# 2020 Washington State Ambient Air Monitoring Network Assessment

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# 2020 Washington State Ambient Air Monitoring Network Assessment

Air Quality Program

Washington State Department of Ecology

Olympia, Washington

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# Acknowledgements

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- Ranil Dhammapala, Author
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# Acronyms

| | |
|---|---|
| AQS | EPA's Air Quality System database |
| BAM | Beta Attenuation Monitor |
| BCAA | Benton Clean Air Agency |
| CBSA | Core-Based Statistical Area |
| CFR | Code of Federal Regulations |
| CO | Carbon Monoxide |
| CSA | Combined Statistical Area |
| CSN | Chemical Speciation Network |
| DV | Design Value |
| Ecology | Washington State Department of Ecology |
| EPA | U.S. Environmental Protection Agency |
| FEM | Federal Equivalent Method |
| FRM | Federal Reference Method |
| IMPROVE | Interagency Monitoring of Protected Visual Environments |
| MSA | Metropolitan Statistical Area |
| NAAQS | National Ambient Air Quality Standard |
| NATTS | National Air Toxics Trends Station |
| NCore | National Core |
| NO | Nitrogen Oxide |
| $NO_2$ | Nitrogen Dioxide |
| $NO_X$ | Oxides of Nitrogen |
| $NO_y$ | Total Reactive Oxides of Nitrogen |
| NWCAA | Northwest Clean Air Agency |
| $O_3$ | Ozone |
| ORCAA | Olympic Region Clean Air Agency |
| Pb | Lead |
| $PM_{2.5}$ | Particulate matter $\leq$ 2.5 micrometers in diameter |
| $PM_{10}$ | Particulate matter $\leq$ 10 micrometer in diameter |
| $PM_{10\text{-}2.5}$ | Particulate matter $\leq$10 microns and > 2.5 micrometers in diameter |
| ppb | parts per billion |
| ppm | parts per million |
| PAMS | Photochemical Assessment Monitoring Station |
| PQAO | Primary Quality Assurance Organization |
| PSCAA | Puget Sound Clean Air Agency |
| PSD | Prevention of Significant Deterioration |
| QA | Quality Assurance |
| QA | Quality Control |
| SLAMS | State and Local Air Monitoring Station |
| $SO_2$ | Sulfur Dioxide |
| SPMS | Special Purpose Monitoring Site |
| SRCAA | Spokane Regional Clean Air Agency |
| SWCAA | Southwest Clean Air Agency |
| STN | Speciation Trends Network |
| TSP | Total Suspended Particulate |
| $\mu g/m^3$ | micrograms per cubic meter |
| VOCs | Volatile Organic Compounds |
| YRCAA | Yakima Regional Clean Air Agency |

# Executive Summary

This document describes the Washington State Department of Ecology's (Ecology's) 2020 Ambient Air Monitoring Network Assessment. On October 17, 2006, EPA amended its ambient air monitoring regulations to require states to conduct detailed assessments of their monitoring networks every five years. The purpose of the 5-year network assessment is to evaluate the effectiveness and efficiency of monitoring networks in accordance with stated monitoring objectives and goals. This is the third 5-year network assessment Ecology has prepared and covers years 2015-2019.

## Purpose

The primary goal of the Washington Ambient Air Monitoring Network (Washington Network) is to characterize air quality in Washington for public health protection. The Washington Network was designed to meet three objectives in support of this goal:

1. Provide air pollution data to the public in a timely manner
2. Support compliance with National Ambient Air Quality Standards (NAAQS) and development of pollution control strategies
3. Support air pollution research

In this assessment, Ecology evaluated the effectiveness and efficiency of the Washington Network in meeting this goal and these objectives. This assessment ensures Ecology and its partners have the information needed to protect human health and the environment for current and future generations in Washington.

## Washington Network Overview

On January 1, 2020, Ecology and its partners operated 75 monitoring sites that were part of the Washington Network. Most of the Washington Network is dedicated to characterizing the two pollutants that have been shown to pose the greatest risk to public health in Washington: fine particulate matter ($PM_{2.5}$) and ozone ($O_3$). The remainder of the network is made up of monitors that measure larger particles ($PM_{10}$), carbon monoxide (CO), sulfur dioxide ($SO_2$), oxides of nitrogen ($NO_x$ and $NO_y$), fine particle chemical composition, air toxics, and meteorological parameters.

## Findings and Recommendations

Overall, the Washington Network is efficient and effective at meeting the monitoring objectives and at providing reliable and high-quality information about air quality conditions to public agencies, researchers, the general public and other data users. Wholesale network changes were found to be unnecessary.

Ecology is particularly cautious about recommending the removal of monitors in this assessment based on the aftermath of network reductions recommended in previous assessments. Ecology removed the Burbank $PM_{10}$ monitoring site in 2012 based on the recommendations in the 2010 Network Assessment. This site was reinstated in 2017 due to the need for representative $PM_{10}$ monitoring in the Wallula Maintenance Area. Based on the recommendations in the 2015 Network Assessment, Ecology removed the Tulalip $PM_{2.5}$ monitoring site. $PM_{2.5}$ monitoring was then reinstated in Tulalip in 2019, as local community monitoring was identified as a priority by EPA Region 10 and the Tulalip Tribes. Since removing and reinstating monitoring sites is much more costly and labor-intensive that continued operations, Ecology is wary of recommending any sites for removal that may need monitoring in the future.

Network summaries and targeted network improvements were identified for the following parameters:

## Ozone

- Ecology ranked the value of the Washington Network ozone monitoring sites using a decision matrix that captured concentrations measured, exceedances and violation risk, and populations represented. The top-scoring sites were those downwind of urban areas that routinely record elevated concentrations (Kennewick and Enumclaw).
- No sites are recommended for removal.

## $PM_{2.5}$

- Ecology ranked the value of the Washington Network $PM_{2.5}$ monitoring sites using a decision matrix that captured concentrations measured, populations and geographic areas represented, and nearby sources. The top-scoring sites were largely located in populated areas impacted by residential wood combustion in the winter (e.g. Marysville, Vancouver, Spokane, Tacoma, and several sites in the Yakima Valley).
- No sites are recommended for removal.
- Expanded use of low-cost $PM_{2.5}$ sensors is recommended in unmonitored areas impacted by smoke from wildfires and prescribed burns. Low-cost $PM_{2.5}$ sensors are also recommended as a survey tool in other unmonitored areas. At Washington Network sites that lack $PM_{2.5}$ monitoring, the addition of $PM_{2.5}$ sensors is recommended in order to alleviate communication challenges during wildfires. Expanded use of $PM_{2.5}$ sensors can only be implemented after development of:
    - bias-correction methods appropriate for the region, season and sensor model;
    - appropriate quality control and quality assurance procedures for sensor deployments; and

  - communication materials to convey key messages about data correction and uncertainty in sensor data.

- Two existing temporary $PM_{2.5}$ monitoring sites (White Salmon and Pomeroy) were found to provide valuable local $PM_{2.5}$ data and ongoing utility for smoke management in their areas. An evaluation of options for continued monitoring in these areas, including use of low-cost $PM_{2.5}$ sensors, is recommended.

## Meteorological

- The Tacoma-Tower Dr meteorological monitoring site was identified as a low priority, and evaluating resource savings that would be achieved by discontinuing the site is recommended. In previous years, the site was used by forecasters to understand regional airflow and regional ozone conditions around central Puget Sound. However, high resolution models have taken the place of this data source in recent years, and Ecology and PSCAA staff surveyed in 2020 did not rely upon the site for permitting or forecasting needs.

## Chemical Speciation Network

- Ecology conducted a source apportionment analysis for its four current $PM_{2.5}$ Chemical Speciation Network sites that have at least three years of data. Identified sources included combustion, sulfate- and nitrate-rich $PM_{2.5}$, and wood smoke, as well as biogenic sources such as sea salt and crustal elements. Five-year trends suggest an increase in $PM_{2.5}$ from gasoline vehicle emissions and a decrease in $PM_{2.5}$ from marine fuel oil.

- The highest correlations between $PM_{2.5}$ sources were found between the Seattle-Beacon Hill and Seattle-10$^{th}$ & Weller monitoring sites. Given the proximity of these two Seattle sites as well as the similarity in observed $PM_{2.5}$ sources, Ecology recommends discontinuing Seattle-10$^{th}$ & Weller. Given that Yakima $PM_{2.5}$ sources are poorly correlated with sources identified in Tacoma and Seattle, Ecology recommends relocating the Seattle-10$^{th}$ & Weller chemical speciation monitoring site to eastern or central Washington to further characterize $PM_{2.5}$ sources in those regions.

# Introduction

On October 17, 2006, EPA amended its ambient air monitoring regulations to require states to conduct detailed assessments of their monitoring networks every five years. The purpose of the 5-year network assessment is to evaluate the effectiveness and efficiency of monitoring networks in accordance with stated monitoring objectives and goals. This is the third 5-year network assessment the Washington Department of Ecology (Ecology) has prepared and covers years 2015-2019.

To meet the network assessment requirement, Ecology assembled a staff team with expertise in the following areas:

- Monitoring
- Quality assurance
- Data analysis
- Modeling
- Policy and planning
- Smoke management
- Permitting

This assessment was conducted in general accordance with EPA guidance on monitoring network assessments. However, Ecology deviated from EPA guidance when more robust analysis methods were available and when analytic approaches tailored to Washington's unique geography were more appropriate than national recommendations.

This document is intended to provide decision-makers with the information needed to maximize the effectiveness of the Washington Ambient Air Monitoring Network (Washington Network) and serve as a guide for future network changes. In addition, the Findings and Recommendations section of this document identifies opportunities for overall improved network efficacy through specific, targeted modifications to Ecology's existing monitoring network. To the extent possible, any resource-savings achieved through these targeted monitoring reductions should be leveraged to address emergent monitoring needs such as the gaps in coverage identified in this document.

# Background

## Monitoring objectives

The Washington Network was designed to meet the three monitoring objectives defined in 40 C.F.R. Part 58 Appendix D:

1. **Provide air pollution data to the public in a timely manner.** Ecology provides timely air quality data to the public in a variety of ways, including:
    - Near-real-time data are available on Ecology's monitoring website.
    - Ecology conducts public outreach and issues alerts and bulletins when air quality is compromised.
2. **Support compliance with National Ambient Air Quality Standards (NAAQS) and development of pollution control strategies.** Ambient air quality data are used to:
    - Determine compliance with the NAAQS
    - Determine the location of maximum pollutant concentrations
    - Track the progress of SIPs
    - Determine the effectiveness of air pollution control programs
    - Develop responsible and cost-effective emission control strategies
    - Assist with permitting work
3. **Support air pollution research.** Ecology and its partners use ambient air quality data to improve our understanding of air pollution and its consequences. Research applications of air quality include:
    - Improving air quality forecasting
    - Evaluating the effects of air pollution on public health
    - Informing dispersion models
    - Identifying air quality trends and emerging pollution issues
    - Analyzing pollution episodes

In order to meet these three objectives, 40 C.F.R. Part 58 Appendix D calls for the design of SLAMS networks to include several different types of monitors. These general types are sites that:

1. Determine the highest pollutant concentrations expected in the area covered by the network.
2. Determine representative pollutant concentrations in areas of high population density.
3. Determine the impact of significant sources or source categories on pollutant concentrations in the ambient air.

4. Determine general background pollutant concentrations.
5. Determine the regional extent of pollutant transport between populated areas.
6. Determine the impacts on visibility or vegetation (welfare impacts) in more rural and remote areas.

Appendix D also provides guidance on spatial scales of representativeness for stations in a SLAMS network. Ideally, the station is located so that its sample represents the air quality across the scale that the station is intended to represent. Appendix D defines the following spatial scales:

1. **Microscale**: Area dimensions between several and 100 meters.
2. **Middle scale**: Areas between 100 and 500 meters, typically several city blocks.
3. **Neighborhood scale**: Areas between 0.5 and 4 kilometers with relatively uniform land use.
4. **Urban scale**: Areas with city-like dimensions between 4 and 50 kilometers. Urban and neighborhood scales can overlap considerably. Heterogeneous urban areas may not have a single representative site.
5. **Regional scale**: Areas from tens to hundreds of kilometers with relatively homogeneous geography and no large sources.
6. **National and global scales**: Scales representing the nation or globe as a whole.

Table 1 summarizes the appropriate spatial scales for each criteria pollutant and applicable site types.

**Table 1. Summary of applicable spatial scales for criteria pollutants and monitoring objectives**

| Scale | $SO_2$ | CO | $O_3$ | $NO_2$ | Pb | $PM_{10}$ | $PM_{2.5}$ | Site Types |
|---|---|---|---|---|---|---|---|---|
| **Micro** | ✓ | ✓ | | ✓ | ✓ | | ✓ | Highest concentration; source impact |
| **Middle** | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | Highest concentration; source impact |
| **Neighborhood** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Highest concentration; population; source impact; general/background |
| **Urban** | ✓ | | ✓ | ✓ | | | ✓ | Highest concentration; population; general/background; regional transport; welfare-related impacts |

| Scale | $SO_2$ | CO | $O_3$ | $NO_2$ | Pb | $PM_{10}$ | $PM_{2.5}$ | Site Types |
|---|---|---|---|---|---|---|---|---|
| **Regional** | ✓ | | ✓ | | | | ✓ | General/background; regional transport; welfare-related impacts |

# Monitoring Partners

Ecology is the Primary Quality Assurance Organization (PQAO) for the Washington Network, which is operated in partnership with a variety of local, tribal and federal agencies.

## Local Clean Air Agencies

- Benton Clean Air Agency
- Northwest Clean Air Agency
- Olympic Region Clean Air Agency
- Puget Sound Clean Air Agency
- Spokane Regional Clean Air Agency
- Southwest Clean Air Agency
- Yakima Regional Clean Air Agency

## Tribal Nations

- Makah Tribe
- Confederated Tribes of the Colville Reservation
- Quinault Indian Nation
- Spokane Tribe of Indians
- Tulalip Tribes
- Yakama Nation

## Federal Partners

- Environmental Protection Agency
- National Park Service

# Washington Core-Based Statistical Areas

The minimum monitoring requirements listed in 40 C.F.R. Part 58 Appendix D are based on the core-based statistical areas (CBSAs) defined by the U.S.  Office of Management and Budget.

Washington's CBSAs are shown in the map in Figure 1 (U.S. Census Bureau, 2013). Note that since publication of this map, Pend Oreille County has been removed from the Spokane-Spokane Valley MSA. Population estimates throughout this document are based on the latest available census figures in these CBSAs (2019 Annual Estimates of the Resident Population, U.S. Census Bureau, 2020). The populations of CBSAs in Washington over 50,000 people are listed in Table 2.

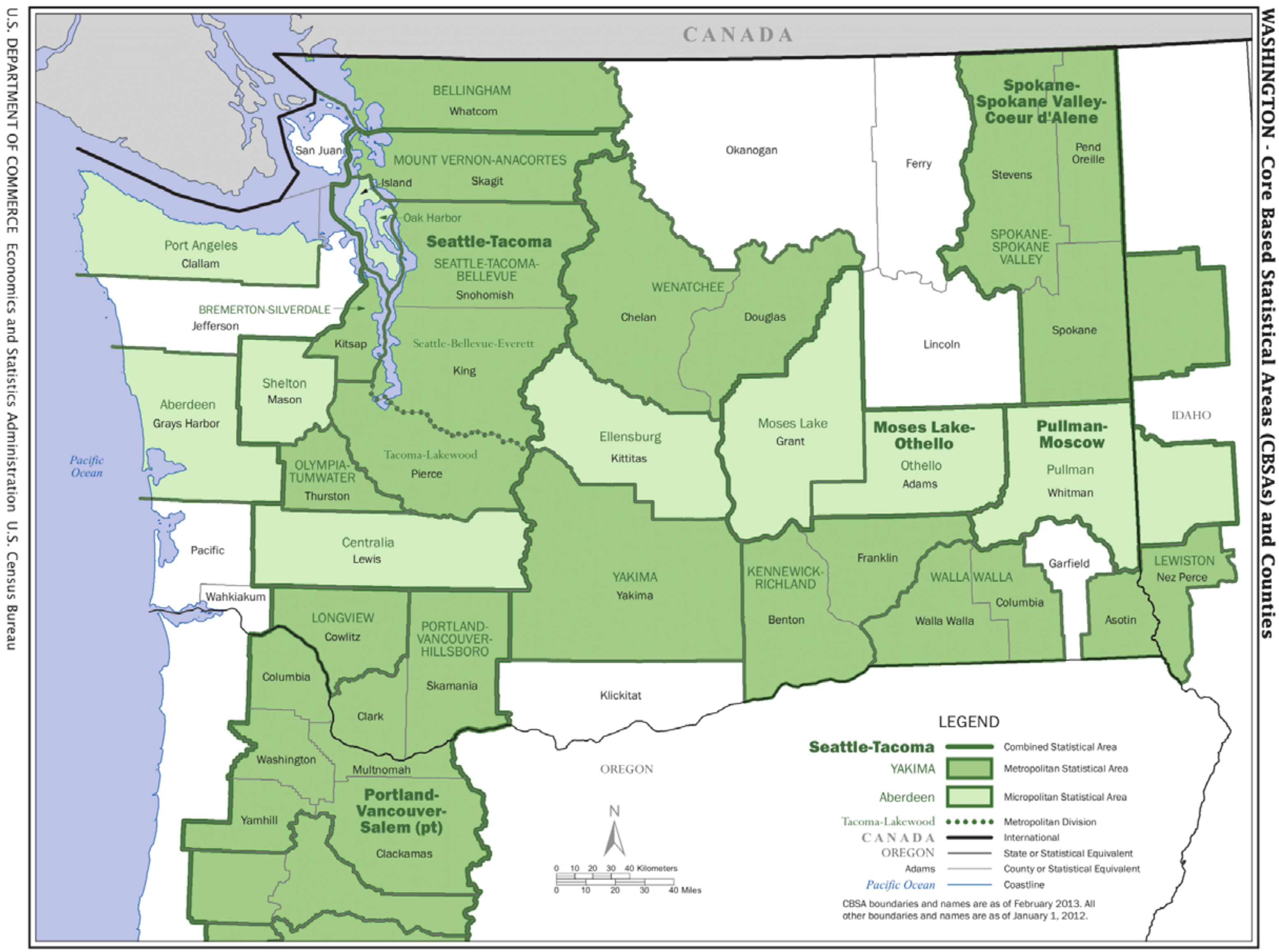


**Figure 1. Washington's Core-Based Statistical Areas (CBSAs), U.S. Census Bureau 2013**

**Table 2. Washington's 2019 CBSA populations over 50,000 (U.S. Census Bureau)**

| Core-Based Statistical Area | 2019 Population |
|---|---|
| Seattle-Tacoma-Bellevue, WA | 3,979,845 |
| Portland-Vancouver-Hillsboro, OR-WA | 2,492,412 |
| Spokane-Spokane Valley, WA | 568,521 |
| Kennewick-Richland, WA | 299,612 |
| Olympia-Lacey-Tumwater, WA | 290,536 |
| Bremerton-Silverdale-Port Orchard, WA | 271,473 |
| Yakima, WA | 250,873 |
| Bellingham, WA | 229,247 |
| Mount Vernon-Anacortes, WA | 129,205 |
| Wenatchee, WA | 120,629 |
| Longview, WA | 110,593 |
| Moses Lake, WA | 97,733 |
| Oak Harbor, WA | 85,141 |
| Centralia, WA | 80,707 |
| Port Angeles, WA | 77,331 |
| Aberdeen, WA | 75,061 |
| Shelton, WA | 66,768 |
| Lewiston, ID-WA | 62,990 |
| Walla Walla, WA | 60,760 |

Washington shares the Portland-Vancouver-Hillsboro CBSA with the state of Oregon. The minimum monitoring requirements for $PM_{10}$, $PM_{2.5}$ and ozone in this CBSA are met through a combination of monitors operated by Ecology and the Oregon Department of Environmental Quality (DEQ).

## Maintenance Areas

Washington has ten maintenance areas for criteria pollutants. Maintenance areas demonstrate continued attainment of the NAAQS either through monitoring or through EPA-approved alternate methods. These methods are summarized in Table 3.

**Table 3. Washington maintenance areas and methods of demonstrating NAAQS attainment**

| Maintenance Area (Pollutant) | End of Maintenance Period | NAAQS Attainment Method |
|---|---|---|
| Seattle ($PM_{10}$) | 5/14/2021 | Estimated $PM_{10}$ from Seattle-Duwamish $PM_{2.5}$ (530330057) |
| Kent ($PM_{10}$) | 5/14/2021 | Estimated $PM_{10}$ from Kent-Central & James $PM_{2.5}$ (530332004) |
| Tacoma ($PM_{10}$) | 5/14/2021 | Estimated $PM_{10}$ from Tacoma-Alexander nephelometer $PM_{2.5}$ (530530031) |
| Thurston County ($PM_{10}$) | 12/4/2020 | Estimated $PM_{10}$ from Lacey-College St nephelometer $PM_{2.5}$ (530670013) |
| Wallula ($PM_{10}$) | 9/26/2025 | Burbank-Maple St $PM_{10}$ monitor (530710006) |
| Spokane ($PM_{10}$) | 8/30/2025 | Spokane-Augusta $PM_{10}$ monitor (530630021) |
| Yakima ($PM_{10}$) | 3/10/2025 | Yakima-4th Ave S $PM_{10}$ monitor (530770009) |
| Tacoma ($PM_{2.5}$) | 3/12/2035 | Tacoma-L St $PM_{2.5}$ monitor (530530029) |
| Yakima (CO) | 12/31/2022 | Modeled CO vehicle emissions |
| Spokane (CO) | 8/30/2025 | Modeled onroad, nonroad and residential wood combustion CO emissions |

Several of the 20-year maintenance periods will be ending in the next five years. No monitoring changes are expected in maintenance areas that use modeling or $PM_{10}$ estimation methods to demonstrate NAAQS attainment (Seattle, Kent, Tacoma, and Thurston County $PM_{10}$, and Yakima and Spokane CO). No monitoring changes are expected at the end of the Spokane and Yakima $PM_{10}$ maintenance periods, as the monitors used to demonstrate NAAQS attainment in those areas are also used to meet minimum monitoring requirements in their CBSAs. Ecology does anticipate requesting to terminate the Burbank $PM_{10}$ monitoring site in the Wallula $PM_{10}$ maintenance area at the end of the 20-year maintenance period, following the requirements described in 40 C.F.R. Part 58.10.

# Climate and topography

Washington is divided into two distinct geographic regions by the north-south Cascade Mountain Range. West of the Cascade Range, summers are relatively cool and dry, and winters are marked by mild cool temperatures and frequent precipitation. Annual precipitation in Western Washington ranges from approximately 20 inches along the Strait of Juan de Fuca to 150 inches on the southwest slopes of the Olympic Range.

Western Washington is more densely populated, containing approximately 60% of the state’s population and most of its major cities. Dominant sources of criteria pollutants include on-road and non-road vehicles, residential wood combustion, and industrial point sources.

Eastern Washington is part of an inland basin spanning several states between the Cascade and Rocky Mountains. Eastern Washington experiences warmer summers, cooler winters and less precipitation than does western Washington. In eastern Washington, annual precipitation ranges from approximately 7-9 inches near the Tri-Cities to approximately 75-90 inches near the Cascade Range, though the majority of the region experiences fewer than 25 inches of precipitation per year (Washington Department of Commerce, Desert Research Institute).

Eastern Washington contains the state's major agricultural areas. Dominant sources of criteria pollutants in eastern Washington include wildfires, on-road and non-road mobile sources, agricultural and silvicultural burning, and dust from tilling, harvesting and roads.

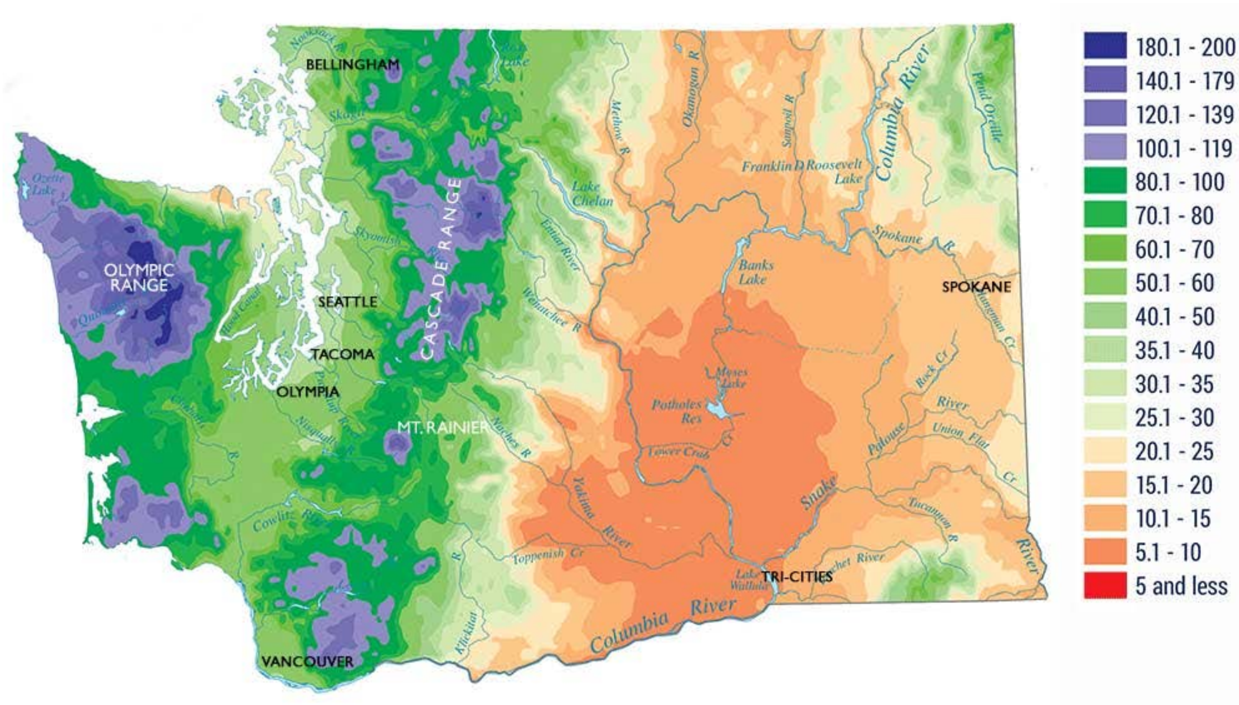


**Figure 2. Washington's annual precipitation (Washington Department of Commerce)**

# Air Quality Monitoring Past and Present

## Criteria pollutants

In the 1970s and 1980s, Ecology's air monitoring program was primarily focused on monitoring CO, $SO_2$ and Pb. Stricter emissions regulations across a variety of sources and industries reduced emissions of these pollutants, and new research emerged on health impacts of particulate matter and ozone pollution in the 1990s and 2000s. Consequently, the focus of Ecology's air monitoring program shifted to $PM_{2.5}$ and ozone, which remain the two pollutants with the largest number of monitoring sites and the greatest investments in their monitoring networks.

Figure 3 shows the number of statewide exceedances by criteria pollutant from 1970-2018. Since the early 2000s, Ecology's $PM_{2.5}$ network has generally recorded more NAAQS exceedances than any other parameter's network. The increase in $PM_{2.5}$ exceedances in 2017 and 2018 can largely be attributed to extreme wildfire smoke conditions in the late summers of those years.

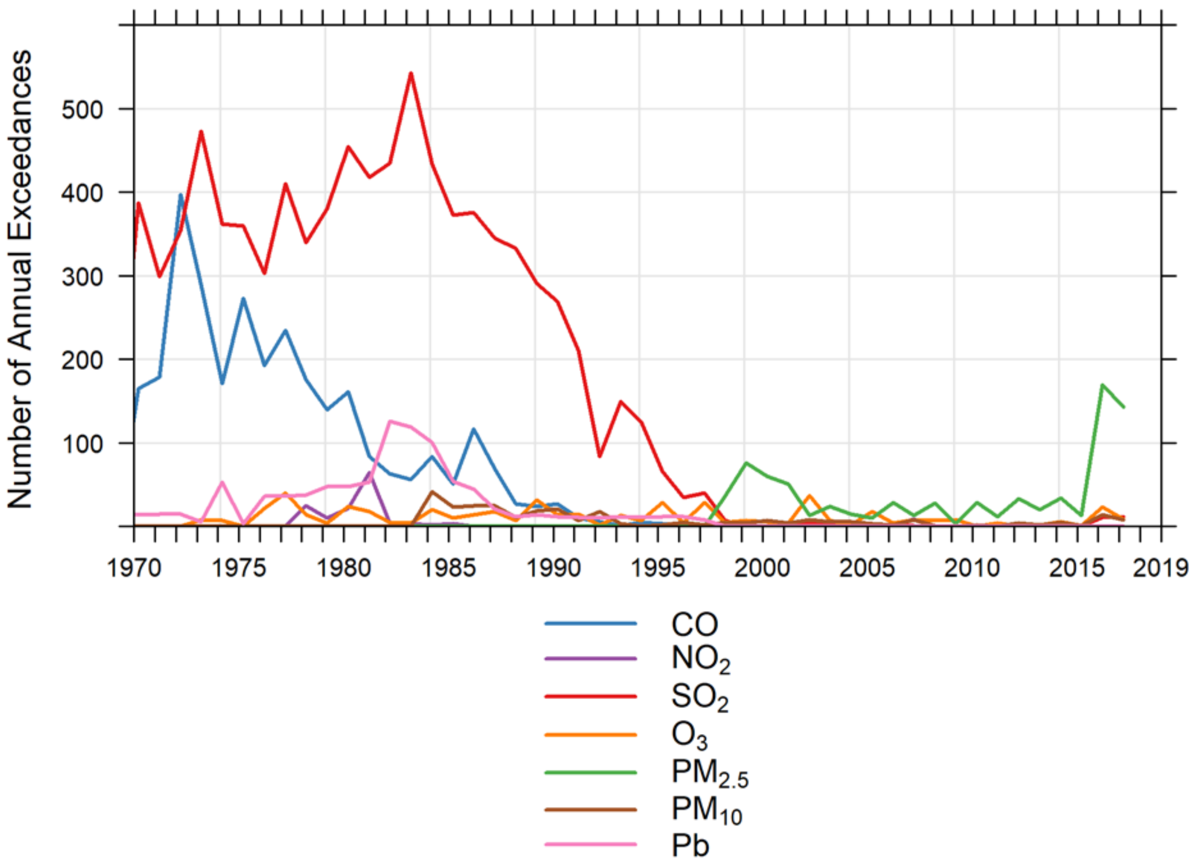


**Figure 3. Number of exceedances by criteria pollutant, 1970-2018**

Figure 4 shows a similar trend in the range of design values relative to the NAAQS for each pollutant. The percent above or below the corresponding NAAQS was calculated for each combination of monitoring site, parameter and year. Within each combination of parameter and year, the 25th-75th percentile of the range of values by site is plotted. $PM_{10}$ was excluded since the form of the design value is not concentration-based, and Pb was excluded due to interruptions in the monitoring record.

Though the general trend is similar to the trend in the number of exceedances, Figure 4 provides additional information about criteria pollutant design values relative to federal standards. Though exceedances of the ozone standard are not as common as $PM_{2.5}$ exceedances, ozone design values generally remain close to the level of the ozone NAAQS. For this reason, Ecology continues to maintain a robust and extensive ozone monitoring network. The recent increase in the range of $SO_2$ design values corresponds to the addition of source-oriented $SO_2$ monitoring sites in Ferndale in 2017.

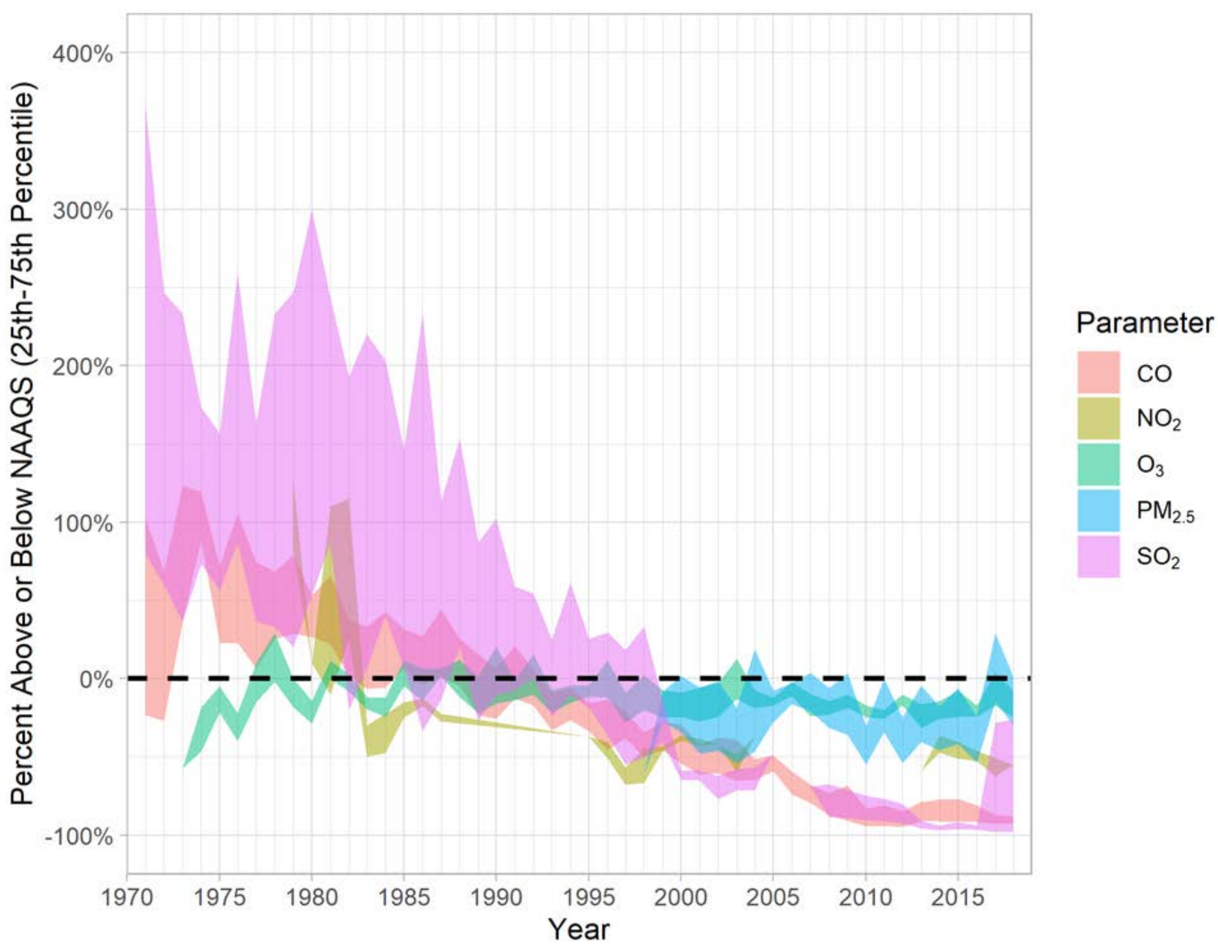


**Figure 4. Percent above or below NAAQS (25th-75th percentile), 1970-2018**

## Carbon monoxide (CO)

Monitoring for CO has been conducted in Washington since the 1960s. Since 1970, when the federal Clean Air Act first mandated motor vehicle emission controls, tailpipe emissions of CO, hydrocarbons, and oxides of nitrogen have decreased. As air quality improved, the CO monitoring network was greatly reduced. Currently, CO is only monitored at trace levels at three monitoring sites: Seattle-Beacon Hill (NCore), Seattle-10th & Weller (Near-road), and Cheeka Peak (NCore).

## Nitrogen dioxide ($NO_2$)

$NO_2$ monitoring in Washington began in 1975. $NO_2$ monitoring was discontinued in 1987 and re-established in 1995 at Seattle-Beacon Hill. During the 1990s, several $NO_2$ studies were conducted to determine concentrations at potential hot spots and evaluate downwind photochemistry. The results from these studies revealed concentrations well below the NAAQS in effect at the time.

In 2007, the $NO_2$ monitor at the Seattle-Beacon Hill NCore site was replaced with a high sensitivity monitor measuring reactive oxides of nitrogen ($NO_y$). Area-wide $NO_2$ monitoring was added to Seattle-Beacon Hill in 2013. Monitoring for $NO_2$ is also conducted at Washington's two near-road monitoring sites (Seattle-10$^{th}$ & Weller and Tacoma-S 36$^{th}$).

## Ozone ($O_3$)

Ozone monitoring began in 1972 at a single station in Spokane. Though ozone has been monitored at over 50 different stations throughout the state, many of these were exploratory in nature and only operated for a year or two. There are currently 13 permanent ozone monitoring sites in the Washington Network. Three operate year-round (Seattle-Beacon Hill, Mt. Rainier Jackson Visitor Center, and Cheeka Peak). The remainder operate during Washington's ozone season of May – September.

## Sulfur dioxide ($SO_2$)

In the early 1970s, there were as many as 28 $SO_2$ monitoring stations located throughout the state. Since then, emissions reductions were realized as: (a) source control measures were implemented, (b) many of the larger $SO_2$ sources shut down, and (c) gasoline and diesel fuel sulfur content was greatly reduced.

As air quality improved and pollution levels dropped well below the NAAQS, $SO_2$ monitoring for compliance with the federal standards was discontinued in favor of trace-level monitoring. Currently, there are three trace-level $SO_2$ monitors in the Washington State network at Seattle-Beacon Hill, Cheeka Peak, and Anacortes. The Seattle-Beacon Hill NCore station measures values representative of the overall region and Cheeka Peak provides background and long-range transport data. The Anacortes $SO_2$ monitor lies upwind of the March Point refineries.

EPA's 2016 Data Requirements Rule required air agencies to characterize air quality around large sources of $SO_2$ using either modeling or monitoring. Washington selected a monitoring approach in the vicinity of two aluminum smelters. In 2017, three associated $SO_2$ monitoring sites were added to the Washington Network: Ferndale-Mountain View, Ferndale-Kickerville, and Malaga-Malaga Hwy. The two Ferndale sites routinely record exceedances of the 1-hour $SO_2$ NAAQS. The Malaga site has never exceeded 2 ppb as operations are currently curtailed at its associated smelter.

## Particulate matter

### Particulate matter 10 µm ($PM_{10}$)

Particulate Matter (PM) monitoring in the form of gross particle fallout and Total Suspended Particulate (TSP) started in the 1960s. By 1971, Washington had over 100 TSP sampling stations, several of which exceeded the primary or the secondary NAAQS for TSP. Ecology began sampling for $PM_{10}$ at 24 stations across the state in 1985. Many of the new $PM_{10}$ monitoring stations exceeded the $PM_{10}$ NAAQS when it was promulgated in 1987, and TSP sampling was phased out by 1996. EPA revoked the annual $PM_{10}$ standard in 2006 due to a lack of evidence linking $PM_{10}$ to chronic health problems but retained the 24-hour standard to address acute health impacts. $PM_{10}$ is still monitored at several sites across Washington. Exceedances of the NAAQS can occur during high-wind dust events and extreme wildfire smoke conditions.

### Particulate matter 2.5 µm ($PM_{2.5}$)

In 1997, EPA issued a new PM standard for particles with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$). The new $PM_{2.5}$ NAAQS were based on human population exposure and laboratory studies that demonstrated the harmful effects of finer particles. In 2006, EPA revised the 24-hour $PM_{2.5}$ NAAQS from 65 $\mu g/m^3$ to 35 $\mu g/m^3$. In 2012, EPA revised the annual standard from 15 to 12 $\mu g/m^3$.

Ecology and its partners currently operate an extensive $PM_{2.5}$ monitoring network comprised of continuous monitors reporting hourly concentrations and filter-based samplers reporting 24-hour averages. The continuous network represents Ecology's single largest ongoing resource investment for any pollutant and provides near-real-time data for a variety of users with a diverse array of data needs and applications. Public health protection is the primary motivation for the siting and configuration of Ecology's extensive $PM_{2.5}$ monitoring network.

Ecology uses the Washington Air Quality Advisory (WAQA) as an alternative to EPA's Air Quality Index (AQI) in order to communicate health concerns associated with $PM_{2.5}$ concentrations. The WAQA uses lower concentration breakpoints than the AQI for the Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy and Hazardous categories in order to provide more protective information about $PM_{2.5}$ health impacts.

## Lead (Pb)

Lead monitoring began in 1979. With the phase-out of leaded gasoline and the regulation of industries that produced lead, concentrations dropped dramatically from 1975 to 1995. By 1996, lead monitoring was conducted at only one site in Seattle. The values from this last station were less than half the NAAQS. Consequently, lead monitoring under the 1978 standard was discontinued in 1997.

In 2008, EPA reduced the level of the lead standard from 1.5 $\mu g/m^3$ to 0.15 $\mu g/m^3$. In its 2010 monitoring rule, EPA lowered the threshold required for establishing monitors to 0.5 tons per year (tpy) near industrial sources of lead. EPA also limited non-source-oriented monitors to NCore sites, rather than require monitoring in every core-based statistical area (CBSA) with a population over 500,000. The 2010 monitoring rule also required that monitors be deployed at selected airports, including two in Washington. Lead monitoring was conducted at Auburn Municipal Airport and Harvey Field Airport from December 2011 to December 2012. Since neither site reported a 3-month rolling average in excess of 50 percent of the NAAQS, monitoring at both airports was terminated in December 2012 (US EPA, 2013).

Lead is currently monitored at the Seattle-Beacon Hill station as part of the National Air Toxics Trends Station (NATTS) and Chemical Speciation Network (CSN) programs. EPA Region 10 has agreed that this monitoring satisfies the relevant CFR requirements. At the request of EPA Region 10, Ecology ceased reporting lead concentrations in $PM_{10}$ as a regulatory parameter and began reporting under a non-regulatory parameter code on January 1, 2019.

# Other networks

## Meteorological

Ecology currently operates 19 meteorological monitoring sites in accordance with EPA's Prevention of Significant Deterioration (PSD) monitoring guidelines. Meteorological sites measure wind speed, direction, and ambient temperature. In addition to these parameters, relative humidity and barometric pressure are also measured at the two NCore sites.

Meteorological monitoring instruments are operated at NCore and Near-road monitoring sites as required by EPA. In addition, Ecology conducts meteorological monitoring at several ozone monitoring sites to provide information on the transport of ozone precursors. Meteorological sites are also operated in locations where on-site meteorological data assist with permitting and/or planning applications.

## Chemical speciation network

There are six current chemical speciation network (CSN) monitoring sites operated as part of the Washington Network. As a complement to $PM_{2.5}$ measurements, CSN data are utilized for annual and seasonal trends assessments, State Implementation Plan development, and comparison to similar data collected from the IMPROVE network. Current CSN monitoring sites include Seattle-Beacon Hill, Seattle-10th & Weller, Tacoma-L Street, Yakima-4th Ave, Seattle-Duwamish, and Tacoma-Alexander Ave. Previous CSN monitoring sites in existence prior to 2015 included Marysville-7th Ave, Vancouver-Fourth Plain Road, and Spokane-Ferry St. Details about monitoring periods for current and historic CSN sites are shown in the Gantt chart below.

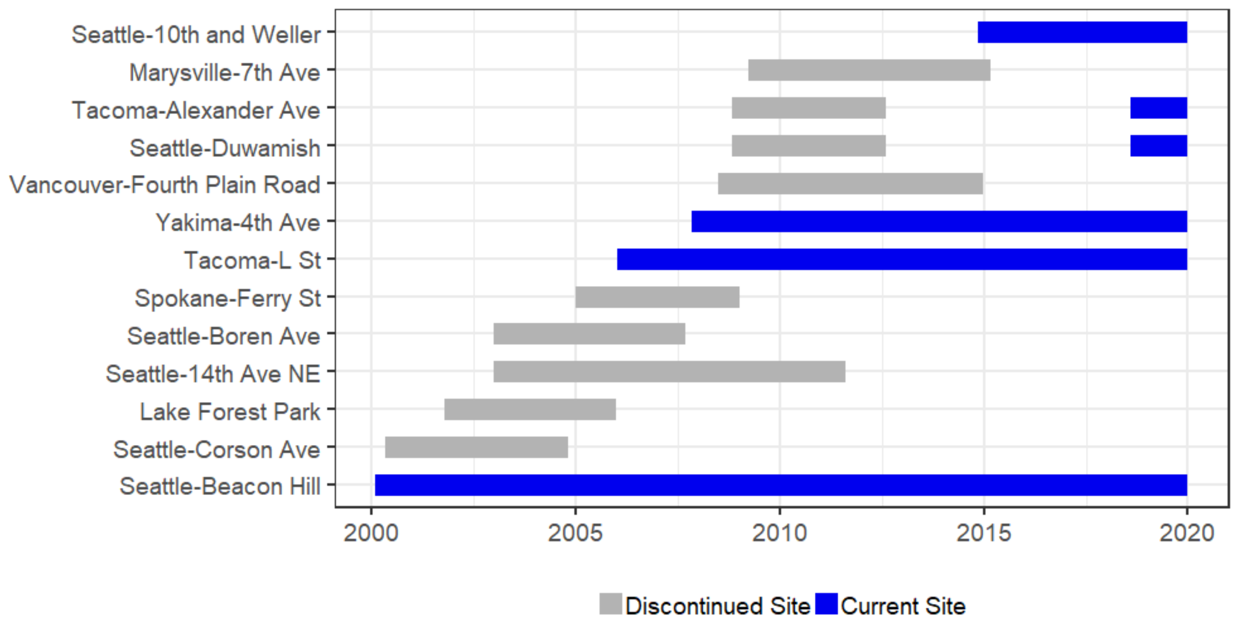


**Figure 5. Gantt chart showing the active monitoring periods for current and discontinued CSN sites**

## Air toxics

Ecology operates one air toxics monitoring site at Seattle-Beacon Hill as part of the National Air Toxics Trends Stations (NATTS) network. The primary purpose of the NATTS network is to track trends in ambient air toxics levels to facilitate measuring progress toward emission and risk reduction goals. Long-term goals of the NATTS program include assessing the effectiveness of emission reduction activities and providing data to evaluate and improve air toxics emission inventories and model performance. The NATTS program provides for long-term sampling of VOC, carbonyls, $PM_{10}$ metals, PAHs, and SVOCs. Air toxics sampling has been conducted at Seattle-Beacon Hill since 2000.

# Other monitoring projects

## Mobile and portable monitors

From 2015-2019, Ecology operated eight temporary monitoring sites. These sites involved mobile trailers equipped with $PM_{2.5}$ nephelometers. Site details are described in Table 4 and Figure 6. With the exception of San Juan, these temporary monitoring sites were located in central and eastern Washington. Average 24-hour estimated nephelometer $PM_{2.5}$ concentrations were substantially below the 24-hour NAAQS for $PM_{2.5}$. Five sites observed multiple days of $PM_{2.5}$ concentrations greater than 35 µg/m$^3$; these high concentrations were associated with wildfire smoke events during the summers of 2017 and 2018. Comparison to nearby monitoring sites show that most nearby permanent monitoring sites sufficiently represent the airshed observed by these temporary monitoring sites. Further site details are described in the following sections.

**Table 4. Summary of temporary monitoring studies in Washington from 2015-2019**

| Temporary Site | Dates in operation | Number of valid days | Completeness (%) | Mean NPM25 ($\mu g\ m^{-3}$) | # days > 20 $\mu g\ m^{-3}$ (non-wildfire) | # days > 35 $\mu g\ m^{-3}$ (non-wildfire) | Correlation (r-value) with nearby site; nearby site vs. temporary site slope |
|---|---|---|---|---|---|---|---|
| **East Wenatchee** | 11/7/2015-12/14/2016 | 372 | 92.3 | 4.2 | 0 (0) | 0 (0) | • Wenatchee: 0.84; 1.1<br>• Leavenworth: 0.69; 1.3 |
| **Metaline Falls** | 12/11/2015-3/15/2017 | 445 | 96.7 | 3.1 | 0 (0) | 0 (0) | • Colville: 0.2; 1.1<br>• Omak 0.75; 1.2 |
| **Okanogan** | 6/6/2017-6/5/2018 | 349 | 98.6 | 12 | 34 (4) | 16 (0) | • Omak: 0.91; 0.8 |
| **Oroville** | 10/9/2013-11/4/2015 | 701 | 92.7 | 8.5 | 22 (6) | 10 (0) | • Omak: 0.99; 1.3 |
| **Pomeroy** | 5/5/2017-12/30/2019 | 844 | 87.1 | 5.8 | 28 (3) | 10 (0) | • Dayton: 0.96; 1.0<br>• Pullman: 0.97; 1.1<br>• Lacrosse: 0.97; 1.1 |
| **San Juan** | 1/30/2019-5/29/2019 | 112 | 94.1 | 4 | 0 (0) | 0 (0) | • Anacortes: 0.76; 1.0 |
| **Suncrest** | 9/30/2014-12/7/2015 | 393 | 90.8 | 8.6 | 27 (5) | 13 (0) | • Spokane Monroe: 0.92; 0.8 |
| **White Salmon** | 6/8/2018-12/30/2019 | 509 | 89.3 | 6.4 | 12 (3) | 5 (0) | • The Dalles (OR DEQ): 0.6; 0.7 |

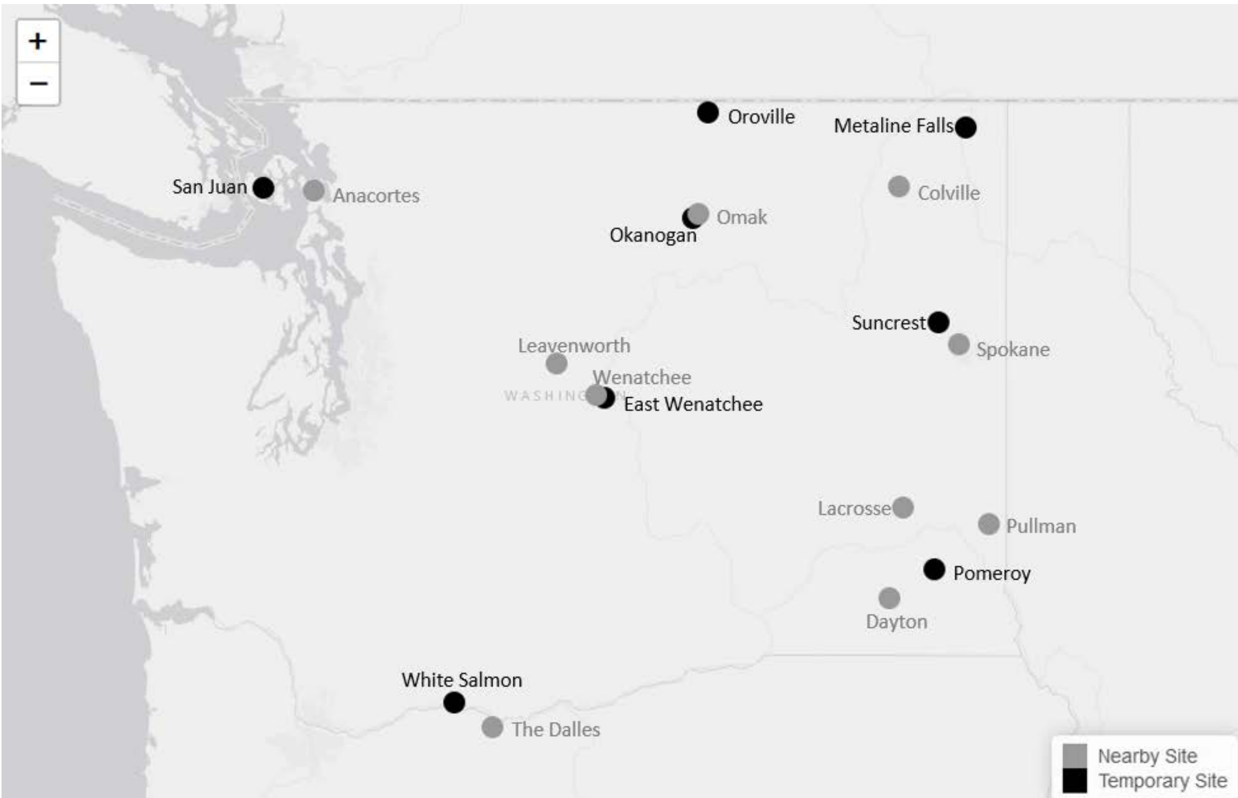


**Figure 6. Locations of temporary monitoring sites and the nearby sites used for comparison**

## East Wenatchee

The temporary monitoring site at East Wenatchee was established to assess if East Wenatchee was adequately represented by the permanent monitoring site in Wenatchee. Calling burn bans across the city of Wenatchee requires calling burn bans in two different counties, as East Wenatchee is in Douglas County and Wenatchee is in Chelan County. Further, no other monitoring site exists in Douglas County. During the temporary monitoring period, there were zero days in which $PM_{2.5}$ concentrations in East Wenatchee were 5 or more μg/m$^3$ greater than observed in Wenatchee. As the permanent site in Wenatchee is representative of entire Wenatchee area, Ecology does not anticipate future monitoring needs in East Wenatchee.

## Metaline Falls

Temporary $PM_{2.5}$ monitoring in Metaline Falls was motivated by the opportunity to characterize a populated area without any previous monitoring data. Nephelometer $PM_{2.5}$ concentrations at Metaline Falls were on average lower than both Omak and Colville; there were zero days in which Metaline Falls observed nephelometer $PM_{2.5}$ concentrations more than 5 μg/m$^3$ greater than those observed at either Omak or Colville. Site correlations indicate Metaline Falls is best represented by the Omak monitoring site. Ecology does not anticipate future $PM_{2.5}$ monitoring needs in Metaline Falls.

### Okanogan

As part of an effort to prevent non-attainment in the Omak region, determine the range of $PM_{2.5}$ influences from a nearby mill, and evaluate seasonal air quality impacts, Ecology established a temporary monitoring site from June 2017 – June 2018. The project also aided community outreach efforts to decrease $PM_{2.5}$ exposure. Comparison to the permanent monitoring site in Omak (approximately three miles away) suggests that monitoring needs in Okanogan are sufficiently represented by the Omak monitoring site.

### Oroville

Temporary monitoring in Oroville took place from October 2013 – November 2015, with the objective to characterize a populated location that did not have prior monitoring data and to assess smoke management needs. There were only eight days in which Oroville observed local $PM_{2.5}$ impacts (characterized by $PM_{2.5}$ concentrations more than 5 $\mu g/m^3$ greater than observed in Omak). Based on the high correlation with the permanent Omak monitoring site and low concentrations observed, Ecology does not anticipate future monitoring needs in Oroville.

### Pomeroy

The temporary monitor in Pomeroy was established in 2017 to support agricultural burning decisions and to assist the U.S. Forest Service with smoke management. The site is important in assessing smoke impacts from wildfires, agricultural and prescribed burning, and woodstove emissions. While Pomeroy compares well to nearby sites (r-values are greater than 0.9), there are days where the Pomeroy monitoring site observed local effects during the October through April months. Specifically, there were three, ten, and one day(s) where Pomeroy observed concentrations more than 5 $\mu g/m^3$ greater than those observed in Lacrosse, Pullman, and Dayton, respectively. These local impacts as well as future smoke management needs indicate an ongoing need for $PM_{2.5}$ monitoring in Pomeroy.

### San Juan

Ecology established a temporary monitoring site at the San Juan County Parks Superintendent offices in Friday Harbor. As the largest population center in San Juan County, Friday Harbor is likely to observe the county's highest $PM_{2.5}$ concentrations. Due to low $PM_{2.5}$ concentrations measured during the temporary monitoring period as well as the correlation and proximity to nearby permanent monitoring sites, Ecology does not anticipate any future monitoring needs in San Juan County. More details can be found in Ecology's publication: https://fortress.wa.gov/ecy/publications/documents/1902020.pdf

### Suncrest

Located about ten miles northwest of Spokane, Suncrest is a populated area (population ~ 9,700) in which no prior $PM_{2.5}$ monitoring studies were conducted. Given Suncrest's proximity and similarity to the permanent monitoring site in Spokane, as well as low $PM_{2.5}$ concentrations, Ecology does not anticipate future monitoring needs in the area.

### White Salmon

As the only monitor in Klickitat County, the temporary monitor in White Salmon satisfied direct requests from local public officials as well as a need to understand local exposure to $PM_{2.5}$. The monitor also was established to aid Ecology's Central Regional Office in burn ban decisions and enforcement. The closest monitor for comparison is Oregon Department of Environmental Quality's monitor in The Dalles. In general, nephelometer $PM_{2.5}$ concentrations at The Dalles were greater than those observed at the White Salmon monitor. However, during the October-April months, there were nine unique days in which White Salmon observed three or more consecutive hours of a difference greater than 5 $\mu g/m^3$. These localized effects as well as the utility of the monitor in smoke management indicate an ongoing need for $PM_{2.5}$ monitoring in White Salmon, which can be accomplished with a nephelometer or a low-cost air sensor.

## Air sensors

In the past several years, the commercial market for low-cost air quality sensors has expanded dramatically, with countless manufacturers now marketing sensors directly to consumers for measurement of various air pollutants, particularly $PM_{2.5}$ (Hagler et al., 2018; Feenstra et al., 2019; Morawska et al., 2018). These developments offer the opportunity to engage citizen scientists to study air pollution in their communities. In addition, the low cost of these devices makes high-density monitoring feasible and affordable at a much larger scale than was previously possible.

However, the widespread use of low-cost air sensors by individuals and community groups presents a number of challenges for monitoring agencies. The accuracy and reliability of sensors can vary widely both within individual sensor models and between different manufacturers, which results in a great deal of uncertainty in their data. While some users of sensors and sensor data understand this uncertainty, others are not aware of these issues. Consumers may be more inclined to trust devices they have purchased themselves rather than regulatory data, regardless of this greater uncertainty. In addition, the proliferation of online air quality maps and data from private companies can sow confusion about the best sources for air quality information and data, and people may turn to private data sources rather than regulatory data from public agencies.

Ecology identified two key priorities in approaching the use of low-cost air sensors:

1. As Washingtonians look to Ecology for accurate, reliable information about air quality conditions, Ecology must be prepared to answer questions about the performance of air sensors using the best scientific information possible.

2. As Ecology consistently faces greater demand for expanded $PM_{2.5}$ monitoring than it can afford to meet with traditional, more expensive monitoring technologies, sensors can provide an opportunity to expand the footprint of Ecology's monitoring network at a much-reduced cost. To be used in this way, sensors must first be well-tested for accuracy, precision, and long-term consistency in a variety of aerosol environments. To present sensor data to the public, Ecology must be able to apply any necessary data

correction factors in a scientifically defensible way, systematically ensure data quality, and characterize and communicate the uncertainty around sensor measurements.

## Sensor performance testing

### *Testing models and locations*

In support of both priorities, Ecology has tested a number of different $PM_{2.5}$ sensor models at various Washington Network sites as shown in Figure 7. In several cases, multiple instruments of the same model were tested simultaneously at the same site. Ecology has not tested low-cost sensors for other pollutants.

The six sensor models Ecology has tested are provided in Table 5. All have retail costs less than $1000.

**Table 5. Low-cost $PM_{2.5}$ sensor models tested by Ecology**

| Manufacturer | Model |
|---|---|
| Purple Air | PA-II-SD |
| Clarity | Node-S |
| Dylos | DC1100 Pro |
| Sensirion | SPS30 |
| Alphasense | OPC-N3 |
| Plantower | PMS5003 |

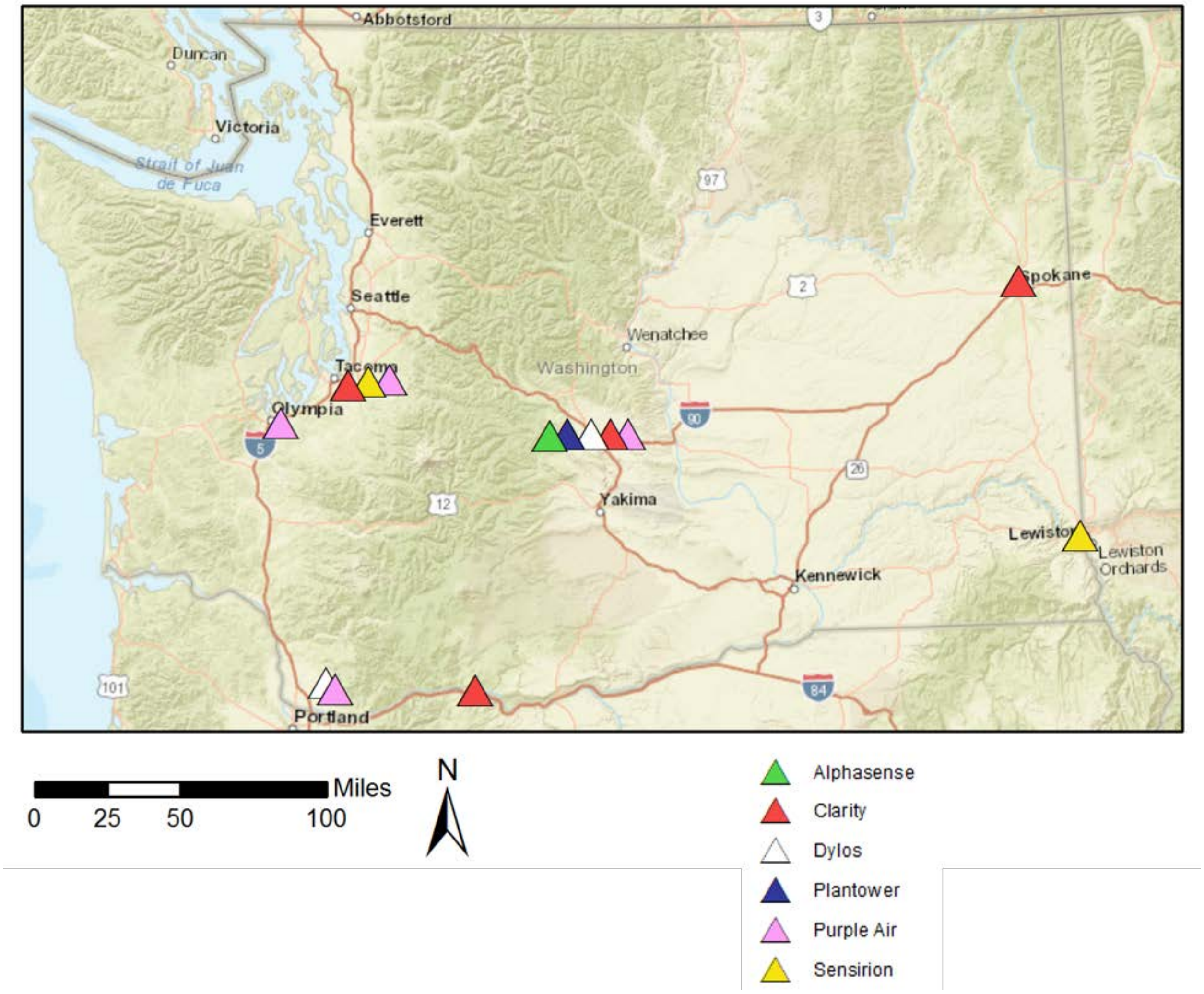


**Figure 7. Low-cost air sensor testing locations**

As the Dylos DC1100 Pro was not built for outdoor use and construction of a suitable shelter proved cumbersome, its performance is not analyzed here.

Ecology began evaluating the performance of the remaining sensors in January of 2018. Sensors were collocated as close to the height of the $PM_{2.5}$ reference instrument as practical, and within 4m horizontal distance. The timelines of the collocated deployments are shown in the chart in Figure 8. When multiple instruments were evaluated at different sites, the span between the earliest and latest deployments is shown on the chart. Although sensors were collocated at sites with a mix of FEM $PM_{2.5}$ and nephelometer monitoring, only comparisons with FEM $PM_{2.5}$ data are described here.

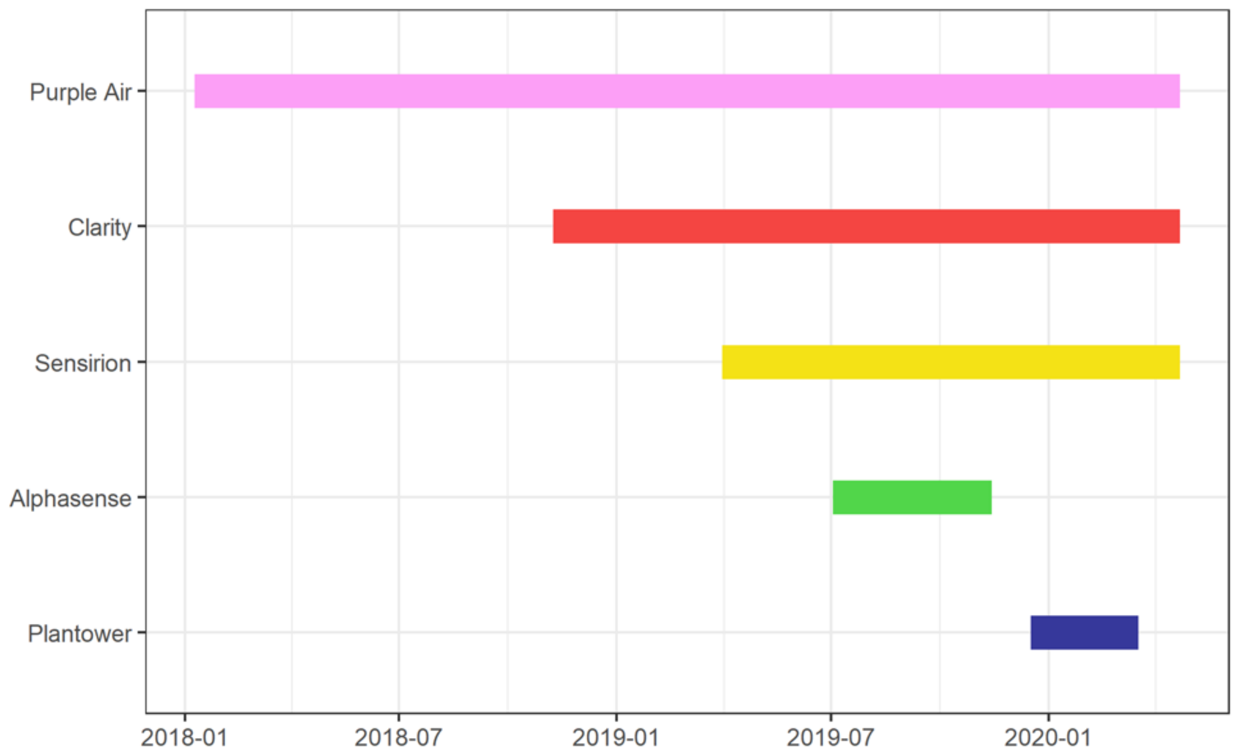


**Figure 8. Timelines of collocated sensor deployments by model**

*Overall sensor performance comparisons*

Ecology evaluated the performance of the remaining sensors in several different ways. For comparisons across multiple sites and instruments, we used two primary metrics: goodness-of-fit ($R^2$) and normalized root mean square error (NRMSE) of an ordinary linear regression model with sensor data as the explanatory variable and FEM $PM_{2.5}$ data as the response variable. All comparisons were conducted on 24-hour average concentrations. $R^2$ is commonly used as a summary statistic in sensor performance evaluations to indicate the amount of variance in the reference $PM_{2.5}$ data that is explained by the sensor data. We also considered the RMSE as a measure of expected error between predicted and reference concentrations. RMSE was normalized to the mean concentration measured by each site/sensor pair to control for variation in the range of concentrations measured in each deployment.

Since not every sensor was deployed in multiple seasons, and since the sensors' measurements of ambient temperature and relative humidity showed inconsistent performance (and some prolonged malfunctions), seasonal and meteorological variables were not included in this analysis.

Figure 9 shows a comparison between $R^2$ and NRMSE for each of the sensor models evaluated, separately by location. The y-axis shows 1-NRMSE so that higher values indicate better performance. The size of the points is scaled to the number of 24-hour paired data points used in the evaluation.

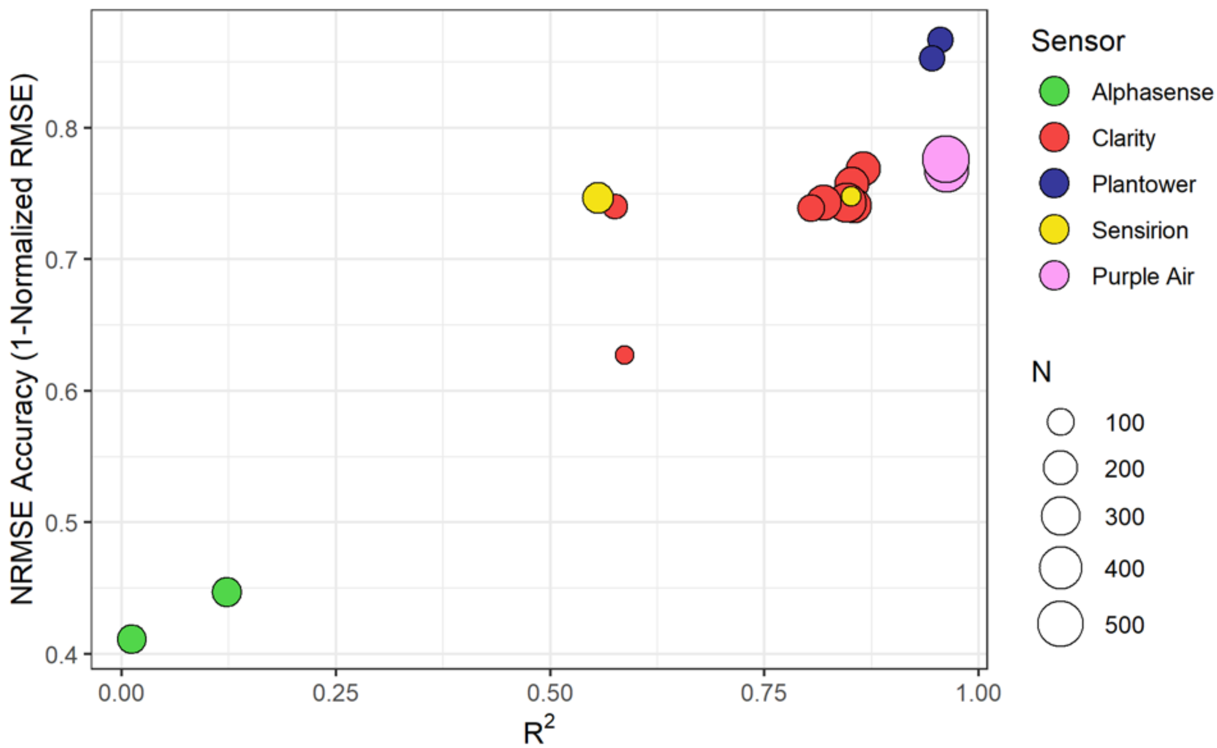


**Figure 9. Air sensor performance by model**

The Plantower PMS5003 sensor showed the best performance, with both the highest $R^2$ and highest 1-NRMSE. However, its deployment period was shorter than that of many of the other sensors, and the deployment period was only in the winter/spring. These results should be approached with caution, as this dataset is likely not comparable to other datasets that span multiple seasons and events such as wildfires.

Notable in Figure 9 is the general consistency in the performance of multiple sensors, including the Plantower, Purple Air and Clarity sensors. This is to be expected, as both the Purple Air and Clarity devices use Plantower PMS5003 sensors inside, though they use different sampling frequencies and averaging intervals, which results in variable performance. The Plantower PMS5003 sensors we used directly had the highest-resolution sampling frequency (1-minute averages with a 1-second sample interval), which is consistent with their higher performance.

Also evident in Figure 9 is that while there is generally good consistency among like instruments (e.g. Clarity, Plantower and Purple Air sensors), outliers do occur. Two Clarity units underperformed the other sensors of their type, as did one of the Sensirion units. These results underscore the need to evaluate the data quality of each sensor individually, as sensors of the same type cannot be assumed to be interchangeable without evaluation.

These results are used to answer questions from the public about the accuracy and precision of various types of air sensors on an ongoing basis. These results will also be used to guide Ecology's broader sensor deployment strategy. While Ecology's sensor deployments thus far have focused on collocation with FEM reference instruments, we anticipate the need for sensor-based tools that can be deployed quickly to unmonitored areas in response to wildfires, prescribed burns, and other events in the future.

The results indicate that while the Alphasense units do not match the performance of the other sensors, any of the remaining models can reasonably be used with adequate data correction, quality control and quality assurance. Ecology plans to select a model for further use from among these options based primarily on cost and feasibility.

*Regional and seasonal differences*

The devices using Plantower PMS5003 sensors (Purple Air, Clarity and Plantower) were further evaluated for regional differences in their degree of bias relative to reference monitors. The slope of the sensor $PM_{2.5}$ data relative to the reference FEM $PM_{2.5}$ data in each site/sensor combination ranged widely from 1.9 - 3.2, indicating the need for regionally-specific correction factors in order to correct sensor bias. In general, the lowest slopes were observed on devices at the Tacoma-S 36$^{th}$ St near-road monitoring site, and the highest slopes were observed in Ellensburg and Spokane, where residential wood combustion is a dominant source of $PM_{2.5}$.

Seasonal differences were also evident in comparisons between PMS5003 sensor and reference $PM_{2.5}$ data, particularly at urban sites such as Tacoma where dominant sources of $PM_{2.5}$ vary throughout the year. Even outside of the heating season, comparisons between sensor and reference $PM_{2.5}$ data differed from the rest of the summer season during the weeks impacted by wildfire smoke. These results indicate the need for season-specific correction factors that account for wildfire smoke, or more sophisticated correction methods such as machine learning models that account for changes in nearby sensor/reference $PM_{2.5}$ relationships in near-real time.

**Summary of next steps**

Ecology plans to use these collocation results to develop a sensor deployment strategy aimed at characterizing air quality in unmonitored areas facing impacts from wildfires, prescribed burns and other events. We also plan to use sensors to evaluate the need for additional monitoring in unmonitored areas outside of event response.

In addition, Ecology has identified $PM_{2.5}$ sensors as a tool that could be added to existing Washington Network monitoring sites that do not have a $PM_{2.5}$ monitor. During events such as wildfires that impact $PM_{2.5}$ concentrations but not other criteria pollutants, these sites often show that air quality conditions are in the "Good" range while nearby $PM_{2.5}$ sites show higher WAQA categories. These discrepancies create challenges for communicating the impacts of wildfire smoke, which would be resolved by providing $PM_{2.5}$ information at every site. Given the frequency and intensity of wildfire smoke episodes over the past several years, this enhancement to non-$PM_{2.5}$ sites is a high priority.

The following steps are needed before sensors can be deployed to new locations for these purposes:

- Develop bias correction methods appropriate for the region, season and sensor model

- Develop a quality assurance project plan guiding quality control and quality assurance procedures for sensor deployments, which accounts for variation in performance within specific sensor models
- Develop communication materials to convey key messages about data correction and uncertainty in sensor data

Ecology plans to prioritize the development of these resources in the coming years in order to leverage sensor data to enhance the $PM_{2.5}$ monitoring network.

## Special monitoring studies

### Quincy

A monitoring site in Quincy, WA was established in August 2017 to measure components present in diesel exhaust emissions, including $PM_{2.5}$, black carbon, and $NO_x$. Meteorological parameters including wind speed, wind direction, and ambient air temperature were also monitored. The measurement campaign lasted until December 2018, although $PM_{2.5}$ and meteorological measurements are still ongoing.

Omitting wildfire events, there were no exceedances of the $PM_{2.5}$ or $NO_2$ NAAQS during the measurement campaign. $PM_{2.5}$ concentrations were similar to nearby monitoring sites in Wenatchee and Moses Lake, and $NO_x$ and black carbon concentrations were significantly lower than those at near-road sites in the state. Diurnal and weekly patterns showed increased pollutant concentrations consistent with traffic emissions. No distinct source directions of measured compounds common in diesel exhaust emissions were present, and a source apportionment analysis could not resolve individual sources of diesel exhaust emissions.

### Tri-Cities Ozone Precursor Study

In 2015, Ecology added an ozone monitoring site in Kennewick to the Washington Network. During the summer of 2015, this new monitoring site routinely recorded elevated concentrations, consistent with model predictions and previous mobile monitoring studies in the area. Though the precursors and favorable conditions for ozone formation are generally well-understood in the Seattle and Portland metropolitan areas, the Tri-Cities do not share many of the characteristics of these areas that are conducive to ozone formation.

In order to better understand the causes of high ozone in the Tri-Cities, Ecology partnered with Washington State University and the Benton Clean Air Agency to conduct the Tri-Cities Ozone Precursor Study (TCOPS) during summer 2016. The TCOPS study measured precursors of ozone, including nitrogen and volatile organic compounds at two sites in the Tri-Cities, as well as from a mobile platform that drove throughout the region. The study found that while concentrations of ozone precursors are relatively low in the Tri-Cities compared to large urban areas, the airshed conditions were found to produce ozone efficiently. Ozone formation chemistry was not found to be limited strongly by the availability of any one precursor, suggesting that either VOC or $NO_x$ emissions reductions could reduce ozone in the airshed. The study recommended a detailed modeling study to further evaluate the potential impacts of reductions in precursor emissions.

The full TCOPS report is available on Ecology's website. Ecology also produced a StoryMap detailing these results.

## Prevent nonattainment

Since 2013, Ecology has conducted a number of state-funded projects known as Prevent Nonattainment projects. These projects involve targeted interventions to reduce air pollution in communities at risk of nonattainment with the NAAQS. The projects conducted since the previous Network Assessment (2015-2019) are described below.

### Tri-Cities ($O_3$)

After the summer 2016 Tri-Cities Ozone Precursor Study described above, Ecology partnered with Benton Clean Air Agency and Benton Franklin Council of Governments to improve on and implement reduction measures and to raise public awareness of ozone pollution. Ecology staff conducted several media briefings and presentations to local groups. An outreach firm was contracted to help spread the word via TV, electronic and print media. Some Spanish language outreach was also conducted. WSU was contracted to build a Tri Cities-specific ozone forecast tool using machine learning techniques. About 75 people signed up to receive automatic email alerts when ozone levels were forecast to be Unhealthy for Sensitive Groups or worse. Ecology developed in-house photochemical grid modeling capabilities and simulated three ozone episodes in the Tri Cities. We assessed the effectiveness of potential emission reductions as identified by stakeholders. More planning and outreach work is expected, but the urgency has waned on account of lower ozone concentrations in 2019.

### Kennewick ($PM_{10}$)

A series of $PM_{10}$ exceedances, due to high wind events, lead to a focus on preventing nonattainment for $PM_{10}$ in the Kennewick/Wallula area and triggered a requirement to develop a mitigation plan. These repeat $PM_{10}$ exceedances at Kennewick lead to the focus on soil erosion reduction in the Horse Heaven Hills area, the area to the south and west of Kennewick. The Kennewick monitor represented the Wallula Maintenance Area (WMA), most recently, from 2004 through 2017. The Burbank monitor was reinstated as the compliance monitor for the WMA as of 2018.

The soil erosion reduction efforts focus on providing incentive to farmers to adopt voluntary soil erosion prevention measures. Ecology works with agricultural partners to promote these control measures, thereby keeping soil on the ground and dirt out of the air.

The 2016 mitigation plan provided for the formation of a High Wind Fugitive Dust Prevention workgroup, comprised of staff from Ecology offices, Conservation Districts and Benton Clean Air Agency. This workgroup began officially in 2019.

Previously grant funding in the 2017-2019 biennium lead to treatment of 2000 acres of farmland, preventing emission of 33 tons of soil, per acre, per year, when compared to conventional farming methods.

The 19-21 funding cycle began in July 2019. Funds are earmarked for a new round of cost share for dryland producers. In addition, Ecology is offering funding for pilot projects for irrigated producers. Signups were extended through March 2020. While $PM_{10}$ exceedances at Burbank and Kennewick are fewer in recent years, efforts to minimize soil erosion continue.

**Omak ($PM_{2.5}$)**

Ecology has also supported activities in Omak to reduce $PM_{2.5}$ pollution since 2017. The objective of Omak's prevent nonattainment work is to reduce $PM_{2.5}$ with direct intervention projects, community engagement projects, and targeted education and outreach. Supported activities include woodstove replacements, events for leaf and yard waste disposal to reduce residential outdoor burning, and increased enforcement, education and outreach. Ecology also participates in the Okanogan River Airshed Partnership, a group with representatives from many agencies and community members to support improved air quality in the Okanogan River Valley.

# Air monitoring – the next five years

This section provides an overview of the recently proposed and final rules as well as the upcoming NAAQS reviews anticipated in the next five years (2020 to 2025) for the six criteria pollutants. The previous monitoring network assessment reviewed ambient air quality monitoring in Washington as of the end of 2014.

## Proposed and final rules affecting ambient monitoring

The following table describes actions EPA has proposed or finalized since the last assessment that will impact ambient air quality monitoring in Washington and the rest of the country over the next five years. For an update of current standards, visit the National Ambient Air Quality Standards page at EPA's website.

**Table 6. Final and proposed EPA actions and standards**

| Pollutant | Most Recent Action | Primary Standard |
|---|---|---|
| Carbon Monoxide (CO) | **August 31, 2011**<br>• The CO standard was retained without revision<br>• CO was required to be included in near-road monitoring for $NO_x$ | • 9 ppm (8 hour)<br>• 35 ppm (1 hour) |
| Particulate Matter ($PM_{10}$ and | **January 15, 2012** | • 35 $\mu g/m^3$ (24 hour $PM_{2.5}$) |

| Pollutant | Most Recent Action | Primary Standard |
|---|---|---|
| $PM_{2.5}$) | • The 24-hour $PM_{2.5}$ standard was retained at 35 µg/$m^3$<br>• The annual $PM_{2.5}$ standard was lowered to 12.0 µg/$m^3$<br>• The 24-hour $PM_{10}$ standard was retained at 150 µg/$m^3$ | • 12 µg/$m^3$ (annual $PM_{2.5}$)<br>• 150 µg/$m^3$ (24-hour $PM_{10}$) |
| Sulfur Dioxide ($SO_2$) | **March 18, 2019**<br>• The primary standard was retained without revision | • 75 ppb (1 hour) |
| Nitrogen Dioxide ($NO_2$) | **April 18, 2018**<br>• The primary standards were retained without revision<br>• The 1-hour standard and annual standard together were determined to provide adequate protection | • 100 ppb (1 hour)<br>• 53 ppb (annual) |
| Ozone ($O_3$) | **October 25, 2015**<br>• The primary standard was revised to 0.070 ppm with the form and averaging time retained | • 0.070 ppb (8 hour) |
| Lead (Pb) | **October 18, 2016**<br>• The primary standard was retained. | • 0.15 µg/$m^3$ (3 month) |

**Additional details on the lead (Pb) standard**

The 2010 lead standard requires ambient monitoring near any facility that emits 0.5 tons per year (tpy) of lead, and the 2015 proposal to retain the lead standard lowered the reporting threshold to 0.5 tpy. Washington's only source above this threshold was Ardagh Glass in Seattle. Ecology modeled the impact of this facility on ambient air and demonstrated that it would not contribute to a maximum Pb concentration in ambient air above 50 percent of the NAAQS. On April 18, 2019, EPA issued Ecology a 5-year waiver for lead monitoring at Ardagh Glass based on the modeling results.

## Ongoing and follow-up requirements from previously finalized NAAQS

### Sulfur dioxide ($SO_2$)

EPA issued final $SO_2$ area designations for 36 counties in Washington in December 2017. EPA designated 34 counties "attainment/unclassifiable" and two counties, Lewis and Thurston, as "unclassifiable" based on limited information. The three remaining counties (Chelan, Douglas, and Whatcom) needed further investigation and were not a part of this round of designations. EPA must designate all remaining areas by December 31, 2020.

In 2017, Ecology established new $SO_2$ monitors near aluminum smelters that emit more than 2000 tpy of $SO_2$. Two of these monitors are located in Whatcom County and one is in Chelan County near the border with Douglas County. Ecology collects $SO_2$ data to support EPA in their designation process.

## Ongoing National Ambient Air Quality Standards reviews

### $PM_{2.5}$

The PM standards are under review at this time. As of April 2020, EPA proposes to retain the current particulate matter standards without revision. Following publication in the Federal Register, EPA will hold a 60-day comment period. The final rule may follow by the end of 2020.

### Ozone

EPA issued a Draft Integrated Science Assessment (ISA) in September 2019. EPA announced that the final Integrated Science Assessment for Ozone and Related Photochemical Oxidants was available on April 20, 2020. A proposed rule may follow later in 2020 with a final rule action by the end of 2020.

# Network Analyses

## Introduction

Ecology evaluated the Washington Network in accordance with its monitoring policy goal and objectives. Ecology generally followed EPA guidance with some modifications to suit Washington's unique environment. Several EPA-provided tools, including the area and population served by each site, are based on a nearest-monitor approach that is not suitable for Washington's complex and mountainous terrain. In addition, correlation matrices and removal bias estimates that span the whole state were not found to be particularly useful given the wide range of air quality conditions across Washington's many unique airsheds.

Ecology developed its own criteria to evaluate the value of each monitoring site based on four types of metrics: measurement criteria, population criteria, source criteria and environmental criteria. The $PM_{2.5}$ and ozone networks were evaluated using decision matrices with these metrics. A decision matrix is a tool that synthesizes multiple criteria into a single value score for each station. Decision matrices were not constructed for other pollutants due to the limited number of monitors.

## Criteria pollutants

On January 1, 2020, Ecology and its partners operated 75 monitoring sites that were part of the Washington Network. Those sites are shown on the map in Figure 10, and the parameters monitored are summarized in Table 7.

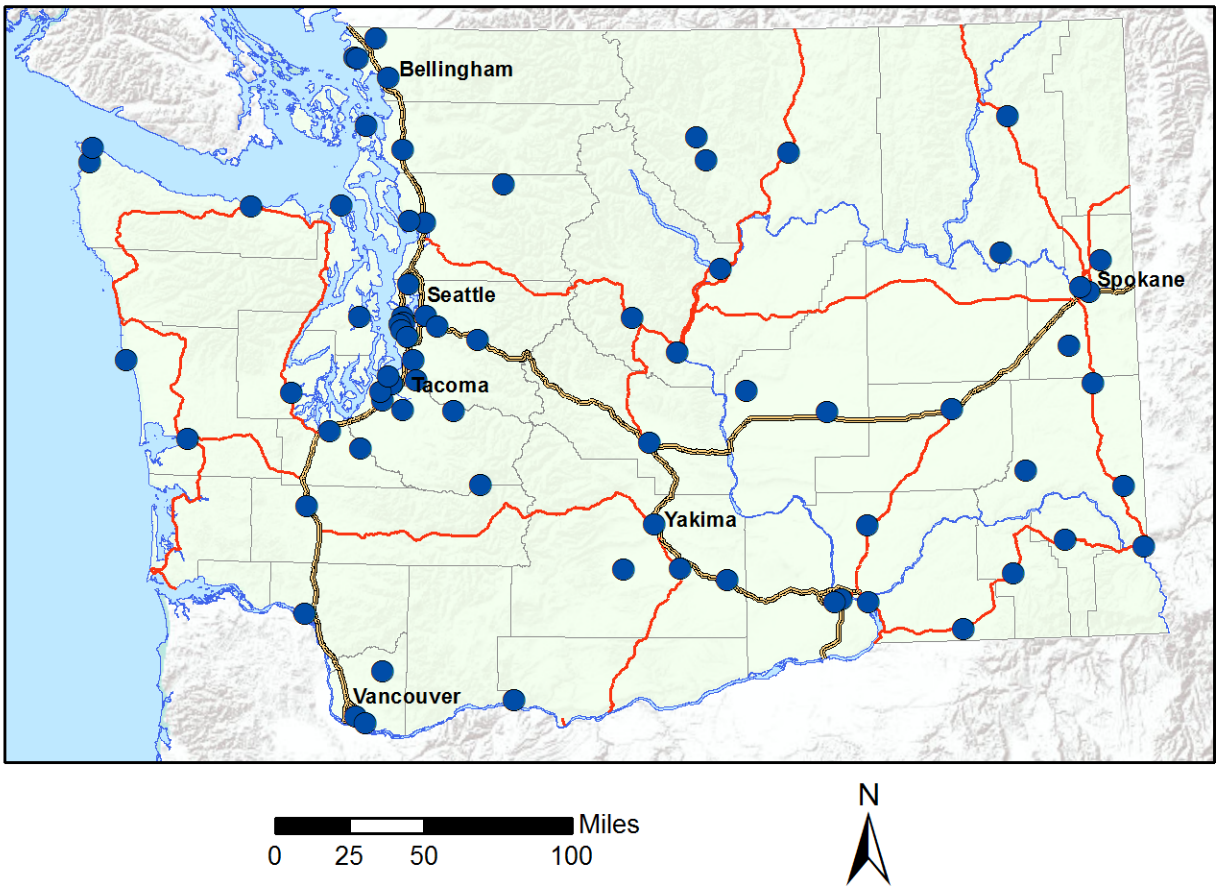


**Figure 10. Map of all Washington Network monitoring sites**

**Table 7. Summary of parameters monitored at Washington Network monitoring sites**

| Site Name | AQS ID | CO | $NO_2$/ $NO_y$ | $O_3$ | $SO_2$ | $PM_{2.5}$ (FRM/FEM) | $PM_{2.5}$ (Non-FRM/FEM) | $PM_{10}$ | Meteor-ological | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Aberdeen-Division St | 530272002 | | | | | | ✓ | | | |
| Anacortes-202 O Ave | 530570011 | | | ✓ | ✓ | ✓ | | | | |
| Auburn-M St | 530330089 | | | | | ✓ | | | | |
| Bellevue-SE 12th St | 530330031 | | | | | | ✓ | | | |
| Bellingham-Pacific St | 530730019 | | | | | ✓ | | | | |
| Bremerton-Spruce Ave | 530350007 | | | | | ✓ | | | | |
| Burbank-Maple St | 530710006 | | | | | | | ✓ | ✓ | |
| Cheeka Peak | 530090013 | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | |
| Chehalis-Market Blvd | 530410004 | | | | | | ✓ | | | |
| Chelan-Woodin Ave | 530070007 | | | | | | ✓ | | | |
| Cheney-Turnbull | 530630001 | | | ✓ | | | | | | |
| Clarkston-13th St | 530030004 | | | | | | ✓ | | | |
| Colville-E 1st St | 530650005 | | | | | ✓ | | ✓ | ✓ | |
| Custer-Loomis | 530730005 | | | ✓ | | | | | | |
| Darrington-Fir St | 530610020 | | | | | ✓ | | | | |
| Dayton-W Main St | 530130002 | | | | | | ✓ | | | |

| Site Name | AQS ID | CO | $NO_2$/ $NO_y$ | $O_3$ | $SO_2$ | $PM_{2.5}$ (FRM/FEM) | $PM_{2.5}$ (Non-FRM/FEM) | $PM_{10}$ | Meteor-ological | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Ellensburg-Ruby St | 530370002 | | | | | ✓ | ✓ | | | |
| Enumclaw-Mud Mtn. | 530330023 | | | ✓ | | | | | ✓ | |
| Ferndale-Kickerville Road | 530730013 | | | | ✓ | | | | | |
| Ferndale-Mountain View Rd | 530730017 | | | | ✓ | | | | ✓ | |
| Issaquah-Lake Sammamish | 530330010 | | | ✓ | | | | | | |
| Kennewick-Metaline | 530050002 | | | | | | ✓ | ✓ | ✓ | |
| Kennewick-S Clodfelter Rd | 530050003 | | | ✓ | | | | | | |
| Kent-Central & James | 530332004 | | | | | ✓ | | | | |
| Lacey-College St | 530670013 | | | | | | ✓ | | | |
| LaCrosse-Hill St | 530750005 | | | | | | ✓ | | | |
| Lake Forest Park | 530330024 | | | | | | ✓ | | | |
| Leavenworth-Evans St | 530070010 | | | | | | ✓ | | | |
| Longview-30th Ave | 530150015 | | | | | | ✓ | | | |
| Malaga-Malaga Hwy | 530070012 | | | | ✓ | | | | ✓ | |
| Marysville-7th Ave | 530611007 | | | | | ✓ | | | | |
| Mesa-Pepiot Way | 530210002 | | | | | | ✓ | | | |
| Moses Lake-Balsam St | 530251002 | | | | | | ✓ | | | |
| Mt Rainier-Jackson Visitors Ctr | 530530012 | | | ✓ | | | | | | |
| Mt Vernon-S Second St | 530570015 | | | | | | ✓ | | | |
| Neah Bay-Makah Tribe | 530090015 | | | | | | ✓ | | | |
| North Bend-North Bend Way | 530330017 | | | ✓ | | | ✓ | | ✓ | |
| Omak-Colville Tribe | 530470013 | | | | | ✓ | | | ✓ | |
| Pomeroy (Temporary) | 530230001 | | | | | | ✓ | | | |
| Port Angeles- E 5th St | 530090017 | | | | | | ✓ | | | |
| Port Townsend-San Juan Ave | 530310003 | | | | | | ✓ | | | |
| Pullman-Dexter SE | 530750003 | | | | | | ✓ | | | |
| Puyallup-128th St | 530531018 | | | | | | ✓ | | | |
| Quincy-3rd Ave NE (Temporary) | 530251003 | | | | | | ✓ | | ✓ | |
| Ritzville-Alder St | 530010003 | | | | | | ✓ | | | |
| Rosalia-Josephine St | 530750006 | | | | | | ✓ | | | |
| Seattle-10th & Weller | 530330030 | ✓ | ✓ | | | ✓ | | | ✓ | CSN |
| Seattle-Beacon Hill | 530330080 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | CSN, NATTS, PAMS |
| Seattle-Duwamish | 530330057 | | | | | ✓ | | | | CSN |
| Seattle-South Park | 530331011 | | | | | | ✓ | | | |
| Shelton-W Franklin | 530450007 | | | | | | ✓ | | | |
| Spokane-Augusta Ave | 530630021 | | | | | ✓ | | ✓ | ✓ | |
| Spokane-Greenbluff | 530630046 | | | ✓ | | | | | | |
| Spokane-Monroe St | 530630047 | | | | | | ✓ | | | |
| Sunnyside-S 16th St | 530770005 | | | | | | ✓ | | | |
| Tacoma- L Street | 530530029 | | | | | ✓ | | | | CSN |
| Tacoma-Alexander Ave | 530530031 | | | | | | ✓ | | | CSN |
| Tacoma-S 36th St | 530530024 | | ✓ | | | ✓ | | | ✓ | |
| Tacoma-Tower Dr | 530531016 | | | | | | | | ✓ | |
| Taholah-Quinault Tribe | 530270011 | | | | | | ✓ | | | |

| Site Name | AQS ID | CO | $NO_2$/ $NO_y$ | $O_3$ | $SO_2$ | $PM_{2.5}$ (FRM/FEM) | $PM_{2.5}$ (Non-FRM/FEM) | $PM_{10}$ | Meteor-ological | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Toppenish-Yakama Tribe | 530770015 | | | | | ✓ | | | ✓ | |
| Tukwila Allentown | 530330069 | | | | | | ✓ | | | |
| Tulalip-Totem Beach Rd | 530610021 | | | | | | ✓ | | | |
| Twisp-Glover St | 530470009 | | | | | | ✓ | | | |
| Vancouver NE 84th Ave | 530110020 | | | | | ✓ | | | | |
| Vancouver-Blairmont Dr | 530110011 | | | ✓ | | | | | ✓ | |
| Walla Walla-12th St | 530710005 | | | | | | ✓ | | | |
| Wellpinit-Spokane Tribe | 530650002 | | | | | | ✓ | | | |
| Wenatchee-Fifth St | 530070011 | | | | | | ✓ | | ✓ | |
| White Salmon (Temporary) | 530390006 | | | | | | ✓ | | | |
| White Swan-Yakama Tribe | 530770016 | | | | | | ✓ | | ✓ | |
| Winthrop-Chewuch Rd | 530470010 | | | | | | ✓ | | | |
| Yacolt-Yacolt Rd | 530110022 | | | | | | ✓ | | | |
| Yakima-4th Ave | 530770009 | | | | | ✓ | | ✓ | | CSN |
| Yelm-Northern Pacific | 530670005 | | | ✓ | | | | | | |

## Carbon monoxide (CO)

There are three CO monitoring sites in the Washington Network. Two sites (Cheeka Peak and Seattle-Beacon Hill) monitor CO as a required NCore parameter and the third (Seattle-10th & Weller) as a required Near-road parameter. As CO monitoring is limited to sites required by federal monitoring programs and CO concentrations are generally well below federal standards, Ecology did not evaluate this network further.

## Nitrogen dioxide ($NO_2$)

There are three $NO_2$ monitoring sites in the Washington Network. Two sites (Seattle-10th & Weller and Tacoma-S 36th) monitor $NO_2$ as a required Near-road parameter and the third (Seattle-Beacon Hill) monitors $NO_2$ to meet the area-wide $NO_2$ monitoring requirement described in 40 C.F.R. Part 58.10. Additionally, Washington's two NCore sites (Seattle-Beacon Hill and Cheeka Peak) monitor $NO_y$ and $NO_y$-NO as required NCore parameters. As $NO_2$ monitoring is limited to sites required by federal monitoring programs and $NO_2$ concentrations are generally well below federal standards, Ecology did not evaluate this network further.

## Ozone ($O_3$)

### Background

Ozone data are used to determine compliance with the NAAQS, provide near-real-time information on air quality for public health protection using EPA's Air Quality Index (AQI), forecast air pollution episodes and make ozone action-day calls, and determine efficacy of control measures.

Ecology used a decision matrix to analyze the relative value of sites in the ozone monitoring network. Stations were ranked in order of value as informed by Ecology's monitoring policy goals and objectives. The decision matrix primarily emphasized the protection of public health. As elevated ozone concentrations are associated with a number of adverse health effects, the decision matrix gave higher scores to sites with higher measured pollutant concentrations and larger populations represented. The combination of measured concentrations and population represented at each site signifies the population exposure risk.

In contrast to many states elsewhere in the U.S., ozone precursor sources in Washington State are less uniformly distributed. Ozone concentrations are relatively low in urban areas, because: (1) there are no major ozone-precursor-source regions upwind, (2) precursors have not yet undergone photochemical reactions during short travel times, and (3) background ozone is subject to $NO_x$ titration. The highest ozone concentrations in Washington State occur in the relatively sparsely populated western foothills of the Cascade Range, which lie downwind of the urban areas of the Puget Sound lowlands, and in the Tri-Cities. High ozone events occur on hot summer days with low to moderate winds. As ozone precursors originating in different areas undergo photochemical reactions during transport, determining relative contributions of each source area is not straightforward. For these reasons, Ecology did not define airsheds and populations specific to each ozone monitor.

### Scoring

The criteria included in the ozone decision matrix are summarized in Table 8 below.

**Table 8. Ozone decision matrix criteria**

| Criterion | Units |
|---|---|
| Design value | ppb |
| 75$^{th}$ percentile | ppb |
| Number of NAAQS exceedances | # days |
| Risk of NAAQS violation | # years |
| Trend | --- |
| Population represented | # people |
| Population growth | % |
| Environmental justice index | --- |
| Forecasting value | --- |

Values were normalized to a range of [0-1]. The final decision matrix scores were summed and scaled to a high of 100 as shown in Figure 11. Sites with the highest scores are considered to provide the greatest relative value to the Washington Network.

The final ozone rankings should be interpreted with caution. The scores in each criterion have an implicit margin of error, and these errors are aggregated in the final scores. In addition, while every attempt was made to scale and synthesize the scores in the most objective manner possible, small adjustments in these methods can lead to changes in the final site rankings. Therefore, small differences in the final scores are likely not significant. Finally, Ecology recognizes that many sites provide value that is not easily quantifiable, such as the value of a long historical record, inclusion in a specific national network (e.g. NCore), or the value of historically low-concentration sites during exceptional events such as wildfires.

All analyses were conducted in R 3.6.3 and ArcGIS 10.2.2.

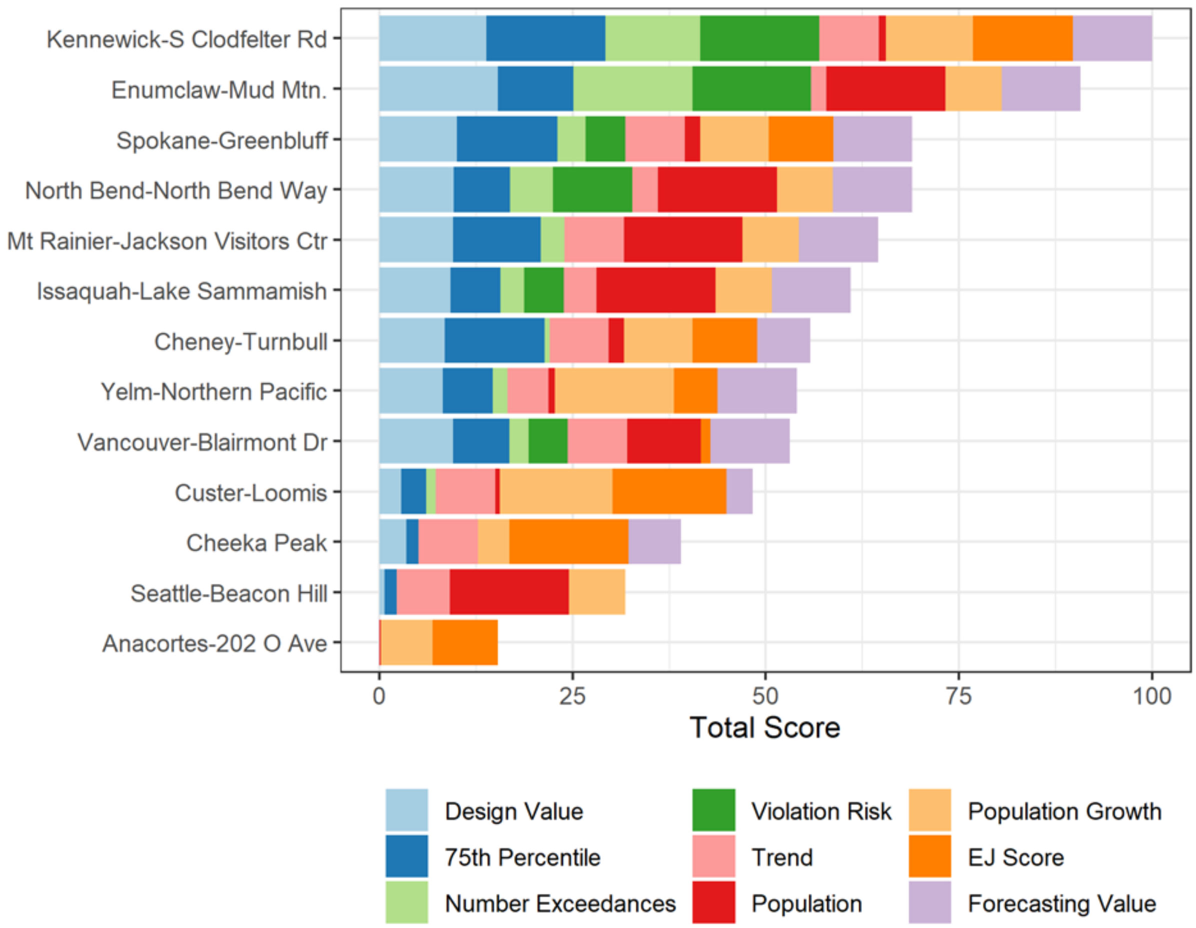


**Figure 11. Final ozone decision matrix scores**

The methods for each criterion are summarized below, and the full rankings in each category can be found in the appendix. Unless otherwise noted, all calculations were performed on 5 years of data when available (2015-2019). Only data from the Washington ozone season (May 1 – Sept 30) was used to ensure comparability across seasonal and year-round sites.

*8-Hour design value*

**Purpose:** Design values are used to determine compliance with the NAAQS. They also provide information on acute exposure to ozone on the highest concentration days of the ozone season.

**Methods:** The form of the ozone design value is the 4th highest daily 8-hour maximum concentration (D8M), averaged over three years. The 5-year 98th percentile (2015-2019) D8M was calculated as a surrogate for the design value for several reasons:

The 5-year 98th percentile represents the five years of data collected since the previous network assessment (2015-2019).

The 98th percentile D8M is equivalent to the 4th high D8M in years with complete data. Using the 98th percentile rather than the 4th high in years with only partial data completeness minimizes bias from missing data.

The 4th highest daily D8Ms are highly variable from year to year. The 98th percentile of a full five years of data is a more stable metric that approximates the mid-range of three years of design values at a given site. Sites with the highest 98th percentile D8Ms were given the highest scores.

*75th percentile*

**Purpose:** While the 98th percentile D8M represents ozone concentrations on highest days in the ozone season, the 75th percentile is a better representation of ozone concentrations on typical days. The distribution of ozone concentrations at a given site varies by region and topography. Sites with high design values may report relatively low concentrations on typical days, while sites that routinely report relatively elevated concentrations may never reach unhealthy concentrations on their worst days. The 75th percentile D8M provides information on chronic levels of exposure to ozone over the long-term.

**Methods:** The 5-year 75th percentile D8M was calculated at each site. Sites with the highest 75th percentile D8Ms were given the highest scores.

*Number of NAAQS exceedances*

**Purpose:** The level of the federal ozone standard (0.070 ppm) is the breakpoint between the Moderate and Unhealthy for Sensitive Groups categories of the AQI. Frequent exceedances of the federal standard indicate greater health risks to sensitive populations as well as an increased risk of violating the NAAQS.

**Methods:** The number of days with D8M greater than 0.070 ppm was calculated for each site. Sites with the highest number of exceedances were given the highest scores.

*Risk of NAAQS violation*

**Purpose:** Like the number of NAAQS exceedances, the risk of a NAAQS violation indicates compromised air quality for sensitive groups as well as a greater likelihood of nonattainment. However, due to the form of the standard as the 3-year average of annual D8Ms, the risk of a

NAAQS violation depends upon not only the number of exceedances but also how those exceedances are distributed across years. Sites with greater than three exceedances in a given year are at a greater risk of violating the NAAQS, which is based on the 4th highest D8M per year.

**Methods:** The number of years with 4th highest D8M greater than 0.070 ppm was calculated for each site. Sites with the highest number of years over 0.070 ppm were given the highest scores.

*Trend*

**Purpose:** Sites at which concentrations are rising rapidly are potential targets for more intensive monitoring and/or interventions to reduce emissions.

**Methods:** The trends in deseasonalized monthly median ozone concentrations were computed as TheilSen slope estimates. The trend at many sites was not statistically significant at $p < 0.05$. These sites were given scores of 0.5. Negative, statistically significant slopes were scaled from [0-0.5]. No sites had positive, statistically significant slopes.

*Population represented*

**Purpose:** Monitors in dense population centers provide information on the exposures of a large number of people. As ozone formation is a complex process involving a mix of regional sources, monitoring sites do not simply represent the geographic areas and populations closest to them. The population of the surrounding core-based statistical area (CBSA) was attributed to each monitoring site in order to reflect the regional nature of ozone formation and transport.

**Methods:** CBSA boundaries were obtained from the U.S. Office of Management and Budget. Monitoring sites were given the attributes of their Metropolitan or Micropolitan Statistical Area (MSA). Sites with the highest 1-year American Community Survey 2019 CBSA estimated populations were given the highest scores.

*Population growth*

**Purpose:** Monitors in areas of rapid population growth are of particular interest because concentrations may rise in tandem with growth and development. These sites may be candidates for more intensive monitoring in the future.

**Methods:** The population living within each monitor's associated CBSA was extracted from the American Community Survey 1-year population estimates for 2015 and 2019. The population growth rate was calculated as the rate of change in population from 2015-2019. Sites whose associated CBSAs had the highest rates of population growth were given the highest scores.

*Environmental justice index*

**Purpose:** Ecology is committed to protecting the residents of Washington State from environmental and health hazards without regard to race, income, education, culture, national origin, or any other demographic factor. Central to Ecology's commitment to environmental justice is the equitable provision of services among the state's demographic groups. Low-income and communities of color typically face higher burdens of environmental pollution and greater susceptibility to environmental health hazards, including air pollution. In light of this, environmental justice is an important consideration in the distribution of monitoring resources. Monitoring sites in communities with environmental justice concerns provide additional value to the network on the air pollution exposures of historically under-represented and under-served populations.

**Methods:** Five socioeconomic indicators were integrated into a single score: linguistic isolation, educational attainment, poverty, unemployment, and housing-burdened low-income households.

Four indicators were extracted from the 2018 5-year American Community Survey within each monitor's associated CBSA:

- Linguistic isolation (percent of households without a member who speaks English "very well" or better)
- Low educational attainment (percent of individuals 25 years and older without a high school diploma or equivalent)
- Poverty (percent of individuals living below 200 percent of the federal poverty level for their household size)
- Unemployment (percent of the civilian work force both eligible and unemployed)

The remaining indicator was obtained from the office of Housing and Urban Development's (HUD's) 2012-2016 Comprehensive Housing and Affordability Strategy (CHAS) database at the census tract level and aggregated to each CBSA:

- Housing-burdened low-income (percent of households living below 80% of the HUD-adjusted median family income for the area who spend more than 30% of their income on housing)

Percent housing-burdened low-income was added as an indicator in order to account for the wide range of cost-of-living conditions in different regions of the state. Income alone is an insufficient measure of economic conditions, as elevated housing costs can make certain areas of the state less affordable in spite of higher incomes.

This method of tabulating environmental justice scores was developed by the California Office of Environmental Health Hazards (OEHHA, 2017). Percentages for each indicator were normalized to a range of [0-1] and summed. Sites with the highest percentages in each socioeconomic category were given the highest scores.

*Forecasting value*

**Purpose:** In the recent past, $O_3$ forecasts have been limited to locations downwind of King/ Pierce County metropolitan areas, the Tri Cities, Spokane and Vancouver. Monitors in these airsheds are routinely examined for 1-3 day histories and coupled with modeled forecasts, to inform the issuance of public messages. Remote monitors are often relied on to assess $O_3$ transport from afar, especially when wildfire smoke is present.

**Methods**: Past experience and best professional judgment were used in ranking sites. Monitors that are used as described above were ranked on a scale of 0 (unimportant, hardly used for these purposes), 1 (slightly important), 2 (used occasionally) and 3 (very important, constantly checked for the presence of ozone).

## $PM_{2.5}$

### Background

$PM_{2.5}$ data are used to determine compliance with the NAAQS, provide near-real-time information on air quality for public health protection through Ecology's WAQA and EPA's Air Quality Index (AQI), forecast air pollution episodes, determine whether to allow or curtail various types of burning, and evaluate the effectiveness of control measures.

Ecology used a decision matrix to analyze the relative value of sites in the $PM_{2.5}$ monitoring network. Stations were ranked in order of value as informed by Ecology's monitoring policy goals and objectives. The decision matrix primarily emphasized the protection of public health. As elevated $PM_{2.5}$ concentrations are associated with a number of adverse health effects, the decision matrix gave higher scores to sites with higher measured pollutant concentrations and larger populations represented. The combination of measured concentrations and population represented at each site signifies the population exposure risk.

Temporary monitoring sites and recently added monitoring sites (such as Tulalip-Totem Beach Rd) were not included in the decision matrix due to their short monitoring records.

### Scoring

The criteria included in the $PM_{2.5}$ decision matrix are summarized in Table 9 below.

**Table 9. $PM_{2.5}$ decision matrix criteria**

| Criterion | Units |
|---|---|
| 24-hour design value | $\mu g/m^3$ |
| Annual mean | $\mu g/m^3$ |
| Exceedances of NAAQS and Ecology's Healthy Air Goal | # days |
| Trend | --- |
| Area represented | Square meters |
| Population represented | # people |
| Population growth | % |
| Environmental justice score | --- |
| Outdoor burning | Tons $PM_{2.5}$ emitted |
| Point source emissions | Distance-weighted tons $PM_{2.5}$ emitted |
| Traffic density | AADT-miles |

| Criterion | Units |
| --- | --- |
| Residential wood combustion | Tons $PM_{2.5}$ emitted |
| Forecasting value | --- |

Values were normalized to a range of [0-1]. The final decision matrix scores were summed and scaled to a high of 100 as shown in Figure 12. Sites with the highest scores are considered to provide the greatest relative value to the Washington Network.

The final $PM_{2.5}$ rankings should be interpreted with caution. The scores in each criterion have an implicit margin of error, and these errors are aggregated in the final scores. In addition, while every attempt was made to scale and synthesize the scores in the most objective manner possible, small adjustments in these methods can lead to changes in the final site rankings. Therefore, small differences in the final scores are likely not significant. Readers are encouraged to interpret the site rankings in broader quantiles rather than by individual scores. For example, it is reasonable to conclude that a site ranked as one of the highest 10 sites is generally more valuable than a site ranked in the bottom 10. However, sites whose scores are separated by only a few points are likely to provide comparable value to the Washington Network.

Finally, Ecology recognizes that many sites provide value that is not easily quantifiable, such as the value of a long historical record, inclusion in a specific national network (e.g. NCore), or the importance of a site for local outreach in specific communities. These qualitative values are not reflected in the site rankings but would be considered in any decision to remove or relocate low-scoring sites.

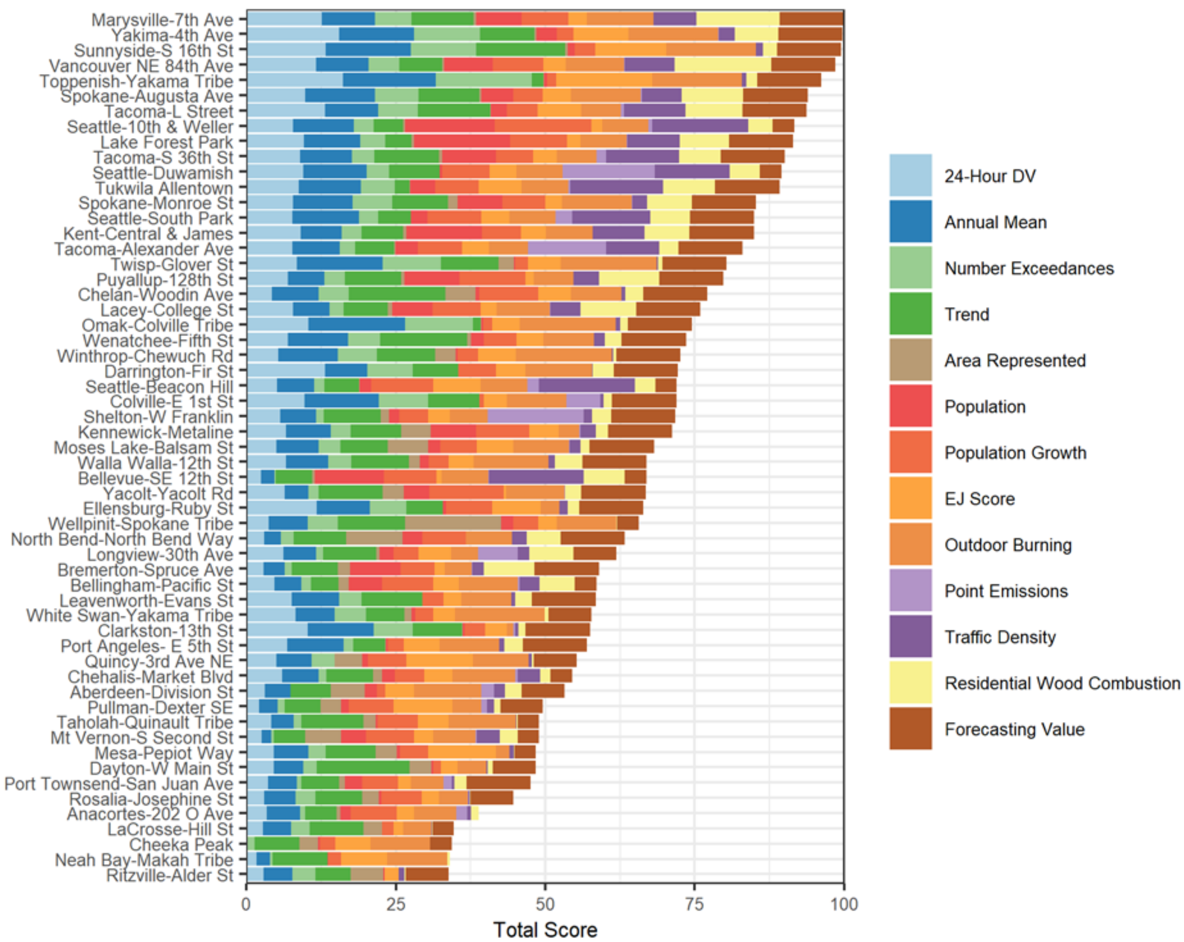


**Figure 12. Final $PM_{2.5}$ decision matrix scores**

The methods for each criterion are summarized below, and the full rankings in each category can be found in the appendix. Unless otherwise noted, all calculations were performed on 5 years of data when available (2015-2019).

*24-hour design value*

**Purpose:** Design values are used to determine compliance with the NAAQS. They also provide information on short-term exposure to $PM_{2.5}$ during periods of the worst $PM_{2.5}$ pollution.

**Methods:** The form of the 24-hour $PM_{2.5}$ design value is the 98$^{th}$ percentile of each year's 24-hour average concentrations, averaged over three years. The 5-year 98th percentile (2015-2019) of heating season (October – March) 24-hour average concentrations was calculated as a surrogate for the design value for several reasons:

The 5-year 98th percentile represents the five years of data collected since the previous network assessment (2015-2019).

Summers 2017 and 2018 were marked by extensive statewide wildfire smoke impacts spanning several weeks. These smoke events had a large impact on measured concentrations and, due to their duration, affected annual summary statistics as well. Since wildfire smoke events can generally be treated as exceptional events within the framework of NAAQS compliance, the 98$^{th}$ percentile of datasets influenced by wildfire smoke is not as useful in assessing the risk of violations of the NAAQS. The 98$^{th}$ percentile of heating-season $PM_{2.5}$ data indicates the degree to which $PM_{2.5}$ concentrations are elevated during the months that typically have the worst $PM_{2.5}$ conditions outside of wildfire season.

Sites with the highest 98$^{th}$ percentile values were given the highest scores.

*Annual mean*

**Purpose:** While the 98th percentile 24-hour average $PM_{2.5}$ concentration represents $PM_{2.5}$ levels in the worst periods of $PM_{2.5}$ pollution, the annual mean represents chronic $PM_{2.5}$ exposure throughout the year. The distribution of $PM_{2.5}$ concentrations varies by region topography, and local sources. Sites with high 24-hour design values may report relatively low concentrations on typical days, while sites that routinely report relatively elevated concentrations may never reach unhealthy concentrations on their worst days. The annual mean concentration also indicates the risk of violating the annual $PM_{2.5}$ design value.

**Methods:** The 5-year mean of 24-hour average concentrations was calculated at each site. Sites with the highest mean concentrations were given the highest scores.

*Exceedances of NAAQS and Ecology's Healthy Air Goal*

**Purpose:** In the Washington Air Quality Advisory (WAQA), which Ecology uses to report the health risk of exposure to monitored $PM_{2.5}$ concentrations, the federal 24-hour $PM_{2.5}$ standard of 35 $\mu g/m^3$ is the breakpoint between the Unhealthy for Sensitive Groups and Unhealthy categories. Frequent exceedances of the 24-hour $PM_{2.5}$ NAAQS indicate greater health risks to exposed populations as well as an increased risk of violating the NAAQS. Ecology maintains a stricter Healthy Air Goal of 20 $\mu g/m^3$, which is the breakpoint between the Moderate and Unhealthy for Sensitive Groups categories of the WAQA. This goal is based on epidemiological evidence of adverse health impacts to sensitive populations below the level of the federal standard. Frequent exceedances of the Healthy Air Goal indicate greater health risks to sensitive populations.

**Methods:** The number of days over 35 $\mu g/m^3$ and the number of days over 20 $\mu g/m^3$ were calculated and summed for each site. This metric intentionally double-counts days over 35 $\mu g/m^3$ in order to give additional weight to sites with frequent NAAQS exceedances. Sites with the highest number of total days over these two breakpoints were given the highest scores.

*Trend*

**Purpose:** Sites at which concentrations are rising rapidly are potential targets for more intensive monitoring and/or interventions to reduce emissions.

**Methods:** The trends in deseasonalized monthly mean $PM_{2.5}$ concentrations were computed as TheilSen slope estimates. The trend at many sites was not statistically significant at $p < 0.05$. These sites were given scores of 0.5. Positive, statistically significant slopes were scaled from [0.5-1], and negative, statistically significant slopes were scaled from [0-0.5].

*Area represented*

**Purpose:** The density of monitoring sites is typically much lower in rural areas than in urban areas. In rural areas, monitors may be spaced tens of miles apart. Isolated monitoring sites provide additional value to the network because they are the only available sites between great distances.

**Methods:** To define the areas represented by each monitoring site, we leveraged a body of work conducted jointly by Ecology and the Oregon and Idaho Departments of Environmental Quality known as "Regional Background Design Values 2014-2017." This project created maps of interpolated design values for criteria pollutants at 4km x 4km grid cell resolution across the three-state area.

The methods are described in detail in the project documentation. Briefly, $PM_{2.5}$ design values were interpolated using the following steps:

1. The medians of daily forecast $PM_{2.5}$ concentrations from July 2017-June 2014 were extracted from the AIRPACT air quality forecasting model at 4km grid cells across Washington. This time period was selected as the most recent three-year period for which (a) model forecasts were available at 4km resolution, and (b) model forecasts and monitoring data were minimally impacted by wildfire smoke.

2. Each $PM_{2.5}$ monitoring site was assigned the 3-year median of the grid cell closest to it, and the ratio between the site's 24-hour design value and 3-year median was calculated.

3. Ratios were interpolated across Washington at 4km resolution using Empirical Bayesian Kriging (EBK), a probabilistic interpolation method. The EBK method uses a weighted average of nearby data points to estimate a value at each 4km grid cell. These weights are optimized using semivariograms, which model the spatial dependence of the data. EBK is more complex than many other commonly used interpolation methods (e.g. inverse distance weighting or ordinary kriging) in that it allows the relationship between each grid cell and its surrounding data points to vary based on empirical data, rather than relying upon static or predetermined assumptions about spatial dependence.

   EBK repeats the process of constructing semivariograms using new data at the input locations in order to generate a distribution of semivariograms. In this exercise, the domain of all monitored values was divided into overlapping subsets of 20 to 100 input data points each. The suite of semivariograms was generated by employing a standard circular search method with a moving circular window across overlapping areas of data points. A model curve was then fitted form this distribution to calculate covariances based on distances between locations. The K-Bessel model was considered the most flexible such model for this exercise because it allows spatial autocorrelation to vary empirically. The model K-Bessel curve was the basis for weighting and interpolating the monitored values, and their corresponding modeled values, from the measured data points to the grid cells.

4. The EBK-derived ratios were then multiplied by the 3-year AIRPACT medians at each grid cell to produce a surface of estimated 24-hour $PM_{2.5}$ design values across Washington at a 4km resolution. That surface is show in Figure 13.

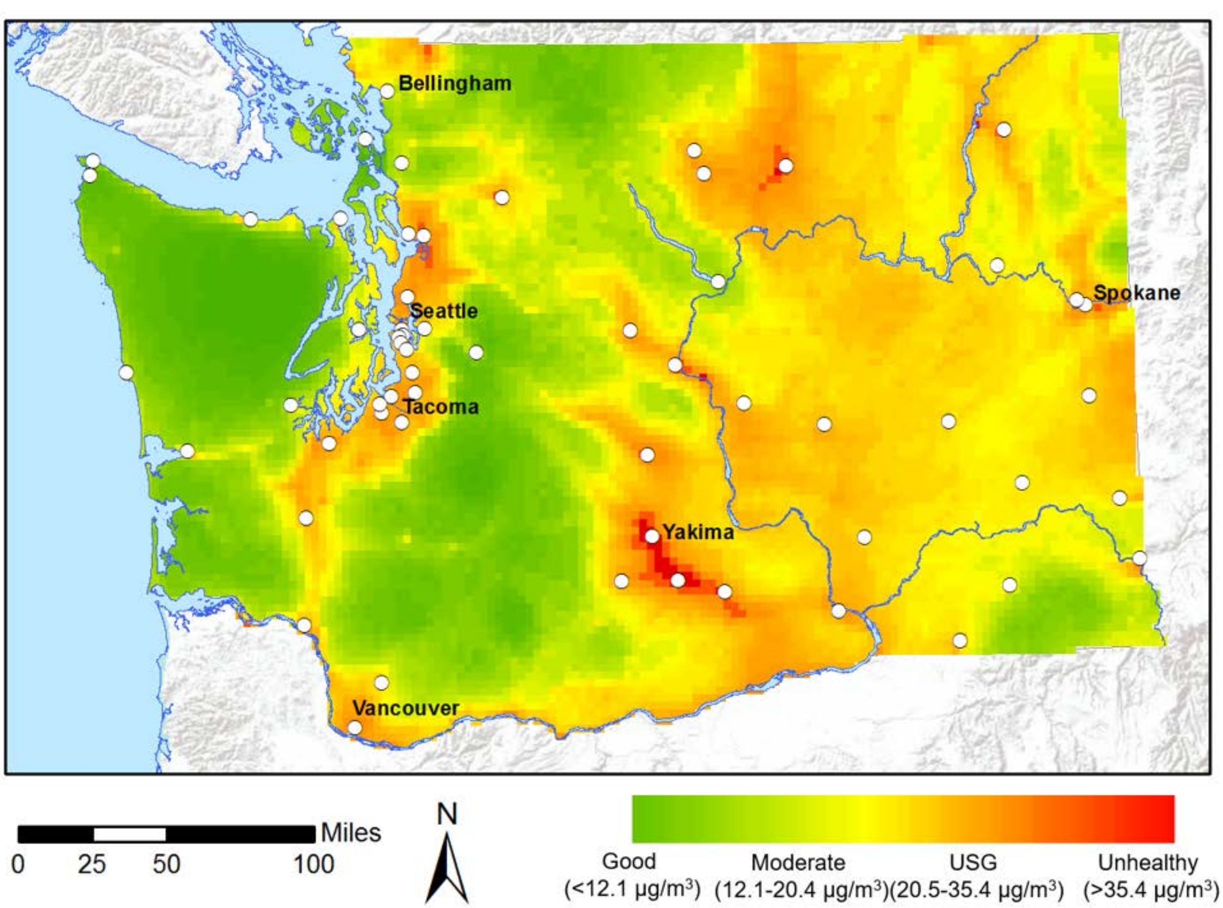


**Figure 13. Interpolated $PM_{2.5}$ design values**

5. To assign a geographic area to each monitoring site, the three nearest monitoring sites to each grid cell were identified. Monitoring sites were considered representative of that grid cell if their measured $PM_{2.5}$ design values were within ±5 $\mu g/m^3$ of the grid cell's predicted design value. Grid cells were assigned their closest representative monitoring site from among their three nearest sites. In other words, if the nearest site was not representative because its design value deviated by more than 5 $\mu g/m^3$ from the grid

cell's predicted design value, the grid cell was assigned its second- or third-nearest site if those met the criteria for representativeness.

6. Grid cells assigned to each monitoring site were then dissolved into contiguous polygons. In many cases, this process resulted in "islands" of noncontiguous areas assigned to each monitoring site. Where more than one separate polygon was assigned to each monitoring site, only the polygon containing the site itself was retained, and the islands were reassigned to other representative monitoring sites if they could be dissolved into contiguous polygons containing those sites. Areas that could not be reassigned to one of their three nearest sites were considered not represented by a monitoring site.

   Another common feature of the initial polygons was the presence of "donut holes", where areas surrounded by a monitor's represented area did not meet the ±5 $\mu g/m^3$ criteria to be considered represented by that monitor. These holes were allowed as unrepresented areas in cases where they spanned three or more contiguous grid cells. Holes of only one or two grid cells were removed, as predictions across such small isolated areas were not considered reliable.

The EBK interpolation method was selected to meet the challenges of predicting $PM_{2.5}$ design values across Washington's complex environment. In many states, design values can be interpolated across unmonitored areas directly from monitoring data where monitors are assumed to be representative of all areas in consistent and predictable patterns. Due to Washington's large mountain ranges, bodies of water, distinct climactic regions, and geographically-varying $PM_{2.5}$ sources, such methods would not be applicable. In contrast, the AIRPACT model, which incorporates terrain, meteorology and emissions, provides daily forecast estimates that are responsive to the complexities of Washington's environment. However, while AIRPACT forecasts produce reliable estimates of relative concentrations, indicating when $PM_{2.5}$ concentrations are higher in one area than another, the accuracy of their absolute predictions is limited, particularly at the upper end of the distribution (e.g. the $98^{th}$ percentile). Therefore, the raw $98^{th}$ percentile or design value of AIRPACT daily forecasts could not be assumed to accurately represent design values in unmonitored areas.

By using AIRPACT 3-year median concentrations as the basis for the geographic variation in concentrations, this method leverages AIRPACT forecasts at the midpoint of their distribution where they are assumed to provide the most reliable relative estimates. Rather than relying on their absolute accuracy, this method scales the AIRPACT medians to monitored design values, using the monitoring network for accuracy. Finally, the EBK method allows the relationship between the modeled and monitored concentrations to vary based on the empirical data. This method is appropriate for Washington's complex terrain, where the model/monitor relationship varies greatly among cities, mountain valleys, agricultural areas, and other distinct geographic features.

The geographic areas represented by each monitoring site are shown in the map in Figure 14, and a close-up of Puget Sound area monitoring sites is shown in Figure 15.

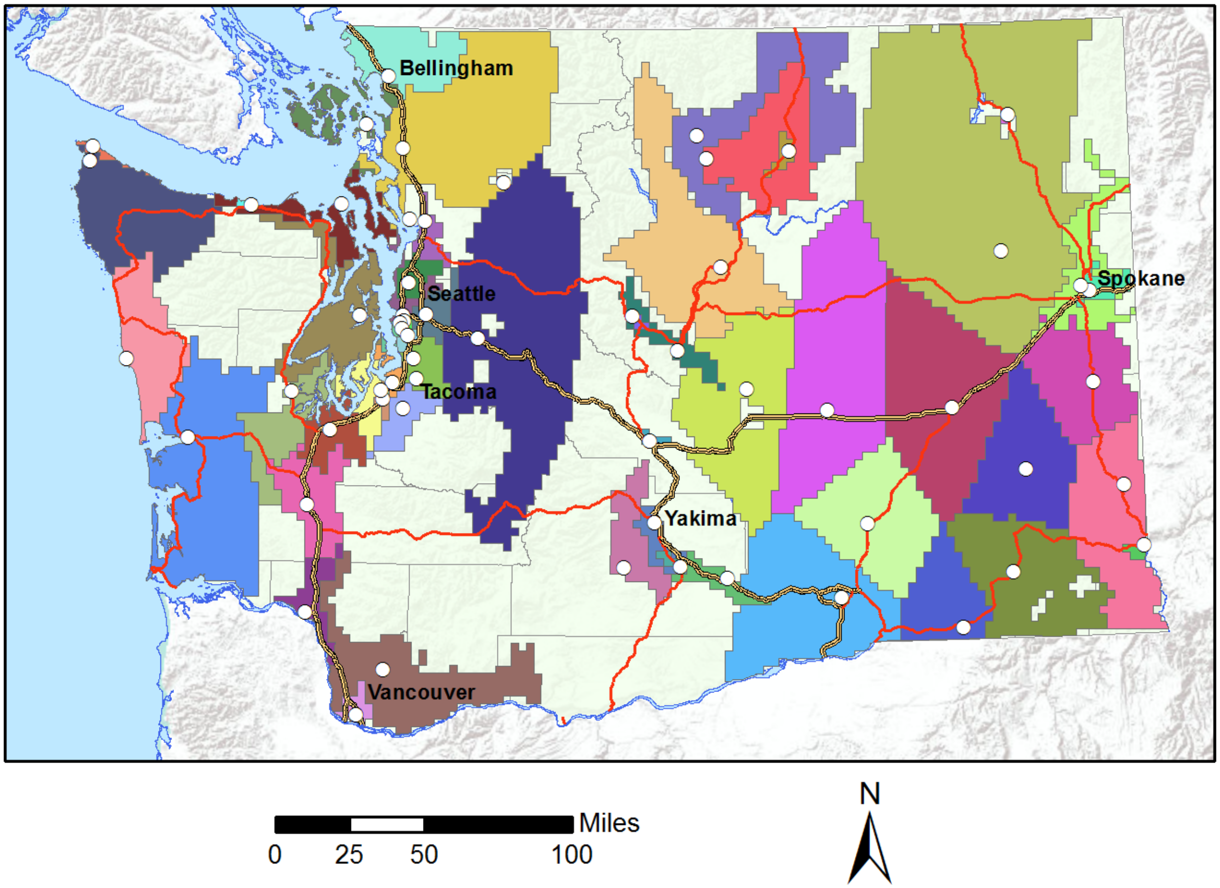


**Figure 14. Geographic area represented by each $PM_{2.5}$ monitoring site**

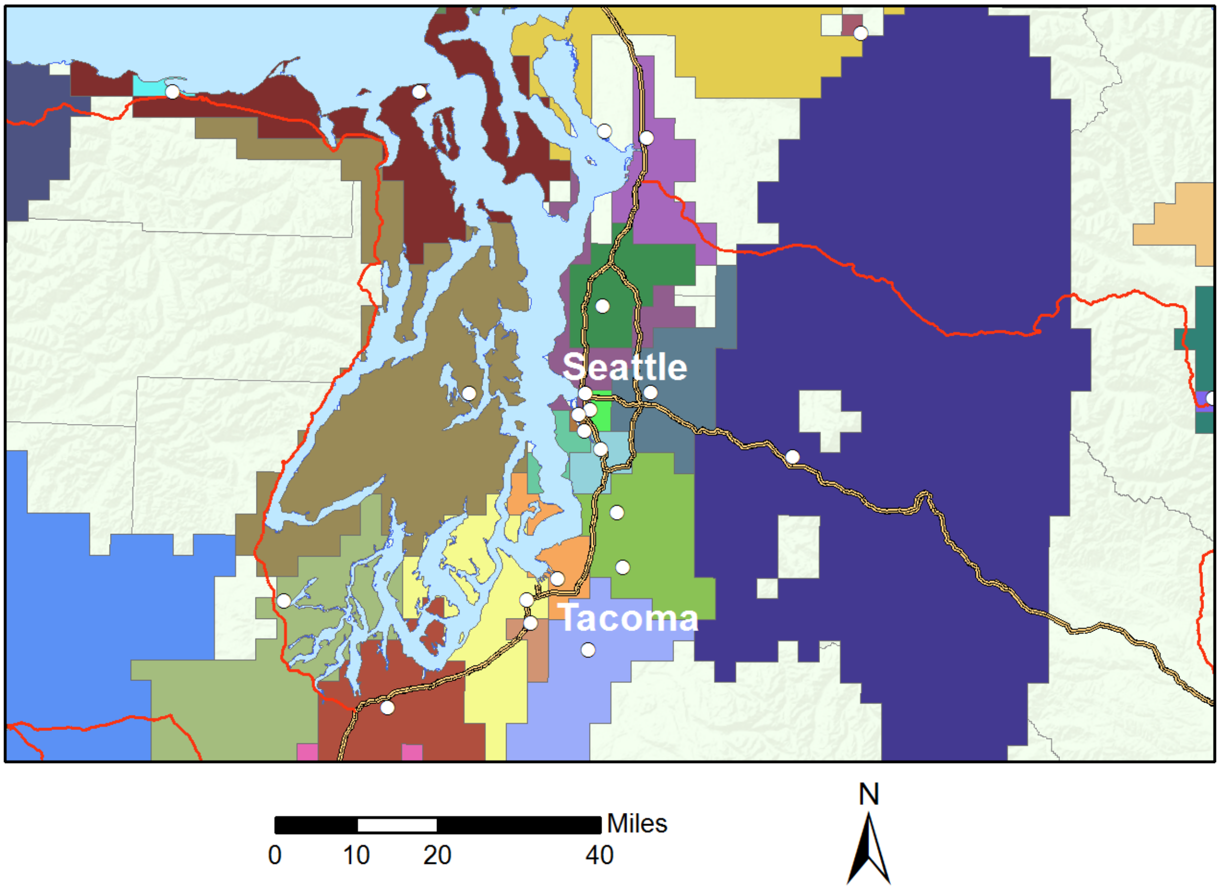


**Figure 15. Close-up of Seattle region geographic area represented by each $PM_{2.5}$ monitoring site**

*Population represented*

**Purpose:** Monitors in dense population centers provide information on the exposures of a large number of people.

**Methods:** The population living within each monitor's geographic area represented was extracted from the Washington Office of Financial Management's (OFM's) 2019 population estimates at the 2010 census block group level. Sites serving the largest populations were given the highest scores.

*Population growth*

**Purpose:** Monitors in areas of rapid population growth are of particular interest because concentrations may rise in tandem with growth and development. These sites may be candidates for more intensive monitoring in the future.

**Methods:** The population living within each monitor's geographic area served was extracted from Washington OFM's 2015 and 2019 population estimates at the 2010 census block group level.  The population growth rate was calculated as the rate of change in population from 2015-2019.  Sites with the highest rates of population growth were given the highest scores.

*Environmental justice index*

**Purpose:** Ecology is committed to protecting the residents of Washington State from environmental and health hazards without regard to race, income, education, culture, national origin, or any other demographic factor.  Central to Ecology's commitment to environmental justice is the equitable provision of services among the state's demographic groups.  Low-income and communities of color typically face higher burdens of environmental pollution and greater susceptibility to environmental health hazards, including air pollution.  In light of this, environmental justice is an important consideration in the distribution of monitoring resources. Monitoring sites in communities with environmental justice concerns provide additional value to the network on the air pollution exposures of historically under-represented and under-served populations.

**Methods:** Five socioeconomic indicators were integrated into a single score: linguistic isolation, educational attainment, poverty, unemployment, and housing-burdened low-income households.

Four indicators were extracted from the 2018 5-year American Community Survey within each monitor's area represented:

- Linguistic isolation (percent of households without a member who speaks English "very well" or better)
- Low educational attainment (percent of individuals 25 years and older without a high school diploma or equivalent)
- Poverty (percent of individuals living below 200 percent of the federal poverty level for their household size)
- Unemployment (percent of the civilian work force both eligible and unemployed)

The remaining indicator was obtained from the office of Housing and Urban Development's (HUD's) 2012-2016 Comprehensive Housing and Affordability Strategy (CHAS) database at the census tract level and aggregated to each CBSA:

- Housing-burdened low-income (percent of households living below 80% of the HUD-adjusted median family income for the area who spend more than 30% of their income on housing)

Percent housing-burdened low-income was added as an indicator in order to account for the wide range of cost-of-living conditions in different regions of the state.  Income alone is an insufficient measure of economic conditions, as elevated housing costs can make certain areas of the state less affordable in spite of higher incomes.

This method of tabulating environmental justice scores was developed by the California Office of Environmental Health Hazards (OEHHA, 2017).  Percentages for each indicator were normalized to a scale of [0-1] and summed.  Sites with the highest percentages in each socioeconomic category were given the highest scores.

*Outdoor burning*

**Purpose:** Particularly in Central and Eastern Washington, $PM_{2.5}$ concentrations are routinely impacted by agricultural, silvicultural, and residential outdoor burning.  Silvicultural burning is expected to increase over the next 10 years due to efforts at the state and federal levels to use expanded prescribed burning as a tool to attempt to reduce wildfire risk.  Monitors in the proximity of these activities provide valuable information on the air quality impacts of these types of burning.

**Methods:** The tons of $PM_{2.5}$ emitted by agricultural, silvicultural and residential outdoor burning were extracted for each county from Washington's 2017 Comprehensive Emissions Inventory and summed.  Monitoring sites were given the sum of $PM_{2.5}$ tons emitted in the counties in which they are located.  Sites with the highest $PM_{2.5}$ tons emitted were given the highest scores.

*Point source emissions*

**Purpose:** Residents living in the proximity of point sources emitting $PM_{2.5}$ may be concerned about the impacts of those sources on their air quality.  Monitoring sites near these sources provide valuable information about these impacts, even if $PM_{2.5}$ concentrations at these sites are generally low.  Monitoring sites near large point sources can also provide valuable information about the impacts of abnormal activities at these facilities.

**Methods:** Annual $PM_{2.5}$ emissions in 2018 from facilities with an air operating permit were extracted from Washington's annual point source emissions inventory.  For each monitoring site, the distance was calculated to its nearest 10 point sources.  The inverse of this distance squared was multiplied by the point source's emissions and summed for each monitoring site.  Weighting point sources by inverse distance squared gives greater weight to proximate point sources.  Sites with the highest distance-weighted emission totals were given the highest scores.

*Traffic density*

**Purpose:** Vehicle emissions contribute to $PM_{2.5}$ concentrations, particularly in urban areas. Near-road pollution concentrations and patterns are a topic of heightened interest in the research community.  Monitored $PM_{2.5}$ values collected near heavily trafficked roadways can be analyzed to identify rates of dispersion and decay of vehicle emissions.

**Methods:** Average annual daily traffic (AADT) counts collected by the Washington State Department of Transportation (2018) were extracted on state and federal highways within 4 km of each monitoring site.  AADT counts were multiplied by the length of the roadway on which the counts were collected and summed to yield total AADT-miles within each site's 4 km radius. The 4 km radius was chosen to be consistent with the maximum extent of neighborhood-scale $PM_{2.5}$ monitoring as defined by EPA.  Sites with the highest number of AADT-miles were given the highest scores.

*Residential Wood Combustion*

**Purpose:** Residential wood combustion is a dominant source of $PM_{2.5}$ in Washington, particularly in winter months. Communities with high rates of residential wood combustion routinely experience impaired air quality conditions during winter, especially during cold and stagnant weather. Monitoring sites in smoke-impacted communities provide valuable information about the relationship among meteorology, smoke emissions, and ambient concentrations of $PM_{2.5}$ in these areas.

**Methods:** County-level $PM_{2.5}$ emissions from residential wood combustion were extracted from Washington's 2017 Comprehensive Emissions Inventory in tons per year. County-level emissions were allocated to 4km x 4km grid cells using spatial surrogates. The spatial surrogates included American Community Survey data on the use of wood as a heat source, type of land development, population density, density of multifamily dwellings (6+ units), and aerial imagery evidence of residential land. The emissions within a 4 km radius around each monitoring site were extracted from these grid cells. Each monitoring site was assigned the sum of the emissions of the grid cells that intersected its 4 km radius, weighted by the proportion of each grid cell that fell within the 4 km radius. Sites with the highest emissions within their radii were given the highest scores.

*Forecasting value*

**Purpose:** Ambient monitors provide one vital piece of information when making air quality forecasts and burn management decisions. The ERO-managed agricultural burn permitting program makes use of a network of agricultural burn (AgBurn) monitoring sites described below. CRO, ERO, DNR, and several local air agencies assess data from different monitors before authorizing outdoor and silvicultural burning, including ditch burning, orchard tearouts, pile burns, and other yard debris disposal. Various monitors are used to forecast wildfire smoke. Decisions to curtail wood burning during home heating season (i.e., "burn bans") are partly based on monitor readings in the affected community.

**Methods**: Past experience and best professional judgment were used in ranking sites. Monitors that are used as described above were ranked on a scale of 0 (unimportant, hardly used for these purposes), 1 (slightly important), 2 (used occasionally) and 3 (very important, constantly checked for the presence of smoke).

### AgBurn network

Ecology's Eastern Regional Office (ERO) regulates agricultural burning and Central Regional Office (CRO) manages outdoor and pile burning in their respective counties. Most burns are conducted in the spring and fall, but hardly any hours of compromised air are ever recorded in the spring months due to active weather and good smoke dispersion.

Eight $PM_{2.5}$ nephelometers (Walla Walla, Mesa, Dayton, Pullman, Ritzville, LaCrosse, Rosalia, and Moses Lake) operate in response to a legal directive and are used to manage smoke from agricultural burning. These sites are collectively known as the AgBurn network. Discussions with ERO smoke forecasters revealed that the LaCrosse monitor was least valuable to them, but data from other sites were closely scrutinized when making daily agricultural burn calls.

CRO's daily decisions on outdoor and pile burning also rely on all available $PM_{2.5}$ monitoring data. This analysis attempts to identify if the current monitors throughout eastern WA are appropriately situated to meet the needs of the ERO and CRO burn managers.

The appropriateness of monitoring locations was assessed by mapping the following metrics:

- $PM_{2.5}$ and wind data during spring and fall burning seasons (defined as February 20 – May 31, and October 1 – November 15, respectively) since the 2015 network assessment were considered. No wildfire smoke influences were present during these time windows, and woodsmoke influences were minimized by only considering data between 9AM and 4PM.

  Most eastern Washington monitors were considered with some exceptions. Only one Spokane area site (Augusta Ave) was considered. Sites in the Methow Valley were not considered primarily due to the lack of representative meteorological data and the fact that little pile burning occurs nearby. Though not the most representative source of meteorology, winds measured at Wenatchee were paired with Chelan and Leavenworth $PM_{2.5}$ data. A few sites across the state boundaries were included to see if Washington smoke consistently moved over state lines.

  For meteorological data, a mixture of on- site measurements and airport data were used, depending on availability and representativeness. Only airports reporting 1-minute data were considered. Wind data at airports are reported as calm whenever 1-hour average speeds drop below 3 knots, but the availability of 1-minute data enables the computation of a true hourly average without the 3-knot truncation. EPA's meteorological data pre-processor "AERMINUTE" was used to process 1-minute data. Hourly NowCast $PM_{2.5}$ concentrations were paired with wind data.

- All burn locations reported in 2016 and used in the 2017 comprehensive emissions inventory are shown. It is assumed that year-to-year variability is minimal in the approximate locations where fields are burned.
- Cities from which smoke complaints were received

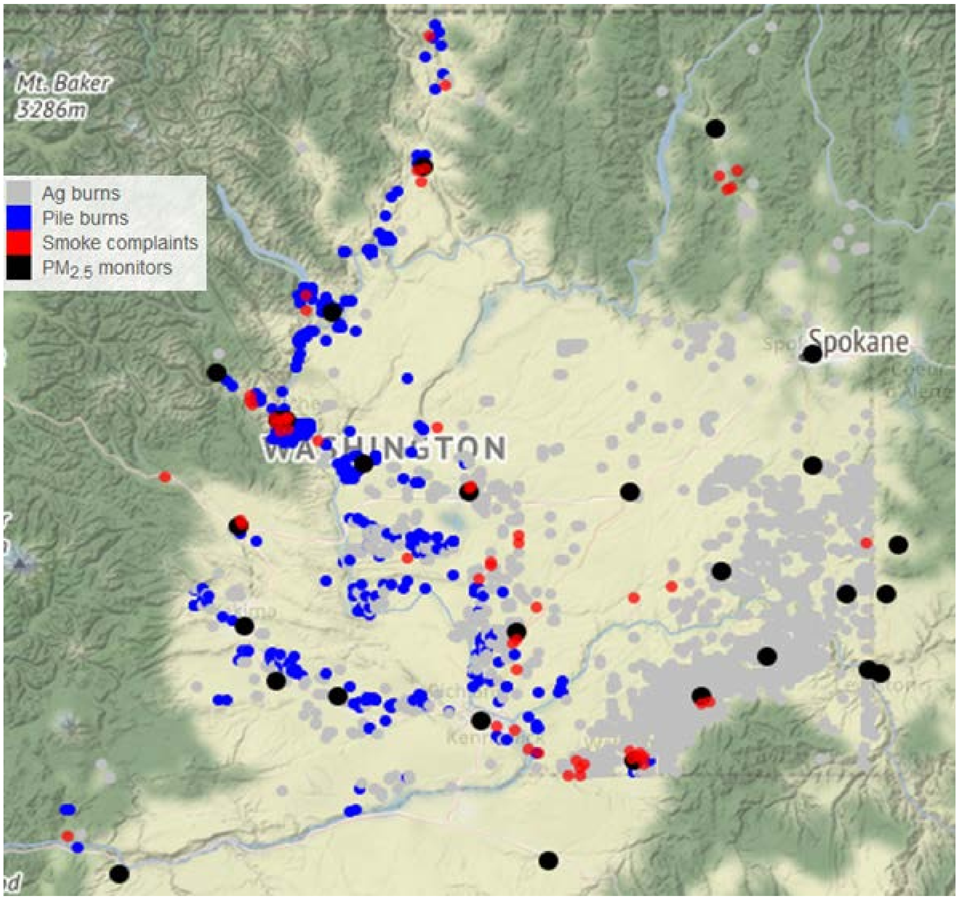


**Figure 16. Locations of agricultural and pile burns, $PM_{2.5}$ monitoring sites and smoke complaints**

The above map suggests that the monitors are mostly located in the correct areas. An interactive version of the map which displays pollution roses at each $PM_{2.5}$ monitor shows that smoke impacts are mostly from the anticipated directions (i.e. when the monitor is downwind of burned areas).

Hourly NowCast $PM_{2.5}$ concentrations were also used to determine the % of daytime hours in Spring and Fall when $PM_{2.5}$ levels were in different air quality categories.

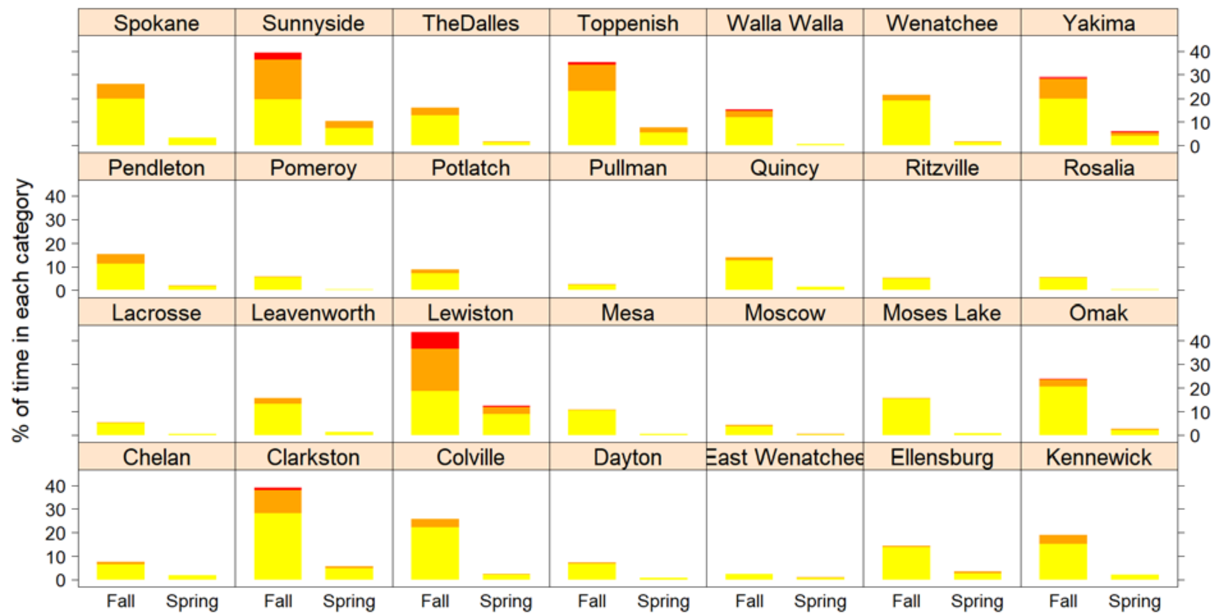


**Figure 17. Percent of hours with elevated $PM_{2.5}$ (Moderate or worse), 9am-4pm, 2015-2019 agricultural burning seasons**

Springtime impacts are on average about half that of the fall, with sites on the eastern slopes of the Cascades showing slightly higher Fall concentrations than sites further east. Lewiston and to a lesser extent, Clarkston, are often impacted by emissions from the paper mill. As the nocturnal inversion breaks, plumes mixed to the surface cause a mid-morning spike year- round. However, some added contributions were observed infrequently during afternoon hours, consistent with agburn smoke drifting in to the area.

Possible gaps in monitoring might be:

- Around Royal City (population ~2,200) or Othello (~8,000 people, but fewer burns nearby)
- Colfax (population ~ 3,000). This might be a better location for the LaCrosse monitor (~350 people).
- It is also possible to address these data gaps by installing low-cost sensors on a short term basis.

### Silvicultural burning-related monitoring needs

The exact locations of future silvicultural burns and the corresponding meteorology on the day of the burn are unknown. However for planning purposes, it is desirable to know how far and wide $PM_{2.5}$ impacts may spread, and where further monitoring might be required to inform public health decisions.

EPA's AERMOD model was run to simulate three burns at randomly chosen locations in Klickitat, Ferry and Pend Oreille Counties. Model inputs were:

- Meteorological data obtained from 2015- 2017 archives of UW's 4km WRF forecasts. WRF grid cells in the middle of forested areas in the above mentioned counties were extracted, representing weather conditions in areas likely to be burned in future.
- It was assumed that 400 tons of biomass would be burned between 9AM and 4PM in the spring and fall months, translating to a $PM_{2.5}$ mass emission rate of 95 g/s.
- The burns were represented as volume sources, 200m long and with an initial plume height of 150m.
- The second highest daily average concentrations were reported every 500m, as shown in the figures below.

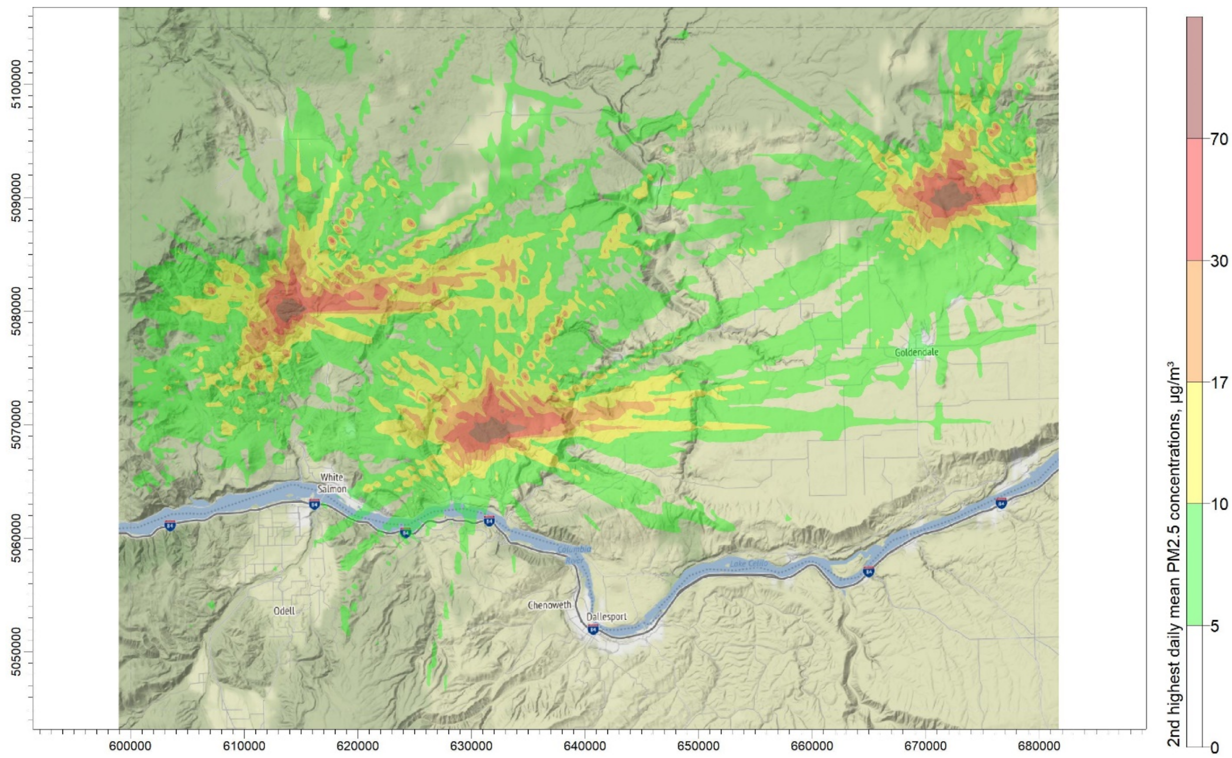


**Figure 18. Anticipated $PM_{2.5}$ impacts from Klickitat County burns at random locations**

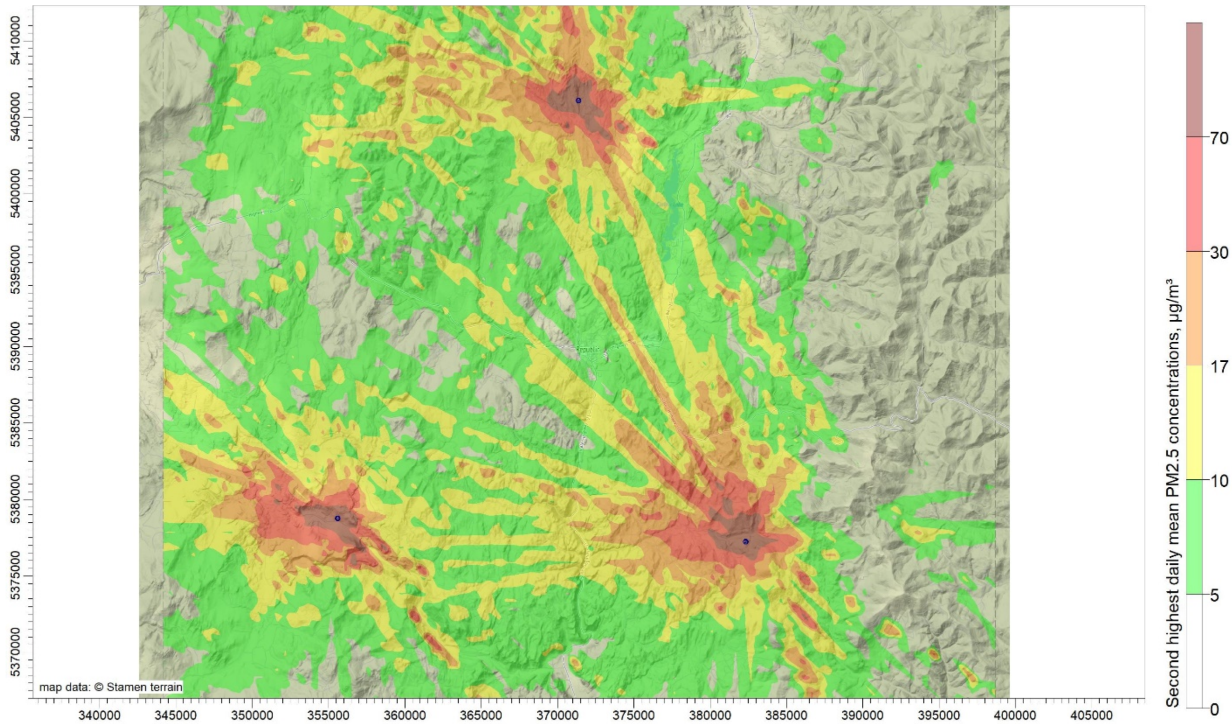


**Figure 19. Anticipated $PM_{2.5}$ impacts from Ferry County burns at random locations**

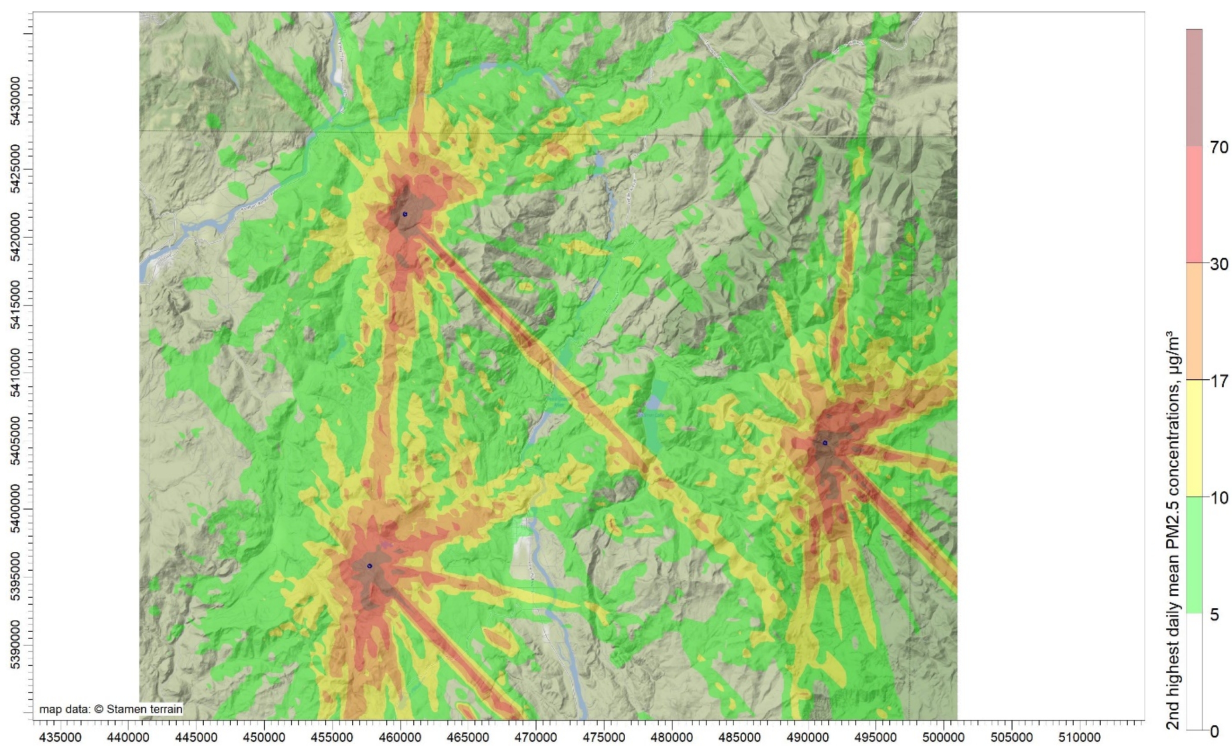


**Figure 20. Anticipated $PM_{2.5}$ impacts from Pend Oreille County burns at random locations**

The color breaks correspond to WAQA category breakpoints, but progressively more buffer space has been reserved for other emissions besides prescribed burns. When higher concentrations occur, it is assumed that pollution from other sources not explicitly modeled will also increase, as air masses stagnate.

These maps do not indicate the actual mass concentrations attributable to each burn, since the location, size and meteorology on the day of the burns cannot be known far in advance. Rather, they suggest that, when terrain effects and seasonal/ regional meteorology are considered, there exists an approximately 10-mile radius where $PM_{2.5}$ impacts from a 400-ton burn can exceed Ecology's program goal of 20 $\mu g/m^3$. Smaller burns could be proportionally closer, assuming all else (including plume rise) remains unchanged.

Extra monitoring resources will likely be required around communities if a lot of silvicultural burning is consistently conducted within this setback distance.

Ecology anticipates that prescribed burning will expand substantially over the next several years. In 2019, state legislation directed the Washington Department of Natural Resources to increase its acres treated with prescribed fire and to allow prescribed burning in urban growth areas (Washington SSHB 1784).

Ecology staff involved in smoke response were surveyed about priority communities likely to see $PM_{2.5}$ impacts as a result of expanded prescribed burning. Staff identified 17 communities where smoke impacts are expected to increase, many of which already experience smoke impacts from prescribed burns. These communities are shown in Figure 21. Most are located in central and eastern Washington.

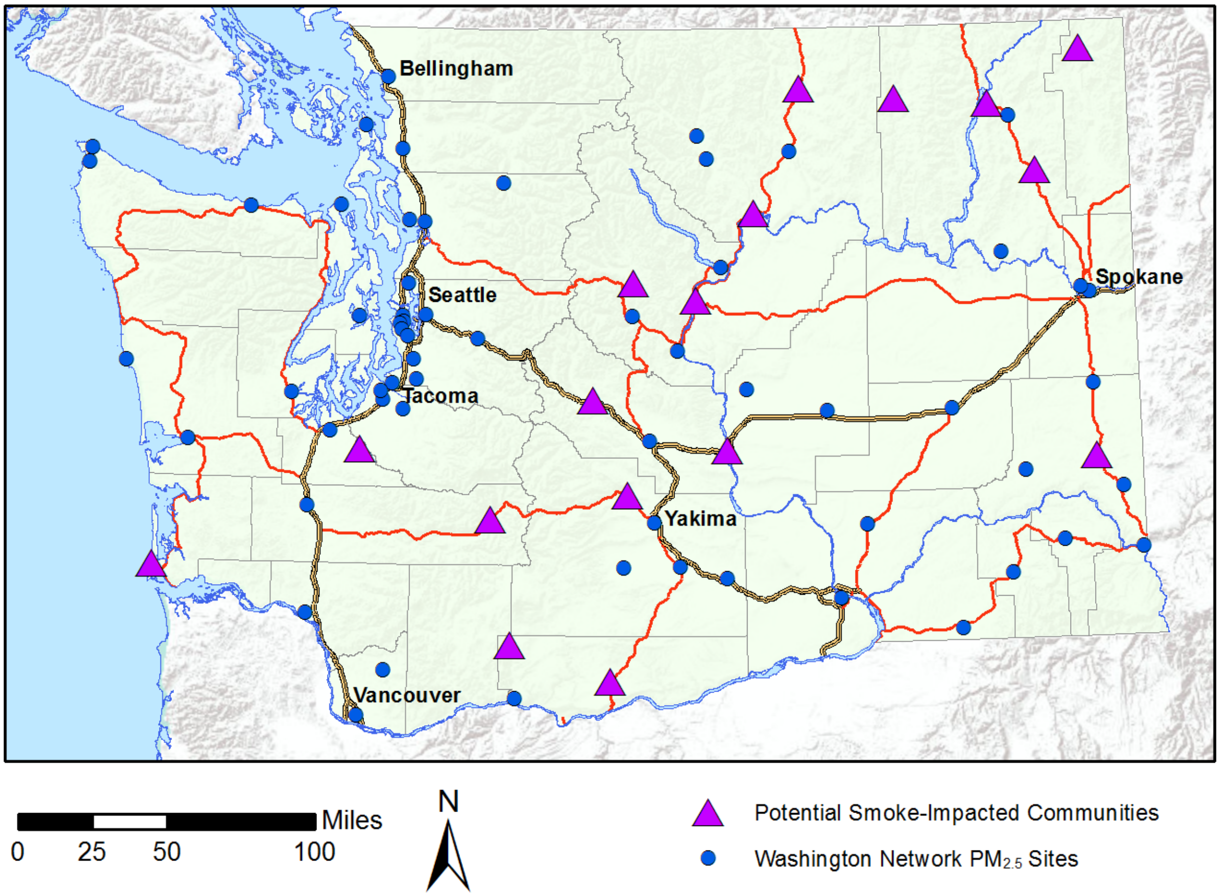


**Figure 21. Potential smoke-impacted communities for expanded $PM_{2.5}$ monitoring**

Ecology plans to explore options for temporary $PM_{2.5}$ monitoring in these communities during the spring and fall burning seasons. Many of these communities also experience wildfire smoke impacts during the summer, so continued temporary monitoring through the summer will also provide valuable information to these communities during wildfires.

Ecology's existing temporary monitoring tools for smoke response include nephelometer trailers and E-Samplers. Adding additional sites of these types to all 17 of these communities would be prohibitively expensive. Low-cost air sensors have shown promising performance after data correction based on Ecology's evaluations over the past two years. Ecology plans to develop a deployment plan for expanded use of $PM_{2.5}$ sensors in unmonitored areas, which includes data-driven bias correction methods, quality control and quality assurance procedures, and messaging around uncertainty in sensor data. The 17 communities shown are priority areas for deployment of low-cost sensors during the silvicultural burning and wildfire seasons, once this deployment plan has been developed.

Greater detail on air sensor performance and Ecology's priorities for expanded use of air sensors are provided in the Air sensors section above.

### Evaluating monitoring needs in unmonitored areas

One of the challenges to evaluating the efficiency and effectiveness of a monitoring network is that air quality conditions in unmonitored areas are largely unknown. Ecology used two tools to better understand air quality conditions outside of monitored areas: the gridded map of interpolated $PM_{2.5}$ design values described in the Area represented section above and publicly available data from the network of Purple Air monitors in Washington.

#### *Publicly-available Purple Air data*

Purple Air is a commercially available low-cost (<$300) monitor that measures $PM_1$, $PM_{2.5}$, $PM_{10}$, ambient temperature and relative humidity. Purple Air monitors have been documented in both laboratory and field conditions to show strong correlations with regulatory data but to overestimate reference concentrations by a significant margin (Tryner et al., 2020). As of late 2019, 203 outdoor Purple Air monitors had been deployed with publicly available data in Washington since 2015, though some had since been discontinued (Figure 22). The prevalence of these monitors throughout the state provides an opportunity to leverage a large volume of data in areas without Washington Network monitoring sites.

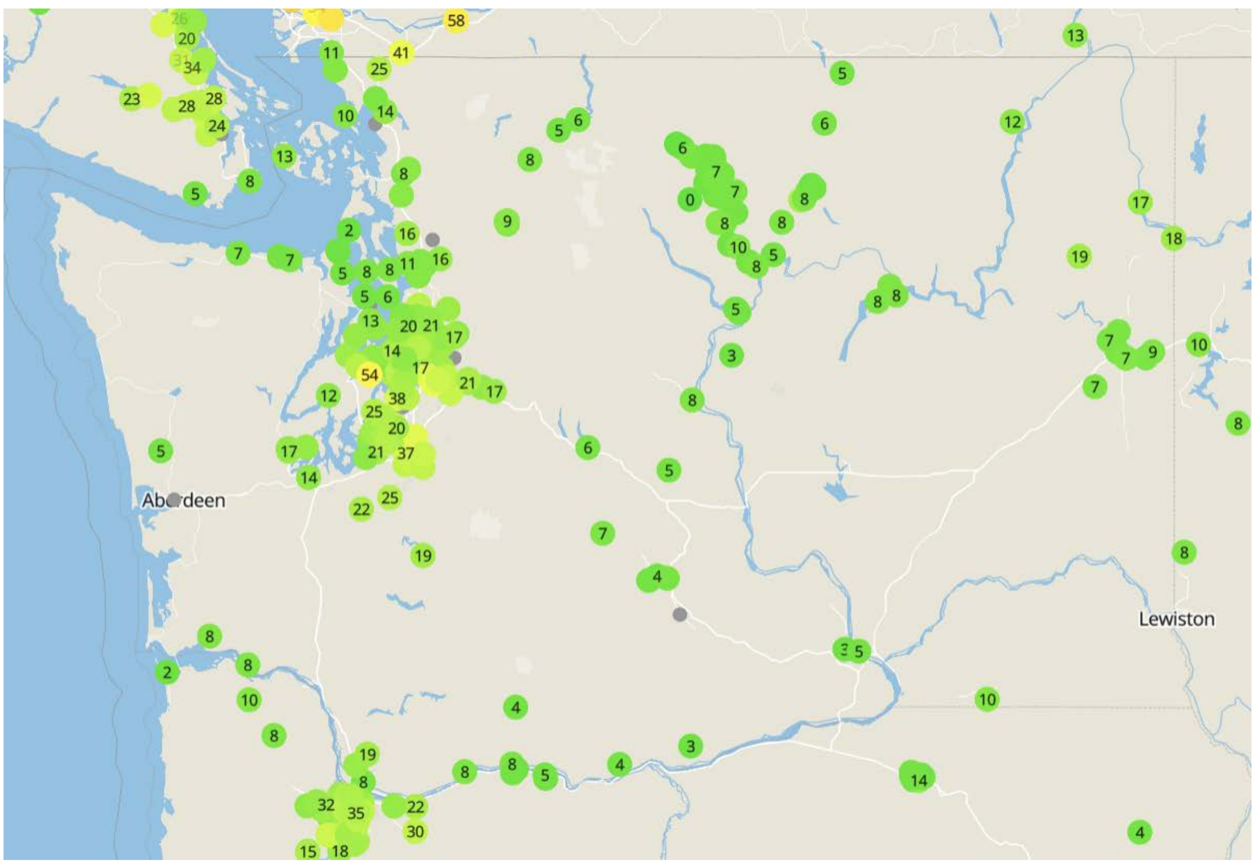


**Figure 22. Outdoor Purple Air monitors deployed in Washington on April 20, 2020 (source: purpleair.com/map)**

Ecology deployed Purple Air monitors at four Washington Network monitoring sites to evaluate their performance in different aerosol environments in Washington, as described in the Air sensors section above. Those sites are shown in the map in Figure 23. Paired data from the two FEM $PM_{2.5}$ monitoring sites (Tacoma-S 36th St and Ellensburg-Ruby St) were used to calculate a Washington-specific correction factor for Purple Air data.

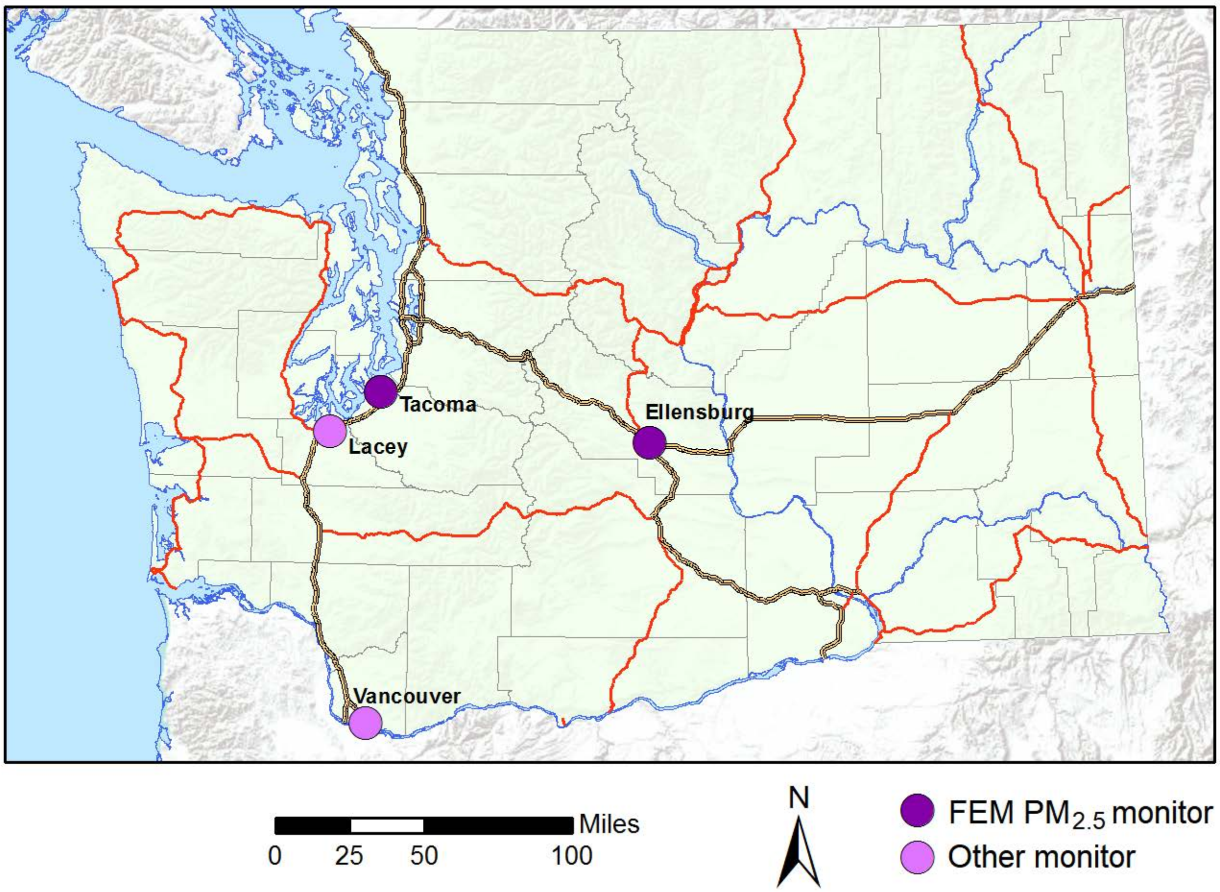


**Figure 23. Map of Ecology-owned Purple Air monitors collocated with Washington Network monitoring sites**

Ecology downloaded all available Purple Air data in Washington from January 2015 through September 2019 from Purple Air's public website. The dataset of $PM_{2.5}$ (CF=1) concentrations at 80-second resolution was screened for several basic data validation criteria:

- Values of 0.0 µg/m$^3$ were removed from the dataset. Though values of 0.0 µg/m$^3$ can be considered valid, they are frequently reported at startup or when a sensor malfunctions.
- Values greater than 4000 µg/m$^3$ were removed from the dataset.
- When the two $PM_{2.5}$ concentrations differed by greater than 500 µg/m$^3$ and one sensor reported a concentration below 250 µg/m$^3$, the value from the higher sensor was dropped.

Hourly average concentrations were then calculated and the following data validation criterion was applied:

- When the two $PM_{2.5}$ concentrations differed by greater than 50 µg/$m^3$ and one sensor reported a concentration below 50 µg/$m^3$, the value from the higher sensor was dropped.

Daily average concentrations were calculated requiring a minimum of 75% of hours to have values. For each day, Purple Air sites were assigned the $PM_{2.5}$ concentration from channel A unless it was missing, in which case they were assigned concentrations from channel B. Concentrations were scaled according to Equation 1, which was developed by applying ordinary linear regression to a pooled 24-hour dataset of Ecology's Purple Air results collocated FEM $PM_{2.5}$ monitors at Washington Network monitoring sites. In order to remove the influence of wildfire smoke on the dataset, 24-hour average concentrations greater than 35 µg/$m^3$ in quarter 3 were removed.

**Equation 1. Washington-specific correction equation for raw Purple Air CF=1 concentrations**

$$PA_{corrected} = PA_{raw} * 0.458 + 1.76$$

For each 4km grid cell, corrected 98$^{th}$ percentile concentrations were calculated from all Purple Air data collected within that grid cell. Those 98$^{th}$ percentile concentrations are shown in Figure 24.

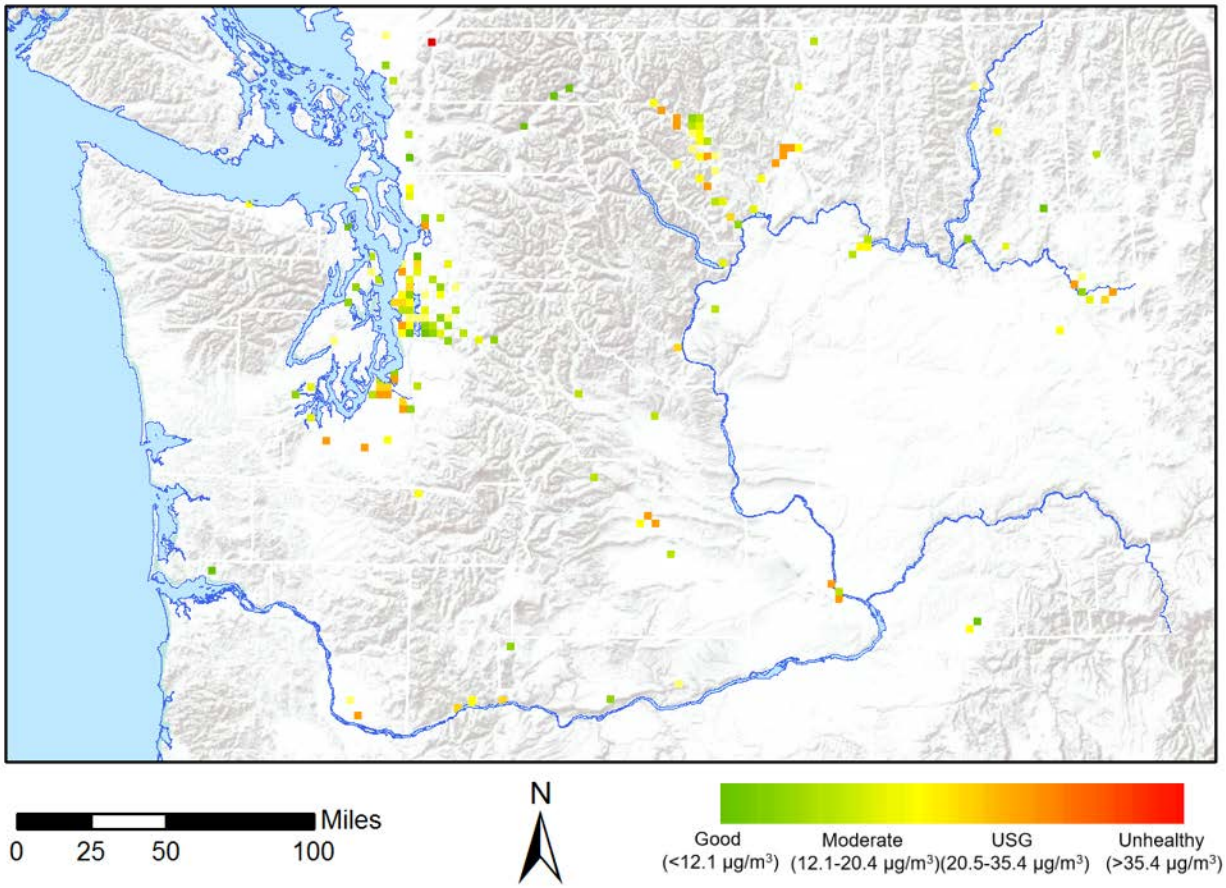


**Figure 24. 98th percentile 24-hour average $PM_{2.5}$ concentrations by grid cell from corrected Purple Air data**

As a final step, the difference between the Purple Air 98th percentile concentrations and the interpolated 98th percentile concentrations was calculated as shown in Figure 25.

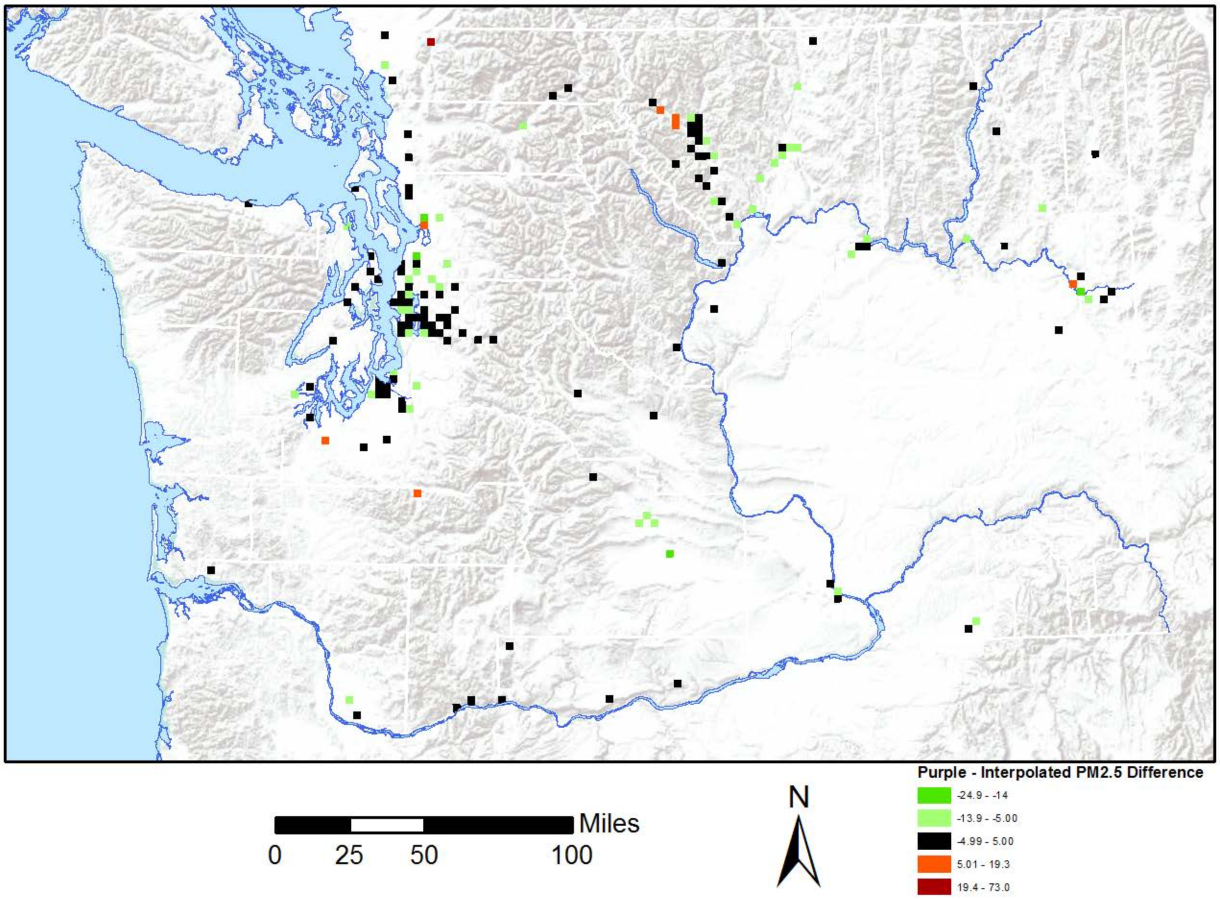


**Figure 25. Difference between interpolated and Purple Air 98th percentile $PM_{2.5}$**

At the majority of grid cells, the Purple Air $PM_{2.5}$ $98^{th}$ percentile and interpolated $98^{th}$ percentile agree within ± 5 µg/m$^3$ (shown in black). At green cells, Purple Air data indicate lower $98^{th}$ percentile concentrations than the interpolation results. Purple Air data only indicate higher $98^{th}$ percentile concentrations than the interpolation results in six areas (shown in orange and red):

- Maple Falls
- Everett/Marysville
- South Lacey/Tumwater
- Elbe
- Upper Methow Valley/Mazama
- Northwest Spokane

The populations and existing data sources in these areas do not indicate a need for Washington Network monitoring in any of these locations. The Northwest Clean Air Agency currently operates a monitoring site in Maple Falls, though it cannot be part of the Washington Network because there is not a location within the small valley community that meets siting criteria for neighborhood-scale $PM_{2.5}$ monitoring. The Everett/Marysville area is well-captured by the existing Marysville-7th Ave site operated by the Puget Sound Clean Air Agency, which routinely measures elevated $PM_{2.5}$ concentrations during the winter season. Similarly, the Lacey area is well-captured by the existing Lacey-College St monitor operated by the Olympic Region Clean Air Agency, and northwest Spokane is represented by the Spokane-Monroe St monitor operated by Ecology. That Purple Air data deviate so distinctly from a nearby regulatory monitor in these areas indicates that the Purple Air monitors are likely not sited or operated in a way that is representative of their broader neighborhoods.

The two remaining areas are located in low-population areas. Elbe had a population of 29 people in the 2010 census. Purple Air data may indicate elevated $PM_{2.5}$ concentrations there, though such a low-population area would not be a target location for neighborhood-scale $PM_{2.5}$ monitoring. Mazama had a population of 158 in the 2010 census. Mazama is located in the upper Methow Valley, approximately 20 miles northwest of Winthrop. As there are currently Washington Network monitoring sites in Winthrop and approximately 8 miles southeast of Winthrop in Twisp, monitoring is already conducted at a relatively high density in the populated areas of the Methow Valley.

The available Purple Air data do not identify populated communities in Washington with elevated $PM_{2.5}$ that are not already captured by our existing monitoring and/or modeling tools. These results indicate that the map of interpolated $PM_{2.5}$ is the best tool at our disposal to identify unmonitored areas with elevated $PM_{2.5}$. In addition to this tool, Ecology uses air quality complaints as well as information about planned and permitted agricultural and silvicultural burns to guide decisions about where to site temporary monitors and sensors, which can be upgraded to permanent monitoring sites if data indicate that permanent monitoring is warranted.

*Interpolated $PM_{2.5}$ map*

The interpolated $PM_{2.5}$ map described in the Area represented section above was used to identify unmonitored areas where 98th percentile $PM_{2.5}$ concentrations were predicted to exceed Ecology's Healthy Air Goal of 20 µg/$m^3$. Figure 26 shows a map of the grid cells with predicted 98th percentile $PM_{2.5}$ over this threshold and with no representative monitoring site. This map only includes grid cells in clusters of three or greater, due to the uncertainty in predicting concentrations in smaller areas.

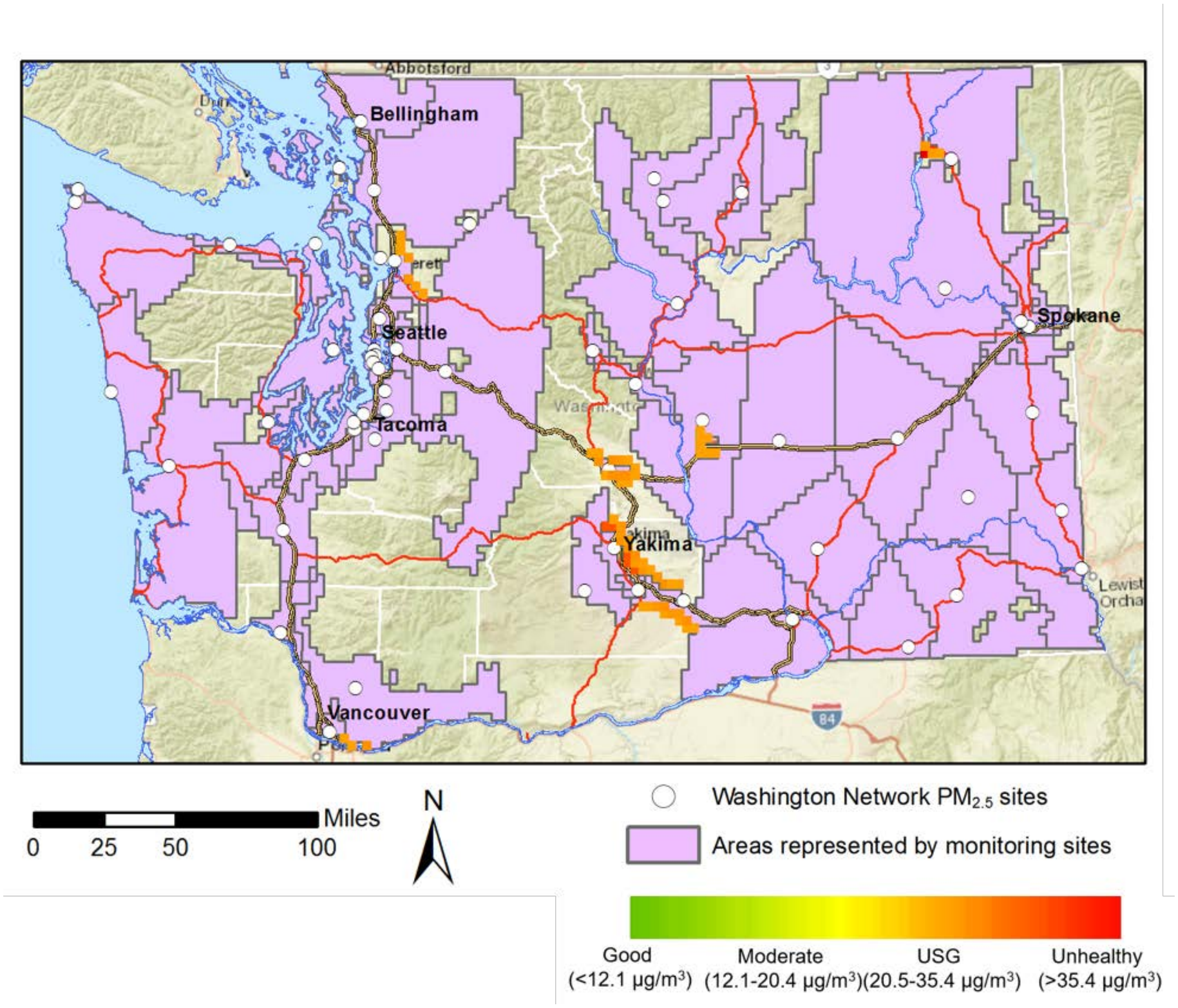


**Figure 26. Unmonitored areas with elevated predicted $PM_{2.5}$**

This analysis identified six currently unmonitored areas with elevated $PM_{2.5}$:

- **Marysville/Arlington.** Areas east of the Marysville-7th Ave site were identified, though these areas were not considered represented by Marysville-7th Ave because their design values were predicted to be more than 5 µg/m³ lower. Since Marysville-7th Ave overestimates $PM_{2.5}$ concentrations in this region, these are not considered priority areas for additional monitoring as data from Marysville-7th Ave provides a conservative overestimate of concentrations there.

- **Camas/Washougal.** Three grid cells east of Vancouver near Camas and Washougal were identified as not represented by either the Vancouver-NE 84th Ave or Yacolt sites. $PM_{2.5}$ monitoring was conducted in Camas from 2001-2002 (530110020), and the highest 24-hour average concentration recorded was 16.8 µg/m³. While air quality conditions could have changed in the years since, these past results do not corroborate the need for additional monitoring. This area can be considered a potential candidate for future expanded monitoring, particularly if population growth east of Vancouver continues.

- **Greater Ellensburg.** Several grid cells surrounding Ellensburg's represented area were identified, though all were predicted to have 98th percentile concentrations 5 µg/m$^3$ or more below the central monitor in Ellensburg. Since Ellensburg is a small community approximately 2.5 miles across with a population of less than 50,000 people, additional monitoring in outlying areas is not a high priority.

- **George.** Several grid cells in the town of George were identified as not represented by the Quincy monitor. However, as George is a town of approximately 500 people with no significant sources of $PM_{2.5}$ beyond regional sources in the surrounding area, this appears to be the result of an anomaly in the interpolation process and not a significant $PM_{2.5}$ hotspot.

- **Greater Yakima Valley.** Several grid cells in outlying areas of the Yakima Valley were identified, though all had predicted 98th percentiles 5 µg/m$^3$ or more lower than those of the nearby Washington Network monitoring sites. As the Yakima MSA has a population of approximately 250,000 people and four Washington Network $PM_{2.5}$ monitoring sites, including two FEM $PM_{2.5}$ monitors, there is already a relatively high density of monitors in this area. However, the extent of elevated $PM_{2.5}$ in outlying areas of the valley may be a topic of interest for future monitoring studies. Academic researchers have already partnered with the Yakama Nation to collect $PM_{2.5}$ information from low-cost sensors in the Yakima Valley (Stampfer et al., 2020), and this body of research can provide additional air quality information beyond data from Washington Network monitoring sites.

- **Kettle Falls.** Several grid cells near the town of Kettle Falls were identified. This area was also recognized by staff as an area of likely impacts from expanded silvicultural burning. Nephelometer monitoring was conducted in Kettle Falls from 2010-2012, and 24-hour concentrations as high as 29.1 µg/m$^3$ were measured. This is a priority area for expanded monitoring in response to future silvicultural burning and likely a suitable candidate location for low-cost $PM_{2.5}$ sensor monitoring.

## $PM_{10}$

There are six $PM_{10}$ monitoring sites in the Washington Network. Five (Colville-E 1st St, Kennewick-Metaline, Seattle-Beacon Hill, Spokane-Augusta Ave, and Yakima-4th Ave S) are required based on the $PM_{10}$ minimum monitoring requirements defined in 40 C.F.R. Part 58 Appendix D. The remaining site (Burbank-Maple St) operates to demonstrate continued attainment of the $PM_{10}$ standard in the Wallula Maintenance Area. As $PM_{10}$ monitoring is limited to sites required for planning purposes or to meet minimum monitoring requirements, and $PM_{10}$ concentrations are generally well below federal standards, Ecology did not evaluate this network further.

# Other networks

## Meteorological

Two meteorological site pairs were identified as being potentially representative of one another, and two sites were also identified as potentially redundant as compared to the respective local airport. Hourly comparisons of wind direction, wind speed, and temperature are described in the subsections below. Quantile-quantile plots are also shown in the subsections below; these comparison plots show how two distributions compare. Site characteristics are noted in Table 10.

**Table 10. Characteristics of meteorological sites assessed**

| Site | Location Setting | Elevation (m a.s.l.) |
|---|---|---|
| **White Swan** | Rural | 295 |
| **Toppenish** | Urban/center city | 216 |
| **Tacoma-Tower Dr** | Suburban | 134 |
| **Tacoma-S 36$^{th}$ St** | Urban/near-road | 108 |
| **Spokane Augusta** | Urban/center city | 585 |
| **Vancouver Blairmont** | Suburban | 5 |

### White Swan and Toppenish

White Swan is located approximately 20 miles west of Toppenish in Yakima County. White Swan is also at a slightly higher elevation (295 meters above sea level) than Toppenish (216 meters above sea level). Quantile-quantile plots show that wind direction at the two sites agree best at less than 120 degrees. Wind speeds also agree best at speeds less than 5 mph. Above 5 mph, Toppenish routinely observes lower wind speeds than White Swan. Observed ambient temperatures at both sites are very similar, as both distributions lie on the 1:1 line. Correlations between the two sites are 0.24, 0.57, and 0.99 for wind direction, wind speed, and ambient temperature, respectively. These correlations are statistically significant at the 95% confidence interval.

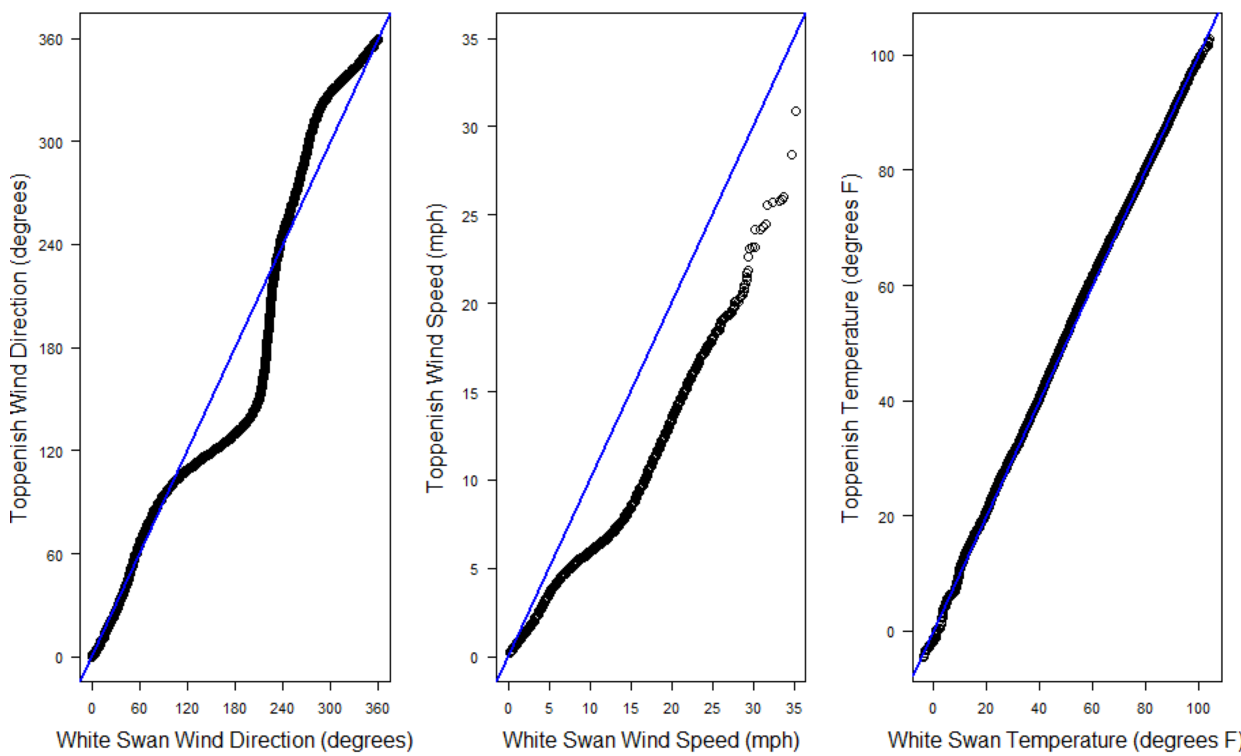


**Figure 27. Quantile-quantile plots of wind direction (left), wind speed (middle), and temperature (right). Blue line is 1:1 line.**

### Tacoma Tower Dr and Tacoma S 36th St

The two Tacoma sites are located only 11 miles apart, although the Tacoma Tower Dr site is located at a higher elevation than the Tacoma S 36th St site. While the two sites observe similar ambient temperature distributions, Tacoma Tower Dr consistently observes higher wind speeds than Tacoma S 36th St. Correlations between the two sites are 0.51, 0.78, and 0.99 for wind direction, wind speed, and ambient temperature, respectively. These correlations are statistically significant at the 95% confidence interval. However, it must be noted that the Tower Dr site was set up to capture these very differences.

The main utility of the Tower Dr site in past years was to assist with forecasting and data analyses. Due to its location and elevation, the site was used as a proxy for regional airflow, to check air movement in the free troposphere. This helped forecasters determine if surface inversions were likely to break soon. Tower Dr data were also used in ozone analyses for matching regional ozone observations with general conditions around central Puget Sound. The advent of high resolution models and a better understanding of ozone patterns in recent years has since led to this site being rarely used by Ecology or PSCAA staff. As far as staff are aware, it has never been used in permit modeling either. Therefore, its discontinuation is not expected to affect operations.

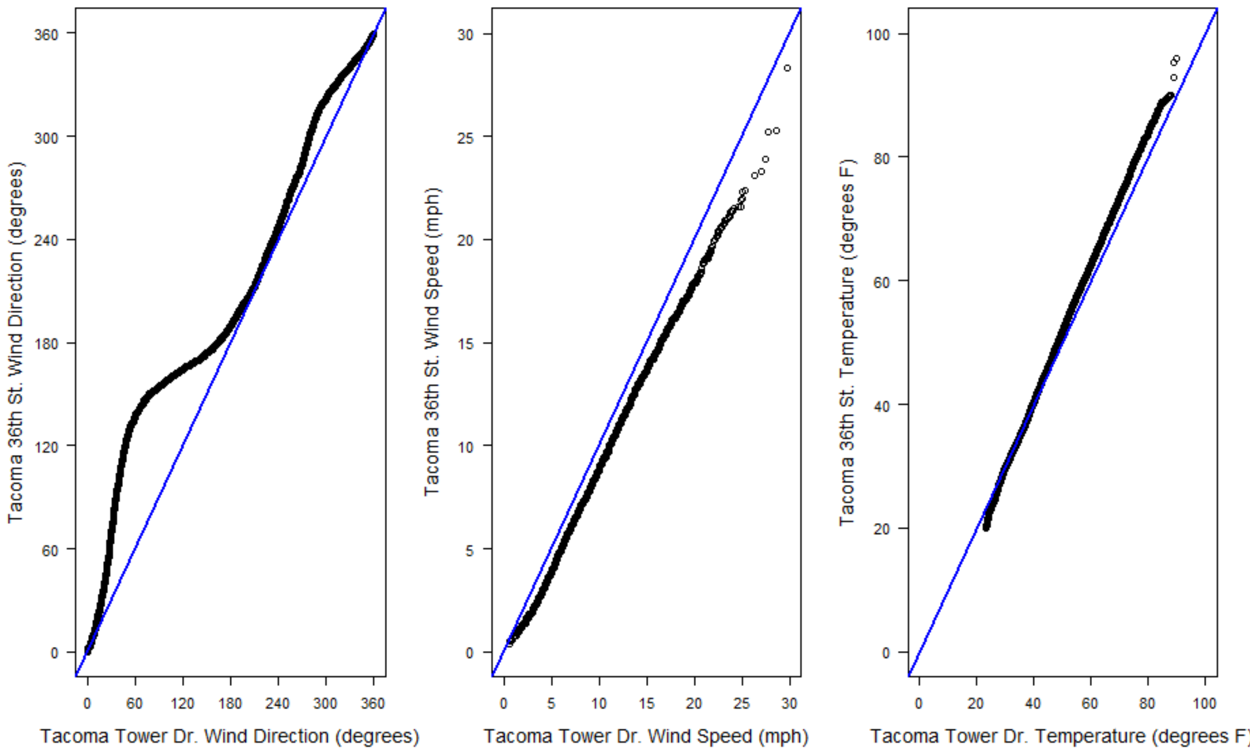


**Figure 28. Quantile-quantile plots of wind direction (left), wind speed (middle), and temperature (right). Blue line is 1:1 line.**

### Spokane Augusta and Spokane Airport

The Spokane International Airport (~727 m a.s.l) is located approximately 5 miles west of downtown Spokane, and approximately 9 miles west of the Spokane-Augusta monitoring site. Quantile-quantile plots shown in Figure 29 demonstrate that the wind directions observed are different between the two sites across the full spectrum of wind directions. The Spokane airport routinely observes wind speeds that are higher than those observed at the Spokane-Augusta monitoring site. Correlations between the two sites are 0.33 and 0.77 (statistically significant at the 95% confidence interval) for wind direction and wind speed, respectively.

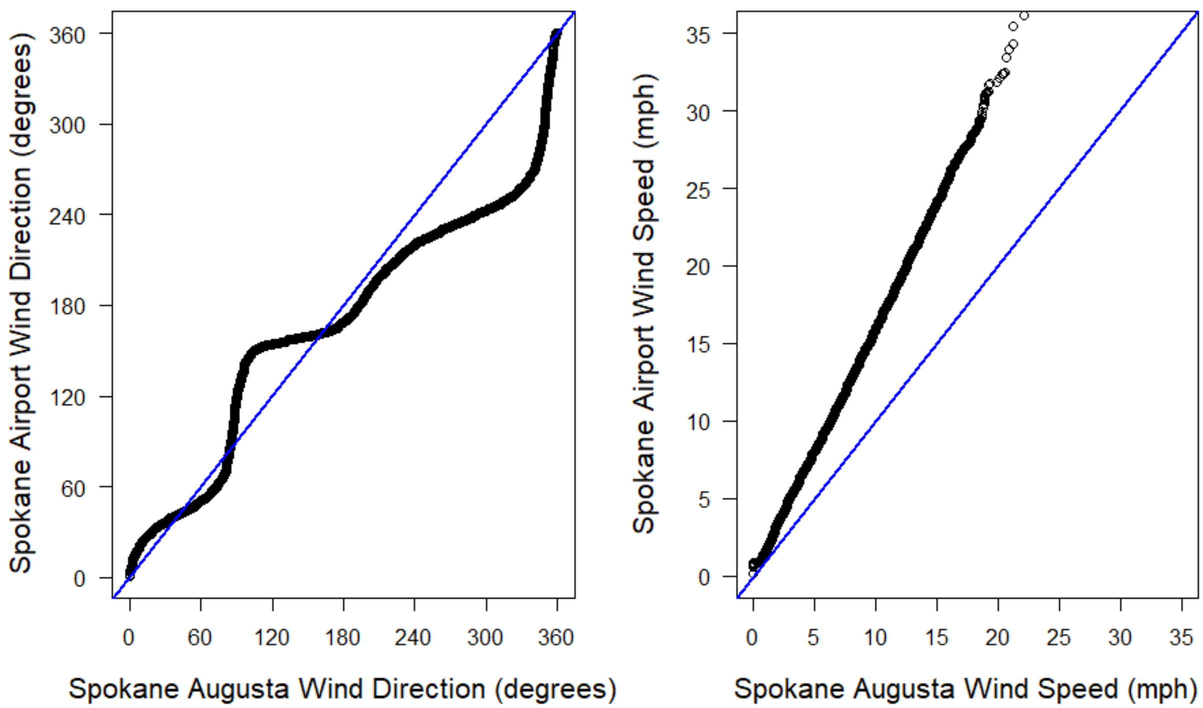


**Figure 29. Quantile-quantile plots of wind direction (left) and wind speed (right). Blue line is 1:1 line.**

### Vancouver Blairmont and Vancouver Airport

The Vancouver Airport (Pearson Field, 8 m a.s.l) is located one mile southeast of downtown Vancouver and approximately 7 miles west of the Vancouver-Blairmont monitoring site. Quantile-quantile plots shown in Figure 30 demonstrate that the wind directions observed are different between the two sites across the majority of the wind direction distribution. Exceptions include between 120-180 degrees and 300-360 degrees. At wind speeds greater than a few mph, the Vancouver airport observes higher wind speeds than the Vancouver-Blairmont monitoring site. Correlations between the two sites are 0.51 and 0.73 (statistically significant at the 95% confidence interval) for wind direction and wind speed, respectively.

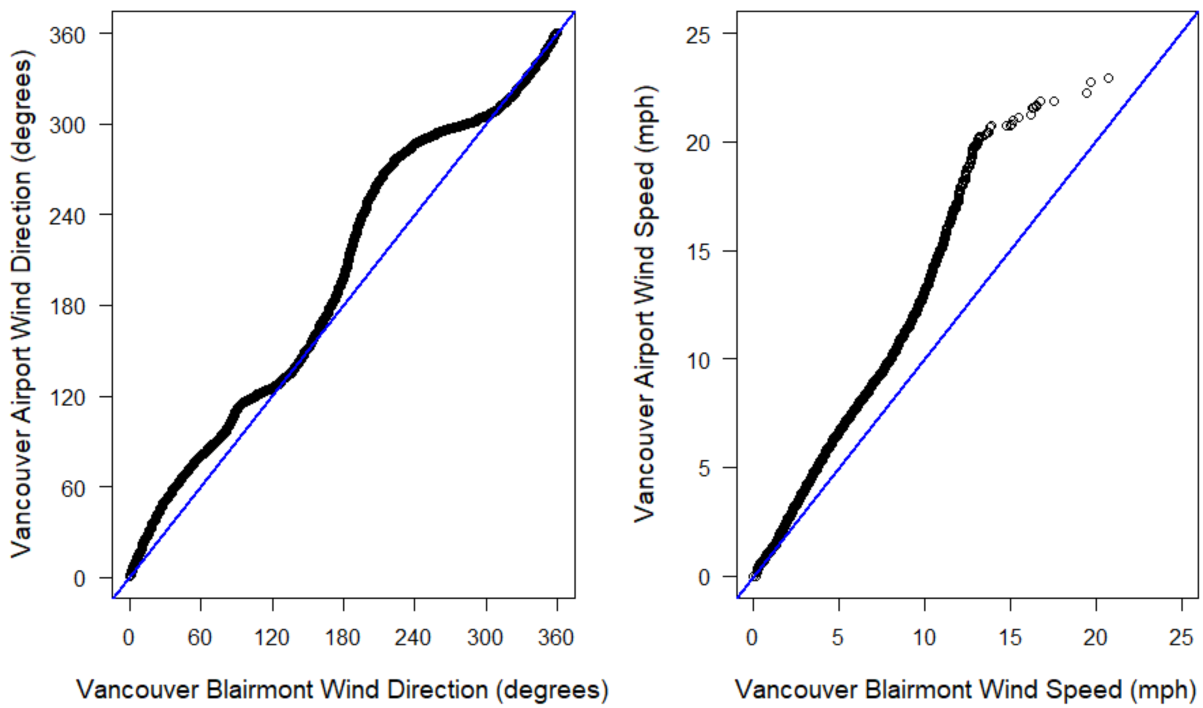


**Figure 30. Quantile-quantile plots of wind direction (left) and wind speed (right). Blue line is 1:1 line.**

As notable differences were found between each of these site pairs, no meteorological sites were recommended for removal based on redundancy with nearby Ecology or airport monitoring sites. However, the Tacoma-Tower Dr meteorological monitoring site was identified as a low priority for reasons described above, and evaluating resource savings that would be achieved by discontinuing the site is recommended.

## Chemical speciation network

Utilizing Positive Matrix Factorization (PMF), a source apportionment analysis was conducted for Ecology's four current $PM_{2.5}$ chemical speciation network sites that have at least three years of data. Chemical speciation network samplers use polytetrafluoroethylene, nylon, and quartz filters to collect 24-hour $PM_{2.5}$ samples for the chemical analysis of metals, ions, and carbon using energy-dispersive X-ray fluorescence, ion chromatography, and thermal optical analysis (Solomon et al., 2014). Speciation samplers at Seattle-10$^{th}$ & Weller, Yakima, and Tacoma-L St collect samples one in every six days; the Seattle-Beacon Hill sampler collects samples once every three days.

PMF solves a receptor-only, unmixing model that assumes a measured dataset conforms to a mass balance of a number of constant source profiles that contribute varying concentrations over time. PMF analysis parses a time series of measured chemical species into a number of prescribed factors, each with a chemical profile and mass contribution to the measured dataset (Paatero and Tapper, 1994).

Sources from PMF analysis were identified based on factor composition, temporal behavior, and source profiles from EPA's SPECIATE database.

PMF analysis of the four sites utilized sampled data from 1/1/2014 to 12/31/2018, aside from 10$^{th}$ & Weller, which started sampling in November 2014. Prior to PMF analysis, CSN data was corrected for field blanks, negative or missing sample values, data completeness, poor signal-to-noise ratios, and any double-county by similar chemical species, following previous CSN PMF analyses (Kotchenruther 2013). Special events (i.e., fireworks and wildfires) were excluded from the data.

## Factor Identification

Identified factors (Figure 31) include vehicle exhaust (gasoline and diesel), nitrate-rich (including ammonium nitrate), sulfate-rich (including ammonium sulfate), unidentified urban, residual marine fuel oil, fresh and aged wood smoke, fresh and aged sea salt, crustal (fugitive dust), and metals. Sites varied in the magnitude of these $PM_{2.5}$ sources. Seattle's 10$^{th}$ & Weller near-road site was dominated by diesel and gasoline exhaust. Gasoline exhaust was the highest contributing $PM_{2.5}$ source at Beacon Hill, Tacoma, and Yakima. Yakima also observes a large contribution from nitrate-rich and wood smoke sources.

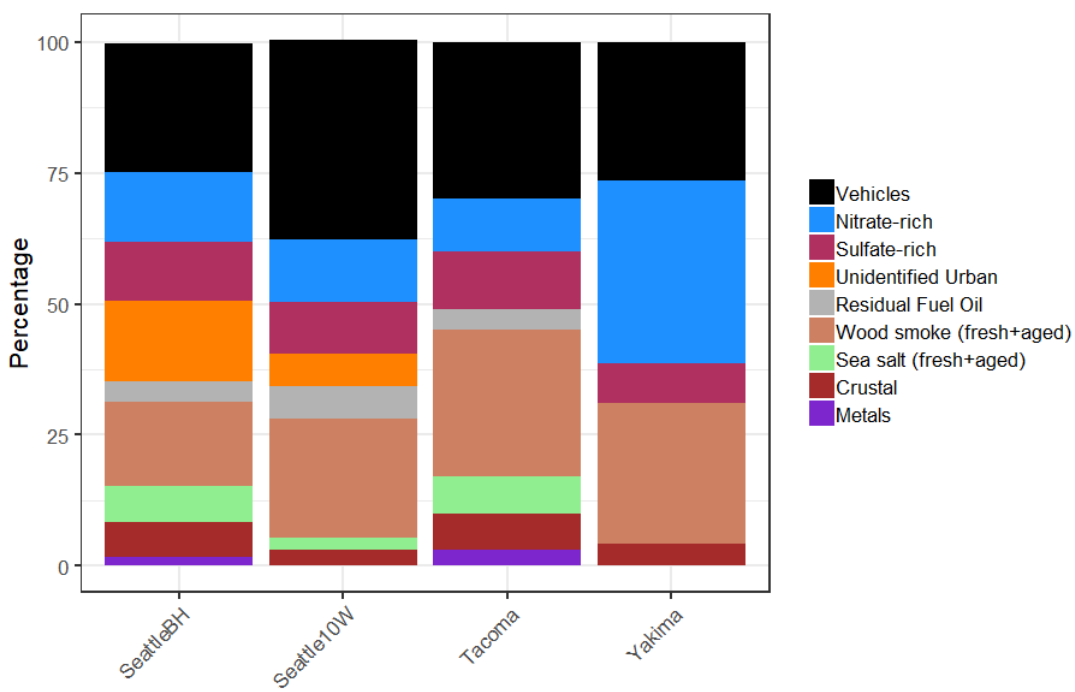


**Figure 31. $PM_{2.5}$ factor identification by site**

Figure 32 shows annual contributions from each identified factor at each site for 2014-2018. Factors showing decreasing contributions include residual fuel oil, consistent with marine fuel regulations that took effect in 2015, and sulfur-rich $PM_{2.5}$. $PM_{2.5}$ associated with gasoline emissions showed increasing contributions at Beacon Hill, Yakima, and Tacoma, and was fairly consistent from 2016-2018 at 10th & Weller.

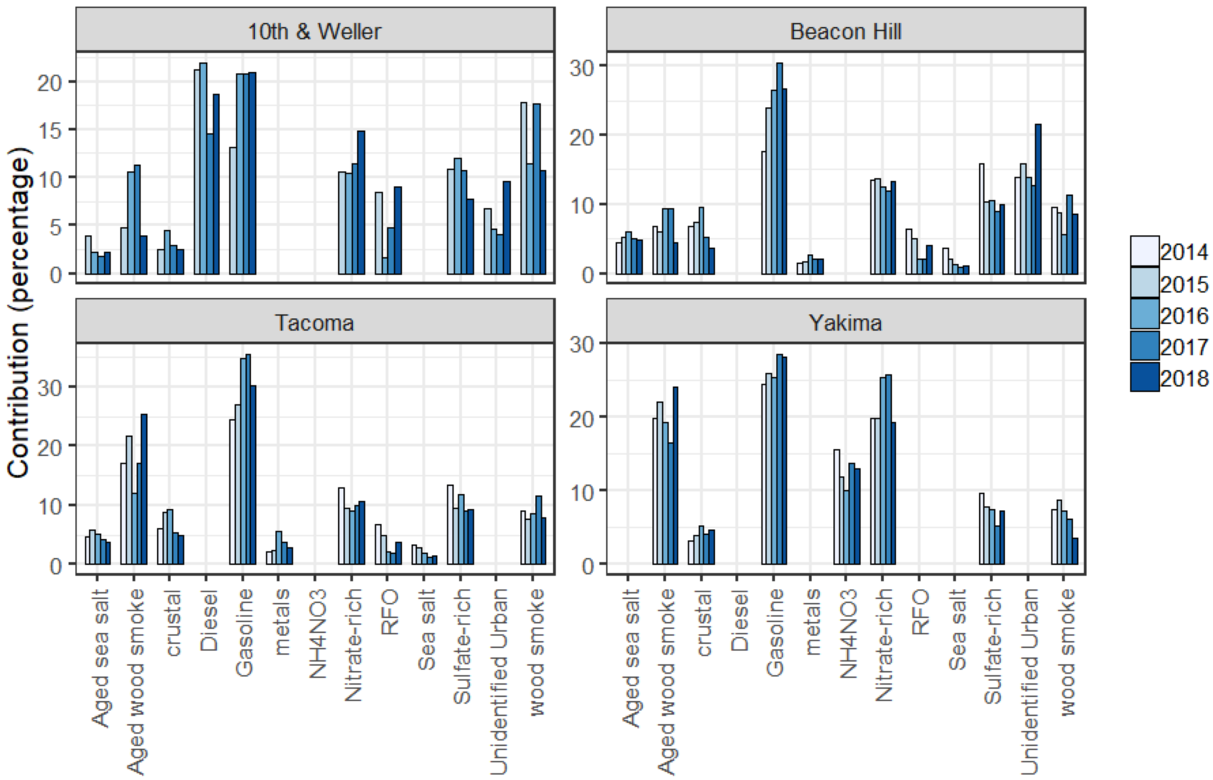


**Figure 32. Factor contributions as a function of site and year**

## Site Correlations

To explore similarities and differences among the four statewide sites, correlations between $PM_{2.5}$ sources and sites are shown in Figure 33. The highest $PM_{2.5}$ source correlations were between Beacon Hill and 10th & Weller, indicating that sources are similar across the Seattle airshed. Seattle and Tacoma sites also exhibit correlation higher coefficient values with each other than with the Yakima site. That Yakima $PM_{2.5}$ sources are not well correlated with sources observed in Seattle and Tacoma confirms that Yakima observes different air masses, and $PM_{2.5}$ sources and trends observed in Seattle and Tacoma should not be applied statewide as well.

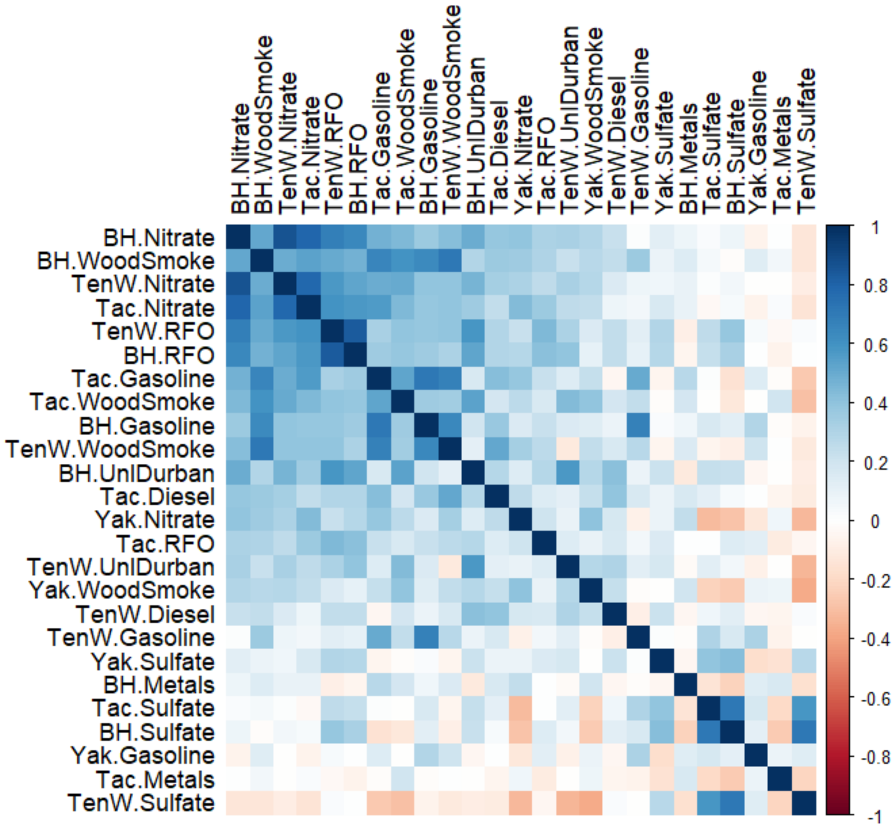


**Figure 33. Correlation matrix of all factors across all sites. The colorbar indicates the r correlation between the two variables.**

## Beacon Hill and 10th & Weller Comparison

Based on the high correlations observed between Seattle-10th & Weller and Seattle-Beacon Hill, and their physical proximity to each other, 10th & Weller and Beacon Hill were further compared to assess if two Seattle sites are needed to assess $PM_{2.5}$ composition in the airshed. $PM_{2.5}$ sources at the two sites are similar; differences exist in the magnitude of factors at both sites. Given 10th & Weller's proximity to Interstate-5, $PM_{2.5}$ associated with diesel emissions contribute substantially to total $PM_{2.5}$ concentrations; these high concentrations of diesel emissions are not observed at Beacon Hill, which is located a few miles away from the freeway (Friedman, 2020). Beacon Hill also observes a small percentage of metal emissions that are not observed at 10th & Weller. These metal emissions are likely from industry south of downtown.

Figure 34 shows comparison boxplots of $PM_{2.5}$ sources that confirm $PM_{2.5}$ sources at both sites are similar aside from diesel and metal sources. Annual concentrations of each factor at each site (Figure 35) also show that $PM_{2.5}$ sources at both sites are similar and differences exist in the magnitude of those sources, as well as the large contribution of $PM_{2.5}$ associated with diesel emissions at 10th & Weller. Mass concentration differences between factors identified at both sites are shown in Figure 36. From 2015-2018, concurrent factors identified at Beacon Hill and 10th & Weller were within 1 µg/m$^3$ of each other 93% of the time and within 0.5 µg/m$^3$ of each other 79% of the time.

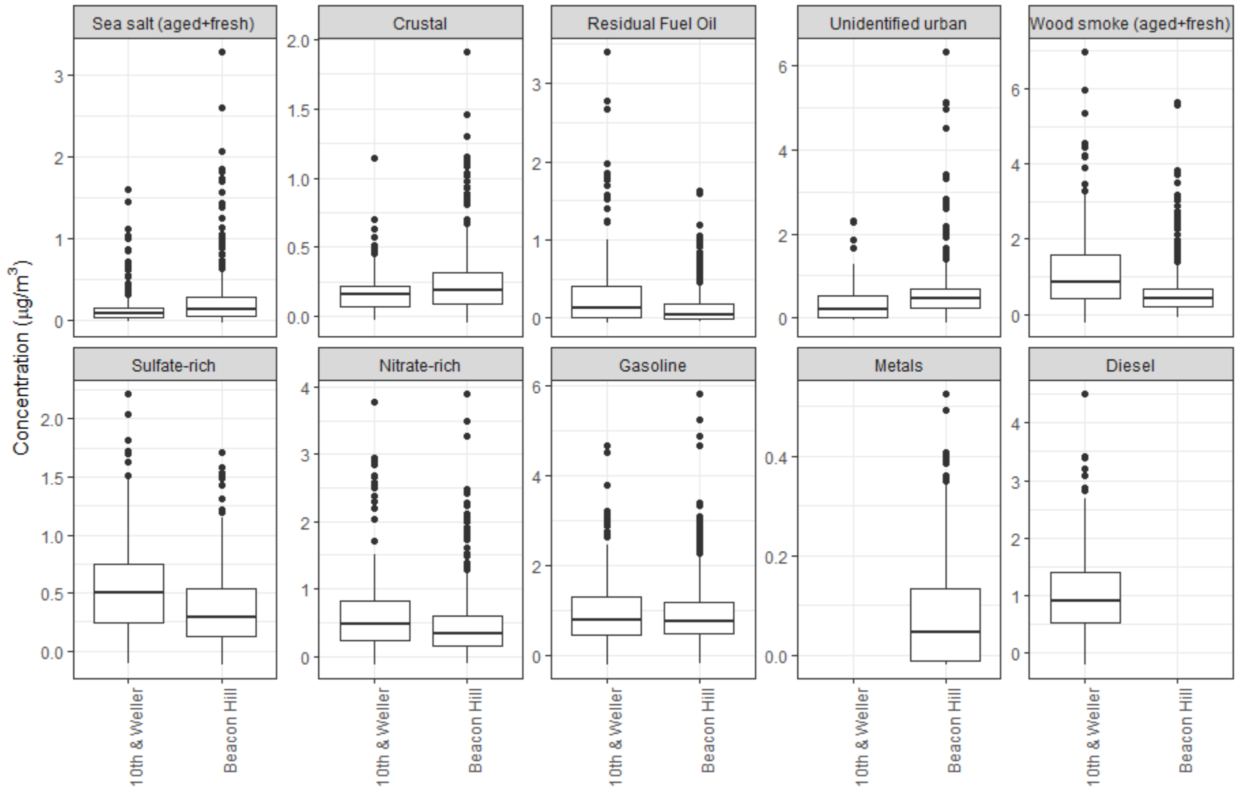


**Figure 34. Comparison of $PM_{2.5}$ factor concentrations at Beacon Hill and 10th & Weller during 2015-2018**

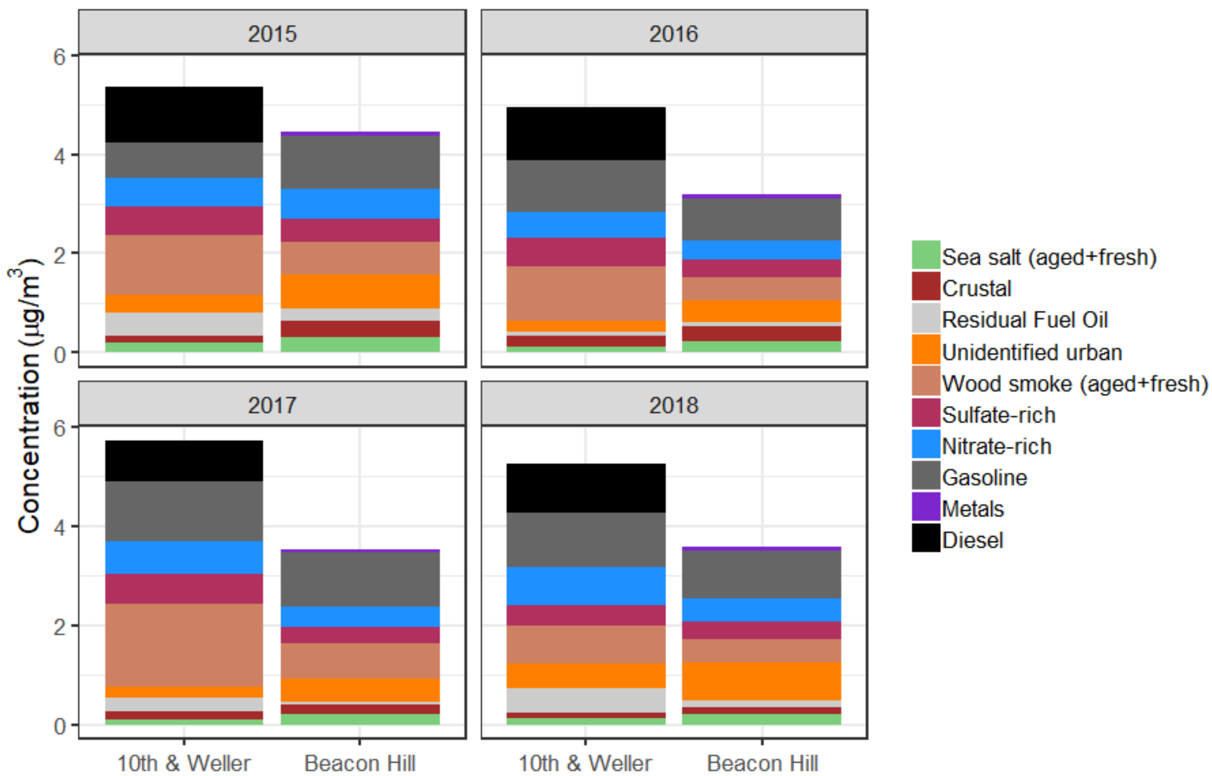


**Figure 35. Annual comparison of $PM_{2.5}$ factor contributions at Beacon Hill and 10th & Weller**

Given the proximity of Seattle-Beacon Hill and Seattle-10th & Weller as well as the similarity in observed $PM_{2.5}$ sources, Ecology recommends discontinuing Seattle-10th & Weller. Given that Yakima $PM_{2.5}$ sources are poorly correlated with sources identified in Tacoma and Seattle, Ecology recommends relocating the Seattle-10th & Weller chemical speciation monitoring site to eastern or central Washington to further characterize $PM_{2.5}$ sources in those regions.

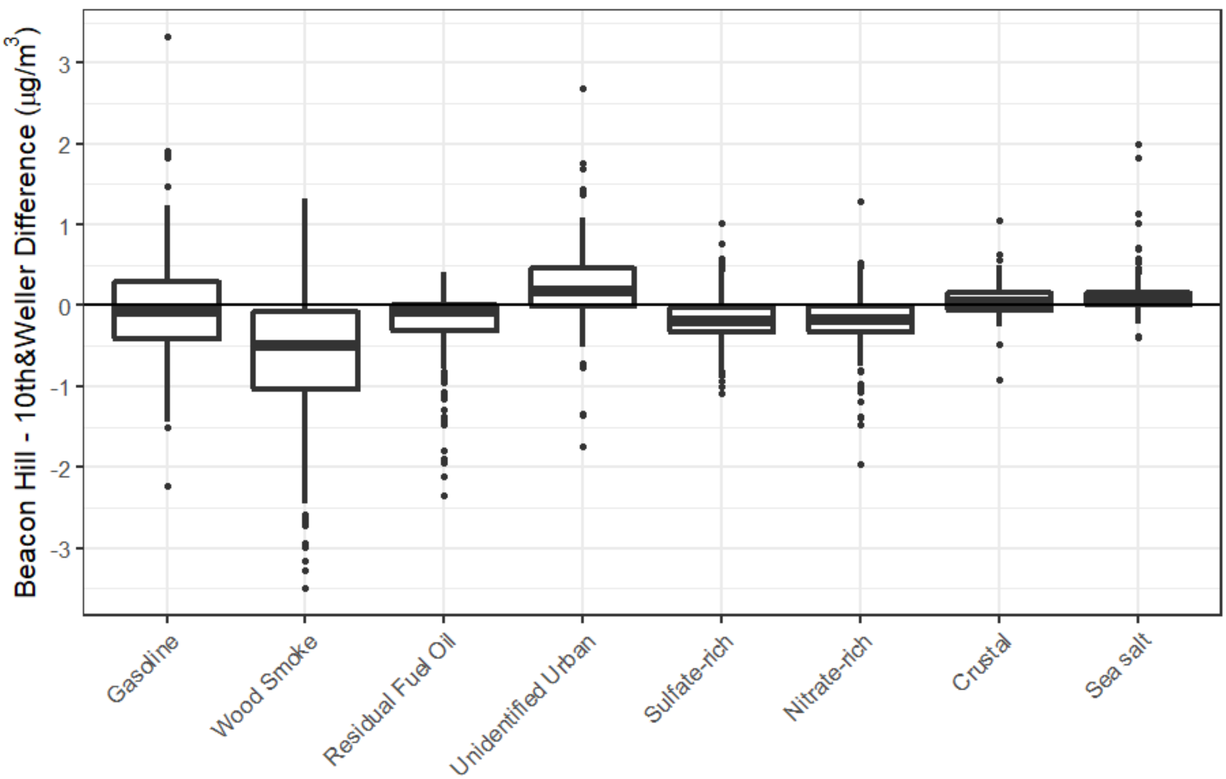


**Figure 36. Mass concentration differences between Beacon Hill and 10th & Weller as a function of $PM_{2.5}$ factor during 2015-2018**

## Trends

Five year factor trends as a function of 2016-2018 factor concentrations are shown in Figure 37. While trend concentrations are small (range from -0.13 to 0.14 µg/m$^3$ per year), significant increasing trends (p-values less than 0.05) include $PM_{2.5}$ sources associated with gasoline at Tacoma and Beacon Hill. However, $PM_{2.5}$ associated with wood smoke sources in Yakima, diesel $PM_{2.5}$ at 10$^{th}$ & Weller, residual fuel oil at Tacoma and Beacon Hill, sulfate-rich sources at Yakima and Beacon Hill, and nitrate-rich sources at Beacon Hill show significant decreasing trends.

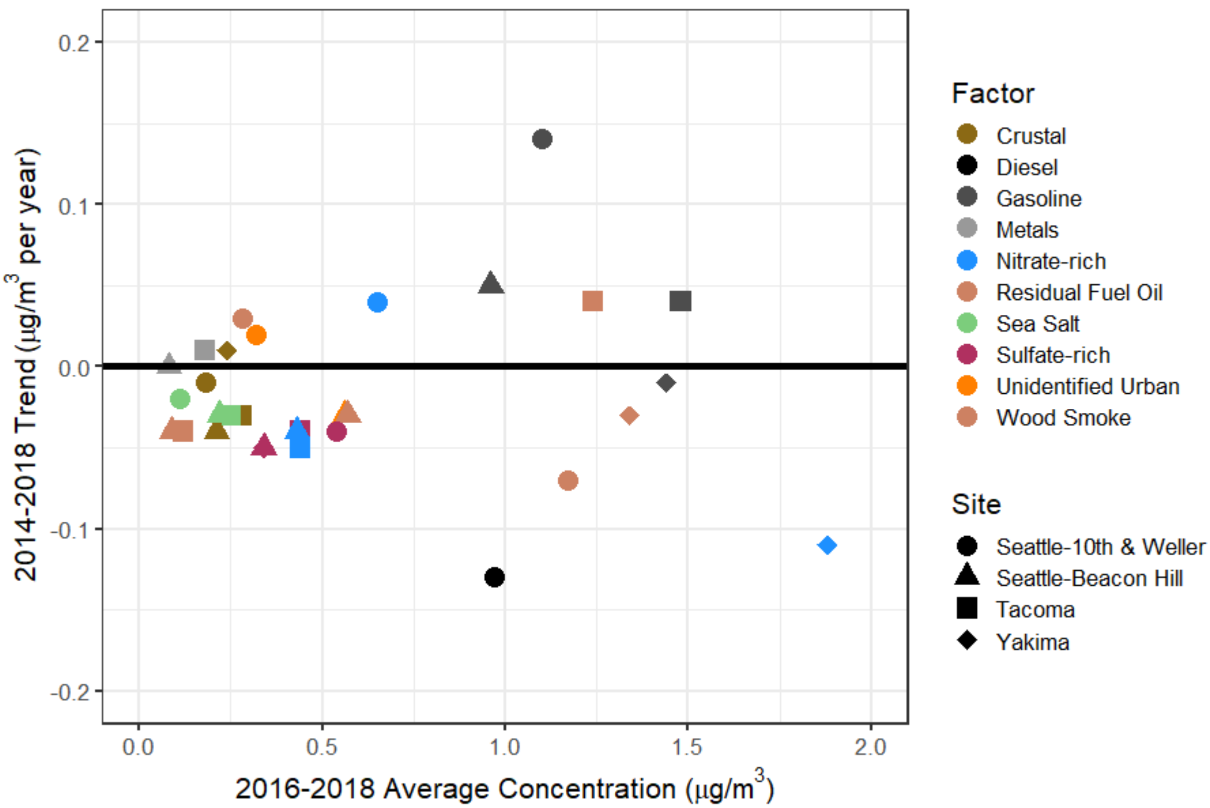


**Figure 37. 2014-2018 trends as a function of 2016-2018 concentrations for each factor and site**

### Factor contributions to exceedances

Four non-wildfire $PM_{2.5}$ exceedances (24-hour $PM_{2.5}$ concentration greater than 35 µg $m^{-3}$) that also overlapped with CSN sampling days occurred from 2014-2018 (Figure 38). Three of those exceedances occurred in Yakima, and were dominated by $PM_{2.5}$ associated with nitrate-rich factors. The single exceedance in Tacoma was dominated by wood smoke. These exceedances all occurred during winter and were likely associated with temperature inversions and stagnation events.

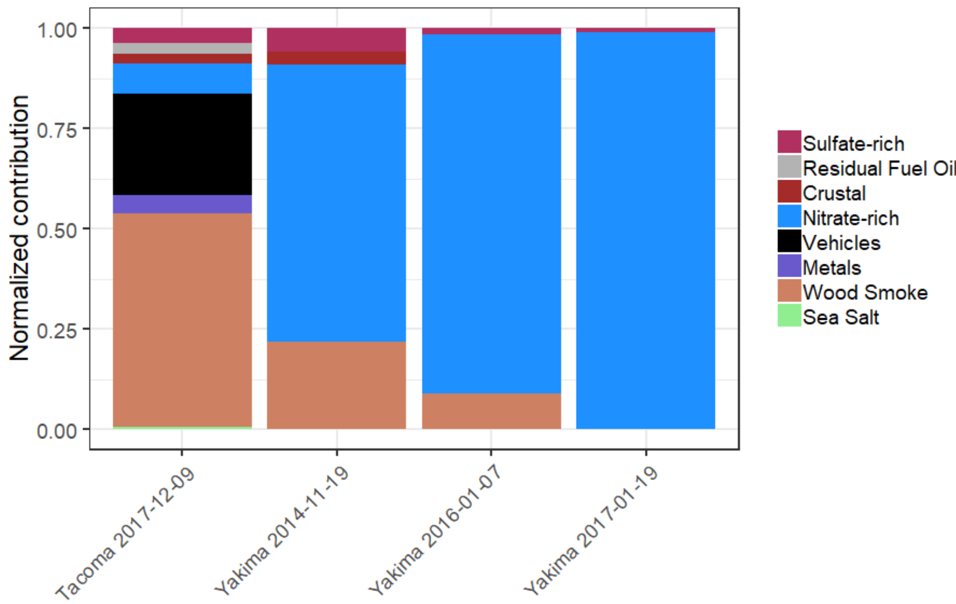


**Figure 38. Contribution of sources to $PM_{2.5}$ exceedances**

### Network analysis: long-term site value

Currently, CSN sites in Washington State are required to monitor for three years to gather enough data for source apportionment analysis. However, most current CSN sites in Washington State have been in operation for more than three years, and Yakima, Tacoma, and Beacon Hill have been in operation for over ten years. This source apportionment analysis was used to assess if CSN monitoring sites should be moved more often than they are currently, and if so, what time period is sufficient for data collection before a CSN monitoring site can be moved.

Figure 39-Figure 41 attempt to illustrate the long-term value of CSN at each long-term monitoring site by comparing each factor's five year mean to each factor's mean from two to five year intervals. If the five year mean represents the "true" long-term mean, the variance between the interval means and the five year mean can provide information about how many sampling years are required before the interval means converge to the five year mean. The figures below suggest that four years is sufficient to characterize anthropogenic $PM_{2.5}$ sources in an airshed. However, this analysis does not take into account meteorology impacts or regulation changes that could impact mean concentration values and bias this analysis.

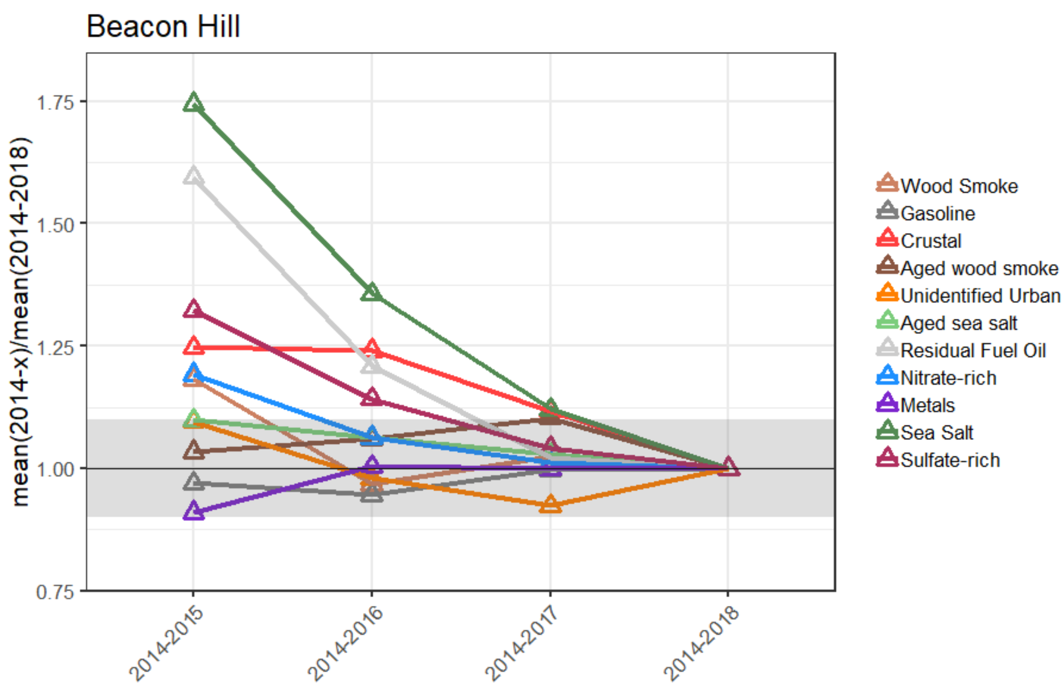


**Figure 39. Long-term site value at Beacon Hill**

Figure 39 shows the comparison of a two- to five-year concentration mean relative to the five year concentration mean for each factor identified at Beacon Hill, as a function of the year interval from which the concentration means were calculated. The line at y=1 indicates the interval concentration mean is equal to the five year concentration mean, and the grey shading is ±10% of y=1.

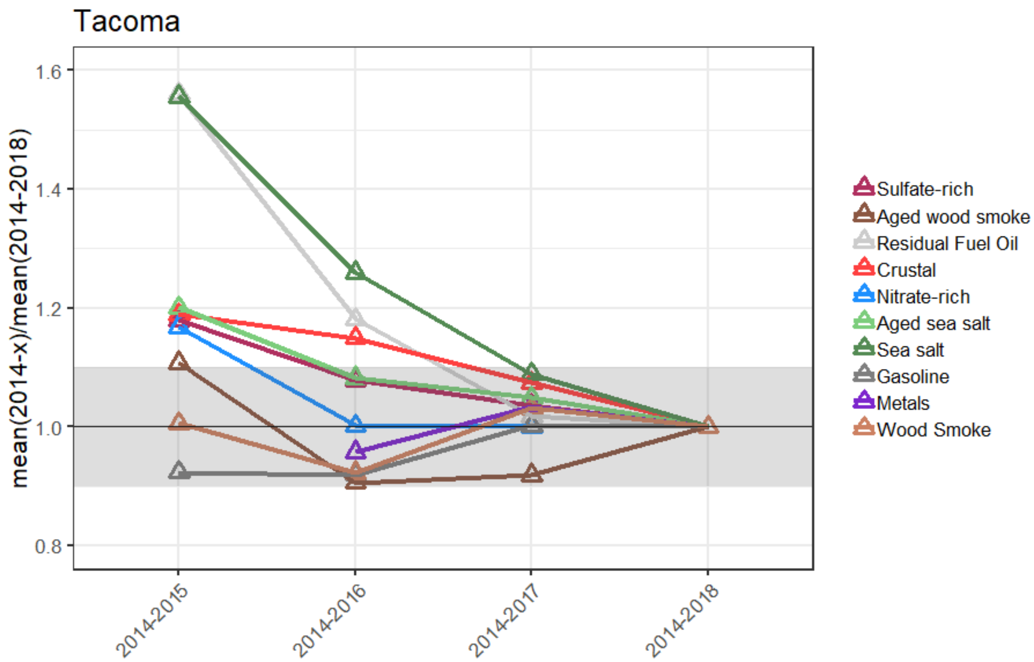


**Figure 40. Long-term site value at Tacoma**

Figure 40 shows the comparison of a two- to five-year concentration mean relative to the five year concentration mean for each factor identified at Tacoma, as a function of the year interval from which the concentration means were calculated. The line at y=1 indicates the interval concentration mean is equal to the five year concentration mean, and the grey shading is ±10% of y=1.

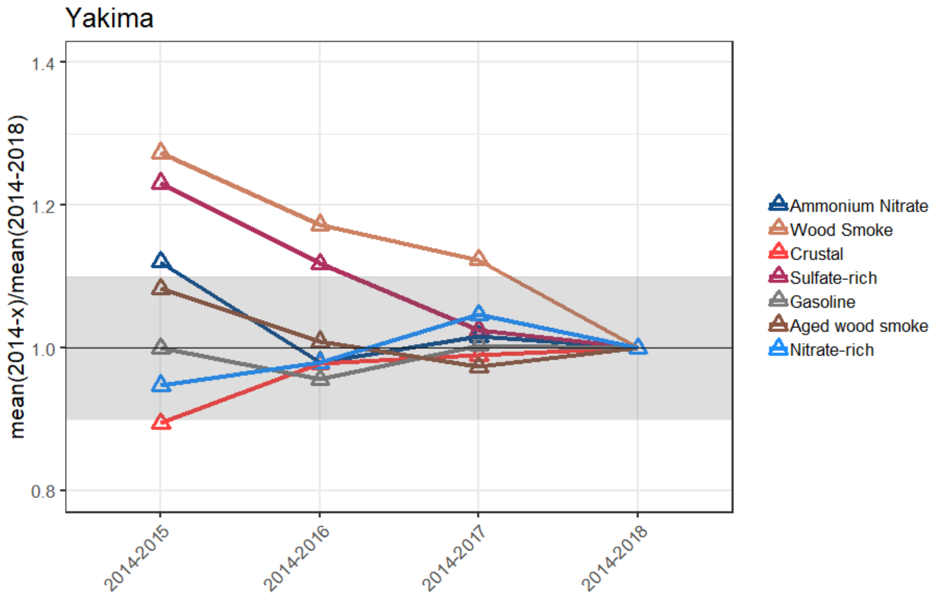


**Figure 41. Long-term site value at Yakima**

Figure 41 shows the comparison of a two- to five-year concentration mean relative to the five year concentration mean for each factor identified at Yakima, as a function of the year interval from which the concentration means were calculated. The line at y=1 indicates the interval concentration mean is equal to the five year concentration mean, and the grey shading is ±10% of y=1.

# Findings and Recommendations

Overall, the Washington Network is efficient and effective at meeting the monitoring objectives and at providing reliable and high-quality information about air quality conditions to public agencies, researchers, the general public and other data users. Wholesale network changes were found to be unnecessary.

Ecology is particularly cautious about recommending the removal of monitors in this assessment based on the aftermath of network reductions recommended in previous assessments. Ecology removed the Burbank $PM_{10}$ monitoring site in 2012 based on the recommendations in the 2010 Network Assessment. This site was reinstated in 2017 due to the need for representative $PM_{10}$ monitoring in the Wallula Maintenance Area. Based on the recommendations in the 2015 Network Assessment, Ecology removed the Tulalip $PM_{2.5}$ monitoring site. $PM_{2.5}$ monitoring was then reinstated in Tulalip in 2019, as local community monitoring was identified as a priority by EPA Region 10 and the Tulalip Tribes. Since removing and reinstating monitoring sites is much more costly and labor-intensive that continued operations, Ecology is wary of recommending any sites for removal that may need monitoring in the future.

Network summaries and targeted network improvements were identified for the following parameters:

**Ozone**

- Ecology ranked the value of the Washington Network ozone monitoring sites using a decision matrix that captured concentrations measured, exceedances and violation risk, and populations represented. The top-scoring sites were those downwind of urban areas that routinely record elevated concentrations (Kennewick and Enumclaw).
- No sites are recommended for removal.

**$PM_{2.5}$**

- Ecology ranked the value of the Washington Network $PM_{2.5}$ monitoring sites using a decision matrix that captured concentrations measured, populations and geographic areas represented, and nearby sources. The top-scoring sites were largely located in populated areas impacted by residential wood combustion in the winter (e.g. Marysville, Vancouver, Spokane, Tacoma, and several sites in the Yakima Valley).
- No sites are recommended for removal.
- Expanded use of low-cost $PM_{2.5}$ sensors is recommended in unmonitored areas impacted by smoke from wildfires and prescribed burns. Low-cost $PM_{2.5}$ sensors are also recommended as a survey tool in other unmonitored areas. At Washington Network sites that lack $PM_{2.5}$ monitoring, the addition of $PM_{2.5}$ sensors is recommended in order to alleviate communication challenges during wildfires. Expanded use of $PM_{2.5}$ sensors can only be implemented after development of:

    - bias-correction methods appropriate for the region, season and sensor model;
    - appropriate quality control and quality assurance procedures for sensor deployments; and
    - communication materials to convey key messages about data correction and uncertainty in sensor data.

- Two existing temporary $PM_{2.5}$ monitoring sites (White Salmon and Pomeroy) were found to provide valuable local $PM_{2.5}$ data and ongoing utility for smoke management in their areas. An evaluation of options for continued monitoring in these areas, including use of low-cost $PM_{2.5}$ sensors, is recommended.

**Meteorological**

- The Tacoma-Tower Dr meteorological monitoring site was identified as a low priority, and evaluating resource savings that would be achieved by discontinuing the site is recommended. In previous years, the site was by forecasters to understand regional airflow and regional ozone conditions around central Puget Sound. However, high resolution models have taken the place of this data source in recent years, and Ecology and PSCAA staff surveyed in 2020 did not rely upon the site for permitting or forecasting needs.

**Chemical Speciation Network**

- Ecology conducted a source apportionment analysis for its four current $PM_{2.5}$ Chemical Speciation Network sites that have at least three years of data. Identified sources included combustion, sulfate- and nitrate-rich $PM_{2.5}$, and wood smoke, as well as biogenic sources such as sea salt and crustal elements. Five-year trends suggest an increase in $PM_{2.5}$ from gasoline vehicle emissions and a decrease in $PM_{2.5}$ from marine fuel oil.

- The highest correlations between $PM_{2.5}$ sources were found between the Seattle-Beacon Hill and Seattle-10$^{th}$ & Weller monitoring sites. Given the proximity of these two Seattle sites as well as the similarity in observed $PM_{2.5}$ sources, Ecology recommends discontinuing Seattle-10$^{th}$ & Weller. Given that Yakima $PM_{2.5}$ sources are poorly correlated with sources identified in Tacoma and Seattle, Ecology recommends relocating the Seattle-10$^{th}$ & Weller chemical speciation monitoring site to eastern or central Washington to further characterize $PM_{2.5}$ sources in those regions.

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# Appendices

## Appendix A. Decision Matrix Scores

### Ozone

**Table 11. Complete ozone decision matrix scores**

| Site | Design Value | 75th Percentile | Number Exceedances | Violation Risk | Trend | Population | Population Growth | EJ Score | Forecasting Value | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|
| Anacortes-202 O Ave | 0 | 0 | 0 | 0 | 0 | 0.2 | 6.69 | 8.45 | 0 | **15.35** |
| Cheeka Peak | 3.47 | 1.62 | 0 | 0 | 7.69 | 0 | 4.04 | 15.38 | 6.84 | **39.04** |
| Cheney-Turnbull | 8.45 | 12.95 | 0.62 | 0 | 7.69 | 1.94 | 8.91 | 8.32 | 6.84 | **55.72** |
| Custer-Loomis | 2.82 | 3.24 | 1.23 | 0 | 7.69 | 0.6 | 14.57 | 14.74 | 3.42 | **48.3** |
| Enumclaw-Mud Mtn. | 15.38 | 9.72 | 15.38 | 15.38 | 2 | 15.38 | 7.24 | 0 | 10.26 | **90.74** |
| Issaquah-Lake Sammamish | 9.21 | 6.48 | 3.08 | 5.13 | 4.25 | 15.38 | 7.24 | 0 | 10.26 | **61.01** |
| Kennewick-S Clodfelter Rd | 13.87 | 15.38 | 12.31 | 15.38 | 7.69 | 0.88 | 11.26 | 12.98 | 10.26 | **100** |
| Mt Rainier-Jackson Visitors Ctr | 9.53 | 11.33 | 3.08 | 0 | 7.69 | 15.38 | 7.24 | 0 | 10.26 | **64.51** |
| North Bend-North Bend Way | 9.64 | 7.29 | 5.54 | 10.26 | 3.35 | 15.38 | 7.24 | 0 | 10.26 | **68.95** |
| Seattle-Beacon Hill | 0.65 | 1.62 | 0 | 0 | 6.9 | 15.38 | 7.24 | 0 | 0 | **31.79** |
| Spokane-Greenbluff | 10.07 | 12.95 | 3.69 | 5.13 | 7.69 | 1.94 | 8.91 | 8.32 | 10.26 | **68.96** |
| Vancouver-Blairmont Dr | 9.53 | 7.29 | 2.46 | 5.13 | 7.69 | 9.52 | 0 | 1.19 | 10.26 | **53.07** |
| Yelm-Northern Pacific | 8.23 | 6.48 | 1.85 | 0 | 5.32 | 0.84 | 15.38 | 5.68 | 10.26 | **54.03** |

## $PM_{2.5}$

To conserve space, scoring criteria are labeled A-M according to the following key:

**A** 24-Hour DV
**B** Annual Mean
**C** Number Exceedances
**D** Trend
**E** Area Represented
**F** Population
**G** Population Growth
**H** EJ Score
**I** Outdoor Burning
**J** Point Emissions
**K** Traffic Density
**L** Residential Wood Combustion
**M** Forecasting Value

**Table 12. Complete $PM_{2.5}$ decision matrix scores**

| Site | A | B | C | D | E | F | G | H | I | J | K | L | M | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aberdeen-Division St | 3.4 | 4.76 | 0 | 8.89 | 6.18 | 2.29 | 1.58 | 5.87 | 3.3 | 2.33 | 1.95 | 3.15 | 7.9 | **51.61** |
| Anacortes-202 O Ave | 3.73 | 6.22 | 0.84 | 8.89 | 0.73 | 1.87 | 8.48 | 3.3 | 1.11 | 2 | 0.8 | 1.36 | 0 | **39.33** |
| Bellevue-SE 12th St | 2.7 | 2.42 | 0.32 | 8.89 | 0.52 | 12.67 | 9.71 | 0.36 | 0 | 0.12 | 17.55 | 7.52 | 3.95 | **66.7** |
| Bellingham-Pacific St | 5.17 | 4.99 | 1.72 | 7.19 | 1.85 | 6.13 | 9.42 | 4.75 | 0.62 | 0.39 | 3.57 | 6.59 | 3.95 | **56.33** |
| Bremerton-Spruce Ave | 3.16 | 3.87 | 1.29 | 8.89 | 2.18 | 9.36 | 6.24 | 2.04 | 1.17 | 0.08 | 2.16 | 9.37 | 11.85 | **61.65** |
| Cheeka Peak | 0 | 0 | 1.47 | 8.89 | 3.44 | 0.31 | 2.84 | 5.87 | 3.2 | 0.01 | 0 | 0 | 3.95 | **29.97** |
| Chehalis-Market Blvd | 6.6 | 6.73 | 1.41 | 8.89 | 1.58 | 2.43 | 5.43 | 5.45 | 1.57 | 0.49 | 4.09 | 1.91 | 3.95 | **50.52** |
| Chelan-Woodin Ave | 4.68 | 8.61 | 5.62 | 14.98 | 5.58 | 0.67 | 10.87 | 5.56 | 1.47 | 0 | 0.78 | 3.28 | 11.85 | **73.96** |
| Clarkston-13th St | 11.31 | 12.17 | 7.26 | 8.89 | 0.07 | 0.34 | 3.88 | 4.25 | 3.82 | 0.35 | 0.56 | 1.32 | 11.85 | **66.04** |
| Colville-E 1st St | 10.73 | 13.67 | 9.14 | 8.89 | 0 | 0.02 | 0.86 | 4.36 | 1.99 | 6.35 | 0.6 | 1.53 | 11.85 | **69.97** |
| Darrington-Fir St | 14.54 | 7.77 | 8.31 | 8.89 | 0 | 0 | 6.96 | 6.32 | 0.55 | 0 | 0.14 | 3.85 | 11.85 | **69.18** |
| Dayton-W Main St | 4.99 | 5.49 | 2.47 | 12.92 | 4.05 | 0.25 | 1.46 | 3.37 | 14.23 | 0 | 0.22 | 0.91 | 7.9 | **58.27** |
| Ellensburg-Ruby St | 12.99 | 9.74 | 6.75 | 8.89 | 0.07 | 0.59 | 8.48 | 8.72 | 0.33 | 0 | 1.49 | 2.14 | 11.85 | **72.04** |
| Kennewick-Metaline | 7.31 | 8.28 | 3.6 | 8.89 | 5.44 | 8.43 | 9.78 | 5.3 | 1.75 | 0.21 | 2.85 | 2.27 | 11.85 | **75.96** |
| Kent-Central & James | 10.03 | 7.49 | 3.67 | 8.89 | 0.61 | 13.96 | 7.15 | 5.24 | 0 | 0.03 | 9.54 | 8.32 | 11.85 | **86.77** |
| LaCrosse-Hill St | 3.09 | 5.13 | 3.44 | 8.89 | 3.44 | 0.08 | 2.07 | 1.83 | 3.84 | 0 | 0.08 | 0 | 3.95 | **35.83** |
| Lacey-College St | 8.57 | 6.8 | 2.56 | 8.89 | 0.84 | 7.41 | 8.82 | 2.89 | 1.61 | 0.09 | 5.58 | 10.22 | 11.85 | **76.13** |
| Lake Forest Park | 10.58 | 10.39 | 4.65 | 8.89 | 0.38 | 17.77 | 10.5 | 2.57 | 0 | 0.03 | 9.74 | 9.07 | 11.85 | **96.41** |
| Leavenworth-Evans St | 8.32 | 8.76 | 4.14 | 8.89 | 0.06 | 0.04 | 3.8 | 2.5 | 1.47 | 0 | 0.6 | 3.14 | 11.85 | **53.58** |
| Longview-30th Ave | 6.83 | 5.98 | 1.29 | 8.89 | 0.66 | 2.64 | 4.61 | 6.28 | 0.8 | 7.34 | 2.21 | 8.08 | 7.9 | **63.51** |
| Marysville-7th Ave | 13.9 | 9.78 | 6.76 | 8.89 | 0.39 | 8.46 | 8.61 | 3.91 | 0.55 | 0.01 | 7.86 | 15.47 | 11.85 | **96.44** |
| Mesa-Pepiot Way | 5.03 | 6.4 | 3.24 | 8.89 | 3.8 | 0.7 | 5.15 | 12.33 | 3.29 | 0.01 | 0.76 | 0.13 | 3.95 | **53.67** |
| Moses Lake-Balsam St | 5.55 | 7.77 | 4.02 | 8.89 | 7.41 | 2.32 | 6.66 | 6.87 | 2.16 | 0.14 | 2 | 1.66 | 11.85 | **67.28** |

| Site | A | B | C | D | E | F | G | H | I | J | K | L | M | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mt Vernon-S Second St | 2.79 | 1.73 | 0.55 | 7.58 | 6.59 | 4.7 | 8.76 | 3.77 | 1.11 | 0.26 | 4.26 | 3.31 | 3.95 | **49.35** |
| Neah Bay-Makah Tribe | 1.86 | 2.43 | 0.48 | 8.89 | 0.07 | 0.03 | 2.47 | 7.67 | 3.2 | 0.01 | 0 | 0.54 | 0 | **27.65** |
| North Bend-North Bend Way | 3.32 | 3.02 | 2.42 | 8.89 | 10.37 | 3.61 | 8.05 | 0 | 0 | 0.01 | 2.69 | 6.25 | 11.85 | **60.46** |
| Omak-Colville Tribe | 11.47 | 17.77 | 12.58 | 8.89 | 0.16 | 0.31 | 1.66 | 5.64 | 1.67 | 0 | 0.83 | 1.4 | 11.85 | **74.23** |
| Port Angeles- E 5th St | 7.53 | 10.38 | 1.84 | 8.89 | 0.01 | 0.42 | 2.99 | 6.62 | 3.2 | 0.02 | 0.89 | 3.44 | 11.85 | **58.06** |
| Port Townsend-San Juan Ave | 3.94 | 5.37 | 0.76 | 8.89 | 1.03 | 3.24 | 6.57 | 2.61 | 1.8 | 1.55 | 0.37 | 2.29 | 11.85 | **50.26** |
| Pullman-Dexter SE | 2.33 | 3.47 | 1.23 | 8.07 | 3.8 | 1.41 | 8.36 | 9.55 | 3.84 | 0.99 | 1.27 | 1.18 | 7.9 | **53.4** |
| Puyallup-128th St | 7.69 | 6.73 | 3.75 | 8.89 | 0.68 | 10.1 | 12.21 | 1.58 | 0.22 | 0.04 | 4.72 | 11.12 | 11.85 | **79.59** |
| Quincy-3rd Ave NE | 5.5 | 6.5 | 4.28 | 0 | 5.06 | 1.03 | 7.14 | 11.65 | 2.16 | 0 | 0.64 | 0.34 | 7.9 | **52.2** |
| Ritzville-Alder St | 3.1 | 5.37 | 4.2 | 7.8 | 6.07 | 0.2 | 0 | 3.5 | 0.62 | 0 | 1 | 0.28 | 7.9 | **40.04** |
| Rosalia-Josephine St | 3.21 | 5.81 | 3.75 | 8.89 | 2.97 | 0.5 | 7.45 | 3.15 | 3.84 | 0.04 | 0.29 | 0.08 | 7.9 | **47.86** |
| Seattle-10th & Weller | 8.61 | 11.19 | 3.7 | 8.89 | 0.27 | 16.6 | 17.77 | 1.71 | 0 | 0.69 | 17.64 | 4.55 | 3.95 | **95.56** |
| Seattle-Beacon Hill | 5.68 | 6.78 | 1.89 | 7.81 | 0.02 | 2.22 | 11.44 | 8.61 | 0 | 2.15 | 17.77 | 3.7 | 3.95 | **72.01** |
| Seattle-Duwamish | 10.52 | 11.61 | 4.23 | 8.89 | 0 | 0.48 | 8.73 | 5.77 | 0 | 17 | 13.81 | 5.58 | 3.95 | **90.56** |
| Seattle-South Park | 8.48 | 12.28 | 3.56 | 8.89 | 0.05 | 3.11 | 9.86 | 5.46 | 0 | 3.08 | 14.37 | 7.32 | 11.85 | **88.3** |
| Shelton-W Franklin | 6.18 | 6.63 | 1.41 | 8.89 | 1.52 | 1.91 | 5.39 | 3.84 | 1.36 | 17.77 | 1.49 | 3.54 | 11.85 | **71.76** |
| Spokane-Augusta Ave | 10.85 | 12.91 | 7.97 | 8.89 | 0.34 | 5.92 | 5.49 | 5.37 | 2.06 | 0.32 | 7.33 | 11.33 | 11.85 | **90.6** |
| Spokane-Monroe St | 8.65 | 10.89 | 7.34 | 8.89 | 1.82 | 8.25 | 7.91 | 3.09 | 2.06 | 0.14 | 2.75 | 8.22 | 11.85 | **81.83** |
| Sunnyside-S 16th St | 14.58 | 15.75 | 12 | 17.77 | 0.47 | 1.27 | 3.76 | 13.04 | 1.6 | 0 | 1.38 | 2.53 | 11.85 | **95.99** |
| Tacoma-Alexander Ave | 8.47 | 8.71 | 2.86 | 8.89 | 0.16 | 4.2 | 8.15 | 5.17 | 0.22 | 14.37 | 9.85 | 3.49 | 11.85 | **86.39** |
| Tacoma-L Street | 14.44 | 9.86 | 7.27 | 8.89 | 0.06 | 3.04 | 5.57 | 8.61 | 0.22 | 0.63 | 11.39 | 10.47 | 11.85 | **92.3** |
| Tacoma-S 36th St | 9.9 | 9.61 | 4.03 | 8.89 | 0.59 | 9.88 | 6.85 | 4.47 | 0.22 | 1.85 | 13.45 | 7.61 | 11.85 | **89.2** |
| Taholah-Quinault Tribe | 4.59 | 4.14 | 1.42 | 8.89 | 2.19 | 0.32 | 7.51 | 6.55 | 3.3 | 0.04 | 0.09 | 0.18 | 3.95 | **43.18** |
| Toppenish-Yakama Tribe | 17.77 | 17.15 | 17.77 | 8.89 | 0.09 | 0.58 | 1.59 | 17.77 | 1.6 | 0 | 0.9 | 1.95 | 11.85 | **97.9** |
| Tukwila Allentown | 9.64 | 11.46 | 6.24 | 8.89 | 0.11 | 4.66 | 8.06 | 8.45 | 0 | 0.33 | 17.18 | 9.6 | 11.85 | **96.46** |
| Twisp-Glover St | 9.26 | 15.91 | 10.68 | 8.89 | 2.75 | 0.3 | 2.34 | 5.8 | 1.67 | 0 | 0.24 | 0.77 | 11.85 | **70.48** |
| Vancouver NE 84th Ave | 12.79 | 9.68 | 5.74 | 7.4 | 0.25 | 9 | 9.42 | 4.61 | 2.17 | 0.12 | 9.2 | 17.77 | 11.85 | **100** |
| Walla Walla-12th St | 7.32 | 7.76 | 4.31 | 8.89 | 2.01 | 1.65 | 3.61 | 4.58 | 17.77 | 0.01 | 1.12 | 5.07 | 11.85 | **75.94** |
| Wellpinit-Spokane Tribe | 4.15 | 7.15 | 5.58 | 8.89 | 17.77 | 2.17 | 4.59 | 3.85 | 1.99 | 0.01 | 0 | 0.18 | 3.95 | **60.26** |
| Wenatchee-Fifth St | 7.68 | 11.07 | 5.92 | 13.17 | 0.72 | 2.35 | 5.94 | 5.09 | 1.47 | 0.01 | 2.08 | 3.09 | 11.85 | **70.43** |
| White Swan-Yakama Tribe | 9.01 | 7.29 | 5.8 | 8.89 | 1.25 | 0.75 | 3.26 | 3.2 | 1.6 | 0 | 0 | 0.73 | 7.9 | **49.68** |
| Winthrop-Chewuch Rd | 5.85 | 11.03 | 7.19 | 8.89 | 3.86 | 0.34 | 3.72 | 7.14 | 1.67 | 0 | 0.19 | 0.61 | 11.85 | **62.34** |
| Yacolt-Yacolt Rd | 7 | 4.48 | 1.84 | 8.89 | 3.84 | 4.83 | 13.65 | 0.34 | 2.17 | 0.05 | 0 | 3 | 11.85 | **61.94** |
| Yakima-4th Ave | 17.13 | 13.76 | 12.14 | 8.89 | 0.4 | 3.75 | 3.07 | 10.15 | 1.6 | 0.06 | 2.97 | 8.04 | 11.85 | **93.8** |