New Hampshire Community Estimates of Residential Wood Burning

With Laconia and Plymouth Monitoring and Expanded Mobile Monitoring

July 2020

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

This study was conducted under EPA grant.

Appreciation to:

- *NHDES monitoring staff for establishing monitoring locations, collecting and processing samples, and performing mobile monitoring.*
- *Authorship, data analysis and editorial assistance:*
    - *Jeffrey Underhill, David Healy and Kathleen Errington*
- *Windshield surveys and Valley modeling:*
    - *Devon Mexcur*
    - *William Matlack*

R-ARD-20-04

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July 2020

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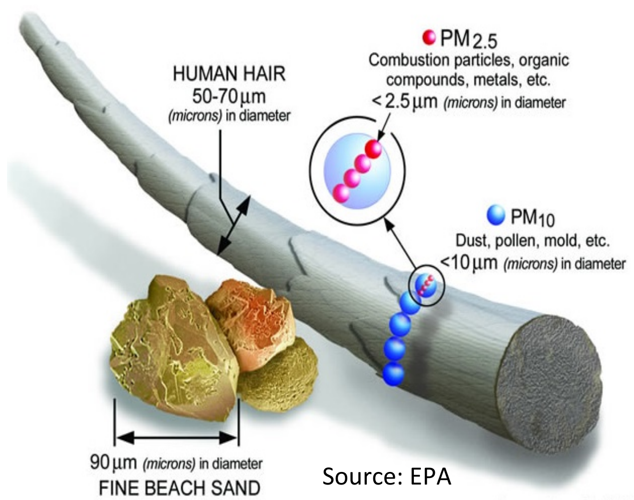
1. INTRODUCTION

Burning wood for heat and ambiance has been a way of life in New Hampshire for many decades. Wood is plentiful in the state and is renewed as new trees replace those that are harvested. As an energy source, it is not only natural, but has close to a zero carbon footprint since the carbon it produces when burned comes from the carbon it consumes while the tree is alive. Overall, burning wood is generally viewed as environmentally friendly, however it does have an impact on the environment when it is not burned cleanly. Incomplete combustion produces carbon monoxide (CO), formaldehyde, benzene, and other aromatic hydrocarbons, and particles, including those smaller than 2.5 microns in diameter ($PM_{2.5}$)(Figure 1.1). A micron is a millionth of a meter. $PM_{2.5}$ can be inhaled deep into the lungs and collect in tiny air sacs (called alveoli) where oxygen enters the blood. This can cause breathing difficulties and sometimes permanent lung damage. People with lung conditions such as asthma, bronchitis, and emphysema are especially at risk for heightened symptoms. Further, $PM_{2.5}$ exposure can lead to increased heart risk for people with heart conditions.

Air pollution is rarely listed as a cause of death, but it might provide a fatal complication to an already compromised individual. Statistically, air pollution in the United States causes thousands of premature deaths and millions of other health complications every year.

Figure 1.1: Size of $PM_{2.5}$ Particle Pollution



Source: EPA

Since this is such an important health issue, the New Hampshire Department of Environmental Service's (NHDES) goal is to continue to investigate communities that may be at risk for periods of unhealthy air quality as a result of residential wood burning. This is a challenging task since records are not kept on the age or type of wood burning device used in residences. Monitoring for $PM_{2.5}$ is complicated and expensive, and thus only a few communities can be monitored within the state. To this end, NHDES has pursued other techniques for identifying potential communities at risk of wood smoke events including mobile monitoring, temporary targeted monitoring, and use of new software tools to identify the nature of New Hampshire's valley communities (for topographic and meteorological reasons, wood smoke can be a particular issue for communities located in a valley; this will be discussed in more detail later in the report). This study uses all three of these tools and uses emissions estimates from the Environmental Protection Agency's (EPA) 2014 National Emissions Inventory (NEI). Based on the $PM_{2.5}$ data collected in previous studies, NHDES identified communities of interest and sorted them into three categories by level of concern: 'Primary communities of interest,' 'Secondary communities of interest,' and 'Others to watch' (Table 1.1).

The short term National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ is 35 micrograms per cubic meter ($\mu g/m^3$) averaged over 24 hours. Recent studies have shown that even shorter periods exceeding this threshold can have health effects.

Table 1.1: Communities of Interest Identified by the 2010-2012 Mobile Air Monitoring Study

Primary	Secondary	Others to Watch
Concord	Hopkinton	Acworth
Keene	Jaffrey	Antrim
Henniker	Lancaster	Belmont
Hillsborough	Lincoln / North Woodstock	Berlin
Newport		Charlestown
West Swanzey	Meredith	Conway
Winchester		Farmington
		Langdon
		Marlow
		Pittsfield
		Plymouth
		Raymond
		Westmoreland

The list of communities of interest will continue to evolve as more is learned about wood smoke emission patterns and location where it accumulates. For example, Laconia and Franklin do not appear on this early list because at that time, the data did not support it. As this study demonstrates, wood smoke can be easily isolated to portions of a city or town. The 2010-2012 mobile monitoring study was a survey of the state and did not pass through areas that this subsequent study later identified.

NHDES also conducted a windshield survey of communities previously identified as being of interest, searching for signs of wood burning such as woodpiles, metal chimneys and other clues to predict if a house did or did not emit $PM_{2.5}$ in the winter.

1.1 HOW DIRTY IS WOOD BURNING?

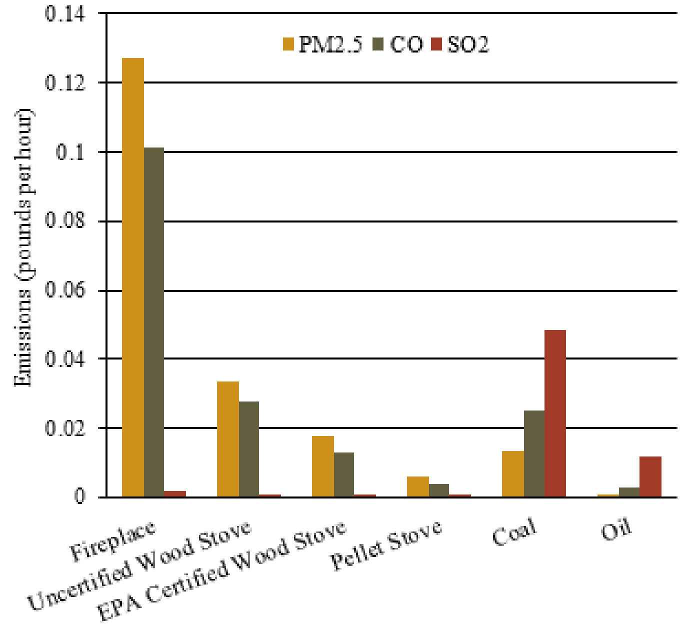
Wood can be burned in many ways. Open burning, such as bonfires or fire pits, can be a great part of an evening out or camping, but the smoke created by it is disproportionately dirty. Care needs to be taken to ensure smoke is not inhaled or sent towards neighbors who might breathe it.

More commonly, wood is used for residential heating and fireplace use. Fireplaces can provide great ambiance, but are not designed to heat homes or burn cleanly. Fireplaces have one of the highest rates of pollution for the amount of wood burned of any residential sources (Figure 1.2). They are inefficient at heating homes as they tend to draw warm air from other rooms to provide for flue draft and then the air is replaced with cold air seeping in from outdoors. The net effect is that one room warms while other rooms cool.

More efficient wood heating is provided by woodstoves, pellet stoves, wood-fired hydronic heaters (outdoor wood boiler or OWB), and forced air furnaces. On average, older uncertified wood stoves are about twice as dirty as newer EPA certified wood stoves. Stoves that burn wood pellets are even cleaner than woodstoves per pound of wood burned.

Advances in wood heater design have resulted in the manufacturing of cleaner-burning units. The use of these cleaner-burning units, in conjunction with best practices, can reduce and minimize any adverse health and environmental impacts associated with using these devices. Best wood-burning practices include burning only dry, seasoned wood and avoiding smoldering, which can lead to lower fire temperature and incomplete combustion. EPA certified stoves are designed to encourage hot fires and complete combustion and as a result, less wood is burned to keep homes warm.

Figure 1.2: Relative $PM_{2.5}$ Emission Rate per Hour Operated



Notes:

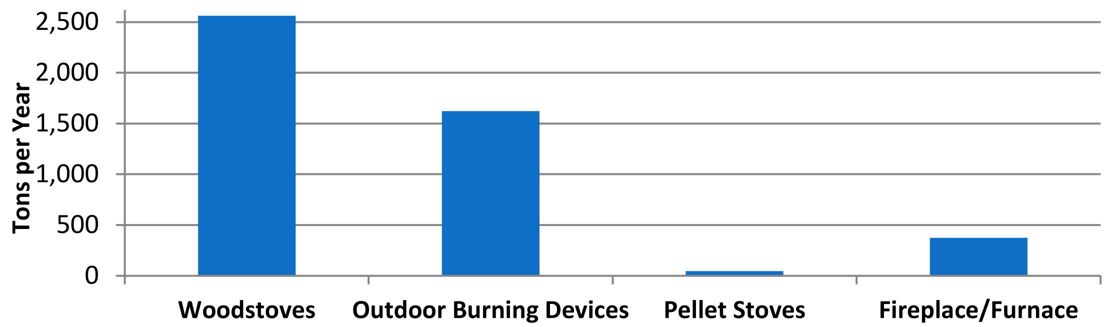
1. CO emissions posted have been divided by 10.
2. Low sulfur oil and biofuels reduces $PM_{2.5}$ emissions and virtually eliminates SO_2 emissions.

Source: NHDES, based on EPA emission factors.

Hydronic heaters can burn cleanly, but have a tendency to smolder and some users tend to burn items besides dry seasoned wood. Therefore, these units are typically one of the dirtier residential wood heating devices. Correct installation and operation of these units is critical to clean operation. Enhanced education and outreach can help.

Figure 1.3 provides state-wide total $PM_{2.5}$ emission estimates by residential heating device. While overall, wood stoves burn cleaner than OWBs and fireplaces, they are much more common in the state and thus their total emissions are greater.

Figure 1.3: State-wide New Hampshire Estimated 2014 $PM_{2.5}$ Emissions Data by Residential Wood Heating Type



The Environmental Protection Agency (EPA) has established a certification program for wood stoves. Certified wood stoves are considerably cleaner than older, conventional wood stoves. New Hampshire does not generally regulate residential wood burning devices, but the state does have requirements regarding the sale, installation, and use of OWBs, and is taking partial delegation regarding the sale of woodstoves compliant with new source performance standards.

1.2 WHEN BURNING WOOD BECOMES A HEALTH PROBLEM

Wood burning is often considered environmentally friendly, but it is not always neighborhood friendly. Smoke from one chimney can disperse and impact the air quality around neighboring homes.

Inhaling wood smoke should be limited as much as possible. Care needs to be taken to make sure smoke does not impact neighbors. Older wood stoves, fireplaces and outdoor wood boilers can particularly affect neighbors, especially when day-to-day smoke exposure takes place. Wood smoke is capable of working its way into homes, so being indoors does not necessarily protect people. Smoke exposure related to dirty wood burning can occur throughout the state.

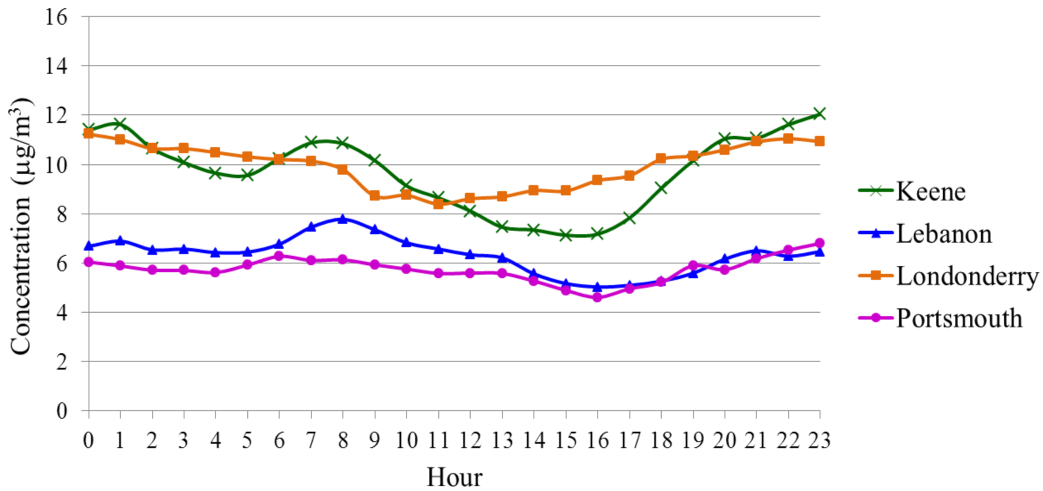
On a broader scale, when many houses within a neighborhood have dirty wood burning devices, the effect can build across a larger geographic area. Again, this phenomenon can occur throughout the state. On an even larger scale, communities that have a lot of wood burning can have more widespread impacts. When numerous houses are involved, wood smoke impacts become greater under certain weather conditions that are enhanced by local topography (this will be discussed further below). The scale of wood burning population exposure includes:

1. Neighbor to neighbor — Can occur anywhere
2. Neighborhood scale — Can occur in any neighborhood where wood burning is common
3. Community scale — Tends to occur in valley communities with common wood burning

Wood smoke is a particular concern in the winter, under certain weather conditions when calm winds trap cold air near the ground, especially in valley areas. Such stagnate conditions are commonly referred to as thermal inversions. Smoldering fires, poor combustion, old stove technology and short chimneys related to residential heating with wood can create a stagnating, heavy smoke close to the ground that becomes a neighborhood nuisance and possibly lead to adverse health impacts and damage to the environment. Stagnation and temperature inversions are an important component to larger scale wood smoke events.

Keene, New Hampshire experiences more recorded wintertime $PM_{2.5}$ events than other locations and generally has the highest average $PM_{2.5}$ concentrations recorded in the state. There are a number of factors that contribute to this phenomenon including topography, rate of wood burning, and calm winds. A study conducted by NHDES in 2015 confirmed that wood burning was indeed the cause of high $PM_{2.5}$ concentrations recorded at the city's air pollution monitor, and the reason for exceedances of the NAAQS for $PM_{2.5}$ (it is important to note that isolated exceedances of the level of the NAAQS do not necessarily constitute a formal violation of the NAAQS).

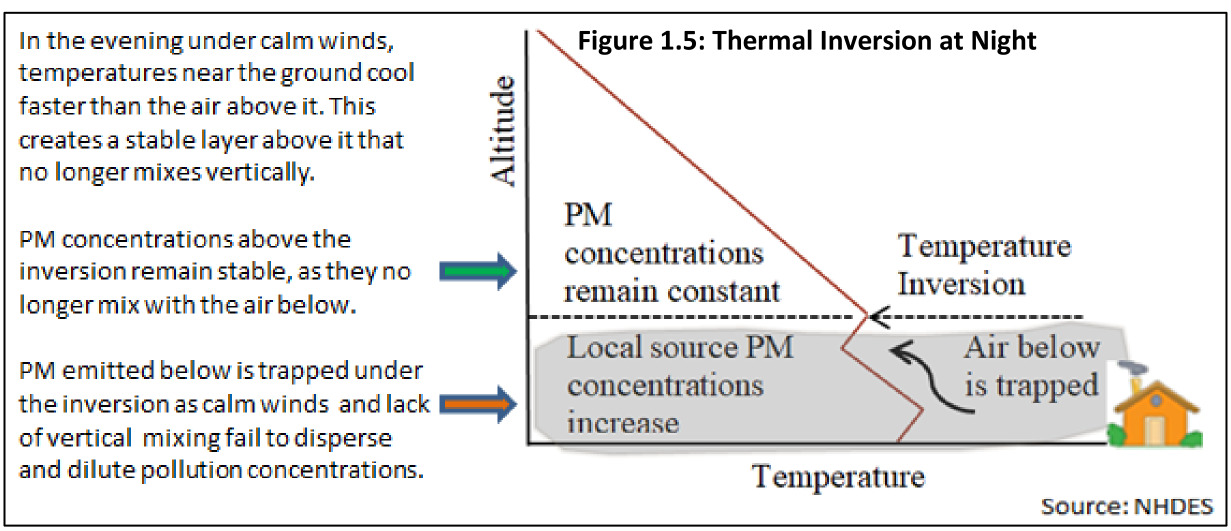
Figure 1.4: Average Winter Month Diurnal Monitored $PM_{2.5}$ Concentrations



In winter, Keene and Londonderry exhibit comparatively higher concentrations than other locations, with greater increases occurring overnight. $PM_{2.5}$ data presented in Figure 1.4 include average values among all days in the winter season, but data for individual days show that Londonderry rarely climbs higher than the mid-20s in micrograms per cubic meter (µg/m^3); in contrast, Keene generally experiences several days per season with a 24-hour average in the high-20s or low to mid-30s µg/m^3. Keene has also recorded a higher frequency of measured one-hour $PM_{2.5}$ concentrations above the level of the Unhealthy for Sensitive Groups (USG) threshold than any other site (USG is a category in EPA's Air Quality Index (AQI); it is also important to note that it is the 24-hour average $PM_{2.5}$ concentration that ultimately determines the AQI level).

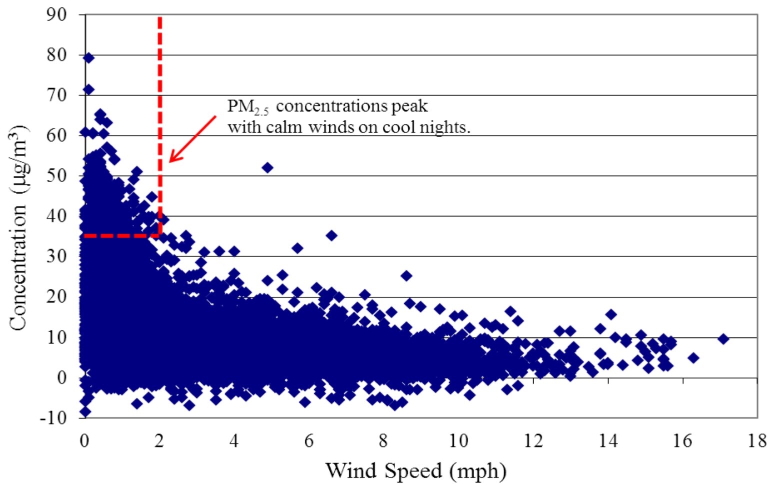
Certain topographical conditions can enhance the trapping of pollutants emitted by wood burning. Keene, for example, lies in a bowl shaped valley. Since it is a moderately sized city, a fair amount of wood burning that occurs there. In this environment, particulate matter can be trapped near the ground on cold, windless nights and can accumulate there until the heat of daybreak initiates vertical atmospheric mixing. This phenomenon is called a thermal inversion (Figure 1.5).

Figure 1.5: Thermal Inversion at Night



Wintertime $PM_{2.5}$ concentrations above the 35 µg/m^3 threshold are most likely when winds are very calm (below two miles per hour). Figure 1.6 shows the correlation between low wind speeds and high $PM_{2.5}$ in Keene on cold winter nights.

Figure 1.6: Hourly $PM_{2.5}$ Concentration as a Function of Wind Speed on Cold Nights ≤ 45°F



Most monitored $PM_{2.5}$ values greater than 35µg/m^3 occurred with wind speeds below 2 miles per hour.

Source: NHDES

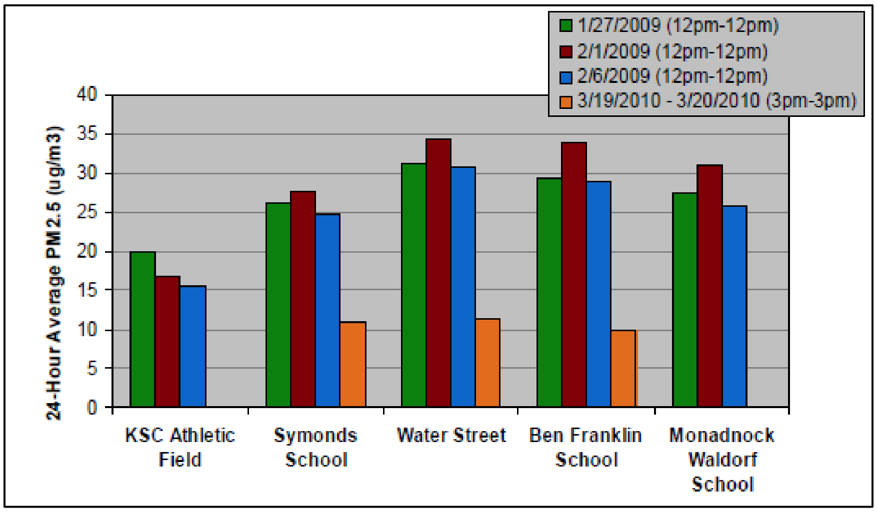
To reduce wood smoke pollution and prevent possible nuisance situations, residents should: always use heating devices in accordance with the manufacturer's specifications; understand and follow local permitting and zoning provisions; and use clean burning practices. Neighborhood friendly devices include EPA-certified stoves or pellet stoves as opposed to older stove models and outdoor wood boilers. EPA's Burn Wise initiative provides information regarding wood-burning heating options and clean burning practices to help homeowners reduce emissions from residential wood burning.

1.3 HISTORY OF WOOD SMOKE MONITORING IN NEW HAMPSHIRE

NHDES awareness of wintertime wood smoke events started when filters that collected particle samples in Keene returned to the lab smelling of wood smoke. At the time, filters were used to collect samples over a 24-hour period and then had to be returned to the lab for weighing and calculation before an air quality concentration could be determined for that 24-hour period. When the first hourly monitors became available, one was deployed to Keene to better understand the role of wood smoke in the community. It was then discovered that concentrations of smoke could be high at night and low during the day. Since 24-hour concentration averages often approached, and sometimes exceeded the level of the health standard, NHDES became concerned that portions of the city could have even worse air quality than what was being measured at the Keene Water Street monitoring station, and if other communities in the state were experiencing similar issues.

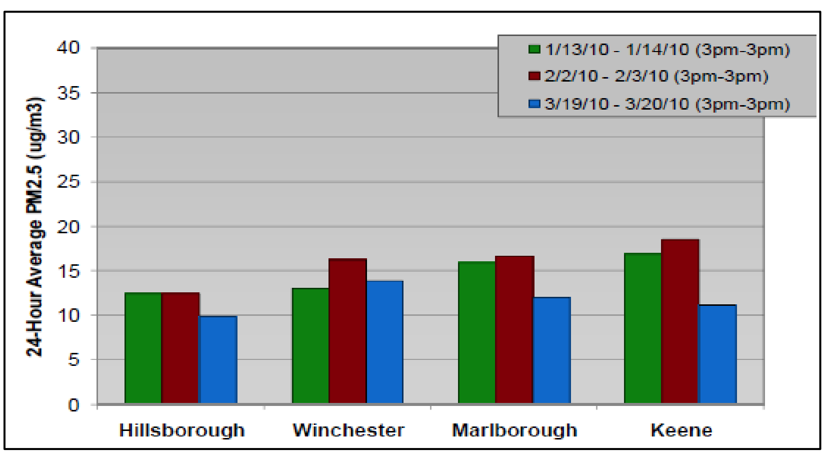
From 2002 to 2010, NHDES continuous $PM_{2.5}$ monitoring during winter months revealed that hourly $PM_{2.5}$ in the City of Keene frequently experienced concentrations surpassing 35 µg/m^3 on a one-hour basis, and occasionally such events were severe enough and lasted long enough to surpass the NAAQS threshold on a 24-hour basis. During the winter of 2009 to 2010, NHDES began field testing. In order to determine if the Water Street NHDES monitoring station was measuring $PM_{2.5}$ concentrations reflective of the worst air quality in the City of Keene, NHDES performed simple filter monitoring for $PM_{2.5}$ during four nights at four locations in the city. Figure 1.7 shows the results of that study, where the Water Street monitor had the highest $PM_{2.5}$ concentrations on each of those nights.

Figure 1.7: 2009-2010 $PM_{2.5}$ Monitoring in Five Keene Locations



NHDES then shifted those monitoring resources to three nearby communities for three nights to see how $PM_{2.5}$ concentrations compare to those measured in Keene. Figure 1.8 shows that concentrations were highest in Keene, but the monitor locations in Marlboro and Winchester also had potential for wood smoke accumulation, even if not to the level experienced in Keene.

Figure 1.8: 2009-2010 $PM_{2.5}$ Monitoring in Four Southwestern New Hampshire Communities



From 2010 to 2012, NHDES focused its efforts on looking for wood smoke in other communities throughout the state. In a large monitoring effort, NHDES established mobile monitoring technology that included a FEM BAM unit monitoring in targeted communities along with a vehicle that was fitted with a real-time $PM_{2.5}$ monitoring device that could be driven around the state measuring for wood smoke.

The results of this study allowed NHDES to develop a list of communities of interest for winter-time wood smoke. $PM_{2.5}$ concentrations were found to be the highest in Keene, but there were several other communities also had elevated $PM_{2.5}$ concentrations. These towns included: Belmont, Concord, Franklin, Hillsborough, Laconia, Lancaster, Lebanon, Lincoln, Meredith, Newport, Northfield, Plymouth and Winchester.

Other findings from the study included:

- Actual midnight-to-midnight wintertime NAAQS threshold exceedances in the exact form of the 24-hour $PM_{2.5}$ NAAQS threshold are rare in Keene and normally require calm conditions, cold temperatures, thermal inversions, and elevated regional $PM_{2.5}$ background levels transported into the region. Exceedances of the 24-hour NAAQS threshold on a rolling basis (not limited to midnight-to-midnight) are more common, but their detection requires special continuous monitoring equipment that has only been deployed in recent years.
- Keene appears to incur the highest wintertime $PM_{2.5}$ concentrations and the most frequent episodes of the larger communities in New Hampshire.
- There is some evidence that a few other communities in the state could, in the worst case, have at least some potential for NAAQS 24-hour threshold exceedances, or more likely exceed the 35 $\mu g/m^3$ threshold for short periods (few hours). But there is no indication that this has happened or that there is a current health risk based on the NAAQS.
- Background levels from emission sources of $PM_{2.5}$ beyond the state are important.

During the winter of 2012 to 2013, NHDES was asked to explore the relative importance of wood smoke to total $PM_{2.5}$ during periods of high $PM_{2.5}$ concentrations in Keene. NHDES collected filter samples during high $PM_{2.5}$ days in Keene and had them analyzed in the laboratory for carbon monoxide, sulfur dioxide, black carbon (soot), arsenic, cadmium, chromium, copper, lead, manganese, nickel, vanadium and levoglucosan. Each of these chemical species acts as a fingerprint of the emission source creating the particle. Levoglucosan is an organic species that is specific to wood combustion, so if it exists in the sample, then wood burning was a contributing source, but how much it contributed to the total depended on the relative ratios of the tracer chemical species to the total measured $PM_{2.5}$.

This study found a very high correlation coefficient between levoglucosan and $PM_{2.5}$ concentrations during high $PM_{2.5}$ nights in Keene. The correlation factor was 0.93, meaning that wood smoke is the dominant $PM_{2.5}$ source during high $PM_{2.5}$ nights in Keene. NHDES estimates that wood smoke is similarly important in its list of communities of interest.

1.4 WOOD STOVE SWAP-OUT PROGRAMS

In October of 2009, NHDES collaborated with the City of Keene to launch a woodstove change out program to provide incentives for owners of older, more polluting wood stoves to trade them in exchange for a $1,000 rebate good towards a new EPA certified woodstove, pellet stove or vented gas- heating appliances. The City's goal was to replace 100 old woodstoves. NHDES estimated that there were 2,200 woodstoves in Keene, which was selected for the woodstove change out program because local air monitoring data at the time indicated levels of particle pollution that sometimes reached or exceeded national air quality standards. Since it has been determined that wood smoke is the dominant contributor to high particle concentrations in the city, it was logical to seek an incentive program to reduce emissions of older, dirtier stoves. According to the EPA, these older uncertified stoves can release 40 to 60 grams of particulate matter per hour, while the newer certified stoves release 2 to 7 grams per hour.

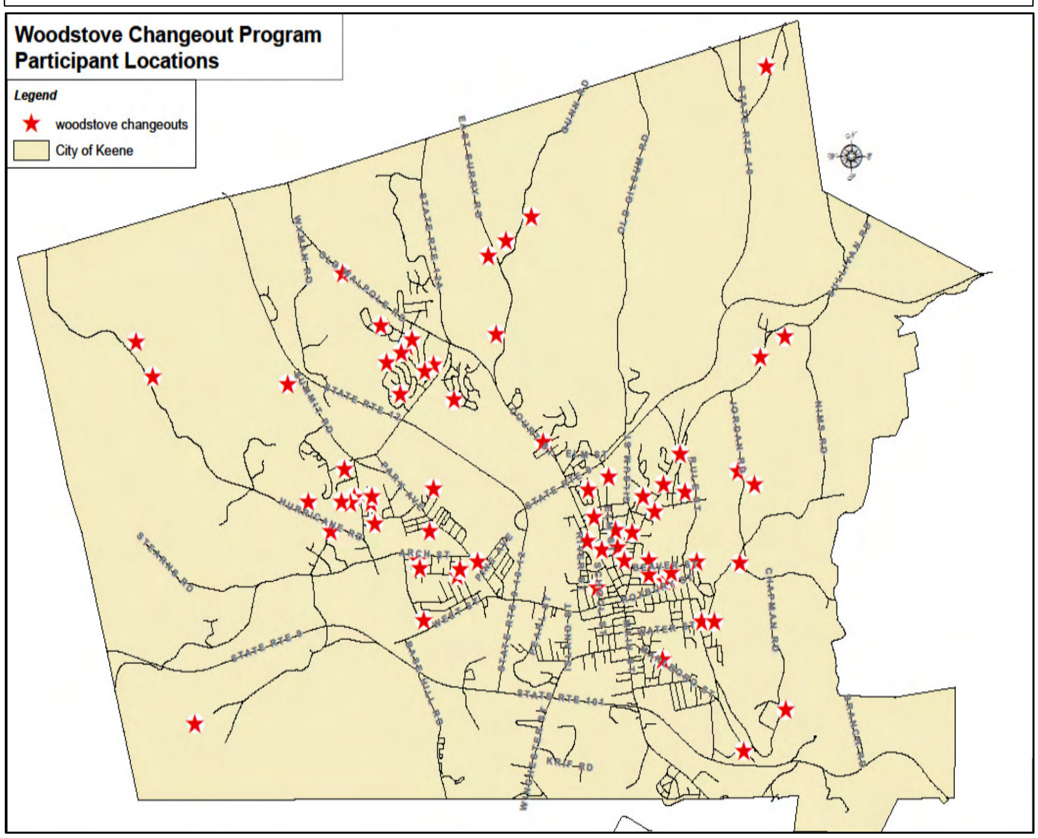
During the course of the campaign, a total of 97 vouchers were issued. However, 11 either expired or were cancelled, primarily because homeowners reconsidered once they became aware of the additional high, out-of-pocket expenses that would be required for installation or chimney improvements. Thus, a grand total of 86 old wood stoves were replaced with new devices, including 63 woodstoves, 15 pellet stoves, and 8 gas appliances. A map of some of the participants' locations can be found in Figure 1.9.

In addition to the rebate voucher that was offered to woodstove change out participants, the program was also able to leverage additional incentives. Most notably, a federal tax credit equal to 30 percent of the costs was available to consumers who purchased and installed Energy Star products (>75 percent efficiency) in existing homes, up to a maximum of $1,500 for improvements "placed in service" starting January 1, 2009, through December 31, 2010. Another available incentive was a free ton of wood pellets to any woodstove change out participant who chose to purchase a pellet stove. The market value for a ton of wood pellets during the campaign was approximately $275. This additional incentive was the result of contributions from participating dealers.

NHDES estimates that this change-out program helped to reduce an estimated 2.3 tons of $PM_{2.5}$ emissions per year and helped to lower the air pollution levels in the Keene area by an estimated 3%.

Additional wood stove change-out programs have been facilitated by the American Lung Association, starting in 2011 and 2015. The first program provided change out vouchers worth up to $3,000 for residents of Merrimack, Hillsborough and Rockingham counties, and the second program provided vouchers worth $1,000 towards an EPA certified woodstove, $1,500 towards a pellet or gas stove, or $4,000 towards a new outdoor wood boiler for those living in Cheshire County.

Figure 1.9: 2009 – 2010 Keene Woodstove Change Out Participant Locations



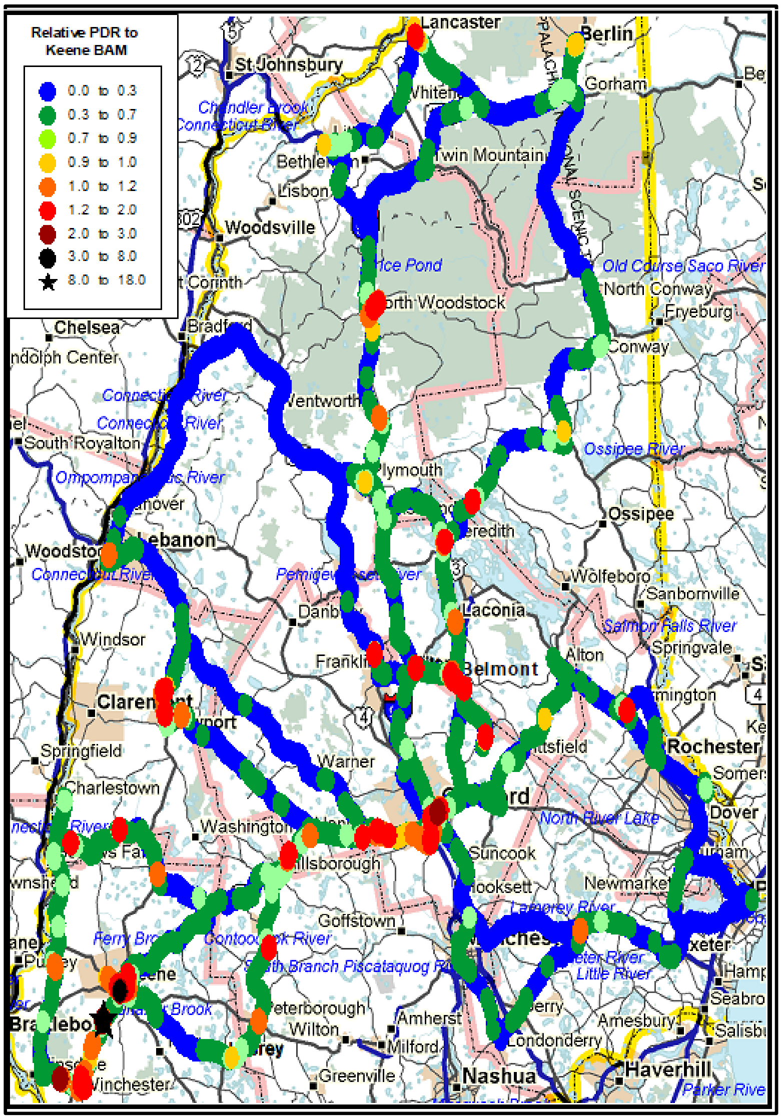
2. IDENTIFYING POTENTIAL COMMUNITIES AT RISK

$PM_{2.5}$ monitoring in Keene has for years measured high enough concentrations to warrant more examination. For example, when are concentrations the highest? What exactly is causing the high concentrations? Are there other communities in the state that could also experience elevated concentrations of $PM_{2.5}$? NHDES studies have confirmed that $PM_{2.5}$ concentrations in Keene peak overnight during thermal inversions and stagnation events, and that the high $PM_{2.5}$ concentrations in Keene are driven by wood smoke.

2.1 MOBILE AIR MONITORING STUDY

NHDES conducted a mobile air monitoring (MAM) study during the winters of 2010-2011 and 2011-2012 to examine other communities in the state during periods susceptible to thermal inversions and stagnation. Monitoring equipment was installed into a vehicle and driven overnight through targeted communities. A map of the results are located in Figure 2.1. The results represent instantaneous $PM_{2.5}$ levels. The colored lines show the driving route, with cooler colors (blue, green, etc.) showing lower levels and warmer colors (e.g., orange through black) showing higher levels. Also, the levels shown are not absolute levels; rather, they are expressed in relation to levels measured in Keene.

Figure 2.1: 2010 – 2012 NHDES Mobile Monitoring Results Relative to Keene



2.2 VALLEY IDENTIFICATION TOOL

This study seeks to learn more about the identified communities of interest and to use a new tool developed by EPA to see if there are other communities in the state that the mobile monitoring study did not identify. The Valley Identification Tool (VIT) was exercised for New Hampshire and then the communities identified by it, as well as those identified by the MAM study, were visited to survey indicators of wood burning in order to estimate how much wood smoke might be emitted in those communities on cold nights.

The Valley Identification Tool (VIT) is a mapping tool developed by EPA to assist in the search for valley communities that might be at risk for wintertime wood smoke stagnation events. The tool has two key components used to measure the dimensions of valleys and to estimate populations living within valleys. This tool was applied for each community of interest identified in the MAM study and to identify other communities that have enough of a population living within a deep valley to indicate some potential for wood smoke accumulation, should there be enough wood burning in the area.

2.2.1 IDENTIFICATION OF VALLEYS

Figures 2.2 and 2.3 show VIT results on the full-state scale. Valleys are indicated in Figure 2.2 in shades of green while darker shades of green indicate deeper valleys. Clearly, the more mountainous the region, the more valleys it has and New Hampshire is a fairly mountainous state. With the exception of the seacoast and southeastern portion of the state, mountains and valleys are widespread. The deepest of the valleys occur where the largest mountains reside, this being in the White Mountain portion of the state. Valleys also follow rivers all along the western portion of the state.

Figure 2.2: VIT Identified Valleys

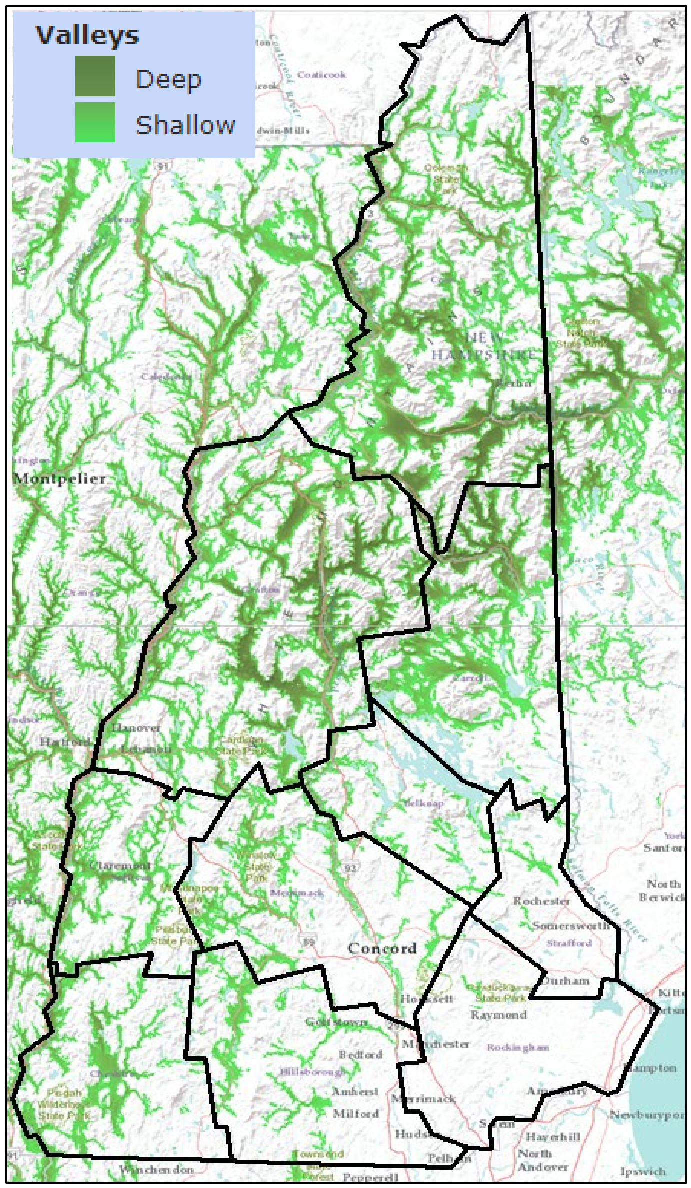


Figure 2.3 overlays shades of red on the valley map using darker shades of red to represent towns and cities with greater populations living within a valley. Thus some smaller communities located in a valley, such as Plymouth, are shown in darker red than larger communities such as Manchester, Nashua and Portsmouth, which are not located in any kind of sizable valley.

Figure 2.4 shows the southwestern portion of New Hampshire in greater detail. This portion of the state has a number of communities identified by mobile monitoring as being of interest that the VIT also identifies.

Figure 2.3: VIT Identified Populations in Valleys

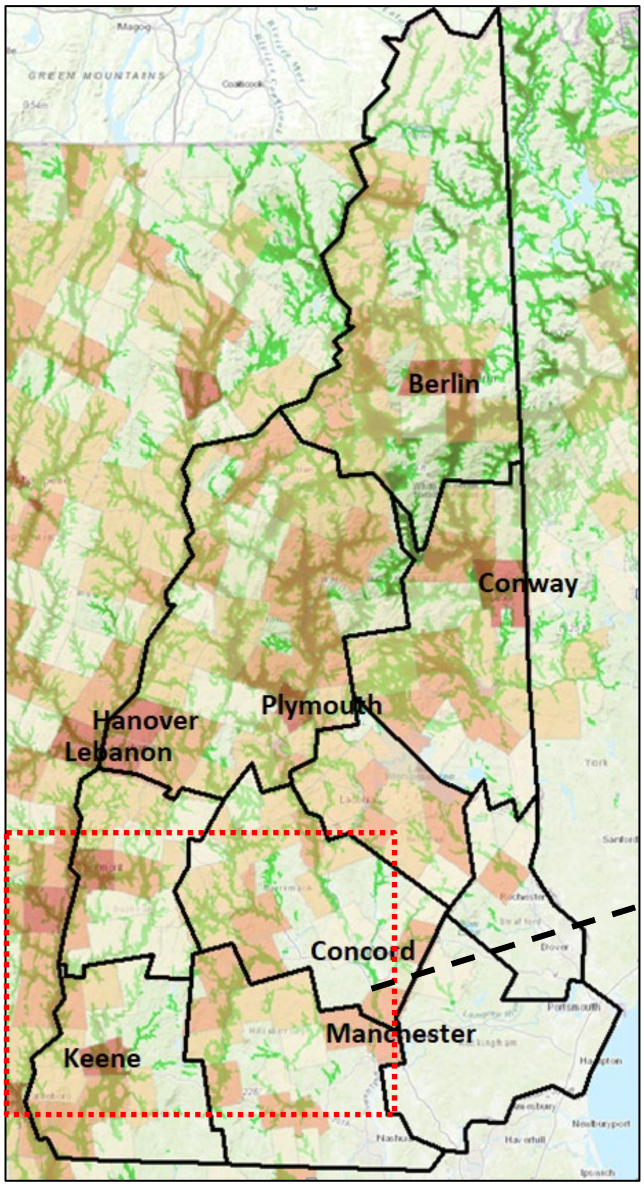
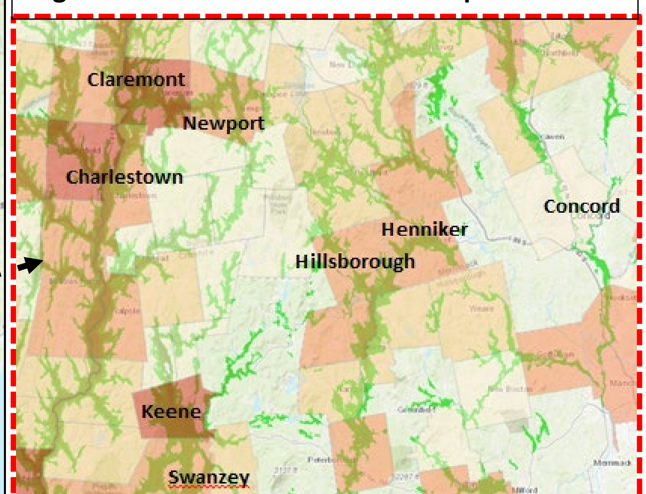


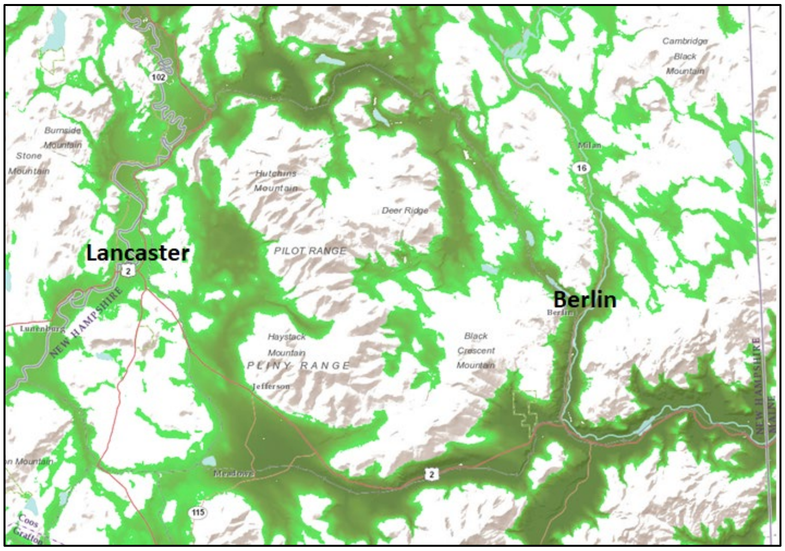
Figure 2.4: Southwestern New Hampshire



Darker shades of red indicate towns and cities with greater populations in a valley.

Each of the communites of interest listed in Table 1.1 are examined by the VIT in greater detail on the following pages.

Figure 2.5: VIT Identified Valleys in Northern New Hampshire



Figures 2.5, 2.6 and 2.7 show the shape and depth of valleys in the northern and northwestern portions of New Hampshire. Lincoln is located in a very deep valley. Berlin and Plymouth are also located in fairly deep valleys and Lancaster, Conway and Hanover are located in moderately deep valleys.

Figure 2.6: VIT Identified Valleys in North-Central New Hampshire

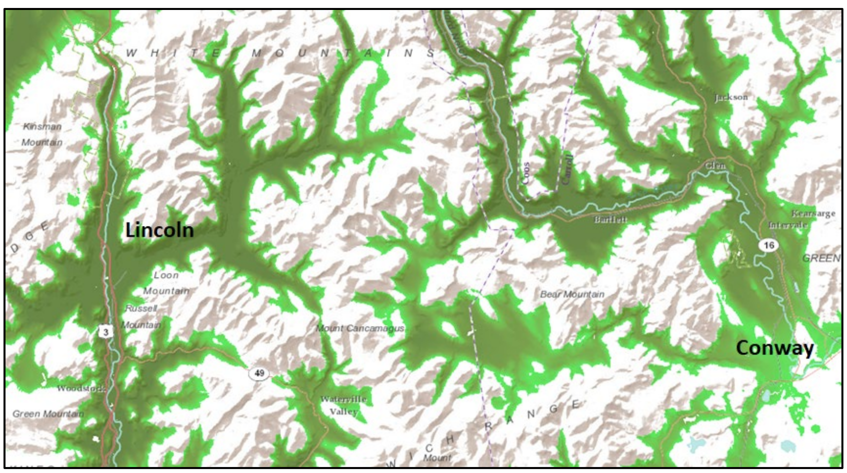
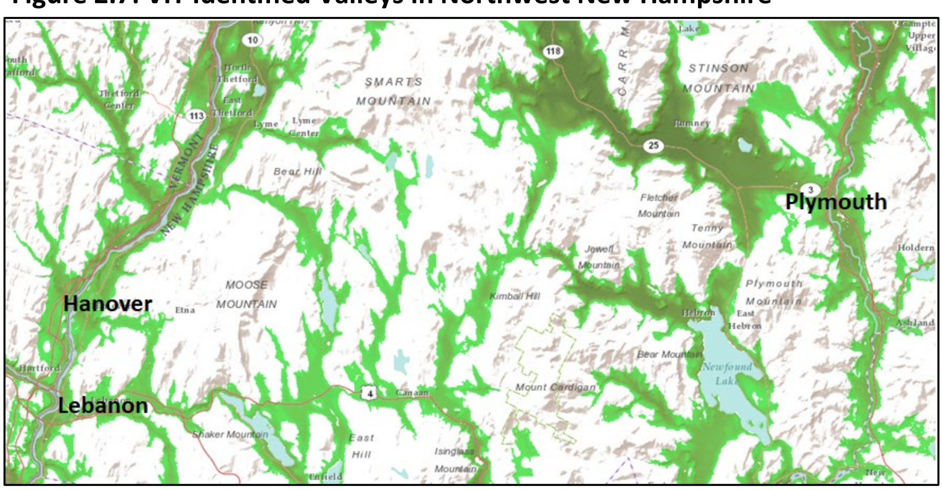


Figure 2.7: VIT Identified Valleys in Northwest New Hampshire



Figures 2.8 through 2.11 show the shape and depth of valleys in the central and western portions of New Hampshire. Acworth, Charlestown and Newport are each located in moderately deep valleys. Belmont, Henniker, Hillsborough and Langdon are located in less deep valleys. Laconia and Meredith are located in a hybrid valley where a valley meets a fairly large lake. Farmington, Marlow and Pittsfield are located in shallow valleys, and only a small portion of Concord is located in a shallow valley.

Figure 2.8: VIT Identified Valleys in Central New Hampshire

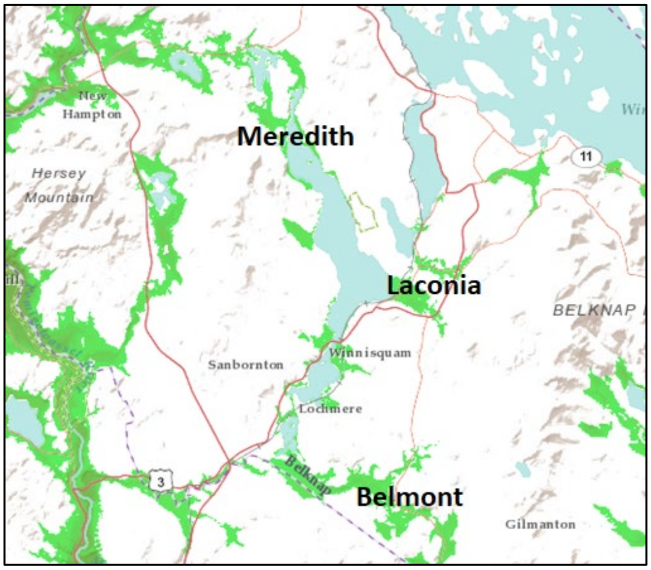


Figure 2.9: VIT Identified Valleys in Southeast New Hampshire

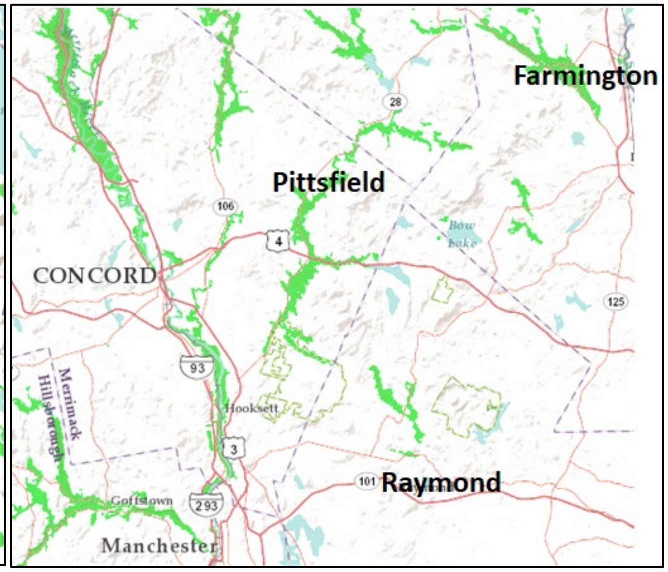


Figure 2.10: VIT Identified Valleys in Southwest New Hampshire

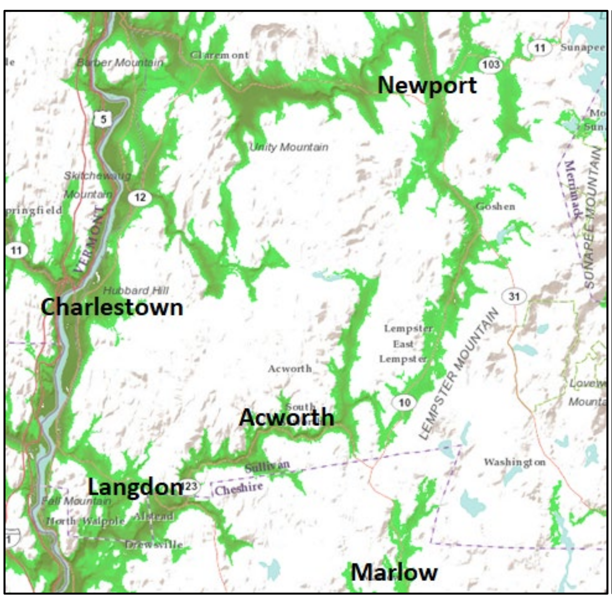
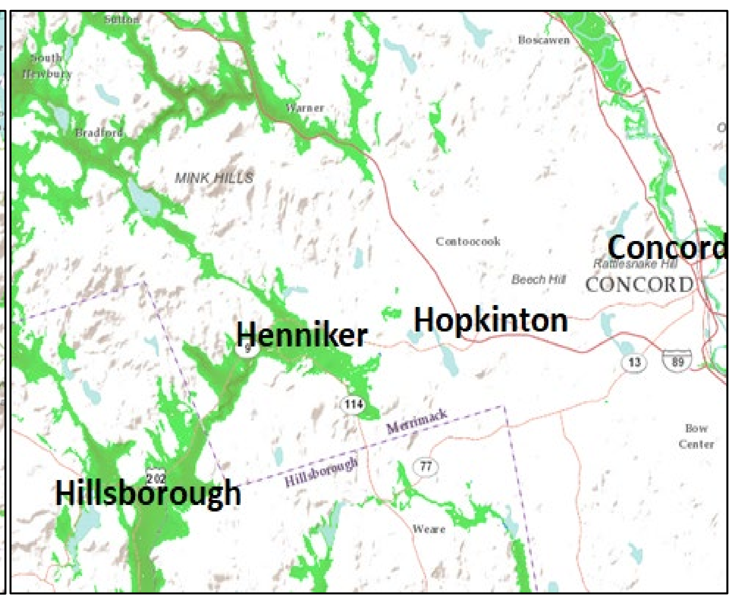
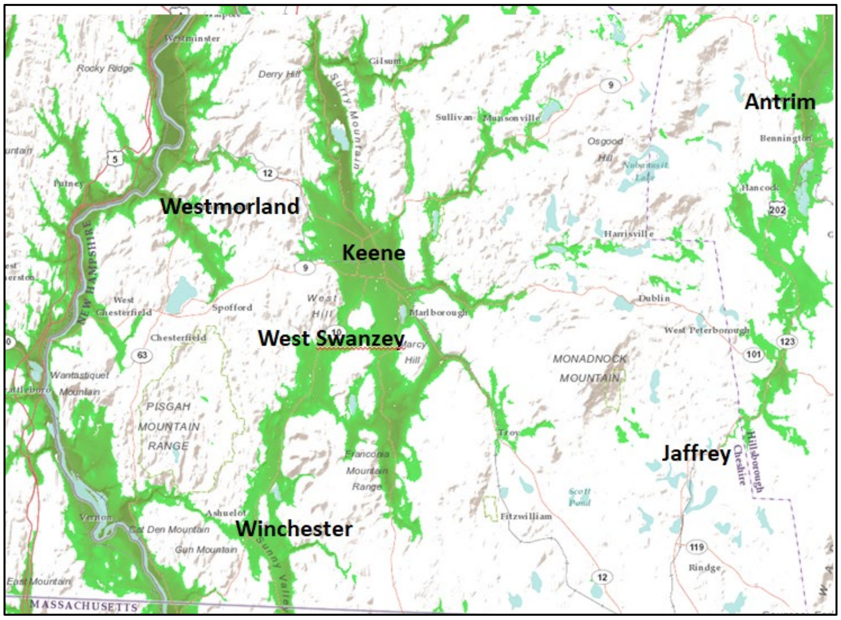


Figure 2.11: VIT Identified Valleys in South-Central New Hampshire



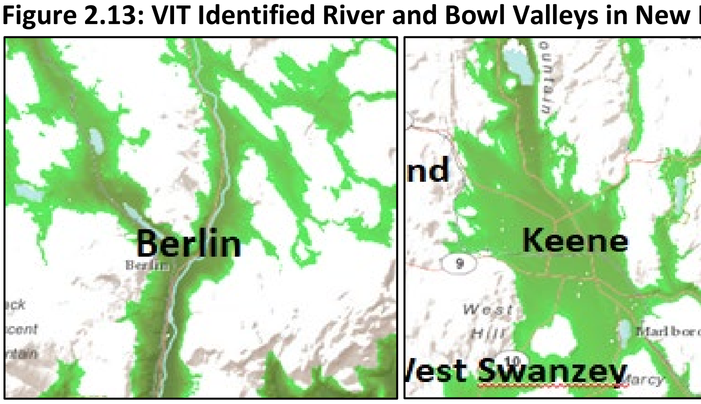
Three main valleys dominate the southwestern New Hampshire region, each running generally from north to south. Several small communities are located on the New Hampshire side of the Connecticut River, located in the western-most valley. A second valley stretches from north of the City of Keene, down to the Massachusetts state border and includes the city of Keene and the communities of Swanzey and Winchester. The third valley begins at the southern edge near Jaffrey and continues northward to Antrim and further north to Hillsborough and Henniker (Figure 2.12).

Figure 2.12: VIT Identified Valleys in Southwest New Hampshire



The VIT helps the user define the type of valley in which a community might be located. NHDES used this to classify valleys as either a river valley or a bowl valley. The main difference is that a river valley has a naturally more narrow shape that is relatively open at either end. The openings may allow winds to blow through the valley, flushing out air pollution emissions. A bowl valley tends to be wider and is shaped in a way that discourages wind flow because the ends are not as open. Figure 2.13 shows two examples. Berlin is a good example of a River Valley and Keene is identified as a bowl valley.

Figure 2.13: VIT Identified River and Bowl Valleys in New Hampshire



2.2.2 IDENTIFICATION OF POPULATION IN VALLEYS

According to the VIT, the Keene Valley is about 3.5 to 5 miles wide and about 500 feet below the nearby mountain rim (Figure 2.14 and 2.15). Most of the city's population resides within the valley.

Figure 2.14: VIT Transect of the Keene Valley with Topographical Display

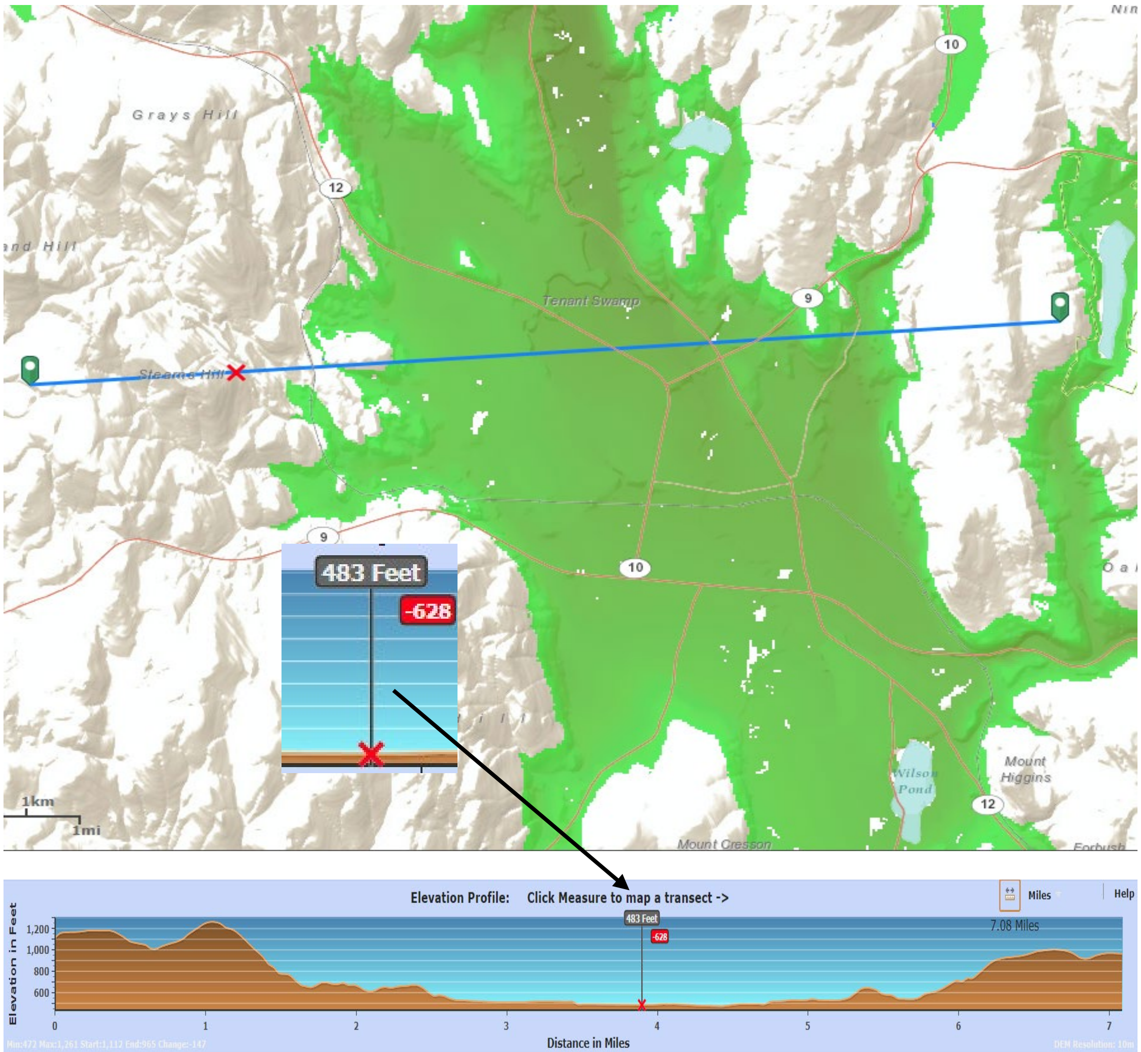
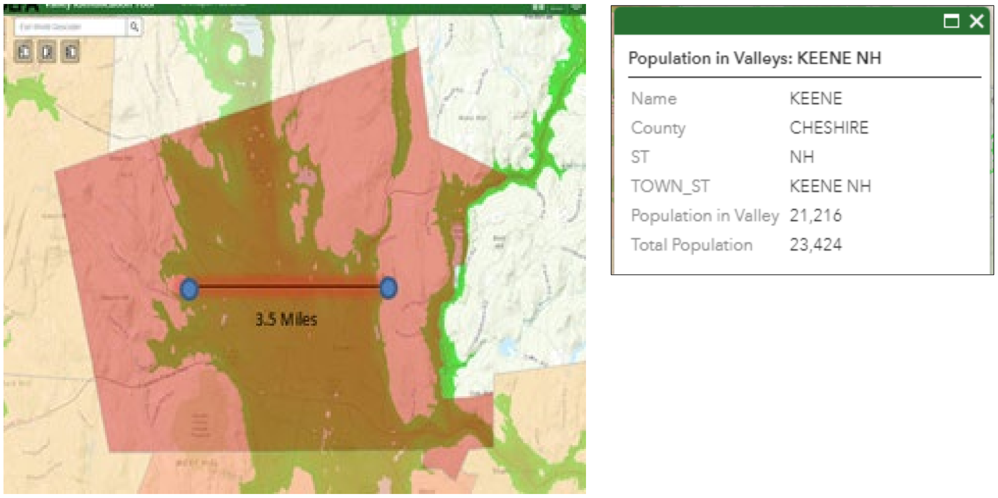


Figure 2.15: VIT Identified Valley Width at Keene



Concord, for example has a narrow valley that is occupied almost entirely by the Merrimack River (Figure 2.16). Only a small fraction of the population lives within the valley portion of the city. As a result, the VIT data suggests that Concord is less likely to have wood smoke stagnation effects due to valley inversions.

A city like Lebanon (Figure 2.17), however, has a valley type similar to that of Keene (Figure 2.15). It is wider than the valley found in Concord and has far more residents within the valley. Since most of the city's center is in the valley, the VIT identifies the population in the valley as 8,710. High emissions within the valley combined with this valley type could potentially produce elevated $PM_{2.5}$ levels in the region on windless winter nights. For this reason, it was deemed a town important enough for a windshield survey.

Figure 2.16: VIT Identified Valley Width at Concord

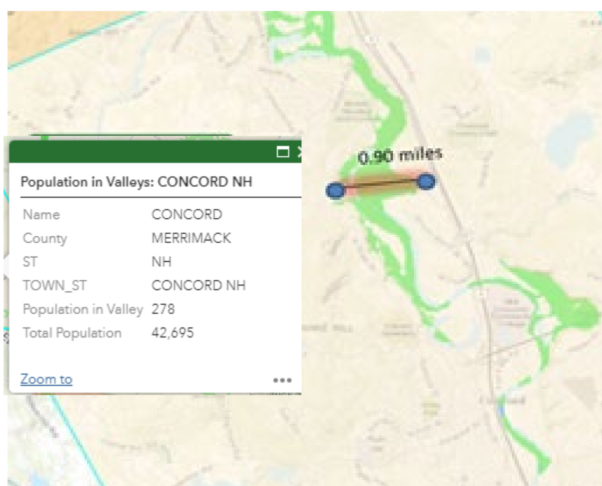
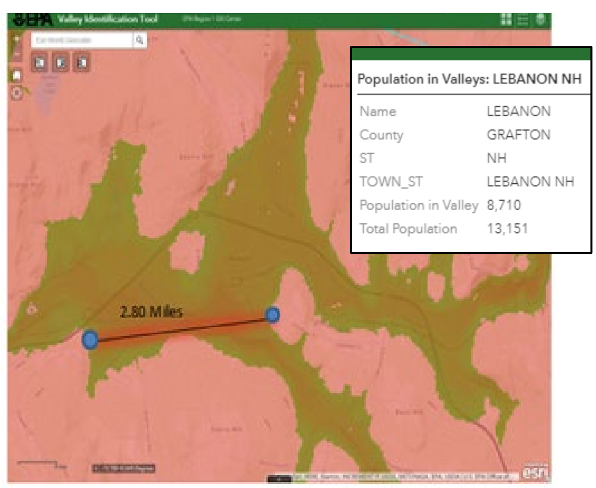


Figure 2.17: VIT Identified Valley Width at Lebanon



A useful feature of the VIT is its ability to export sortable tables. For the purpose of this project, NHDES used a table sorted by valley population to identify some obvious candidates for elevated wintertime $PM_{2.5}$ levels (Table 2.1). The top ten highest valley populations (highlighted yellow) were investigated as potential communities to visit (Laconia, which is also highlighted yellow, was used as a "test" run for the field survey. See Section 2.4 below). Most of the communities listed in Table 2.1 were visited during the mobile monitoring study, the results of which contributed to the decision of which ones to study further. For example, mobile monitoring identified higher concentrations in a heavily populated portion of Laconia, while Charleston showed lower $PM_{2.5}$ concentrations.

Table 2.1: Valley Populations in Descending Order

Town	County	Valley Type	Population in Valley*	Total Population*
KEENE	CHESHIRE	Bowl	21,216	23,424
CLAREMONT	SULLIVAN	Bowl	9,391	13,355
LEBANON	GRAFTON	River	8,710	13,151
HANOVER	GRAFTON	River	8,322	11,260
BERLIN	COOS	River	8,117	10,051
CONWAY	CARROLL	Bowl	6,412	10,119
PLYMOUTH	GRAFTON	Bowl	5,650	6,990
SWANZEY	CHESHIRE	Bowl	4,949	7,211
FRANKLIN	MERRIMACK	River	4,887	8,477
CHARLESTOWN	SULLIVAN	River	4,211	5,114
LACONIA	BELKNAP	River (Lake)	3,737	15,950
HILLSBOROUGH	HILLSBOROUGH	River	3,692	6,003
LITTLETON	GRAFTON	River	3,636	5,928
NEWPORT	SULLIVAN	River	3,568	6,507
HAVERHILL	GRAFTON	River	3,548	4,697
HINSDALE	CHESHIRE	River	3,252	4,046
WINCHESTER	CHESHIRE	Bowl	2,794	4,341
GORHAM	COOS	Bowl	2,769	2,848
HENNIKER	MERRIMACK	River	2,486	4,836
FARMINGTON	STRAFFORD	River	2,471	6,786
WALPOLE	CHESHIRE	River	2,309	3,734
LANCASTER	COOS	Bowl	2,142	3,507
GOFFSTOWN	HILLSBOROUGH	River	2,108	17,651
ENFIELD	GRAFTON	River	2,039	4,582

**Populations provided by VIT*

2.3 TOWN EMISSIONS CALCULATIONS

The next factor considered in searching for potentially high wintertime $PM_{2.5}$ levels was the volume of emissions released in each town. Emissions data, which is taken from the National Emissions Inventory (NEI), is only available by county, not town, as seen in Figure 2.18. Therefore, NHDES estimated town emissions using population data from the 2014 US Census. This involved calculating the percentage of a county's population made up by each town. The percentage was multiplied by the county's total emissions resulting in each specific town's $PM_{2.5}$ emissions. It is important to note that this is an approximation based on the assumption that towns burn wood proportionately to their population. This calculation was conducted for each town identified as a community of interest in the MAM and each town identified as a community of interest using the VIT. An example calculation for Hanover is provided in Figure 2.19.

Figure 2.18: Total $PM_{2.5}$ County Emissions

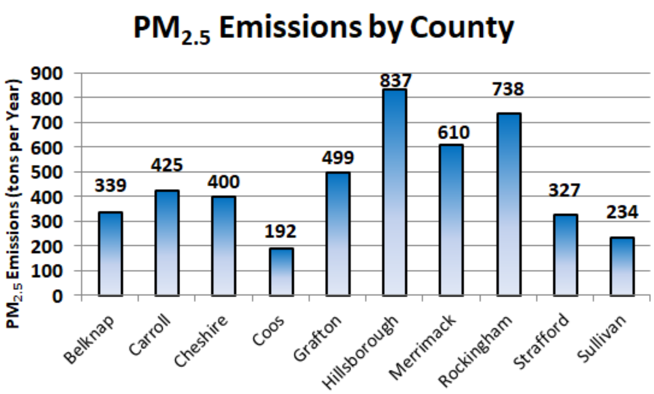
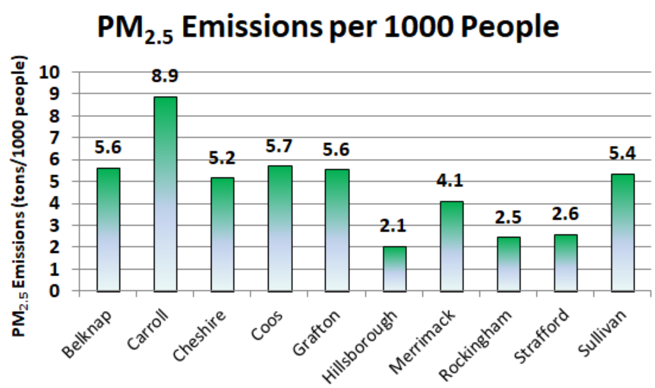


Figure 2.19: $PM_{2.5}$ County Per Capita Emissions



Sample $PM_{2.5}$ Town Emissions Example Calculation

Hanover (Town) 2014 Population Estimate: 11,370
Grafton (County) 2014 Population Estimate: 89,658 Grafton 2014 $PM_{2.5}$ Emissions (tons): 498.8

Step 1: 11,370 ÷ 89,658 = 0.127

Step 2: 0.127 × 498.8 $PM_{2.5}$ tons = **63.3 tons of $PM_{2.5}$ contributed by Hanover**

2.4 COMMUNITIES OF INTEREST

The data from the VIT and NEI was used to create a list of potential towns for windshield surveys based upon multiple factors. The $PM_{2.5}$ town emissions statistic was plotted on the y-axis with valley population on the x-axis and the resulting graph is shown in Figure 2.20. This figure helps illustrate how much of an outlier Keene is due to its unique environment.

The lower left corner of Figure 2.20 shows the other towns that are of concern (Figure 2.21). Towns in the bottom left corner represent those of least concern and towns in the top right represent those of most concern. Therefore, NHDES was interested in surveying those towns in the top right corner. Laconia, was surveyed first as a test run in 2018 to determine the effectiveness of the technique being used. Lebanon and Hanover were subsequently surveyed followed by Claremont, Keene, Plymouth and Conway/North Conway. Charlestown was selected as a potential town of interest (see Table 2.1) but ultimately was not surveyed due to time constraints and relatively low mobile monitoring concentrations. Additional communities were surveyed in 2019, including Berlin, Franklin, Laconia, Northfield and Tilton.

Figure 2.20: Emissions and Population Data with Outlier Communities

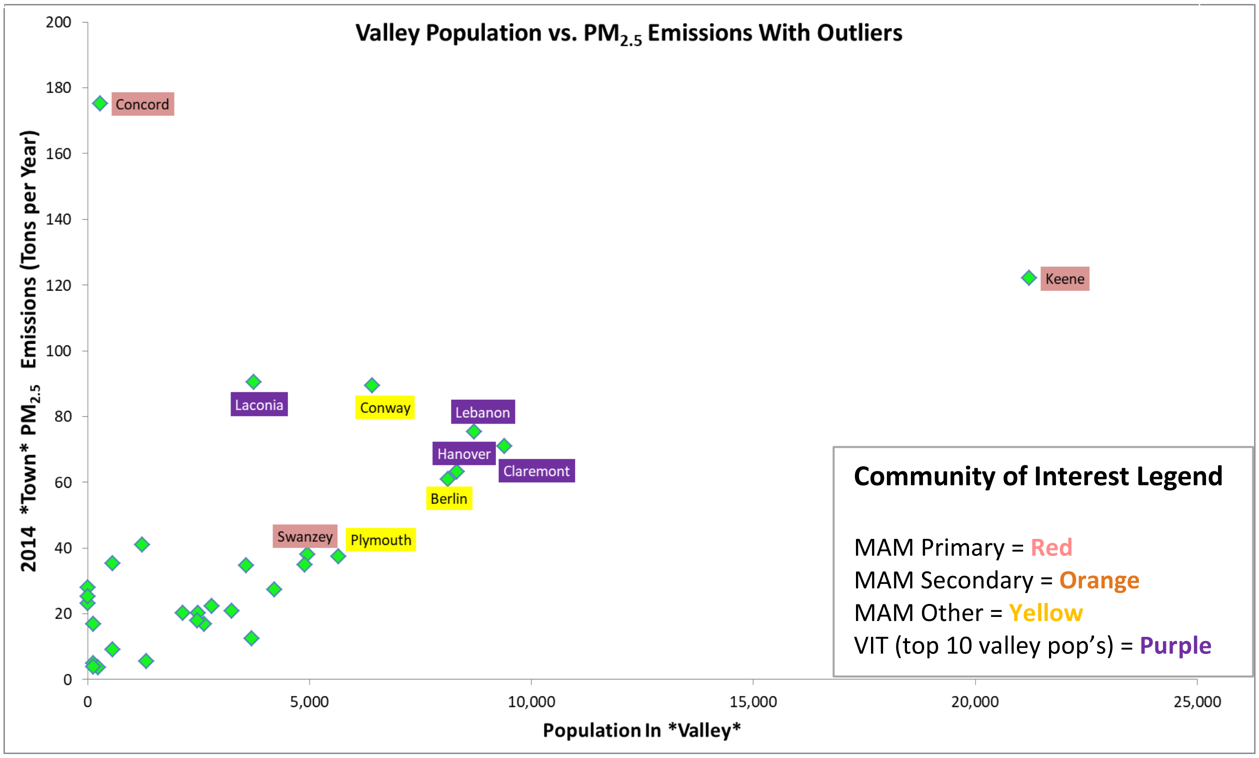
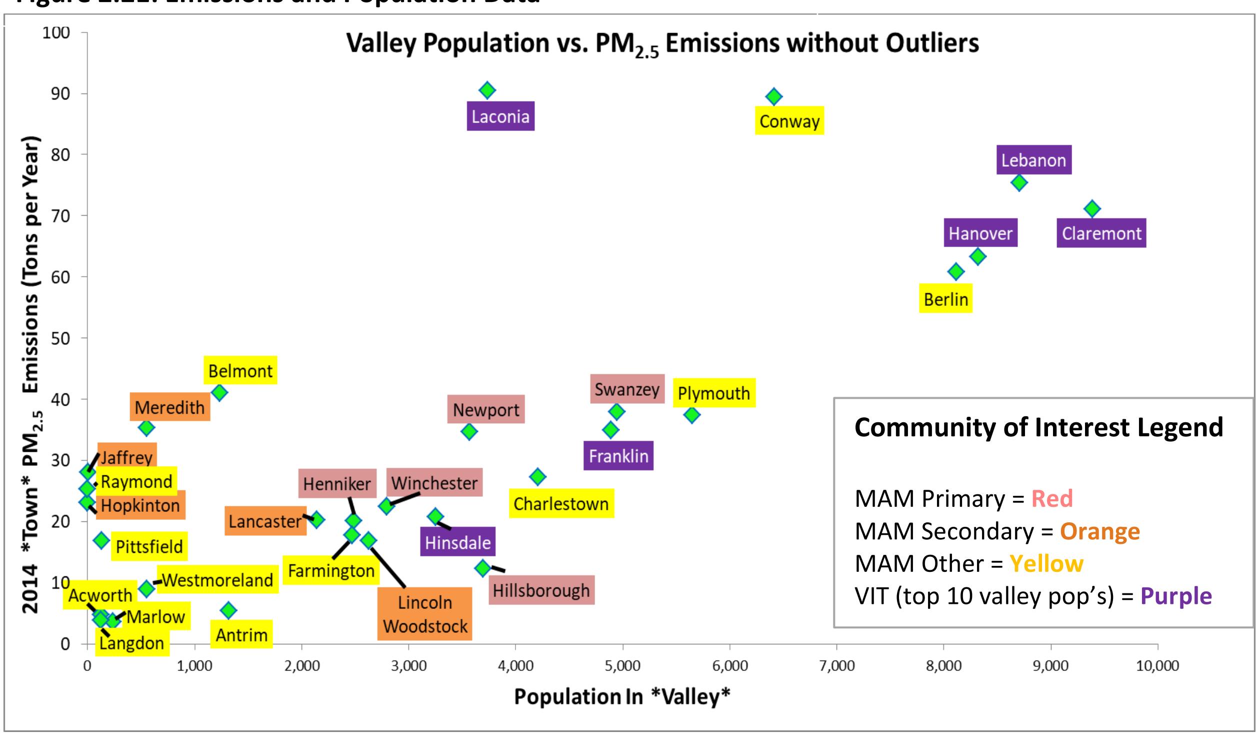


Figure 2.21: Emissions and Population Data



3. FIELD SURVEYS

3.1 PROCEDURE

The purpose of conducting windshield surveys was to analyze the wood burning tendencies of towns with high valley populations. The surveying involved visiting each town and documenting signs of wood burning such as chimneys, wood piles, etc. All surveys were conducted by NHDES in state vehicles during the summer, so visible smoke was not observable, but neighborhoods were examined thoroughly for indications of wood burning.

For each town surveyed, NHDES used the VIT to identify the deepest sections of the valley. Google Earth was then used to search for neighborhoods within these valleys and they were chosen based on the following characteristics: houses in close proximity to each other, efficiency of driving the neighborhood, and houses near the road, making it easier to see any signs of wood burning.

Each road was visited multiple times to count different indicators such as chimneys, wood piles, and propane tanks (an indication that a home may **not** use wood for primary heating). If a house had two chimneys or more, only one was counted. If a house had both a metal chimney and a brick chimney, only the metal chimney was counted. In some communities, the count of propane tanks is skewed because some small propane tanks meant for a grill were accidentally counted a few times. Propane tank count was not heavily relied upon in this study and was qualitatively used to indicate local availability of gas for residential heating.

Figure 3.1 shows examples of metal chimneys counted in this survey.

Figure 3.1: Metal Capped Chimneys

Source: Underhill 2020

Figure 3.2 shows examples of larger propane tanks designed for residential heating that were counted in the surveys.

Figure 3.2: Propane Tanks

Source: Underhill 2020

Wood piles are a key indicator of residential wood burning but are the most difficult to assess without actually entering private yards. As a result, surveyed amounts are likely under-counted, as many wood piles would be in backyards or locations not visible from the road.

3.2 COMMUNITY VISITS

Field surveys were conducted during the summers of 2017 and 2019 and included the communities of:

- Berlin
- Claremont
- Franklin
- Hanover
- Keene
- Laconia
- Lebanon
- North Conway
- Northfield
- Plymouth

Source: Underhill 2020

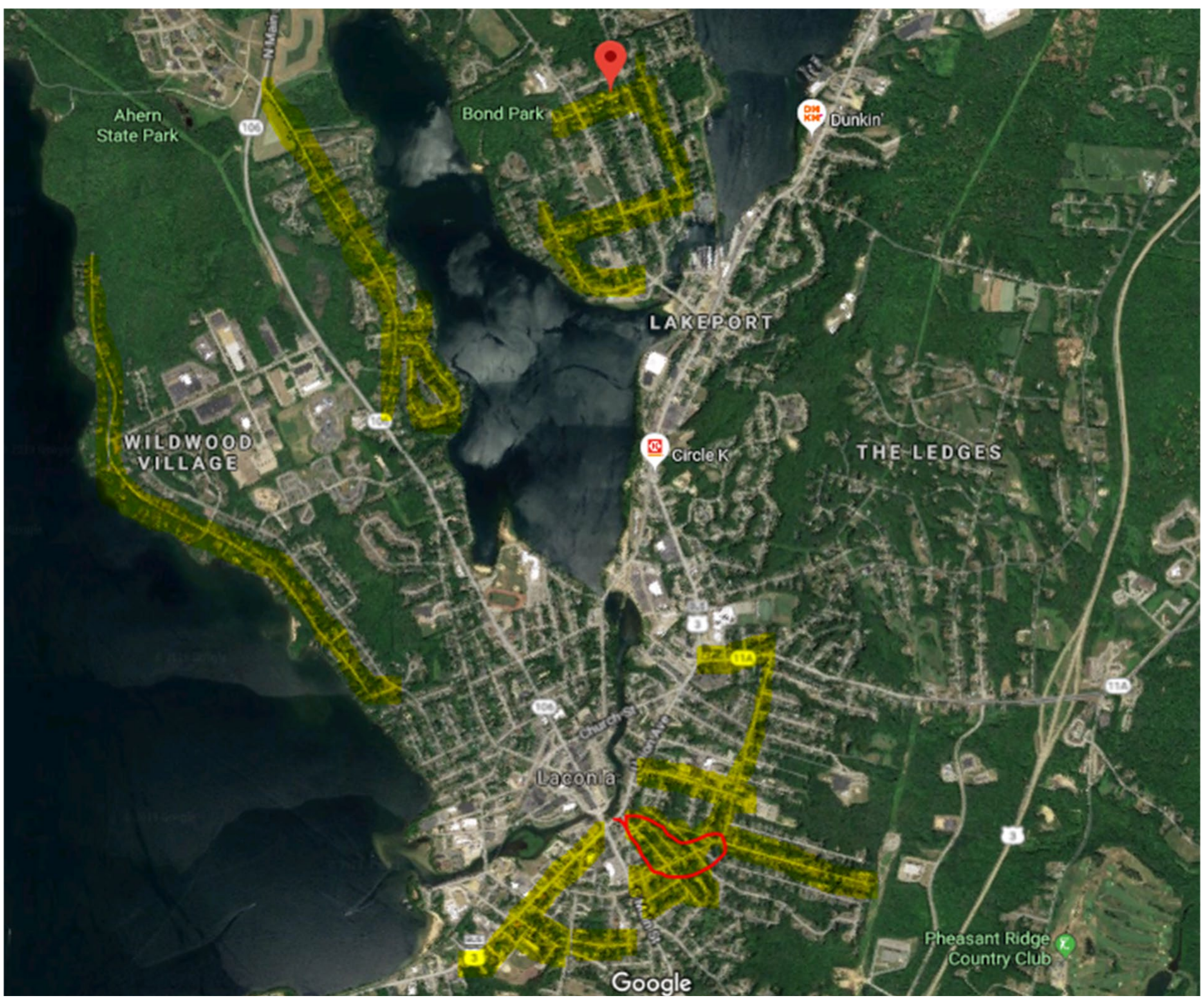
The following subsections provide written summaries of the field surveys conducted.

3.2.1 LACONIA – JULY 10, 2018 AND JULY 22, 2019

Laconia was not originally of high concern compared to other towns in the state because only 3,737 people live in its valley. During the first visit, the survey crew was performing its first survey and every chimney on a house was counted towards the chimney total. The surveyors also did not differentiate between metal-capped chimneys and open-topped chimneys. Generally, metal-capped chimneys are associated with regular wood burning. During all subsequent visits, survey crews only counted a maximum of one chimney per house, the number of metal-capped chimneys and the number of large (non-grill-sized) propane tanks.

Housing in Laconia was found to be denser than in virtually all other areas surveyed in this study. As a result, emission sources are closer together and each can affect a greater population. Because metal capped chimneys were not specifically counted, the number of wood piles counted becomes important to assess data collected during the first visit.

Figure 3.3: Surveyed Neighborhoods in Laconia

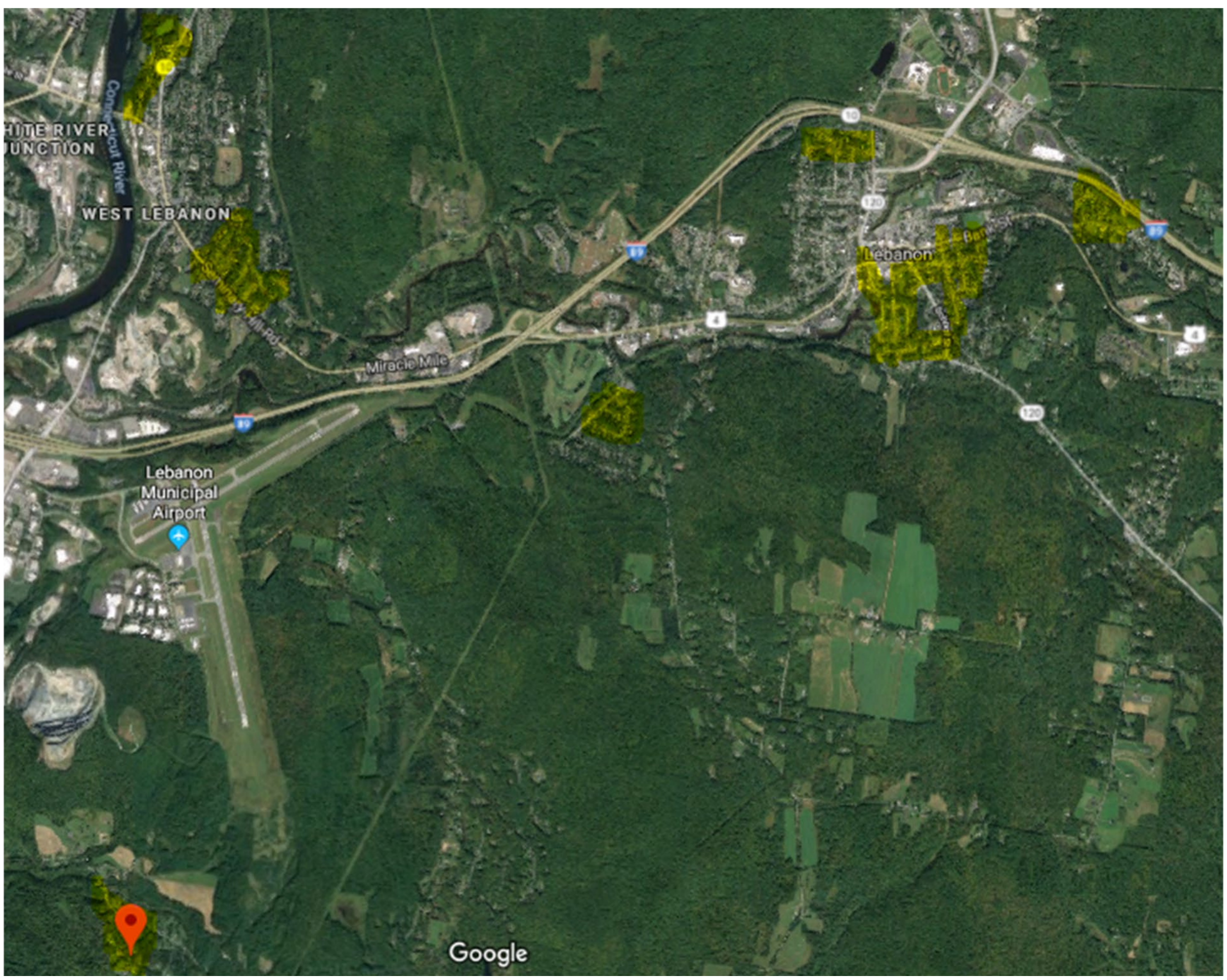


3.2.2 LEBANON - JULY 12, 2018

Nine separate neighborhoods were visited in Lebanon. These neighborhoods were located in valley regions such as downtown Lebanon, downtown West Lebanon and rural Lebanon. The area with the highest amount of observable wood burning was rural Lebanon, not far from the town's center. This region is located on the edge of the valley so it is unknown if the $PM_{2.5}$ emissions would be locally trapped during the winter. Another area of interest is comprised of Water, Church, Pine and Valley streets, as seen in Table A2. This neighborhood was interesting because the four streets are in a deep, flat valley near the town center. This could potentially be a concentrated area that experiences elevated wintertime $PM_{2.5}$ levels. In general, the town had many chimneys and metal pipe vents, but not many definitive wood burning signs such as wood piles.

Note to this and subsequent figures: Areas that were surveyed are shown in yellow highlight.

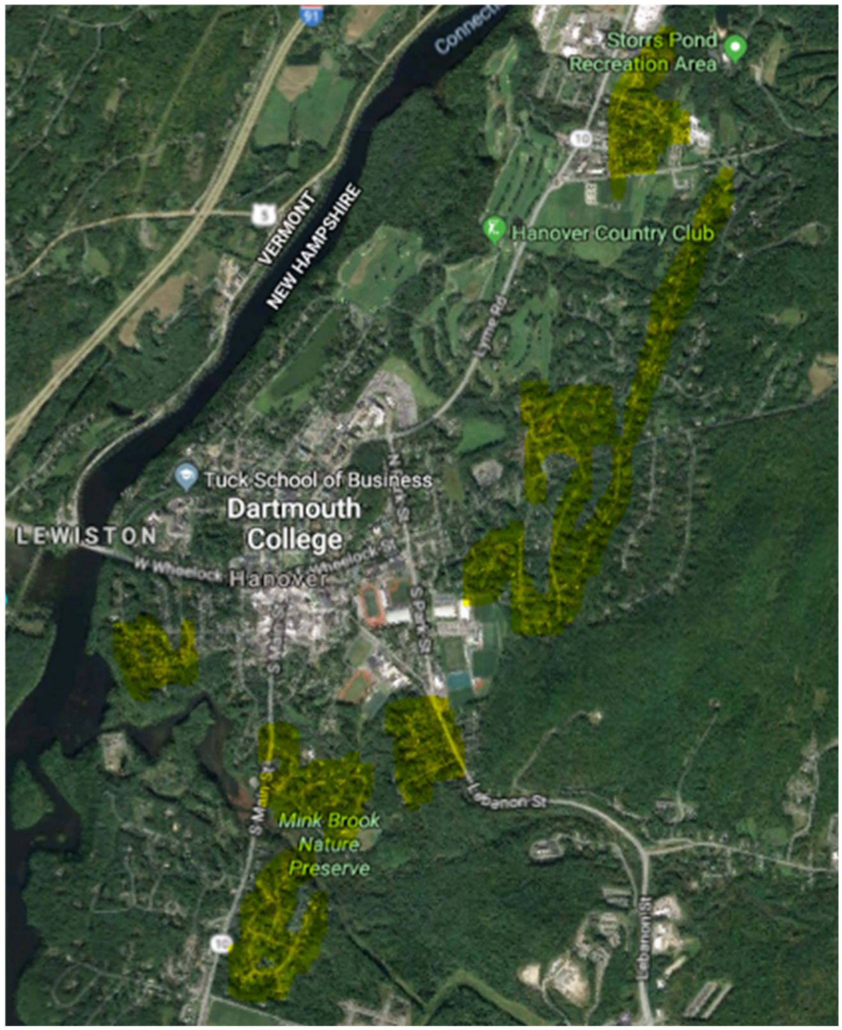
Figure 3.4: Surveyed Neighborhoods in Lebanon



3.2.3 HANOVER - JULY 19, 2018

Eight separate regions were visited in the Hanover area and they all lie within the Connecticut River valley. Most neighborhoods had chimneys on every house, but only a few houses had wood piles visible from the road. Two neighborhoods, had a fair amount of wood piles visible from the road so these two neighborhoods have the potential to experience elevated $PM_{2.5}$ levels during the winter. If the other neighborhoods surveyed, with less visible woodpiles, do have the same number of woodpiles as the first two neighborhoods, then Hanover could be experiencing elevated $PM_{2.5}$ levels in the winter. In general, this town appeared to have a substantial amount of wood burning and would be interesting to follow up on in the winter.

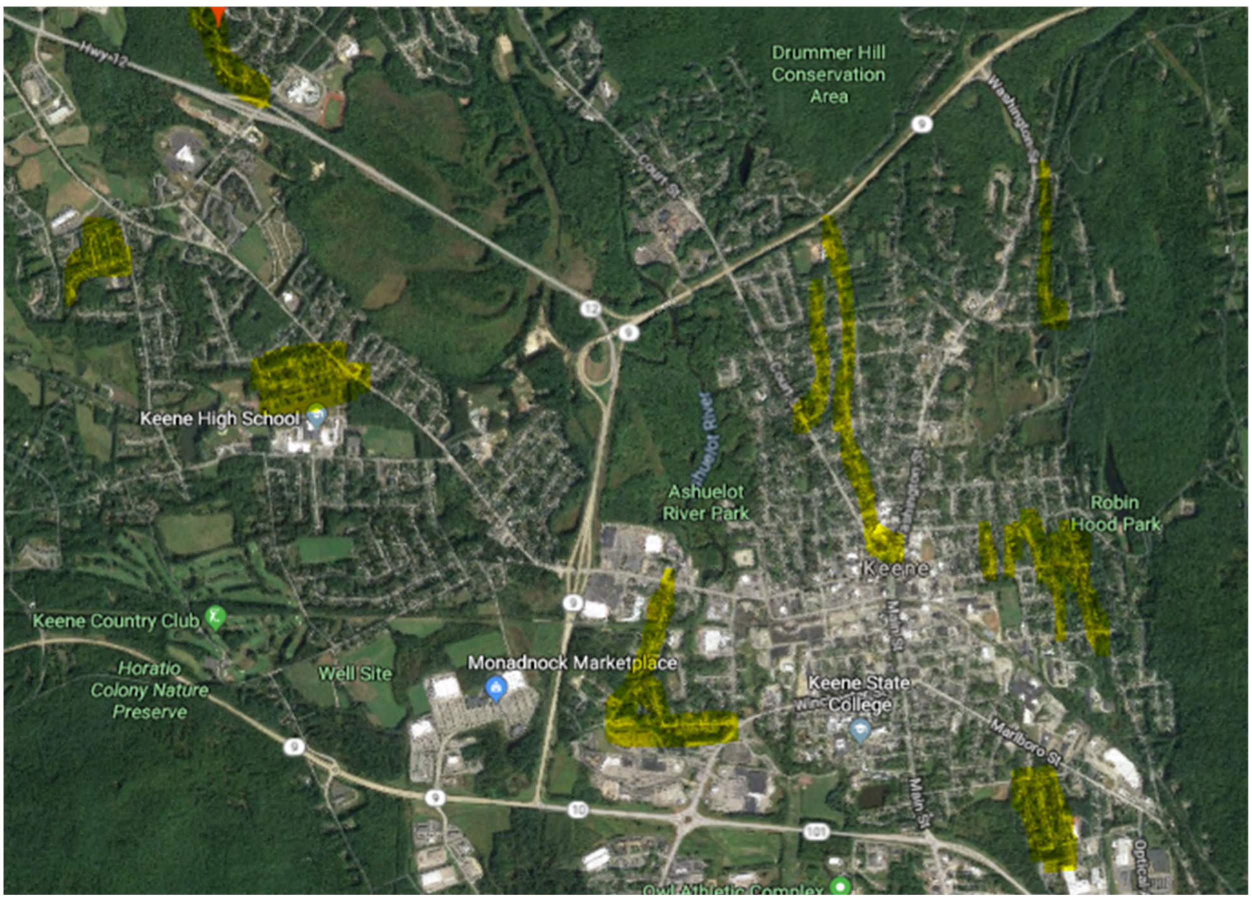
Figure 3.5: Surveyed Neighborhoods in Hanover



3.2.4 KEENE – JULY 24, 2018

Nine regions throughout Keene were visited and, like most towns in New Hampshire, nearly every house had at least one brick chimney. In general, many of Keene's neighborhoods had fenced in yards and houses in close proximity to each other making it difficult to locate signs of wood burning such as wood piles. However, in neighborhoods with many metal woodstove chimneys, it could be inferred that there was a moderate amount of wood burning occurring even without visible woodpiles. This is because these chimneys are relatively modern, and it is unlikely a homeowner would install one on an old house unless they were going to use it for wood burning. Overall, survey observations did not reveal as many clear indicators of wood burning in Keene as anticipated. It was similar to Lebanon and Hanover in overall wood burning signs. However, it did not appear to contain as much wood burning as Hanover/Lebanon per house. This indicates that valley population and valley shape may be factors of higher importance than the percentage of houses that burn wood.

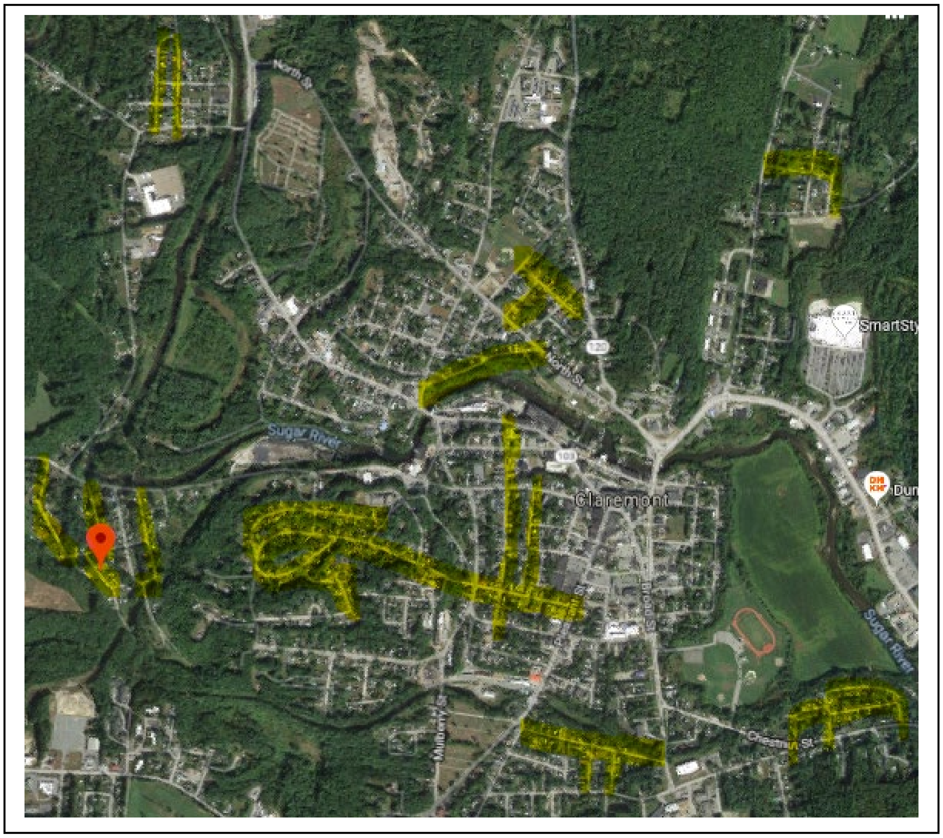
Figure 3.6: Surveyed Neighborhoods in Keene



3.2.5 CLAREMONT – JULY 26, 2018

Eight regions covering Claremont were visited and they exhibited a below average to average amount of wood burning indicators. In terms of woodpiles per house it was similar to Keene, however, Claremont's valley population is about half that of Keene. Therefore, Claremont does not appear to have enough wood burning to experience town-wide increased wintertime $PM_{2.5}$ levels. However, certain individual neighborhoods may experience high localized $PM_{2.5}$ levels.

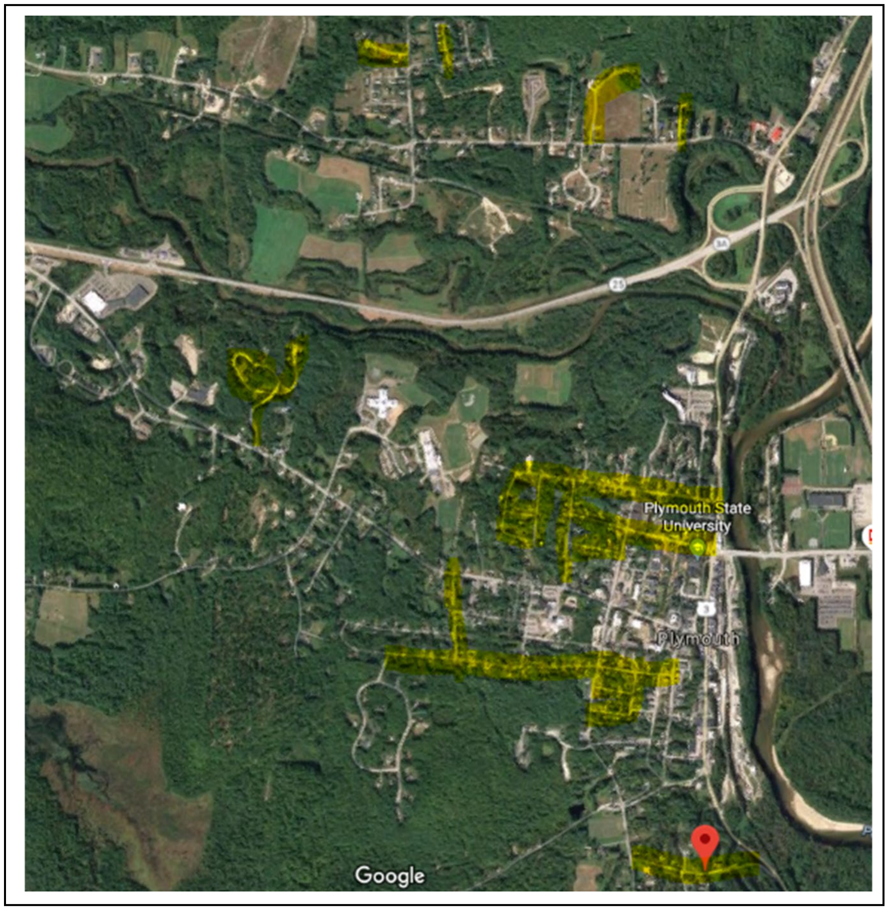
Figure 3.7: Surveyed Neighborhoods in Claremont



3.2.6 PLYMOUTH - JULY 31, 2018

Seven regions throughout Plymouth were visited and due to town size, it had the second lowest number of houses surveyed compared to all others. It still had an impressive 30 woodpiles, so per household it had an average to above average amount of wood burning potential. Though it was closest to Hanover/Lebanon in amount of wood burning indicators per house, Plymouth is fairly small and does not produce above average $PM_{2.5}$ levels according to the 2014 emissions data estimates. Although it has a high rate of wood burning signs, its low valley population makes it a town of little concern for elevated wintertime $PM_{2.5}$ levels.

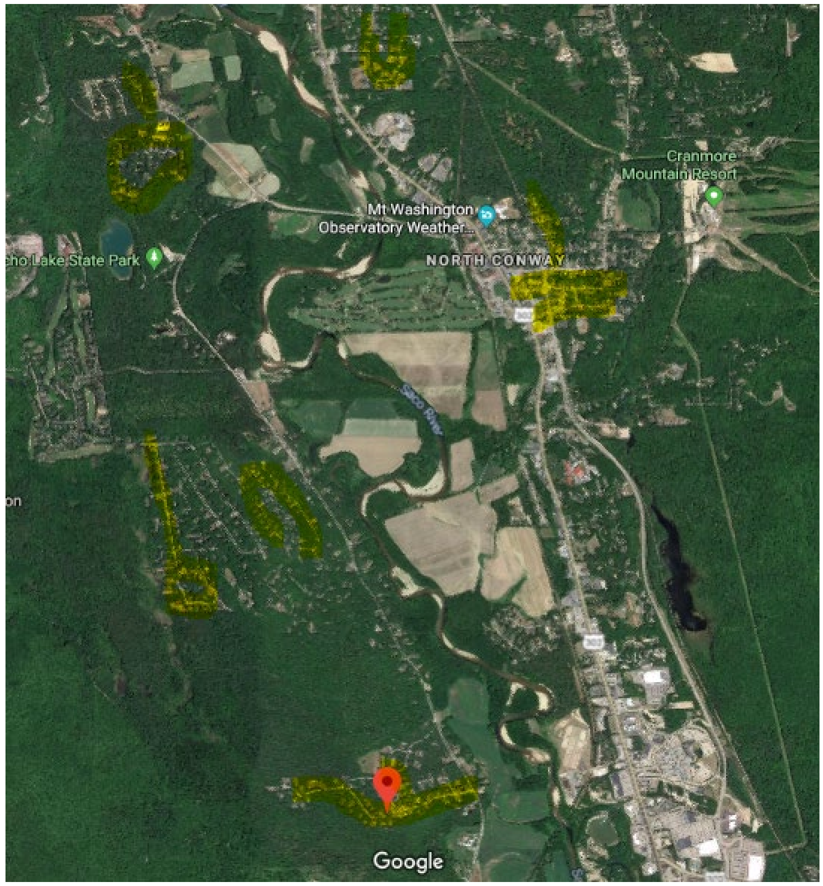
Figure 3.8: Surveyed Neighborhoods in Plymouth



3.2.7 NORTH CONWAY - AUGUST 3, 2018

Five regions covering North Conway were visited and it was found to have the most wood burning indicators of any town surveyed. Some of this may be due to winter tourist preference for a wood burning ambiance at rental properties. However, the neighborhoods are fairly spread out and the overall town population in the valley is not significant. These neighborhoods might be of concern in terms of localized $PM_{2.5}$ but overall is not a major concern.

Figure 3.9: Surveyed Neighborhoods in North Conway



3.2.8 FRANKLIN - JULY 22, 2019

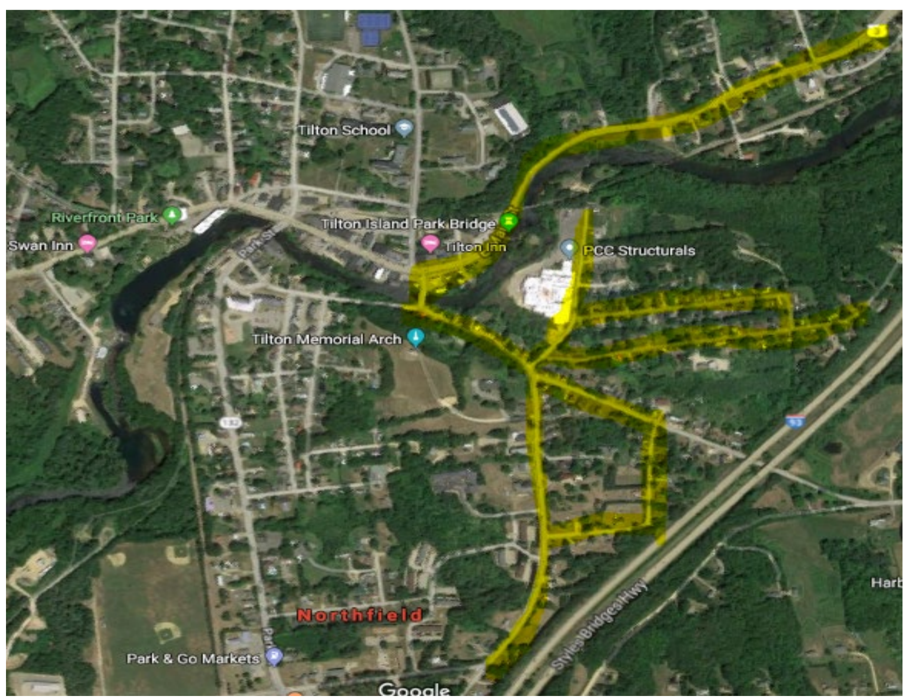
Franklin has among the highest metal chimney count per house in the survey, suggesting that the residences are wood burning capable even if woodpiles were not spotted. Franklin was the only community in the survey where an outdoor wood boiler (OWB) was spotted. In the trailer park area of Franklin, a few propane tanks were spotted attached to the residences. It is possible more trailers in this area also run off of propane but the tanks were out of sight and it is unknown what source of heat is used.

Figure 3.10: Surveyed Neighborhoods in Franklin

3.2.9 NORTHFIELD - JULY 22, 2019

Northfield, compared to other locations, has the highest wood burn rate, the biggest indicator of $PM_{2.5}$. This combined with the high percentage of chimneys to houses makes Northfield a potential high $PM_{2.5}$ area. Northfield residences are very spread out and the houses are not nearly as compact as those located in Laconia or Franklin.

Figure 3.11: Surveyed Neighborhoods in Northfield



3.2.10 BERLIN - AUGUST 12, 2019

Three neighborhood in the City of Berlin were surveyed. A significant number of metal chimneys (81) were observed of the 440 homes, suggesting that many residences are wood-burning capable. Also, a fair number of woodpiles (16) were observed. Although Berlin is located in a river valley, which is not as conducive to trapping pollution as a bowl valley, the number of metal chimneys and woodpiles observed suggest that individual neighborhoods may have the potential to experience elevated $PM_{2.5}$.

Figure 3.12: Surveyed Neighborhoods in Berlin

3.3 RESULTS

3.3.1 SUMMARY OF COMMUNITY FIELD SURVEYS

Table 3.1 displays the quantitative results from each town survey. Propane tanks were counted in order to determine if a house was heated with that method rather than wood burning, however, some houses used both propane and wood burning. After the first two surveys, metal chimneys became a fairly strong indicator of estimated wood burning rates. At first, NHDES was counting all metal pipes that could be seen on house roofs. However, with the exception of the first Laconia survey (Laconia 1), this was later corrected to count only metal chimneys that are specifically used for woodstoves/fireplaces. Excluding the Laconia 1 tally, the brick chimney count was nearly as high as the overall house count due to nearly every house in New Hampshire having a brick chimney. As a result, the brick chimney count is not an accurate indicator for wood burning because many of these chimneys are not regularly active. The number of outdoor wood boilers (OWBs) or hydronic heaters, is valuable because many emit high volumes of particulate pollution. NHDES, however, only recorded seeing two OWBs in the areas included in this survey, thus they do not appear to be a major factor for neighborhood wood smoke concentrations in these areas.

Table 3.1: Overall Wood Burning Indicators by Town

Town	# Propane Tanks	# Metal Chimneys	# Brick Chimneys	# OWBs	# Pellet Stoves	# Wood Piles	# Houses Surveyed	Wood piles/ Houses	Metal Chimneys/ Houses
Berlin	17	81	325	0	0	16	440	4%	18%
Claremont	13	24	165	1	1	18	293	6%	8%
Conway	11	59	133	0	0	65	253	26%	23%
Franklin	11	55	81	0	0	11	171	6%	32%
Hanover	22	0	252	0	0	52	325	16%	0%
Keene	16	41	248	0	2	38	378	10%	11%
Laconia 1	NA[a]	NA[b]	599	0	0	28	510	5%	NA
Laconia 2	6	7	157	0	1	20	210	10%	3%
Lebanon	45	0	250	0	0	47	284	17%	0%
Northfield	5	26	81	1	0	19	125	15%	21%
Plymouth	13	24	145	0	1	30	211	14%	11%

a – Propane tanks were not counted during the first Laconia survey.
b – Both metal chimneys and exhaust pipes were counted during the first Laconia survey, so this tally would be inconsistent with the rest of the data presented.

Pellet stoves are very difficult to count since they usually cannot be seen from outside. They generally use the same metal chimney or chimney caps that regular wood stoves use, thus the only indicator the survey could use was stacks of pellets stored in a driveway, garage, or other outdoor area. Because the survey was conducted in the summer, many people who have a pellet stove may not have had a ready stockpile of pellets in storage. As a result, this survey likely undercounted pellet stoves.

The wood burning rate discussed in section 3.3.2 refers to the number of wood piles to the number of houses. A ratio of the number of metal chimneys to the number of houses was also considered.

Figure 3.13: Wood Piles as a Wood Burning Indicator

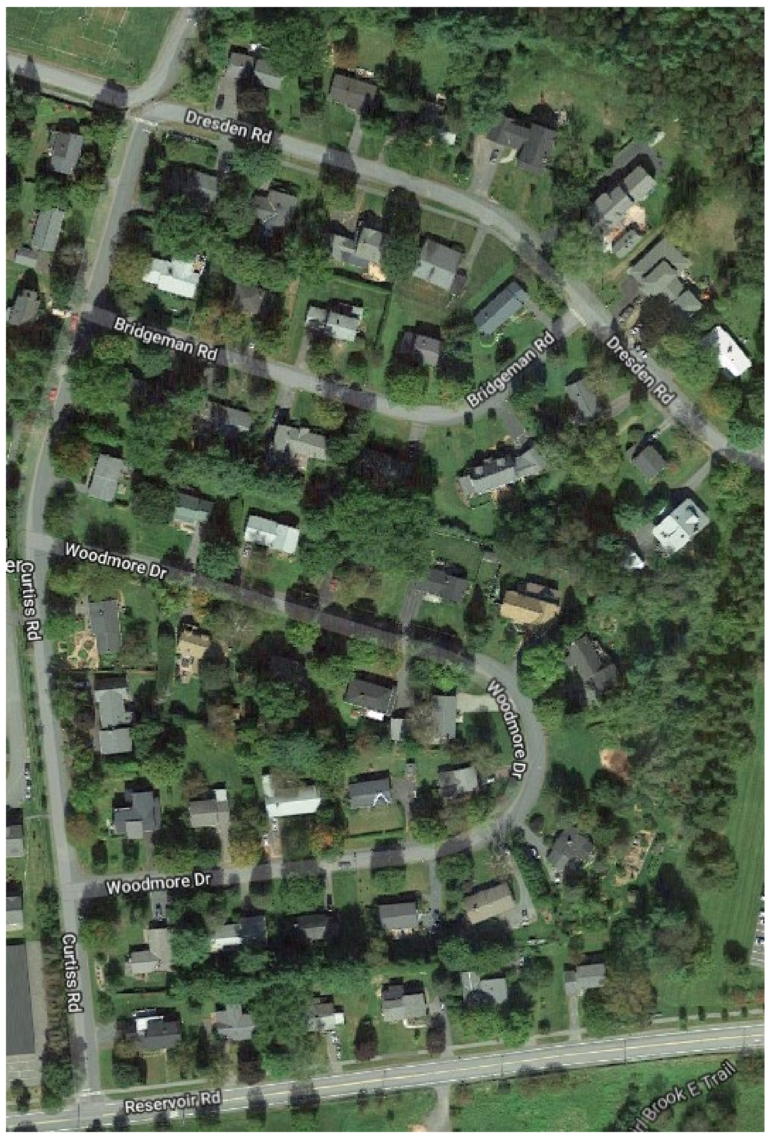
Source: Underhill 2020

3.3.2 AREAS IDENTIFIED FOR HIGH WOOD BURNING RATES

The main goal of the field surveys was to identify areas where select indicators suggest that wood burning rates may contribute to high wintertime $PM_{2.5}$ concentrations on a neighborhood or community-wide scale. For example, Keene had the second lowest wood burning rate of surveyed towns, but has experienced 10 measured $PM_{2.5}$ exceedances since the NAAQS was established in 1997. This is due to its almost circular bowl valley and large population within. Its valley population of 21,216 is more than double the second highest valley population which is 9,391 in Claremont. NHDES learned through use of the VIT and observations in the field that there are no other towns or cities with the same valley shape/population density combination of Keene.

Since NHDES began studying the potential for wintertime wood smoke events in other communities, it has been determined that there are portions of some communities that have the potential to develop high wood smoke concentrations. Towns such as Hanover and Conway have neighborhoods in specific low-lying parts of their valleys that displayed a large number of wood burning indicators and these neighborhoods may be at risk of localized elevated $PM_{2.5}$ levels in the winter.

Figure 3.14: Hanover Neighborhood with Many Wood Burning Indicators



Hanover

One of these neighborhoods is in Hanover (shown in Figure 3.14) in a neighborhood including Woodmore Drive, Bridgeman Road and Dresden Road. The neighborhood resides in a flat area of a larger valley. On Woodmore Drive, over 50% of the houses had visible wood piles. This neighborhood could have neighborhood scale wood smoke issues, but because of the topography, it is unlikely to be involved in a community-wide wood smoke issue.

Overall, Hanover displayed a moderate rate of wood burning and is expected to experience moderate concentrations of $PM_{2.5}$ during winter nights.

North Conway

North Conway had among the highest number of visible indicators of wood burning of any community included in this survey. Despite the high rates of likely wood burning, neighborhoods with high wood burning rates were widely spread across the valley and lacked the density needed to form community-wide wood smoke problems. North Conway is expected to experience moderate concentrations of $PM_{2.5}$ during winter nights. There, however, can be local and neighborhood areas of concern as a result of the high wood burning rates. One particular neighborhood located on the southwest side of town had woodpiles at over 75% of the houses. This neighborhood included Dandiview Road, Linden Road and Evergreen Drive (Figure 3.15).

Figure 3.15: Conway Neighborhood with Many Wood Burning Indicators

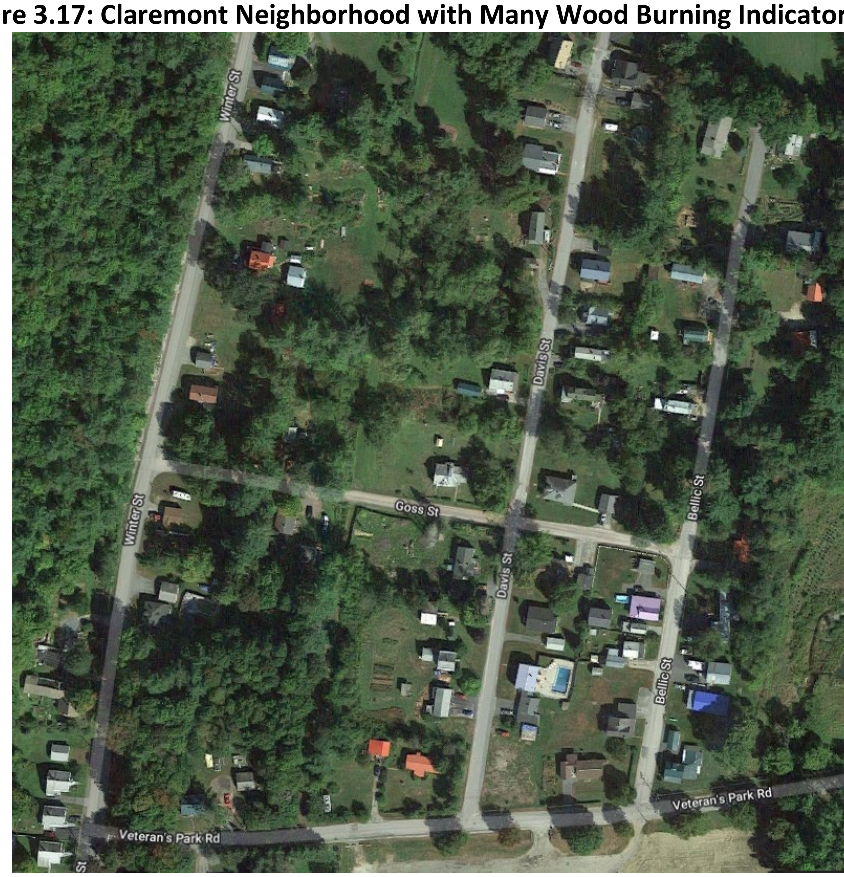
Lebanon

Figure 3.16: Lebanon Neighborhood with Many Wood Burning Indicators

An isolated Lebanon neighborhood on the south side of town had some of the highest wood burning indicators in the study. This area includes Tuck Road, Nottingham Circle and Wellington Circle (Figure 3.16). Since the neighborhood resides on a hillside that allows for drainage of smoke down into a nearby valley, the neighborhood is not expected to be involved in a community-wide wood smoke buildup, but there could be localized smoke issues. Overall, Lebanon displayed a moderate rate of wood-burning and is expected to experience moderate concentrations of $PM_{2.5}$ during winter nights.

Claremont

Figure 3.17: Claremont Neighborhood with Many Wood Burning Indicators



A small neighborhood on the northeast side of Claremont had many signs of wood burning. This neighborhood includes Bellic Street, Davis Street and Goss Street (Figure 3.17) and is located at the bottom edge of a nearby hillside. Because of the small size of the neighborhood, there is little concern of it driving community-wide wood smoke events, but local and neighborhood scale wood smoke could be of concern.

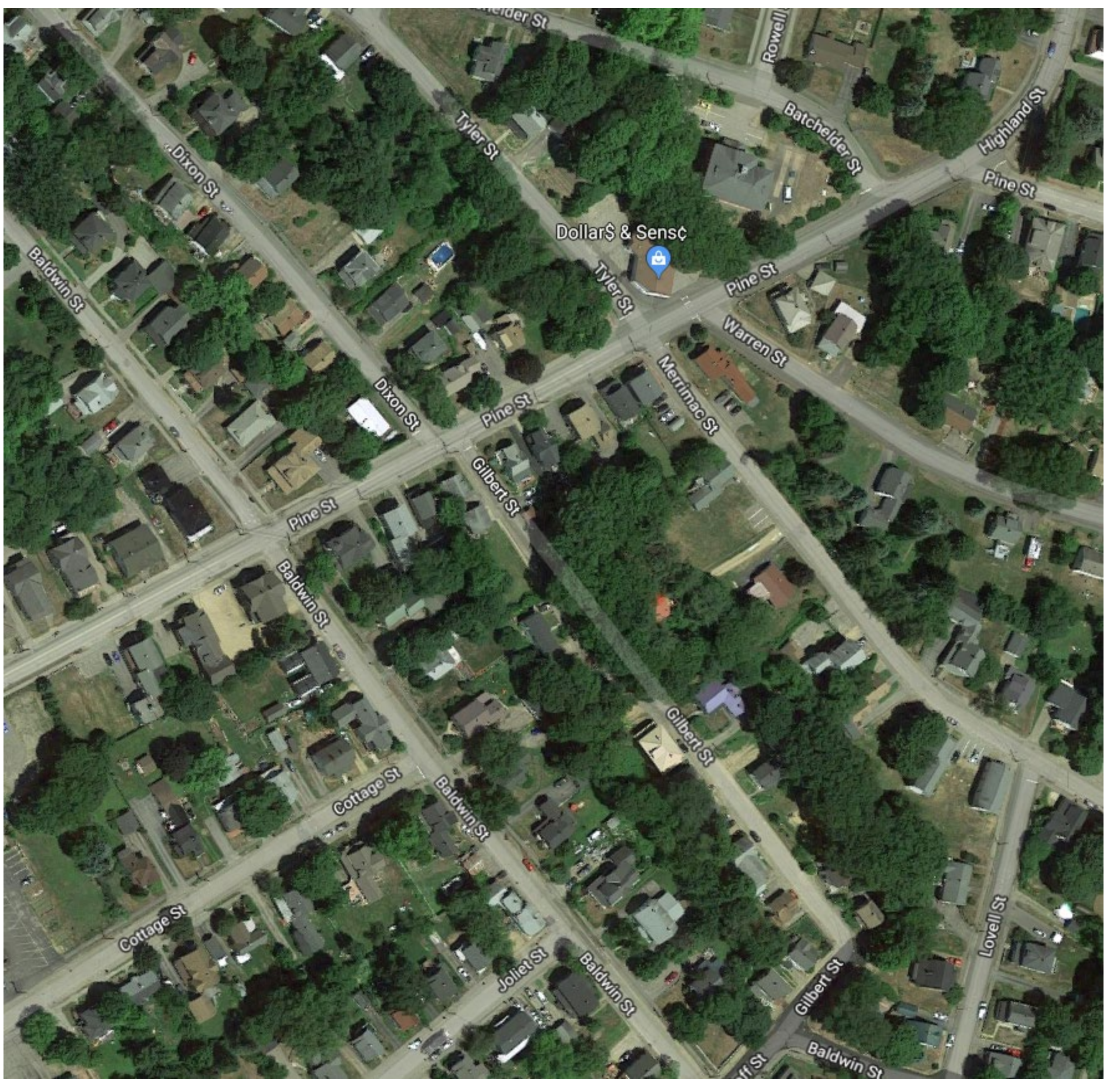
Overall, Claremont displayed a lower than average rate of wood burning and is not expected to experience particularly high concentrations of $PM_{2.5}$ during winter nights.

Laconia

Laconia did not have as high a rate of wood burning indicators, but houses in one central neighborhood, including Baldwin Street, Dixon Street, Gilbert Street and Pine Street (Figure 3.18), were densely spaced and had a high enough rate of wood burning to potentially create neighborhood-wide smoke events. There is a hillside in this area that helps to trap air pollutants, preventing them from dispersing. This neighborhood is located near Wyatt Park where smoke events were recorded, potentially suggesting a connection. Residences near Memorial Park were less densely spaced and showed fewer signs of wood burning.

Overall, Laconia displayed a low rate of wood burning, but because of the density of residential structures and localized clustering of wood burning, portions of the city, such as the neighborhood shown in Figure 3.18 below, may experience nights where $PM_{2.5}$ concentrations reach elevated levels. Other portions of the city may also experience moderately high $PM_{2.5}$ concentrations on some winter nights.

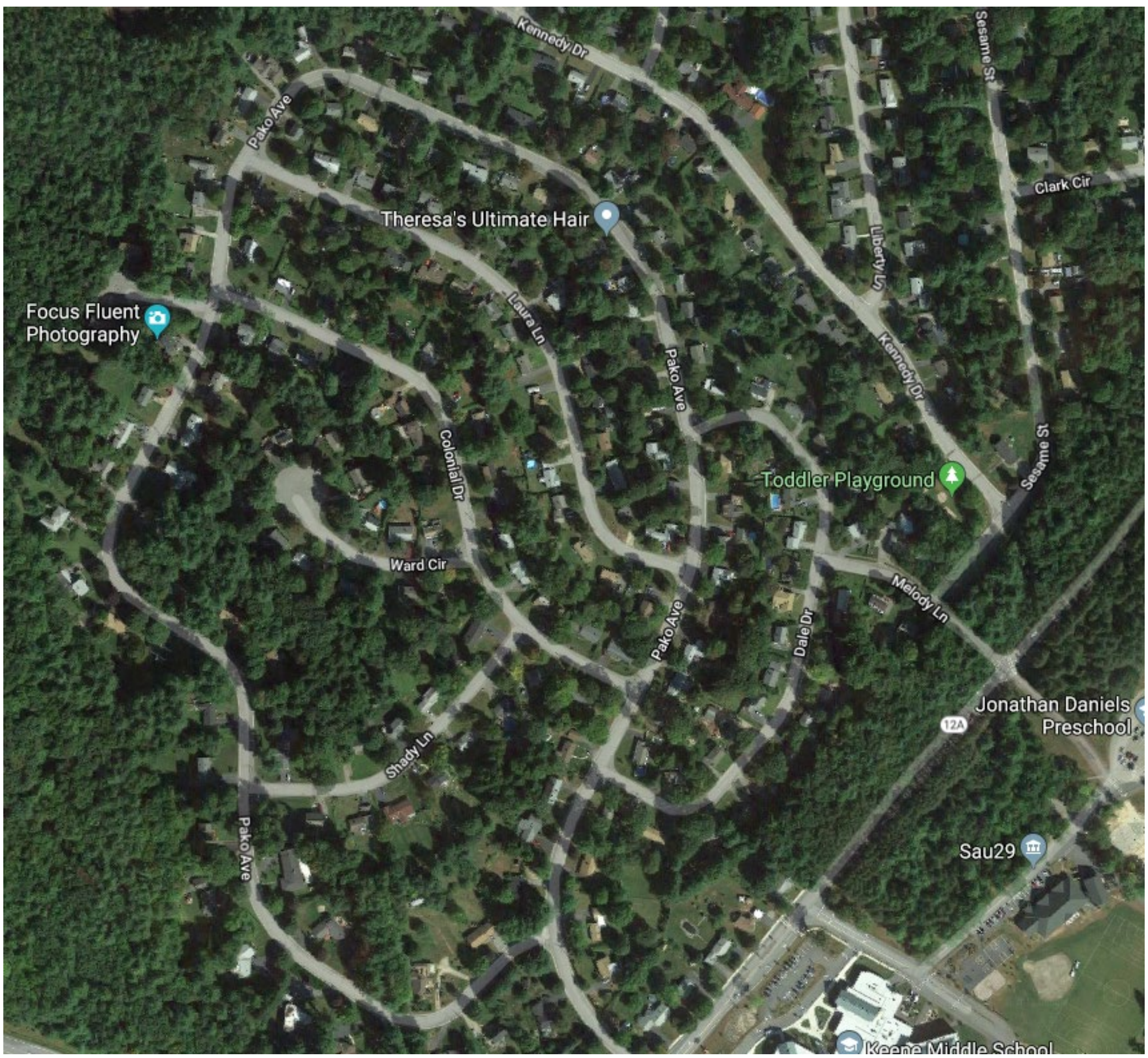
Figure 3.18: Laconia Neighborhood with Many Wood-Burning Indicators



Keene

The City of Keene has been well documented by NHDES as a community prone to thermal inversions due to the valley topography. Wood smoke concentrations can become elevated, resulting in $PM_{2.5}$ levels in the unhealthy for sensitive groups (USG) range during some winter nights (please see page 5 for a brief description of USG). According to this survey, Keene actually has a lower than average wood burning rate, but because of the housing density the amount of wood burned within the city area is appreciable in some areas. For example, one northwestern Keene neighborhood (including Pako Avenue – Figure 3.19) had a high rate of metal chimney caps suggesting wood burning, but since many yards were fenced in, it was difficult to confirm if wood piles were present. While this neighborhood is not near the NHDES $PM_{2.5}$ monitoring station in the central city, this area has shown higher $PM_{2.5}$ concentrations during mobile monitoring studies conducted by Keene State College.

Figure 3.19: Keene Neighborhood with Many Wood-Burning Indicators



4. EXPANDED $PM_{2.5}$ MONITORING

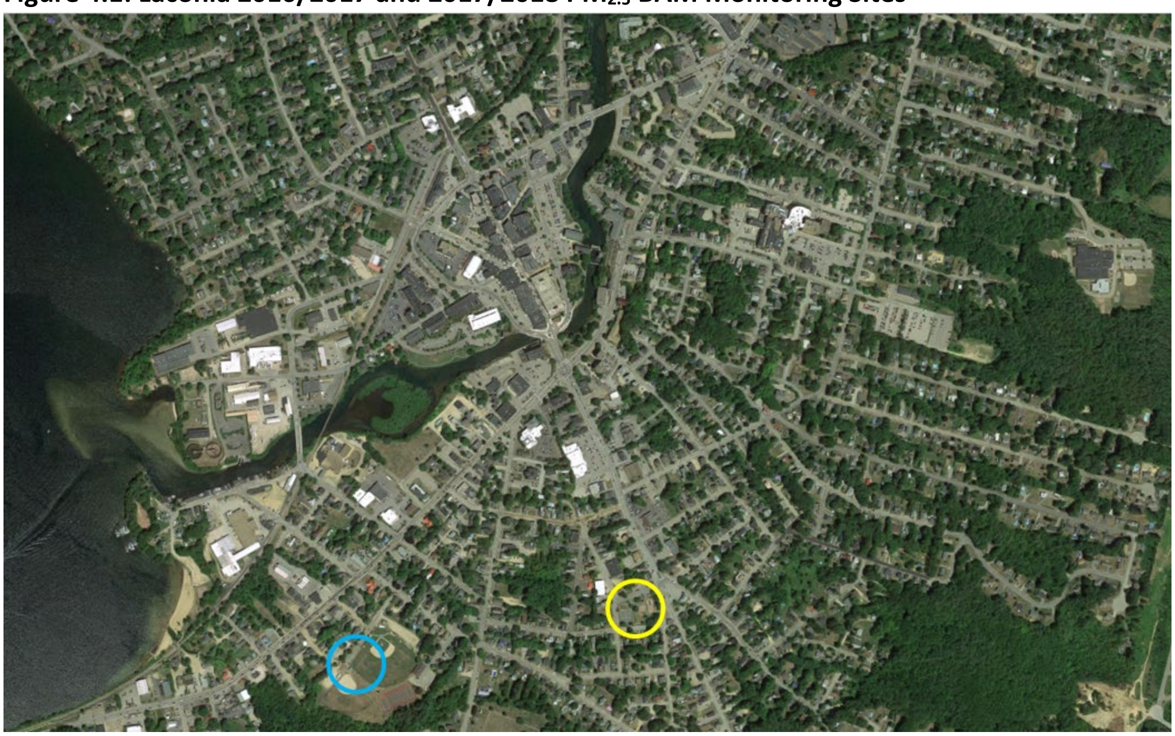
Under an EPA grant, targeted $PM_{2.5}$ monitoring was conducted for the purposes of better understanding potential unhealthy air quality in communities that lack regular monitoring. In this phase, Laconia and Plymouth were identified for temporary $PM_{2.5}$ monitoring in residential areas. The first phase was completed during the winter of 2016-2017 in both communities and then NHDES returned to Laconia, in a different location, during the winter of 2017-2018. During the winter of 2018-2019, mobile monitoring was conducted to look at smaller scale variations within these communities, including examining elevation gradients along hilly residential roads.

4.1 BACKGROUND

Laconia and Plymouth were identified by earlier mobile monitoring, operation of the VIT, and by resident complaints, as being targeted communities for this study. By extrapolation, information learned in this study is extended to other communities throughout the state to update the list of communities of interest.

During the 2016-2017 monitoring, Wyatt Park in Laconia served as the temporary monitoring site (yellow circle in Figure 4.1). It is located in the valley portion of the city and surrounded by residential areas. A new location at Memorial Park (blue circle in Figure 4.1) was used for winter 2017-2018 monitoring. This location was a little more removed from residential areas.

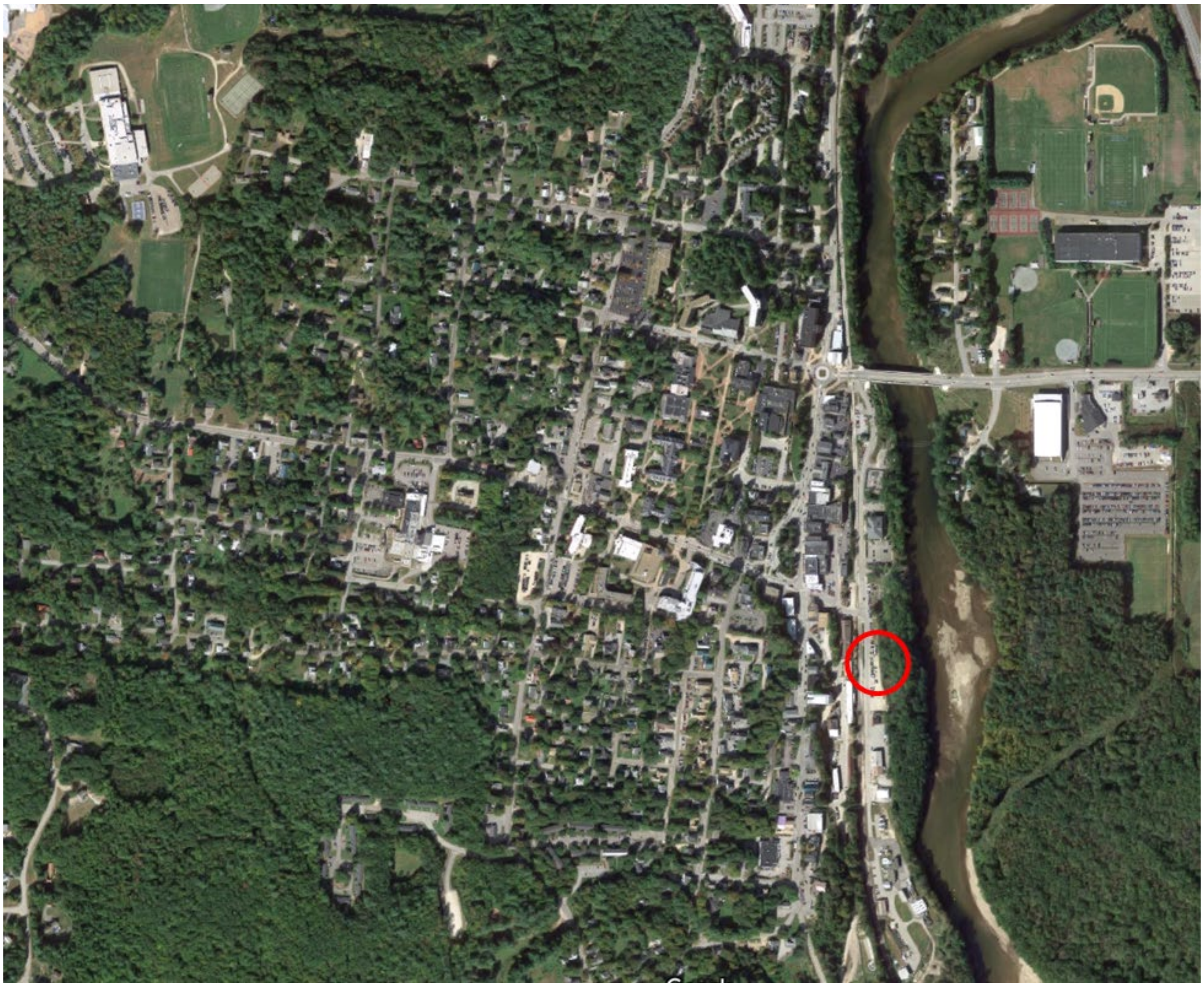
Figure 4.1: Laconia 2016/2017 and 2017/2018 $PM_{2.5}$ BAM Monitoring Sites



The yellow circle marks the site for 2016-2017 monitoring and 2017-2018 is marked by a blue circle. BAM stands for Beta Attenuation Monitor, a specialized piece of equipment for measuring $PM_{2.5}$ in the air.

In Plymouth, a location just east of Green Street was selected for monitoring (red circle in Figure 4.2). The location is near residential areas and the Merrimack River within the Plymouth valley. This station was only active during the winter of 2016-2017.

Figure 4.2: Plymouth 2016/2017 $PM_{2.5}$ BAM Monitoring Site



4.2 LACONIA

4.2.1 WINTER 2016-17 $PM_{2.5}$ MONITORING

The 2016-2017 Laconia Wyatt Park temporary monitoring station was equipped with a Met One Instruments BAM 1020, an hourly $PM_{2.5}$ monitoring device, a meteorology station recording temperature, wind speed and wind direction, and a data logging device. This equipment was housed in a specialized trailer with climate control, electrical services, and an internet connection for real-time reporting. All monitoring at this station was conducted according to EPA specifications and quality control. Data was collected at this location from October 19, 2016 to April 18, 2017. The Laconia 2016-2017 monitoring station and the $PM_{2.5}$ monitoring device are shown in Figure 4.3.

Figure 4.3: Laconia (Wyatt) 2016/2017 BAM Monitoring Trailer and Equipment

Source: NHDES

The Laconia 2016-2017 $PM_{2.5}$ measurement program recorded a 1-hour maximum concentration of 44.1 µg/m^3 and a 24-hour average concentration of 21.9 µg/m^3 (Table 4.1). The federal National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ is 35 µg/m^3 averaged over 24-hours measured from midnight to midnight. All measured midnight to midnight $PM_{2.5}$ concentrations were well below the NAAQS, however there were short periods when instantaneous levels were above the 35 µg/m^3 threshold. Since this occurred at least seven times during the winter season, Laconia will remain as a Community of Interest.

As mentioned above, the NAAQS is measured midnight to midnight, which is a result of health studies that depended on sample filter collections that collected data only from midnight to midnight. NHDES calculates a rolling 24-hour daily maximum $PM_{2.5}$ concentration in addition to the midnight to midnight form. These values tend to be a little higher than the midnight to midnight average concentrations, but these too were below the 35 µg/m^3 threshold. The maximum rolling 24-hour maximum concentration was 23.5 µg/m^3 on January 9, 2017.

Table 4.1: Laconia (Wyatt) 2016/2017 Monitoring Four Highest $PM_{2.5}$ Concentrations

	24-Hour Midnight to Midnight		24-Hour Rolling		1-Hour Peak	
	Conc. (µg/m^3)	Date	Conc. (µg/m^3)	Date	Conc. (µg/m^3)	Date
1st Maximum	21.9	1/10/2017	23.5	1/9/2017	44.1	4/11/2017
2nd Maximum	21.1	12/17/2016	23.1	12/16/2016	41.0	2/25/2017
3rd Maximum	20.1	12/20/2016	21.9	1/10/2017	38.8	12/11/2016
4th Maximum	18.6	1/2/2017	21.1	12/17/2017	38.8	4/14/2017

Figure 4.4 presents hourly $PM_{2.5}$ concentrations for the Laconia 2016-2017 monitoring at Wyatt Park. There is considerable concentration variability, which is normal for monitoring, but there were several periods where hourly levels exceeded 35 µg/m^3 in concentration as discussed earlier.

Figure 4.4: Laconia (Wyatt) 2016/2017 Hourly $PM_{2.5}$ Monitoring Concentrations

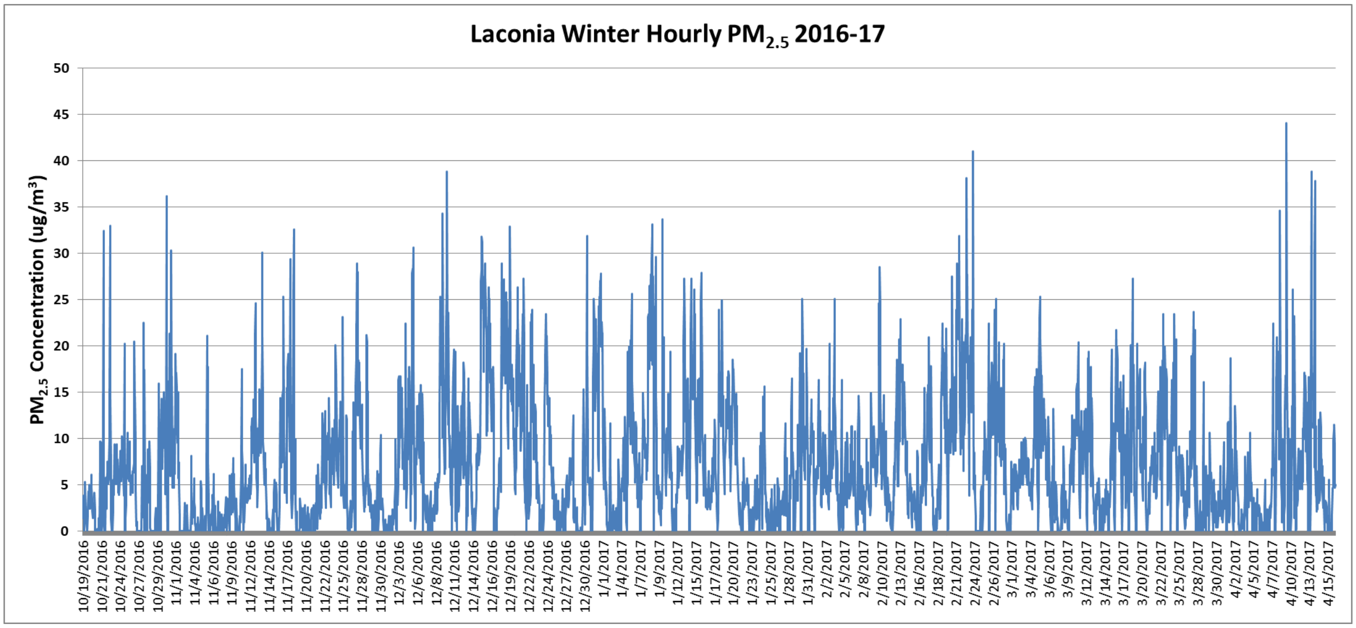
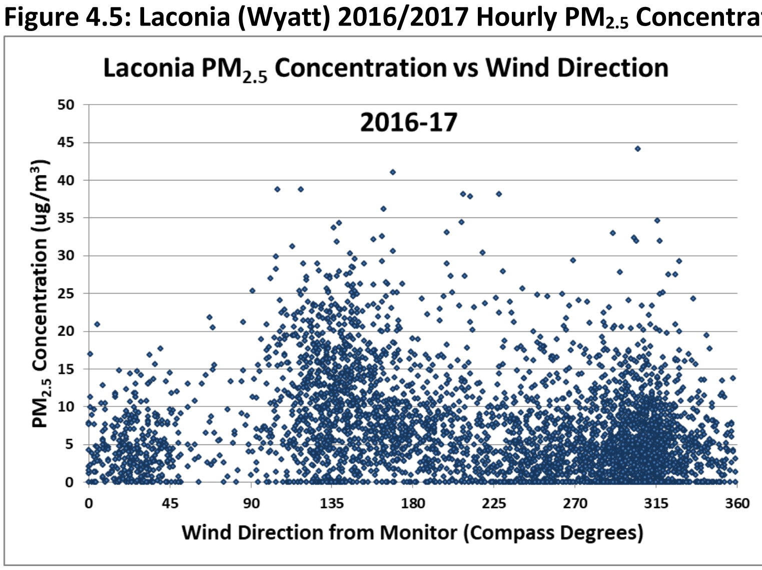


Figure 4.5 presents hourly $PM_{2.5}$ concentrations as a function of the wind direction at the time it was measured. A minimum wind speed of 0.5 meters per second was allowed in order to provide for a meaningful wind direction for each measurement. This analysis helps to identify the direction of dominating emission sources. Note that hourly data points with calm winds were removed from Figures 4.5 and 4.6.

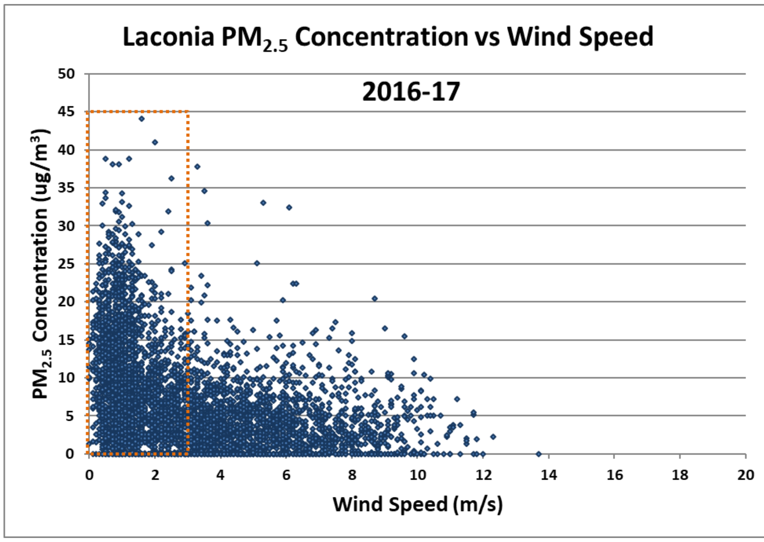
Figure 4.5: Laconia (Wyatt) 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Direction



Wind directions at the monitoring station frequently came from the northwest and rarely came from the east during the monitoring period. Highest $PM_{2.5}$ concentrations did not appear specific to any wind directions except that the upwind directions of north through east (0 to 90 degrees) were relatively clean. There were modestly higher concentrations approaching the monitoring station from the southeast (110 to 160 degrees).

Figure 4.6 presents hourly $PM_{2.5}$ concentrations as a function of the wind speed at the time it was measured. This analysis helps to identify the likelihood that locally produced emission sources might be the cause of elevated $PM_{2.5}$ concentrations in the area.

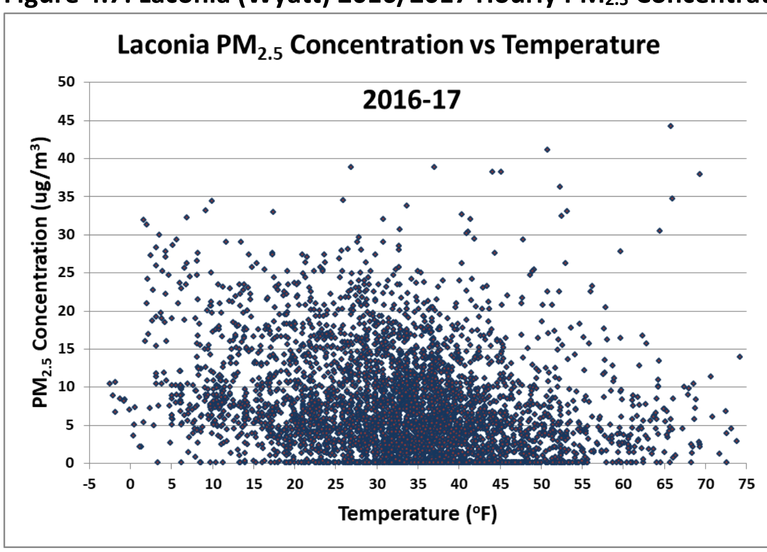
Figure 4.6: Laconia (Wyatt) 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Speed



Wind speeds measured at the monitoring station mostly stayed below 10 meters per second (or about 22 miles per hour). Focusing on the area highlighted by the red box, most of the higher $PM_{2.5}$ concentrations at this location occur when winds are below 3 meters per second (under 7 MPH). This indicates that there is stagnation of locally produced $PM_{2.5}$ in the area, most likely from residential wood burning.

Hourly $PM_{2.5}$ concentrations were also examined as a function of the ambient temperature (Figure 4.7) corresponding to when it was measured. This analysis helps to identify if high $PM_{2.5}$ concentrations are due to the need for residential heating (i.e., cold enough to need heating).

Figure 4.7: Laconia (Wyatt) 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Temperature



Most $PM_{2.5}$ measurements were collected with the temperature between 10 and 55 degrees Fahrenheit, which is to be expected for the season data was collected and when residential heating is needed. Peak concentrations did not appear for any specific temperature ranges, thus it appears that temperatures just need to be cool enough to need residential heating. The cause of the 4 points of more than 30 $\mu g/m^3$ collected with temperatures above 60F is unknown.

4.2.2 WINTER 2017-18 $PM_{2.5}$ MONITORING

The 2017-2018 Laconia Memorial Park temporary monitoring station was equipped with a Met One Instruments BAM 1020, an hourly $PM_{2.5}$ monitoring device, a meteorology station recording temperature, wind speed and wind direction, and a data logging device. This equipment was housed in a specialized trailer with climate control, electrical services and an internet connection for real-time reporting. All monitoring at this station is conducted according to EPA specifications and quality control. Data was collected at this location from November 20, 2017 to April 9, 2018. The Laconia 2017-2018 monitoring station and $PM_{2.5}$ monitoring device are shown in Figure 4.8.

Figure 4.8: Laconia (Memorial) 2017/2018 BAM Monitoring Trailer and Equipment

Source: NHDES

The Laconia 2017-2018 $PM_{2.5}$ measurement program recorded a 1-hour maximum concentration of 36.2 μg/m^3 and a maximum 24-hour average concentration of 17.7 μg/m^3 (Table 4.2). The NAAQS is 35 μg/m^3 averaged over 24-hours measured from midnight to midnight. All measured midnight to midnight $PM_{2.5}$ concentrations were well below the NAAQS, however there was one short period with instantaneous levels above the 35 μg/m^3 threshold on November 24, 2017. The rolling maximum 24-hour concentration was 22.9 μg/m^3 on February 10, 2018.

Table 4.2: Laconia (Memorial) 2017/2018 Monitoring Four Highest $PM_{2.5}$ Concentrations

	24-Hour Midnight to Midnight		24-Hour Rolling		1-Hour Peak	
	Conc. (μg/m^3)	Date	Conc. (μg/m^3)	Date	Conc. (μg/m^3)	Date
1st Maximum	17.7	2/10/2018	22.9	2/10/2018	36.2	11/24/2017
2nd Maximum	14.3	1/27/2018	17.0	2/9/2018	32.0	2/11/2018
3rd Maximum	14.0	1/3/2018	16.6	1/3/2018	30.0	1/27/2018
4th Maximum	12.8	2/9/2018	14.3	1/27/2018	30.0	2/11/2018

Figure 4.9 presents hourly $PM_{2.5}$ concentrations for the Laconia 2017-2018 monitoring at Memorial Park. As with monitoring for the previous year, there is considerable concentration variability, however there were fewer sampling periods during the winter of 2017 to 2018 at Memorial Park where hourly levels exceeded 35 μg/m^3 in concentration (1 versus 7).

Figure 4.9: Laconia (Memorial) 2017/2018 Hourly $PM_{2.5}$ Monitoring Concentrations

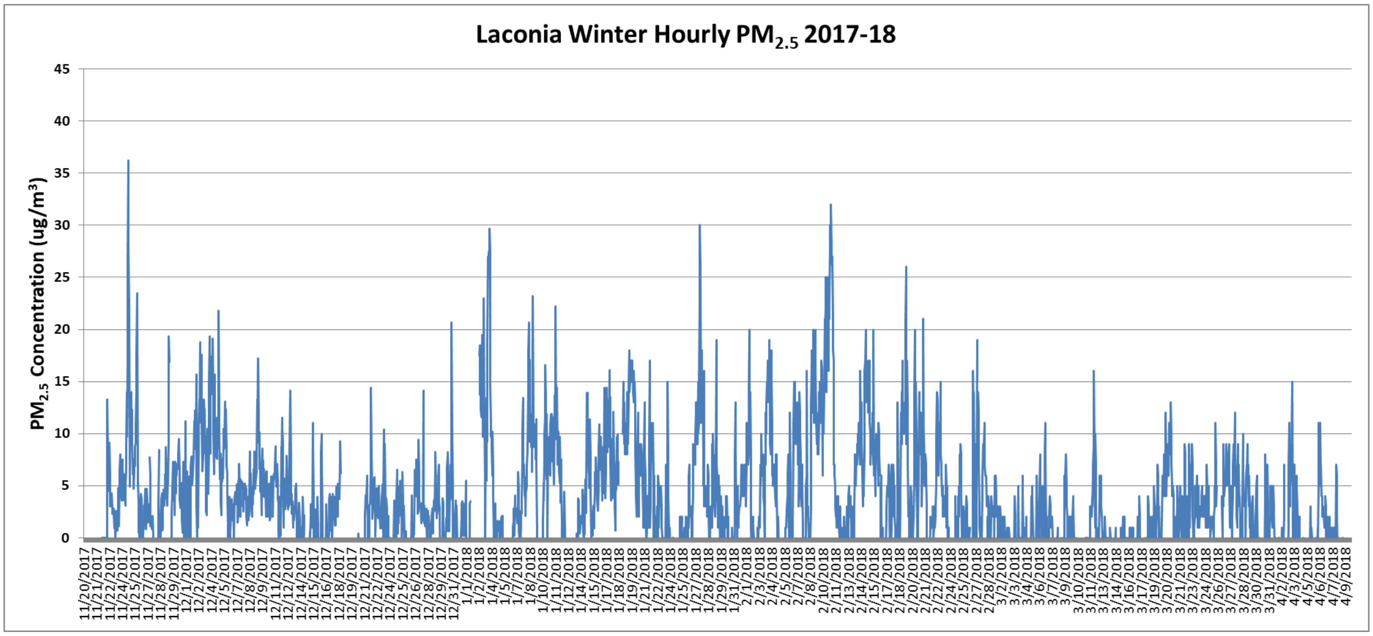
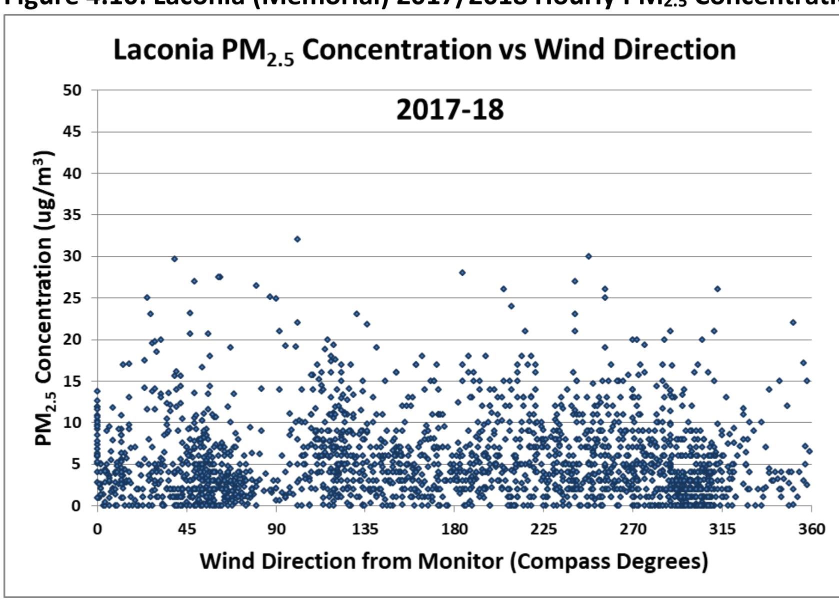


Figure 4.10 presents hourly $PM_{2.5}$ concentrations as a function of the wind direction at the time it was measured. This analysis helps to identify the direction of dominating emission sources. $PM_{2.5}$ monitoring at Memorial Park not only produced lower concentrations than Wyatt Park, but swirling winds in the area made it difficult to pinpoint emission source directions. The data does not clearly show higher concentrations favoring any particular wind directions. Note that hourly data points with calm winds were removed from Figures 4.10 and 4.11.

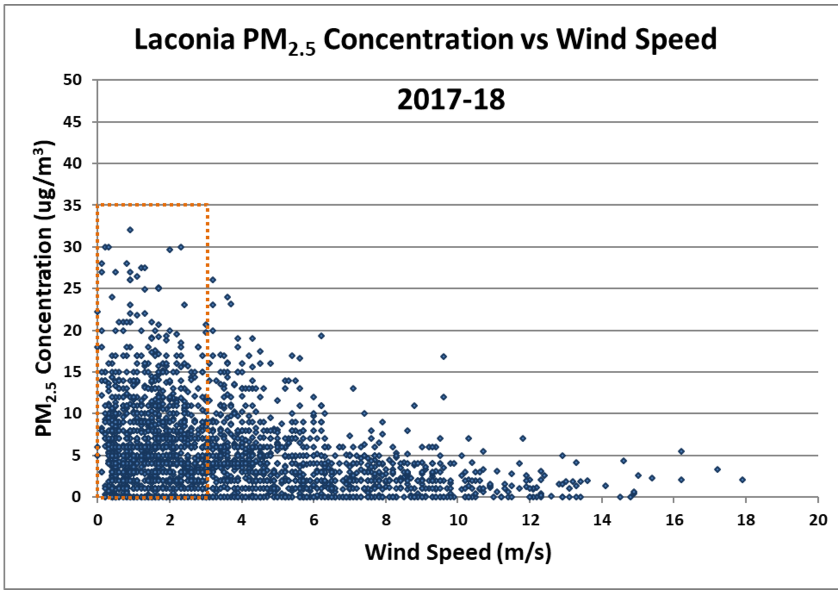
Figure 4.10: Laconia (Memorial) 2017/2018 Hourly $PM_{2.5}$ Concentrations vs. Wind Direction



Wind directions at the monitoring station were highly variable, but there was some increased frequency coming from the northeast (20 to 70 degrees) and northwest (290 to 340 degrees). Highest $PM_{2.5}$ concentrations did not appear specific to any wind directions.

Figure 4.11 presents hourly $PM_{2.5}$ concentrations as a function of the wind speed at the time it was measured. This analysis helps to identify the likelihood that locally produced emission sources might be the cause of elevated $PM_{2.5}$ concentrations in the area. Monitoring at Memorial Park shows a small tendency for higher concentrations under calm to light winds (red box in Figure 4.11). This suggests that at least some emission sources are in the vicinity.

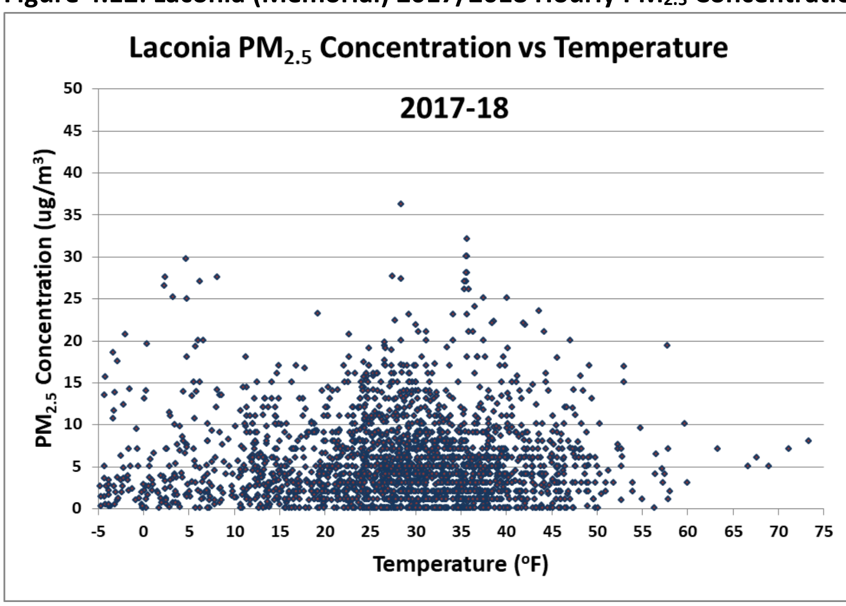
Figure 4.11: Laconia (Memorial) 2017/2018 Hourly $PM_{2.5}$ Concentrations vs. Wind Speed



Wind speeds measured at the monitoring station mostly stayed below 10 meters per second (or about 22 miles per hour). Focusing on the area highlighted by the red box, there is a tendency for higher $PM_{2.5}$ concentrations to occur when winds are below 3 meters per second (under 7 MPH). This indicates that there is stagnation of locally produced $PM_{2.5}$ in the vicinity most likely from residential wood burning.

Hourly $PM_{2.5}$ concentrations were also examined as a function of the ambient temperature (Figure 4.12) corresponding to when it was measured. This analysis helps to identify if high $PM_{2.5}$ concentrations are due to the need for residential heating (i.e., cold enough to need heating). The data clearly show a tendency for higher $PM_{2.5}$ concentrations at Memorial Park during temperatures cold enough to warrant residential heating.

Figure 4.12: Laconia (Memorial) 2017/2018 Hourly $PM_{2.5}$ Concentrations vs. Temperature



In this location there was a clearer signal for cooler air being connected to higher concentrations. Hourly $PM_{2.5}$ concentrations above 25 μg/m^3 were only recorded at temperatures below 40 degrees Fahrenheit, linking them to periods favoring residential heating.

Monitoring at Memorial park in 2017-2018 indicates that the area experiences lower $PM_{2.5}$ concentrations than seen at Wyatt Park in 2016-2017. Because the weather conditions were not significantly different over the two different winters, it is likely that Wyatt Park is closer to high emitting wood burning units than Memorial Park.

4.3 PLYMOUTH

4.3.1 WINTER 2016-17 $PM_{2.5}$ MONITORING

The 2016-2017 Green Street temporary monitoring station was equipped with similar equipment as the temporary Laconia stations included in this study (Wyatt and Memorial Parks). Data was collected at this location from November 2, 2016 to March 31, 2017. The Plymouth 2016-2017 monitoring station and $PM_{2.5}$ monitoring device are shown in Figure 4.13.

Figure 4.13: Plymouth 2016/2017 BAM Monitoring Images

Source: NHDES

The Plymouth 2017-2018 $PM_{2.5}$ monitoring program recorded a 1-hour maximum concentration of 136.1 µg/m^3 and a maximum 24-hour average concentration of 16.5 µg/m^3 (Table 4.3). The rolling maximum 24-hour concentration was 17.0 µg/m^3 on February 10, 2018. All measured midnight to midnight $PM_{2.5}$ concentrations were well below the health standard, however there were short periods of very high hourly $PM_{2.5}$ concentrations which are considered to be outlier points. Outlier points can be caused by a local source of sample contamination such as an idling truck or a nearby (non-residential heating) fire. NHDES does not consider these outliers to be representative of the community and present two sets of data, with and with the outliers.

Table 4.3: Plymouth 2016/2017 Monitoring Four Highest $PM_{2.5}$ Concentrations (w/Outlier)

	24-Hour Midnight to Midnight		24-Hour Rolling		1-Hour Peak	
	Conc. (µg/m³)	Date	Conc. (µg/m³)	Date	Conc. (µg/m³)	Date
1st Maximum	16.5	1/7/2017	17.0	2/18/2017	136.1	11/26/2016
2nd Maximum	14.8	1/10/2017	16.9	1/6/2017	73.8	11/29/2016
3rd Maximum	14.5	12/21/2016	16.5	1/7/2017	71.5	11/29/2016
4th Maximum	13.8	12/20/2016	15.4	11/25/2016	60.1	1/7/2017

Plymouth 2017-2018 $PM_{2.5}$ data with outliers removed are presented in Table 4.4. The maximum recorded 1-hour concentration is 37.1 µg/m³ and the maximum midnight to midnight 24-hour average concentration is 14.8 µg/m³. The rolling maximum 24-hour concentration was 17.0 µg/m³ on February 10, 2018. All measured midnight to midnight $PM_{2.5}$ concentrations were well below the NAAQS, however, there was one short period with hourly levels that exceeded 35 µg/m³.

Table 4.4: Plymouth 2016/2017 Monitoring Four Highest $PM_{2.5}$ Concentrations (w/o Outlier)

	24-Hour Midnight to Midnight		24-Hour Rolling		1-Hour Peak	
	Conc. (µg/m³)	Date	Conc. (µg/m³)	Date	Conc. (µg/m³)	Date
1st Maximum	14.8	1/10/2017	17.0	2/18/2017	37.1	2/18/2017
2nd Maximum	14.5	12/21/2016	14.8	1/10/2017	34.7	2/18/2017
3rd Maximum	13.8	12/20/2016	14.7	12/20/2016	27.3	12/20/2016
4th Maximum	13.8	2/23/2017	14.7	1/9/2017	26.3	3/13/2017

Figures 4.14 and 4.15 present hourly $PM_{2.5}$ concentrations with and without data outliers. Data outliers in Figure 4.14 are quite apparent with two occurring during November 2016 and one in January 2017. These outliers occur suddenly and under conditions that typically don't correspond to local stagnation, so they probably did not occur due to residential heating. Given the magnitude of the outliers, it is difficult to assess $PM_{2.5}$ concentrations during the remainder of the monitoring period with Figure 4.14.

With the outliers removed, a more typical hourly concentration pattern emerges in Figure 4.15 with only one period with an hourly concentration exceeding 30 µg/m³. The bulk of hourly concentrations were below 15 µg/m³ and only eight periods exceeded 25 µg/m³. Monitoring at this location in Plymouth represents a typical community pattern with some effect.

Figure 4.14: Plymouth 2016/2017 Hourly $PM_{2.5}$ Monitoring Concentrations (with Outlier)

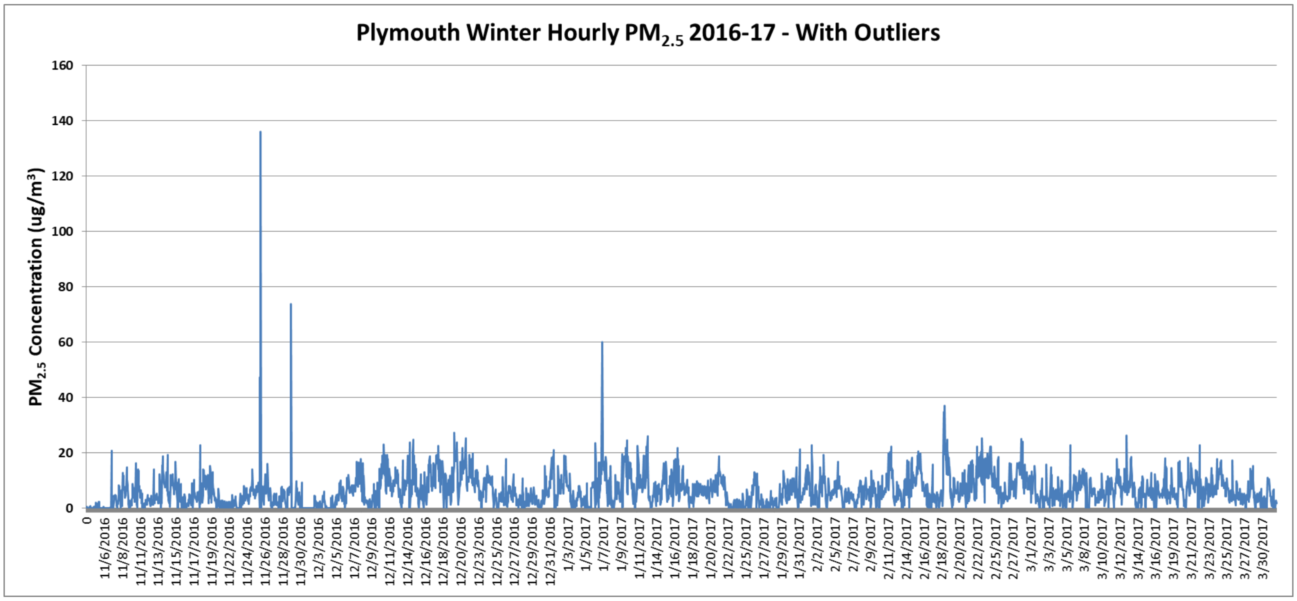
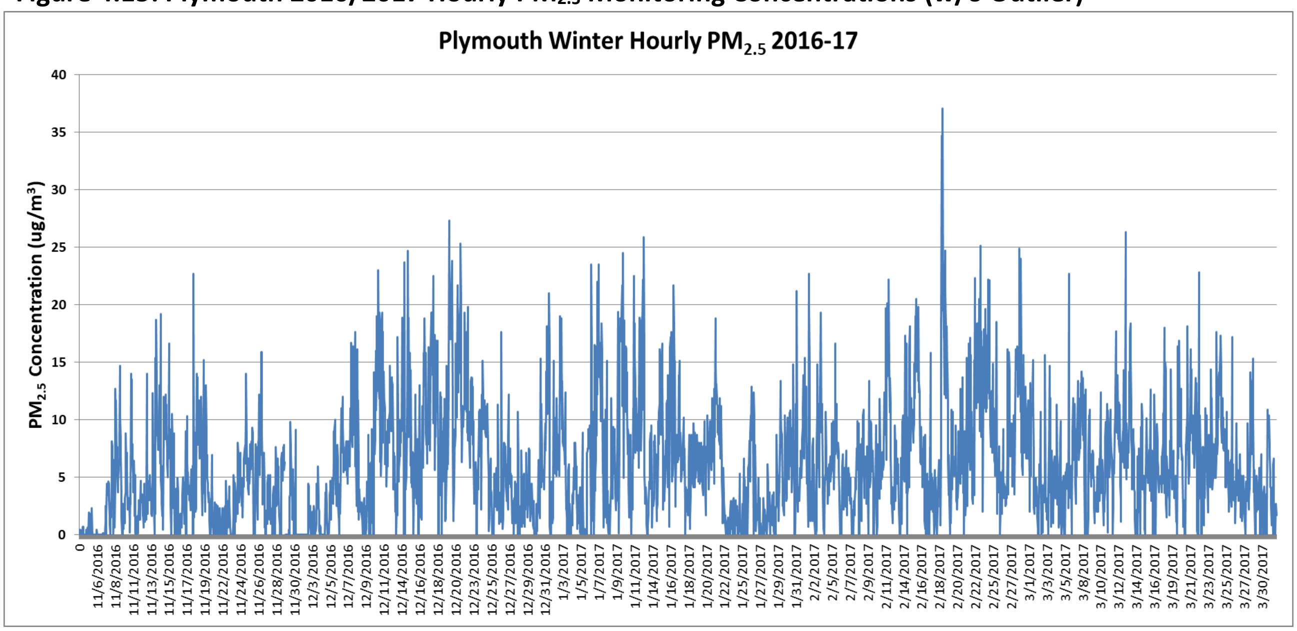


Figure 4.15: Plymouth 2016/2017 Hourly $PM_{2.5}$ Monitoring Concentrations (w/o Outlier)



Correlation of wind direction with corresponding $PM_{2.5}$ concentrations are presented in Figures 4.16 (with outliers) and 4.17 (without outliers). This analysis helps to identify the direction of dominating emission sources. Note that hourly data points with calm winds were removed from Figures 4.19 through 4.20.

Figure 4.16: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Direction (with Outlier)

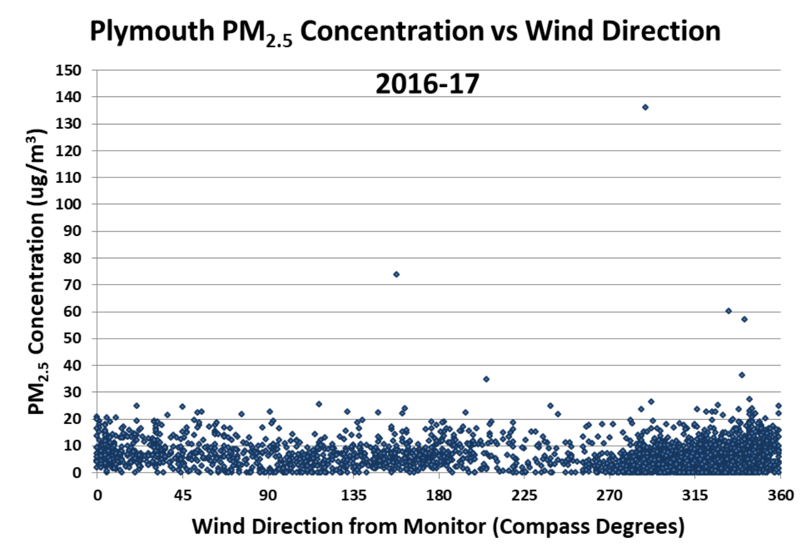


Figure 4.16 shows the outliers occurred with winds coming from various directions including the north, northwest and south. Otherwise there appears to be little connection between wind direction and $PM_{2.5}$ concentrations. The source for the outlier points could have come from any direction, considering that they occurred under very light winds (see Figure 4.18) which reduces the reliability of the measured wind direction.

Figure 4.17 shows a bunching of concentrations with a wind direction from the northwest, most likely due to the alignment of the street and nearby river. Concentrations of up to 25 µg/m^3 are common with any wind direction, but the highest hourly concentrations occur with wind directions from the north and from the south. Plymouth residential areas are located mostly to the west of the monitoring station.

Figure 4.17: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Direction (without Outlier)

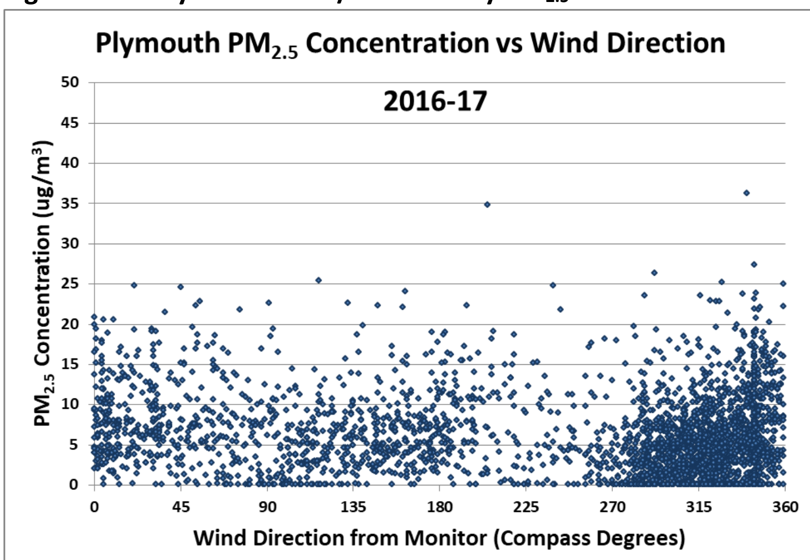


Figure 4.17 removes the outliers from Figure 4.16 and reveals a clustering for concentrations when winds came from the north and northwest, while the wind appears to have come from the southwest considerably less often during the sampling period. $PM_{2.5}$ concentrations of greater than 20 µg/m^3 occurred without much connection to wind direction.

Correlation of wind speed with corresponding $PM_{2.5}$ concentrations are presented in Figures 4.18 (with outliers) and 4.19 (without outliers). This analysis helps to identify the likelihood that locally produced emission sources might be the cause of elevated $PM_{2.5}$ concentrations in the area. In general, there appears to be some degree of stagnation of locally emitted smoke in the Plymouth area, but not as much as seen in Keene and Laconia.

Figure 4.18: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Speed (with Outlier)

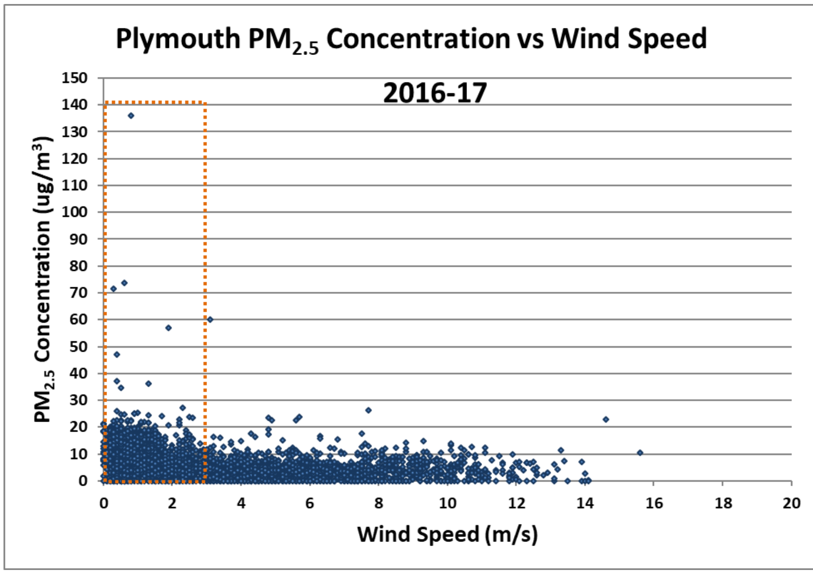


Figure 4.18 shows that the top three outliers occurred during very light winds, which render the directions identified in Figure 4.16 to be of little value. The next two highest outlier points occurred with winds between 2 and 4 meters per second. The pattern for the remainder of the data points demonstrate a small tendency for highest concentrations to occur with calm to very light winds, suggesting some degree of local stagnation.

Figure 4.19 replicates Figure 4.18, but removes the outlier data so that the pattern for the remaining data can be seen better.

Figure 4.19: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Wind Speed (w/o Outlier)

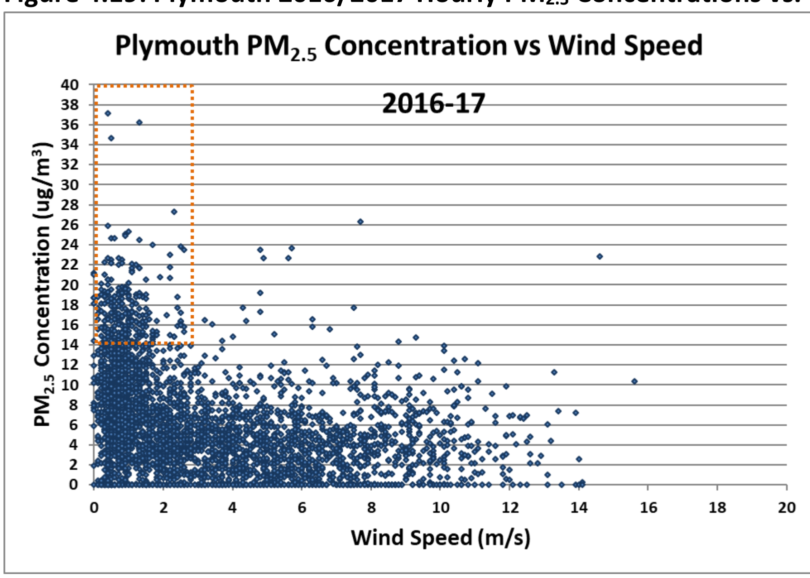
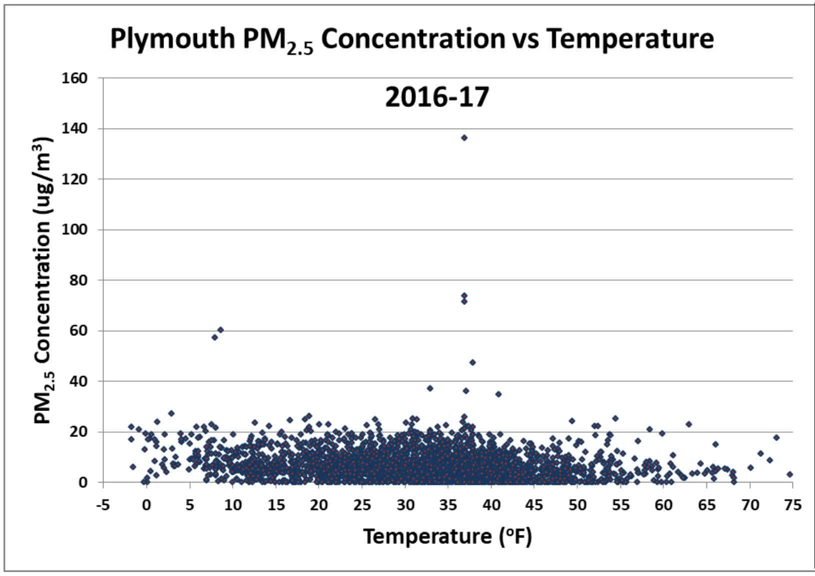


Figure 4.19 removes the outlier points from Figure 4.18 to enhance any remaining patterns. As mentioned above, there is some tendency for higher concentrations (greater than 10 $\mu g/m^3$ in this case) to occur under light wind speeds. The wind speed to concentration patterns suggest some degree of local stagnation, but less so than seen in other communities such as Keene and Laconia.

Figures 4.20 and 4.21 present $PM_{2.5}$ concentrations as a function of temperature, with and without outlier points. This analysis helps to identify if high $PM_{2.5}$ concentrations are due to the need for residential heating (i.e., cold enough to need heating). Outliers occurred during temperatures of 8°F and 38°F which suggests that it could be a single nearby residential heating device, but given the location, an idling vehicle is more likely.

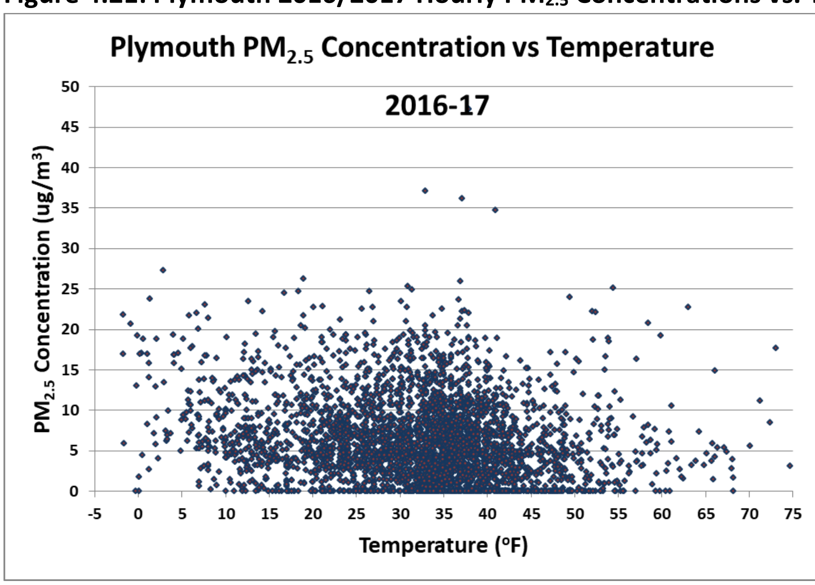
Figure 4.20: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Temperature (with Outlier)



Outliers occurred during temperatures of 8°F and 38°F which suggests that it could be a single nearby residential heating device, but given the location, an idling vehicle is more likely.

Figure 4.21 presents the data with outliers removed and there is no clear pattern suggesting the residential heating devices are strongly connected with $PM_{2.5}$ concentrations measured at this location. Higher concentrations are relatively evenly distributed across the temperature range, with the exception of a small reduction of concentrations with higher temperatures. The data for Plymouth strongly suggest a connection between local residential wood burning and $PM_{2.5}$ concentrations in the community, but stagnation patterns were not strong enough to cause risk of developing unhealthy conditions for sensitive populations in the Plymouth area.

Figure 4.21: Plymouth 2016/2017 Hourly $PM_{2.5}$ Concentrations vs. Temperature (w/o Outlier)



Highest $PM_{2.5}$ concentrations did not occur favoring any specific temperatures other than showing some degree of tailing off at temperatures higher than 55 degrees Fahrenheit. This suggests a connection between residential wood combustion and $PM_{2.5}$ concentrations. Even the higher temperatures reported occurred on days when night temperatures were cold enough to require residential heating.

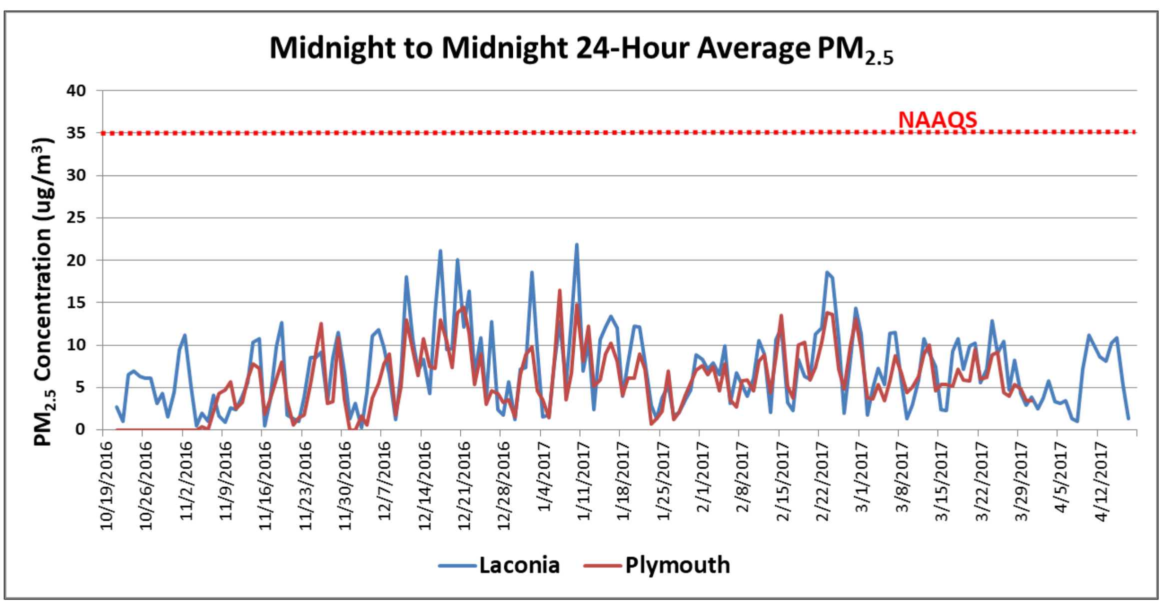
4.4 MONITORING RESULTS DISCUSSION

In order to provide a direct comparison of hourly $PM_{2.5}$ measurements to the NAAQS, the data needs to be tabulated into daily 24-hour and annual averages. The annual NAAQS considers the three-year average of annual $PM_{2.5}$ averages. Since $PM_{2.5}$ data for Laconia and Plymouth were not collected for a full three-year period, a direct comparison to the NAAQS cannot be made, but shorter term exceedances and USG and Moderate $PM_{2.5}$ days can be identified (USG, as described earlier, and Moderate are categories of EPA's Air Quality Index).

$PM_{2.5}$ data collected in Laconia and Plymouth were calculated into 24-hour averages, from midnight to midnight, and into maximum rolling 24-hour averages. As previously mentioned, the rolling 24-hour average tends to be slightly higher than the midnight to midnight calculation because the start and end time is not limited and the highest 24-hour consecutive period is captured, even if it rolls over midnight, which is common for wood smoke.

Figure 4.22 presents daily 24-hour $PM_{2.5}$ averages for Laconia (Wyatt) and Plymouth, measured from midnight to midnight. The red dotted line represents the level of the NAAQS and if a 24-hour $PM_{2.5}$ concentration rises above the line, it would be considered a $PM_{2.5}$ exceedance or unhealthy day for sensitive people (as described earlier in this report, please note that isolated exceedances don't necessarily constitute a formal violation of the federal NAAQS). During the period of October 20, 2016 to April 18, 2017, there were no $PM_{2.5}$ exceedances at either location. The maximum $PM_{2.5}$ concentrations were 21.9 µg/m^3 at Laconia and 16.5 µg/m^3 at Plymouth. The values are well below the $PM_{2.5}$ NAAQS threshold of 35 µg/m^3. No comparison of the two communities for the winter of 2017-2018 is possible because $PM_{2.5}$ was not measured in Plymouth during this period.

Figure 4.22: 2016-2017 24-Hour $PM_{2.5}$ Concentrations for Laconia (Wyatt) and Plymouth (Midnight to Midnight)



The 24-hour $PM_{2.5}$ NAAQS is in the form of the three-year average of the 98th percentile of the daily 24-hour averages, measured from midnight to midnight. DES also considers data collected over any continuous 24-hour period for health advisories and data analysis to enhance public protection.

Figure 4.23 presents daily maximum rolling 24-hour $PM_{2.5}$ averages for Laconia and Plymouth. The red dotted line represents the level of the NAAQS and if a 24-hour $PM_{2.5}$ concentration rises above the line, it would be considered a $PM_{2.5}$ exceedance or unhealthy day for sensitive people. During the period of October 20, 2016 to April 18, 2017, there were no rolling 24-hour $PM_{2.5}$ exceedances at either location. The maximum $PM_{2.5}$ concentrations were 23.5 µg/m^3 at Laconia (Wyatt) and 17.0 µg/m^3 at Plymouth. The values are well below the NAAQS threshold of 35 µg/m^3.

Figure 4.23: 2016-2017 24-Hour $PM_{2.5}$ Concentrations for Laconia (Wyatt) and Plymouth (Rolling 24-Hour)

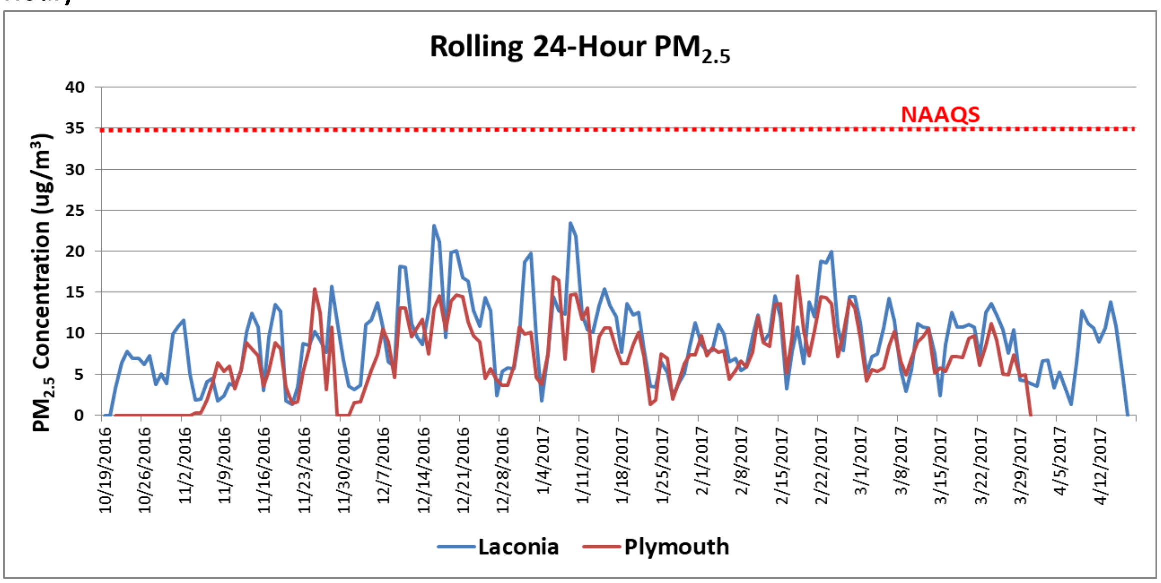


Figure 4.24 compares the differences between daily 24-hour $PM_{2.5}$ averages for Laconia, measured from midnight to midnight, and the daily maximum rolling 24-hour $PM_{2.5}$ average concentration. During the period of October 20, 2016 to April 18, 2017, the daily maximum rolling 24-hour $PM_{2.5}$ concentrations were almost always higher than the daily 24-hour average $PM_{2.5}$ measured from midnight to midnight. The average difference was 2.3 µg/m^3.

Figure 4.24: Comparison of Midnight to Midnight 24-Hour to Rolling 24-hour $PM_{2.5}$ Concentrations for Laconia (Wyatt) (2016/2017)

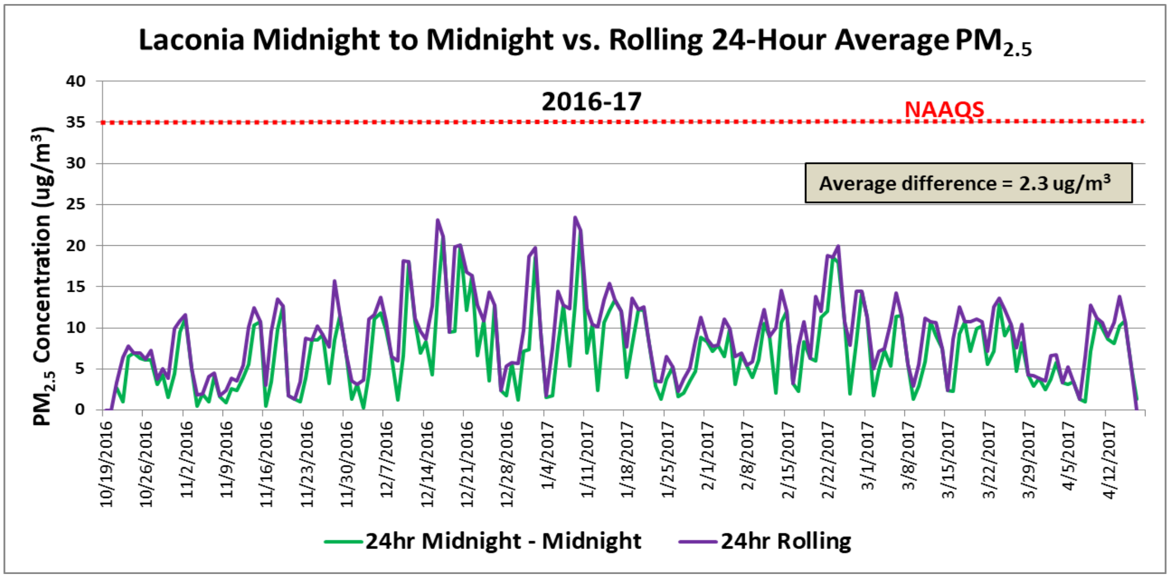


Figure 4.25 is similar to Figure 4.20 except it shows data from November 22, 2017 to April 9, 2018 at Laconia (Memorial), and again the daily maximum rolling 24-hour $PM_{2.5}$ concentrations were almost always higher than the daily 24-hour average measured $PM_{2.5}$ from midnight to midnight. The average difference was 2.0 µg/m^3.

Figure 4.25: Comparison of Midnight to Midnight 24-Hour to Rolling 24-hour $PM_{2.5}$ Concentrations for Laconia (Memorial)(2017/2018)

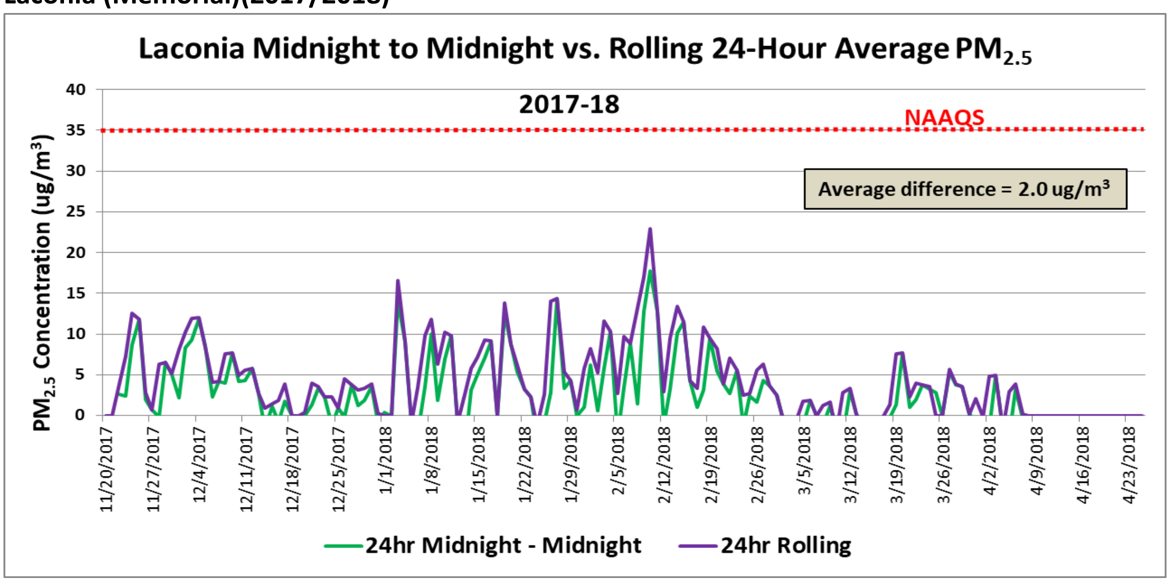


Figure 4.26 compares the differences between daily 24-hour $PM_{2.5}$ averages for Plymouth, measured from midnight to midnight, and the daily maximum rolling 24-hour $PM_{2.5}$ average concentration. During the period of November 4, 2016 to March 31, 2017, the daily maximum rolling 24-hour concentration was almost always higher than the daily 24-hour average measured from midnight to midnight. The average difference was 1.7 µg/m^3.

Figure 4.26: Comparison of Midnight to Midnight 24-Hour to Rolling 24-hour $PM_{2.5}$ Concentrations for Plymouth (2016/2017)

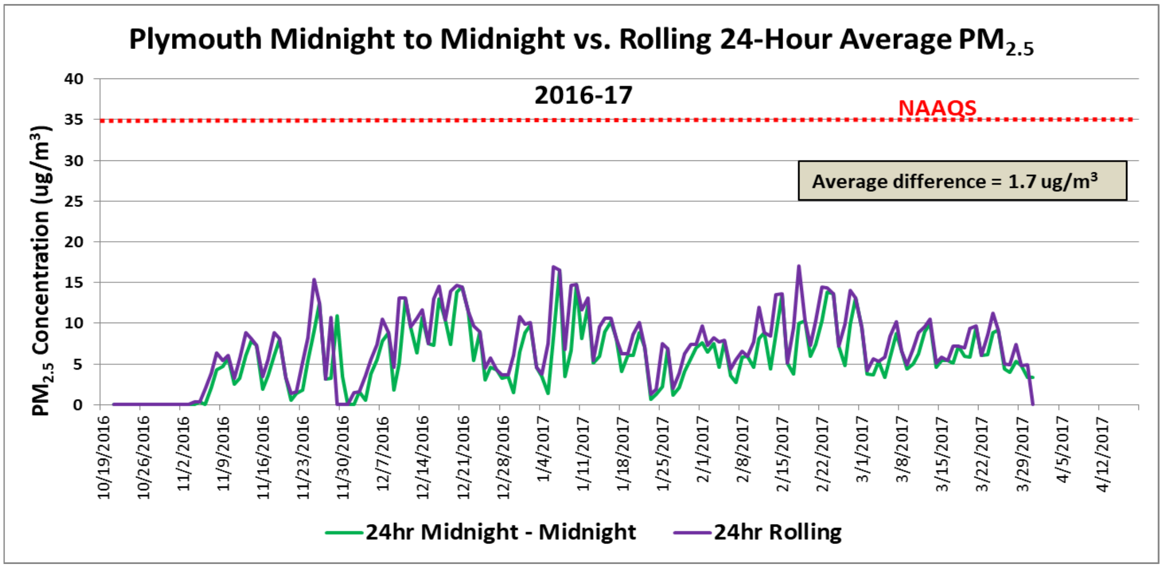
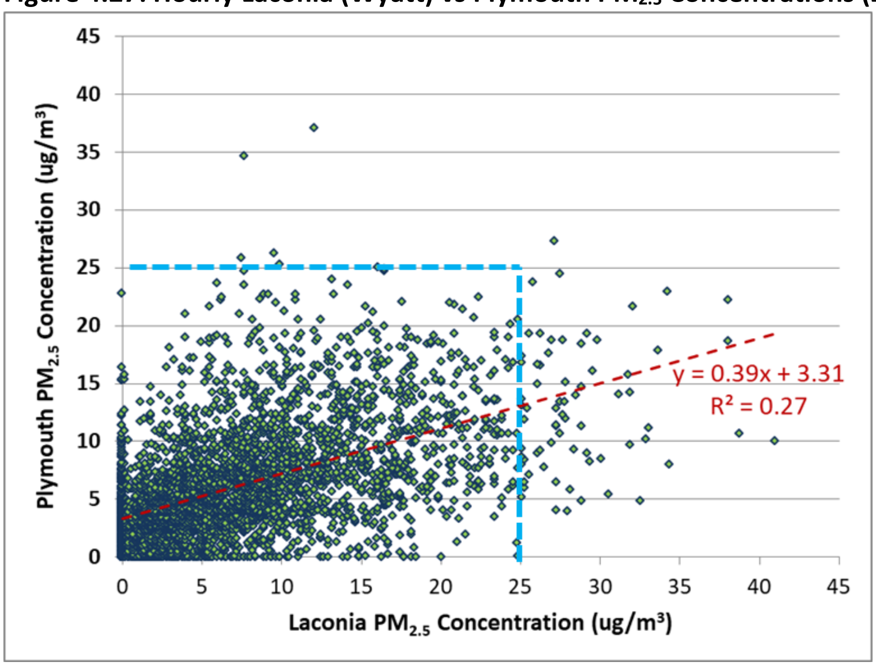


Figure 4.27 provides a community to community comparison of hourly $PM_{2.5}$ concentrations in Laconia (Wyatt) and Plymouth (outliers removed). Data points represent concentrations measured at the same time in the two locations. There were many more $PM_{2.5}$ hourly measurements above 25 µg/m³ at Laconia than at Plymouth.

Figure 4.27: Hourly Laconia (Wyatt) vs Plymouth $PM_{2.5}$ Concentrations (2016/2017)



4.4 WINTER 2019 LACONIA AREA MOBILE MONITORING

NHDES conducted a mobile monitoring study during the winters of 2010/2011 and 2011/2012 using a BAM device and a portable $PM_{2.5}$ monitoring device that could be mounted into a moving vehicle. Details of how the study was conducted can be found in the NHDES Mobile Monitoring report.[1] The purpose of the new mobile monitoring project is to identify how wood smoke varies in the neighborhoods of Laconia and nearby communities since monitoring in the city during 2017/2018 differed significantly from data collected in a different neighborhood in 2016/2017. Nearby communities consisted of Belmont, Franklin, Northfield and Tilton.

4.4.1 MOBILE AIR MONITORING PROJECT DESCRIPTION

NHDES currently operates a continuous $PM_{2.5}$ BAM unit at the Laconia Green Street station which is located outside and to the north of the city neighborhoods. While this station does not experience significant wood smoke events, the proximity of the station to the inner city makes it a convenient station for field calibrating the mobile sampling device. The goal was to drive a designated route during a forecasted $PM_{2.5}$ event to map neighborhoods with higher wood smoke concentrations than others. Should an area of higher wood smoke concentrations be identified, NHDES may consider long term monitoring in the area.

NHDES $PM_{2.5}$ sampling equipment for this study includes a Met One BAM (FEM EQPM-0308-170) and a Personal DataRAM 1500 (pDR). Project design plans called for operating the pDR from a moving vehicle, referred to as the Mobile Monitoring Unit (MMU), to record real-time concentrations in a series of target communities. The pDR used in the MMU is not a Federal Reference Method (FRM) or Federal Equivalent Method (FEM); however, the BAM unit at Green Street is a FEM. For quality assurance, NHDES parked the MMU next to the BAM for a full hour at least once, sometimes twice, during each mobile monitoring run to provide a snapshot of the pDR performance compared to the FEM BAM.

Mobile air monitoring took place during a forecasted event night with predicted high-moderate concentrations of $PM_{2.5}$. Start and end times were based on typical winter event diurnals and meteorology expected for the coming night. Drivers worked in two shifts to capture evening-to-midnight and early morning peaks, completing all sampling by approximately 8-9AM when concentrations tend to drop. They diverted from the route as needed to investigate the sight or smell of smoke or a sudden increase in concentration, though they found it difficult to spot actual emissions sources in the dark.

Throughout this study, NHDES followed all appropriate equipment and quality assurance practices. MMU operators worked in pairs so that one person could focus on safe vehicle operations. Specifically, NHDES adhered to federal quality assurance guidelines when operating any equipment designated as a federal equivalent or reference method. All co-location of portable monitoring equipment with monitors in the state's current ambient air monitoring network conformed to federal and state operational specifications for permanent equipment.

[1] New Hampshire Mobile Air Monitoring Report

4.4.2 MOBILE MONITORING UNIT (MMU)

NHDES converted a compact car into a MMU to be driven through target communities during peak $PM_{2.5}$ hours. Figure 4.28 shows the MMU and its internal configuration. It consists of a Dell laptop, GPS unit with Delorme mapping software, Thermo pDR (continuous $PM_{1.0}$ to $PM_{1.87}$ range monitor), Davis Instruments car chip, emergency kit, and a power inverter to provide electrical power for the sampler. Minimal modifications to the vehicle were needed.

Inside the vehicle, the portable pDR measured fine continuous particle data (PM_{fine}). As NHDES configured the pDR, with the blue SCC 1.062 cyclone and a flow rate of 2.0 LPM, the pDR measures particles 1.87 microns (µm) in diameter and smaller. This contrasts with the BAM, which measures particles 2.5 microns and smaller.

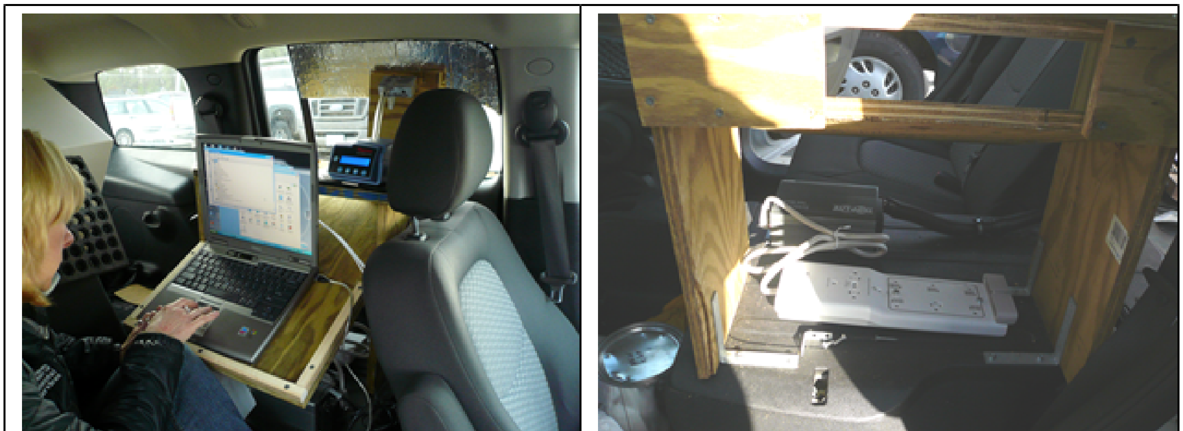
The difference in methodology between the two instruments affects their correlation. The pDR is a light scattering monitor, while the BAM relies on beta ray attenuation. Because wood smoke is more effective at light scattering than the typical aerosol, the pDR is likely to produce particulate matter concentrations greater than the BAM during wood smoke events. Therefore, the difference in size cut should have a negligible impact on the data comparison between the pDR and BAM because nearly all wood smoke particles measure under 1.0 µm, and particles in the 0-1.0 µm are measured by both instruments. For this reason, NHDES will reference both pDR and BAM data as $PM_{2.5}$ in subsequent sections of this report.

NHDES programmed the pDR to record one-minute intervals when monitoring. Concurrently, a Global Positioning System (GPS) unit logged the exact time, latitude/longitude, and elevation of the samples. The GPS and a car chip also tracked vehicle speed.

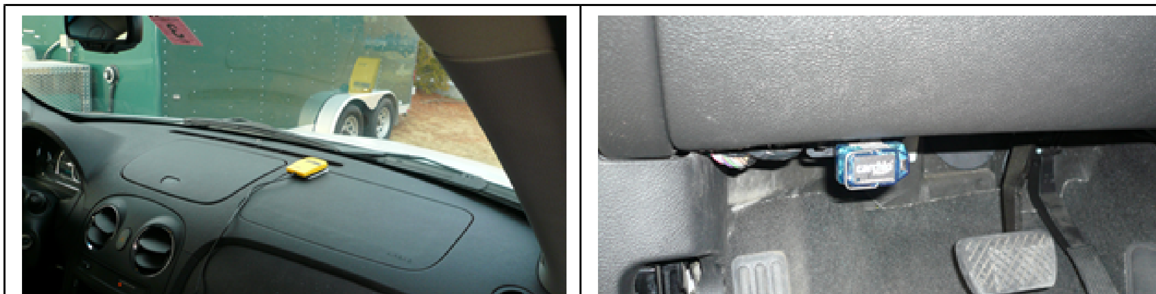
Figure 4.28: MMU Images

MMU – Probe (left) and pDR 1500 (right)

MMU – Computer logging (left) and electrical conversion (right)



MMU – GPS positioning sensor (left) and car chip (right)

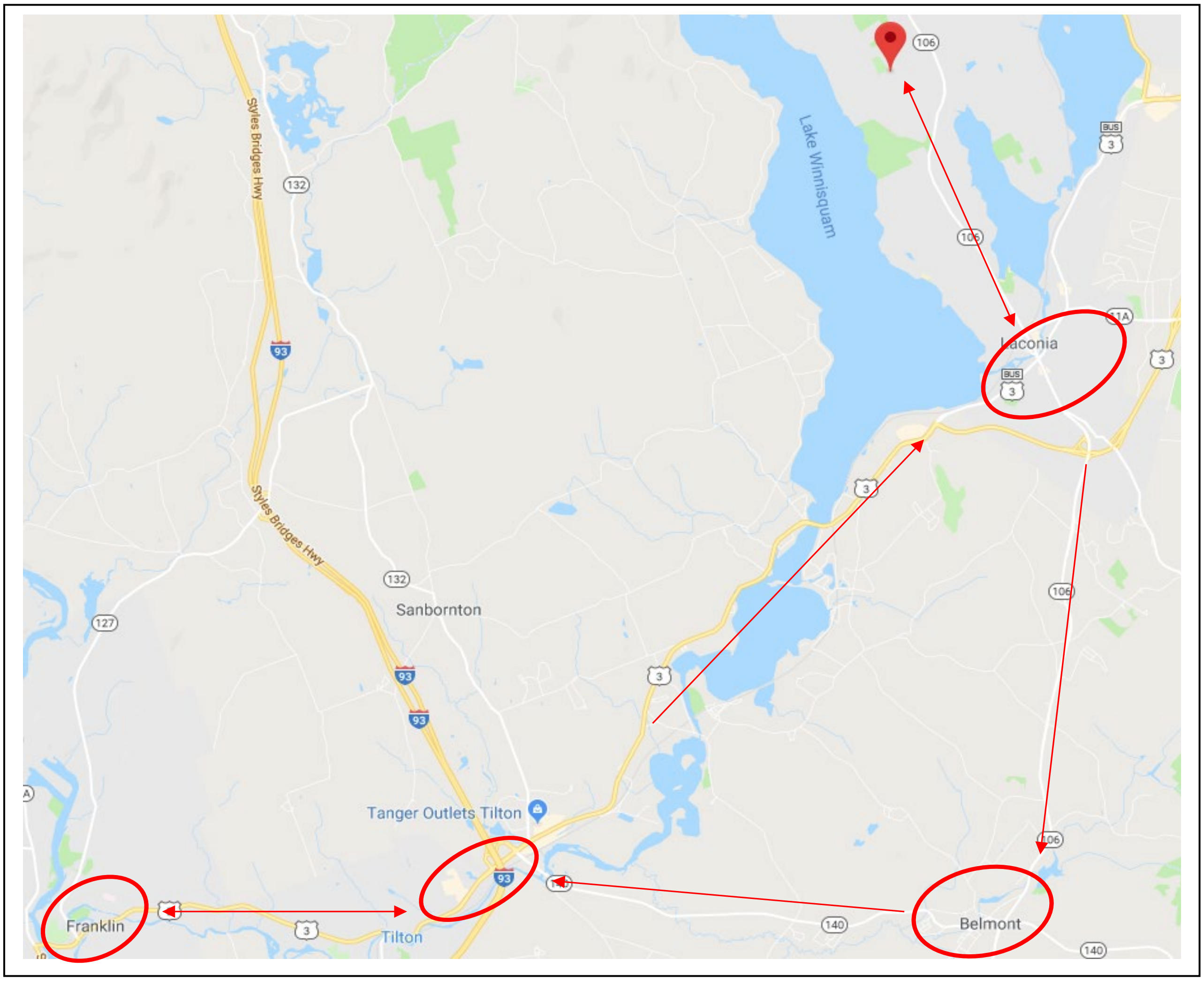


Source: NHDES

4.4.3 MMU TARGET SAMPLING ROUTE

Based on experience from previous $PM_{2.5}$ mobile monitoring studies, NHDES grouped several communities in the vicinity of Laconia for a fresh look at overnight $PM_{2.5}$ concentrations. Sampling began and ended at the NHDES BAM monitoring station on Green Street near Laconia (marked with a red pointer in Figure 4.29). Monitoring then proceeded into and throughout Laconia, Belmont, Franklin and Tilton. While each of these communities was visited with previous mobile monitoring, this study attempted to visit most neighborhoods within these communities in order to identify patterns.

Figure 4.29: Target Mobile Sampling Loop



Figures 4.30 and 4.31 show the streets and topography for Laconia where mobile monitoring occurred. The NHDES BAM is located on a hill near the top left corner of Figure 4.30. Most of the Laconia neighborhoods are located at lower elevations to the southeast of the NHDES monitoring station.

Figure 4.30: Sampling Map for Laconia (Northern with BAM)

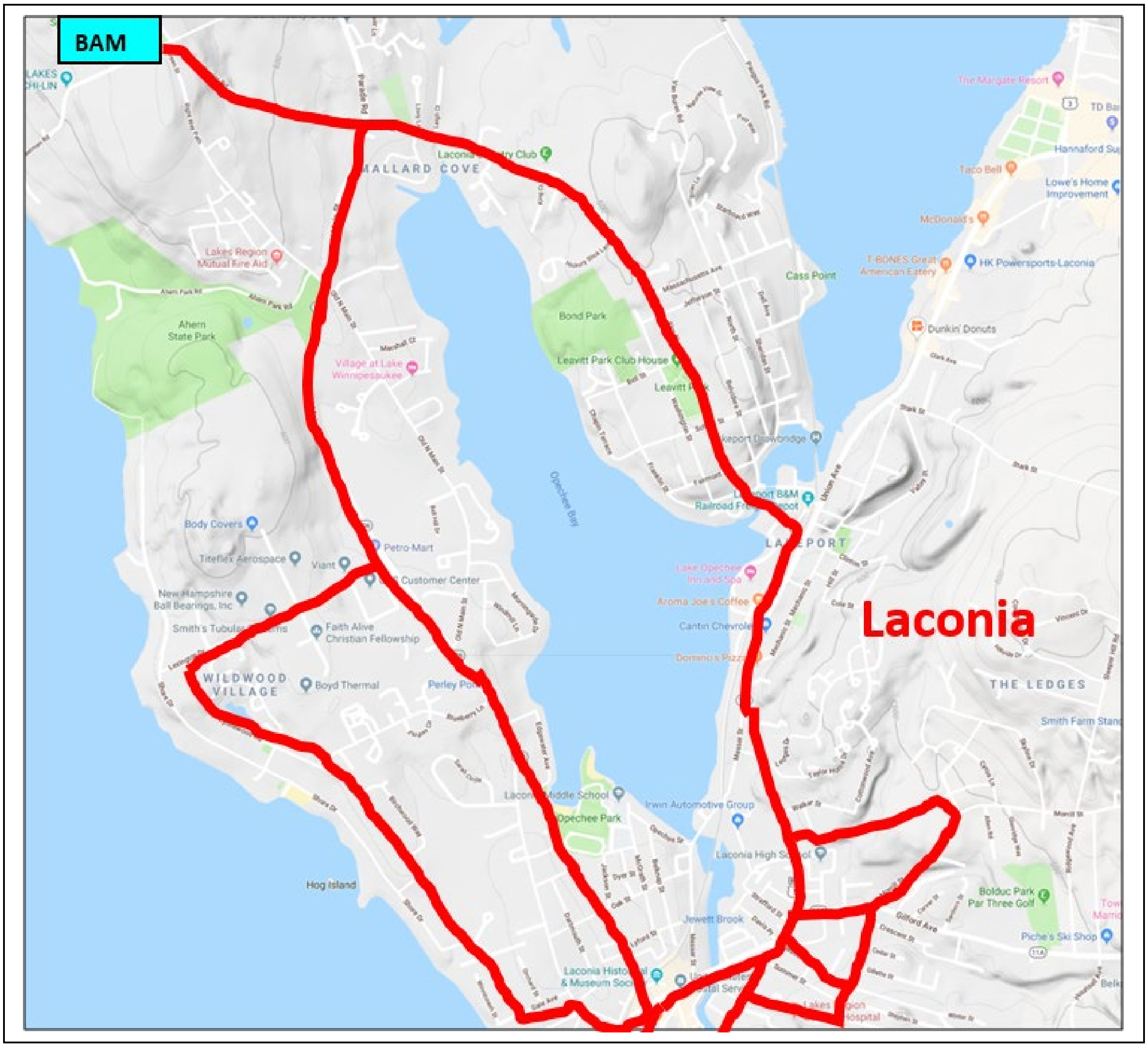


Figure 4.31 shows that hills rise towards the east and south sides of the center of Laconia, forming a "bowl"-like area near the center of town. There is also a residential community located in a smaller portion of the bowl just to the north of U.S. Route 3 on the southwest side of town.

Figure 4.31: Sampling Map for Laconia (Southern)

Figure 4.32 presents Northfield and Tilton, which are other river valley communities. The Winnipesaukee River runs from east to west through town with hills rising along the north side of the river. Northfield neighborhoods located on the south side of town are at low enough elevation to present some possibilities for wood smoke stagnation.

Figure 4.32: Sampling Map for Northfield and Tilton

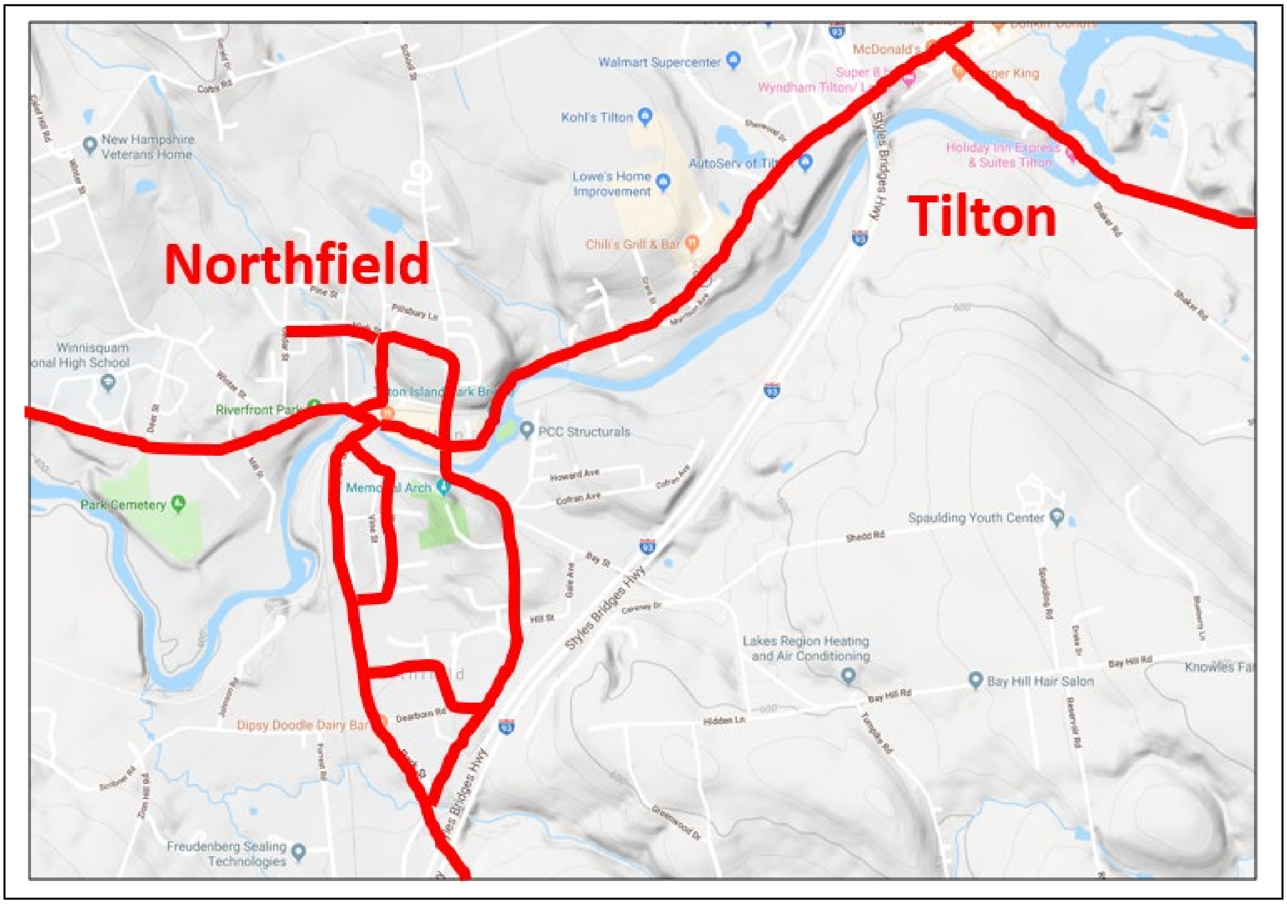


Figure 4.33 shows Franklin, a community where the Pemigewasset and Winnipesaukee Rivers meet, breaking the community into valleys and plateaus. Residential areas located to the south and southwest of the center of town are the most likely areas for stagnation to occur and local wood burning emissions to gather.

In Figure 4.34, Belmont presents itself as an area of rolling terrain. The center of town is located in a small valley and there is a stream-made valley extending to the west of the center of town.

Figure 4.33: Sampling Map for Franklin

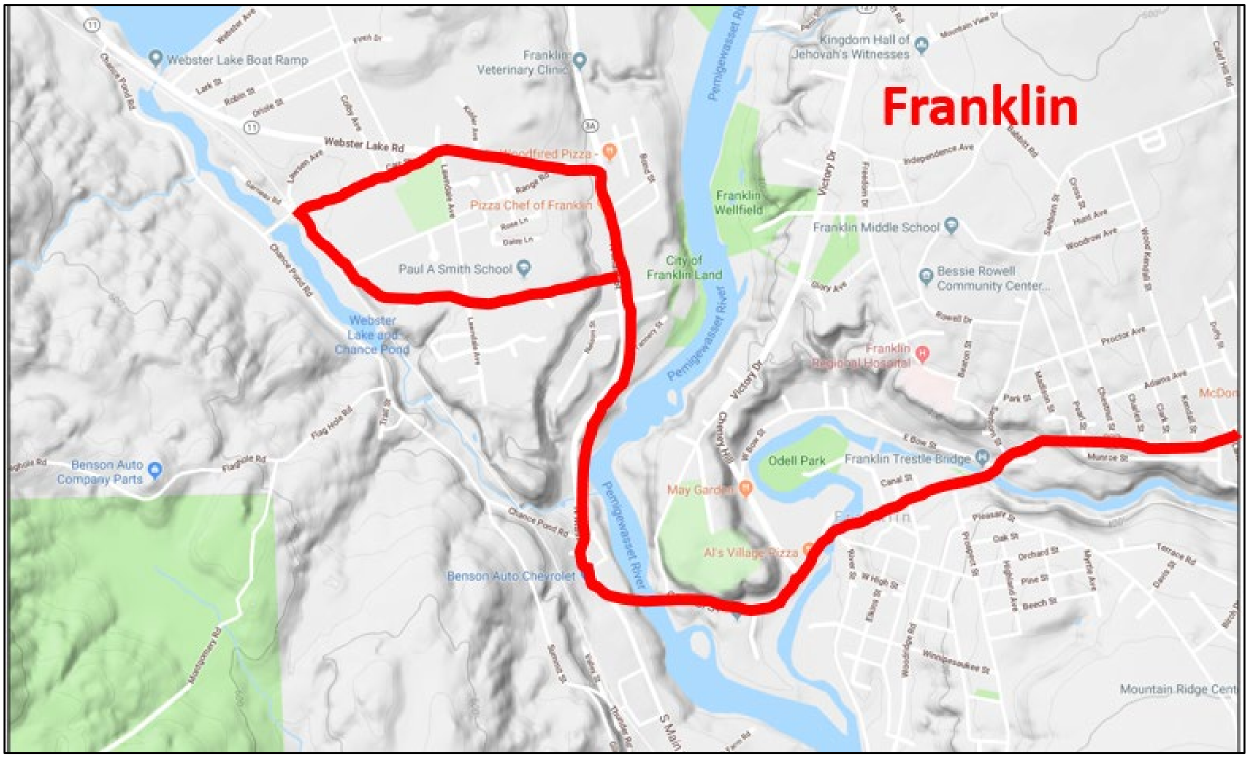
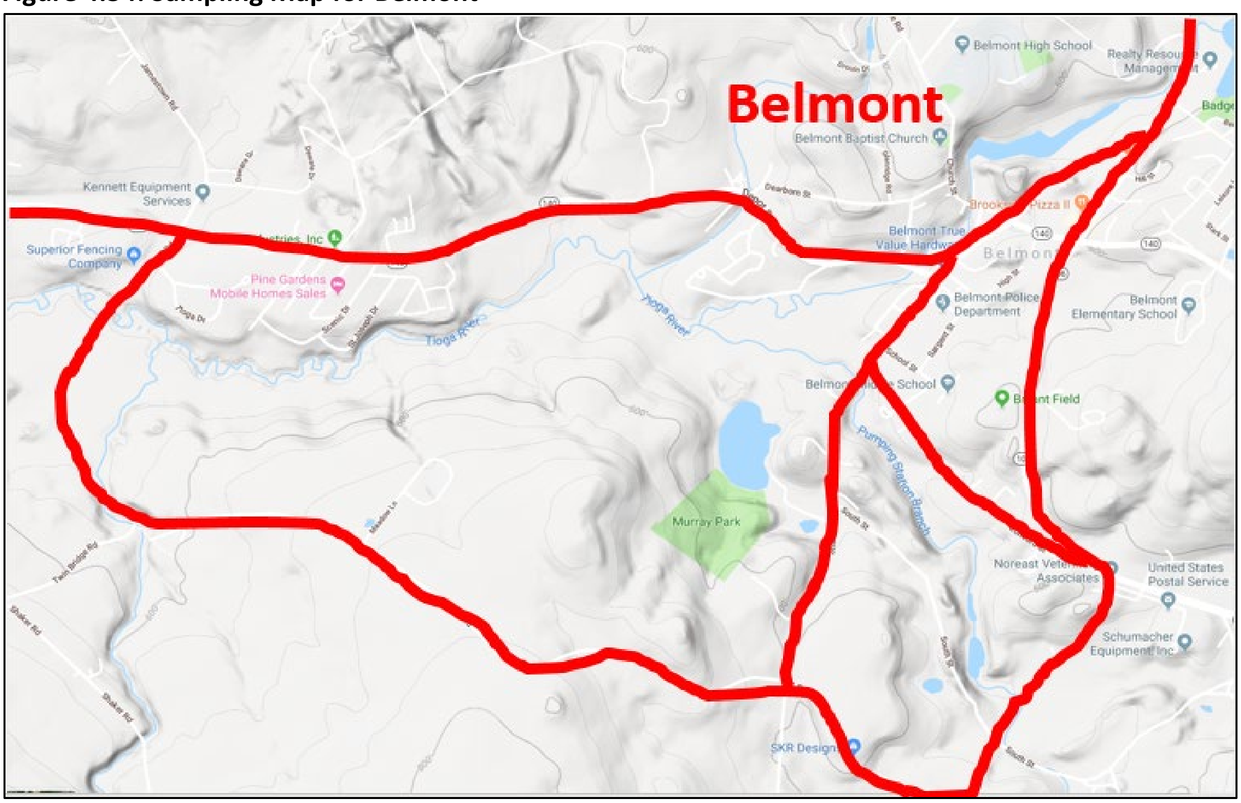


Figure 4.34: Sampling Map for Belmont



4.4.4 QUALITY ASSURANCE: CO-LOCATION OF MONITORING DEVICES

To ensure sampling consistency with federal equivalent method (FEM) units, NHDES collocated the pDR with the Keene BAM for about 28 days. The co-location occurred from March 6, 2019 through April 2, 2019. Figure 4.35 demonstrates hourly $PM_{2.5}$ data from both units for the duration. pDR data, shown in blue, tended to be somewhat higher than BAM data shown in red.

Figure 4.35: Hourly pDR and BAM Co-location data measured in Keene

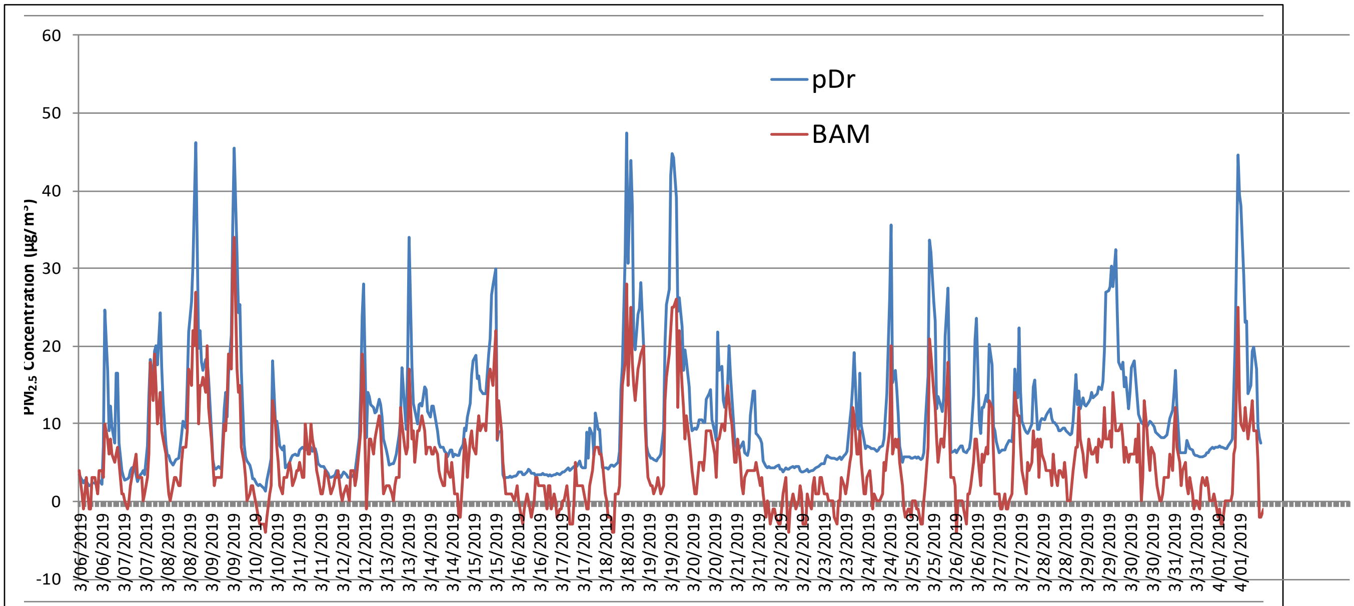


Figure 4.36: Hourly pDR and BAM Co-location Correlation - Keene

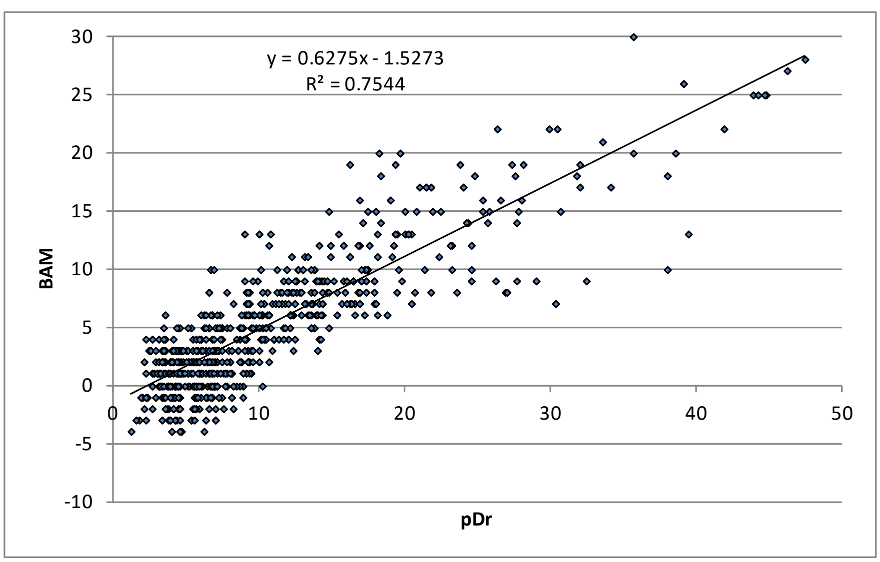


Figure 4.36 demonstrates the $PM_{2.5}$ concentration correlation between the pDR and BAM units in Keene. As mentioned above, the pDR tended to record higher $PM_{2.5}$ concentrations than the BAM, especially when overall $PM_{2.5}$ concentrations increased. Nevertheless, the overall correlation is fairly strong, with an R^2 of 0.75 and a slope of 0.63. NHDES applied the equation for this best-fit line to adjust pDR readings to equivalent BAM $PM_{2.5}$ levels in subsequent data analysis.

The equation to calibrate pDR data in this report is: **$PM_{2.5} = 0.6275(pDR) - 1.5273$ (EQ1)**

Note: BAM $PM_{2.5}$ units actually measure concentrations only 42 minutes of each hour (:03-:45). For comparison, NHDES calculated corresponding pDR averages from instantaneous values within the same interval.

4.4.5 RESULTS OF MOBILE MONITORING

NHDES successfully completed the planned sampling loop and co-location during a forecasted period of high-moderate $PM_{2.5}$ concentrations in certain New Hampshire valley communities. Mobile sampling began at the Laconia BAM monitoring station on March 2, 2019 and concluded approximately 4 hours later. Technicians operated the equipment and instrumentation according to procedure and without malfunction. The quality assurance co-locations of the pDR and TSU BAM took place for several minutes near the beginning of the sampling run.

Figure 4.37: One Minute pDR Measured $PM_{2.5}$ Concentrations

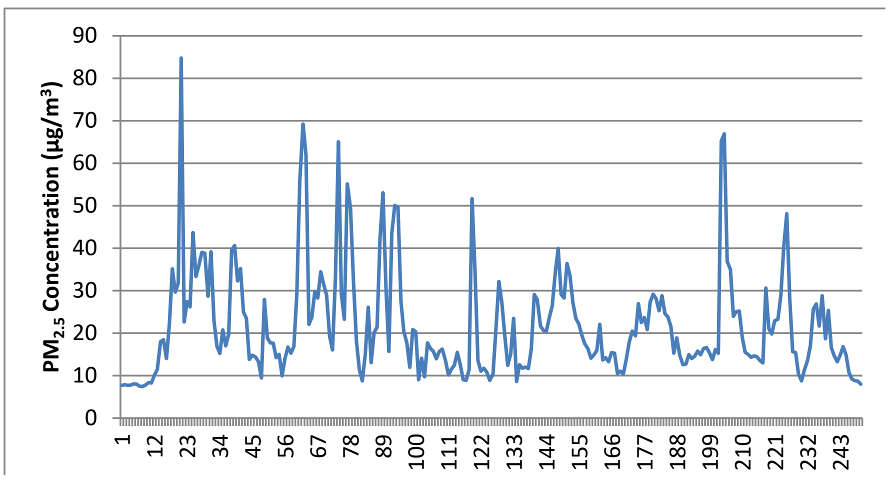
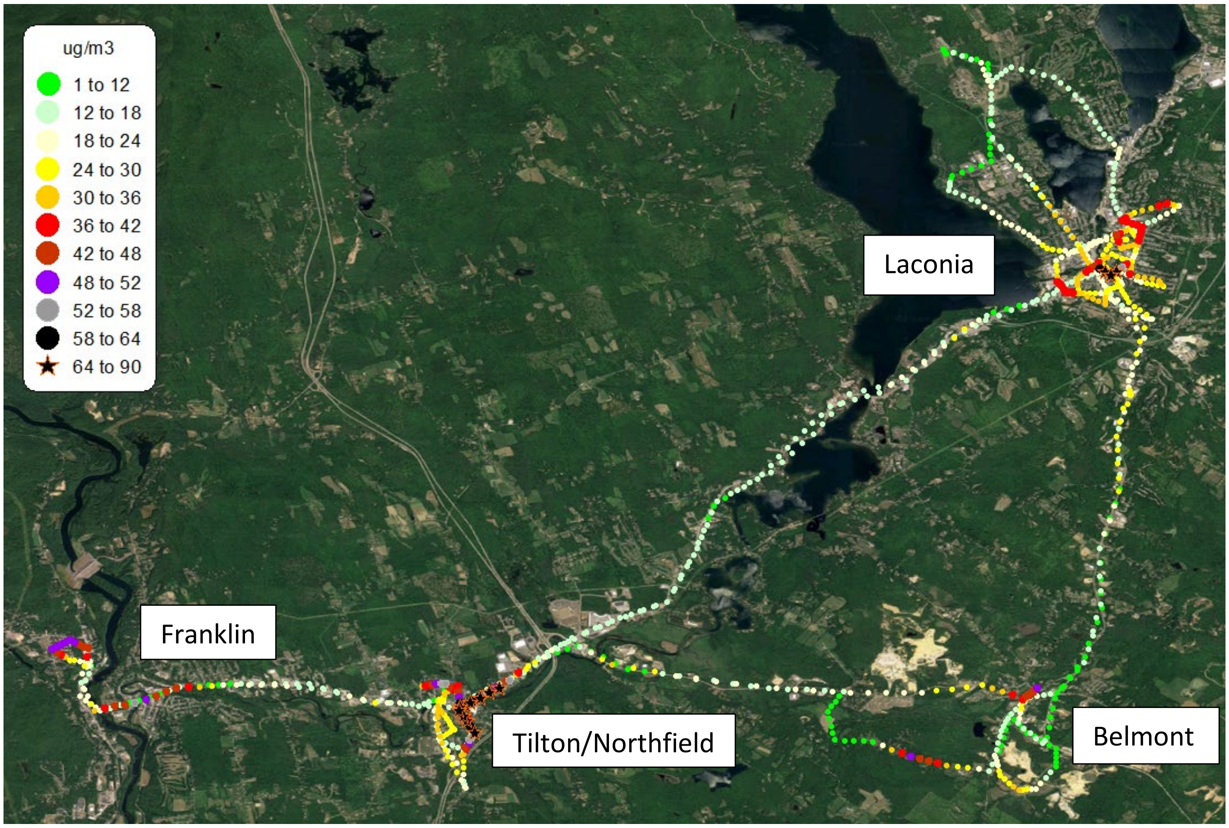


Figure 4.37 presents unadjusted $PM_{2.5}$ concentrations presented by sampling minute (minutes since sampling began). As expected, short-term concentrations were highly variable as a function of vehicle location. There were several brief periods where unadjusted concentrations exceeded 35 µg/m³ with a maximum 1-minute unadjusted concentration of 84.8 µg/m³ occurring early in the sampling effort.

Important: Instantaneous data collected by the MMU neither confirms nor refutes the existence of health risk from exposure to $PM_{2.5}$ air pollutants. However, locations with higher measured values may be at greater risk than those with lower values. EPA currently defines $PM_{2.5}$ ambient air concentrations averaging over 35 micrometers per cubic meter (µg/m³) over a period of 24 hours (midnight to midnight) as unhealthy for sensitive populations.

Running unadjusted (raw) $PM_{2.5}$ data from the MMU pDR overlaid on a Laconia area map is shown in Figure 4.38. Data was recorded every 60 seconds by the MMU along the route. The data was then interpolated down to 10 second intervals for mapping purposes. Such raw particle concentrations can be useful in identifying potential areas of concern, but should not be compared to the National Ambient Air Quality Standards (NAAQS) since they are of very short duration and are not calibrated. Highest particle concentrations were measured in the south end of Laconia and the east side of Northfield. Additional areas with higher than average particle concentrations were measured to the north and west of Belmont, and in-town Franklin and in a neighborhood on the northwest side of Franklin.

Figure 4.38: Laconia Area Map of Raw MMU $PM_{2.5}$ Values – In Motion



Data values in Figures 4.38, 4.39, 4.40 and 4.41 are instantaneous and do not represent the 24-hour form of the $PM_{2.5}$ NAAQS. Data values were collected on different days and times and are not necessarily comparable. Some high concentrations marked in this figure may be localized to a single source and brief in duration.

Figure 4.39 shows adjusted data where raw MMU concentration values are adjusted to one-minute $PM_{2.5}$ concentrations based on the Keene co-location best-fit equation (EQ1) developed in Section 4.4.4. In cases where the MMU traversed a route more than once, the highest values were retained for plotting purposes. In general, adjusted concentrations are about 40 percent lower than the raw concentrations, but even with the adjustment, concentrations in the south end of Laconia and the east side of Northfield were higher than 35 µg/m^3. In general, $PM_{2.5}$ concentrations were higher in more populated areas and lower in locations between communities. Highest concentration by town is shown in Table 4.5. There was one exception to this pattern, where elevated $PM_{2.5}$ concentrations were measured along a rural road (S Road) to the west of Belmont. This may have been due to an isolated residence producing high emissions.

Figure 4.39: Adjusted Laconia Area Map of MMU $PM_{2.5}$ Values – In Motion

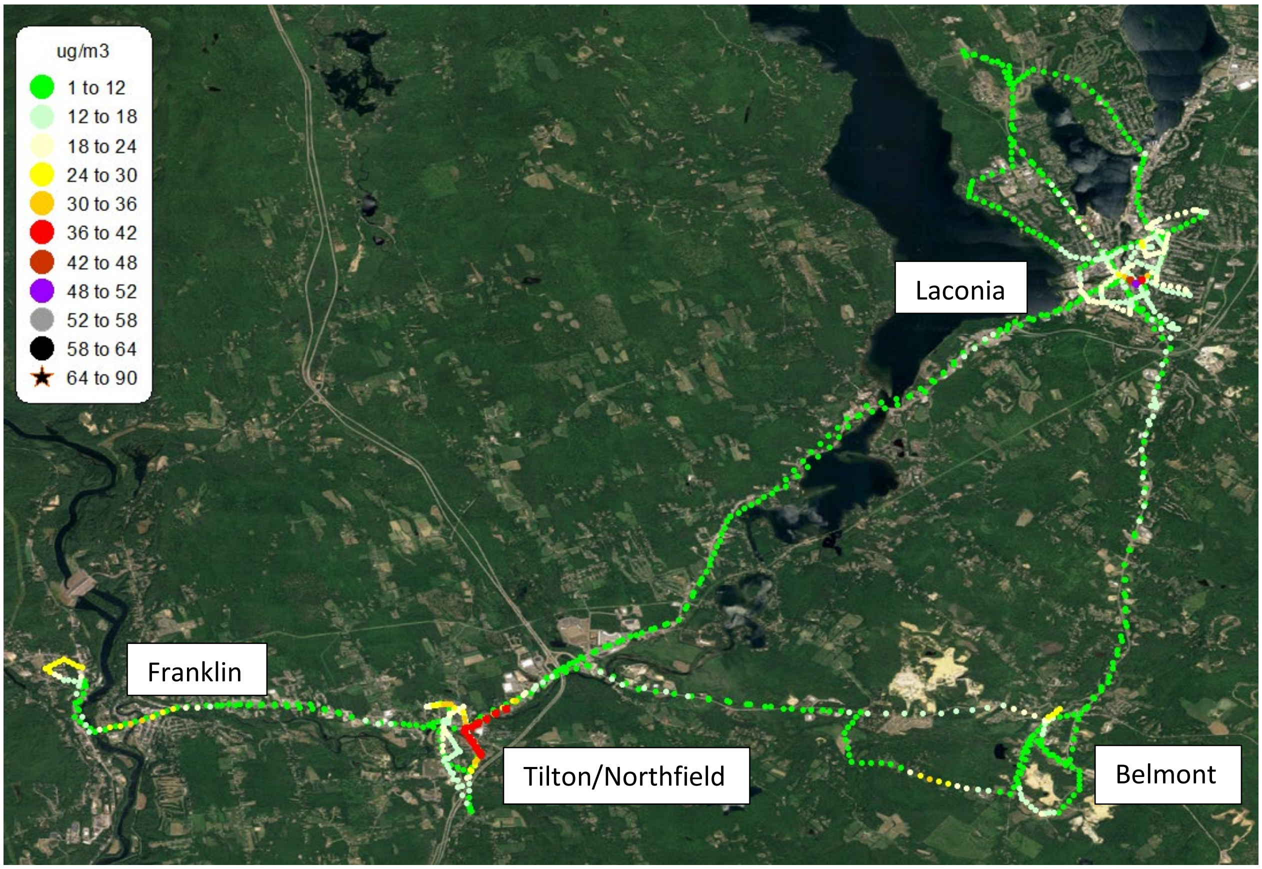


Table 4.5: Highest Measured 1-Minute Mobile $PM_{2.5}$ Concentrations

Location	Local Time	Adjusted MAM Concentration (µg/m^3)
Belmont	01:08:44	28.6
Franklin	22:52:44	31.8
Laconia	21:44:44	51.7
Northfield	22:25:44	41.9
Tilton	01:01:44	17.7
Rural Near Belmont	23:22:44	30.9

Figure 4.40 presents greater detail for adjusted $PM_{2.5}$ concentrations in the Laconia area. Significant differences can be seen in the neighborhoods of the city. Highest $PM_{2.5}$ concentrations were measured in a neighborhood just south of the center city, including Baldwin, Dixon, and Pine Streets. Another area of higher $PM_{2.5}$ was located just north of Lakes Region General Hospital. Compared to $PM_{2.5}$ concentrations outside of Laconia, virtually the entire city was measured with $PM_{2.5}$ between 6 and 12 µg/m^3 higher.

Figure 4.40: Adjusted Laconia Map of MMU $PM_{2.5}$ Values – In Motion

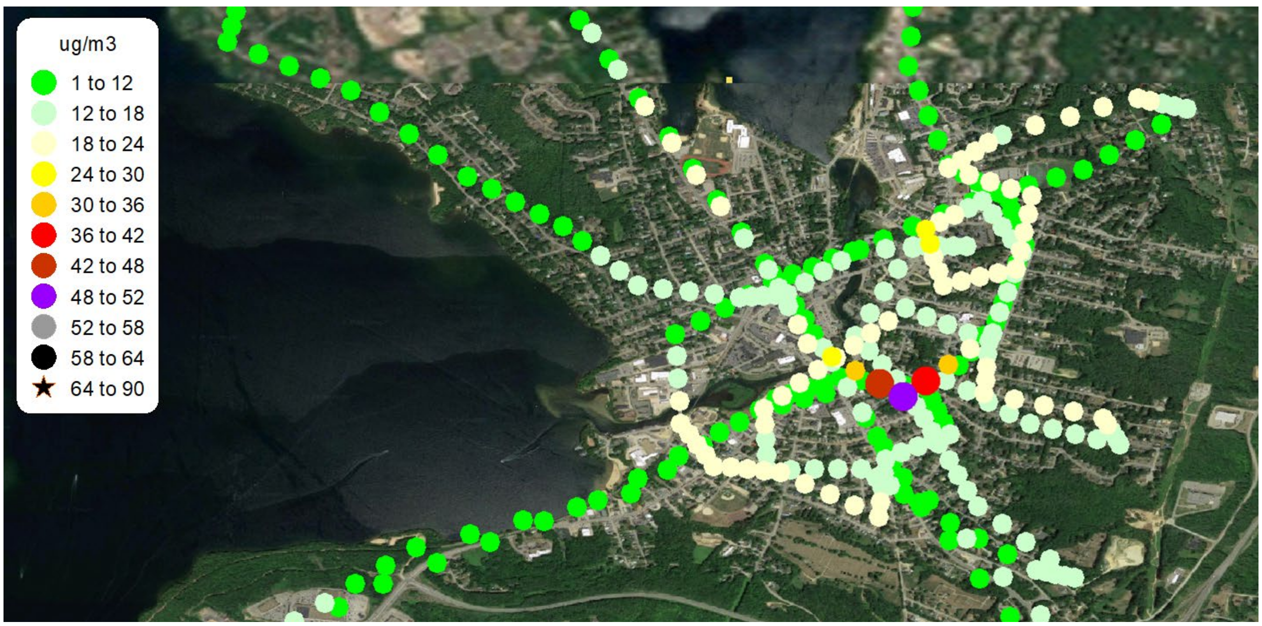
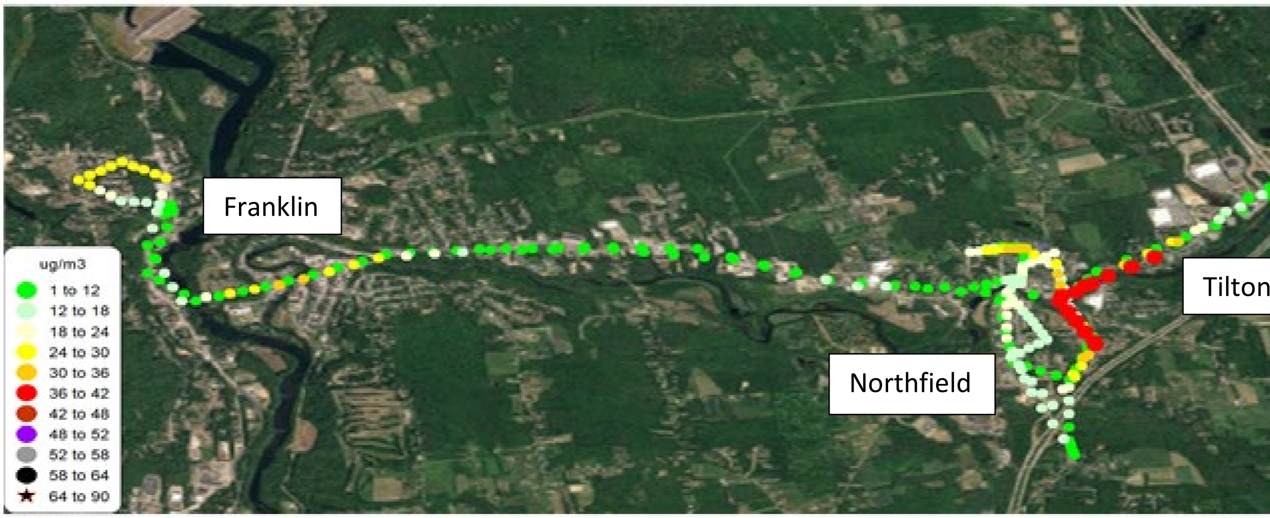


Figure 4.41 presents greater detail for adjusted $PM_{2.5}$ concentrations in the Franklin and Northfield area. Highest $PM_{2.5}$ concentrations were measured along Summer, Elm, and Eastern Main Streets in Northfield. Concentrations were also elevated along High Street. In Franklin, highest $PM_{2.5}$ concentrations were measured along Central and Carr Streets and along the in-town portion of Webster Lake Road.

Figure 4.41: Adjusted Franklin and Northfield Area Map of MMU $PM_{2.5}$ Values – In Motion



5. SUMMARY

NHDES has performed a series of investigative analyses and monitoring looking for wintertime wood smoke events in communities where wood combustion is an important part of residential heating. Under some conditions, wind speeds will slow down overnight and the thermal structure of the atmosphere will shift so that emissions released near the ground get trapped there and without the wind will fail to disperse. As a result, concentrations of smoke (and $PM_{2.5}$) can build up in some locations to levels that are unhealthy for sensitive groups, and even unhealthy for the general population.

5.1 VALLEY IDENTIFICATION TOOL ANALYSIS

The VIT was used on communities throughout New Hampshire and it identified 16 communities with over 3000 people living within the topography of a valley (listed in order of declining population living in a valley): Keene, Claremont, Lebanon, Hanover, Berlin, Conway, Plymouth, Swanzey, Franklin, Charlestown, Laconia, Hillsborough, Littleton, Newport, Haverhill and Hinsdale. Living in a valley does not automatically create a potential wood smoke accumulation risk. Some communities have higher wood burning rates than others and some have greater risk of overnight calm winds and thermal inversions. Most of the communities listed were visited during the mobile monitoring project and others have had other NHDES $PM_{2.5}$ monitoring.

NHDES estimated $PM_{2.5}$ emissions for 31 communities and compared them to the population of the community that lives in a valley to help target potential community risk. The City of Keene had by far the highest emissions and people living in a valley, and thus tops the list for potential community-wide wood smoke risk in the state. Claremont, Hanover, and Lebanon were closely clustered into the next tier and then at lower risk were Berlin, Conway, Franklin, Laconia, Plymouth, and Swanzey. All of these communities were targeted for field visits except for Swanzey, which was included in previous Keene area studies. In addition, Laconia and Plymouth were selected for targeted monitoring for hourly $PM_{2.5}$.

5.2 FIELD SURVEYS


Source: Underhill 2020

NHDES sent survey teams to Berlin, Claremont, Conway, Franklin, Hanover, Laconia, Lebanon, Northfield and Plymouth to look for wood burning indicators on a neighborhood basis. Neighborhoods were selected based on proximity to valleys. Surveyors looked for chimneys, metal capped chimneys, wood piles, and propane tanks. The surveyors also looked at residential spacing and general positioning. The study identified several neighborhoods with high rates of wood burning indicators. Portions of Keene and

Laconia rated high on housing density and potential for wood burning in certain valley areas.

Neighborhoods in Claremont, Conway, Hanover and Lebanon were found to have relatively low density housing and/or remoteness of neighborhoods with high rates of wood burning indicators. In some cases, wood burning sources were spaced out in communities, which lessens the cumulative effect of wood burning.

In most cases, NHDES estimates that most communities included in the field surveys are likely to experience maximum wood burning concentrations in the moderate range and should practice clean burning techniques to minimize personal and community health effects. There is risk in some neighborhoods for concentrations to reach unhealthy for sensitive groups during overnight periods, but not for a full 24-hour period. Isolated high emission wood burning units can cause localized health effects and be a neighborhood nuisance.

5.3 TARGETED MONITORING IN LACONIA AND PLYMOUTH

Between 2016 and 2018, NHDES performed targeted $PM_{2.5}$ monitoring in the cities of Laconia and Plymouth. During the first winter, hourly $PM_{2.5}$ BAM monitors sampled at Wyatt Park in south-central Laconia and near the Pemigewasset River in Plymouth. The maximum rolling 24-hour $PM_{2.5}$ concentrations were 23.5 µg/m^3 for Laconia Wyatt Park and 17.0 µg/m^3 for Plymouth. Overall, concentrations measured in Plymouth were considerably lower than those measured at Laconia's Wyatt Park, where eight hours were measured above 35 µg/m^3, versus one for Plymouth. During the winter of 2017-2018, Laconia was again monitored, but in a different location, Memorial Park located on the southwest side of the city. The maximum rolling 24-hour $PM_{2.5}$ concentration was 22.9 µg/m^3. While this maximum concentration was similar to that measured at Wyatt Park the previous year, the frequency of higher $PM_{2.5}$ nights was much lower (only one).

5.4 2019 MOBILE $PM_{2.5}$ MONITORING STUDY

On the night of March 1 - 2, 2019, NHDES performed mobile $PM_{2.5}$ monitoring in Belmont, Franklin, Laconia, Northfield and Tilton. This intention of this study was to take a closer look at the neighborhood scale of wood smoke in the communities. The monitoring revealed some pockets in Laconia that had high $PM_{2.5}$ measurements, while other parts of town, including the NHDES Green Street monitor, had low concentrations. The neighborhood with the highest concentrations was relatively near Wyatt Park. The monitoring also revealed moderately high $PM_{2.5}$ concentrations in eastern Northfield and northwestern Franklin.

5.5 UPDATED LIST OF COMMUNITIES OF INTEREST FOR WOOD SMOKE

Table 1.1 at the beginning of this report presents the original (proposed in 2012) table of Communities of Interest in New Hampshire. This table is now updated based on information collected from VIT analysis, community field visits, targeted monitoring and additional mobile monitoring. No communities were removed from the list, but five were added, including Claremont, Franklin, Hanover, Marlborough, and Northfield. Laconia and Marlborough were added to the top "Primary" category, while Henniker, Hillsborough and Winchester were lowered to the "Secondary" category and Concord was lowered to the

"Others to Watch" category. Claremont, Hanover and Northfield were added to the "Secondary" category and Franklin was added to the "Others to Watch" category.

While Laconia was increased to the highest level, the highest risk of wood smoke exposure is limited to just a portion of the city. Mobile monitoring identified the valley neighborhood in the south-central portion of the city to have the greatest risk of exposure. Other portions of the city have much lower risk of wood smoke exposure.
This study confirms that it does not appear that there are any New Hampshire towns at equal or greater risk than Keene for $PM_{2.5}$ exceedances, however, localized $PM_{2.5}$ exceedances can exist near any individual or neighborhood clustering of high emitting wood burning units.

Table 5.1: Updated Communities of Interest Identified by Mobile Air Monitoring, Community Surveys and the Valley Identification Tool

Primary	Secondary	Others to Watch
Keene	Belmont	Acworth
Laconia	Berlin	Antrim
Marlborough	Claremont	Charlestown
Newport	Conway/North Conway	Concord
West Swanzey	Hanover	Farmington
	Henniker	Franklin
	Hillsborough	Hopkinton
	Lancaster	Jaffrey
	Lincoln / North Woodstock	Langdon
	Meredith	Marlow
	Northfield	Pittsfield
	Winchester	Plymouth
		Raymond
		Westmoreland

5.6 CONCLUSION

Burning wood for heat is commonplace in New Hampshire, especially in communities distant from natural gas pipeline supplies. Use of residential wood burning for heat showed an increase during periods of higher oil and natural gas prices, which are both lower in 2019.

NHDES encourages residents to use clean burning practices when choosing to burn wood for heat, and to upgrade to cleaner burning EPA certified wood stoves when possible. Pellet stoves are another alternative for wood burning that is much cleaner than older wood stoves. If you have a hydronic heater (outdoor wood boiler), only burn seasoned wood as the manufacturer specifies and consider neighbors and family by ensuring that it is installed according to setback and stack height requirements. When burning wood in any stove or boiler, always use seasoned fire wood and don't let the fire smolder. And finally, minimize use of regular fireplaces because they are very high smoke emitters and are inefficient at providing household heat.

Because many are choosing cleaner wood burning practices in New Hampshire, wood smoke concentrations have been declining slowly across the state. As this study has determined, there are still locations in New Hampshire that are prone to higher concentrations of wood smoke due to demographic and geographic patterns. There are also still very localized “hot spots” resulting from individual high emitting wood stoves or hydronic heaters. Where these hot spots occur, there is the possibility that people living nearby may experience concentrations of small particles that reach unhealthy for sensitive groups or worse, sometimes frequently during colder months.

While this report generally finds beneficial trends, it also highlights that there are still problem areas. There is also the likelihood that when the price of oil or natural gas increase, the amount of wood combustion will increase, potentially with older, more polluting wood burning devices coming out of retirement. Burning wood can provide an efficient and convenient source of heat as long as clean burning practices are followed and the pattern for cleaner burning devices continues.

APPENDIX A – FIELD DATA

Table A1 – Claremont Survey

Street	# propane	# of metal chimneys	# of wood piles	# of brick chimneys	# of houses	# other
Baker St	1	0	0	7	7	
Bellic St	1	3	2	8	14	
Cedar St	1	1	0	11	17	
Centennial St	0	0	0	10	14	
Chellis St	0	0	0	5	7	
Congress St	0	1	0	10	12	
East St	1	0	0	6	14	
Edgewood Ave	0	0	0	10	10	
Goss St	1	4	3	4	5	
Grove St	2	1	2	11	28	
Hartford St	0	0	2	8	11	
Henry St	0	0	2	6	8	
Leferve Ave	1	1	0	2	3	
Lonsdale Ave	0	1	1	4	9	
Memorial Dr	3	5	1	6		1 pellet
Myrtle St	1	1	2	15	34	
Osgood Ave	1	1	0	5	12	
Pawtucket Ave	0	0	1	5	14	
Pearl St	0	1	0	5	21	
Spring St	0	3	0	7	6	1 OWB
Walnut St	0	0	0	6	17	
Woodland St	0	0	0	4	19	
Woonsocket Ave	0	1	2	10	11	
Total	**13**	**24**	**18**	**165**	**293**	**-**

Table A2 – Conway Survey

Street	# propane	# of metal chimneys	# of wood piles	# of brick chimneys	# of houses	Other
Allard Farm Cir	1	10	8	21	21	
Ash St	0	5	6	15	30	
Blueberry Ln	1	5	3	12	24	
Bow Ln	2	3	5	15	17	
Chapel St	0	12	10	5	27	
Dandiview Rd	0	10	11	15	34	
Forbes Dr	0	7	7	8	22	
Grove St	2	1	4	12	26	
Linden Rd	2	0	4	4	7	
Maple St	1	3	4	4	10	
Oak St	1	0	1	13	21	
Seavy St	1	3	2	9	14	
Total	**11**	**59**	**65**	**133**	**253**	**0**

Table A3 – Hanover Survey

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys	# of houses	Other
Barret Rd	1		2	6	8	
Barrymore Rd	1		1	10	9	
Beacon Rd	2		2	6	5	
Bridgman Rd	0		1	6	9	
Brockway Rd	1		0	8	6	
Butternut Ln	0		0	7	8	
Cambridge Pl	0		2	5	6	
Chase Rd	1		3	9	6	
Claflin Cir	2		1	8	8	
Conant Rd	0		3	10	13	
Curtis Rd	1		0	9		
Dayton Dr	0		0	7	7	
Dresden Rd	1		2	12	14	
Fairview St	0		1	5	8	
Gilson Rd	0		4	16	21	
Granger Cir	1		1	8	8	
Highland Ave	1		2	4	7	
Kingsford Rd	2		2	20	26	
Lash Rd	0		1	5	6	
Lewnin Rd	0		1	5	4	
Longwood Ln	1		1	8	11	
Mitchell Ln	1		0	9	11	
Rayton Rd	0		2	3	19	
Read Rd	0		2	5	6	
Ridge Rd	0		2	7	10	
Rip Rd	1		7	25	42	
River Ridge Rd	1		2	7	8	
Weatherby Rd	1		0	4	11	
Woodmore Dr	3		7	13	19	
Woodrow Rd	0		0	3	7	
Wren Ln	0		0	2	2	
Total	**22**	**0**	**52**	**252**	**325**	**0**

Table A4 – Keene Survey

Street	# propane	# of metal chimneys	# of wood piles	# of brick chimneys	# of houses	# other
Arlington Ave	1	3	2	13	13	
Armory St	0	2	2	11	13	
Belmont St	0	0	6	8	23	
Colby St	1	2	1	9	24	
Congress St	2	0	1	10	17	
Crescent St	0	2	1	11	17	
Edwards St	0	0	0	9	11	
Elm St	0	0	2	17	17	
Evans Cir	0	0	4	12	20	
Evans Ln	0	1	3	11	20	
Forest St	0	0	1	14	21	
Gurnsey St	0	2	0	7	9	
Hardy Ct	2	2	0	10	11	
Knight St	0	0	2	9	8	2 Pellets
Pako Ave	2	11	5	30	44	
Pearl St	2	0	0	9	9	
Pinehurst Ave	0	2	0	9	13	
Probate St	2	0	0	8	14	
Royal Ave	0	4	2	6	16	
S Lincoln St	0	4	1	8	21	
Sullivan St	4	2	3	15	16	
Valley St	0	4	2	12	21	
Total	**16**	**41**	**38**	**248**	**378**	**-**

Table A5 – Laconia Surveys

Survey 1

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys*	# of houses	Other
Baldwin				69	30	
Clearwater				1	11	
Court				54	25	
Franklin			3	32	52	
Gilford			6	75	67	
High				32	25	
Jefferson			2	16	17	
Morningside			3	41	33	
Mulberry				1	11	
Old North Main			3	47	44	
Pine				77	46	
School (in valley)			2	7		
School (out of valley)			2	37		
Sheridan			7	35	38	1
Shore				75	111	
Total	**-**	**-**	**28**	**599**	**510**	

Survey 2

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys*	# of houses	Other
Baldwin Street	0	0	1	30	32	0
Cottage Street	0	1	2	9	13	0
Dixon Street	0	0	3	16	18	0
Gilbert Street	0	0	2	8	9	0
Gilford Avenue	0	1	0	14	16	0
Highland Street	1	3	5	37	45	0
Merrimac Street	1	0	3	6	7	0
Pearl Street	4	1	0	12	18	0
Pine Street	0	0	2	18	25	0
Tyler Street	0	0	1	2	3	0
Webster Street	0	1	1	15	24	0
Total	**6**	**7**	**20**	**157**	**210**	**0**

Table A6 – Lebanon Survey

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys	# of houses	Other
Barnes	2		0	5	5	
Batchelder Ave	0		2	14	15	
Beyerle Ave	1		2	4	4	
Cedar	1		1	6	6	
Chandler Ave	0		2	6	6	
Chelsea Circle	1		2	6	8	
Church	3		3	15	16	
Crafts Ave	2		2	14	12	
Denton	0		1	5	8	
Elm	4		2	16	12	
Floyd Ave	2		2	10	16	
Green St	0		1	13	16	
Hall Road	1			4	8	
Jones Ave	0		0	11		
Lilac	1		1	6	4	
Nottingham Cr	3		9	9	14	
Pine	1		0	6	14	
Riversdale Pkwy	3		1	14	14	
Shaw	1		2	13	12	
Spring St	3		2	7	10	
Tuck Rd	3		4	5	9	
Union	3		1	11	14	
Valley	3		0	3	3	
Walnut	0		0	4	4	
Water	2		4	14	9	
Whitcomb Ave	0		1	14	13	
Winoa	2		1	6	22	
Winter St	3		1	9	10	
Total	**45**	**0**	**47**	**250**	**284**	**0**

Table A7 – Plymouth Survey

Street	# propane	# of metal chimneys	# of wood piles	# of brick chimneys	# of houses	Other
Batchelder St	1	3	5	8	10	0
Broadway St	0	1	4	15	16	0
Brookside Dr	2	3	0	2	9	0
Crescent St	1	0	0	8	11	0
Emerson St	0	0	2	11	17	0
Garland St	0	2	2	5	8	0
High St	0	0	2	8	11	0
Keeble St	2	1	0	8	8	0
Merrill St	0	1	0	10	22	0
Parker St	1	2	2	10	9	0
Pleasant St	2	0	2	19	25	0
Randolph St	0	1	1	6	7	0
River Ridge Rd	1	3	3	16	22	0
Rogers St	0	2	0	6	9	0
Shirleys Way	3	1	1	0	8	0
Silver Ln	0	0	2	3	4	0
Welch Ave	0	2	2	2	6	0
Wentworth St	0	2	2	8	9	0
Total	**13**	**24**	**30**	**145**	**211**	**0**

Table A8 – Franklin Survey

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys*	# of houses	Other
Carr St	0	4	1	5	11	0
Daisy Lane	1	6	0	0	13	0
Daniel Webster Dr.	1	1	0	3	6	0
Hemlock Circle	0	0	1	7	7	0
Ivy Lane	1	6	0	0	8	0
Lawdale Avenue	1	4	0	15	23	0
Lawsen Ave	0	2	4	16	21	0
Lawson Avenue	0	1	1	6	7	0
Laxon Avenue	1	1	2	3	6	0
Lilac Lane	4	6	0	0	9	0
Lily Lane	0	3	2	0	4	0
Pinecrest Circle	0	1	0	7	8	0
Range Road	0	8	0	7	18	0
Rose Lane	2	7	0	0	10	0
Webster Lake Road	0	5	0	12	20	0
Total	**11**	**55**	**11**	**81**	**171**	**0**

Table A9 – Northfield Survey

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys*	# of houses	Other
Bay Street	1	3	0	11	15	0
Cofran Avenue	0	4	3	11	19	1
Elm St.	0	0	1	9	11	0
Gale Avenue	0	1	1	7	10	0
Granite Street	2	4	1	1	4	0
Hill Street	0	1	3	4	6	0
Howard Avenue	1	4	3	6	12	0
Main Street	0	4	4	20	28	0
Summer Street	1	5	3	12	20	0
Total	**5**	**26**	**19**	**81**	**125**	**1**

Table A10 – Berlin Survey

Street	# propane	# metal chimneys	# of wood piles	# of brick chimneys*	# of houses	Other
4th Avenue	3	14	1	40	54	0
5th Avenue	0	10	2	31	43	0
6th Avenue	2	6	4	25	35	0
Madison Avenue	1	12	2	48	66	0
Willard Street	3	9	1	51	69	0
Jasper Street	1	7	2	14	22	0
Norway Street	4	11	1	51	65	0
Sweden Street	0	7	2	30	43	0
Denmark Street	3	5	1	35	43	0
Total	**17**	**81**	**16**	**325**	**440**	**0**

APPENDIX B – MOBILE MONITORING INFORMATION

Setting up the Mobile Monitoring Unit for Special Study Data Collection

Inverter
- Turn on power for inverter by flipping toggle switch
- Start car
    - -Make sure that the fan to the inverter continues to run
    - -Plug in computer
    - -Plug in pDR-1500
- There is another power strip for use in back of the inverted if needed. This also has an on/off button.

Computer
-Be sure the USB cables for the pDR-1500 (via white USB cable) and GPS are plugged into the computer prior to starting up the computer.
-Start up computer. Password: super2007

pDR Set-Up
-Mount the pDR-1500 onto the wooden platform in the back seat of the HHR by clipping the metal belt clip to the black piece of canvas attached to the platform
-Insert prefabricated window insert into the rear driver's side window of the HHR. Use the automatic window button to secure its place firmly in the window.
- Attach stainless steel manifold through the window insert so that it is sticking outside of the window at a 90 º angle.
-Make sure the Blue Cyclone is properly inserted into the pDR-1500- **Or perform zero check (see below)**
-Attach plastic tubing attached to the cyclone to the stainless steel manifold
- From the desktop, open up the pDR Port software
-Select serial Port # 7 and hit Show Instrument Panel. You can now navigate through the pDR-1500 via the computer keypad or the pDR-1500 keypad.

*****NOTE:** You may have substantial problems getting the pDR to connect to the computer. If you experience these issues, you can just set up the pDR to collect data from the buttons on the pDR and download the run afterwards.

pDR-1500 Zero Check
-Power on the pDR-1500 (hold power button down for **3 seconds**), and from the Operate Menu press enter. Use the ↓↑ buttons to key to the Zero Instrument Screen.
-Perform a zero check on the pDR-1500 by placing the HEPA filter into the total inlet and press Enter (Do not Zero through the cyclone)
-It will take approximately 2-3 minutes for the cycle to complete at which time the instrument will indicate that the Zero is complete in the status.

pDR Run Set-Up
-The pDR-1500 will be pre-configured for the run, so from the Operate Menu on the screen, press Enter to Start a Run *, then Enter again to begin the instrument sampling.
-At the end of the sampling period select Stop through the Operate screen and it will automatically prompt you to save the file in the pDR Port file folder.

GPS Set-up

- Make sure the GPS is placed on the dashboard to the HHR and securely fastened using the Velcro on the back of the GPS unit.
- Open up the Street Atlas USA 2011 software from the desktop.
- When ready, hit the yellow GPS button on the top window of the Street software. This will start GPS tracking
- At the end of the sampling period, hit the yellow button on the top window of the Street software to stop the tracking. Follow the prompts to save the file. Save as: year-month-day_ loop name.

Car Chip

-Insert the car chip into the OBD plug at the bottom left of the steering wheel.
-This will start collecting data immediately upon starting the vehicle; there is no further action to be taken until you stop. At that point simply unplug and bring back upstairs for data downloading.

Voice Recorder

- Slide button on side up
- Hit the red record button to record notes
- Hit the black play/stop button to stop recording
- Once you are back in the office, translate your voice recordings into the Log page located in the NHDES ARD network under the directory for this study.

*****RECORD ALL START TIMES ON LOGSHEET AND TRY TO SYNC THE START OF THE CAR CHIP, PSR-1500, AND THE GPS AS CLOSELY IN TIME AS POSSIBLE*****

During the MAMS run, please take note of the following whenever applicable:

TRAVEL

- When getting on/off the highway.
- When starting motion (from where).
- When stopping (where).
- When beginning a significant/rapid climb in elevation (approx. location).
- When beginning a significant/rapid descent in elevation (approx. location).
- When entering/leaving any distinct area (residential, commercial, etc.).

SOURCES

- Large or numerous chimney plumes (also note orientation if possible).
- Outdoor wood fired boilers (OWBs).
- Vehicle fumes.
- Any unusual or especially large/numerous sources.

DATA

Whenever $PM_{2.5}$ concentrations rise or drop suddenly, make any relevant observations that might explain the change.

B1 SAMPLE DATASETS

Sample Car Chip Log

	Elapsed Time	Speed (MPH)	Engine Speed (RPM)	Battery Voltage (V)	Intake Air Temperature (°F)
1	0:00:00	0	794	14.80	80.6
2	0:00:30	0	779	14.66	69.8
3	0:01:00	0	781	14.43	71.6
4	0:01:30	0	769	14.43	69.8
5	0:02:00	0	759	14.41	69.8

Sample GPS Log

```
BEGIN TRACK trk001
Latitude, Longitude,Time,GPS Status,Heading (°T),Track Elevation (feet),Speed (MPH)
43.218497, -71.514460, 01/26/2011 03:07:39, 3-D DGPS, 0.00, 372.14566040, 0.00000000
43.218496, -71.514460, 01/26/2011 03:07:40, 3-D DGPS, 0.00, 372.11285400, 0.00000000
43.218496, -71.514460, 01/26/2011 03:07:41, 3-D DGPS, 0.00, 372.11285400, 0.11507795
43.218496, -71.514460, 01/26/2011 03:07:42, 3-D DGPS, 0.00, 372.08007813, 0.11507795
43.218495, -71.514460, 01/26/2011 03:07:43, 3-D DGPS, 0.00, 372.11285400, 0.00000000
43.218496, -71.514460, 01/26/2011 03:07:44, 3-D DGPS, 0.00, 372.14566040, 0.11507795
```

Sample MMU (PDRpDR) Log

```
>"Model Number", "PDRpDR-1500", 01.30
"Serial no.  ", "1016843143"
"Tag Number  ", 7
"Start Time  ", 17:03:52
"Start Date  ", 25-Jan-2011
"Log Period  ", 00:00:30
"Number      ", 1287
"CalFactor   ", 1.000000
"Unit        ", 0
"Unit Name   ", "ug/m3"
"TEMPUNITS   ", C
"RH CORRECT  ", "DISABLED"
"Max Disp    ", 474.177122
"Max Disp @ ", 20:43:55  25-Jan-2011
"Max STEL    ", 59.134579
"Max STEL @ ", 01:14:52  26-Jan-2011
"Avg point ", 27.740884
"ALARM       ", "DISABLED"
"ALARM_LEVEL ", 0.000000
"Errors      ", 0000
"Inlet Type  " "BLUE CYCLONE"
"FlowRate    ", 2.000000
"50% AED     ", 1.843519
"Site Name   ", "Factory default"

   record,  "ug/m3", Temp, RHum , AtmoPressure, Flags
     1,      17.87,  10.9,   27,   758,             00 ,  17:04:22,  25-Jan-2011
     2,      22.19,  10.8,   29,   758,             10 ,  17:04:52,  25-Jan-2011
     3,      22.35,  10.6,   30,   758,             00 ,  17:05:22,  25-Jan-2011
     4,      23.82,  10.5,   30,   758,             00 ,  17:05:52,  25-Jan-2011
     5,      20.60,  10.3,   30,   758,             00 ,  17:06:22,  25-Jan-2011
```

Sample Voice Log

TIME:	COMMENT: please note visible smoke, major land use changes, large emission sources…
4:13	Junction of rt 10 an 103 pdr1500 15.9 ug and steadily climbing
4:15	pdr1500=15.3 ug, Off Route-McDonolds Drive Thru
4:20	Back on 10 North pdr1500=18.2 ug, GPS log file 4202
4:25	pdr1500=22 ug, visual smoke, GPS log file 4204
4:27	North of Newport Visual smoke, pdr1500=29 ug, speed 45 mph, GPS log 4647
4:28	Increasing traffic, 2-3 cars every 1/2hr,

Sample Consolidated Trip Data Log

Date	Time	Latitude	Longitude	Elevation	Speed	Ext Temp	PDR	TSU	BAM	Notes
14-Jan-2011	17:42:16	43.218616	-71.514766	380.81	0.12	10.4	10.62	4	5.5	
14-Jan-2011	17:42:46	43.21843	-71.514644	383.73	14.85	10.3	1.62	4	5.5	
14-Jan-2011	17:43:16	43.217401	-71.515764	377.85	9.32	10.3	1.54	4	5.5	
14-Jan-2011	17:43:46	43.214374	-71.51775	364.14	35.90	10.3	1.49	4	5.5	
14-Jan-2011	17:44:16	43.211187	-71.518894	337.20	37.63	10.3	1.11	4	5.5	
14-Jan-2011	17:44:46	43.209318	-71.525038	256.04	38.55	10.3	1.18	4	5.5	
14-Jan-2011	17:45:16	43.208933	-71.52801	254.04	0.00	10.3	1.44	4	5.5	
14-Jan-2011	17:45:46	43.208951	-71.528595	256.69	25.89	10.3	1.65	4	5.5	Bridge St. Concord, stopped at a traffic light- moderate to heavy traffic.
14-Jan-2011	17:46:16	43.208985	-71.530712	265.75	0.12	10.3	1.48	4	5.5	
14-Jan-2011	17:46:46	43.208997	-71.531034	267.03	1.84	10.3	1.91	4	5.5	
14-Jan-2011	17:47:16	43.209	-71.531037	266.50	0.12	10.3	1.82	4	5.5	
14-Jan-2011	17:47:46	43.209001	-71.531039	270.96	0.00	10.3	2.48	4	5.5	
14-Jan-2011	17:48:16	43.208992	-71.531082	270.41	5.29	10.3	2.71	4	5.5	
14-Jan-2011	17:48:46	43.20891	-71.532701	260.76	21.40	10.4	4	4	5.5	Getting onto 93 South from Exit 14