PM2.5 Saturation Study
Mason County, Washington

June 2019 through June 2020

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1.0 Executive Summary

The Olympic Region Clean Air Agency (ORCAA) maintains at least one air quality monitor in each of its six regulated counties: Clallam, Grays Harbor, Jefferson, Mason, Pacific, and Thurston. A saturation study is one method used to determine the best location for air monitor placement. The following report describes the year-long saturation study conducted in Mason County between June 2019 and June 2020.

The goals of this study were:

1. Determine whether the data collected from the air monitor at the Mason County fire station in downtown Shelton, Washington represents regional ambient air quality,
2. Evaluate seasonal air quality variability,
3. Identify the primary sources of regional PM2.5,
4. Identify whether a new location would be more appropriate for the permanent monitor.

Four temporary air monitors were installed around Mason County between June 2019 and June 2020. Initially these monitors were the optical particle counters previously used in the Clallam, Jefferson, and Thurston County saturation studies. Advances in sensor technology dramatically lowered the cost of new sensors while increasing the flexibility in placement requirements and datalogging capabilities. After vetting the data quality, ORCAA switched to Purple Air sensors to conduct the Mason County saturation study.

In addition to collocating a Purple Air sensor with the permanent PM2.5 monitor at the Central Mason Fire & EMS building located on Franklin St. in Shelton, three additional sensors were placed at the Timberlakes' Community Center, the North Mason Fire District station in Belfair, and at Bordeaux Elementary School in Shelton.

One year of PM2.5 data at all four sites verifies the monitor currently in downtown Shelton represents air quality around the county well. PM2.5 data collected in Belfair was compared with PM2.5 measurements in nearby Bremerton to determine if the Bremerton monitor might be more representational of North Mason County. This was not the case. This study shows the air monitor in Shelton best represents North Mason County relative to the monitor in Bremerton.

Based on the information from this study, a decision was made to keep the permanent air monitor at its current location in downtown Shelton.

2.0 Acknowledgements

This study could not have been accomplished without the assistance of several people. We would like to thank Marcus Vind of Timberlakes Community Center, Assistant Chief Scott Cooper of North Mason Fire Authority, and Chris Walton of the Shelton School District for their assistance installing air sensors at the Timberlakes Community Center, the Belfair Fire Station, and Bordeaux Elementary School in Shelton.

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Acronyms

ECY – Washington State Department of Ecology

EPA – United States Environmental Protection Agency

FEM – Federal Equivalent Method

FRM – Federal Reference Method

NAAQS – National Ambient Air Quality Standard

ORCAA – Olympic Region Clean Air Agency

PA – Purple Air (Air Quality Sensors)

PM – Particulate matter

PM2.5 – Mass concentration of all atmospheric particles with diameters less than 2.5 microns

PM10 – Mass concentration of all atmospheric particles with diameters less than 10 microns

USG – Unhealthy for Sensitive Groups

Units

nm – nanometer (0.000000001 meters)

m – meter

MPH – miles per hour

µg – microgram (0.000001 grams)

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4.0 Introduction

The Olympic Region Clean Air Agency (ORCAA) maintains at least one air quality monitor in each of its six regulated counties: Clallam, Grays Harbor, Jefferson, Mason, Pacific, and Thurston. County air monitors are placed in populated neighborhoods exposed to the poorest ambient air quality in the region. ORCAA defines ambient air quality as the air quality affecting an airshed or whole community, rather than the localized air quality impacted by a particular source. A saturation study is one method used to determine the best location for placing a county's air monitoring station.

Many pollutants affect air quality. PM2.5 is the pollutant of primary concern and is measured at almost all air monitoring sites in Washington. PM2.5 refers to all particulate matter in the atmosphere having a diameter less than 2.5 micrometers (µm). PM2.5 is reported as a mass of particles per volume of air and has units of micrograms per meter cubed of air ($\mu g\ m^{-3}$). Health studies have shown these size particles, and smaller, more negatively impact human health compared to larger particles. Other pollutants occasionally monitored in Washington state include nitrogen oxides (NOx and NOy), carbon monoxide (CO), sulfur dioxide (SO_2) ozone (O_3), and a selection of air toxics. Regional scale modeling indicates ambient concentrations of these pollutants are not significant enough to warrant monitoring in Mason County (IDEQ, 2018). This study looks only at ambient PM2.5 measurements.

During a saturation study several air quality monitors are placed in various locations in a specified region. The study may last a couple of months, a year, or multiple years depending on objectives. Supplemental measurements, such as meteorology, may be used to provide additional information about air pollution sources and air quality response to weather conditions.

Saturation studies are used to:

1. Determine the best location for each county's air monitor,
2. Assess regional air quality variability,
3. Evaluate daily and seasonal air quality variability,
4. Identify primary sources of air pollution in a region,
5. Determine how changes in industry and/or population affect air quality.

The following report describes the year-long saturation study conducted in Mason County between June 2019 and June 2020. A brief discussion of the regional air quality, industry, population, and climate is followed by a description of the study design, the monitoring network, data analysis, and results.

5.0 Background

This is the first saturation study to be conducted in Mason County. It is the fourth saturation study to be completed in ORCAA's jurisdiction since 2010. Prior to this, ORCAA carried out saturation studies in Clallam County, Jefferson County, and Thurston County. Data from the Grays Harbor saturation study has been collected and is awaiting analysis and report. A preliminary study plan for Pacific County is in process. All saturation studies are specific to PM2.5 pollution, which is the primary pollutant routinely monitored in ORCAA's region.

5.1 Historical Air Quality in Mason County

ORCAA started monitoring PM2.5 in Shelton in May 2001. The first air monitors were located at Mason County General Hospital and consisted of a nephelometer and a federal reference method (FRM) gravimetric PM2.5 sampler. The FRM collects particles on a filter over a 24-hour period and provides an average daily concentration. Although FRM data are considered more robust, they can't resolve hourly data and the daily data are not available until one to two weeks after sample collection. The nephelometer indirectly measures PM2.5 and has higher uncertainty, however it provides hourly data in real time. It measures the amount of light scattered (Bscat) by particles in the air. Bscat is converted into PM2.5 using a factor developed through a linear regression comparison between the FRM gravimetric PM2.5 and the Bscat data (Figure 5.1).

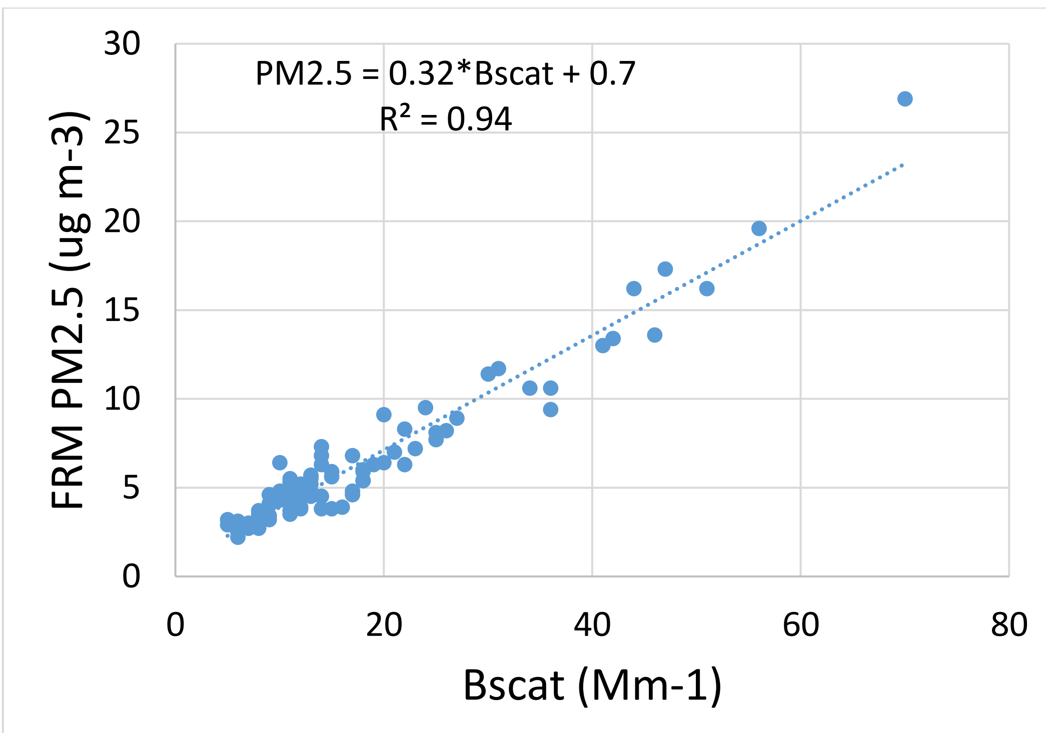

Figure 5.1 Correlation between federal reference method for PM2.5 and light extinction measured by the M903 Radiance research nephelometer.

PM2.5 can be related to Bscat (light extinction) using aerosol mass extinction efficiency (MEE) via the following equation: PM2.5 = (1/σ)*Bscat, where σ is the MEE, which is typically reported with units of $m^2\ g^{-1}$. In this case, conversion of Mm^{-1} and g to ug cancel each other and the math and units work. Solving for σ yields a MEE of 3.1 $m^2\ g^{-1}$ at Mason County General Hospital.

In March 2011, ORCAA moved the Mason County monitoring site from the hospital to the Central Mason Fire & EMS building (hereafter called the Shelton fire station) located in downtown Shelton. As the new site was only a few miles away, general aerosol characteristics were assumed to be the same and the Washington State Department of Ecology (Ecology) continues to use the MEE developed above to convert Bscat to equivalent PM2.5.

There are many factors governing PM2.5 MEE: density, size distribution, and chemical composition being the primary determinates. Atmospheric humidity also affects MEE. When relative humidity (RH) exceeds 70 to 75 percent, aerosol particles absorb atmospheric moisture, which increases particle size. These particles release the moisture and "crystallize" and shrink when RH drops below 50 percent. The exact humidity at which a particle will deliquesce, or crystallize, depends on chemical composition. To mitigate this effect, sampled air is heated to ensure RH is less than 50 percent. Reported MEE varies from 1.6 to 6 $m^2\ g^{-1}$ however much of the reported difference can be attributed to changes in RH (Chow et al., 2012; Hand & Malm, 2007)

ORCAA collocated nephelometers and FRM analyzers at 5 locations around the Olympic peninsula: Lacey, Aberdeen, Shelton, Port Angeles, and Port Townsend. The average MEE obtained for the region is 3.6 (+/- 0.53) $m^2\ g^{-1}$. Ecology standard operating procedures for the M903 nephelometer further allows a 10 percent error in Bscat values relative to a known span gas signal (Clouse, 2016). After propagating uncertainties in both Bscat measurement and the calculated MEE value, PM2.5 values derived from nephelometer data are subject to an 18 percent uncertainty relative to FRM or federal equivalent methods (FEM).

The Environmental Protection Agency (EPA) has set two national ambient air quality standards (NAAQS) for ambient PM2.5 concentrations; an annual average standard and a 24-hour standard. In March 2024, EPA revised the annual PM2.5 standard from 12 ug m^{-3} to 9 ug m^{-3}. To maintain air quality attainment status, the annual average PM2.5 concentrations should not exceed 9 ug m^{-3} over a period of 3 years. The second PM2.5 NAAQS is a 24-hour standard, set at 35 ug m^{-3}. If an FRM or FEM monitor records a 24-hour average PM2.5 concentration greater than 35 ug m^{-3} more than 7 times a year for 3 years running, that site will be considered in non-attainment for PM2.5. The three-year average of the 98^{th} percentile maximum 24-hour average PM2.5 concentration is called the design value.

Since PM2.5 measurements began in 2001, air quality in Shelton has generally fallen in the "good" category both with respect to annual average PM2.5 concentrations and the Air Quality Index (AQI), which is based on the 24-hour average.

EPA classifies Mason County as in attainment/non-classifiable. A PM2.5 FRM has not been operated in the county since 2001 when the MEE value was created for nephelometer Bscat data. Per EPA regulations (*40 CFR part 50*), if the Bscat derived PM2.5 DV is within 15 percent of the 24-hour NAAQS, an FRM or FEM monitor would have to be installed. Annual average Mason County PM2.5 over the last 20 years is shown in Figure 5.2 and the running three-year DV for the past 17 years is shown in Figure 5.3. These data show, even with uncertainties in the nephelometer derived PM2.5, Mason County meets the annual and daily PM2.5 NAAQS except in the case of wildfire smoke intrusions.

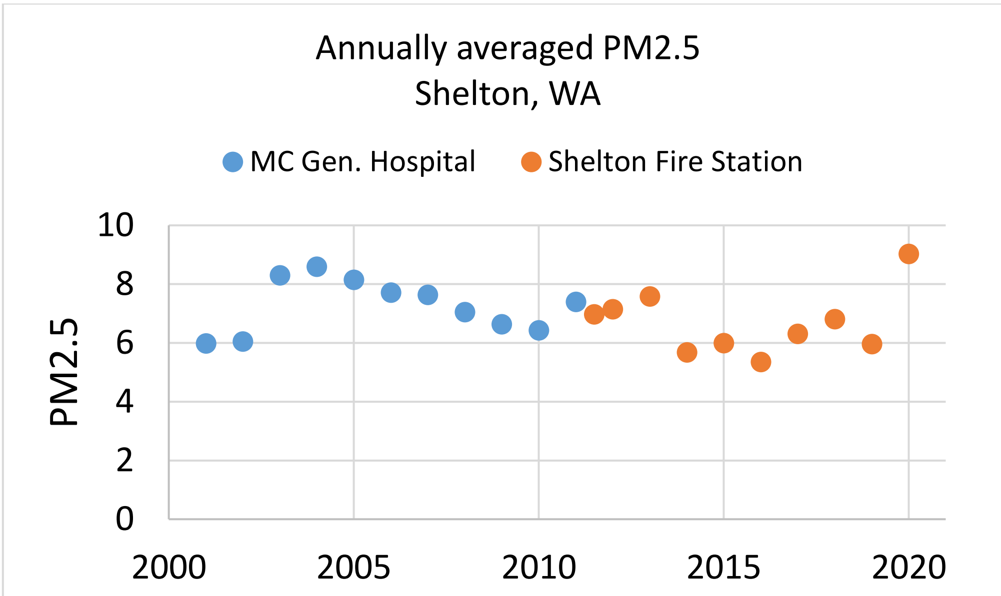

Figure 5.2 Annually averaged PM2.5 in Shelton

Mason county's annual average PM2.5 has not exceeded 10 µg m^{-3} since monitoring began. Annual average PM2.5 has generally trended downwards since 2003. The anomalously high annual average for 2020 with respect to the last decade, was due to a particularly bad wildfire smoke event when PM2.5 levels were above 200 µg m^{-3} for 5 days. Subtracting these wildfire smoke days brings the annual average to 5.5 µg m^{-3}, consistent with the general downward trend.

As with the annual average PM2.5, the 24-hour PM2.5 design values for Shelton have generally decreased between 2003 and 2016. That trend seems to have reversed beginning in 2017. A closer look at the data reveals recent wildfire smoke intrusions from outside the region have caused design value to increase. Figure 5.4 shows the same data as figure 5.3, but with wildfire smoke impacted days omitted. The data presented in figures 5.3 and 5.4 show pollution for woodstoves and outdoor burning have decreased by 50 percent, but recent increases in wildfire smoke events are countering this progress.

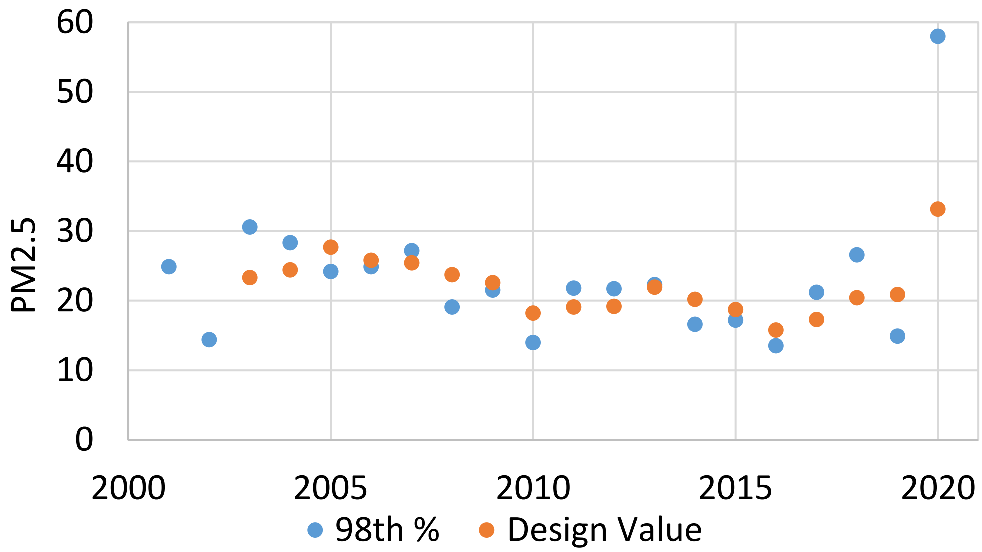

Figure 5.3 98th percentile maximum daily values per year and Shelton Design Values: a 3-year running average of the 98th percentile max daily value

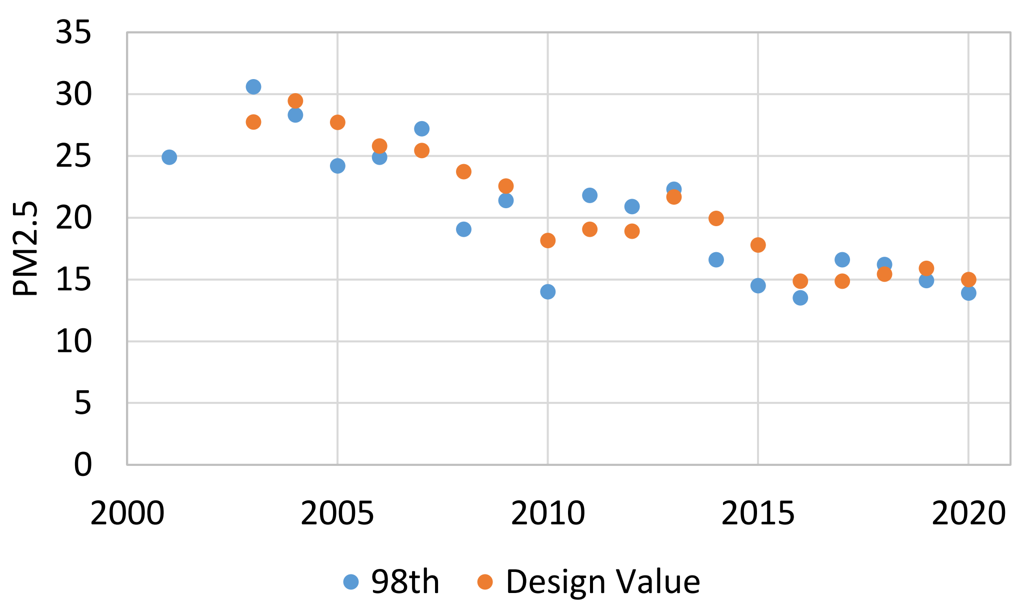

Figure 5.4 98th percentile maximum daily values per year and Shelton Design Values: a 3-year running average of the 98th percentile max daily value after removing days impacted by wildfire smoke.

5.2 Climate

Mason County lies between the eastern slopes of the Olympic Mountains and Hood Canal. As with most of western Washington, Mason County is temperate. Average annual temperature is 51 °F with winter lows averaging around 35°F and summer highs averaging 76°F. Average rainfall here is 91.2", 2.5 times the state average. Over 90 percent of the precipitation falls between September and April and nearly 50 percent falling between November and January. Wind direction is most often between 165° (southerly) and 255° (westerly). Average wind speed is 11.5 MPH with some seasonal variability. Summer wind speeds average around 9 MPH and 15 MPH during the winter months (USA.com, 2024). Measured wind speed and direction during this saturation study matches the above averages as shown by the seasonal wind roses Figure 5.5.

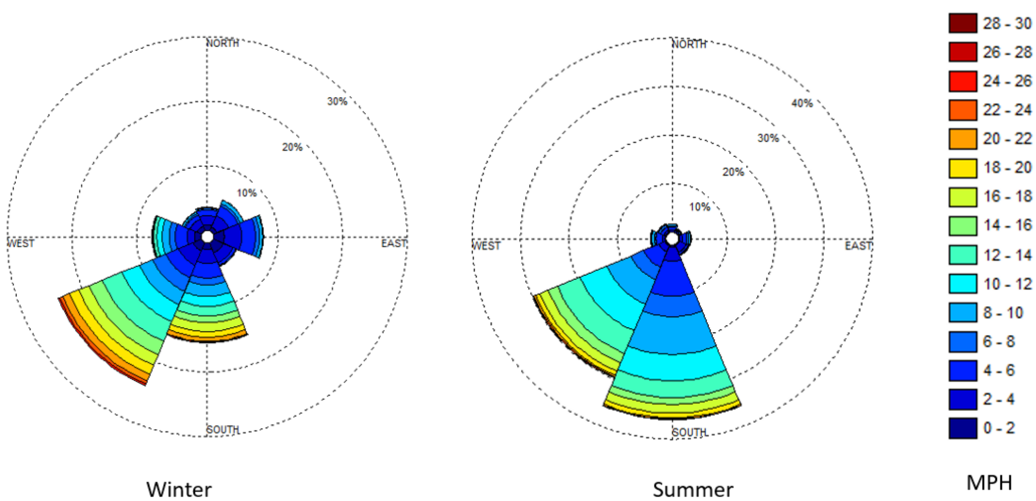

Figure 5.5 Wind roses with respect to wind speed in Mason County for winter and summer months.

5.3 Population and Industry

Mason County population has increased steadily over the last twenty years, growing from roughly 50,000 in the year 2000 to nearly 66,000 by 2020 (CensusBureau, 2023; Neilsberg, 2022). Shelton is the only incorporated city in the county and also the county seat. In 2020 Shelton's population was roughly 10,000, accounting for roughly 15 percent of the total county population. Based on the 2010 census, median income per household in Mason County was roughly $48,000 per year with 15 percent of population living below the poverty line. Low income combined with the rural nature of the Mason County makes woodstoves a more economic option for home heating compared to gas or electric. The rural environment also leads to more residential and land clearing fires compared to urban communities. Wood smoke emissions in Mason County are likely to be higher per capita compared with more heavily populated communities of nearby Seattle or Tacoma.

During the data collection phase of this study there were 74 registered air pollution sources in Mason County. Most of these are minor sources comprising gas stations, autobody spray booths, asphalt and concrete plants, small lumber mills, and other small miscellaneous businesses. Sierra Pacific Industries is the only major (Title V) source in Mason County. It is located approximately 1700', albeit generally downwind, from the permanent air monitoring site in downtown Shelton.

6.0 Study Objectives & Design

The goals of this study were to:

1. Determine whether the air monitor at the Shelton fire station provides accurate representation of regional ambient air quality,
2. Evaluate neighborhood scale air quality variability,
3. Identify the primary sources of PM2.5 in the region,
4. Identify whether a new location would be more appropriate for the permanent monitor.

6.1 Instrumentation

The Mason County saturation study marks a departure from other county saturation studies recently conducted by ORCAA. ORCAA replaced the optical particle counters (OPC) used to carry out the previous studies with smaller Purple Air (PA) low-cost sensors. The sensors cost a fraction of the OPC, do not need to be annually recertified, and transmit data directly to the Purple Air website making the data immediately accessible to everyone. This eliminates the need for ORCAA to create, install, and maintain datalogging capabilities, while also alleviating the burden of public records keeping, since the data are available on-line. The number of these sensors owned by private citizens continues to increase and their data may be incorporated into future saturation studies, thereby increasing the number of locations included in each study without added expense and time deploying sensors. The Environmental Protection Agency (EPA) has already shown the feasibility of this by incorporating and applying corrections to publicly owned sensor data on their Fire & Smoke map (Evans et al., 2023).

EPA, ECY, ORCAA and several other government and research institutions have evaluated PA sensors, among others, over the past several years (Barkjohn et al., 2021; Delp & Singer, 2020; Tryner et al., 2020; Wallace et al., 2021). These studies generally show the data to be precise, but not very accurate. The PA sensor data correlates well to PM2.5 data collected using FRM and Federal Equivalence Methods (FEM), however overreports PM2.5 concentrations by a factor of 1.5 to 5 (Tryner et al., 2020; Wallace et al., 2021). In southern, dry regions of the US, PA sensors overpredict PM2.5 by about 30 to 50 percent with respect to FRM and FEMs (Tryner et al., 2020). In wetter climates the Purple Air sensors overpredict PM2.5 by a factor of 2 to 4

(Wallace et al., 2021). EPA has developed a correction incorporating the RH measured by the sensor to account for this with some success (Barkjohn et al., 2021). The Purple Air on-line, real-time map offers several corrections for users to choose and apply directly to the sensors on the map. The appropriate correction will depend on location and dominant PM2.5 chemistry.

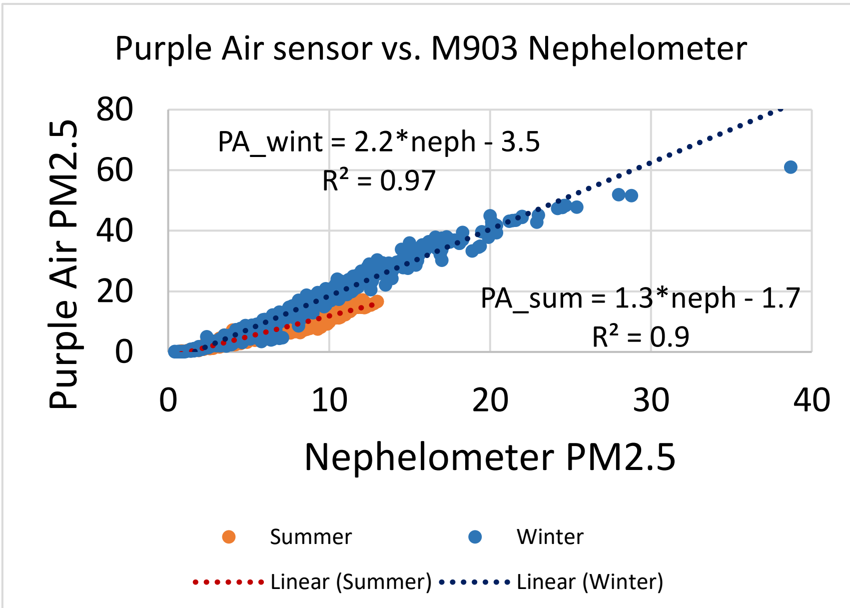

Figure 6.1 Purple Air sensor data vs. the nephelometer in summer and in winter

For the Mason County saturation study, ORCAA developed correction factors unique to the region using data from a collocated PA sensor and reference monitor (M903 nephelometer) in Mason County. Despite the nephelometer not being an FEM as used in the above cited studies, comparison between this PA sensor and the nephelometer is consistent with the published results. In summer months, the sensor reported PM2.5 concentrations about 1.3 times higher than the reference monitor (Figure 6.1). In winter, the PA sensors report concentrations twice that of the reference monitor. To account for seasonal differences a new scaling factor was determined each month using the collocated data and applied to all sensor data in the region. As shown in Figure 6.1, the linear relationship between the sensors and the nephelometer drops off when the PA sensors report PM2.5 concentrations greater than 50 µg m^{-3}. This finding is also consistent with the published literature (Barkjohn et al., 2022). We account for this by applying a modified correction factor when the PA sensors report PM2.5 above this threshold.

6.2 Sensor Locations

EPA and ECY have strict guidelines on where and how neighborhood scale PM air monitoring sites are placed (Clouse, 2016). The main requirements are as follows:

1. The sample inlet must be between 2 and 15 meters above the ground and at least 1 meter from a supporting structure.
2. Sample inlet should be placed at least 100 meters from a wood burning device and a quarter mile from any fugitive dust source.
3. Distance to nearest road should be at least 10 meters for every 1000 vehicles driven per day. This is based on average daily traffic counts.
4. An open horizontal arc of at least 270° must surround the sample inlet.
5. The sample inlet must be at least 10 meters from the tree drip line.

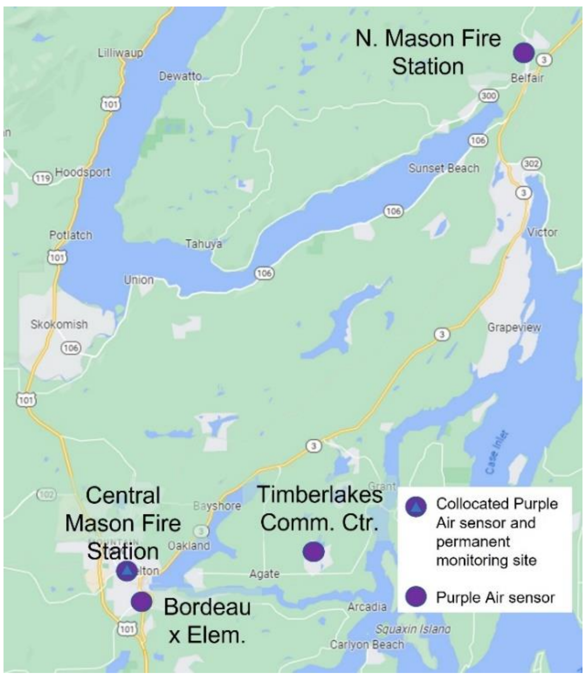

Figure 6.2 Map of sensors and reference monitor

With the exception of requirement 1 & 4, ORCAA followed these guidelines in choosing and placing the PA sensors. The manufacturer recommends placing the PA sensors under the eaves of a building to protect it from extreme weather. In addition to state and federal monitoring station placement requirements, practical logistics were considered. Sites were required to have access to power and internet connection via a wi-fi network. The instruments and data logger had to be easily accessible by ORCAA staff, and secure from tampering and vandalism. The chosen monitoring locations represented ambient air quality in populated and therefore higher exposure risk. Lastly, one of the sensors was collocated with the reference monitor, the nephelometer, at the Shelton fire station in Shelton. This provided a continuous comparison between the reference site and sensor data throughout the study. The other three sensors were placed at: Bordeaux Elementary in Shelton, Timberlakes' Community Center, and North Mason Fire Station in Belfair (Figure 6.2).

In addition to EPA site criteria, the saturation study sites were specifically chosen for the following reasons.

1. *__Timberlakes Community Center:__* ORCAA receives multiple complaints every year regarding woodstove smoke impacting residents. There are over 750 homes in this community according to USPS route delivery data (https://eddm.usps.com/eddm/select-routes.htm). Assuming an average of 4 people per residence, the population is around

3000 people, making it one of the more populated residential communities in Mason County. The community center is sufficiently far from any specific residential chimney and therefore represents general ambient air quality in the neighborhood. Both the smoke complaints and population density made this site a great location for evaluating air quality and testing if the Shelton monitor sufficiently captures air quality in the Timberlakes community.

2. *North Mason Fire Station, Belfair*: Belfair is the 2nd most populated town in Mason County after Shelton and is located near the northern county border. It is geographically closer to the Bremerton air monitor operated by Puget Sound Clean Air Agency than to the Shelton air monitor. This site was chosen to determine if North Mason County air quality was better represented by the Shelton or Bremerton air monitor.

3. *Bordeaux Elementary:* This site sits only a few miles from the permanent air monitoring site at the Central Mason Fire and EMS station in downtown Shelton. While downtown Shelton sits at sea level adjacent to two significant air pollution sources, Bordeaux Elementary is on a bluff 200 ft above the city and generally upwind of both the mills and the permanent monitor.

7.0 Results

The primary study goal is to evaluate how well the air monitor at the Shelton fire station represents air quality in Mason County. A secondary goal is to ensure the permanent site generally measures the worst ambient air quality in Mason County relative to the other saturation study sites. Lastly, both seasonal and daily differences in PM2.5 are examined to determine primary PM2.5 sources and drivers in Mason County.

During the study period, air quality was classified as good (daily average < 12 $\mu g\ m^{-3}$) over 90 percent of the days at all four monitoring locations (Figure 7.1). At all locations, 60 to 70 percent of the daily PM2.5 values were below 7 $\mu g\ m^{-3}$ and 2 to 5 percent were moderate (daily average PM2.5 between 12 and 35 $\mu g\ m^{-3}$). No daily averages greater than 20 $\mu g\ m^{-3}$ were recorded during this study. This is notable as wildfires inundated the region with smoke creating unhealthy levels of smoke for several days during summer months in 2017, 2018 and 2020. The summer of 2019 experienced almost no smoke intrusions into Western Washington and these data represent a summer free of wildfire smoke.

With respect to overall air quality, the daily frequency distributions shown in Figure 7.1 are similar at all four locations. The blue bars represent the nephelometer and sensor collocated at the Shelton fire station.

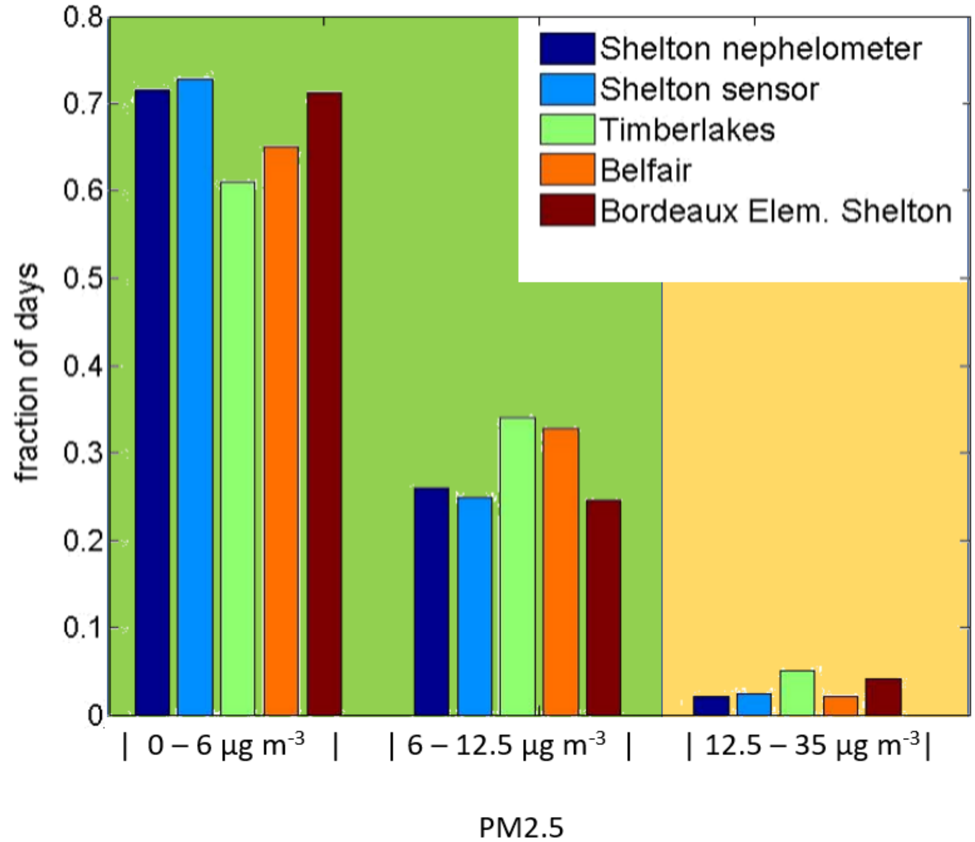

Figure 7.1 Fraction of days falling within specified PM2.5 concentration ranges at all monitoring locations during the Mason Co saturation study. Green indicates “good’ air quality and yellow indicates “moderate” air quality as defined by EPA’s PM2.5 air quality index (AQI). The monitor and sensor collocated at the Mason County Fire District building in Shelton are represented by dark and light blue bars respectively.

7.1 Inter-Site comparison

While the data shown in Figure 7.1 indicate annual PM2.5 exposure is similar throughout Mason County, it doesn’t reveal whether the air monitor in downtown Shelton is a good indicator of air quality throughout the region on any given day. One way to determine how well the reference monitor represents regional air quality is to look at how well the data correlate with data collected at the other sites. Using scatter plots and a linear regression (Figure 7.2), the correlation coefficient and linear relationship between all four sites and the reference monitor is calculated. The slope(m) and intercept(B) of the linear fit is shown on each plot in Figure 7.2. The coefficient of determination (R^2) for each site relative to the others are shown in Table 7.1. A R^2 equal to 1 means there is a mathematical relationship between the two data sets whereby a data point from one set can be used to calculate the data point in the second set with 100 percent accuracy. As there are uncertainties associated with all measurements made in this study, an R^2 equal to 1 is statistically improbable. An R^2 near or equal to zero means there is no statistical or mathematical relationship between the two data sets.

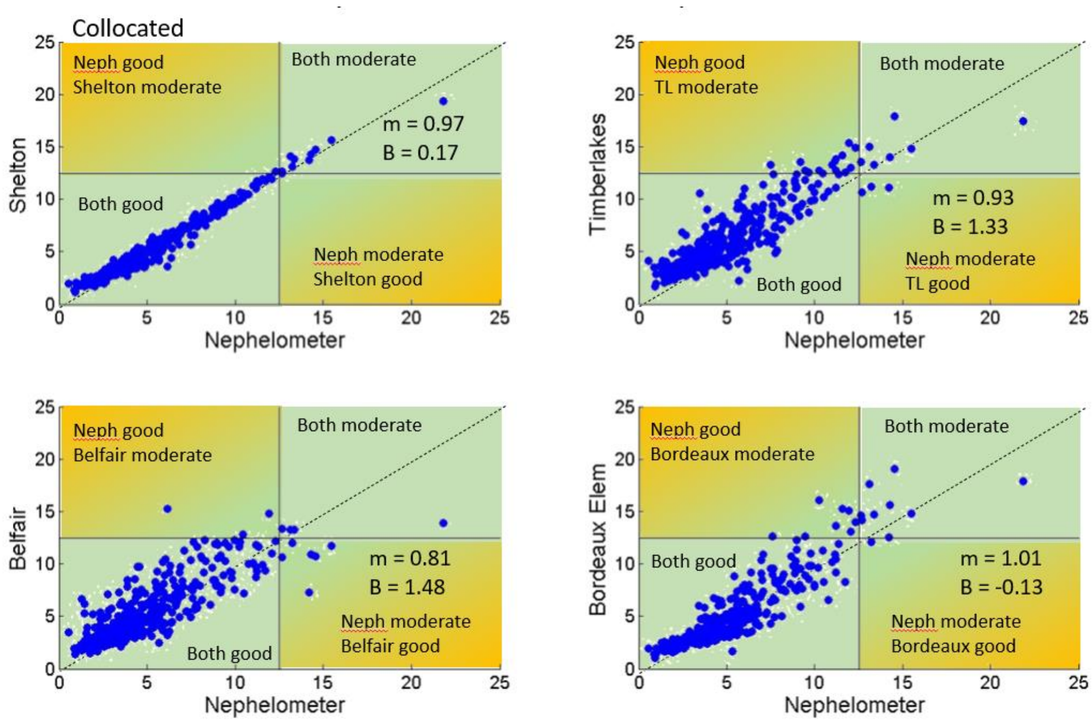

Figure 7.2 Scatter plots of all four Purple Air sensors vs. the nephelometer at the Mason Co Fire Station in downtown Shelton. Axis are PM2.5 in ug m^{-3}.

The nephelometer data at the Shelton fire station serves as the reference measurement for the four PA sensors. The Shelton PA sensor is highly correlated with the nephelometer at R^2 = 0.96 with data falling close to the 1:1 ratio line (m = 0.97). This demonstrates the collocated sensor and nephelometer are reporting comparable values for PM2.5. The other 3 sites are also significantly correlated to the nephelometer data. R^2 values decrease with distance from the reference site (Table 7.1, column 1). The Bordeaux Elementary sensor, located just under a mile away, is the next most highly correlated with an R^2 value of 0.83. The Timberlakes PA sensor is almost 6 miles west of the reference site and has an R value of 0.81. Belfair is the furthest site at 21 miles away. The R^2 value between the Belfair and Shelton data is the lowest at 0.66. All scatter plots indicate a linear fit with a slope close to or less than 1 (Figure 7.2), meaning the PM2.5 concentrations are generally the same at all 4 locations. When the slope is less than 1, the measured PM2.5 at the saturation site is generally less than that measured at the reference site.

Table 7.1 Coefficient of determination (R2) for daily PM2.5 concentration comparisons between all measurement sites and the reference monitor

	Nephelometer	Shelton	Timberlakes	Belfair	Bordeaux E.
Nephelometer	--	0.96	0.79	0.66	0.83
Shelton	0.96	--	0.83	0.69	0.86
Timberlakes	0.79	0.83	--	0.72	0.81
Belfair	0.66	0.69	0.72	--	0.67
Bordeaux E.	0.83	0.86	0.81	0.67	--

The corresponding PM2.5 AQI categories are shown as a grid over the scatter plots in Figure 7.2. In March 2024, EPA lowered the PM2.5 threshold between the 'good' and 'moderate' AQI classification from 12 µg m^{-3} to 9 µg m^{-3}. Figure 7.2 represents the previous AQI threshold, valid at the time this study was conducted. For the nephelometer to represent air quality throughout Mason County and sufficiently protect the public, the AQI categories should match for each point on the plot. When there is an AQI category discrepancy, the nephelometer should register in the higher AQI category. Figure 7.2 data points are ideally placed in every quadrant except the upper left. When PM2.5 is near the boundary between good and moderate, 12 µg m^{-3}, measurement uncertainties and small differences in PM2.5 concentrations can cause a discrepancy in the category. This region is marked by green shading in Figure 7.2 and does not constitute a verifiable AQI category disparity.

The Timberlakes sensor recorded the 14 moderate days when the Shelton sensor reported good air quality. All 14 days were within 3 µg m^{-3} of the "good" AQI. The average PM2.5 difference between good air quality and measured PM2.5 for these 14 days was 0.84 $\pm$ 0.77 µg m^{-3}, generally within instrument uncertainty. The Belfair sensor reported only 3 moderate days when the Shelton sensor reported good air quality. During all three days the Belfair sensor was within 3 µg m^{-3}. The sensor at Bordeaux Elementary had 8 days in the moderate while less than a mile away Shelton still measured good air quality. The average difference between the Bordeaux sensor and the good AQI on these days was 1.6 $\pm$ 1.3 µg m^{-3}.

Given the 26-mile distance between Belfair and Shelton and the 13-mile distance between Belfair and the Bremerton site, PM2.5 data from the Bremerton and Shelton air monitoring sites are compared to the Belfair sensor data. This analysis evaluates whether the Shelton or Bremerton monitoring site best represents air quality in Belfair. Figure 7.3 shows the scatter plot and linear fits between the Shelton nephelometer and the Belfair sensor data (blue) and the Bremerton nephelometer and the Belfair sensor(red). As stated above, the R^2 value between the Belfair and Shelton data is 0.66 and the 0.59 between Belfair and Bremerton data.

While both the Shelton and the Bremerton nephelometer data are similarly correlated with the Belfair sensor data, the PM2.5 concentration at the Shelton site agrees better with the Belfair data. The slope of the fitted line is less than 1 at 0.81. Linear regression between the Belfair and Bremerton data yields a slope of 1.25, indicating PM2.5 measured in Belfair is about 25 percent higher than in Bremerton. There are two explanations. First, home heating with woodstoves is more prevalent in rural communities like Shelton and Belfair relative to Bremerton. Second, Belfair generally lies downwind of Shelton and upwind of Bremerton, with southerly winds being dominant in winter when woodstove use peaks. Given these results, Belfair air quality is best represented by the Shelton monitor despite a closer proximity to the Bremerton monitor.

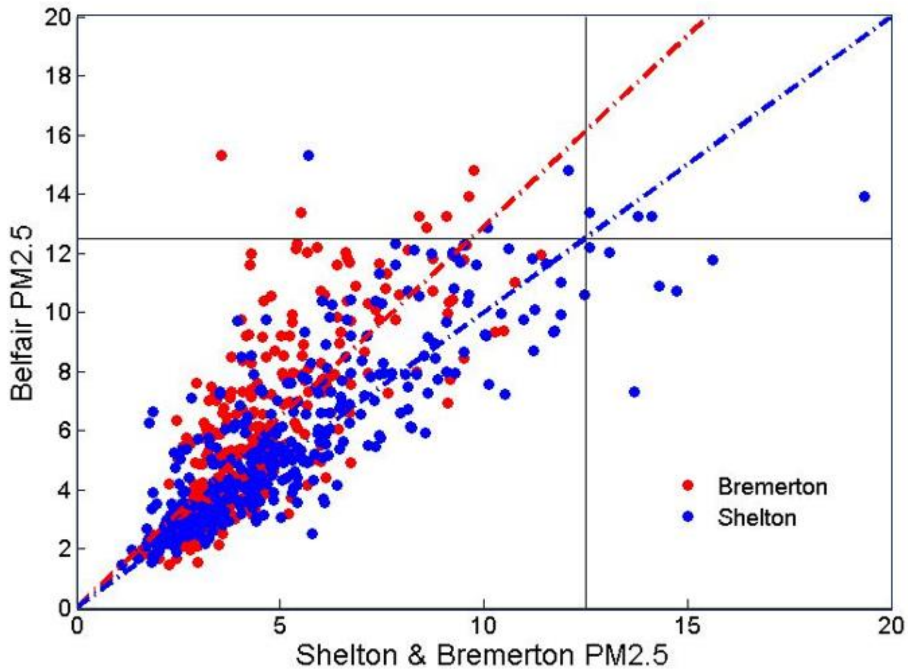

Figure 7.3 Scatter plots showing the Belfair PM2.5 daily data relative to that measured in Shelton (blue) and in Bremerton (red).

7.2 PM2.5 Sources in Mason County

There are several potential PM2.5 sources in Mason County. Woodsmoke from wildfires, controlled outdoor burning, and woodstove and fireplace use are all major sources. Other PM2.5 sources are traffic and local industry like sawmills, gravel pits/rock crushers, and other small point sources. Seasonal changes in meteorology strongly influence the relative source importance. Daily, weekly, and seasonal changes in human behavior can also affect PM2.5 emissions. Looking at PM2.5 variability with respect to season, weekday, and hour of the day provides insight into the most significant regional PM2.5 sources.

7.2.1 Seasonal Variability

Mason County's saturation study air quality data were divided into summer (April – September) and winter (October – March) with fall and spring divided between the two extremes. During the winter, PM2.5 concentrations in Mason County occasionally pushed air quality into the moderate AQI category (Figure 7.4). At all four sites, over 90 percent of winter days were classified as good. The number of moderate AQ days recorded at each site were: seven, seventeen, six, and fourteen at Shelton, Timberlakes Community Center, Bordeaux Elementary, and Belfair respectively. During the summer months only one day in Belfair fell in the moderate category and all other days were good. These data are reflective of increased woodstove use in winter and further indicate outdoor burning and recreational fires in summer do not significantly impact air quality. In other years, wildfire smoke intrusion has caused a significant number of summer days when PM2.5 reached unhealthy and very unhealthy levels in this area. Although wildfire smoke was not a factor during this study, it did significantly impact the region a few months after the study conclusion in September 2020.

Seasonal differences in meteorology also play a factor in PM2.5 concentrations measured in Mason County. As previously shown in Figure 5.5, wind direction is consistently southerly or south westerly in both winter and summer. Figure 7.5 shows PM2.5 concentrations relative to winter and summer wind directions. In winter, wind direction does not strongly affect PM2.5 concentrations. In summer the highest PM2.5 concentrations are associated with rare northerly to easterly winds. Large industrial and urban centers around Seattle and Tacoma lie to the northeast of Shelton. Summer months are hotter and drier and northerly winds are associated with high pressure systems bringing warm dry weather. This could correspond to more dust in the air or photochemical haze transported from urban areas.

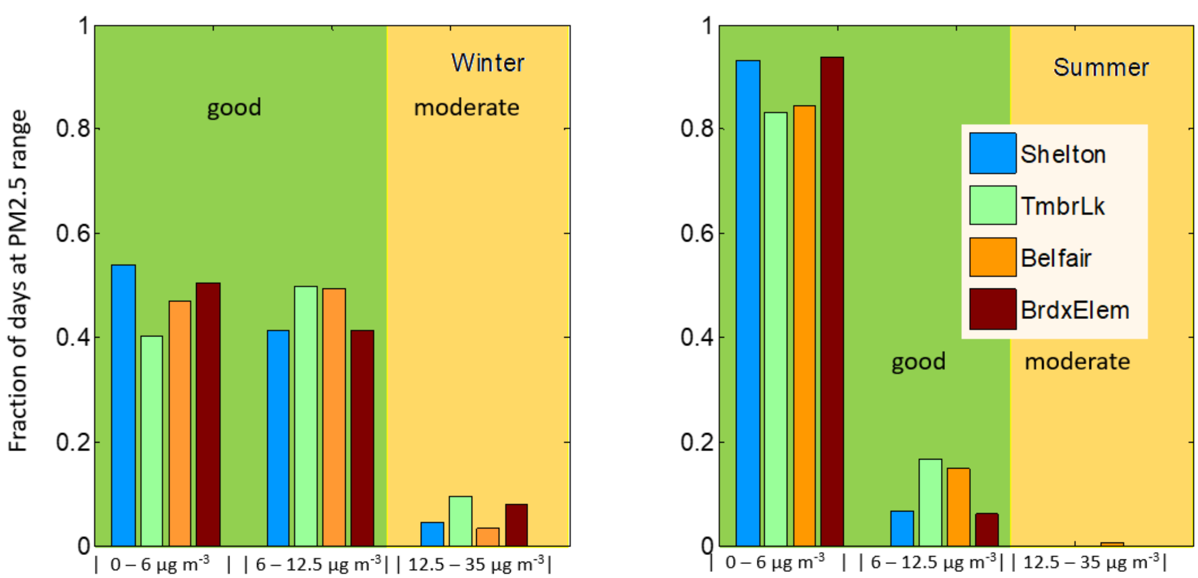

Figure 7.4 Seasonal Fraction of days falling within PM2.5 concentration ranges.

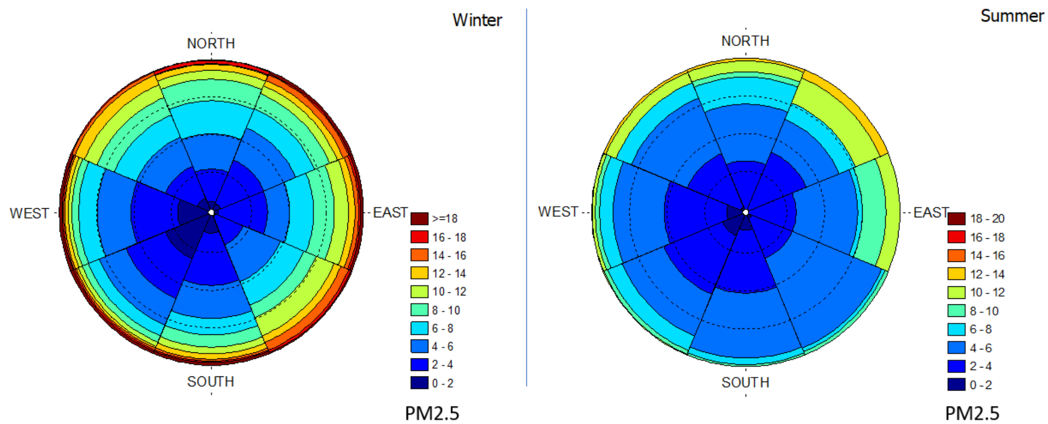

Figure 7.5 Normalized, seasonal wind rose with respect to PM2.5. Shows the frequency distribution of PM2.5 as a function of wind direction.

7.2.2 Daily & Weekly Variability

The winter and summer average hourly Shelton nephelometer PM2.5 concentration for each weekday are shown in Figure 7.6. Winter PM2.5 profile displays morning and evening peaks commonly associated with woodstove use. As temperatures drop in winter, more people light wood stoves and fireplaces to heat their homes leading to an increase in emissions. Woodstove use is more prevalent in rural communities like Mason County compared to urban and suburban areas. Stove operation occurs most frequently in the evening and through the night when people are home from work and school. The highest PM2.5 concentrations are typical between 4 and 6 p.m. coinciding with typical ignition times when stove emit the highest concentration of particulate matter. PM2.5 concentration gradually come down throughout the evening but remain elevated until early morning hours. A second smaller peak is observed between 6 and 9 a.m. A daily minimum in PM2.5 between noon and 4 p.m. reflects minimal woodstove use while families are away from home. Solar heating from late morning to afternoon breaks up the nighttime inversion and allows deeper mixing of pollutants in the boundary layer, further reducing PM2.5 concentrations.

Morning and afternoon commute hours in urban areas create similar diurnal variability, however there are clear differences between commute hour and woodstove use data profiles. When traffic is the cause, the double peak is present year-round and generally shows up only during the weekdays. As shown in Figure 7.6, summer PM2.5 in Shelton has no discernible diurnal features and looks the same Monday through Sunday. That said, the morning PM2.5 peak is absent on Saturday and Sunday in the winter data as well, which could indicate winter morning commutes contributes to diurnal PM2.5 features. The weekday scatter in morning PM2.5 concentrations is within instrument uncertainty and therefore inconclusive. The two primary factors causing the evening PM2.5 peak observed in winter is a combination of woodstove use and nighttime inversions trapping pollutants close to the surface.

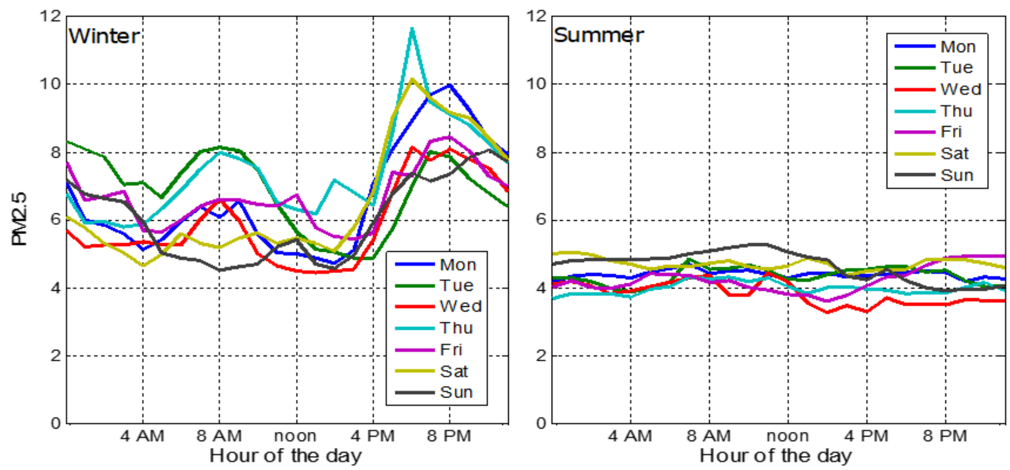

Figure 7.6 Average PM2.5 concentration for each hour of the day and day of week for winter and for summer.

8.0 Conclusions

The monitor at the Shelton fire station is generally representative of air quality throughout Mason County. Sensors occasionally indicated moderate air quality at the Belfair (3 days), Timberlakes (14 days), and Bordeaux Elementary (8 days) locations when the Shelton sensor indicated good air quality. All these days occurred when PM2.5 concentrations were close to the cut point differentiating good from moderate air quality and the differences were often below the limit of detection. The monitor will remain at its current location as a good representation of Mason County air quality. Future data collected here will add to the historical record and allow evaluation of air quality trends in the region without interruption. The dominant PM2.5 sources in the region are woodstoves and more recently, although not impacting this study, long-range transport of wildfire smoke.

9.0 References

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