PM2.5 Saturation Study

Thurston County, Washington

October 2015 through January 2017

Prepared by:

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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. Prior to this study, the most recent Thurston County air quality saturation study was conducted during winter 1994/95 and winter 1995/96. Data from this study confirmed the monitoring site Mt. View Elementary in Lacey, WA as the best location for the Thurston County monitor. The following report describes the year-long saturation study conducted in Thurston County between October 2015 and January 2017.

The goals of this study were:

1. Determine whether the Mt. View Elementary nephelometer data represents regional ambient air quality in Thurston County
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

Four temporary air monitors were installed around Thurston County between September 2015 and September 2016. One was collocated with the Lacey nephelometer at Mt. View Elementary (MTV) school; one placed at Fire Station 3 (FS3) on Boulevard Ave in East Olympia; another installed in West Olympia at the Olympic Region Clean Air Agency (ORCAA) headquarters on Limited Lane NW; lastly, we placed a monitor at Rochester Middle School (RMS) in south Thurston County. Data collected at all fours sites were significantly correlated, although the magnitude of PM2.5 concentrations differed dramatically. MTV, the current long-term monitoring site, reflected regional ambient air quality well. PM2.5 concentrations measured at MTV and RMS were the highest of the four sites. Although the RMS monitor occasionally measured PM2.5 concentration peaks higher than that of MTV, statistically the data were similar.

Analysis of particle absorption properties, seasonal and daily PM2.5 variability, and meteorology in conjunction with PM2.5 helped identify the primary PM2.5 sources. Residential wood heating is the dominant source of ambient PM2.5 during cold winter months. Concentrations are highest in the mornings and evenings when ambient air pollution levels are considered “moderate” under the Washington Air Quality Advisory (WAQA). Morning and evening maxima coincide with the time of day when most people are home, and fireplaces and wood stoves are operational. Often strong temperature inversions set up in the evening and last into morning, further exacerbating poor air quality at night. During the day, the inversions weaken, or lift altogether, which helps clear out the air. Winter midday air quality was about the same as average summer air quality and considered “good” in the WAQA index.

The RMS monitor was in a region of the county where outdoor burning is permitted and was therefore more heavily impacted by residential and land clearing burning. The other three monitors were all located within city limits or the urban growth area where all outdoor burning is prohibited. On average there are about three thousand outdoor burn permits issued in Thurston County every year. None of those permits are valid in the Olympia, Lacey, and Tumwater city limits or urban growth area. Based on PM2.5 data collected at MTV and RMS, residential woodstove and fireplace use create similar PM2.5 concentrations in city limits as caused by open burning in rural communities.

The average summertime PM2.5 concentrations were “good” at all four monitoring sites and data showed no significant daily variability. Summertime air pollution sources are a mix of exhaust from I-5, local industry, and wind-blown dust. We are maintaining MTV as the permanent location for the Thurston County air quality monitoring site.

2.0 ACKNOWLEDGEMENTS

ORCAA would like to acknowledge Olympia Fire Department, Rochester Middle School, and Mountain View Elementary for hosting air quality monitoring equipment and providing power and internet access. We want to specifically thank Fire Chief Gregory Wright and the Fire Station 3 crew from the Olympia Fire Department and Larry Quarnstrom for all their help installing and maintaining two of our air quality monitors.

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3.0 LIST OF ACRONYMS

CPO – Cheeka Peak Atmospheric Observatory

ECY – Department of Ecology, Washington State

EPA – Environmental Protection Agency

FEM – Federal Equivalent Method

FRM – Federal Reference Method

OFS3 – Olympia Fire Station 3

MTV – Mountain View Elementary School

NAAQS – National Ambient Air Quality Standard

NOC – Notice of Construction

OFD – Olympia Fire Department

OPC – Optical Particle Counters

ORCAA – Olympic Region Clean Air Agency

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

RMS – Rochester Middle School

TEOM – Tapered Element Oscillating Microbalance

USG – Unhealthy for Sensitive Groups

WAQA – Washington Air Quality Advisory

<u>UNITS</u>

nm – nanometer ($meter^{-9}$)

m – meter

MPH – miles per hour

MW – megawatt ($watt^{6}$)

µg – microgram ($gram^{-6}$)

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 where ambient air quality is generally the poorest for that region and a large population is represented. A saturation study is one method used to determine the best location for placing a county's air monitoring station.

During a saturation study several air quality monitors are placed in various locations in a community or communities. The study may last a couple of months, a year, or multiple years. 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:

- determine the best location for each county's air monitor
- assess regional air quality variability
- evaluate daily and seasonal air quality variability
- identify primary sources of air pollution in each region
- determine how changes in industry and/or population have affected air quality

The following report describes the year-long saturation study conducted in Thurston County between October 2015 and January 2017. A brief discussion of the regional air quality, industry, population, and climate is followed by a detailed description of the study design, the monitoring network, data analysis, and results.

5.0 BACKGROUND

Prior to this study, the most recent Thurston County air quality saturation study was conducted during the 1994/95 and 1995/96 winters. The study ran from November 1994 through February 1995 and again between December 1995 and March 1996 [*Moody and Werner*, 1997]. Since PM2.5 National Ambient Air Quality Standards (NAAQS) were not implemented until 1997, the previous saturation study measured ambient PM10 (mass of atmospheric particles with diameters less than 10 microns per cubic meter of air). EPA introduced the national PM2.5 standard on July 18, 1997. The PM2.5 standards are more stringent than previous PM10 standards and initiated a switch from PM10 measurements to PM2.5 in Washington State's air quality monitoring network plan. The current study evaluated ambient PM2.5 concentration, rather than PM10. PM2.5 is the mass of atmospheric particles with diameters less than 2.5 microns per cubic meter of air. PM10 is the mass of all atmospheric particles with diameters less than 10 microns per cubic meter of air.

In the twenty years since the PM10 saturation study was completed, Thurston County population experienced a 36% increase from 192,000 to 270,000. Population growth has

significantly increased traffic on city streets and on Interstate 5. Despite the population increase, outdoor burning and woodstove use has declined, and air quality has improved.

5.1 Air Quality

ORCAA, previously called the Olympic Air Pollution Control Authority (OAPCA), has monitored several air quality parameters in various locations around Thurston County since 1963. In 1987, EPA instigated a new national ambient air quality standard (NAAQS) for PM10 (Table 1). In August 1987, the Olympia, Lacey, and Tumwater region of Thurston County was declared a Group 1 non-attainment area for PM10, due to several exceedances of the daily NAAQS. Air quality in the region has never exceeded the annual standard. OAPCA instituted new regulations pertaining to woodstoves and outdoor burning to improve air quality and bring the region into attainment.

ORCAA has monitored ambient particulate matter at Mt. View Elementary School (MTV) since 1985. The earliest measured data was the total suspended particulate (TSP) in the atmosphere and was not defined by particle size. A PM10 sampler replaced the TSP measurement in 1987. PM10 data remained as 24-hour averages collected once every six days. In 1993, OAPCA installed a Tapered Element Oscillating Microbalance (TEOM) that measured hourly ambient PM10 concentrations. A Rupprecht & Patashnick Co Partisol – FRM (Federal reference method) PM2.5 Air Sampler was added to the site in 1998. The FRM sampler directly measured 24-hour average PM2.5 concentrations once every 3 days and operated through December 2002. Like the PM10 sampler, this instrument pulled a known volume of air through a filter for 24 hours. Both PM10 and PM2.5 filters were collected weekly and sent to Manchester environmental lab for gravimetric analysis. Data were available to ORCAA and the public after the filters were validated and weighed. This could take up to three weeks after the day a sample was collected.

Correlations between the FRM PM2.5 concentrations and the nephelometer's light scatter data provided a factor to convert the hourly nephelometer data into equivalent PM2.5 (Figure 1). For the range of PM2.5 values observed at this site, a linear regression is sufficient [*Charlson et al.*, 1968; *J. C. Chow et al.*, 2006]. Although the FRM measurements were discontinued after 2002, the nephelometer continued to produce hourly PM2.5 data that are made available to ORCAA staff and the public in near real time. Between 1999 and 2013 bscat data were converted using the original FRM data collected between 1999 and 2004. The conversion equation was updated in 2014 after new FRM PM2.5 data were collected in winter 2013/2014. The change in the calculation falls within the uncertainty of the original comparison (Figure 1).

Table 1: Historical PM10 and PM2.5 NAAQS.

Date	Pollutant	Averaging Time	Standard
1987	PM10	24-hour annual	**150 µg m^{-3}** **50 µg m^{-3}**
1997	PM2.5	24-hour annual	**65 µg m^{-3}** **15 µg m^{-3}**
2006	PM2.5 PM10	24-hour Annual 24-hour Annual	**35 µg m^{-3}** 15 µg m^{-3} 150 µg m^{-3} Revoked
2012	PM2.5	24-hour annual	35 µg m^{-3} **12 µg m^{-3}**

Changes from a previous standard are bold.

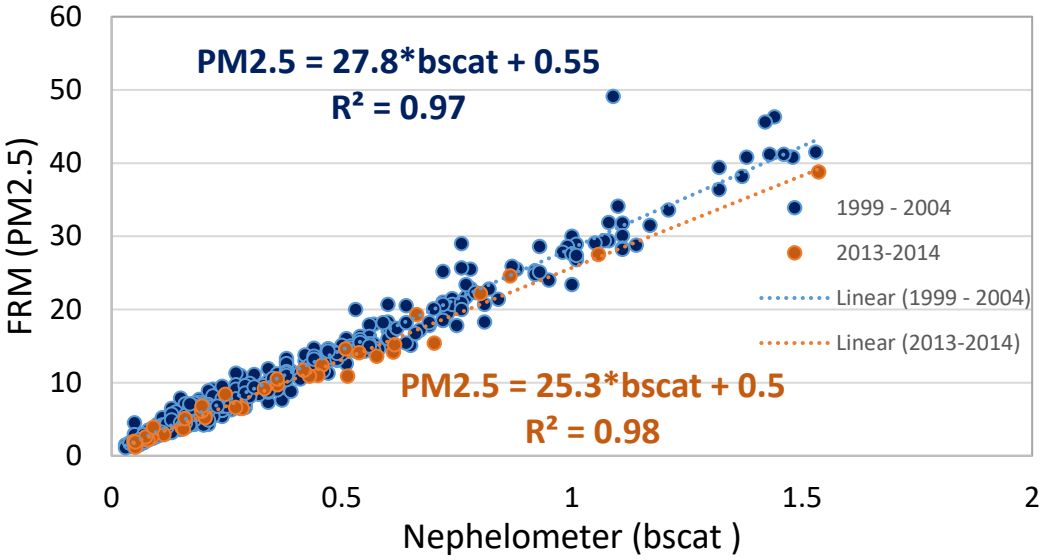

Figure 1) Correlation between nephelometer light scatter and FRM PM2.5 measurements. Original data are shown in dark blue and the more recently collected data in orange.

Figure 2 depicts monthly averaged ambient PM2.5 measured at Mt. View Elementary, Lacey, WA between January 1996 and December 2015. PM2.5 concentrations follow a strong annual cycle with the highest PM2.5 concentrations found in winter and lowest in summer. Prior to 2009, average monthly PM2.5 concentrations in winter regularly exceeded 15 µg m^{-3}, 3 times the average summer monthly concentrations and classified by EPA as "moderate" air quality. Wintertime air quality was considered moderate most of the time and occasionally crept into the unhealthy for sensitive groups. While a winter maximum was still observed after 2009, average monthly averages stayed below 15 µg m^{-3}. Summertime monthly averaged PM2.5 concentrations have not changed significantly since 1999, remaining relatively constant, at 5 +/-2 µg m^{-3}.

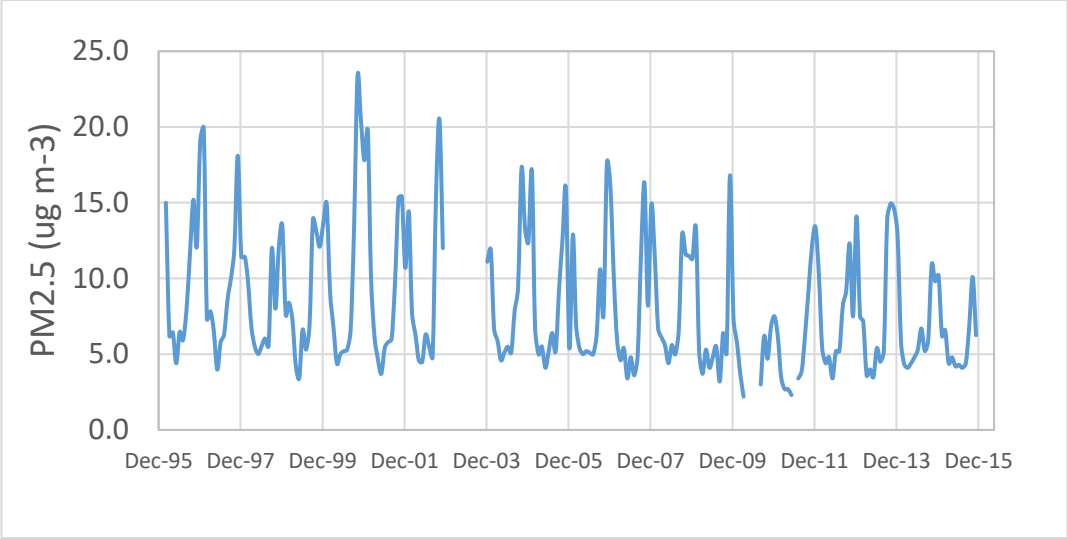

Figure 2) Historical air quality record for Thurston County WA.

5.2 Climate

Thurston County sits at the bottom of the Puget Sound and serves as the gateway between Washington State and the Olympic Peninsula. The county averages 50" of rain a year. Measurable precipitation generally falls on 45% of the days in given year. Winds are typically southerly or south westerly throughout the year. While uncommon, northerly winds are observed more frequently in summer months. Thurston County is temperate. Summer highs are around 80°F and lows around 50°F. Winter lows average 35°F and highs around 50°F.

5.3 Population and Industry

Since the last saturation study conducted in 1994/95, Thurston County's population has increased from 192 thousand to 290 thousand. Roughly half the population increase occurred in the cities of Lacey, Olympia, and Tumwater, while the remaining 50 thousand in population growth was in the county. The population of both Tumwater and Lacey has roughly doubled since 1995. That air quality has markedly improved over the last 20 years, despite a significant increase in population is a testament to the efficacy of state and local air quality policies and regulations aimed at improving air quality.

There are currently 271 registered air pollution sources in Thurston 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. There are two title V sources in Thurston Co, however neither are significant emitters of PM2.5.

6.0 STUDY DESIGN

The goals of this study were to:

a) Determine whether air monitor at Mt. View Elementary (SMS) provides accurate representation of regional ambient air quality in Thurston County

b) Evaluate neighborhood scale air quality variability
c) Identify the primary sources of PM2.5 in the region
d) Identify whether a new location would be more appropriate for the permanent monitor

6.1 Instrumentation

ORCAA used four optical particle counters (OPC) manufactured by MetOne (Profiler 212) as temporary air monitors during the year-long study. The OPC operates similarly to the nephelometers used throughout Washington State's air quality network. Both instruments use particle light-scattering properties to determine PM2.5 concentrations. The nephelometer produces a measure of light extinction due to scattering [*M Z Hansen and Evans*, 1980]. The OPC converts the light scattered from individual particles to a specific size bin and produces particle number concentrations at 8 different diameters between 0.3 and greater than 10 microns [*Iwasaki et al.*, 2007]. Number counts from the OPC correlated well to nephelometer bscat and TEOM, FEM (Tapered Element Oscillating Balance, federal equivalence method) (Figure 3).

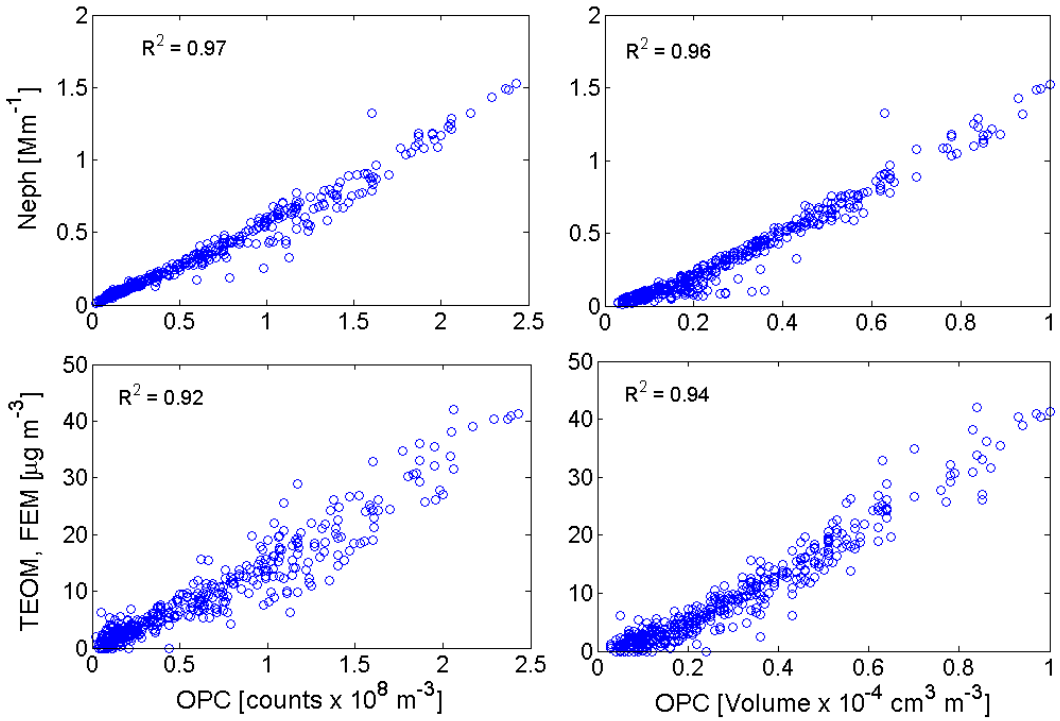

Figure 3) Linear regression comparison between the OPC, the nephelometer and the TEOM.

Total particle volume was estimated from the OPC data assuming all measured particles were spheres. Light scatter, or nephelometer data, correlates most highly with total particle number concentration. Particle mass concentration (PM) corresponds directly to volume concentration (V) using the following equation PM = ρV, where ρ is the

particle density. The scattering efficiency of a particle strongly depends on size and the relationship between particle mass concentration and light scatter will differ depending on the aerosol density and size distribution [*J. C. Chow et al.*, 2006]. This may be observed in the bottom two panels of Figure 4, where the OPC volume concentration correlates more highly with TEOM mass measurements than the OPC counts. Both OPC particle counts and volume concentration correlate most highly with the nephelometer, as both instruments rely on aerosol light scattering properties.

All OPC data were converted to equivalent PM2.5 using the linear correlation between the collocated OPC and the permanent nephelometer at MTV (Figure 5). The correlation was checked monthly throughout the study.

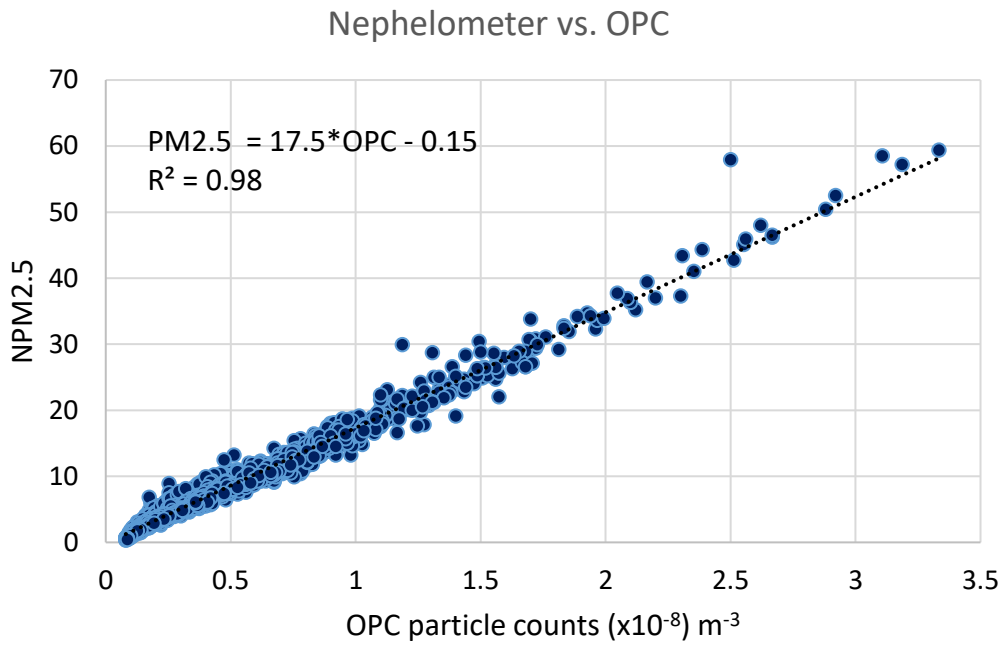

Figure 5) Linear regression between hourly OPC particle counts and nephelometer PM2.5 for December 2016 and January 2017 at Mt. View Elementary

In addition to the OPC, ORCAA installed an aethalometer at MTV. The aethalometer measures the amount of light absorbed by black or brown particles. These light absorbing particles are emitted during combustion and their color provides information on the fuel type burned. Diesel and oil-based fuels produce very black particles that absorb light strongly across the visible spectrum. Biomass fuels tend to produce particulate that absorbs ultraviolet and visible light of shorter wavelengths (blue to green) much more strongly than at longer wavelengths (yellow to red). These particles appear brown in the atmosphere.

Figure 6) Housing for OPC, data logging system, modem, and UPS.

The OPCs, data loggers, modems, and an uninterrupted power supply (UPS) were integrated in portable boxes (Figure 6). Meteorological and OPC data were both stored on the computer and transmitted daily to a cloud server owned by ORCAA. This allowed ORCAA staff to remotely check on instrument performance and ensured better data recovery, as well as providing back-up data storage.

6.2 Monitor Locations

The Environmental Protection Agency (EPA) and the Washington State Department of Ecology (ECY) have strict guidelines on where and how neighborhood scale PM air monitoring sites are placed [*Thompson*, 2008]. ORCAA followed these guidelines in choosing and placing the saturations study monitors. 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.

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. The instruments and data logger had to be easily accessible by ORCAA staff, and secure from tampering and vandalism. The chosen monitoring locations ideally represented ambient air quality in communities with the highest population and

therefore highest exposure risk. Lastly, one of the sites had to be collocated with the nephelometer at Mt. View Elementary (MTV), providing a continuous comparison between the two instruments and data continuity. The other three were placed at: ORCAA Head Quarters (ORCAA), Olympia Fire Station 3 (OFS3) on Boulevard Rd SE, and Rochester Middle School (RMS) (Figure 7).

The MTV monitoring shelter sits in an athletic field behind the elementary school, surrounded by single family residences. OFS3 is a firehouse at the intersection of two moderately busy roads. It is also surrounded by single family, residential neighborhoods. ORCAA is located near a high school in a commercial area. It is surrounded by apartment buildings and office buildings. RMS is in a mostly rural community. There is a commercial log yard across the road from the school, otherwise small businesses and single-family homes surround the school. A county highway used mostly by local residences, logging trucks, and other heavy-duty diesel vehicles runs adjacent to the school.

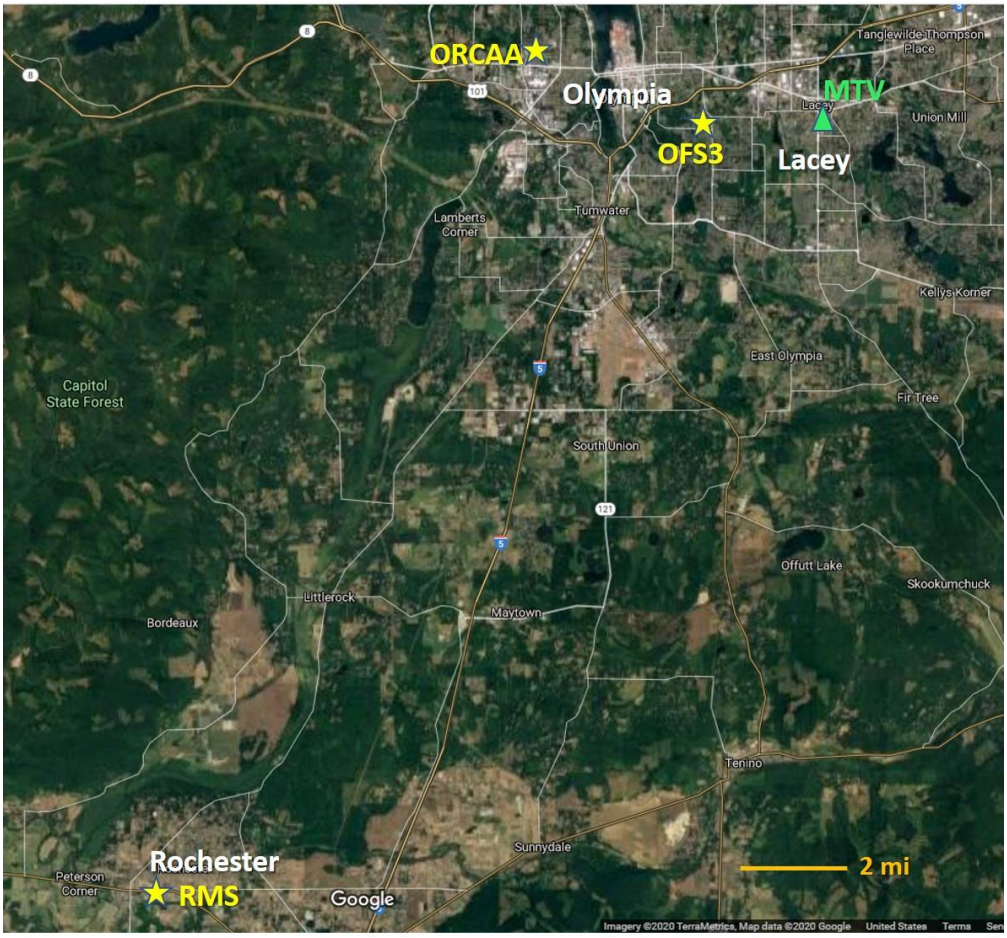

Figure 7) Thurston County Saturation Study map. Yellow stars mark temporary OPC locations, green triangle is the permanent air monitoring site in Thurston Co.

6.3 Data

All data were validated and processed to hourly and daily averages. Hourly data provided information on daily trends and sources of air pollution. Daily averages provided information on weekly, monthly, and seasonal air pollution patterns.

Meteorological data comprised wind direction, wind speed, and temperature. Analyzed in conjunction with the PM2.5 concentrations, these data offered further evidence of potential sources and was used to isolate meteorological effects on air pollution from changes in source emissions.

7.0 RESULTS

7.1 Inter-Site comparison

The primary goal of this study was to determine how well the monitor at Mt. View Elementary represents air quality in Thurston county. A secondary goal was to ensure the site was generally reflective of communities with the poorest air quality.

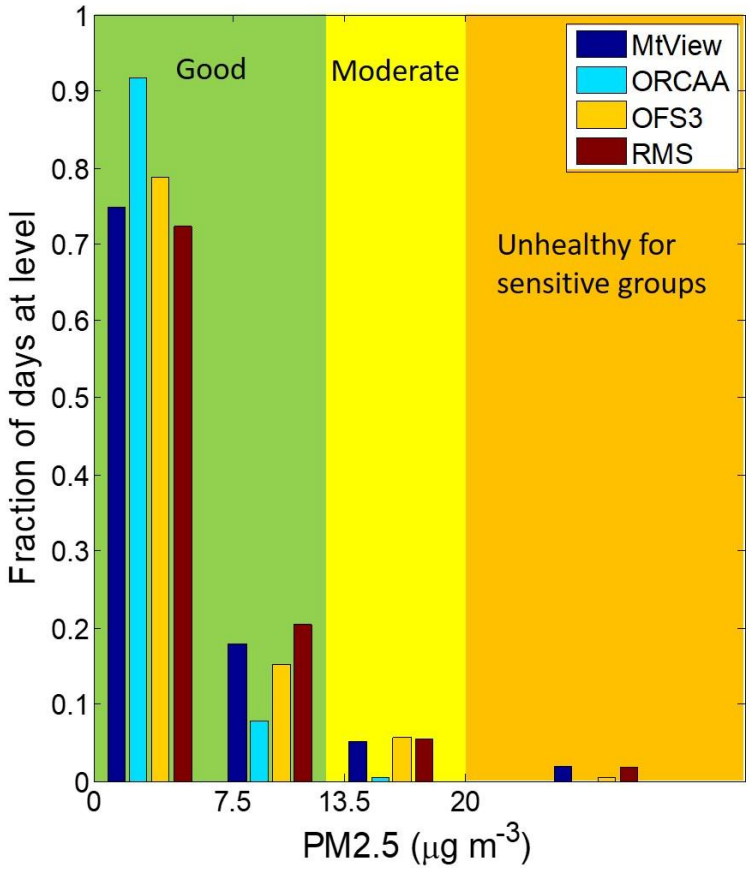

Figure 8) Distribution of daily PM2.5 concentration for all days between January 2016 and January 2017

Air quality in Thurston County was classified as good over 90% of the time at all 4 monitoring locations (Figure 8). The distribution of PM2.5 measured at Mt. View Elementary (Lacey), Fire Station #3 (East Olympia), and Rochester Middle School (Rochester) were similar throughout the year-long study. In west Olympia at the ORCAA HQ offices, air quality was good over 99% of the days.

A second metric of how well the air monitoring site at MTV represents the county is to compare how often the ORCAA, OFS3 or RMS sites recorded moderate or worse air quality days not reported at the MTV site. During the dates when all 4 sites were operating, MTV reported 330 good air quality days, 6 moderate days, and 2 USG days. Of the 330 good MTV days, OFS3 reported 1 moderate day and RMS reported 11 moderate and 3 USG days. Of the 6 moderate days reported at MTV, RMS reported 1 USG day. At no time did the ORCAA site report an AQ category worse than that reported at MTV. These numbers are illustrated in Figure 9, which shows the time series of PM2.5 concentrations at all 4 sites.

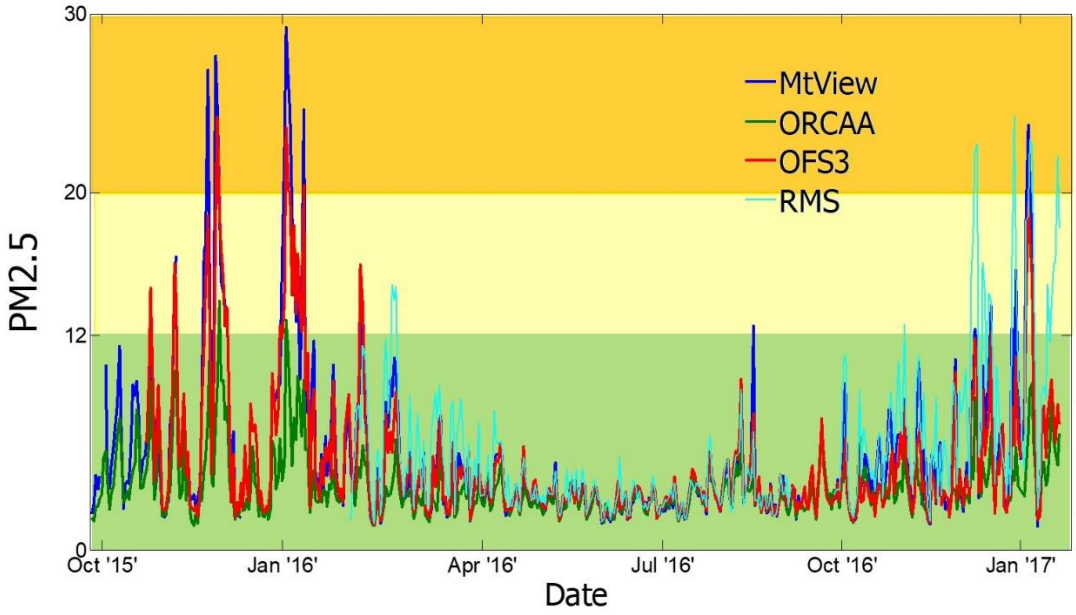

Figure 9) Time series of daily PM2.5 at all 4 sites

The RMS monitor in south Thurston Co was further from the reference MTV site at 19 miles to the SW. The Chehalis PM2.5 monitor, operated by WA state Dept. of Ecology is 9 miles SE of RMS. Figure 10 shows a comparison of the RMS PM2.5 with the MTV and Chehalis monitors.

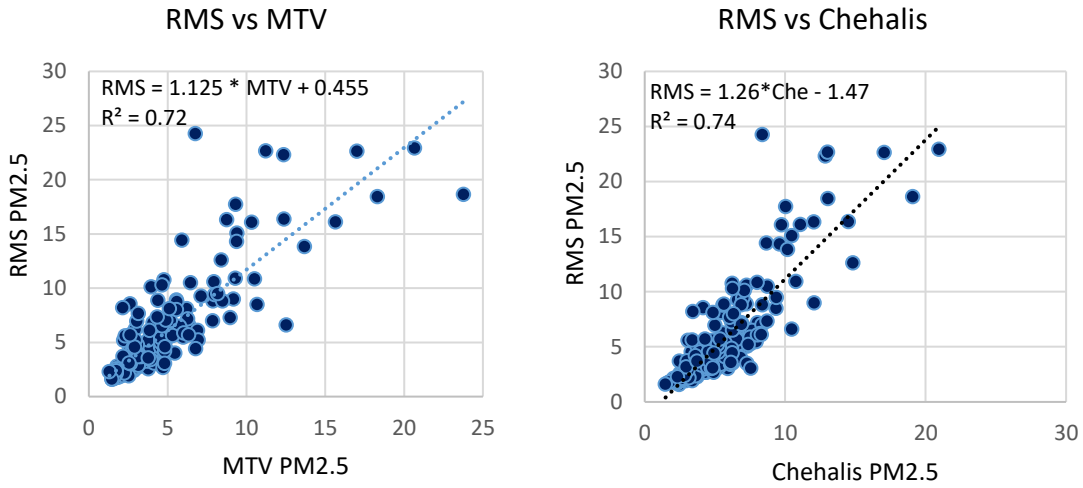

Figure 10) Comparison of daily RMS PM2.5 with PM2.5 reported at the MTV and Chehalis permanent monitoring sites

On average, PM2.5 at RMS was about 10% higher than MTV, with an R-square coefficient equal to 0.72. Correlation between RMS and Chehalis PM2.5 was marginally better at an R-square equal to 0.74. The Chehalis and MTVE data were more highly correlated to each other (R^2 = 0.8) and a slope and intercept equal to 0.81 and 1.89 respectively. These data show the ambient air quality was generally the same between Lacey and Chehalis WA and that both sites were representative of the region between them.

7.2 Seasonal Variability

During the winter, PM2.5 levels occasionally pushed air quality into moderate and unhealthy for sensitive groups (USG) on 10 to 15% of the days at the Lacey (MTV), east Olympia (OFS3) and Rochester (RMS) (Figure 11b). Fewer than 2% of the winter days were moderate at the west Olympia (ORCAA) site and no days registered USG or worse. In summer, PM2.5 was below 7.5 µg m^{-3} at all 4 sites over 98% of the time (Figure 11a).

Since completion of this study, summer air quality has worsened dramatically due to increased wildfire smoke. In July, August, and September, smoke is frequently transported to the region from British Columbia, Eastern Washington, Oregon, and California. Wildfires are rare in ORCAA's counties and those that do ignite are remote, relatively small, and do not produce a large quantity of smoke.

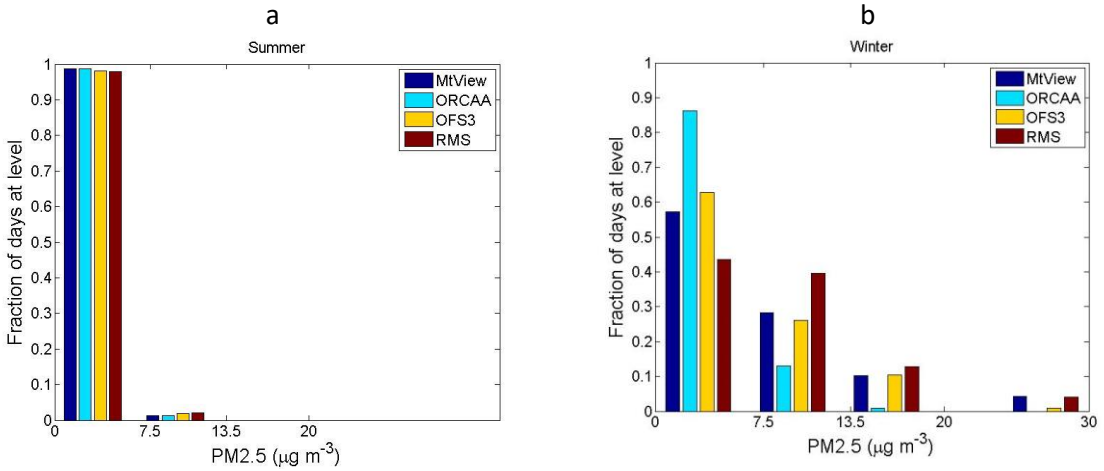

Figure 11) Distribution of daily PM2.5 concentration for a) summer and b) winter.

7.3 Hourly Variability

Summer and winter days look different with respect to PM2.5. The average hourly profile of measured PM2.5 at the MTV site in summer (Figure 12a) and winter (Figure 12b) indicates different PM2.5 sources (Figure 10). In addition to PM2.5, black carbon, or soot, was also measured at MTV using a dual wavelength aethalometer. The aethalometer data allow for soot from fossil fuel combustion to be differentiated from that of wood or biomass combustion.

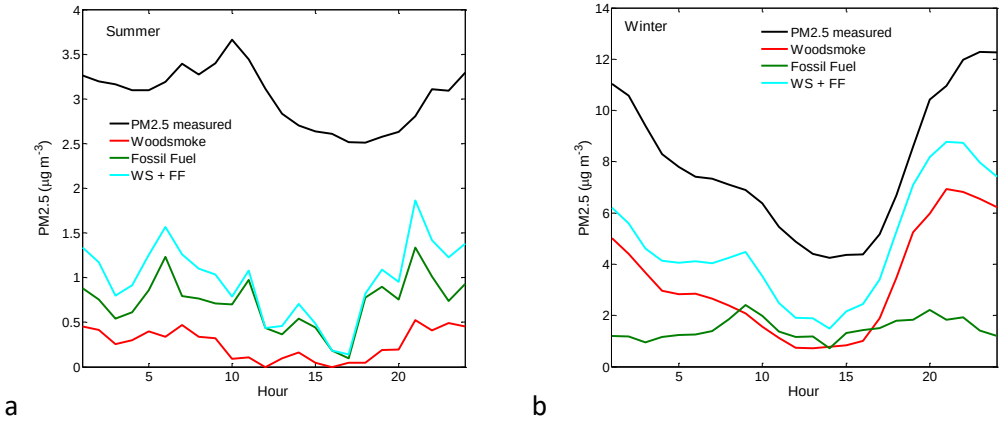

Figure 12) Average hourly PM2.5 in a) summer and b) winter at MTV elementary.

The aethalometer measures the mass of light absorbing particles at two wavelengths, 880 nm and 370 nm [*A D A Hansen*, 2003]. High efficiency combustion and fossil fuels produce very black soot that has a light absorption spectrum closely following the relationship: abs = λ^{-1}, where λ is the wavelength of light [*T. W. Kirchstetter and Novakov*, 2007]. Wood smoke and other biomass fuels burn less efficiently and produce more organics. These particles absorb ultraviolet and shorter wavelengths (370 nm) more efficiently than longer wavelength light (i.e. 800 nm) [*Hadley et al.*, 2008; *T. W.*

Kirchstetter et al., 2004; *T.W. Kirchstetter and Thatcher*, 2012]. A comparison of particle absorption at both wavelengths can be used to distinguish woodstove (fireplace) emissions from fossil fuel combustion.

The aethalometer assumes the absorption (abs_{ff}) spectra of all particles follows the relationship:

$$abs_{ff} = k_{ff} * \lambda^{-1} * BC_{ff} \quad (1)$$

where k is a constant and BC is the mass of black carbon. The subscript ff denotes "fossil fuel". While equation 1 is generally true for combustion particles derived from fossil fuel combustion [*Bergstrom et al.*, 2007; *A D A Hansen*, 2003], wood smoke particles contain a significant fraction of organics, which absorb strongly at short wavelengths and very little at longer wavelengths. The wood smoke absorption (abs_{ws}) spectra follow the relationship [*T.W. Kirchstetter and Thatcher*, 2012] :

$$abs_{ws} = k_{ws} \lambda^{-1.89} * BC_{ws} \quad (2)$$

When a significant amount of wood smoke is present, the aethalometer BC data from the 370 nm wavelength channel are enhanced relative to the data at 880 nm. Equations 1 & 2 were used to calculate the relative fraction of absorbing particles from wood smoke and from fossil fuel combustion. Since the enhancement is only evident in the 370 nm channel, abs_{ff} and abs_{ws} are equal when λ = 880 nm. To calculate the relative absorption enhancement in the 370 nm channel, kws must first be solved; k_{ff}, BC_{ff}, and BCws are set equal to 1, λ = 880 nm.

$$k_{ws} = 880^{0.89} = 417.4 \quad (3)$$

$$abs_{ws}/abs_{ff} = k_{ws} * (370^{-1.89+1}) = 2.16 \quad (4)$$

From the Beer-Lambert law, absorption is linearly related to concentration and thus a factor of 2 enhancement in absorption translates to double the BC. Thus, when the BC concentration from the 370 nm channel was more than twice that of the 880 nm channel, the light absorbing material was determined to be entirely from wood smoke. When the two channels were equal, the particles were assumed to be from fossil fuel combustion. A mix of diesel and wood smoke was calculated when the absorption enhancement was greater than 1 and less than 2. There are significant and undetermined uncertainties associated with these calculations and these results are a best estimate. The uncertainties arise from varying degrees of woodstove and fireplace combustion efficiencies that alter absorption characteristics. For example, a small amount of wood smoke that absorbs more strongly at shorter wavelengths mixed with diesel soot would appear to have a higher wood smoke fraction.

PM2.5 from each source was estimated in Figure 12 using published values for the black carbon mass fraction (BCMF) of PM2.5 in woodsmoke and in fossil fuel exhaust. Depending on combustion conditions the black carbon mass fraction of PM2.5 varies, but typically ranges from 5 – 15% for residential wood combustion and 6 – 38% for on-road gasoline vehicles [*Judith C. Chow et al.*, 2011]. For this study we used 10% BCMF for woodsmoke and 20% for fossil fuel combustion, acknowledging there is significant uncertainty in these estimates.

In winter, wood smoke accounts for 30% to 50% of the morning PM2.5 and 50% to 65% of the evening and night-time PM2.5. Wood smoke only makes up about 20% of the particulate between noon and 4 PM. PM from fossil fuel combustion accounts for 10-20% of the PM2.5 in the morning and evening hours and 20-30% (about 2 µg m^{-3}) during the day. The average winter concentration of unidentified PM2.5 is between 1 and 5 µg m^{-3}. In the summer months, wood smoke is almost non-existent, fossil fuel derived PM2.5 is around 1+0.5 µg m^{-3}, and the unidentified fraction is around 2 µg m^{-3} (Figure 10a).

The diurnal winter and summer PM2.5 variability at the other 3 sites generally matched MTV measurements, indicating a similarity in sources (Figure 13). Average summer PM2.5 showed slight variability during the day, but PM2.5 values were typically between 2.5 and 3.5 µg m^{-3}. As observed at MTV, winter PM2.5 was elevated at night and during the early morning at the RMS and OFS3 sites. Winter PM2.5 at the ORCAA site was only slightly elevated (+~2 µg m^{-3}) relative to summer. These data indicate woodstoves emissions impacted the MTV, OFS3, and RMS sites in winter, but were hardly detectable at the ORCAA office. MTV and OFS3 were in suburban residential neighborhoods, RMS was a largely rural site, and the ORCAA office is in a commercial and high-density residential neighborhood (apartments), where woodstove use is minimal.

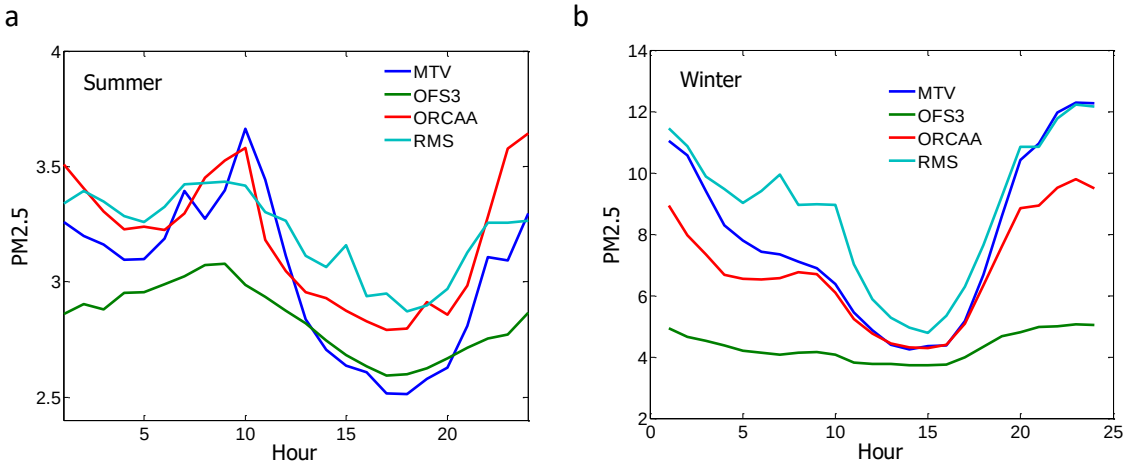

Figure 13) Average hourly PM2.5 in a) summer and b) winter at all 4 study sites

7.4 Meteorology

Meteorology also affects PM2.5 concentrations, especially with respect to woodsmoke emissions. As temperatures drop in winter, more people light wood stoves and fireplaces leading to an increase in emissions. Stove operation occurs most frequently in the evening and through the night when people are home from work and school. This pattern is consistent with the diurnal winter PM2.5 shown in Figures 11 and 12. The coldest winter temperatures generally occur under high pressure conditions when the atmosphere is stable and temperature inversions set up. This traps smoke near the surface and lack of wind allows particulate concentrations to increase to unhealthy levels. Inversions occur most frequently at night after the sun goes down, further driving up nighttime concentrations.

Figure 13 shows winter PM2.5 concentration as a function of wind direction at MTV and RMS. There is no clear directional component to higher concentrations of PM2.5 at MTV. This is consistent with monitor placement in the center of a residential neighborhood surrounded by wood burning stoves and fireplaces. At RMS, higher PM2.5 is clearly associated with westerly and south westerly winds. The highest density neighborhoods are located north and east of the RMS monitor. West and southwest is mostly farmland. This would suggest that outdoor burning (land clearing and residential) is the primary PM2.5 source in Rochester. Outdoor burning is allowed in this part of the county, but not in city limits or urban growth areas where the other three sites are located.

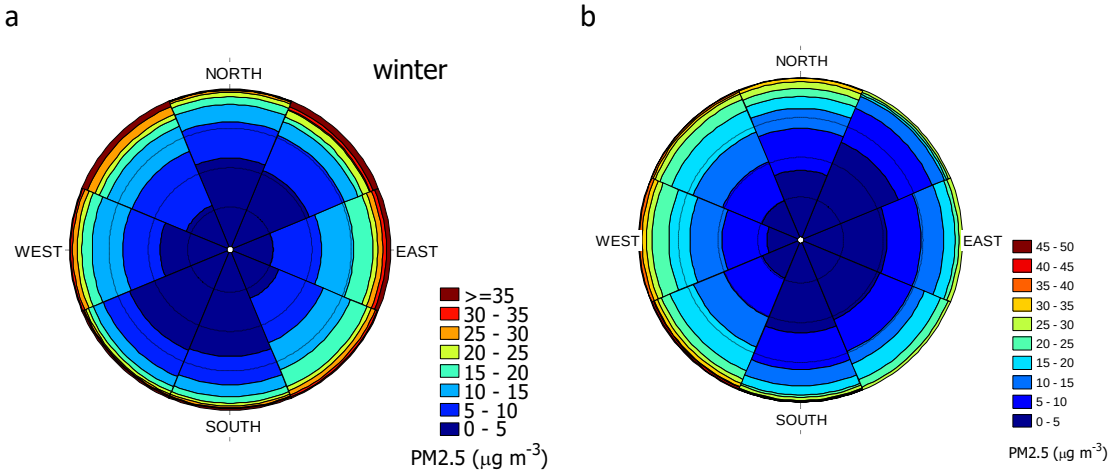

Figure 13) Winter PM2.5 concentration frequency as a function of wind direction at a) MTV and b) RMS

7.5 Sources

The daily and seasonally resolved PM2.5 data provide insight to the largest regional sources. The higher winter concentrations, combined with the seasonally resolved daily pattern, suggest a significant wintertime PM2.5 emission source that is most prevalent

for a few hours in the winter morning and again in the evening. This source is insignificant in the summer months. Residential woodstoves are consistent with this pattern and the aethalometer data which suggest woodsmoke makes up at least 50% daily PM2.5 in the winter.

Daily PM2.5 concentrations are similar at all 4 locations in the summer and are good over 99% of the time. By all metrics, MTV and OFS3 look similar in the winter months. Hourly variability during the day shows the same nighttime peaks and mid-day lows. The distribution of PM2.5 is the same and OFS3 recorded an AQ category higher than MTV only once, however both were near the category breakpoint. The ORCAA site reported significantly lower concentrations in both winter and summer. Data show, this area is not strongly impacted by residential burning or woodstoves.

On 11 days, RMS recorded moderate air quality when MTV reported good. On 2 days AQ at RMS was USG, even though MTV was reporting good air quality. This is most likely because outdoor burning is allowed in the county and not in city limits or urban growth areas. Plotting the wind rose distribution of PM2.5 at RMS, indicates most of the PM2.5 comes from the west and southwest which has a much lower population density compared with neighborhoods to the north and east of the site. Outdoor burning, rather than woodstoves, is likely the primary source of PM2.5 at this location.

8.0 CONCLUSIONS

The monitoring site at Mountain View Elementary continues to be generally representative of air quality in Thurston County. Although there were several days at Rochester Middle School when the WAQA was worse than that reported at Mountain View Elementary, 85% of daily PM2.5 was consistent between the two sites. The high PM2.5 values measured at RMS are most likely due to outdoor burning, which is allowed in the county and not in city limits or urban growth areas (UGAs) where the other monitors were located. One large fire can easily impact a monitor for 2 or 3 days depending on the size of the burn pile. The highest PM2.5 peaks measured during this study occurred at MTV in winter 2016 (Figure 8), prior to the RMS monitor installation. These spikes, caused by woodstove use, were significantly higher than winter spikes measured at RMS the following winter. During cold stagnant periods, the number of woodstoves in the cities and UGAs will cause higher PM2.5 concentrations than outdoor burning.

ORCAA will maintain the Thurston county air quality monitor at Mt. View Elementary for the following reasons:

1) MTV generally represents air quality monitored around the county and typically reports the most protective air quality category for the region. While the RMS site

did occasionally report higher PM2.5 values, the population served by that location is significantly lower than at MTV.

2) The site is readily accessible, secure, and has additional space and power for adding temporary monitors for special air quality studies.
3) A long-term historical PM2.5 data record from the same site is valuable in assessing long term changes in regional air quality. Moving the monitor would prevent continuation of the data record.

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