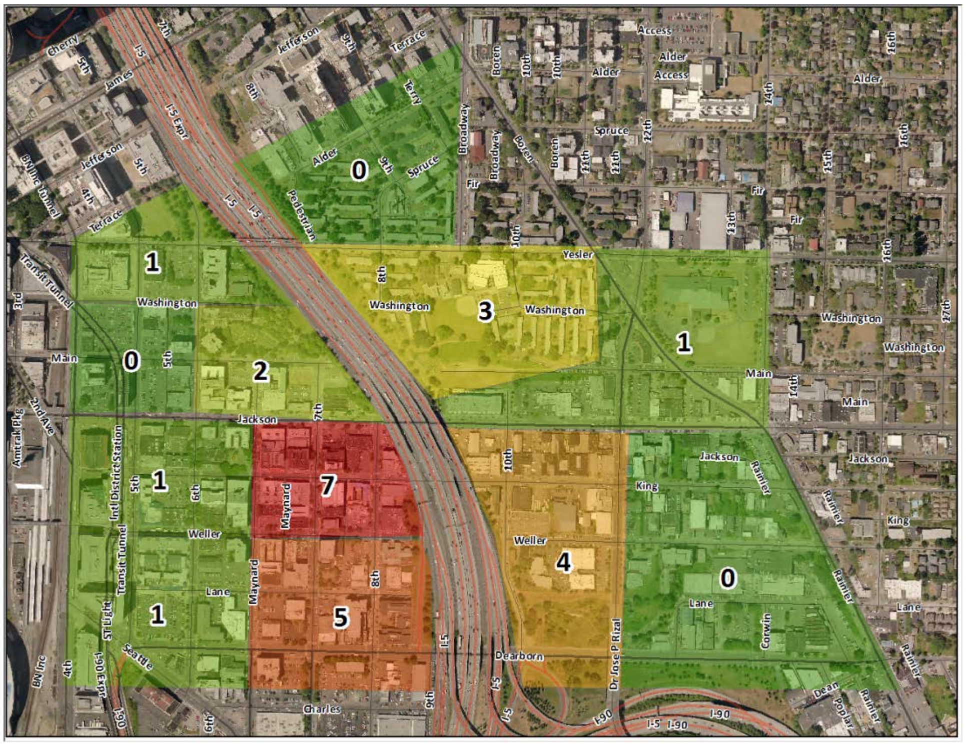


Figure E-28. Survey participant votes of self-identified as white (online survey only)



Appendix F. Community-directed sampling results

Box plots and Maps

Figure F-1. Box plots key

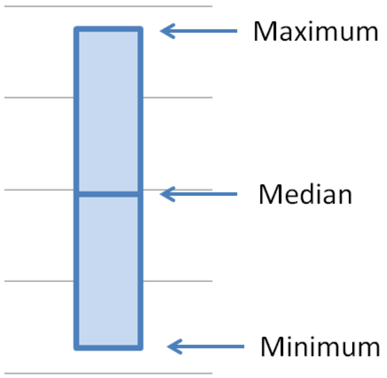
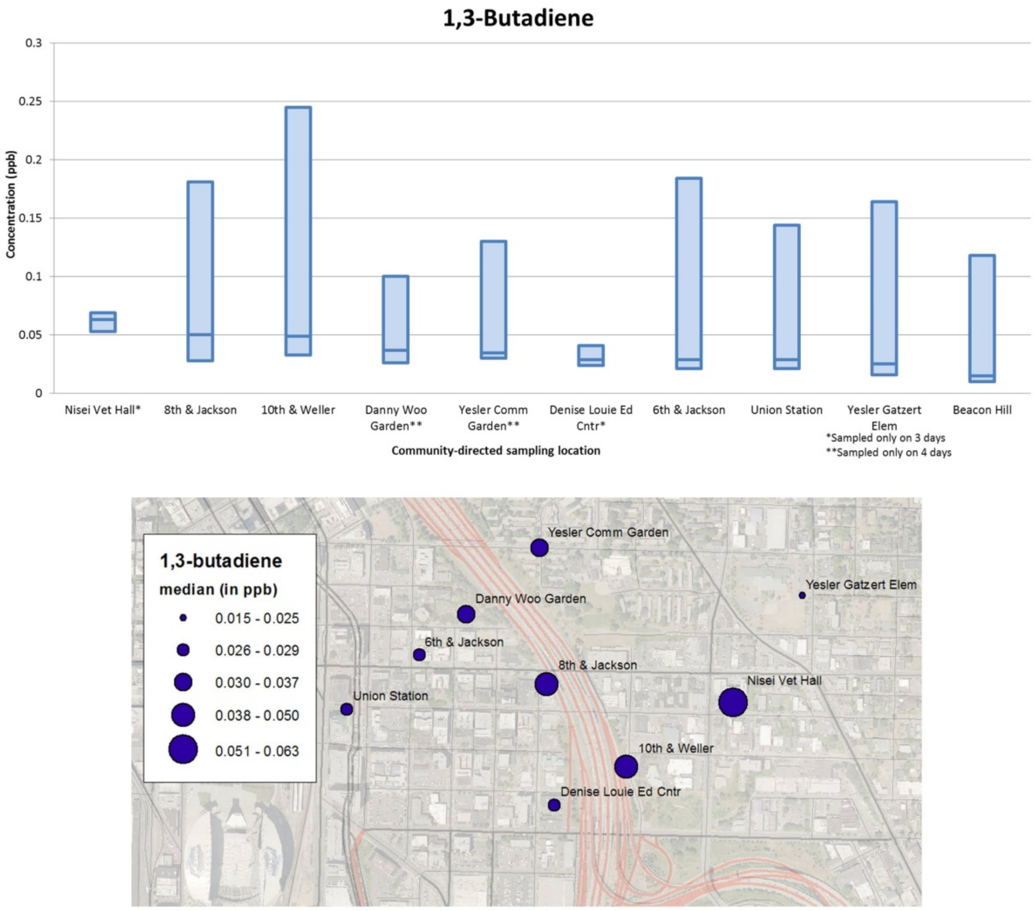


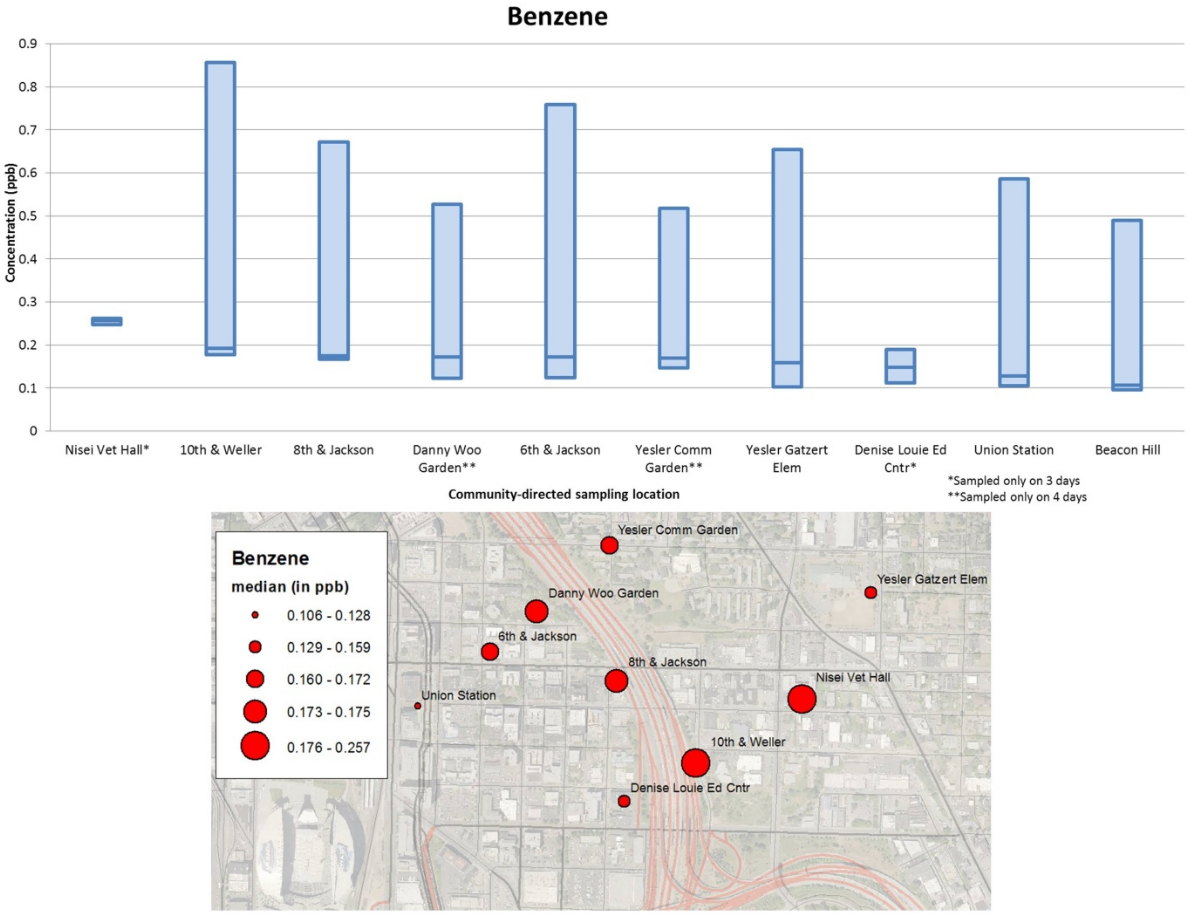
Figure F-2. 1,3-butadiene and map with relative median comparison



*Sampled only on 3 days

**Sampled only on 4 days

Figure F-3. Benzene and map with relative median comparison



*Sampled only on 3 days
**Sampled only on 4 days

Figure F-4. Acrolein and map with relative median comparison

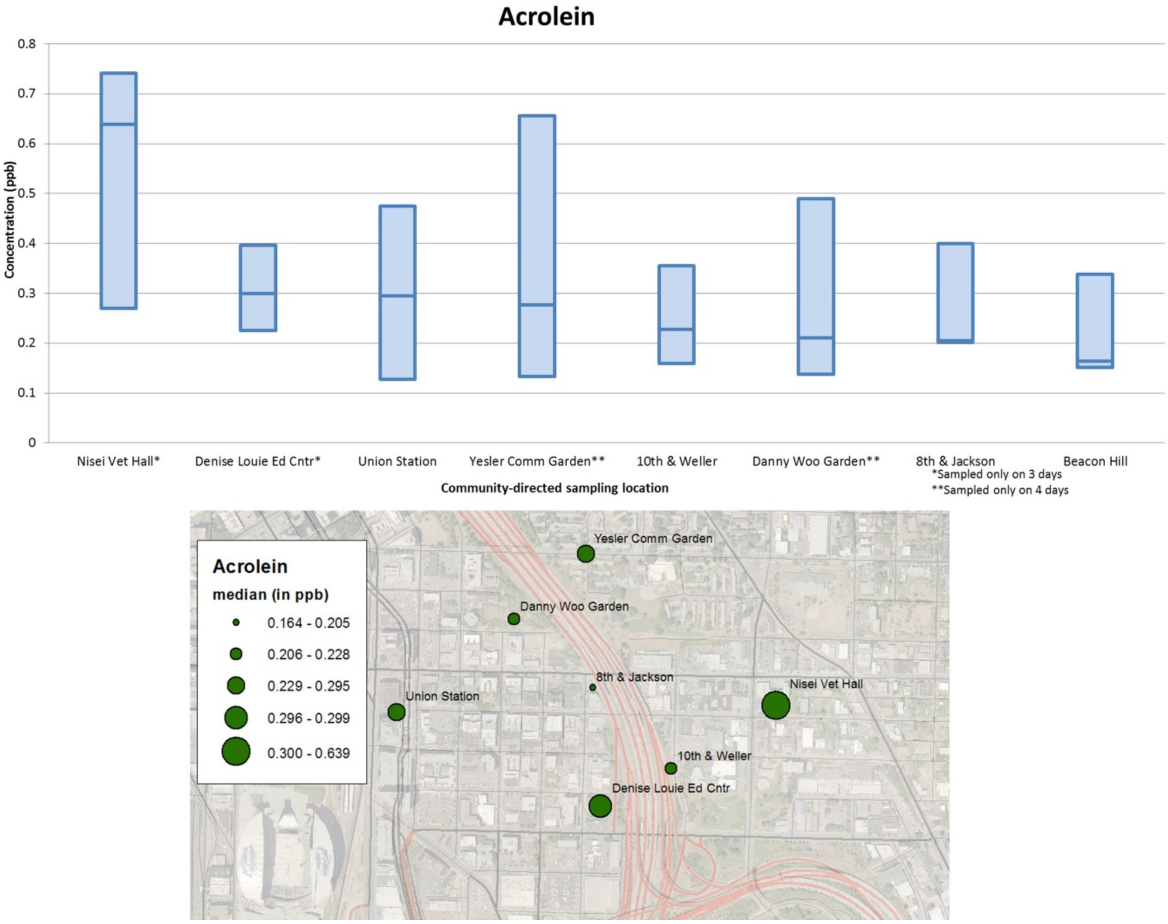


Figure F-5. Carbon tetrachloride and map with relative median comparison

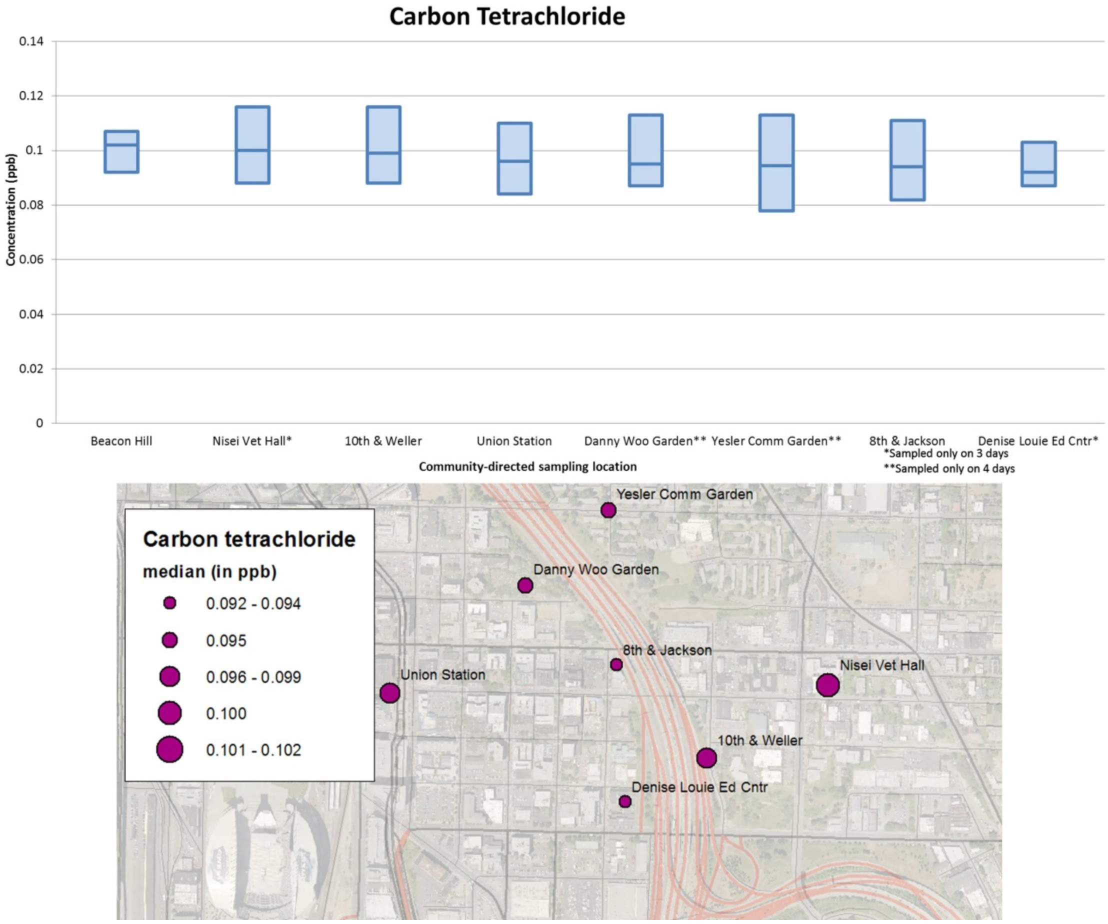


Figure F-6. Chloroform and map with relative median comparison

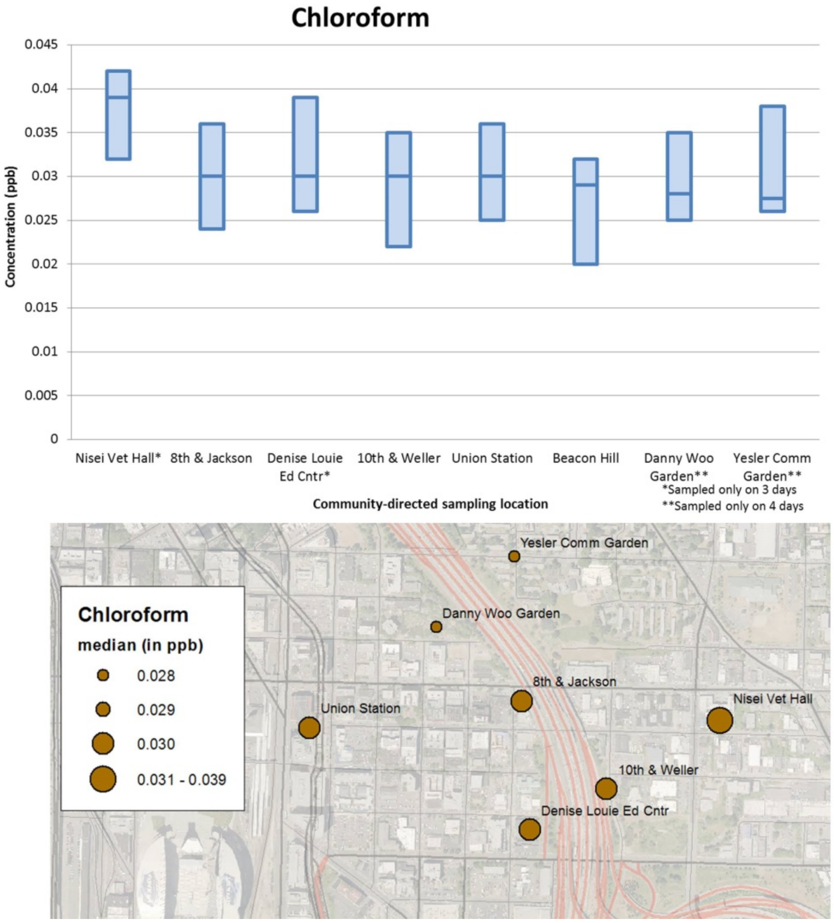
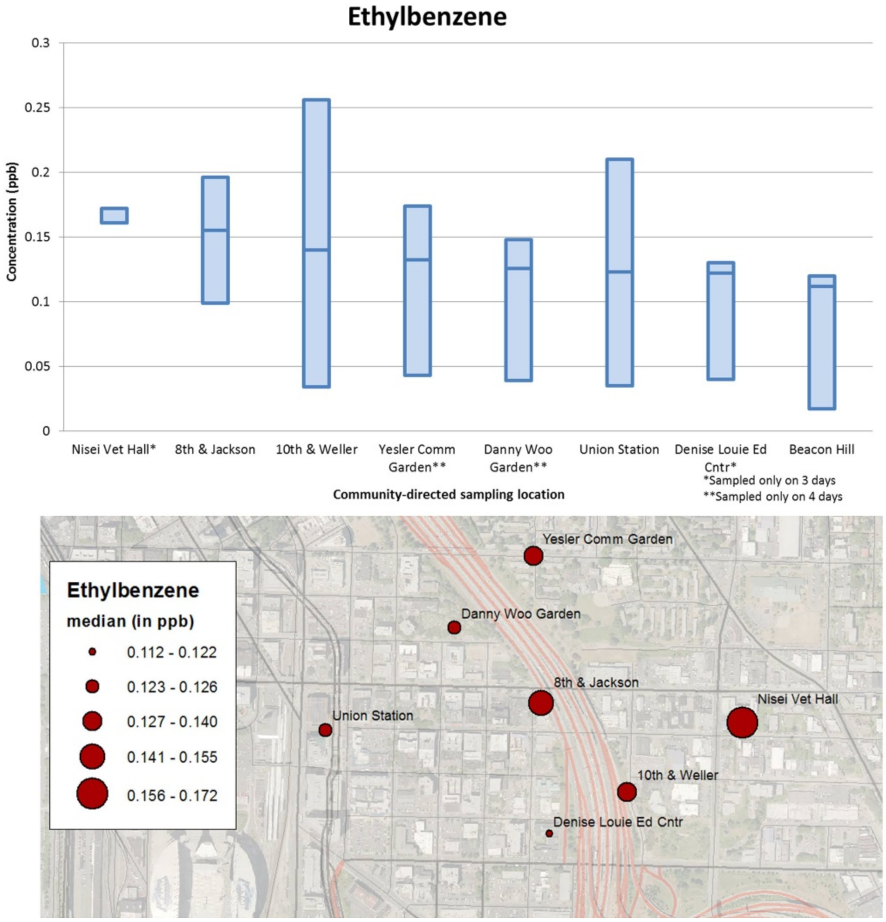


Figure F-7. Ethylbenzene and map with relative median comparison



*Sampled only on 3 days
**Sampled only on 4 days

Figure F-8. Tetrachloroethylene and map with relative median comparison

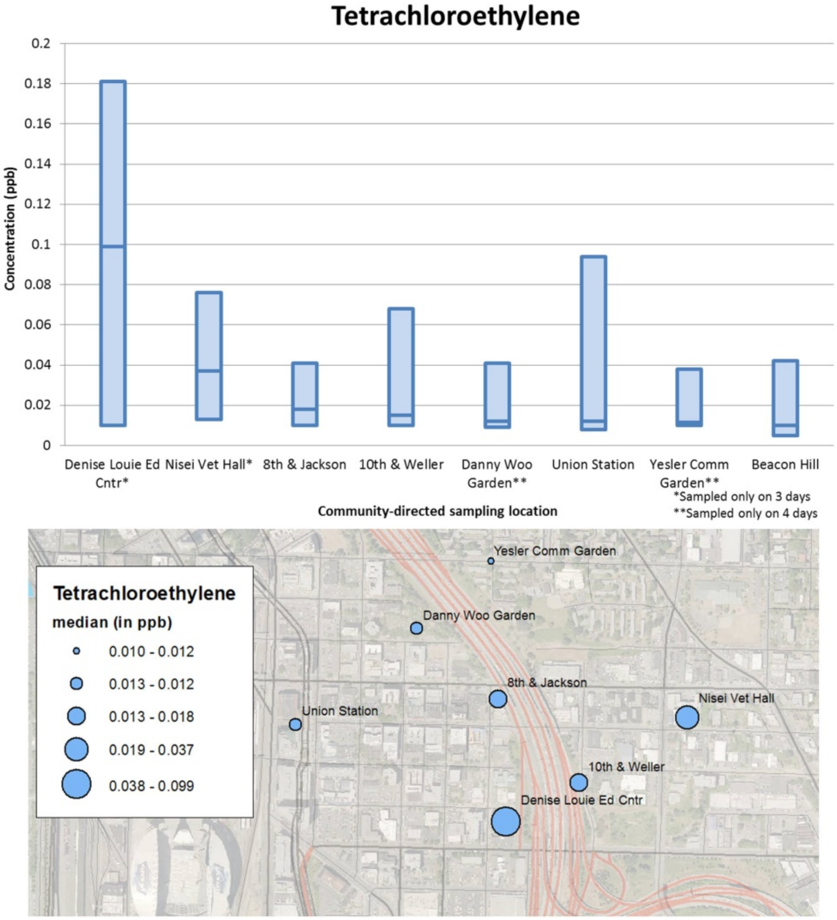


Table F-1. Sites and distances to I-5.

Site	Distance in meters
10th & Weller	51
8th & Jackson	61
Danny Woo Garden	114
Denise Louie Ed Cntr	124
8th & Yesler	149
6th & Jackson	273
Nisei Vet Hall	342
Union Station	554
Beacon Hill	567
Bailey Gatzert	663

Figure F-9. Median site concentrations for 1,3-butadiene vs distance to I-5.

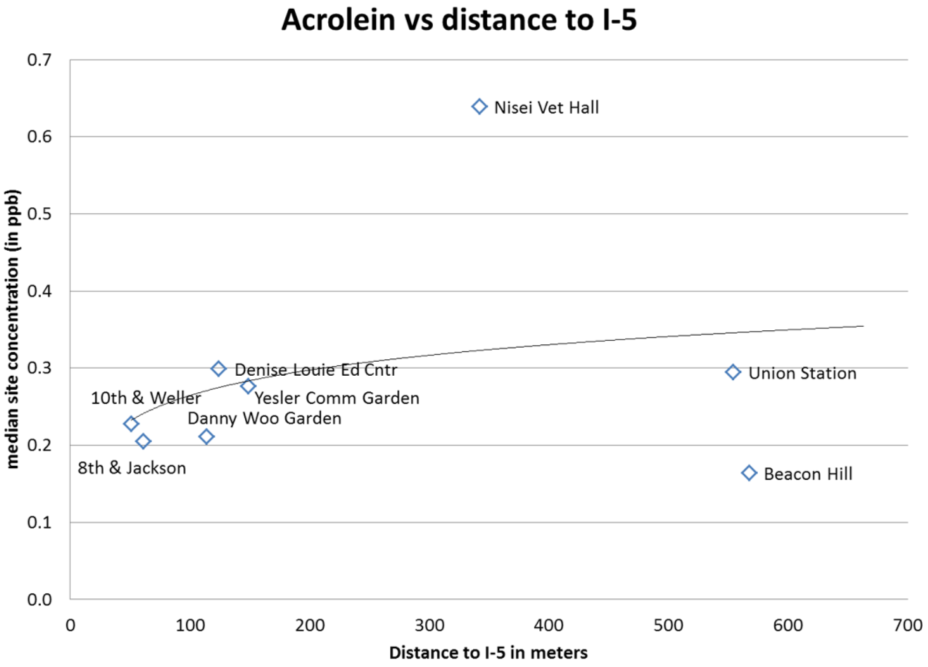


Figure F-10. Median site concentrations for carbon tetrachloride vs distance to I-5.

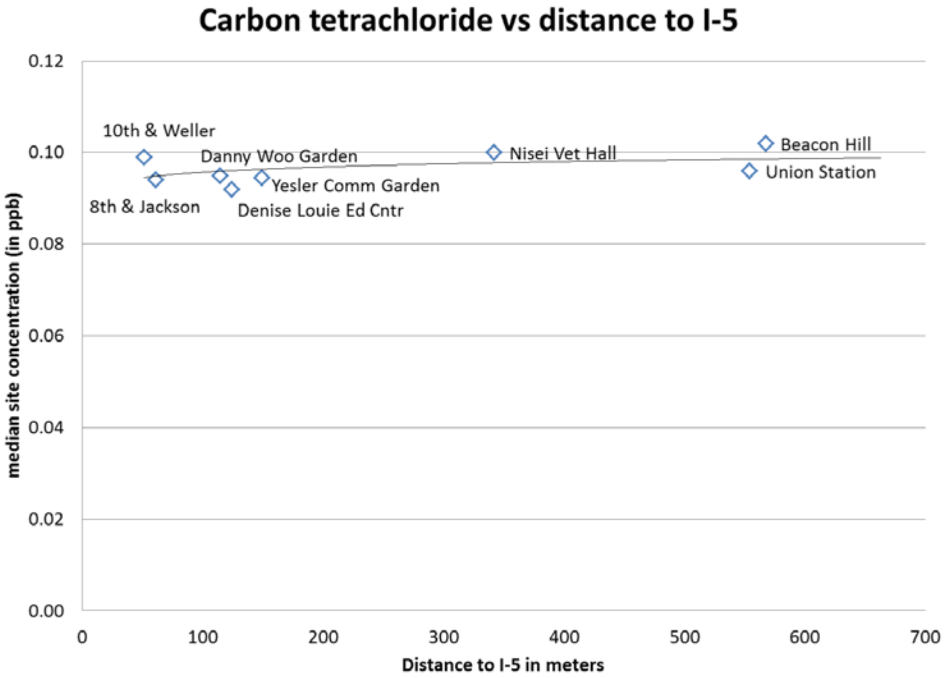


Figure F-11. Median site concentrations for chloroform vs distance to I-5.

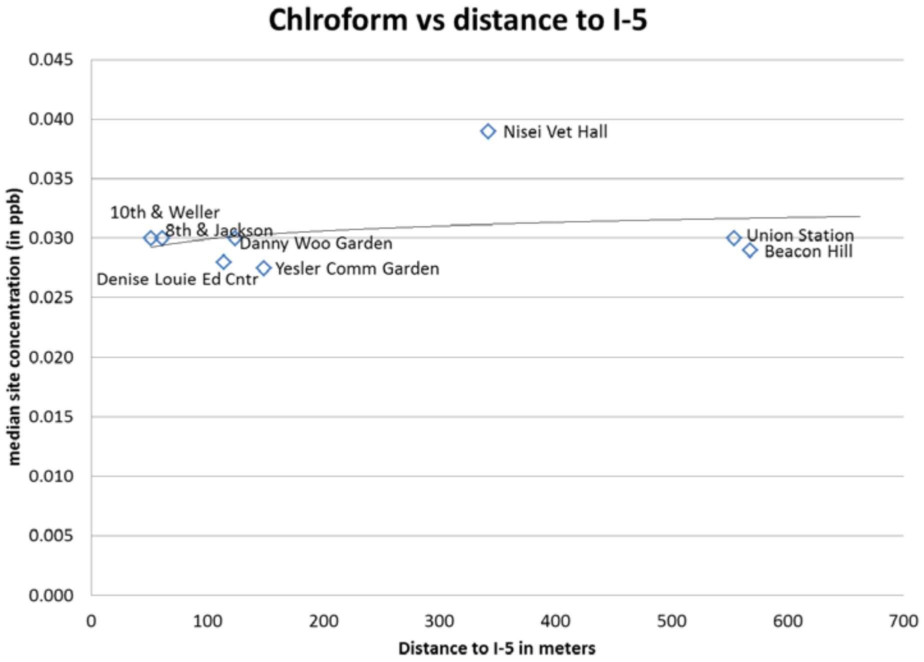


Figure F-12. Median site concentrations for ethylbenzene vs distance to I-5.

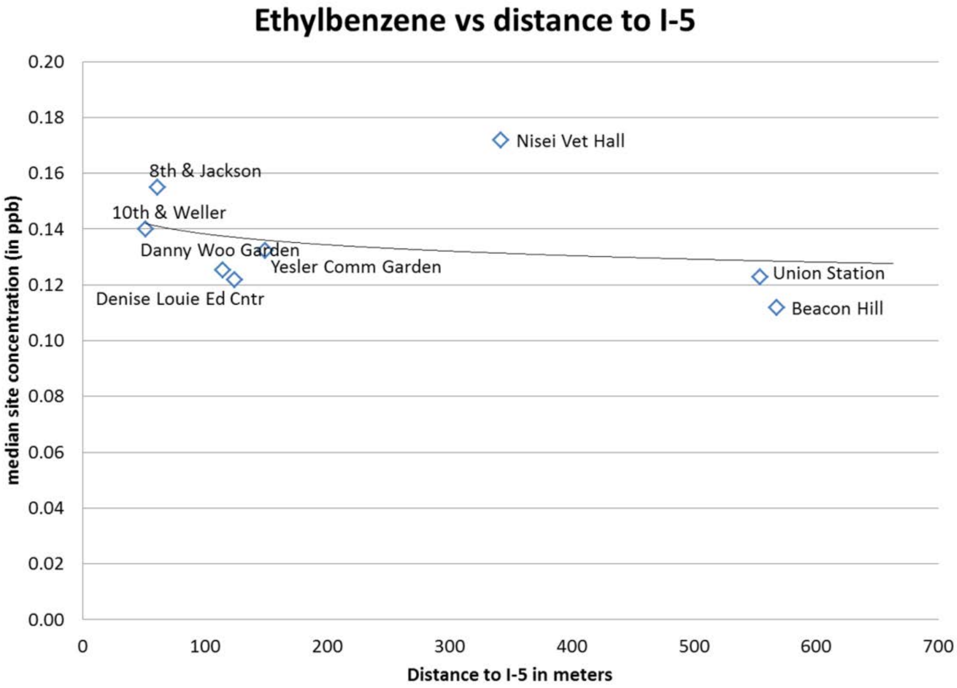
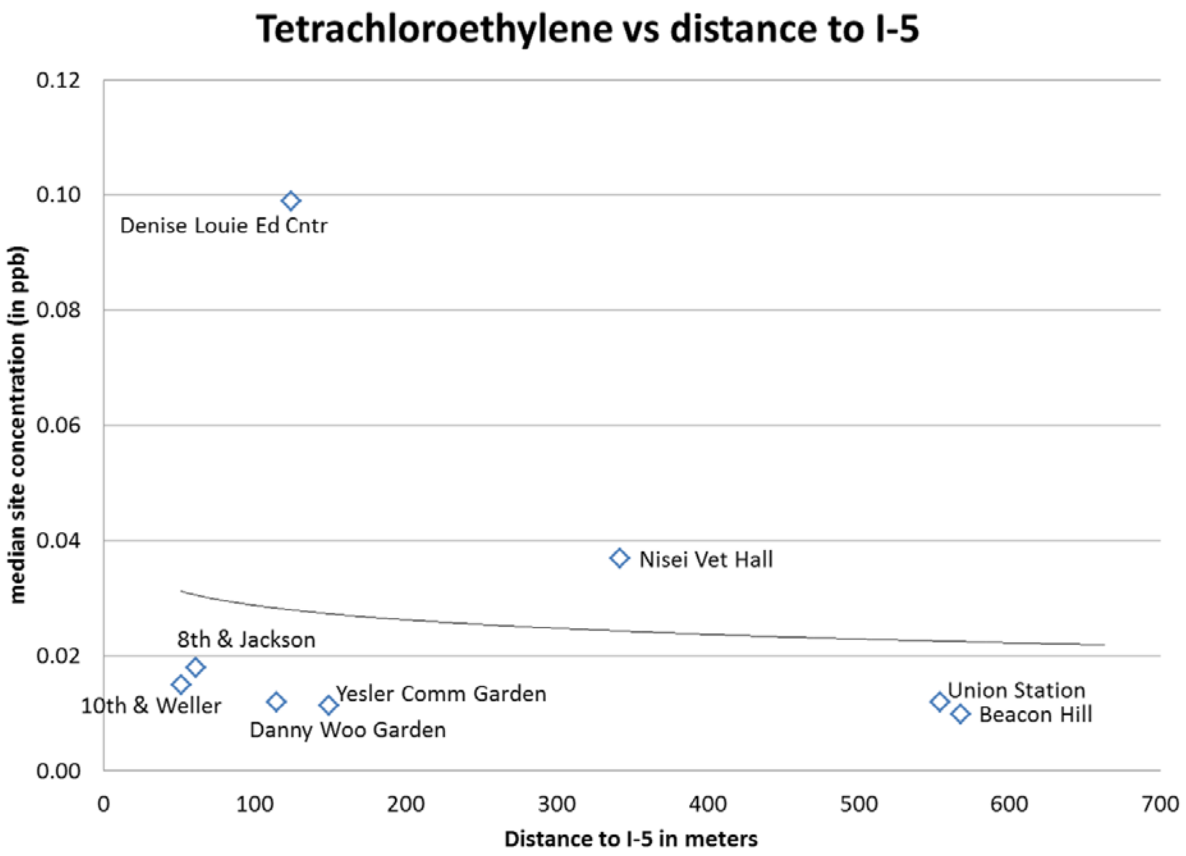


Figure F-13. Median site concentrations for tetrachloroethylene vs distance to I-5.



Appendix G. Historical Beacon Hill trends

Figure G-1. Carbon Tetrachloride Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

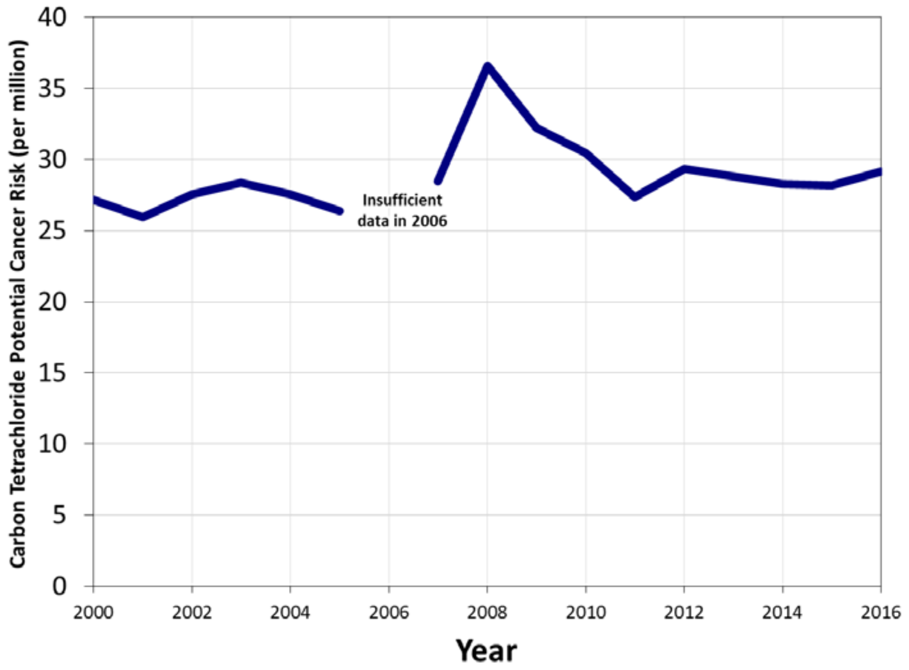


Figure G-2. Benzene Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

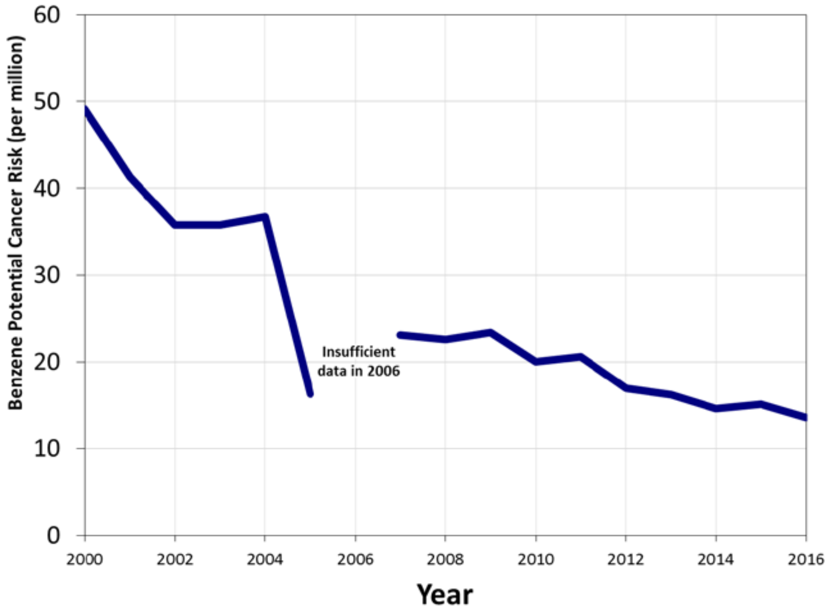


Figure G-3. 1,3-butadiene Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

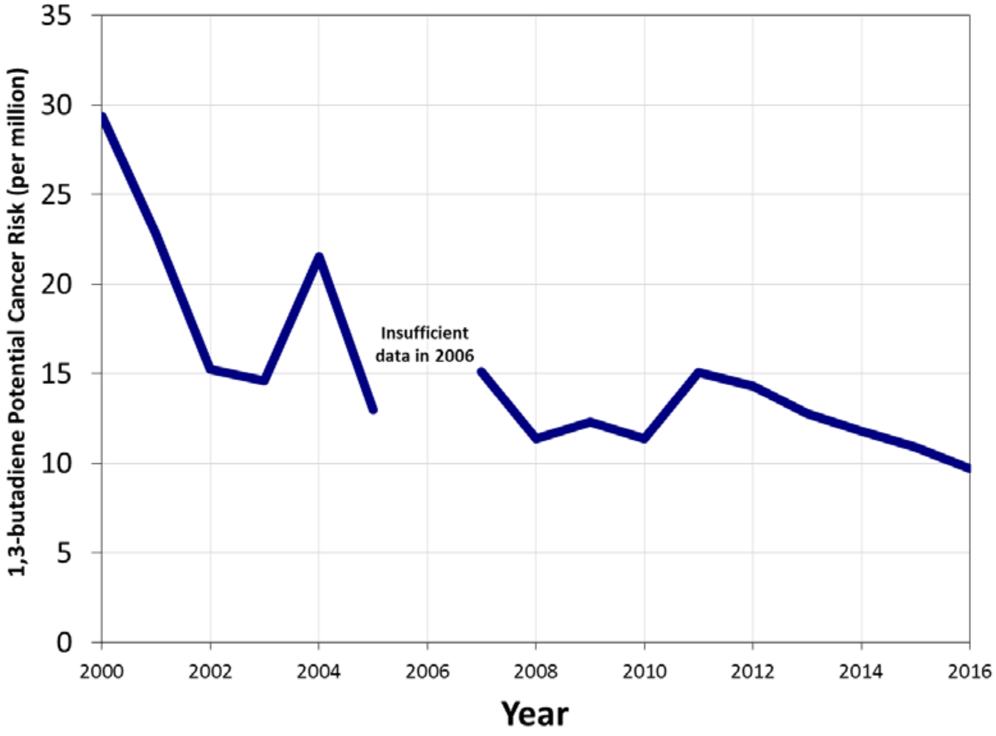


Figure G 4. Formaldehyde Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

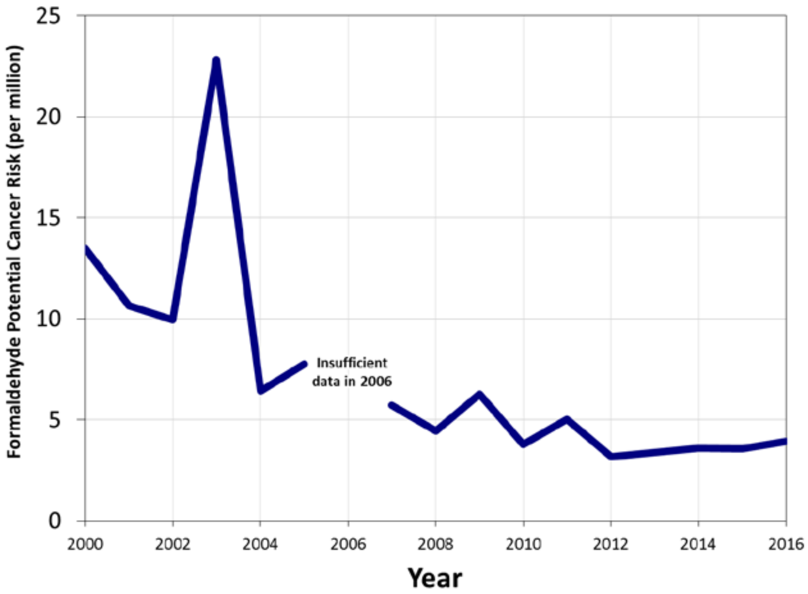


Figure G-5. Chloroform Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

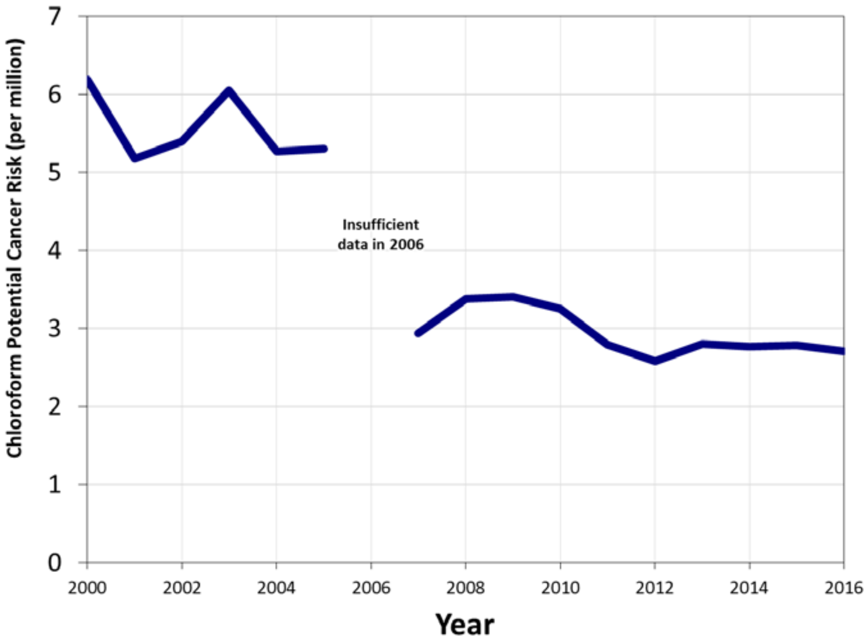


Figure G-6. Acetaldehyde Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

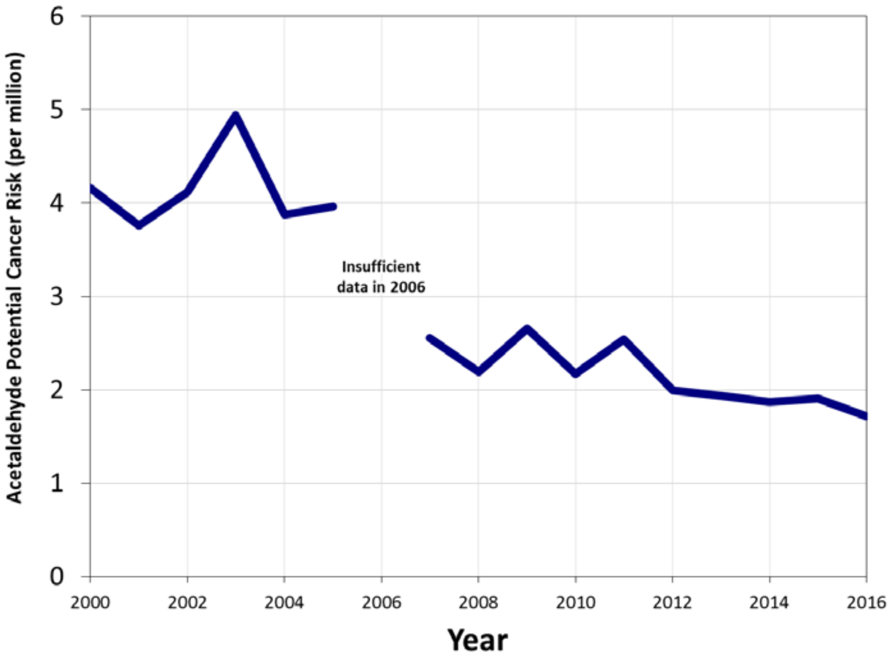


Figure G-7. Arsenic Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

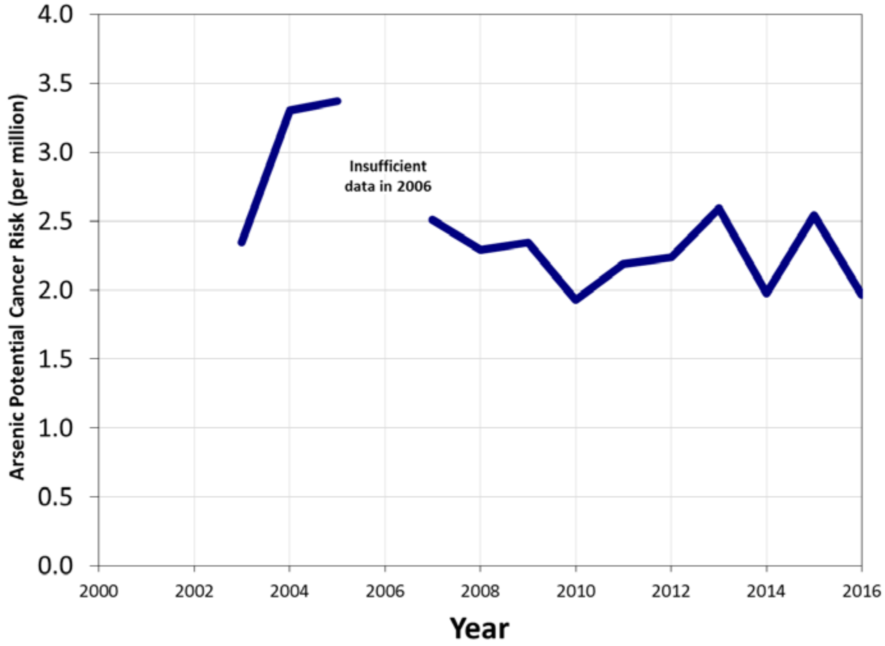


Figure G-8. Naphthalene Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

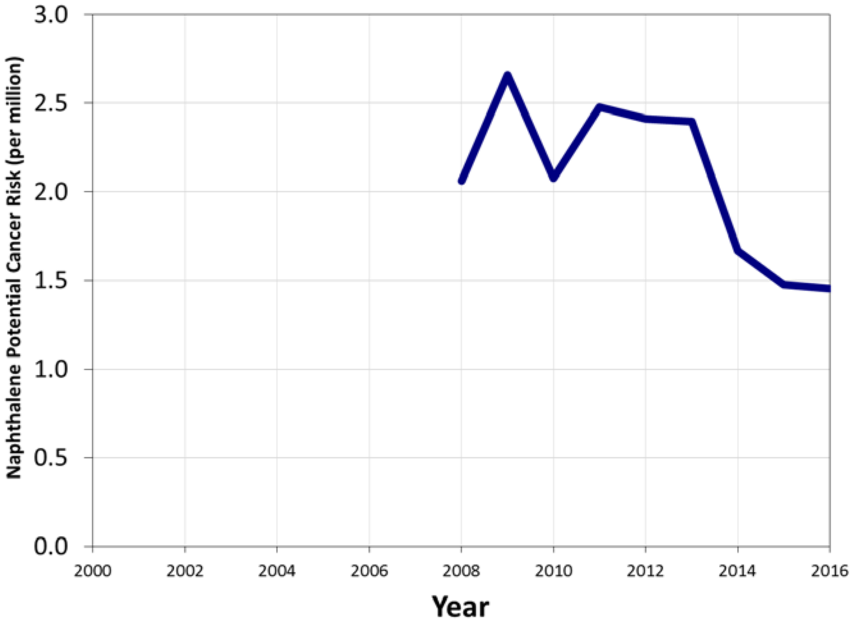


Figure G-9. Ethylbenzene Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

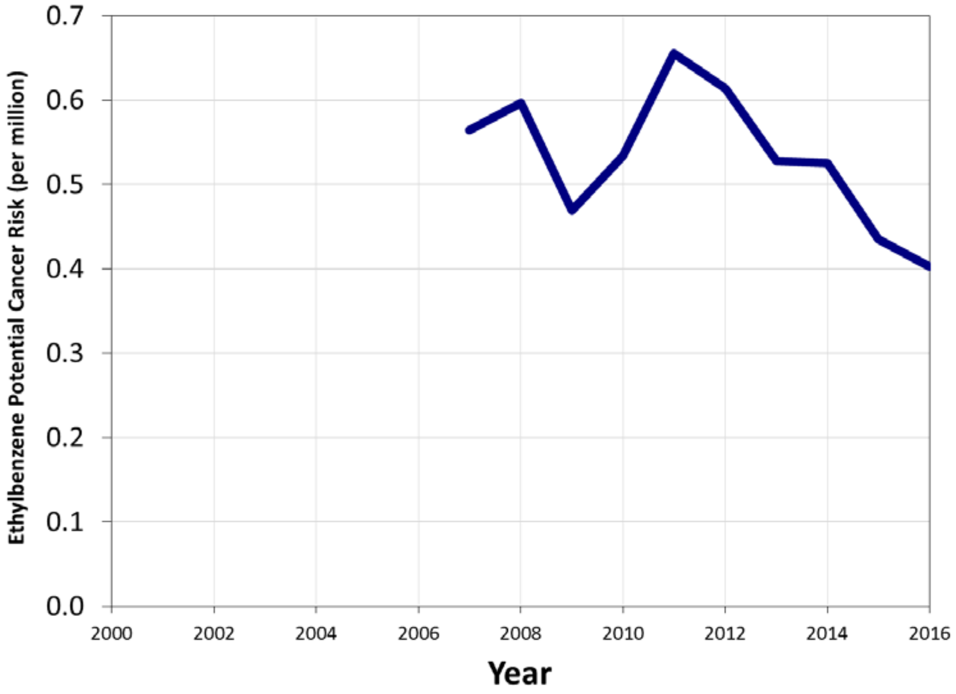


Figure G-10. Nickel Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016

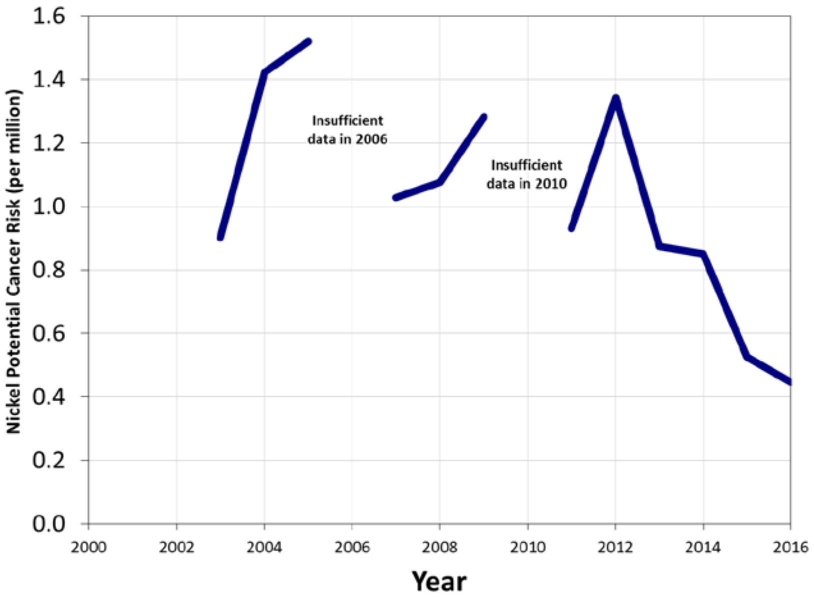
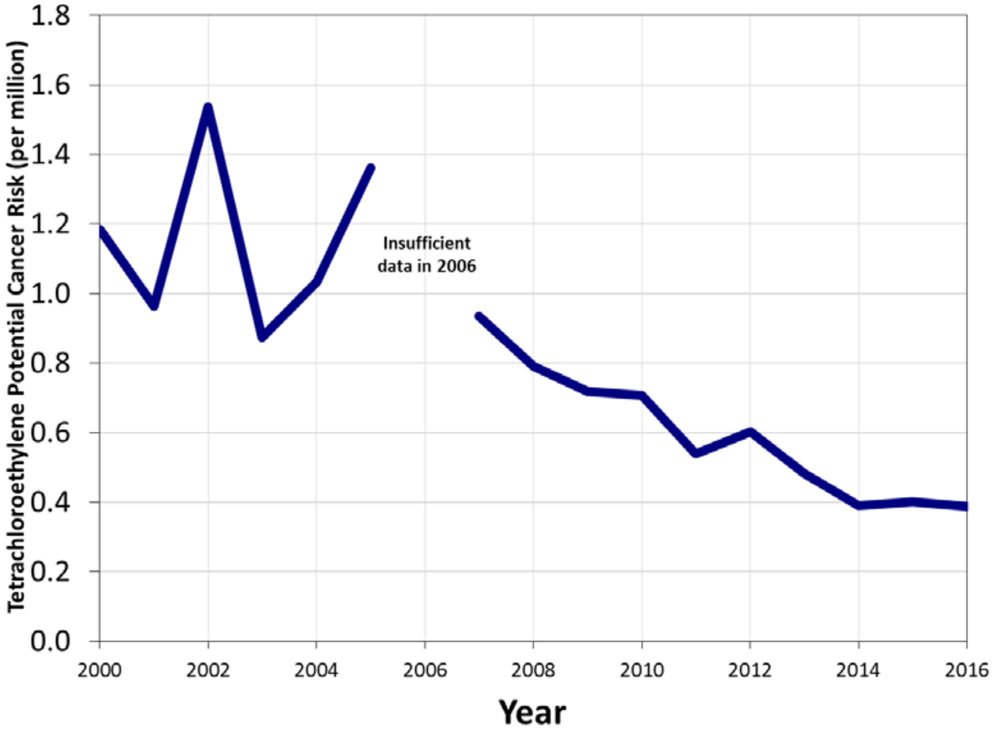


Figure G-11. Tetrachloroethylene Annual Average Potential Cancer Risk at Beacon Hill, 2000-2016



Appendix H. Quality Assurance Project Plan

The Quality Assurance Project Plan followed in this study, and that was approved by EPA in August 2016, is available upon request.