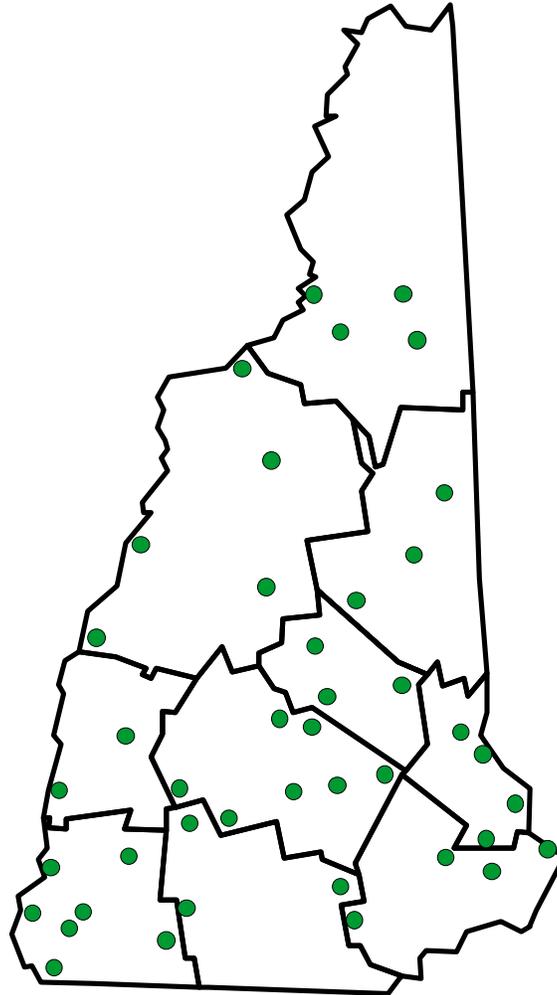


New Hampshire
Mobile Air Monitoring
Special Study on Small Particles, 2010-2011 and 2011-2012
Executive Report



August 2012

1.0 Introduction

The New Hampshire Department of Environmental Services (NHDES) conducted the Mobile Air Monitoring (MAM) Special Study during the winter of 2010-11 to identify New Hampshire communities at health risk for wintertime wood smoke stagnation events. NHDES followed with additional mobile monitoring over the 2011-12 winter season.

The concept of a mobile air monitoring study originated when continuous fine particle air pollution (PM_{2.5}) monitoring at the Keene air monitoring station recorded notably high levels of PM_{2.5} in winter while other New Hampshire monitors have rarely exceeded moderate levels of PM_{2.5} at any time of year. High PM_{2.5} concentrations in Keene generally occur during cold, windless nights as pollution accumulates under stagnant “valley inversion” conditions. Smoke from residential heating with wood releases much of the PM_{2.5}. In fact, PM_{2.5} filters collected for laboratory weighing smell strongly of wood smoke when concentrations are high.

NHDES began investigating the extent of the wood smoke issue in Keene during the winter of 2008-09; filter samples taken in multiple locations confirm a city-wide impact. Over the winter of 2009-10, NHDES partnered with Keene State College to run special filter samples in three surrounding towns during forecasted periods of high PM_{2.5}. These data indicate a potential for PM_{2.5} buildup in other communities as well.

Periodic stagnation events can create unhealthy conditions for citizens living in the affected communities; however, establishing air pollution monitors in every community is not financially feasible. Therefore, NHDES acquired mobile monitoring equipment to perform limited sampling of PM_{2.5} concentrations in numerous communities during forecasted events over the 2010-11 and 2011-12 seasons.

Results from this study should improve understanding of how localized emission and stagnation patterns vary across the state, especially in relationship to the well-documented patterns found in the Keene area.

2.0 Background

2.1 Potential Health Effects of PM_{2.5}

The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment, and the standards established by EPA are codified in 40 CFR part 50.

Table 1: National Ambient Air Quality Standards for PM_{2.5} ($\mu\text{g}/\text{m}^3$ = micrograms per cubic meter)

PM _{2.5}	primary and secondary	Annual	15 $\mu\text{g}/\text{m}^3$	annual mean, averaged over 3 years
		24-hour	35 $\mu\text{g}/\text{m}^3$	98th percentile, averaged over 3 years

It should be noted that compliance with the NAAQS health standard for PM_{2.5} is based on a three-year average of data not exceeding the levels defined in Table 1. Individual PM_{2.5} exceedances of the NAAQS threshold may qualify as Unhealthy for Sensitive Groups (USG) events (or similar), but do not individually meet the definition of violating the NAAQS.

PM_{2.5} can penetrate deep into the lungs when inhaled, potentially affecting the health of sensitive groups. Individuals susceptible to adverse effects of short-term (e.g., 24-hour) PM_{2.5} exposure comprise a large fraction of the U.S. population (as high as 50%), including those with existing respiratory disease, heart disease, or diabetes; older people; and young children. Health effects of short-term exposure in these populations include premature death; respiratory hospital admissions and emergency room visits; aggravated asthma; acute respiratory symptoms, including aggravated coughing and difficult or painful breathing; decreased lung function; and work and school absences.

Studies of long-term exposure to PM_{2.5}, as addressed by the annual PM_{2.5} NAAQS, have shown associations with increased mortality from all causes, lung cancer incidence and mortality, adverse respiratory endpoints, and reduced lung function growth in children (CCME 2004).

While the current NAAQS for PM_{2.5} includes only categories for 24-hour and annual exposure, the deployment of new, continuous (hourly) PM_{2.5} monitors is enabling more research to be focused on the health effects of very short-term spikes in PM_{2.5} (on the order of minutes to hours). These spikes could be of particular concern for communities such as Keene that experience cold-weather PM_{2.5} episodes from wood smoke. Some recent studies have suggested that short-term spikes in PM_{2.5} (1-12 hours) may be associated with acute cardiovascular and respiratory events, including myocardial infarction in older adults and asthma symptoms in children.

Fine particles also play a major role in the formation of regional haze. Regional haze degrades visibility and can diminish the enjoyment of natural and scenic areas.

2.2 Historical PM_{2.5} Monitoring in New Hampshire

Ambient air concentrations of PM_{2.5} in New Hampshire have declined over the past 10 years. Figures 1 and 2 illustrate New Hampshire PM_{2.5} trends based on yearly 98th percentiles (approximately the fourth highest value per year at each monitor). When averaged over three consecutive years, the 98th percentile is valid for comparison to the National Ambient Air Quality Standard (NAAQS).

While PM_{2.5} has generally been improving throughout New Hampshire, some areas periodically exceed the NAAQS threshold of 35µg/m³

Figure 1: PM_{2.5} Concentration Trends (98th Percentiles) in Northern and Western New Hampshire 2001-2010

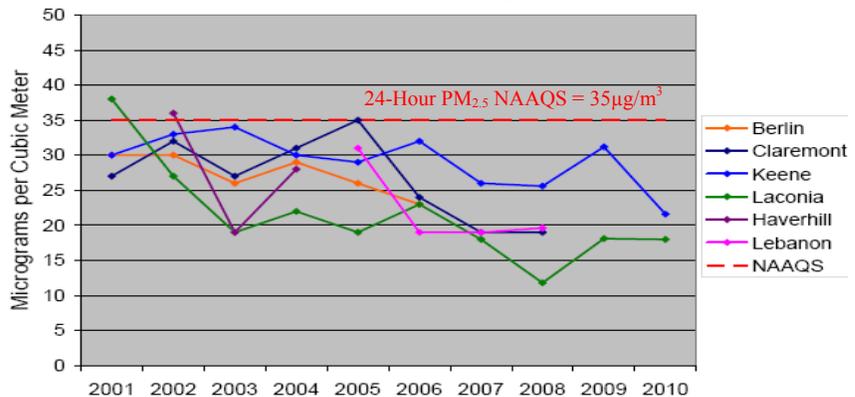
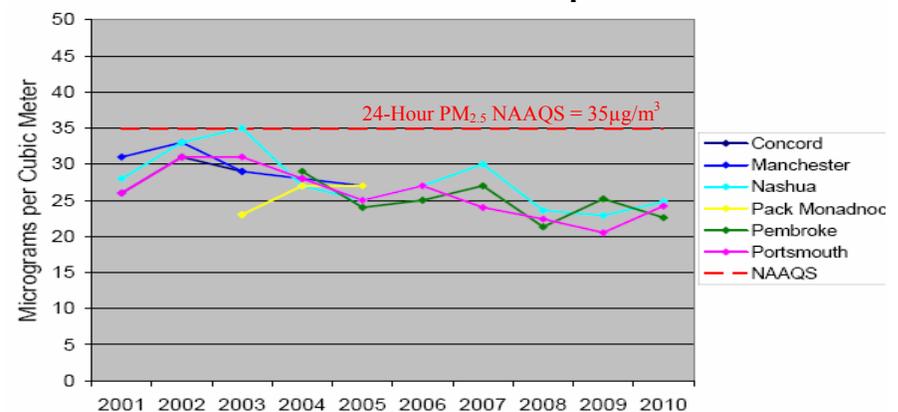


Figure 2: PM_{2.5} Concentration Trends (98th Percentiles) in Southern and Southeastern New Hampshire 2001-2010



for health. For example, smoke from extensive wildfires can blow into the state from long distances away. Large Canadian wildfires during the summers of 2002 and 2010 not only produced unhealthy air quality in New Hampshire, but people could see and smell the smoke. Other than wildfires, the transport of sulfate, nitrate, and organic soot from upwind areas usually has the greatest impact on PM_{2.5} concentrations in New Hampshire.

However, stagnation of locally sourced pollution can occasionally dominate, and the combination of stagnation and transport creates the conditions most ripe for localized air pollution events. The most distinct cases of stagnation in New Hampshire result from temperature inversions during cold, calm winter nights (Figure 3). In winter, the main source of PM_{2.5} in most areas of New Hampshire is wood burning for residential heating.

Lack of air circulation can lead to poor air quality. Figure 4 shows the correlation between low wind speeds and high PM_{2.5} in Keene during cold winter nights; extreme values tend to occur only when wind speeds fall below two miles per hour. In Figure 5, hourly data over a four-day period highlight how Keene PM_{2.5} concentrations rise when winds die down.

Figure 3: Thermal Inversions

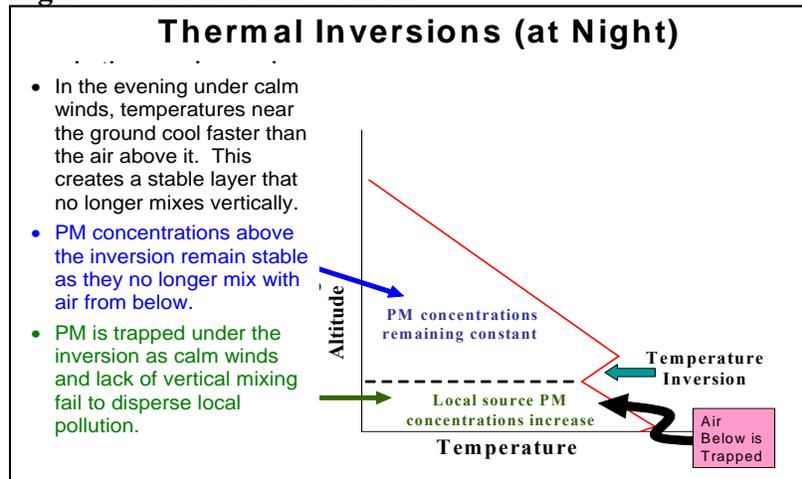
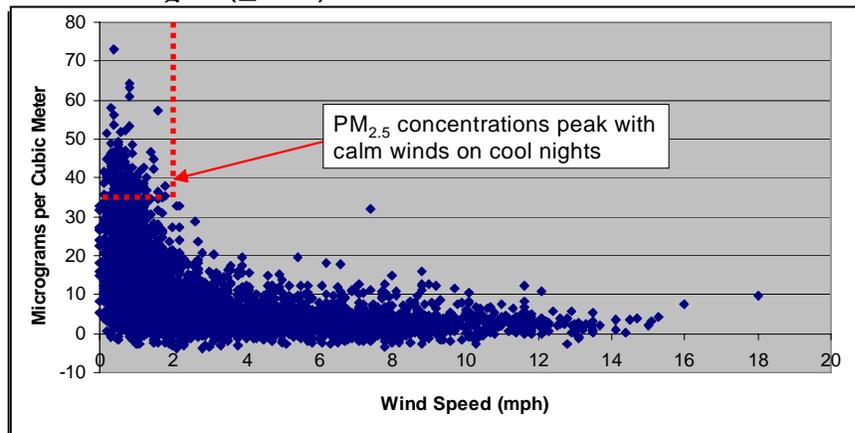
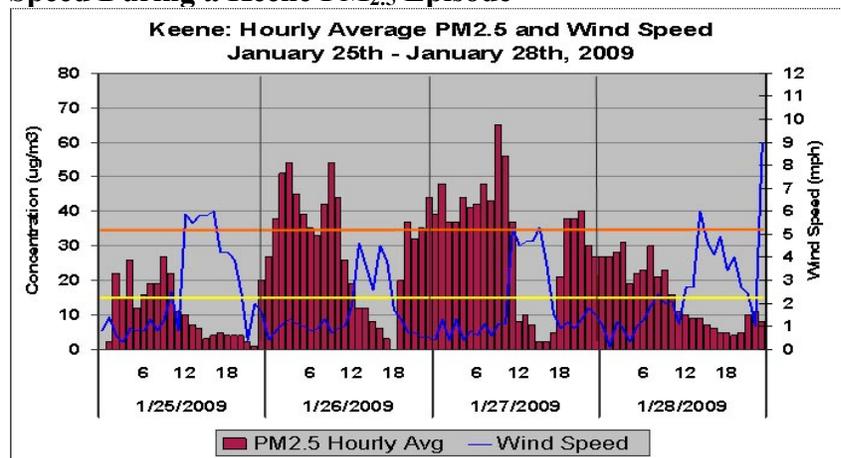


Figure 4: PM_{2.5} Concentration as a Function of Wind Speed on Cold Nights (≤ 45F)



Note: All monitored PM_{2.5} values greater than 35µg/m³ occurred with wind speeds below 2 MPH.

Figure 5: PM_{2.5} Concentration Patterns as a Function of Wind Speed During a Keene PM_{2.5} Episode



Note: PM_{2.5} values (red bars) and wind speed (blue line) have an inverse relationship. PM_{2.5} values drop when wind speeds increase during daylight hours. Orange and yellow lines indicate 24-hour and annual NAAQS levels.

2.3 Continuous PM_{2.5} Monitoring

Between 2002 and 2007, NHDES installed the Tapered Element Oscillating Microbalance (TEOM) at six locations to supplement federal reference method (FRM) data with continuous monitoring. NHDES has since replaced each of these unofficial TEOMs with the Beta Attenuation Monitor (BAM). The BAM, a continuous Federal Equivalent Method (FEM), reports average PM_{2.5} concentrations every hour. The introduction of this new technology showed that PM_{2.5} concentrations can vary significantly throughout the day. In some locations, it was not unusual for air quality to be in the good range all day, but quickly stagnate into the unhealthy ranges at night.

The typical diurnal pattern discerned from continuous PM_{2.5} monitoring differs markedly from summer to winter. Most of the year, the predominant air flow brings in pollution from other areas, creating fairly uniform PM_{2.5} concentrations throughout the day and similar average levels at each monitoring location (Figure 6).

In contrast, winter PM_{2.5} tends to exhibit diurnal fluctuations, with highest readings occurring at night (Figure 7). Concentrations rise in the evening, remain elevated overnight, dip toward morning, and rebound briefly around 8AM before settling to minimum daytime levels.

Weather favorable to localized wintertime PM_{2.5} USG events are likely to occur in Keene a few times every winter. Keene’s valley topography makes it especially susceptible to winter inversions that trap smoke from the city’s significant number of wood-burning homes (Keene PM_{2.5} FRM filters often smell of wood smoke).

Figure 6: Average Summer PM_{2.5} Diurnal for Keene, Lebanon and Manchester (June – August 2009)

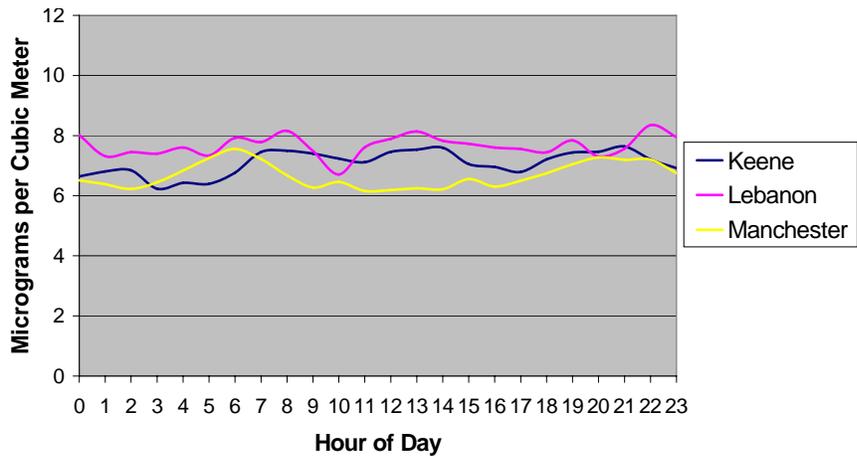
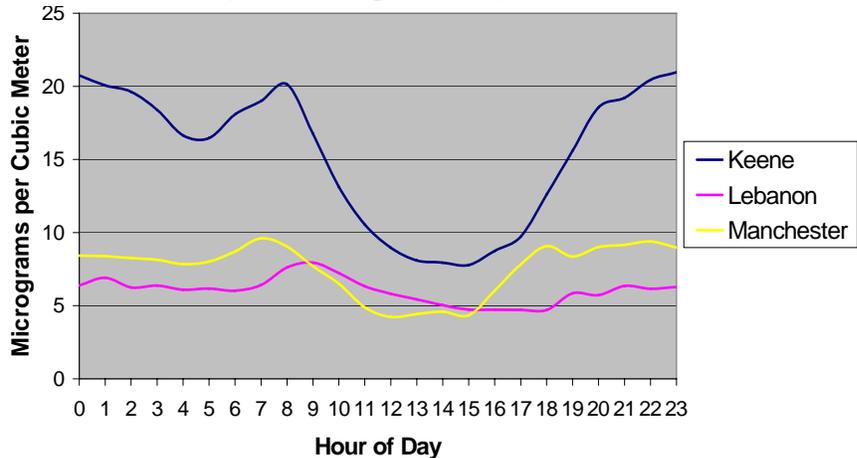


Figure 7: Average Winter PM_{2.5} Diurnal for Keene, Lebanon and Manchester (June – August 2009)



2.4 Who contributes to Wintertime PM_{2.5} Concentrations in New Hampshire?

In general, there are five categories of PM_{2.5} sources found in New Hampshire.

1. *Source-specific* – very localized and usually a single emission source. Sometimes source-specific emissions cover only a very small area with high PM_{2.5} levels. At other times a specific source can be large enough to significantly contribute to high PM_{2.5} levels over a large area. A single, high polluting woodstove or wood boiler would be an example of a source pertinent to this study.
2. *Local* – multiple emission sources spread over a neighborhood or several city blocks. A neighborhood where widespread wood burning is common is an example.
3. *Community-wide* – urban emissions from multiple residential, mobile, and industrial sources. Communities with a number of wood burning homes and significant vehicular traffic are common examples.
4. *Regional* – multi-state (urban and industrial) emissions transported over hundreds to thousands of miles. Distant forest fires and distant large uncontrolled industrial emissions are pertinent examples.
5. *Global* – international and intercontinental transport of industrial and environmental (dust) emissions. Eastern Asia is often blamed for international transport, but international transport can be from industrial emissions anywhere in the world. Volcanic, oceanic, and wind blown soils are also contributors to this category.

Local emissions and stagnation conditions are normally only small contributors of summertime PM_{2.5} in New Hampshire. When high summertime PM_{2.5} concentrations are forecasted in New Hampshire, there is usually a very large regional contribution from upwind urban, industrial, or forest fire sources.

During wintertime PM_{2.5} events in New Hampshire, usually local, community-wide, and regional emissions all play important roles, but local and community-wide sources can dominate due to stagnation. During periods of stagnation, concentrations of PM_{2.5} can vary widely, especially if wood is not burned cleanly over a neighborhood to community-wide scale. While local wood burning can create conditions considered unhealthy for sensitive groups, it usually needs an extra boost of PM_{2.5} from community background and/or regional transport to send concentrations into that range. Therefore, when air pollution forecasters see a mass of air (regional transport) already loaded with moderate levels of PM_{2.5} blowing into New Hampshire at a time favorable for overnight thermal inversions and stagnation, there is a strong possibility that an air pollution event could be forecasted.

Source-specific driven PM_{2.5} events can occur anytime of year in near proximity to the source when that source is in operation. Effects from single sources can be minimized if clean burning practices are used and manufacturer-suggested stack heights and property set-backs are followed. Local permitting and zoning provisions should always be followed.

3.0 MAM Project Description

Continuous PM_{2.5} data from the Keene monitoring station on Water Street and extra sampling during the winters of 2008-09 and 2009-10 revealed the nature of wood smoke buildup in and around Keene. Concerned about the health risk to Keene and communities with similar topography and demographics, NHDES employed mobile monitoring in the winters of 2010-11 and 2011-12 to assess the extent of risk. The goal was to drive designated routes during forecasted PM_{2.5} events to identify potential hot spots not covered by the established stationary monitoring network.

Project design plans called for NHDES to locate a BAM in one place along each sampling route while operating the Personal DataRAM 1500 (pDR) from a moving vehicle to record real-time concentrations in a series of target communities. Mobile air monitoring took place during four forecasted event nights. Start and end times were based on typical winter event diurnals and meteorology expected for the coming night.

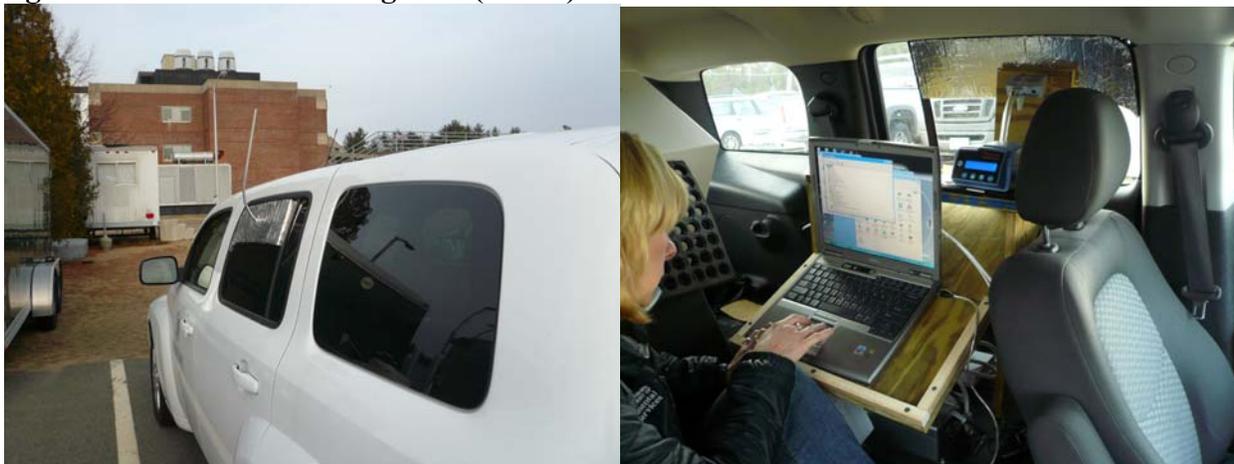
The pDR used in the MMU is not a Federal Reference Method or Federal Equivalent Method; however, the BAM units involved in the study are FEMs. For quality assurance, NHDES parked the MMU next to the TSU for a full hour at least once, sometimes twice, during each mobile monitoring run to provide a snapshot of the pDR performance compared to the FEM BAM. Throughout this study, NHDES followed all appropriate equipment and quality assurance practices. 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.

3.1 Equipment Configuration

3.1.1 Mobile Monitoring Unit (MMU)

NHDES converted a compact car into a mobile monitoring unit (MMU) to be driven through target communities during forecasted peak PM_{2.5} hours. The vehicle was equipped with a Dell laptop, GPS unit with Delorme mapping software, Thermo pDR (continuous PM_{1.0-1.87} monitor), and a power inverter to provide electrical power for the sampler. Minimal modifications to the vehicle were needed.

Figure 8: Mobile Monitoring Unit (MMU)



3.1.2 Temporary Stationary Unit (TSU)

Supplementing the mobile unit, a temporary stationary unit (TSU) housed a PM_{2.5} BAM in a climate controlled trailer that could be placed in a strategic location along each route. The unit could be plugged into a host electrical supply or operate by means of an electrical generator.

Figure 9: Temporary Stationary Unit (MMU)



3.2 Target Communities and Sampling Routes

NHDES compiled a list of target communities for sampling based on physical characteristics associated with smoke buildup in Keene as a reference. Keene lies in a flat area encircled by ridges of higher elevation. Thermal inversions commonly form in this “bowl” and can lead to overnight accumulation of ground-level PM_{2.5} in the city. Staff conducted visual inspections of some towns to confirm signs of wood burning, but compiled most of the information from maps, Census reports, and personal knowledge of the landscape. To narrow down target communities, NHDES considered several factors; topography, population density, and rate of wood burning for residential heating.

4.0 MAM Project Results

4.1 FRM Sampling in Keene and Surrounding Areas

City-wide PM_{2.5} sampling in Keene (2008-2009) found uniformity of PM_{2.5} concentrations throughout Keene, clearly indicating that winter PM_{2.5} events are community-wide.

PM_{2.5} sampling in surrounding communities (2009-2010) (Hillsborough, Marlborough, and Winchester) suggested that other nearby communities may experience some degree of winter wood smoke stagnation.

4.2 Consolidated Mobile Run Map Overlays

Data collected from each of the mobile sampling loops were consolidated and mapped to allow visual interpretation. These data are plotted on a background base map using multiple methodologies to narrow down areas of greatest concern. Figures 20 to 23 present continuous MMU PM_{2.5} concentration data and data normalized as described below.

- Figure 10 shows PM_{2.5} data measured by the MMU during every 30 seconds for all sampling loops.
- Figure 11 filters the data from Figure 10 to remove source-specific data spikes to allow a clearer perspective of neighborhood and community scale PM_{2.5} levels.
- Figure 12 shows MMU PM_{2.5} data normalized to a common location (Keene air monitoring station) measured every 30 seconds for all sampling loops.
- Figure 13 shows the same normalized data presented in Figure 12 but filters it to remove source-specific PM_{2.5} data spikes.

Before drawing conclusions from these maps, one must recognize that PM_{2.5} samples were collected on different days with differing weather patterns and residential heating needs. The night of the Southwestern and Southeastern Loops produced much higher concentrations in Keene than the other three loops. Factors such as temperature, thermal inversion timing and strength, and the presence of transport affected each event uniquely.

Some of these maps are based on comparisons of MMU and stationary Keene BAM data. Data collected by the MMU is instantaneous, but BAM data is hourly, and the PM_{2.5} NAAQS is based on a 24-hour average. Without data to support any possibility or assumption that instantaneous data would be consistent over one or 24 hours, interpretations must also consider this incongruity among datasets.

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 ($\mu\text{g}/\text{m}^3$) over a period of 24 hours (midnight to midnight) as unhealthy for sensitive populations.

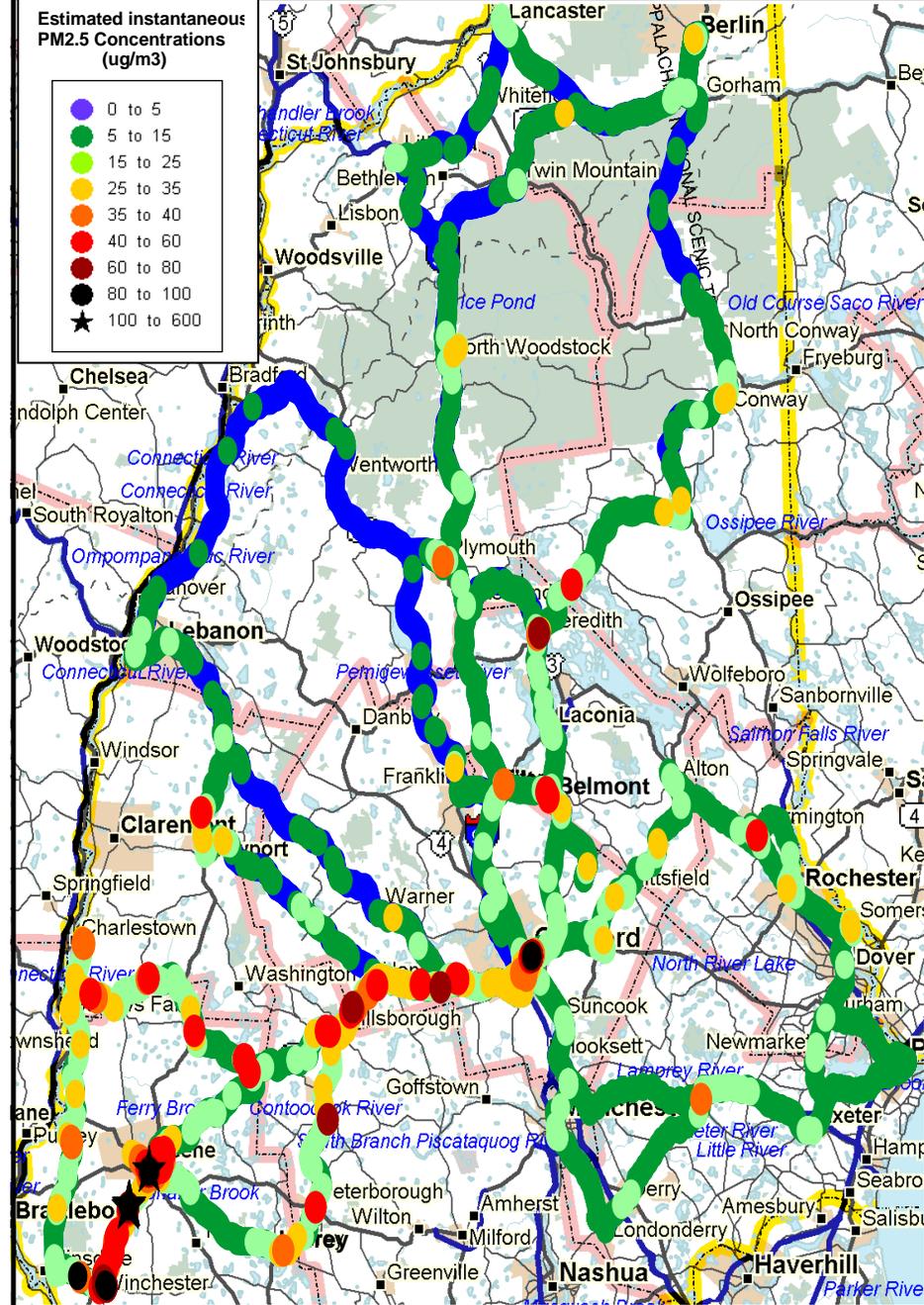
4.2.1 MMU Running Data (Instantaneous Concentrations $\mu\text{g}/\text{m}^3$)

Figure 10 tracks 30-second data from the MMU along each route. For consistency with the BAM, raw MMU concentration values are adjusted based on the best-fit line generated from the Concord and Winchester co-locations. Where drivers traversed part of the route more than once, the highest concentration is plotted after dismissing any spike known to be caused by an isolated source, such as an idling truck.

Many of the communities in the southwestern portion of the state recorded instantaneous values of $35 \mu\text{g}/\text{m}^3$ or higher, whereas most of the remainder of the state recorded lower levels. This is largely due to more extreme event conditions during the southwestern loop.

Elevated $\text{PM}_{2.5}$ concentration measurements were less uniform in the central and northern portions of the state, with hot spots appearing among areas with otherwise low concentrations. This pattern highlights how localized wood smoke buildup can be. Sudden jumps in $\text{PM}_{2.5}$ concentration occurred near communities such as Newport, Plymouth, Lincoln, and Meredith.

Figure 10: Composite Statewide Map of MMU $\text{PM}_{2.5}$ Values $\mu\text{g}/\text{m}^3$

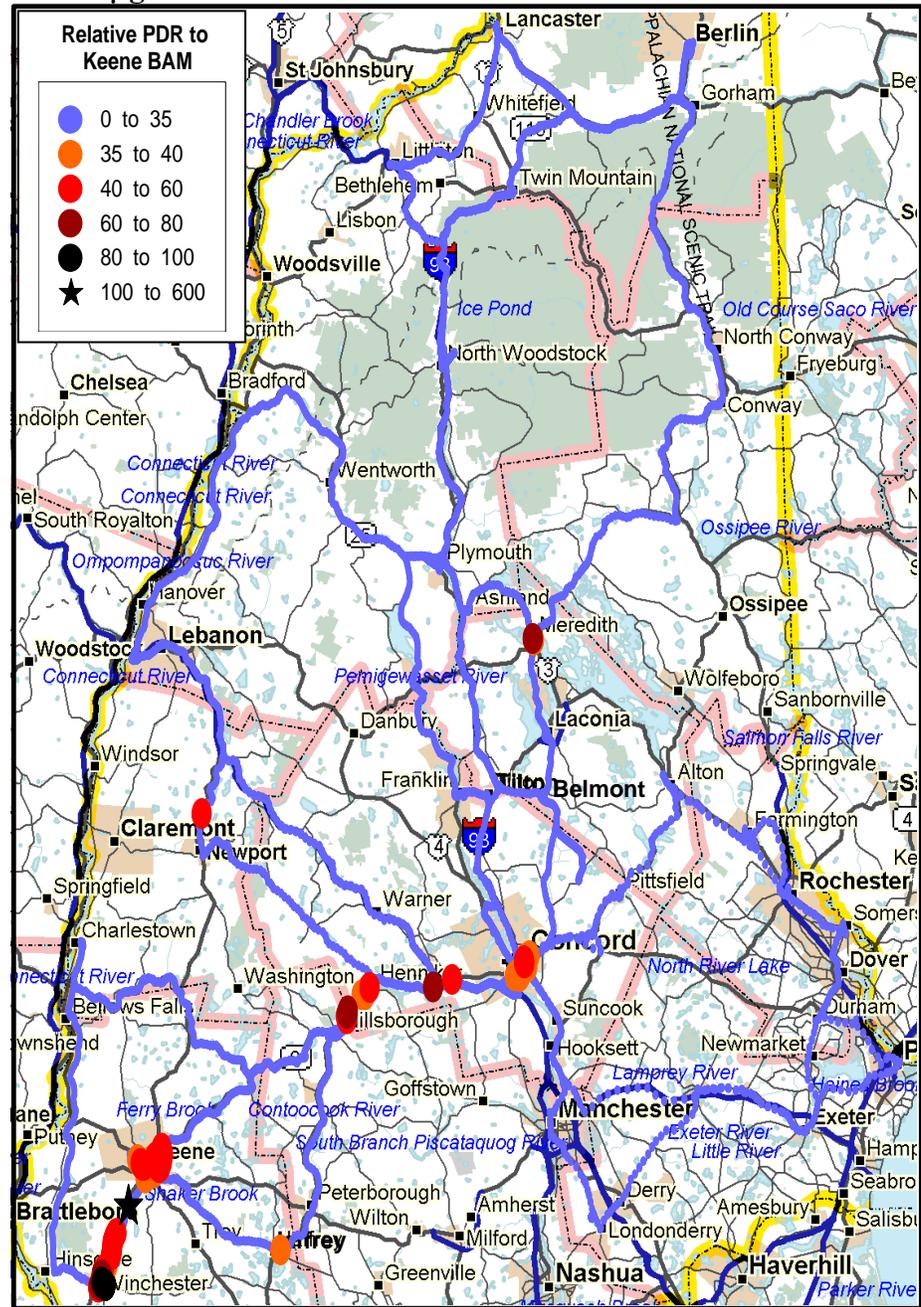


Data values are instantaneous and do not represent the 24-hour form of the $\text{PM}_{2.5}$ NAAQS. Data values were collected on different days and times and are not necessarily comparable. Some high concentrations marked in this figure may be localized to a single source and brief in duration.

Figure 11 represents a second look at the MMU data by applying a filter to account for “noise.” The filter reduces the signal for low and moderate PM_{2.5} concentration sample data (below 30 µg/m³) and removes brief PM_{2.5} spikes (failure to stay above 30 µg/m³ for 90 seconds while the MMU was in motion – 120 seconds for the Southeastern Loop). The purpose of selecting sustained concentrations on the high end of the concentration spectrum is to filter out localized individual smoke sources (residences, businesses, or vehicles) and instead distinguish communities or neighborhoods at risk for PM_{2.5} events.

The filtered map highlights two stretches where concentrations were recorded at continuously high levels. Communities between Winchester and Keene show the highest concentrations found by the MMU in this study. Several measurements above the NAAQS threshold of 35 µg/m³ were also detected along the route from Concord to Hillsborough.

Figure 11: Filtered Composite Statewide Map of MMU PM_{2.5} Values µg/m³



Data values 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.

4.2.2 Normalized MMU Data (Time-aligned ratio comparison to Keene)

To account for differing weather conditions among the sampling loops, NHDES employed a normalization technique. Since NHDES focuses much of its wood smoke event forecasts on the city of Keene, this method normalizes mobile air samples to Keene BAM data during the same time periods. Hourly averaged MMU values adjusted by the best-fit equation to the BAM were matched by time stamp to corresponding hourly Keene BAM data, and an MMU to BAM ratio was determined for each point on the map.

Figure 12 presents these ratios for all data along a color scale, where factors less than one indicate concentrations lower relative to Keene, and factors greater than one indicate concentrations higher relative to Keene.

The normalizing ratio helps account for variations in weather patterns, temperatures, and other variables among different sampling days. For example, raw concentrations in Littleton were fairly low, but Keene’s PM_{2.5} was also relatively low that night. When normalized, Littleton is seen as more important than the raw calibrated data in Figure 20 suggest. For a fuller understanding of the potential risk of a community for PM_{2.5} events, both datasets need to be considered.

Figure 12: Normalized Composite Statewide Map of MMU PM_{2.5} Values Relative to Keene BAM (MMU/Keene)

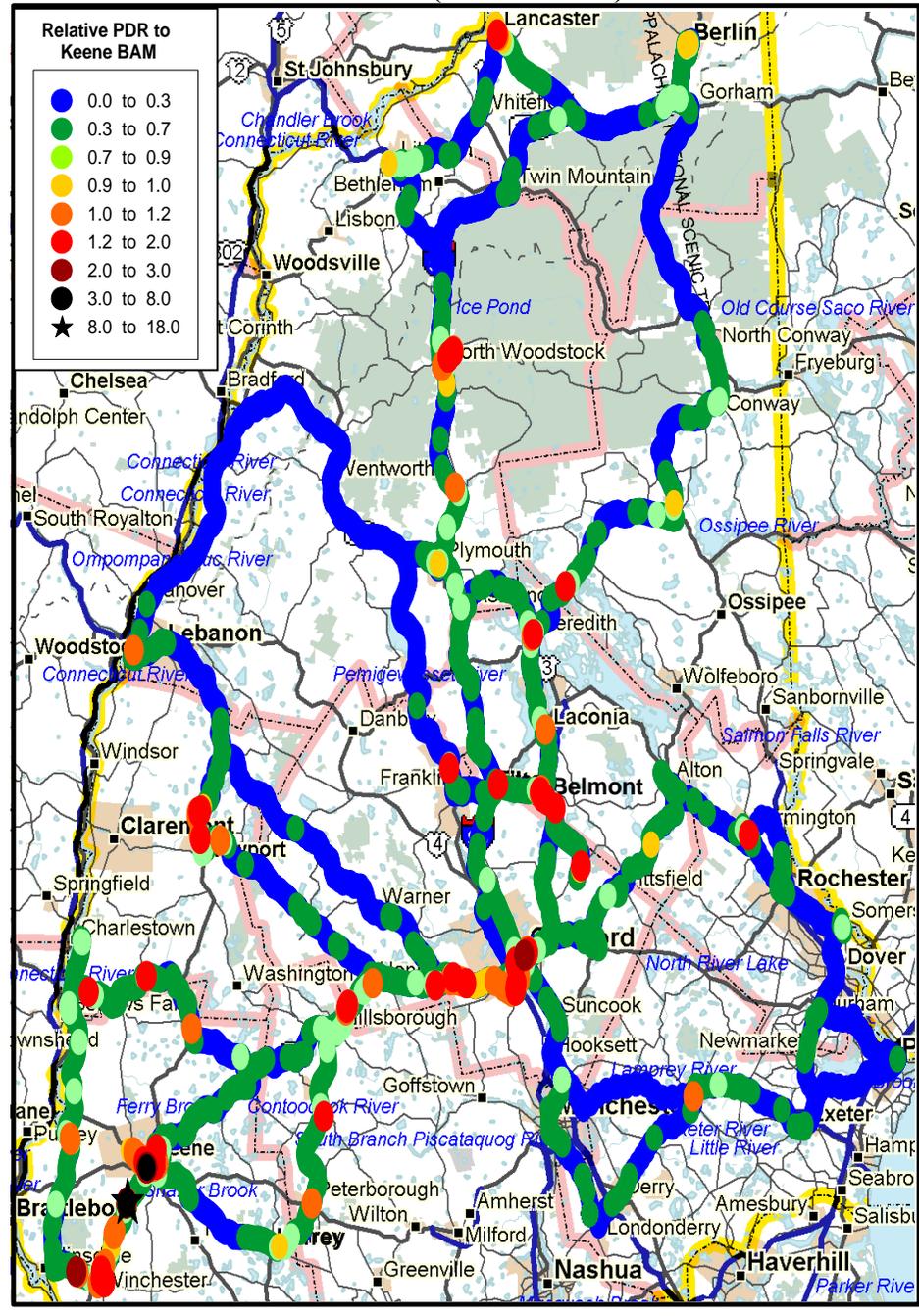
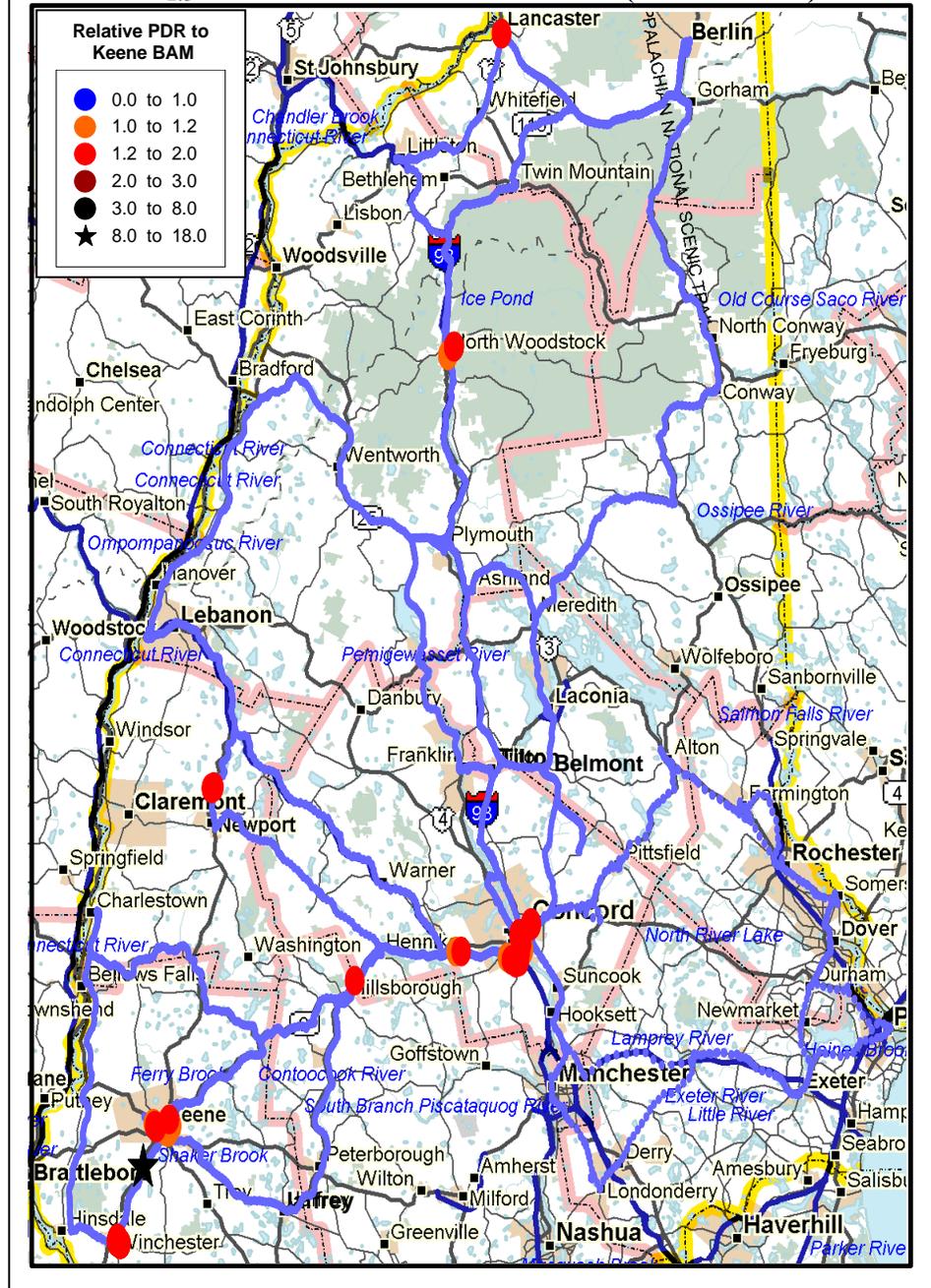


Figure 13 follows the same approach, but only includes filtered data (those with a normalization ratio higher than 1.0 and lasting more than 90 seconds while the MMU was in motion – 120 seconds for the Southeastern Loop). Communities that stand out most include West Swanzey, Winchester, and Concord. Also having a high ratio are Newport, Hopkinton, Hillsborough, Lincoln, and Lancaster.

Figure 13: Filtered Normalized Composite Statewide Map of MMU PM_{2.5} Values Relative to Keene BAM (MMU/Keene)



5.0 Summary and Conclusions

- In general, this study looked to identify community-wide risk areas where more than one or two city blocks are at risk for PM_{2.5} events. These areas generally have several or more sources contributing to routine stagnation buildups that can affect a larger population.
- Actual midnight-to-midnight wintertime NAAQS threshold exceedances in the exact form of the 24-hour PM_{2.5} NAAQS 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.
- Regional transport can play a significant role in overnight winter PM_{2.5} events. Transported PM_{2.5} forms a base level that local stagnation builds upon. The higher the base, the less local contribution is needed to form an event.
- Based on this study, Keene appears to incur the highest wintertime PM_{2.5} concentrations and the most frequent episodes among the larger communities in New Hampshire.
- However, certified monitoring data through 2011 show that Keene is not violating the current form of the PM_{2.5} NAAQS.
- Additional stationary monitoring in towns near Keene indicates that other communities have at least some potential for PM_{2.5} event risk.
- Data collected by the portable MMU unit provides only a snapshot of what PM_{2.5} levels were at the moment of collection. A high sample result does not necessarily mean that the location is at risk for a long enough exposure to be considered a health hazard. Conversely, a low reading is no guarantee that higher values do not sometimes occur.
- Mobile monitoring identified a few other locations in the state that could have some potential for NAAQS 24-hour threshold exceedances, or more likely exceed the 35 µg/m³ threshold for short periods (few hours). But there are no data showing that actual exceedances have happened or that there is a current health risk based on the NAAQS.
- Areas of isolated risk were found in many portions of the state. Such areas appear to be dominated by single sources and provided only brief spikes in measured concentrations as the MMU passed by. These may be neighborhood nuisances, and concerns should be raised to local officials.

- Communities of interest emerging from this study are as follows:

Table 2: Potential Communities of Interest:

Primary	Moderate Potential	Others to Watch
Sustained >35 $\mu\text{g}/\text{m}^3$ <u>and</u> a normalized ratio >1.0	Sustained >35 $\mu\text{g}/\text{m}^3$ <u>or</u> a normalized ratio >1.0	Notably local high concentration <u>or</u> normalized ratio
Concord	Hopkinton	Acworth
Keene	Jaffrey	Antrim
Henniker	Lancaster	Belmont
Hillsborough	Lincoln / North Woodstock	Berlin
Newport	Meredith	Charlestown
West Swanzey		Conway
Winchester		Farmington
		Langdon
		Marlow
		Pittsfield
		Plymouth
		Raymond
		Westmoreland

Notes:

1. “Sustained” refers to at least three consecutive 30-second pDR $\text{PM}_{2.5}$ concentrations from the Central, Southwest, North 1, North 2 MAM loops or at least two consecutive 60-second pDR $\text{PM}_{2.5}$ concentrations from the Southeast MAM loop
2. Not every town in New Hampshire has been sampled. The list above reflects only towns measured during this study.