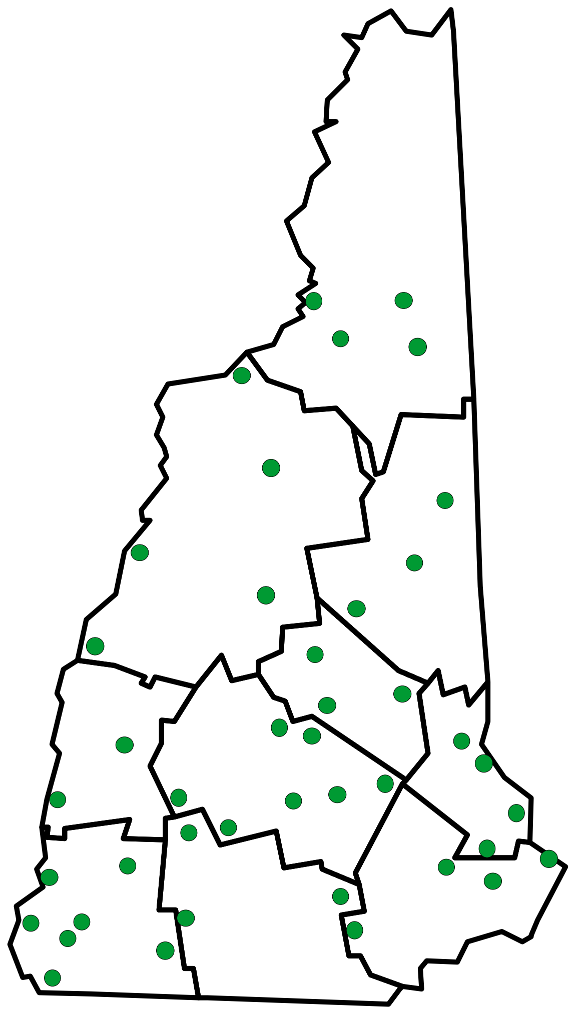
New Hampshire
Mobile Air Monitoring

Special Study on Small Particles ($PM_{2.5}$), 2010-2011 and 2011-2012



NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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. This project description and summary of results fulfills a requirement of the Environmental Protection Agency (EPA) for the funding that made this study possible.

The concept of a mobile air monitoring study originated when continuous fine particle (small 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 is believed to release 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.

These 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.

This report reviews the design, results, and implications of the New Hampshire mobile air monitoring study. NHDES anticipates that the results will improve wintertime air pollution forecasts for communities throughout New Hampshire through better understanding of localized emission sources and how those emissions can stagnate in relationship to the well-documented patterns found in the Keene area.

1.1 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. The Clean Air Act further identifies two types of NAAQS, primary and secondary. *Primary standards* provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. *Secondary standards* provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. For fine particle air pollution ($PM_{2.5}$), the secondary NAAQS is currently set equal to the level set as primary (Table 1).

Table 1: National Ambient Air Quality Standards for $PM_{2.5}$

$PM_{2.5}$	primary and secondary	Annual	15 µg/m^3	annual mean, averaged over 3 years
		24-hour	35 µg/m^3	98th percentile, averaged over 3 years

(µg/m^3 = micrograms per cubic meter)

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 $PM_{2.5}$ events exceeding the NAAQS threshold on a single event basis may considered as Unhealthy for Sensitive Groups event (or similar), but do not individually meet the definition of failing to meet the NAAQS health standard.

$PM_{2.5}$ can penetrate deep into the lungs when inhaled, potentially affecting the health of people with heart or lung diseases and respiratory conditions, as well as older adults and children. A reference of general health risks for $PM_{2.5}$ concentration ranges is provided below in Table 2. Often, $PM_{2.5}$ concentration levels might be referred to as "low" to generally indicate "good" air quality on a short-term basis (or longer), or "high" to similarly reflect $PM_{2.5}$ concentrations in the unhealthy for sensitive groups (USG) and higher classifications.

Table 2: Air Quality Guide Particle Pollution – Air Quality Index (AQI)

	$PM_{2.5}$	Populations Affected & Recommended Actions
Air Quality Descriptor	**24-hour concentration (µg/m^3)**	**Particle Pollution (fine particles)**
GOOD	0 – 15.4	No health impacts expected in this range.
MODERATE	15.5 – 35.0	Unusually sensitive people* should consider limiting prolonged exertion.
UNHEALTHY FOR SENSITIVE GROUPS	35.1 – 65.4	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.
UNHEALTHY	65.5-150.4	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion.
VERY UNHEALTHY	105.5 – 250.4	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
HAZARDOUS	≥ 250.5	Everyone should avoid all physical activity outdoors; people with respiratory or heart disease, the elderly and children should remain indoors and keep activity levels low.

* Unusually sensitive refers to individual people who are highly vulnerable to the effects of air pollution.

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 (Johnson and Graham 2005). 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 (U.S. EPA 1997).

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 (Pope et al. 2006; Mar et al. 2005; Adamkiewicz et al. 2004; Delfino et al. 2004; Peters et al. 2001).

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.

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U.S. EPA (1997). *Health and Environmental Effects of Particulate Matter*. Office of Air & Radiation. Office of Air Quality Planning & Standards. July 17, 1997.

1.2 NHDES Project Team

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Scott Klose	Route driver
Tom Fazzina	Route driver
John Colby	Health risk advisor
Charles Martone	Report editing

George Allen of Northeast States for Coordinated Air Use Management (NESCAUM) provided additional technical support for this study.

1.3 Commonly Used Acronyms

AQI	Air Quality Index – a measure of total air quality used to determine air pollution health risk
BAM	Beta Attenuation Monitor – a continuous $PM_{2.5}$ monitor unit
EPA	Environmental Protection Agency
FDMS	Filter Dynamic Measurement System - compensate for loss of volatiles
FEM	Federal Equivalence Method
FRM	Federal Reference Method – a federal monitoring standard methodology
MAM	Mobile Air Monitoring – Used in this study to refer to mobile $PM_{2.5}$ monitoring
MMU	Mobile Monitoring Unit – a car-based monitoring station – contains a pDR
NAAQS	National Ambient Air Quality Standard – federally established health standard
NHDES	New Hampshire Department of Environmental Services
pDR	Personal DataRam (pDR1500) – a small, hand-held $PM_{2.5}$ monitoring device
$PM_{2.5}$	Fine particulate matter smaller than 2.5 microns in diameter
R^2	Coefficient of determination - a direct relation to correlation.
TEOM	Tapered element oscillating microbalance –continuous $PM_{2.5}$ monitoring device
TSU	Temporary Stationary Unit – a trailer-based monitoring station - used in this study to house a BAM unit
$\mu g/m^3$	Micrograms per cubic meter – a $PM_{2.5}$ air concentration metric
USG	Unhealthy for sensitive groups – health risk level

1.4 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). Historical $PM_{2.5}$ trends are derived from Federal Reference Method (FRM) 24-hour filter samples which are generally measured once every three or six days.

While $PM_{2.5}$ has generally been improving throughout New Hampshire, some areas periodically exceed the NAAQS threshold of 35µg/m³ 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 the smoke could also be seen and smelled. 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.

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

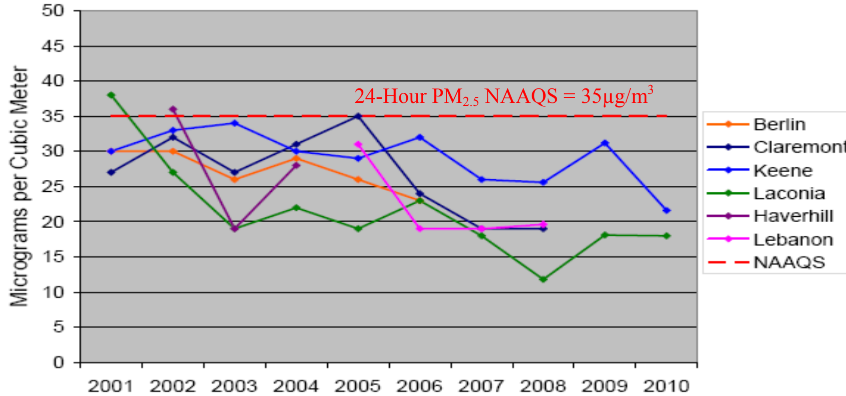
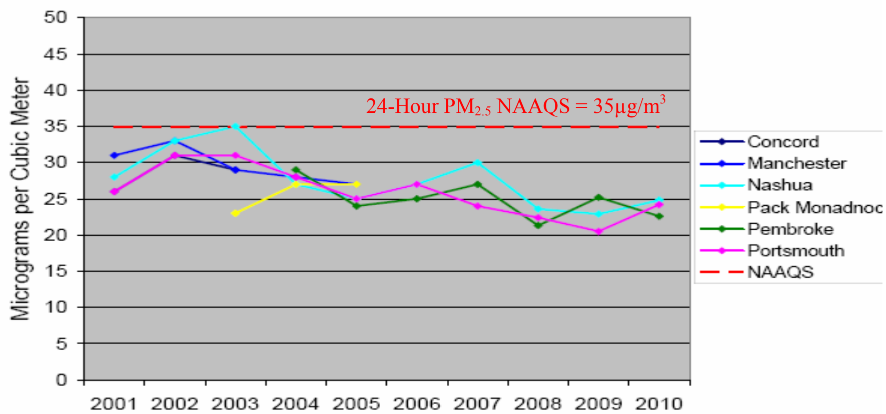


Figure 2: $PM_{2.5}$ Concentration Trends (98th Percentiles) in Southern and Southeastern New Hampshire 2001-2010

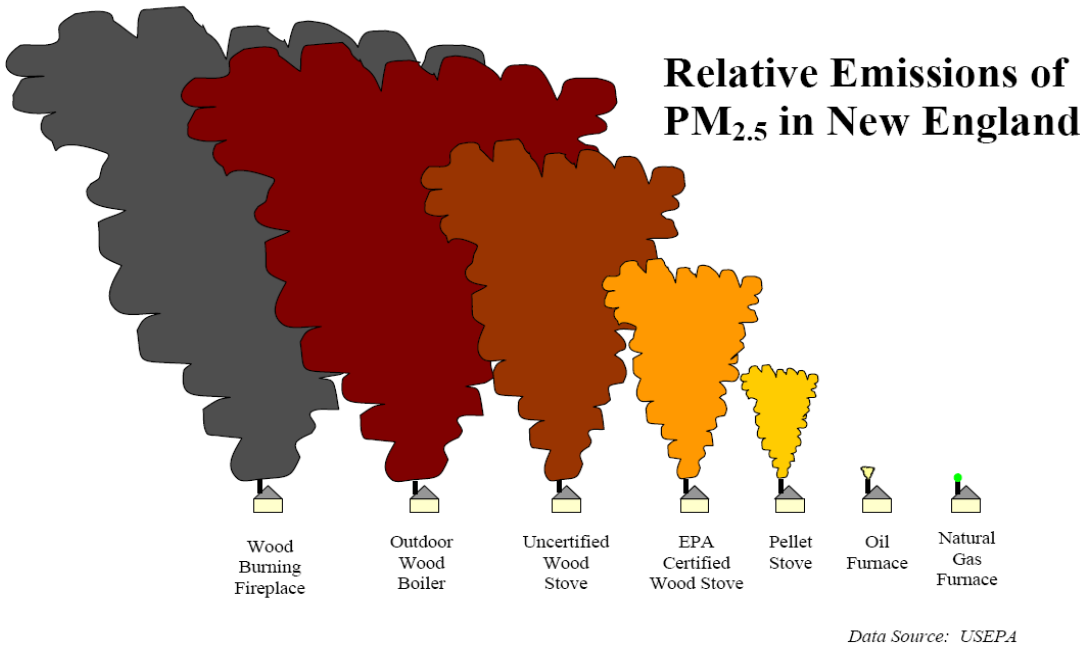


However, stagnation of locally sourced pollution can occasionally dominate, and the combination of stagnation and transport creates the conditions most ripe for localized air pollution events. The most distinct cases of stagnation in New Hampshire result from temperature inversions during cold, calm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

Residential heating with wood can take place in indoor wood stoves (both EPA certified and non-certified), pellet stoves, fireplaces and outdoor wood boilers (OWBs). $PM_{2.5}$ emission rates vary widely among the different types of units and thus they can have very different localized effects. While New Hampshire does not regulate residential wood burning devices, we offer best management practices for wood burning and there are requirements for the sale, installation, and use of OWBs in the state.

Source-specific driven $PM_{2.5}$ events can occur anytime of year in near proximity to a source in operation. Such events can be minimized or even eliminated by using cleaner wood burning devices (see Figure 3). Always use heating devices in accordance to the manufacturer's specifications and ensure local permitting and zoning provisions are followed. More information regarding wood burning heating options and clean burning practices, visit: http://www.epa.gov/burnwise/appliances.html.

Figure 3: Relative $PM_{2.5}$ Emissions by Heating Source Type



To better understand the nature of wood burning habits in New Hampshire, NHDES performed a series of studies in conjunction with a 2009 wood stove change-out program. The first survey was done in December 2009 by Keene State College students at the transfer station before the wood stove change-out program. The second was done after the wood stove change-out program in mid June 2010. A third survey was conducted over the summer and fall of 2010 by an intern making phone calls to 529 respondents.

Most of the people in the Keene area burn seasoned hardwood and no other materials. Of the survey respondents, 6% use wood as a primary source of heat and 14% as a secondary source. Of the total 105 wood users, 31 burn wood as a primary source and 16 of them are EPA certified. Fourteen of those combined thought that their stove was likely EPA certified. Of the 74 secondary source users 12 of them are EPA certified. Forty percent of the woodstoves in Keene are (most likely) EPA certified. Some respondents did not know if their stoves were EPA certified. Over the course of the surveys, there was only one respondent stating that they use an outdoor wood boiler.

For the purposes of this report, the different types of wood heating units are collectively referred to as wood burning devices and are not distinguished in type.

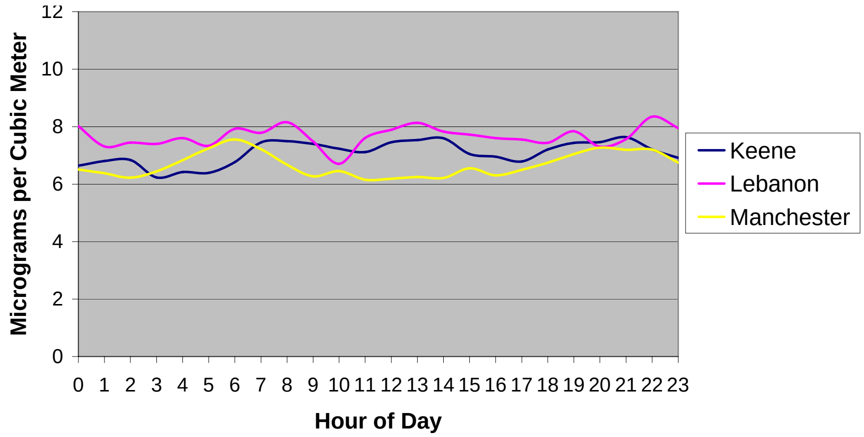
1.5 Continuous $PM_{2.5}$ Monitoring

Due to limitations associated with filter-based monitors, NHDES initiated continuous monitoring. Continuous monitoring began with installation of the Tapered Element Oscillating Microbalance (TEOM) at six sites between 2002 and 2007; these were later reduced to the five locations of greatest interest. NHDES has more recently replaced each of these unofficial TEOMs with the

Beta Attenuation Monitor (BAM) in Keene, Lebanon, Portsmouth, Londonderry, and on the summit of Pack Monadnock. The BAM, a continuous Federal Equivalent Method (FEM), reports average $PM_{2.5}$ concentrations every hour.

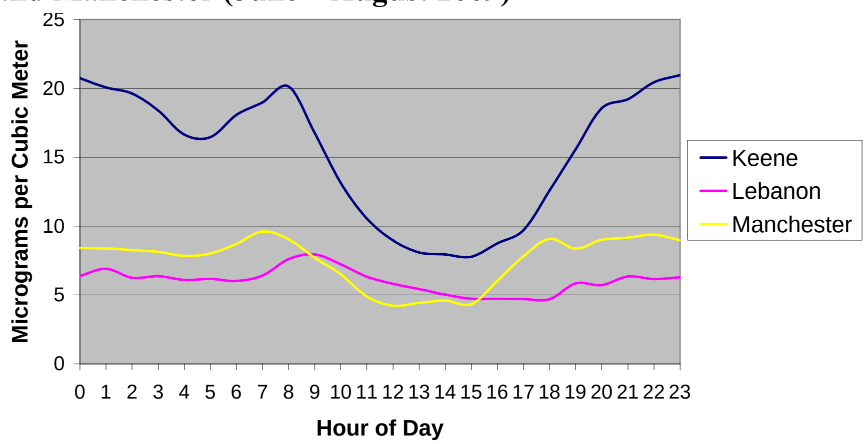
The typical diurnal pattern discerned from continuous $PM_{2.5}$ monitoring differs markedly from summer to winter. Most of the year, the predominant air flow brings in pollution from other areas, creating fairly uniform $PM_{2.5}$ concentrations throughout the day and similar average levels at each monitoring location (Figure 4).

Figure 4: Average Summer $PM_{2.5}$ Diurnal for Keene, Lebanon and Manchester (June – August 2009)



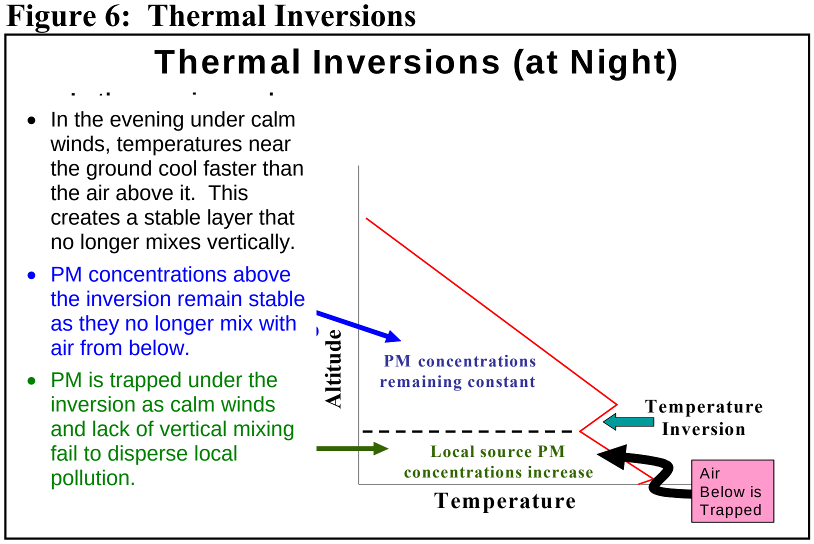
In contrast, winter $PM_{2.5}$ tends to be highest at night (Figure 5). Concentrations rise in the evening, remain elevated overnight, dip toward morning, and rebound briefly around 8AM before settling to minimum daytime levels.

Figure 5: Average Winter $PM_{2.5}$ Diurnal for Keene, Lebanon and Manchester (June – August 2009)



This winter pattern, most sharply illustrated by Keene data, results from periodic thermal inversions (Figure 6). An inversion traps pollution near the ground, where it accumulates until the heat of daybreak initiates vertical mixing. The primary source of the $PM_{2.5}$ that builds overnight is residential wood burning. The evening rise and morning peak coincide with the hours residents commonly stoke their woodstoves after arriving home or before leaving for work.

Figure 6: Thermal Inversions



1.6 Keene $PM_{2.5}$ Events

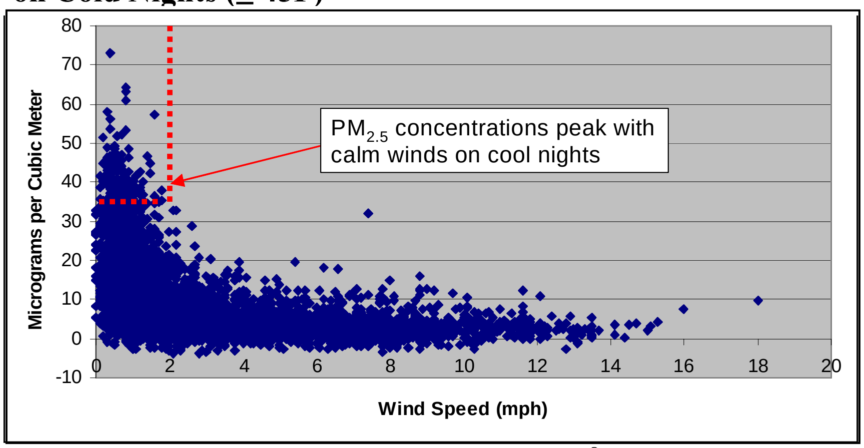
NHDES began continuous monitoring in Keene in October 2007 with the TEOM and upgraded to a Federal Equivalent Method with installation of the BAM in October 2008. Previous filter-based monitoring was limited to one 24-hour filter-based sample collected every sixth day and could not depict the diurnal pattern. In contrast, continuous monitoring drew attention to wintertime particle concentrations in Keene that approach and sometimes exceed levels defined as unhealthy for sensitive groups (USG) (35 micrograms per cubic meter on a 24-hour basis). The newly visible diurnals revealed for the first time the potential height of particle buildup on winter nights.

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. In fact, Keene $PM_{2.5}$ FRM filters sometimes smelled of wood smoke.

Lack of air circulation can lead to poor air quality. Figure 7 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 8, hourly data over a four-day period highlight how Keene $PM_{2.5}$ concentrations rise when winds die down.

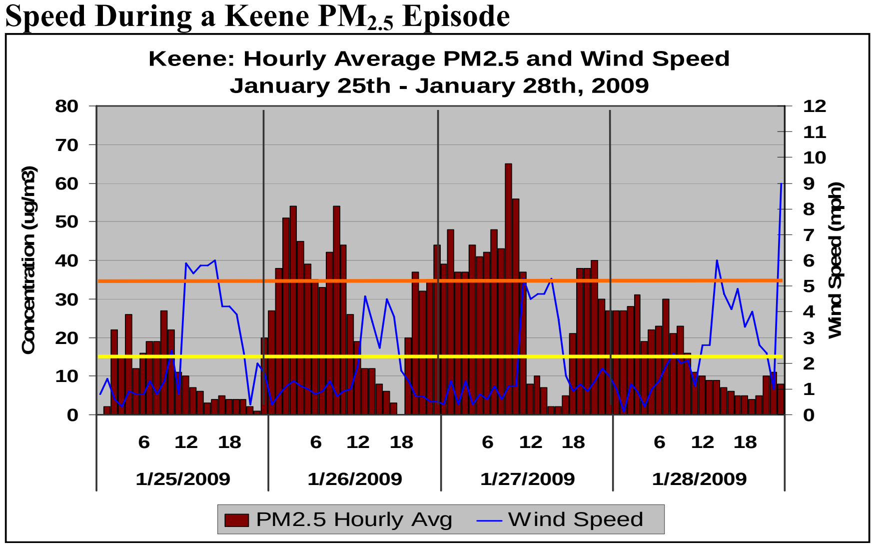
The restricted number of FRM samples and lack of historical continuous data make it difficult to determine whether localized wood smoke events are more frequent today than years ago, but continuous monitoring demonstrates that hourly concentrations can briefly reach unhealthy levels even when the area technically meets 24-hour NAAQS health threshold of 35 $\mu g/m^3$.

Figure 7: $PM_{2.5}$ Concentration as a Function of Wind Speed on Cold Nights (≤ 45F)



Note: All monitored $PM_{2.5}$ values greater than 35$\mu g/m^3$ occurred with wind speeds below 2 MPH.

Figure 8: $PM_{2.5}$ 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.

1.7 Special $PM_{2.5}$ Studies in Keene

In light of recent data from Keene's continuous monitor, NHDES has undertaken a comprehensive $PM_{2.5}$ sampling project over the past four winters, culminating in the 2010-12 MAM Study. Each season, NHDES focused on a specific question about the wood smoke issue:

- **Winter 2008-2009:** Are overnight $PM_{2.5}$ concentration peaks in Keene isolated to the location of the air monitoring station, or do they represent levels throughout the city?
- **Winter 2009-2010:** Are these USG events limited to Keene, or do similar $PM_{2.5}$ levels occur in other nearby communities?
- **Winter 2010-2011:** Beyond the handful of communities sampled in the southwestern portion of the state, are there other locations throughout the state at similar risk for unhealthy wintertime levels of $PM_{2.5}$? What can we learn from mobile monitoring in the southwestern, west-central, and northern parts of the state?
- **Winter 2011-2012:** Are there $PM_{2.5}$ USG event risks in communities in the southeastern part of the state? Can we gather more data for communities of highest risk based on last winter's mobile monitoring?

Data collected during the winter 2008-2009 and 2009-2010 seasons have not been formally reported and are summarized in this report.

1.7.1 City-wide $PM_{2.5}$ Sampling in Keene (2008-2009)

Figure 9 shows results from the Keene monitoring station on Water Street compared to four temporary samplers positioned in Keene approximately north, south, east, and west of the Water Street monitor. NHDES collected filter-based 24-hour samples during four separate events from January to February 2009; the chart also includes a sample taken the following season in March 2010.

The data show surprising uniformity of $PM_{2.5}$ concentrations throughout Keene, clearly indicating that winter $PM_{2.5}$ events are community-wide.

Figure 9: 24-Hour $PM_{2.5}$ Concentrations Measured Throughout Keene (2008-2009)

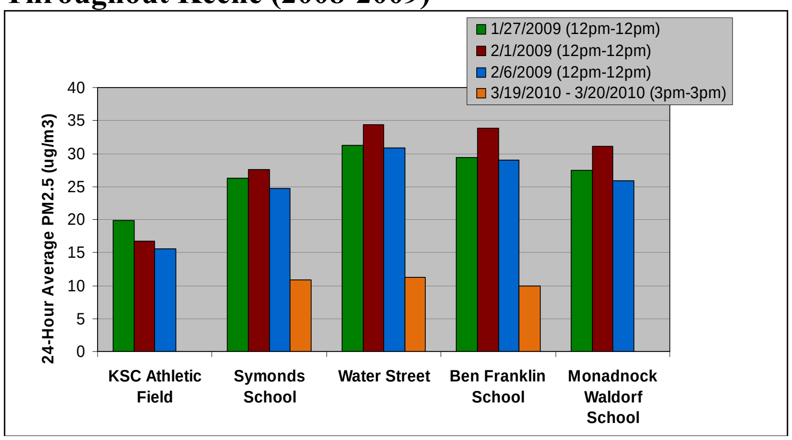
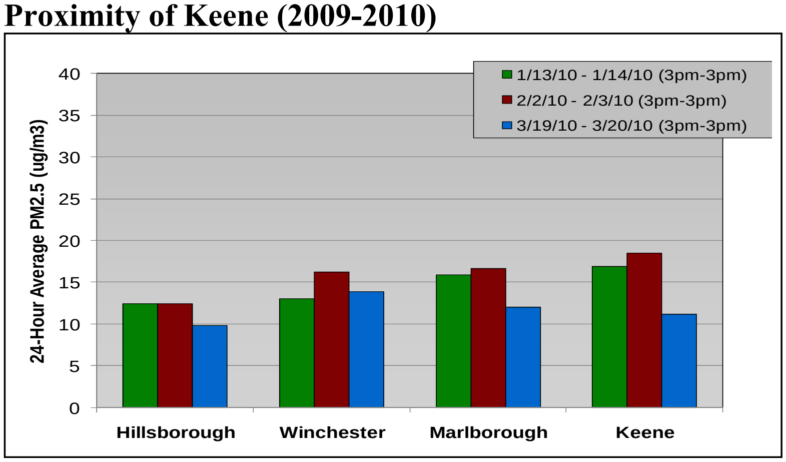


Figure 10: 24-Hour $PM_{2.5}$ Concentrations Measured in Proximity of Keene (2009-2010)



1.7.2 $PM_{2.5}$ Sampling in Surrounding Communities (2009-2010)

Figure 10 presents additional filter data collected January-March 2010 in Keene, Hillsborough, Marlborough, and Winchester. Like Keene, the three neighboring towns are located in low-lying areas of southwestern New Hampshire and contain a significant number of homes reliant on wood for heat. While the $PM_{2.5}$ concentrations during this phase were below those measured within Keene during the 2008-09 study, the data suggest that other nearby communities may experience some degree of winter wood smoke stagnation.

1.7.3 Statewide Mobile $PM_{2.5}$ Monitoring

$PM_{2.5}$ monitoring results from the 2008-09 and 2009-10 monitoring studies confirm that elevated $PM_{2.5}$ is a city-wide issue in Keene and that there is a strong possibility other New Hampshire communities experience wood smoke stagnation events. NHDES proceeded during the winter of 2010-11 to investigate a wider geographic area with mobile monitoring. Mobile monitoring routes traversed northern, central/western, and southwestern sections of the state.

During winter 2011-12, NHDES scheduled another mobile run to explore southeastern New Hampshire and strategically placed a temporarily sited BAM on Hazen Drive in Concord for this study (see Section 2.1.2). Subsequent sections assess mobile monitoring and related $PM_{2.5}$ data in detail.

1.8 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 and other times a source-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 could be an example of this type of source pertinent to this study.

2. Local – multiple emission sources spread over a neighborhood or several city block scale. 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 scales of 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 sector.

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 sectors 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 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.

2.0 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 exposed 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 monitoring network.

To develop a mobile air monitoring unit, NHDES requested an EPA supplemental distribution from FY 2010 State and Tribal Assistance Grant (STAG) funds. Grant money funded equipment and the staff time for project design, data collection, analysis, and reporting.

With the EPA Mobile Air Monitoring grant, NHDES purchased a $PM_{2.5}$ Met One BAM (FEM EQPM-0308-170) and an even more portable Personal DataRAM 1500 (pDR). Project design plans called for NHDES to park the BAM in one place along each route while operating the 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. 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 sources in the dark.

The pDR used in the MMU is not a Federal Reference Method (FRM) or Federal Equivalent Method (FEM); however, the BAM installed in the Temporary Stationary Unit (TSU) and the BAMs located at the Keene and Lebanon continuous monitoring stations 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.

Although some co-location between the pDR and the FEM BAM took place during the mobile monitoring runs, these one or two hour periods were insufficient to develop a general correlation between the instruments. To this end, NHDES took advantage of time before and after events to set up extended MMU pDR and TSU BAM co-locations. These took place for a total of about 50 days during three separate periods in two locations: Concord and Winchester.

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.

2.1 Equipment Configuration

2.1.1 Mobile Monitoring Unit (MMU)

NHDES converted a compact car into a mobile monitoring unit (MMU) to be driven through target communities during peak $PM_{2.5}$ hours. The pictures in Attachment A show the MMU and its internal configuration.

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 fall under the 1.0um, and particles in the 0-1.0um 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 at 30-second intervals for 2010-11 mobile monitoring and at one-minute intervals when monitoring in 2011-12. 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.

Drivers referred to written instructions to operate equipment and kept a log of the most critical information, such as town boundaries, landmarks, and the sight or smell of smoke (Attachment B). They recorded on a voice recorder their observations and the time they occurred, and a technician transcribed the notes after each run.

Attachment C shows sample outputs from the various data loggers, including the car chip, GPS, pDR, and voice recorder. All comments and data, each in its unique format, were imported into a common spreadsheet. Time stamps facilitated data consolidation, but aligning voice recorder comments was somewhat imprecise. The pDR time could be a minute or two different than the computer time noted by the driver, and any lapse between the statement of the time and the full description of the observation added uncertainty. NHDES drew on the comprehensive log of all critical parameters to generate the episode charts and maps presented in Sections 3.4-3.5 and Attachments E-I.

2.1.2 Temporary Stationary Unit (TSU)

Supplementing the mobile unit, a temporary stationary unit (TSU) housed a $PM_{2.5}$ BAM in a trailer that could be placed in a strategic location along each route. Attachment D shows the TSU and its internal configuration.

The TSU unit was set up days to weeks ahead of events to allow the unit to stabilize and collect meaningful data in a community of interest. At least once during the overnight period, the MMU was parked alongside the TSU for a full hour of co-location between the BAM and pDR.

2.2 Target Communities and Sampling Routes

NHDES compiled a list of target communities for sampling based on characteristics of 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 conducive to thermal inversions
- moderately high population density
- relatively high rate of wood burning for residential heating

Based on these criteria, NHDES grouped a number of suitable candidates into sampling areas. The timing of sampling runs was an additional consideration in the study design. Although Keene often experiences high moderate $PM_{2.5}$ throughout the winter, extreme events ideal for sampling runs are infrequent. Anticipating up to three testing opportunities during the 2010-11 season, NHDES focused on three regions of the state: central, southwest, and north. The North became two loops because of the extra travel time required to reach the area, so NHDES planned four loops small enough for each to be completed in one night. NHDES later planned a fifth loop (Southeastern) for the 2011-12 season to explore the southeastern part of the state.

Listed below are the target communities assigned to the five sampling loops. Co-locating the pDR with an FEM BAM was key to quality assurance; co-location sites are bolded below. NHDES parked the TSU BAM in a populated community along each route; TSU locations are underlined below. Subsequent sections provide maps and descriptions of each route.

- ***Central Loop (Event 1)*** - Concord, Franklin, Bristol, Plymouth, Orford, <u>Lebanon</u>, Hanover, Newport, Bradford, Henniker

- ***Southwestern Loop (Event 2)*** - <u>Concord</u>, Hillsboro, Marlow, Acworth, Charlestown, Walpole, Chesterfield, Hinsdale, Winchester, **Keene**, Jaffrey, Peterborough, Antrim

- ***Northern Loops***
  - ***Run 1 (Event 3)*** - North Woodstock - Lincoln, <u>Gorham</u>, Berlin, Conway, Meredith, Laconia, Belmont, Tilton
  - ***Run 2 (Event 4)*** - North Woodstock - Lincoln, Gorham, <u>Berlin</u>, Lancaster, Littleton, Franconia, Meredith, Laconia, Belmont, Tilton

- ***Southeastern Loop (Event 5)*** – Concord**,** Alton, Farmington, Rochester, Somersworth, Dover, Durham, **Portsmouth**, Exeter, Raymond, **Londonderry**, Manchester, and Pembroke

2.2.1 Central Loop

The Central Loop explores the hills and valleys west of Concord and north of Keene (Figure 11). Communities targeted for this loop are Newport, Lebanon, Franklin, and Plymouth. The TSU was placed in a residential area of the Lebanon valley in contrast to the hilltop position of the permanent monitoring station at Lebanon Airport (elevation difference of about 200 feet).

2.2.2 Southwestern Loop

The Southwestern Loop expands on data previously attained in the southwest corner of the state (Figure 12). It covers communities in the Monadnock region and along the lower Connecticut River valley. Communities of special interest included Concord, Charlestown, Hillsborough, Jaffrey, Keene, Peterborough, Westmoreland, and Winchester. The TSU was parked in Concord, just outside the NHDES building.

Figure 11: Central Loop Map

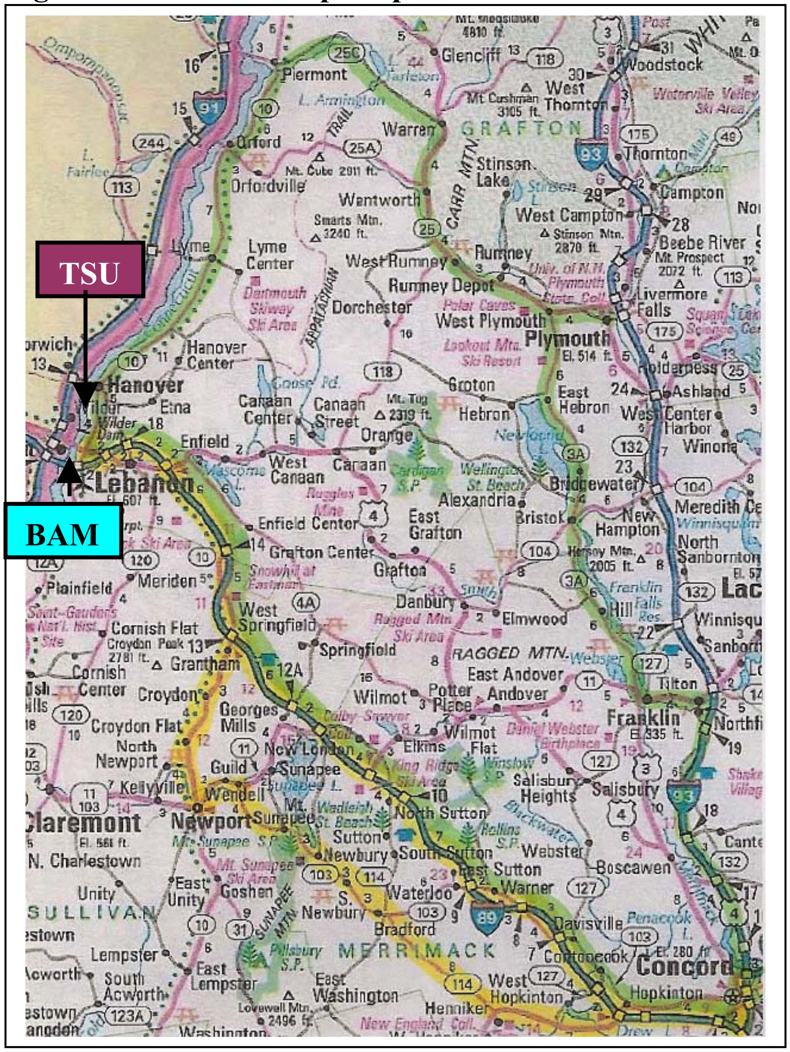
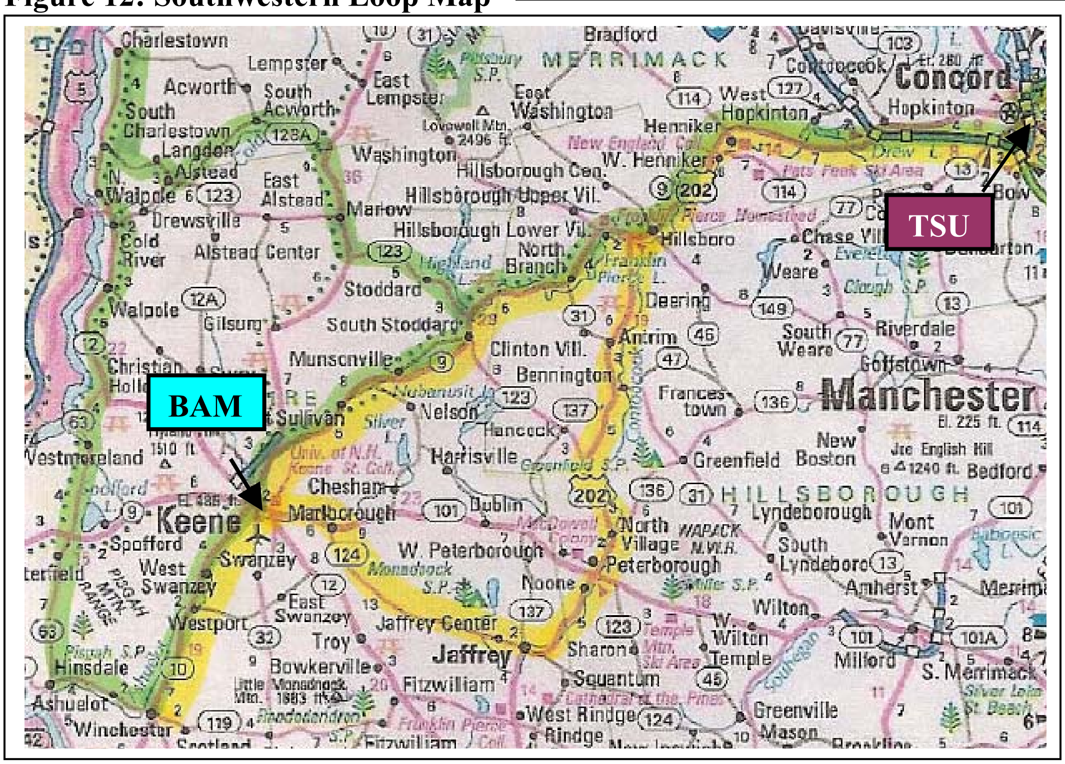


Figure 12: Southwestern Loop Map

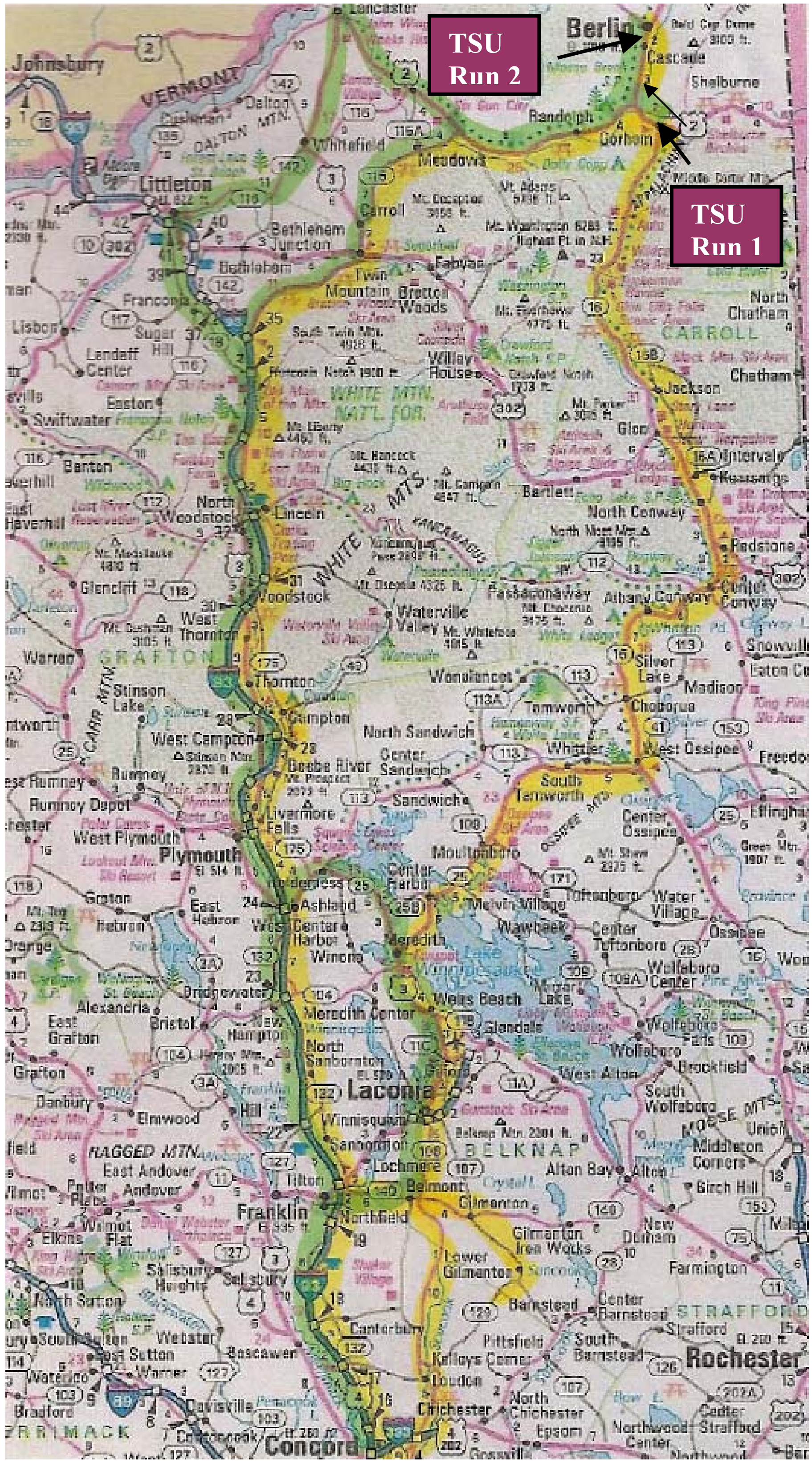


1st Run
2nd Run

2.2.3 Northern Loop (Runs 1 and 2)

The aim of the Northern Loop was an improved understanding of conditions in the northern region of the state. Communities of special interest included Berlin, Conway, Gorham, Lancaster, Lincoln, Littleton, and Meredith. Because of the distances involved, the area was divided into two runs to be sampled on separate event nights. The TSU was located in Gorham during Run 1 and moved to Berlin for Run 2. Figure 13 illustrates both parts of this route.

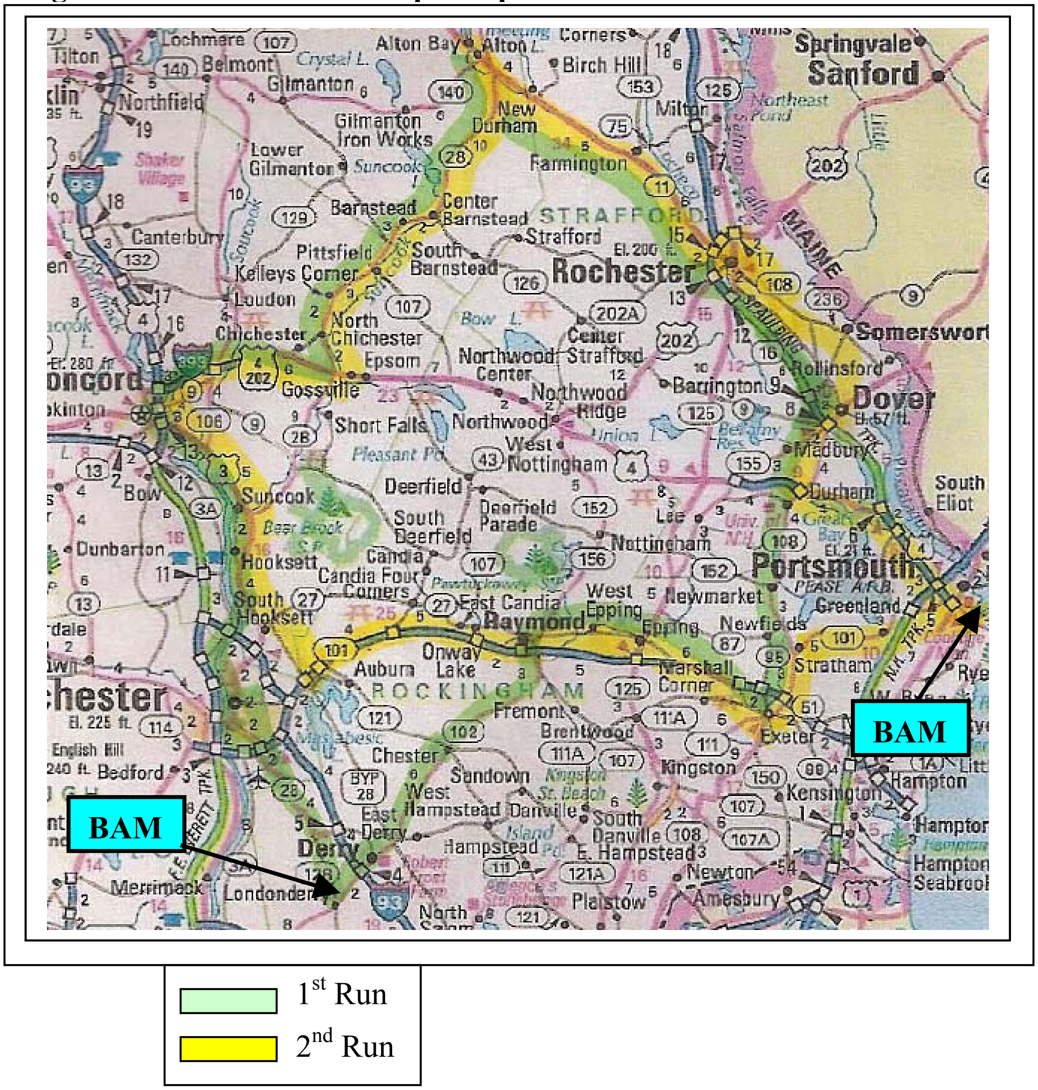
Figure 13: Northern Loop Map



1st Run
2nd Run

2.2.4 The Southeastern Loop

Figure 14: Southeastern Loops Map



The aim of the Southeastern Loop was to complete the geographic coverage of the state excluded from the 2010-2011 sampling. This portion of the state has less vertical variation in elevation (is less mountainous), higher population density, and greater access to cleaner burning natural gas for residential heating as compared to most of the rest of the state.

Alton, Rochester, Dover, Durham, Exeter, Raymond, Derry, and Pembroke were focus communities in this sampling loop. MMU co-location took place in Portsmouth for the first half of the sample run of the Southeastern loop and in Londonderry during the second half. Figure 14 illustrates the intended route for the MMU Southeastern Loop.

3.0 Data and Results

NHDES successfully completed the planned sampling loops and co-locations during five forecasted events over the two winter seasons. 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 one hour near the beginning and one hour near the end of the Central and Southwestern runs. Because of the long driving distance of the Northern Loops, the pDR and BAM co-location was done for only one hour near the middle of the night.

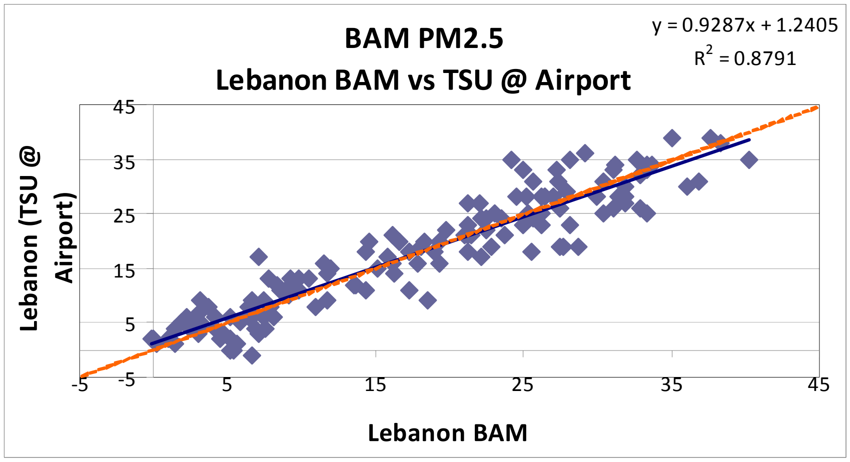
Although the goal was to capture five similarly extreme events, actual conditions varied considerably from one run to the next. Section 3.4 details $PM_{2.5}$ concentrations, meteorology, and regional background levels for each mobile monitoring event period.

NHDES charted running $PM_{2.5}$ data from the MMU pDR along with other relevant parameters (Attachments E-I); overlaid MMU pDR data onto New Hampshire road maps using multiple methodologies (Figures 20-23); and examined stationary BAM data from the TSU and permanent air monitoring network stations in depth. As discussed in the remainder of this report, NHDES was able to use these data to postulate the degree of risk to target communities relative to the $PM_{2.5}$ events recorded in Keene.

3.1 TSU Quality Assurance: Co-location of TSU BAM and Network BAM

To ensure consistency with other FEM units, NHDES initiated field operation of the newly purchased TSU BAM by co-locating it with the Lebanon Airport monitoring station for about six days (Figure 15). This location served out of convenience, since the Lebanon station is on the first sampling route. The two BAMs demonstrate little bias and a nearly one-to-one relationship and a coefficient of determination (R^2) of 0.88 (a direct relation to correlation).

Figure 15: Correlation of TSU BAM with Lebanon Airport BAM (December 30, 2010 – January 5, 2011)



3.2 pDR Quality Assurance: Extended Co-location of pDR and BAM

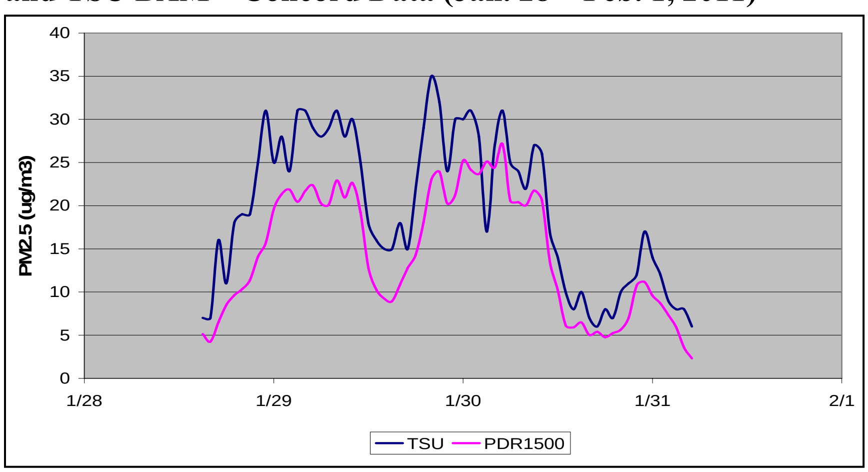
NHDES selected the pDR for the mobile monitoring study because it is a handheld device capable of real-time $PM_{2.5}$ measurements in a moving vehicle. To support informed comparisons between the pDR and BAM, NHDES assessed their relative performance with several periods of co-location.

NHDES equipped the TSU simultaneously with the BAM and pDR and co-located the devices in Concord and in Winchester for a total of 33 days during the winter of 2010-2011. For a more robust comparison, NHDES repeated the co-location in Concord in the first months of 2012. pDR data collected concentrations in thirty-second and one-minute intervals require averaging for comparison with hourly BAM data. Figures 16-18 display hourly data from each multi-day co-location.

The first Concord co-location lasted less than three days (Figure 17), but captured two nights of high moderate concentrations. The pDR consistently measured lower than the BAM by several µg/m³.

In Winchester, the pDR runs extended from mid-March to mid-April (Figure 17). Despite a month of co-location, $PM_{2.5}$ observations remained mostly in the good to moderate range because inversions became less

Figure 16: Hourly $PM_{2.5}$ During Co-location of MMU pDR and TSU BAM – Concord Data (Jan. 28 – Feb. 1, 2011)



frequent and less intense near the onset of spring. The pDR ran a little lower than the BAM at lower concentrations (25 µg/m^3 and lower) and higher, sometimes considerably higher, than the BAM at higher concentrations (above 35 µg/m^3).

NHDES again operated the pDR with the BAM in Concord for several weeks in 2012 (Figure 18). Here, the pDR generally ran lower than the BAM, except at the highest peaks, when the two agreed well.

Patterns at the two sites differed slightly. While the pDR tended to exceed the BAM at concentrations over 25µg/m^3 in Winchester, it usually stayed below the BAM at similar levels in Concord.

The pDR and BAM tracked more closely at good and moderate concentrations in Winchester than in Concord. While co-located in Winchester, the pDR averaged within about 2.5-3.0 µg/m^3 of BAM values, but when in Concord, the pDR ran about 4.5-5.5 µg/m^3 lower than the BAM when ambient $PM_{2.5}$ concentrations were low. The cause of the discrepancy is unknown. Possibly, the nature of the particles in the two communities varied, but

Figure 17: Hourly $PM_{2.5}$ During Co-location of MMU pDR and TSU BAM – Winchester Data (Mar. 15 – Apr. 14, 2011)

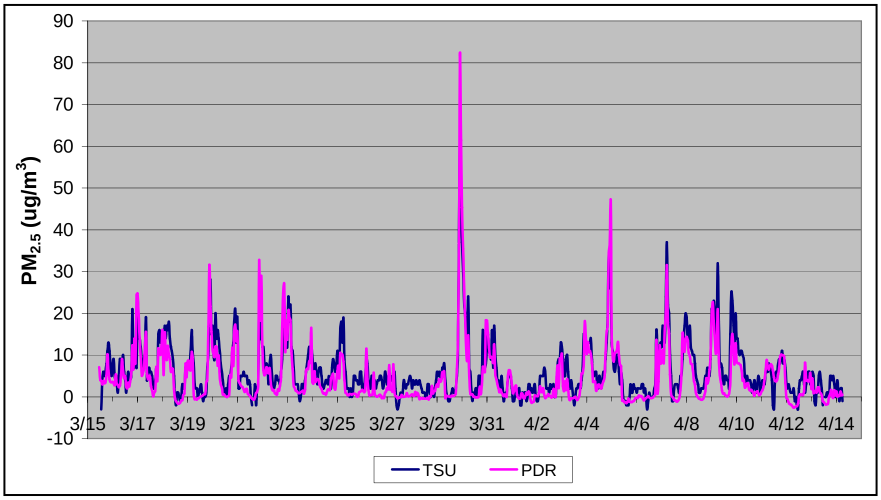


Figure 18: Hourly $PM_{2.5}$ During Co-location of MMU pDR and TSU BAM – Concord Data (Jan. 26 – Feb. 8, 2012)

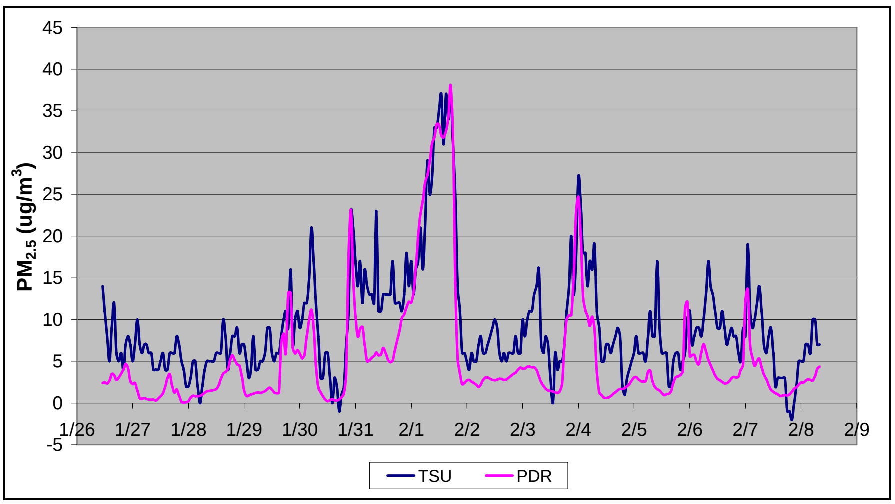
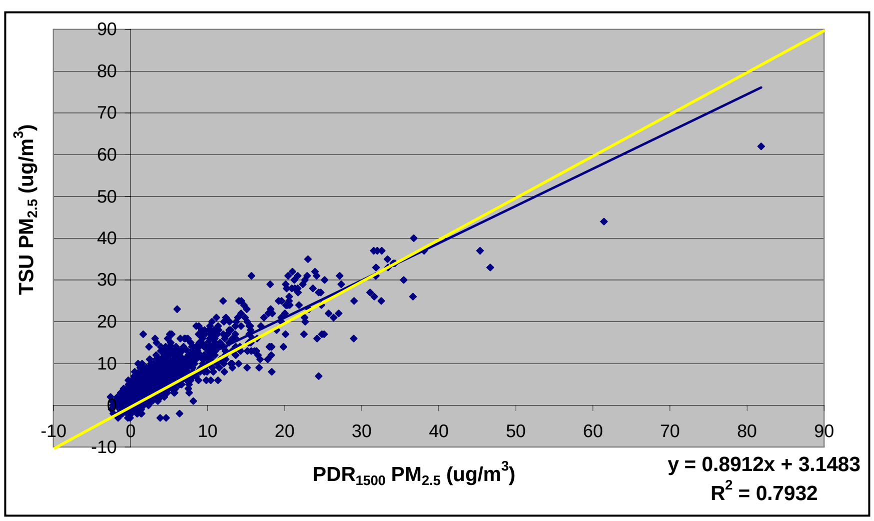


Figure 19: Correlation of MMU pDR to TSU BAM – Concord and Winchester Co-locations



different sample sizes and times of season may also have been factors.

Figure 19 combines data from all three co-locations. At low-to-moderate concentrations, the pDR measurements were most often lower than those of the BAM. At high concentrations, above 35 µg/m^3, the pDR tended to record values higher than the BAM. Nevertheless, the overall correlation is fairly strong, with an R^2 of 0.79 and a slope of 0.89. 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: **$PM_{2.5}$ = 0.8912(pDR) + 3.1483 (EQ1)**

This equation uses a linear best-fit line, which, while it may produce reasonable results, may not produce the perfect fit for the data. As Figure 20 indicates, the best-fit equation may introduce a corrected bias in the direction of higher corrected $PM_{2.5}$ concentrations when levels are greater than 40 µg/m^3. Since the bias does not appear to be a factor when concentrations are lower than the USG threshold of 35 µg/m^3, it is not likely to alter the findings of this report.

3.3 pDR Quality Assurance: 1-Hour Co-locations of pDR and BAM

For validation of pDR data during the mobile sampling portion of the study, NHDES performed one or two co-locations of the pDR and BAM during each monitoring loop. Because the BAM one-hour average represents 42 minutes of each hour (:03-:45), NHDES calculated corresponding pDR averages from instantaneous values within the same interval. Table 3 presents one-hour co-location results:

Table 3: 1-Hour Co-locations of pDR and BAM During Mobile Monitoring Runs

Date	Hour	Loop	BAM Location	1-Hour[1] $PM_{2.5}$ (µg/m^3) BAM	Raw pDR	Adjusted[3] pDR
1/14/2011	19:00	Central	Lebanon TSU	5	1.6	4.6
1/15/2011	6:00	Central	Lebanon TSU	20	9.4	11.5
1/25/2011	19:00	SW	Keene Station	37.1	37.2	36.3
1/26/2011	7:00	SW	Keene Station	39	35.0	34.3
2/17/2011	4:00	N #1	Gorham TSU	6	5.2	7.8
3/4/2011	2:00	N #2	Berlin TSU	20	9.5[2]	11.6
2/9/2012	22:00	SE	Londonderry Station	7.2	4.2	6.9
2/10/2012	4:00	SE	Portsmouth Station	9.5	6.9	9.3

[1] Hour average represents 3-45 minutes past the hour.
[2] MMU arrived late, so hour average starts at 6 minutes past the hour.
[3] pDR average adjusted based on best line correlation to BAM per EQ1 Section 3.2. (pDR_{adj} = 0.8912*pDR_{raw} +3.1483)

Co-location results are mixed, but generally indicate quality data capture. pDR co-located averages from the morning of the Central Loop and from the second Northern Loop are about half the hourly average recorded by the BAM, however, all other co-locations, including the initial Central Loop co-location, are within a few µg/m^3 based on adjusted pDR values. Significantly, high averages from both Southwestern Loop co-locations agree well, though the pDR tends to slightly underestimate $PM_{2.5}$ concentrations.

3.4 Mobile Monitoring Event and Sampling Overviews

NHDES conducted mobile sampling on different nights. Since weather conditions vary from day to day, wind and thermal inversions can cause stagnation conditions to be different during each night sampling occurred. Graphics in Attachments E through I portray a summary of the weather conditions during each sampling night, including thermal inversions soundings, regional $PM_{2.5}$ transport, hourly temperature patterns, and measured $PM_{2.5}$ concentrations. The following provides an overview of each event as a foundation for understanding the mobile and other monitoring data.

Inversions trapping local emissions are a primary driver of wintertime USG events, but transport of additional $PM_{2.5}$ from upwind can elevate levels further. Vertical temperature profiles consist of HYSPLIT-generated temperature soundings upward from ground level in Keene based on NAM12k weather forecasting model results; for USG events, these typically indicate the presence and degree of thermal inversions (where warmer air lies above colder air trapped at ground level, creating a stable atmosphere where air does not mix vertically). AIRNow maps depict regional peak $PM_{2.5}$ levels for the day before and after the overnight periods of each mobile monitoring run. The hourly charts show data from permanent BAM sites in the New Hampshire $PM_{2.5}$ network.

Attachments E-I also provide comprehensive charts of the MMU and other data from the five mobile monitoring periods. The charts are split into two portions. The lower portion displays continuous $PM_{2.5}$ concentration data from the MMU as it traveled its course. This chart section also includes hourly $PM_{2.5}$ concentration averages from the BAMs in the TSU and selected NHDES monitoring stations. Dotted lines enclose data collected within one geographic area, as labeled. The upper portion of each chart plots the speed and elevation of the MMU.

Because the MMU's 30- and 60-second pDR data show short-term variability not observable in the BAM hourly averages, the MMU may detect the impact of individual sources as well as community-wide $PM_{2.5}$ buildup. The following sections briefly discuss TSU and MMU results from each mobile monitoring sampling loop.

Graphics are provided in the referenced Attachments which will assist the comprehension of the description of the data in the following sections.

3.4.1 Central Loop (January 14-15, 2011) - Attachment E

During the Central Loop, smoke buildup did not develop to the degree anticipated, but it was strong enough to make sampling worthwhile. A thermal inversion set up in Keene by 7PM and persisted past the end of the mobile monitoring period. Keene $PM_{2.5}$ climbed to over 30 $\mu g/m^3$ by 9PM and then fluctuated between about 25 and 40 $\mu g/m^3$ for the rest of the night. Winds were generally one mile per hour or less after 8PM, but erratic wind speed shifts between near-zero and one mile per hour coincided with the ups and downs in concentration.

No appreciable regional $PM_{2.5}$ concentration buildup occurred in New England prior to the event, but patches of moderate $PM_{2.5}$ concentrations further south moved into southwestern New Hampshire by the second day. BAM data from Portsmouth, Londonderry, and Lebanon Airport gradually crept toward the moderate $PM_{2.5}$ concentration threshold overnight. This corresponded with an approaching regional $PM_{2.5}$ plume, increased local emissions from morning activities, and

declining temperatures. $PM_{2.5}$ jumped briefly to about 25 μg/m^3 at 8AM in Portsmouth, but Londonderry and Lebanon Airport $PM_{2.5}$ did not get much higher than 15 μg/m^3.
The $PM_{2.5}$ concentrations measured at the in-town Lebanon TSU station mirrored the $PM_{2.5}$ concentrations measured at the Lebanon Airport BAM, but at several μg/m^3 higher. The MMU recorded its highest $PM_{2.5}$ concentrations in Newport, Plymouth, Franklin, and Concord. There were a few spikes when the MMU concentrations briefly approached or exceeded the NAAQS threshold, particularly in the Plymouth/Franklin area and around Newport. Otherwise, instantaneous MMU $PM_{2.5}$ measured in other communities and in-between communities stayed well below Keene's hourly BAM readings.

3.4.2 Southwestern Loop (January 25-26, 2011) - Attachment F

During the Southwestern Loop, transported $PM_{2.5}$ and local emissions combined to create the most prolonged period of high $PM_{2.5}$ in Keene among the mobile runs and peak values second only to the 2012 Southeastern Loop. The Keene BAM recorded an official 24-hour $PM_{2.5}$ concentration of 32.5 μg/m^3 from midnight to midnight on January 26, 2011 and an unofficial maximum rolling 24-hour average of 41.8 μg/m^3 from 2PM on the 25th to 2PM on the 26th.

This event was preceded by the broadest regional $PM_{2.5}$ plume and longest stretch of calm winds of all the mobile air monitoring events in this study. Keene concentrations were already almost 20 μg/m^3 before the evening climb began. From this point, they rose to a maximum of 62.8 μg/m^3 at 11PM, fell to an overnight low of 33.2 μg/m^3 at 6AM, then jumped back to the high 40's and low 50's until winds picked up and concentrations fell to moderate levels after noon.

While Lebanon lagged behind somewhat, Portsmouth and Londonderry $PM_{2.5}$ concentrations tracked very well with Keene values throughout the episode. Portsmouth's high $PM_{2.5}$ concentrations almost matched Keene's and occurred only one hour earlier. Maximum rolling 24-hour averages in Londonderry, Portsmouth, and Lebanon for the 24th-25th were 38.7, 37.5, and 30.3 μg/m^3, respectively.

Concord TSU $PM_{2.5}$ concentrations surpassed Keene's during the 6PM to 9PM buildup, peaking at about 50 μg/m^3. However, Concord's $PM_{2.5}$ concentrations declined as Keene's steadily rose to a maximum of about 63 μg/m^3 by 11PM and remained higher than Concord overnight.

Communities where the MMU unit measured $PM_{2.5}$ instantaneous concentrations higher than hourly Keene BAM values for at least 90 seconds include: Hopkinton, Hillsborough, West Swanzey, and Winchester. One extreme value measured at a Keene McDonald's appears to have been due to an idling truck parked nearby.

West Swanzey and Winchester experienced a string of readings well above the NAAQS threshold of 35 μg/m^3, including $PM_{2.5}$ concentrations near or above 100 μg/m^3. The MMU traversed both towns twice at each end of the event. In West Swanzey, values were high both times, but extreme $PM_{2.5}$ concentration peaks occurred only on the first pass, around 8:45PM. Winchester was the opposite case, with a steady climb and fall as the MMU traveled through around 5:30AM.

3.4.3 Northern Loop - Run 1 (February 16-17, 2011) - Attachment G

During Run 1 of the Northern Loop, Keene BAM $PM_{2.5}$ concentrations stayed at or below 25 $\mu g/m^3$ until about 3AM when they rose to and hovered around 35 $\mu g/m^3$. A jump to 2-3 mph from 10-11PM interrupted generally dropping wind speeds the evening of the first day and prevented more significant $PM_{2.5}$ accumulation. After this late start, winds stayed very calm until a few hours after the mobile monitoring run.

Portsmouth and Londonderry $PM_{2.5}$ concentrations slowly increased over the night. Only Lebanon Airport's $PM_{2.5}$ concentrations started higher than Keene's, but they fell into the 15-25 $\mu g/m^3$ range around midnight as Keene's values rose to surpass them. After completion of mobile monitoring, Lebanon $PM_{2.5}$ again climbed to near the level of Keene concentrations before all sites settled at moderate $PM_{2.5}$ concentration levels toward midday.

Only scattered areas of moderate $PM_{2.5}$ concentrations in New England precede the Northern Loop Run 1 monitoring period. This includes a swath overlapping western New Hampshire that likely explains the higher initial levels at Lebanon Airport. By the second day, $PM_{2.5}$ spread over an extensive area of the Northeast. Transport flow and a strengthening thermal inversion correlate with higher second-day morning and daytime $PM_{2.5}$ concentrations at each site.

Run 1 of the Northern Loop showed generally low concentrations throughout the sparsely-populated North Country. The MMU measured instantaneous concentrations exceeding the Keene BAM hourly data for at least 90 seconds in Concord and Lincoln. A very large spike also occurred when the MMU followed a truck up a long steep hill near Twin Mountain; concentrations were considerably lower on a second climb of the hill without the influence of the truck. (Note: Data reflecting this truck event has been removed from Figures 20-23.)

$PM_{2.5}$ measured by the Gorham TSU was relatively unremarkable, staying below 15 $\mu g/m^3$ throughout the mobile sampling event.

3.4.4 Northern Loop – Run 2 (March 4, 2011) - Attachment H

Only mild $PM_{2.5}$ buildup occurred during the final mobile air sampling run of the 2010-11 season; $PM_{2.5}$ was generally low. Keene BAM data stabilized in the moderate $PM_{2.5}$ concentration range of 20 to 25 $\mu g/m^3$. Mobile monitoring took place between midnight and 7AM, but Keene $PM_{2.5}$ peaked before and after this period: late evening and early morning.

This is the only mobile sampling event where the thermal inversion did not develop by 7PM. Winds dropped to under two miles per hour by 7PM, but did not fall below one mile per hour until 4AM. While Keene had its hourly maximum of 34.4 $\mu g/m^3$ at 9PM, Portsmouth, Londonderry, and Lebanon $PM_{2.5}$ climbed gradually as conditions became more stagnant and did not reach their maximum levels until just after the end of the mobile monitoring period.

The Berlin TSU $PM_{2.5}$ concentrations tracked closely to data measured at the Keene BAM over almost the entire sampling period, while the Lebanon BAM generally tracked about 10 $\mu g/m^3$ lower than both Berlin and Keene. One exception was a short period around 6AM when the Berlin TSU and Lebanon Airport BAM rose to around 28 $\mu g/m^3$, about 8 $\mu g/m^3$ higher than Keene. The highest MMU instantaneous $PM_{2.5}$ concentrations were measured in Belmont, Lancaster, Littleton, and Lincoln.

One reason for developing a second run of the Northern Loop was to take a closer look at the $PM_{2.5}$ concentrations in Berlin, where the TSU had been moved from Gorham. Berlin's concentrations were higher than Lebanon's most of the night, perhaps because the hilltop position of the Lebanon station limits stagnation compared to lower elevations. Nevertheless, no site experienced a strong $PM_{2.5}$ event during the mobile run, and $PM_{2.5}$ near the NAAQS threshold was not detected in Berlin at any time over the twelve days the TSU ran there. Higher concentrations in Berlin had been anticipated.

On the other hand, the small community of Belmont measured $PM_{2.5}$ concentrations higher than expected. In two out of three passes made through Belmont between the first and second runs of the Northern Loop, the pDR measured instantaneous $PM_{2.5}$ a few µg/m^3 higher than the Keene BAM data for the encompassing hour.

3.4.5 Southeastern Loop (February 9-10, 2012) - Attachment I

Peak $PM_{2.5}$ concentrations in Keene were higher during the Southeastern Loop than any other, including the Southwestern Loop. Keene had a maximum of 79.3 µg/m^3 and four consecutive hours over 60 µg/m^3 between midnight and 3AM. However, this event was slower to build and shorter lived than the Southwestern Loop. During the latter, levels were over 30 µg/m^3 by 5PM, not falling below 40 µg/m^3 until 1PM the next day. In contrast, Keene concentrations during the Southeastern Loop surpassed 30 µg/m^3 at 7PM and fell below this threshold at 8-9AM.

Also unlike the Southwestern Loop, this event seems isolated to Keene. No other permanent BAM captured $PM_{2.5}$ concentrations over 20 µg/m^3. Concentrations in Portsmouth and Londonderry varied between 5 and 10 µg/m^3 over most of the monitoring period. Lebanon $PM_{2.5}$ stayed in the single digits until past midnight, though it climbed to 15-20 µg/m^3 from 3-6AM.

Only patchy regional $PM_{2.5}$ concentration buildup occurred during the Southeastern Loop, with more moderate $PM_{2.5}$ concentrations appearing the second day. Winds started decreasing by 6PM and did not get higher than one mile per hour from 8PM to 7AM. There were several hours very near zero miles per hour, more than there were over any other mobile monitoring period.

The thermal inversion strengthened over the night. Nevertheless, one-hour peaks near 80 µg/m^3 were impressively higher than those of the Southwestern Loop, despite lower regional background levels; a shorter, albeit consistent and generally lighter, period of calm winds; warmer temperatures; and a thermal inversion of similar strength.

Concentrations remained in the good or moderate range throughout this mobile route. Little transport influenced this event, and the buildup that occurred most directly impacted the Southwest. Moreover, mobile monitoring teams were transitioning in Concord during the hours of peak concentrations in Keene and may have missed maximum concentrations in the Southeast.

Nevertheless, the MMU did capture several areas where concentrations rose into the 20's µg/m^3. Often these increases represent a larger geographic area (neighborhood to community-wide scales) rather than one or two brief spikes from source-specific emissions, as was more often the case in the other loops. Rochester and the Raymond-Epping area had the largest quantity of data at this level. The highest pDR concentration was 44.2 µg/m^3 in Farmington, adjacent to Rochester. Other towns with several moderate $PM_{2.5}$ concentration values include Derry, Somersworth, Pittsfield, and Chichester.

3.5 Consolidated Community Mobile Run Map Overlays

NHDES consolidated and mapped data from each of the mobile sampling loops to allow visual interpretation. NHDES plotted these data 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 20 shows $PM_{2.5}$ data measured by the MMU during every 30 seconds for all sampling loops (data adjusted by EQ1 – Section 3.2).
- Figure 21 filters the data from Figure 20 to remove source-specific data spikes to allow a clearer perspective of neighborhood and community scale $PM_{2.5}$ levels.
- Figure 22 shows MMU $PM_{2.5}$ data normalized to a common location (Keene air monitoring station) measured every 30 seconds for all sampling loops.
- Figure 23 shows the same normalized data presented in Figure 22 but filters it to remove source-specific $PM_{2.5}$ data spikes.

Before drawing conclusions from these maps, one must recognize that NHDES collected $PM_{2.5}$ samples 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 ($\mu g/m^3$) over a period of 24 hours (midnight to midnight) as unhealthy for sensitive populations.

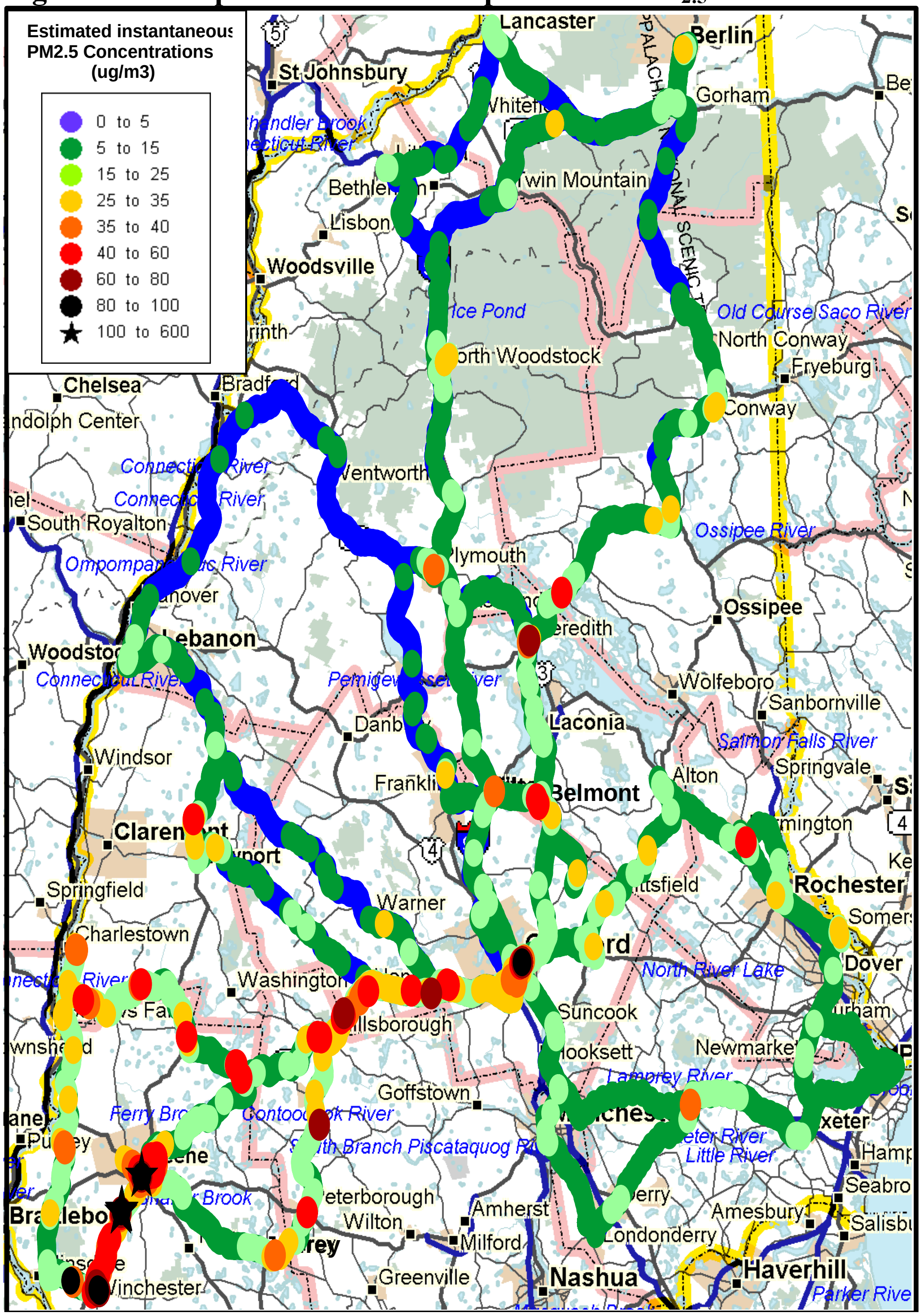
3.5.1 MMU Running Data

Figure 20 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 (EQ1 - Section 3.2). 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 µg/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 $PM_{2.5}$ 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 $PM_{2.5}$ concentration occurred near communities such as Newport, Plymouth, Lincoln, and Meredith.

Figure 20: Composite Statewide Map of MMU $PM_{2.5}$ Values

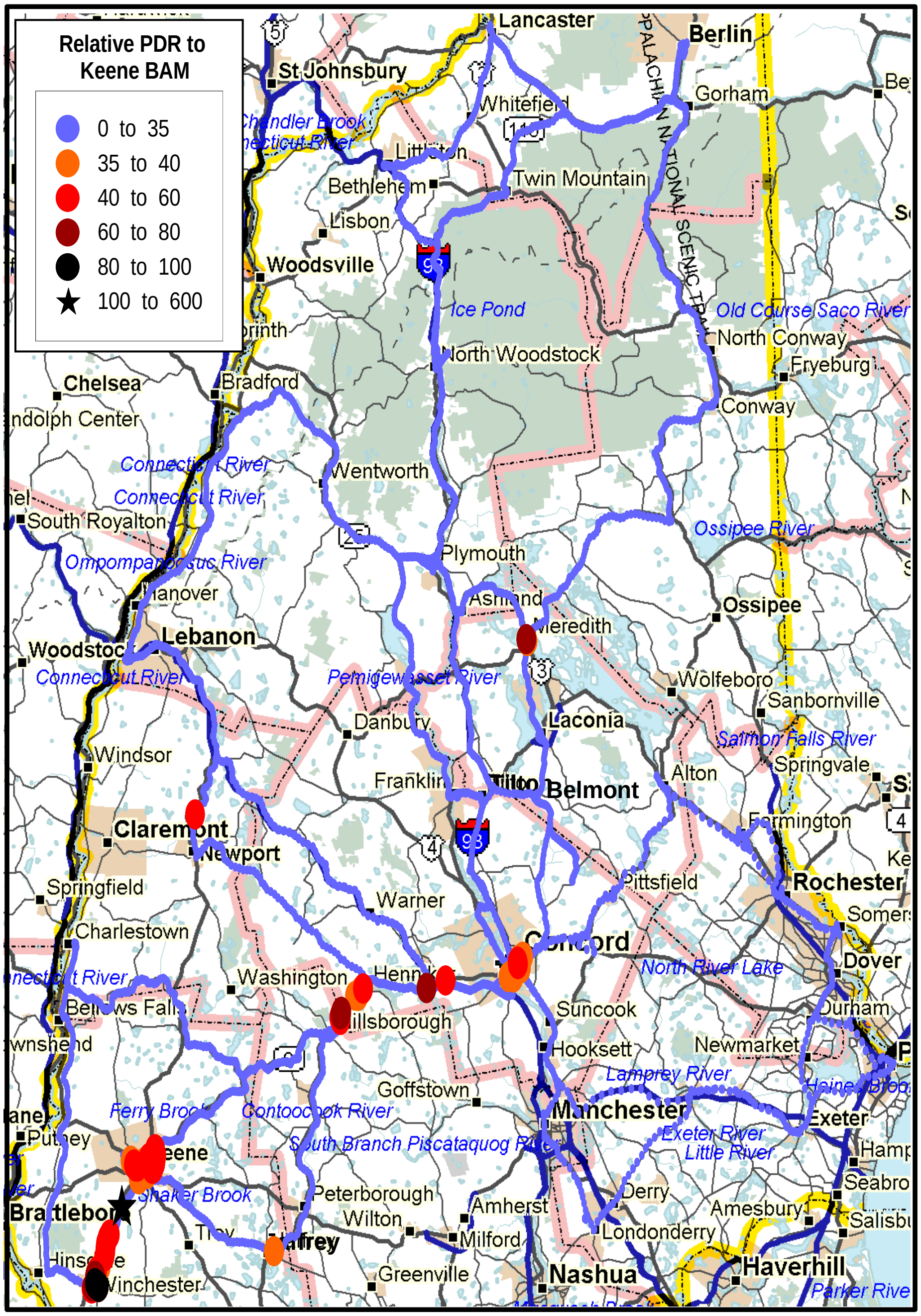


Data values are instantaneous and do not represent the 24-hour form of the $PM_{2.5}$ NAAQS. Data values were collected on different days and times and are not necessarily comparable. Some high concentrations marked in this figure may be localized to a single source and brief in duration.

Figure 21 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 $\mu g/m^3$) and removes brief $PM_{2.5}$ spikes (failure to stay above 30 $\mu g/m^3$ 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 $\mu g/m^3$ were also detected along the route from Concord to Hillsborough.

Figure 21: Filtered Composite Statewide Map of MMU $PM_{2.5}$ Values – In Motion



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.

3.5.2 Normalized MMU Data

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. By matching time stamped instantaneous MMU values adjusted by the best-fit to BAM equation (EQ1 – Section 3.2) to corresponding hourly Keene BAM data, NHDES determined an MMU to BAM ratio for each point on the map. Figure 22 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 adjusted 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 22: Normalized Composite Statewide Map of MMU $PM_{2.5}$ Values Relative to Keene BAM

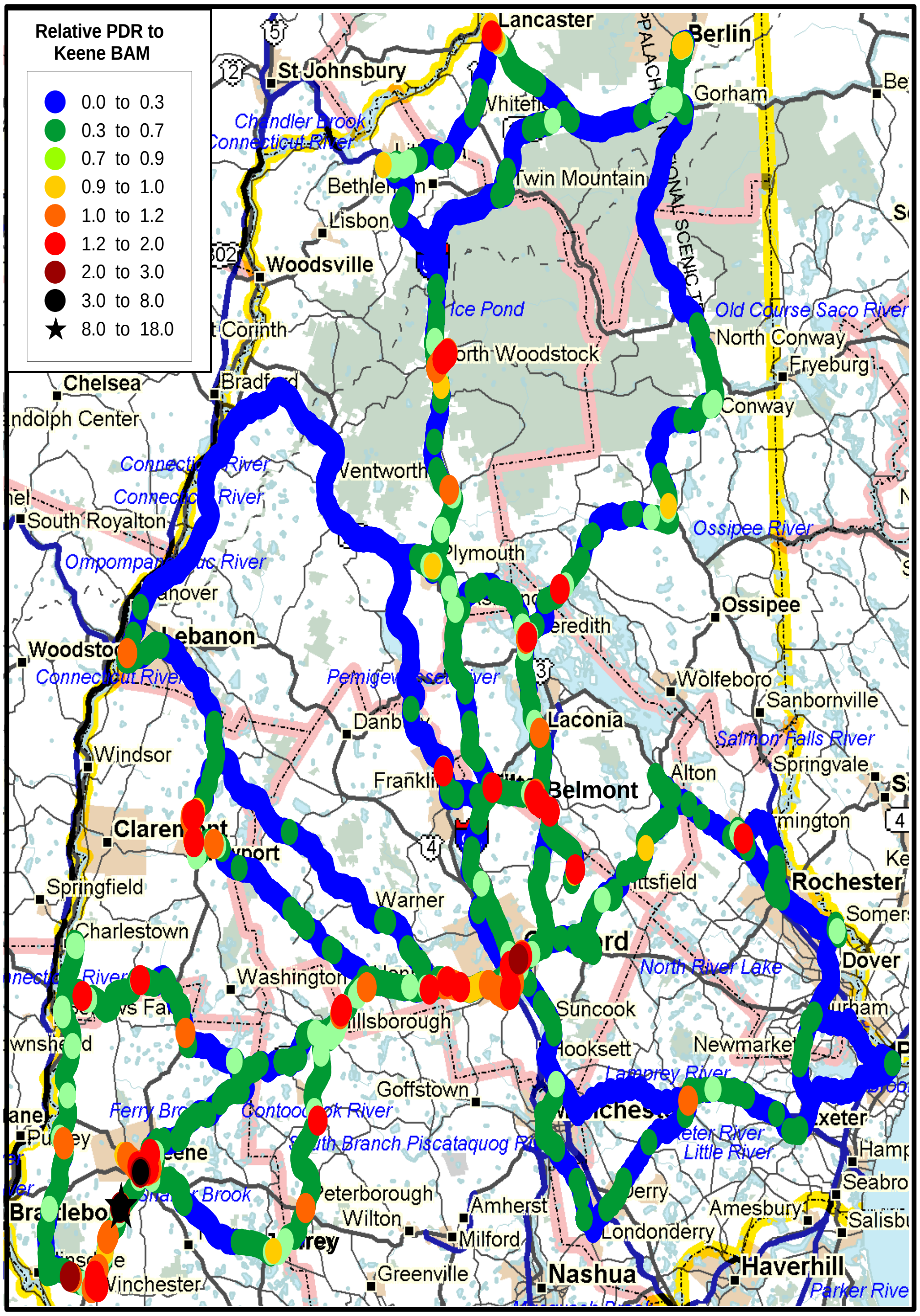
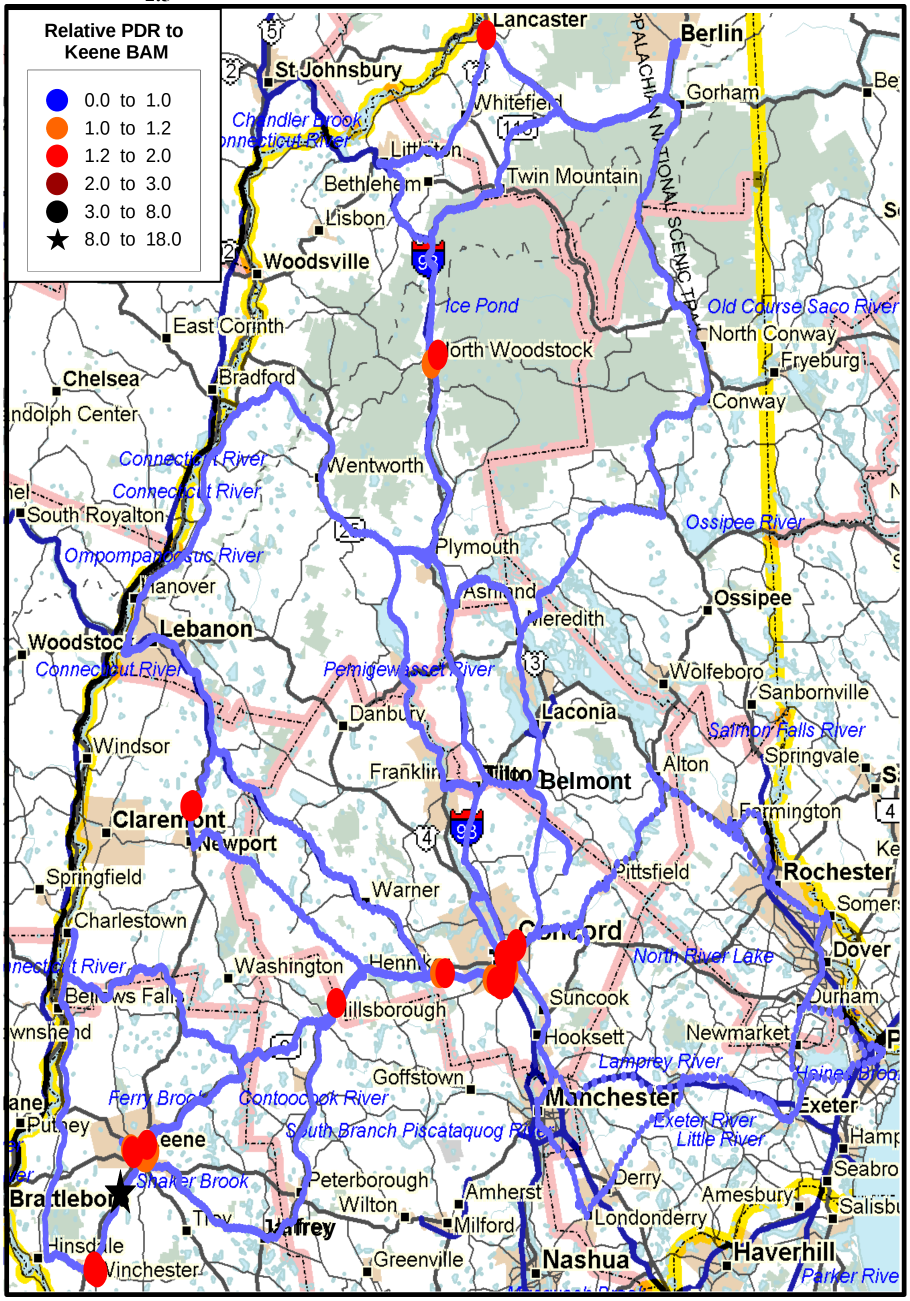


Figure 23 follows the same approach, but only includes filtered data (those with a normalization ratio higher than 1.0 and lasting more than 90 seconds while the MMU was in motion – 120 seconds for the Southeastern Loop). Communities that stand out most include West Swanzey, Winchester, and Concord. Also having a high ratio are Newport, Hopkinton, Hillsborough, Lincoln, and Lancaster.

Figure 23: Filtered Normalized Composite Statewide Map of MMU $PM_{2.5}$ Values Relative to Keene BAM – In Motion



3.6 Stationary $PM_{2.5}$ Monitoring Assessment

The following sections take a closer look at how each continuous $PM_{2.5}$ monitoring station compares to the one in Keene. These comparisons not only offer insight into how the different communities compare to Keene, but by comparing all stations to a common station, the relative differences in the statistics offers insight into how communities compare to each other.

Tables 4 and 5 below summarize correlation data and best-fit linear equations between Keene and various communities with available stationary $PM_{2.5}$ monitoring data. Table 4 compares data on an hourly basis where continuous monitoring took place with BAM, TEOM, or TSU units. Table 5 summarizes available data on a daily (24-hour average) basis and considers data from continuous monitoring equipment as well as filter-based FRM units.

When comparing data between two different locations, slope, correlation coefficient (R^2), and the number of data points are all important statistics to consider. A slope of 1.0 would indicate the magnitude of the dataset collected at community "y" averages the same magnitude as the dataset measured at Keene and has the same general direction of data (when one location increases, so does the other by about the same amount, on average).

The R^2 factor is a measure of how well the data clusters along the best-fit relationship line. R^2 factors range from zero to 1.0 where a value of 1.0 indicates a perfect relationship between data collected at both locations, even if the slope of that data differs. High R^2 values indicate that the data pack tightly along the best-fit line while low R^2 values indicate that the data scatter in a more random fashion. R^2 values between 0.8 and 1.0 indicate very strong relationships, between 0.6 and 0.8 mean good relationships, between 0.4 and 0.6 means there is some relationship, and lower numbers indicate weaker and more random relationships, if any. Low R^2 values reduce confidence in calculated slope data since a best-fit line may be only marginally better than another fit.

The number of data points is another important metric to consider because the more data included in the calculations, the more reliable the summary statistics become. This is sometimes referred to as statistical significance. NHDES considered data based on a low number of data points with care since there are less overall data to confirm the statistics.

One other point of data offered below in the best-fit equation is the y-intercept. A non-zero value indicates that the best-fit line does not go through the chart's origin, or in the case of this study, when one site measures concentrations of zero the other site is generally not zero. This can indicate that one site has a greater background $PM_{2.5}$ concentration than the other site (on a consistent basis), or that the relationship between sites is not linear. It is likely that both of these explanations are true to some degree.

On an hour-by-hour basis (Table 4), Concord TSU Part 1 (1/25/2011 – 1/31/2011) is the stationary monitor showing the closest slope and R^2 to Keene data. It is not known why TSU data collected during Part 1 differ from Part 2 (12/8/2011 – 2/21/2012) to the degree that they do, but Part 1 data appear to align reasonably well with daily (24-hour) data collected by the FRM unit in Concord which lends it additional credibility. Data collected in Gorham shows little resemblance to Keene data.

The R^2 from daily FRM data provided in Table 5 suggest Manchester, Claremont, and to a lesser degree, Concord, track best with episodic patterns found in Keene on a 24-hour basis, while slope data suggest $PM_{2.5}$ concentration magnitudes are on average 12, 33, and 20 percent lower, respectively, than concentrations found in Keene. $PM_{2.5}$ data collected on the summit of Mt. Sunapee show a low correlation to Keene $PM_{2.5}$ and average concentrations about 76% lower.

It is interesting to note that the maximum $PM_{2.5}$ concentration measured for each of the comparable time periods is almost always measured in Keene. The exceptions include Berlin, Claremont, and Laconia, and in each case, the value that was higher than Keene's was recorded over 10 years ago (November 14, 1999 for Berlin, November 26, 1999 for Claremont, and January 12, 1999 for Laconia). Keene's highest values have been more recent.

Table 4: Community to Keene Hourly $PM_{2.5}$ Best-Fit Correlation Data (Winter Data)

Community	Best-Fit Linear Equation[1]	Slope	R^2	Community "y" max (μg/m³)	Keene "K" max (μg/m³)	Dates	Number of Data Points
Berlin TSU	y = 0.41(K) + 2.72	0.41	0.42	28.0	46.1	3/2/2011 – 3/14/2011	281
Concord TSU Part 1	y = 0.61(K) + 7.83	0.61	0.65	49.0	62.8	1/25/2011 – 1/31/2011	133
Concord TSU Part 2	y = 0.33(K) + 5.95	0.33	0.34	39.0	79.3	12/8/2011 – 2/21/2012	1,754
Gorham TSU	y = 0.14(K) + 4.84	0.14	0.21	26.0	64.8	1/31/2011 – 3/2/2011	695
Lebanon TSU	y = 0.37(K) + 6.30	0.37	0.41	31.0	42.5	1/10/2011 – 1/24/2011	323
Lebanon BAM	y = 0.33(K) + 2.98	0.33	0.37	57.1	81.9	12/2008 – 3/2011	8,880
Manchester "BAM"[2]	y = 0.45(K) + 2.73	0.45	0.52	59.2	81.9	11/2008 – 3/2011	10,186
Portsmouth BAM	y = 0.42(K) + 3.45	0.42	0.40	61.6	71.1	1/2010 – 3/2011	4,113
Winchester TSU	y = 0.55(K) + 2.26	0.55	0.34	62.0	48.1	3/15/2011 – 4/14/2011	710

1. *K = corresponding hourly value from Keene BAM monitor*
2. *Manchester "BAM" is TEOM data adjusted by the best-fit line based on a one-year co-location of the BAM and TEOM in Keene. ("BAM" = 1.1399*TEOM + 0.9254)*

Table 5: Community to Keene 24-Hour $PM_{2.5}$ Best-Fit Correlation Data (Winter Data)

Community	Best-Fit Linear Equation[1]	Slope	R^2	Community "y" max (μg/m³)	Keene "K" max (μg/m³)	Dates	Number of Data Points
Berlin FRM	y = 0.41(K) + 4.86	0.41	0.33	51.4	35.1	1/1999 – 12/2006	155
Claremont FRM	y = 0.66(K) + 1.84	0.66	0.75	47.2	43.4	1/1999 – 12/2008	210
Concord FRM	y = 0.80(K) + 0.73	0.80	0.69	35.0	35.1	1/1999 – 12/2003	99
Haverhill FRM	y = 0.31(K) + 3.32	0.31	0.57	16.1	35.1	11/2002 – 12/2004	53
Laconia FRM	y = 0.41(K) + 1.21	0.41	0.34	53.3	35.1	1/1999 – 3/2011	237
Lebanon BAM	y = 0.51(K) + 0.73	0.51	0.68	30.6	48.9	12/2008 – 3/2011	373
Lebanon FRM	y = 0.49(K) + 2.27	0.49	0.56	26.0	43.4	1/2005 – 12/2008 & 1/2011 – 3/2011	102
Manchester FRM	y = 0.88(K) + 1.09	0.88	0.76	33.6	35.1	11/1999 – 12/2005	125
Manchester "BAM"[3]	y = 0.60(K) + 0.77	0.60	0.71	40.9	48.9	11/2008 – 3/2011	432
Nashua FRM	y = 0.62(K) + 1.74	0.62	0.61	35.0	43.4	1/1999 – 3/2011	276
Pembroke FRM	y = 0.58(K) + 2.56	0.58	0.66	36.0	43.4	1/2004 – 3/2011	179
Portsmouth BAM	y = 0.61(K) + 1.33	0.61	0.68	31.3	48.9	1/2010 – 3/2011	172
Portsmouth FRM	y = 0.54(K) + 2.05	0.42	0.49	35.5	43.4	1/1999 – 3/2011	253
Sunapee FRM	y = 0.24(K) + 1.38	0.24	0.32	10.8	27.8	1/1999 – 3/2002	51

1. *K = corresponding hourly value from Keene BAM monitor*
2. *FRM 24-hour concentrations are not collected on a daily basis. Instead collection is gathered on an every 3, 6, or 12 day basis. This leaves data gaps that can explain differences between BAM/TEOM data and FRM data.*
3. *Manchester "BAM" is TEOM data adjusted by the best-fit line based on a one-year co-location of the BAM and TEOM in Keene. ("BAM" = 1.1399*TEOM + 0.9254)*

Greater detail of data collected at stationary monitoring locations on a location-by-location basis is provided in the following sections.

3.6.1 Extended BAM to BAM Comparisons for NHDES Network Monitoring Stations

Because the MMU and TSU contribute valuable, but incomplete, portraits of wintertime $PM_{2.5}$ patterns throughout New Hampshire, the analysis is enhanced with data from locations where NHDES has ongoing operations of continuous $PM_{2.5}$ monitors. In addition to the Keene BAM installed Fall 2008, NHDES has run a BAM in Lebanon since Fall 2008 and in Portsmouth since the start of 2010. Moreover, while not a Federal Reference or Federal Equivalent Method, the TEOM in Manchester provides continuous $PM_{2.5}$ monitoring from 2008 to 2011. Finally, FRM 24-hour data are available historically at several other locations.

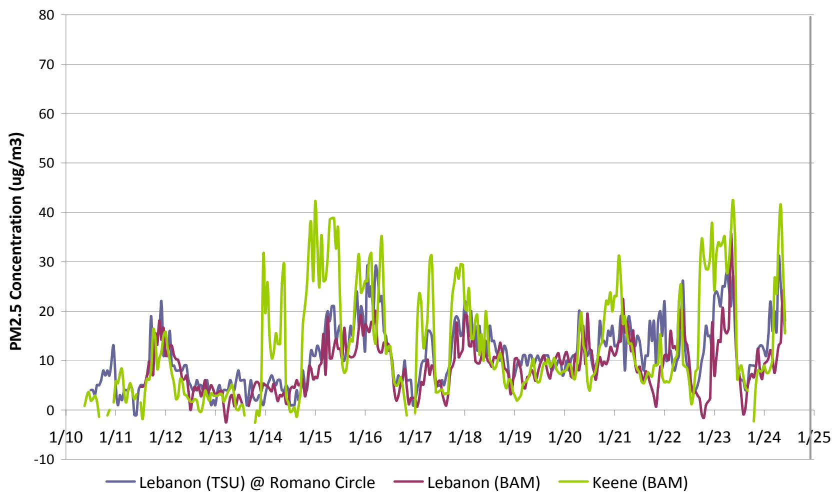
3.6.1.1 Lebanon

NHDES began ongoing BAM operations at the Lebanon airport in December 2008. As part of this study, NHDES conducted in-town continuous $PM_{2.5}$ monitoring when it parked the TSU BAM in a residential area of the Lebanon valley from January 10-24, 2011. NHDES also ran 1-in-6-day FRM filters at the Lebanon Airport from January 2005 to December 2008.

3.6.1.1.a TSU (January 10 – 24, 2011)

Figure 24 compares BAM data collected at the Lebanon Airport (on a hill above the valley) to the TSU in the Lebanon valley (about 0.75 miles to the north and 200 feet lower in elevation) for about 14 days in January. The chart also includes Keene BAM data for comparison. In general, Lebanon valley $PM_{2.5}$ tracked slightly higher than the airport. This is not surprising since thermal inversions most effectively trap emissions in valleys.

Figure 24: Hourly $PM_{2.5}$ from Lebanon Valley TSU, Lebanon Airport, and Keene BAM Units (January 10-24, 2011)



The TSU recorded some moderately-high $PM_{2.5}$ concentration peaks similar to Keene, but $PM_{2.5}$ at both Lebanon locations accumulated more slowly or fell far behind Keene's overnight highs on other nights. For instance, Keene's $PM_{2.5}$ reached 40 µg/m^3 on the night of the 14th-15th when Lebanon's maximum did not surpass 20 µg/m^3.

Figure 25: Hourly Correlation of Lebanon TSU and Lebanon Airport $PM_{2.5}$ BAM Units (January 10-24, 2011)

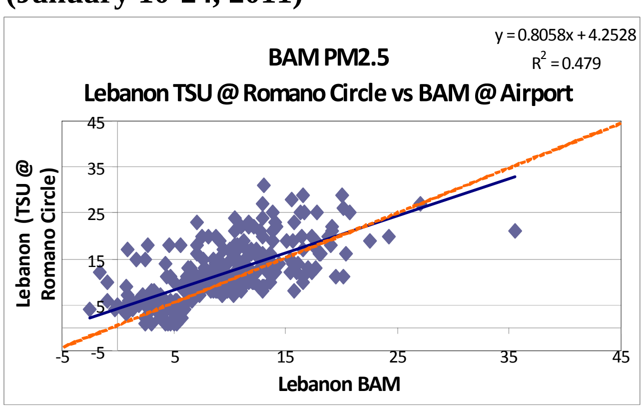


Figure 26: Hourly Correlation of Lebanon Valley TSU and Keene $PM_{2.5}$ BAM Units (January 10-24, 2011)

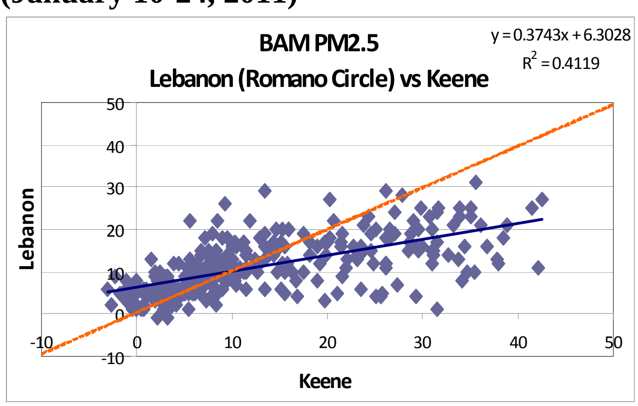


Figure 25 displays the hourly correlation between the Lebanon valley TSU and airport BAM. Most data points appear above the 1:1 line, suggesting higher background $PM_{2.5}$ closer to community emission sources in the valley. Concentrations barely at the moderate $PM_{2.5}$ concentration threshold at the airport often correspond to $PM_{2.5}$ in the mid to high 20's µg/m^3 in the valley. However, the dataset includes no extreme values, and a slope of 0.81 indicates the sites did not differ greatly.

Figure 26 shows the correlation between the Lebanon valley TSU and the Keene BAM. $PM_{2.5}$ hourly averages in the Lebanon valley frequently reached moderately-high $PM_{2.5}$ concentration levels, but never went much above 30 µg/m^3. Evident from the low slope, Lebanon $PM_{2.5}$ tends to be considerably lower than Keene as concentrations increase.

3.6.1.1.b BAM (December 2009 – March 2011)

Three winters of airport BAM data reveal that Lebanon was consistently lower than Keene when Keene experienced very high $PM_{2.5}$ concentrations. Figures 27 and 28 show hourly and 24-hour correlations, respectively.

Hourly concentrations in Lebanon approached or exceeded the NAAQS threshold much less frequently than in Keene. Keene's $PM_{2.5}$ often peaked over 40 µg/m^3, with hourly maximums near 80 µg/m^3, while Lebanon saw only a handful of hours with $PM_{2.5}$ between 40 and 60 µg/m^3. Over the midnight-to-midnight 24-hour period on days with data from both sites, Lebanon values were slightly higher than 30 µg/m^3 twice compared to thirteen values between 30 and 40 µg/m^3 and one near 50 µg/m^3 in Keene.

Figure 27: Hourly Correlation of Lebanon Airport and Keene $PM_{2.5}$ BAM Units (Winters December 2008 – March 2011)

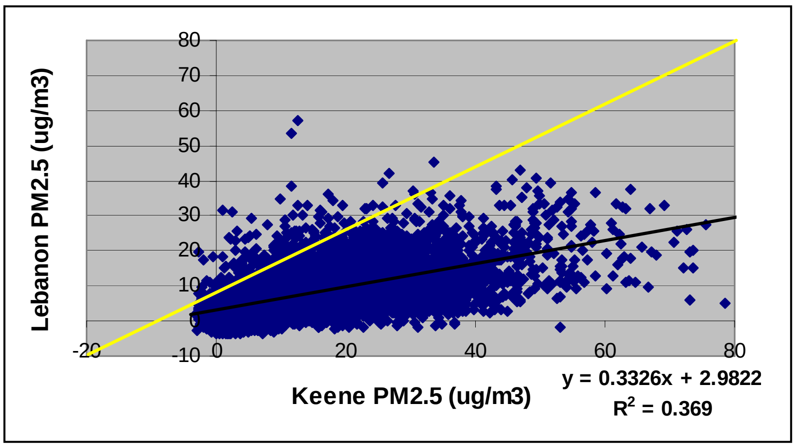
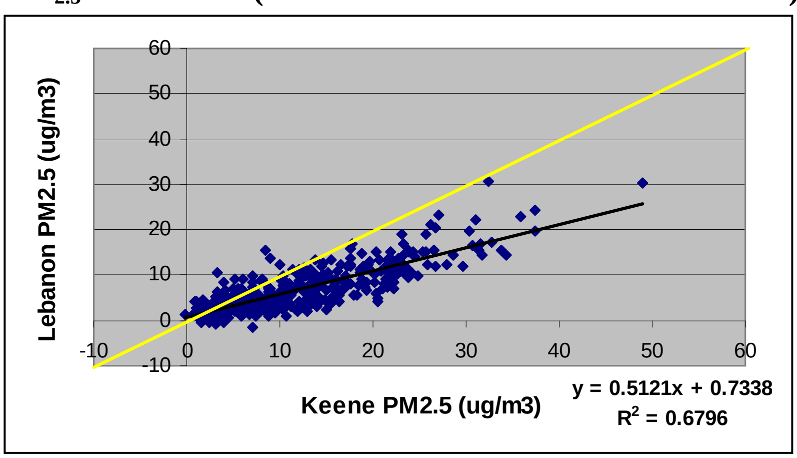


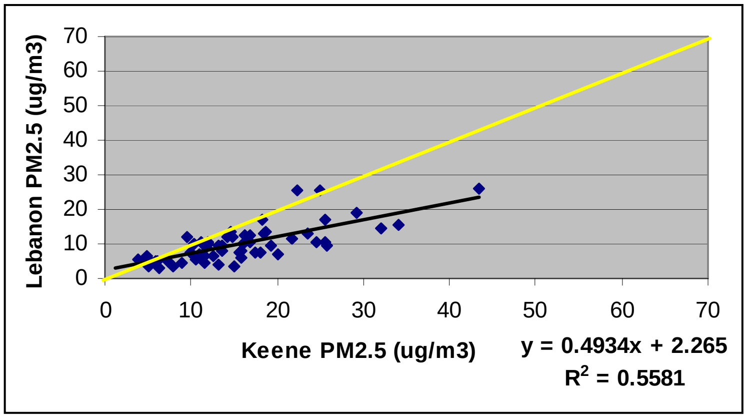
Figure 29: 24-Hour Correlation of Lebanon Airport and Keene $PM_{2.5}$ BAM Units (Winters December 2008 – March 2011)



3.6.1.1.c FRM (Filters)

The Lebanon filter-based $PM_{2.5}$ FRM operated January 2005 to December 2008. The correlation plot in Figure 29 also includes measurements from FRM sampling resumed in 2011. There were a relatively small number of samples, only a few above 30 µg/m^3 in Keene, but they support the above results: at moderate to high 24-hour levels in Keene, Lebanon levels are likely to be considerably lower.

Figure 29: 24-Hour Correlation of Lebanon Airport and Keene FRM $PM_{2.5}$ (Winters January 2005 – December 2008, January – March 2011)



3.6.1.2 Portsmouth

Ongoing Portsmouth BAM operations began in January 2010. NHDES also ran 1-in-3-day filter-based $PM_{2.5}$ FRM filters at the Pierce Island station in Portsmouth January 1999 to February 2011.

3.6.1.2.a BAM (January 2010 – March 2011)

There are only two shared seasons of BAM data between Keene and Portsmouth, the first beginning in January 2010. Figures 30 and 31 display hourly and 24-hour correlations, respectively.

Portsmouth appears higher in $PM_{2.5}$ than Lebanon, but still much lower than Keene. Based only on periods when Keene had valid data, Lebanon experienced seven hours over 40 µg/m^3 in two winters, while Portsmouth had 19 hours in one (2010-11). However, both totals were insignificant compared to well over 100 hourly concentrations above 40 µg/m^3 in Keene each of these seasons.

While nearly all 24-hour data points correlating Lebanon to Keene fall under the 1:1 line. However, Portsmouth $PM_{2.5}$ was sometimes similar to Keene at high concentrations. This dataset does not reveal 24-hour midnight-to-midnight concentrations much above 30 µg/m^3 for Portsmouth despite concentrations of up to 50 µg/m^3 in Keene.

Figure 30: Hourly Correlation of Portsmouth and Keene $PM_{2.5}$ BAM Units (Winters January 2010 – March 2011)

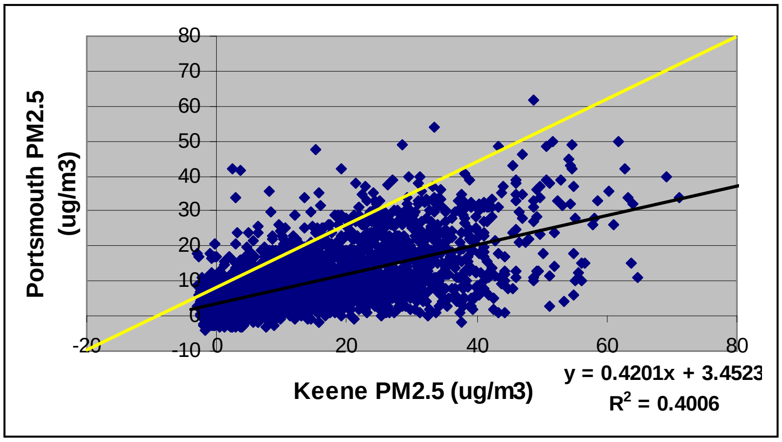
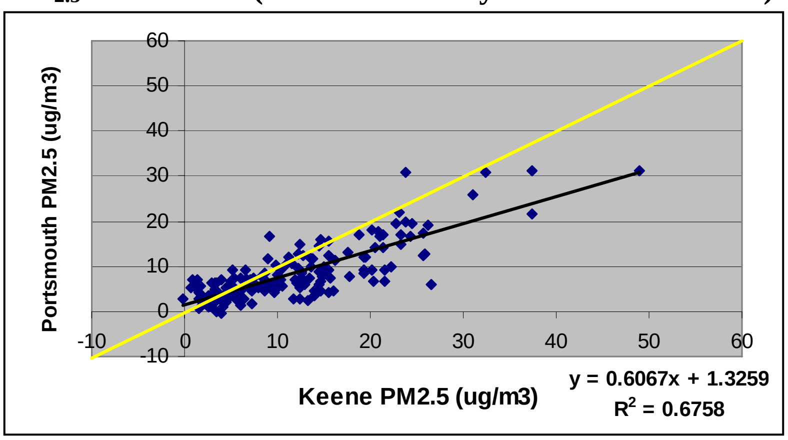


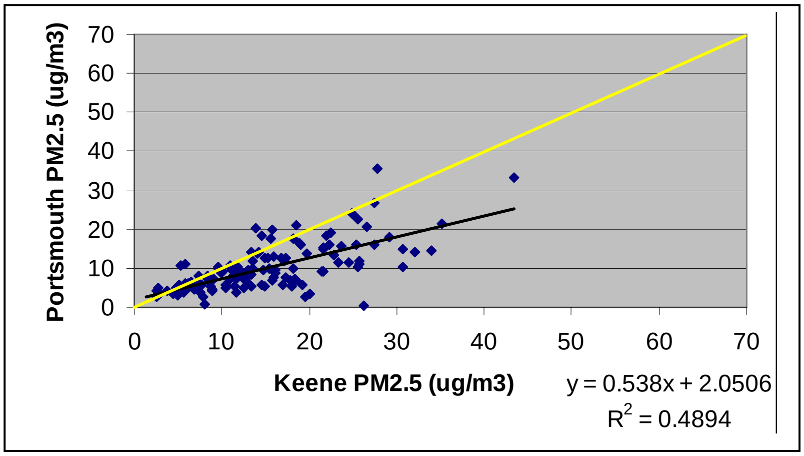
Figure 31: 24-Hour Correlation of Portsmouth and Keene $PM_{2.5}$ BAM Units (Winters January 2010 – March 2011)



3.6.1.2.b FRM (Filters)

Figure 32 shows the correlation of filter-based FRM $PM_{2.5}$ data between Portsmouth and Keene. Portsmouth's robust FRM database spanning 12 winters captures only two 24-hour averages above 30 µg/m^3, while Keene's FRM measured six. A Portsmouth NAAQS threshold exceedance of 35.5 µg/m^3 was recorded on February 7, 2002, when Keene $PM_{2.5}$ only reached 27.8 µg/m^3, which shows that Portsmouth has the potential to maintain prolonged periods of unhealthy $PM_{2.5}$ levels for sensitive groups.

Figure 32: 24-Hour Correlation of Portsmouth and Keene FRM $PM_{2.5}$ (Winters January 1999 –March 2011)



3.6.1.3 Manchester

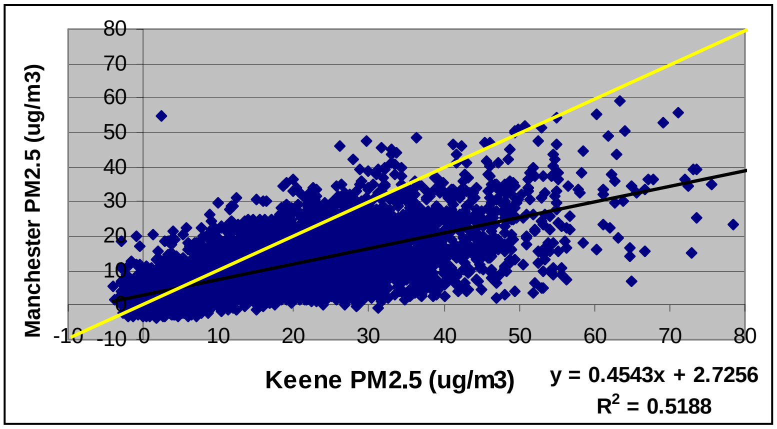
NHDES operated a continuous TEOM $PM_{2.5}$ monitor in Manchester from November 2008 to August 2011. NHDES did not travel through downtown Manchester during any MAMS runs; thus the MMU did not co-locate with this unit. NHDES also ran 1-in-3-day FRM filters on Commercial Street in Manchester December 1999 to March 2001 and on Pearl Street in Manchester April 2001 to December 2005.

3.6.1.3.a TEOM (November 2002 – March 2011)

The Manchester TEOM provided about nine winters of continuous $PM_{2.5}$ data. Because the TEOM tended to run lower than the BAM, NHDES adjusted the Manchester TEOM data based on a best-fit correlation line between the TEOM and the BAM during a one-year co-location in Keene (October 2008 through September 2009). This approximation reduces but does not completely eliminate all discrepancy between the two methods.

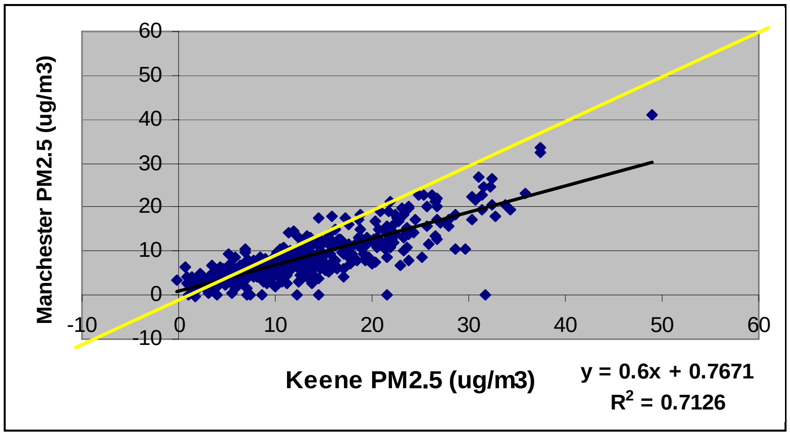
For the overlapping winter months from 2008 to 2011 (3 winter seasons), Figure 33 shows that the hourly correlation between Manchester and Keene has a small positive intercept and a slope of 0.45. Keene's hourly concentrations extended to nearly 80 µg/m^3, while Manchester's maximum was about 20 µg/m^3 lower. Year-to-year variation was considerable in Manchester, with nine, zero, and 34 hourly concentrations over 40 µg/m^3 per season.

Figure 33: Hourly Correlation of Manchester TEOM and Keene $PM_{2.5}$ BAM Units (Winters November 2008 – March 2011)



Based on the 24-hour averages in Figure 34, Manchester data were consistently lower than Keene's when Keene values climbed above 18 µg/m^3. Although Keene's $PM_{2.5}$ peaks far surpassed Manchester's on the majority of very high $PM_{2.5}$ days, some data points stayed relatively close to the 1:1 line even up to nearly 50 µg/m^3 in Keene when Manchester measured just over 40 µg/m^3.

Figure 34: 24-Hour Correlation of Manchester TEOM and Keene $PM_{2.5}$ BAM Units (Winters November 2008 – March 2011)



Although unofficial and without corresponding data in Keene, the TEOM provided continuous $PM_{2.5}$ back to 2002 and recorded only one 24-hour NAAQS threshold exceedance based on unadjusted data, or two after adjusting to BAM-equivalent data. These high days occurred consecutively January 7-8, 2008.

3.6.1.3.b FRM (Filters)

Figure 35: 24-Hour Correlation of Manchester and Keene FRM $PM_{2.5}$ (Winters November 1999 – December 2005)

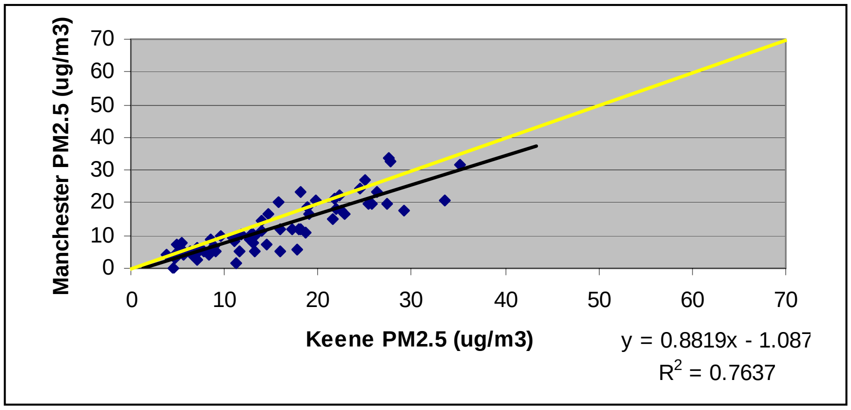


Figure 35 shows the filter-based FRM $PM_{2.5}$ data correlation between Manchester and Keene. Manchester FRM data are a combination of two downtown locations.

Despite six seasons of FRM sampling, Keene and Manchester had only two samples over 30 µg/m^3 and no winter NAAQS threshold exceedances based on days with data from both sites. However, one Manchester 24-hour average did surpass the NAAQS threshold at 35.9 µg/m^3 on January 29, 2002, when there were no corresponding data from Keene. (Nashua, Portsmouth, and Concord also recorded high moderates on that date.)

Manchester and Keene FRM data agreed remarkably well, with a slope of 0.88 and an R^2 of 0.76. This compares to a slope of 0.54 and R^2 of 0.49 for the Portsmouth to Keene correlation. Why this FRM slope of 0.88 is much higher than the 0.60 for the adjusted TEOM at the same Manchester station is uncertain, but may be attributed to inherent differences in the methods or the nature of the years sampled.

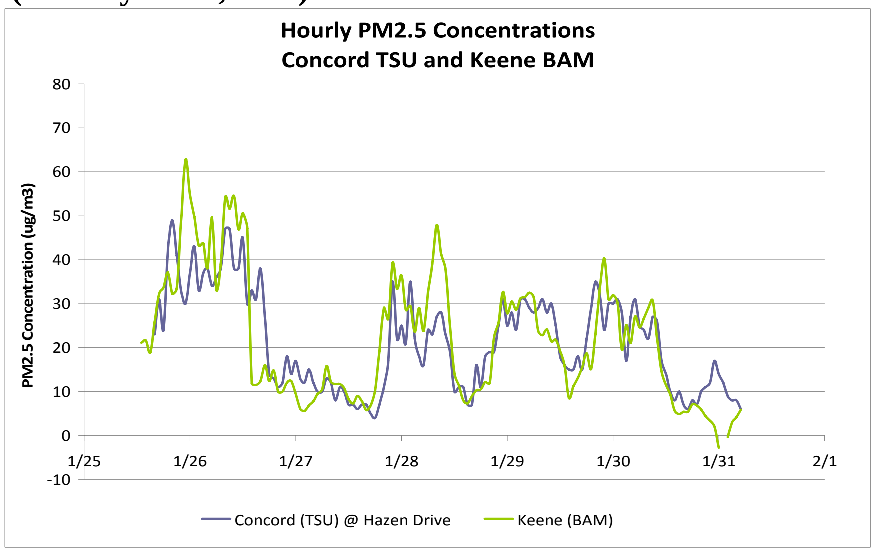
3.6.1.4 Concord

The only continuous Concord $PM_{2.5}$ data comes from the TSU parked on Hazen Drive January 25-31, 2011 and December 8, 2011 to February 21, 2012. NHDES also ran 1-in-6-day FRM filters on the roof of the State Annex building in Concord from January 1999 to December 2003.

3.6.1.4.a Concord TSU Part 1 (January 25 – 31, 2011)

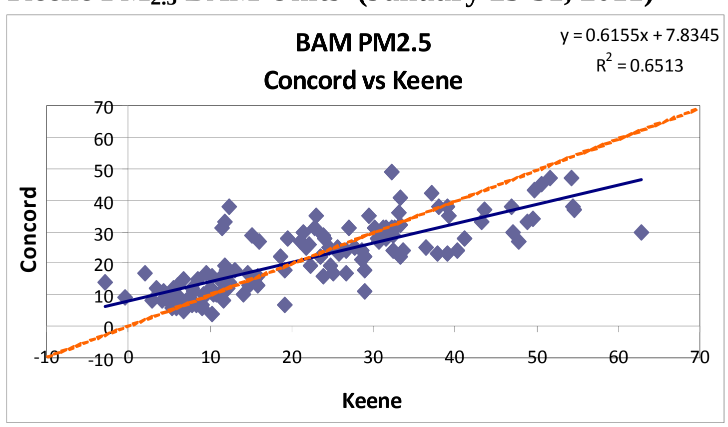
Figure 36 compares about six days of BAM data between the Keene station and the TSU placed on Hazen Drive in Concord. Concord $PM_{2.5}$ mirrored Keene's with slightly less severity during several high periods, and the cities tracked unexpectedly well considering their differences in population, emission sources, and topography. Hazen Drive's position on a ridge above downtown raises the question of whether concentrations would be different deeper in the valley, more below the thermal inversion and nearer urban emissions.

Figure 36: Hourly $PM_{2.5}$ Data for Concord and Keene BAM (January 25-31, 2011)



The correlation of hourly averages in Figure 37 has a slope of 0.62 and a R^2 of 0.65 which are both among the highest of the study in relation to Keene. Several data points lie close to the 1:1 line even at Keene concentrations over 40 and 50 µg/m^3.

Figure 37: Hourly Correlation of Concord TSU and Keene $PM_{2.5}$ BAM Units (January 25-31, 2011)



3.6.1.4.b Concord TSU Part 2 (December 8, 2011 – February 21, 2012)

Because the January 2011 $PM_{2.5}$ data from the TSU on Hazen Drive in Concord correlates strongly with Keene, NHDES placed the TSU at the same location for much of winter 2011-12. Figures 38 and 39 display hourly values from December 8, 2011 to February 21, 2012, a period that contains several nights of high concentrations.

Despite a mild 2011-12 winter season, hourly average $PM_{2.5}$ in Keene frequently peaked at 40-70 µg/m^3. Although Concord data mimicked the Keene pattern and often experienced high moderates, Concord $PM_{2.5}$ concentrations failed to climb above 40 µg/m^3.

The previous 2010-11 study (Part 1) captured Concord averages in the mid-40's, but these were short lived, and the maximums for the night of January 25-26, 2011 were about 10 µg/m^3 lower than in Keene. Figure 40 illustrates the correlation of Concord and Keene for the 2011-12 winter period. The positive intercept reveals background levels in the vicinity of 6 µg/m^3, but the slope and R^2 values are much lower than implicated by 2010-11 data (Concord Part 1), about half as great.

Subsequent measurements at higher concentrations in 2011-12 suggest a more limited risk of NAAQS threshold exceedance events in Concord than earlier suspected. While Concord may have the potential for winter overnight $PM_{2.5}$ buildup, the events captured in Part 2 suggest Concord is less likely to have significant $PM_{2.5}$ concentration build-ups than Part indicated.

Figure 38: Hourly $PM_{2.5}$ Data for Concord and Keene BAM (December 8, 2011 – January 14, 2012)

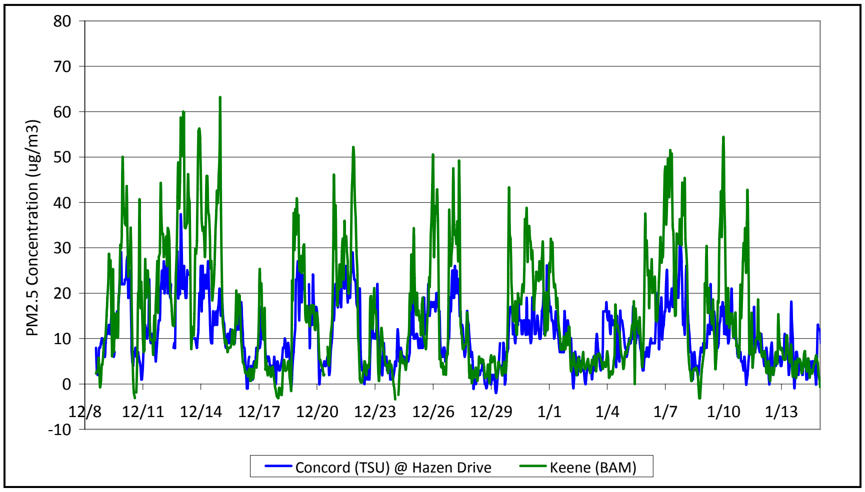


Figure 39: Hourly $PM_{2.5}$ Data for Concord and Keene BAM (January 15 – February 21, 2012)

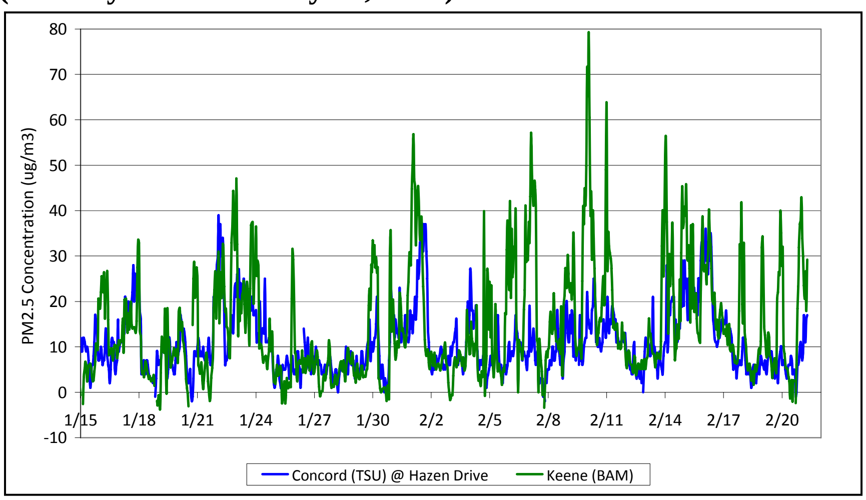
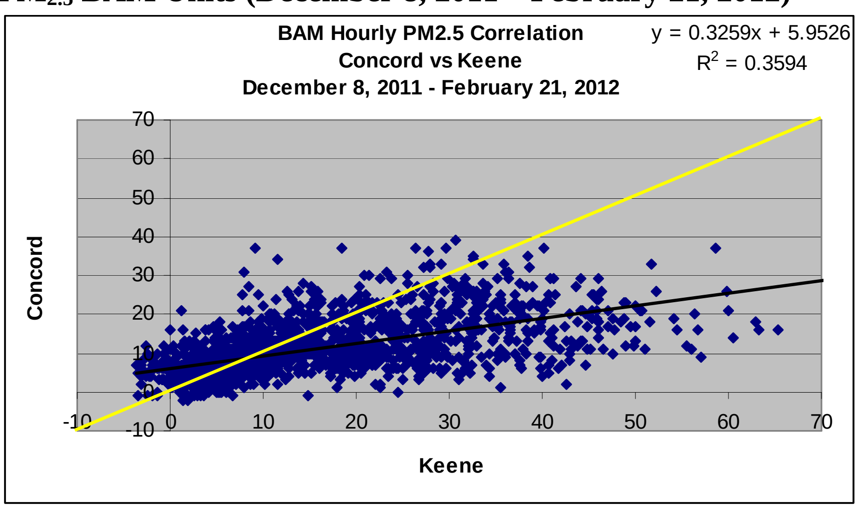


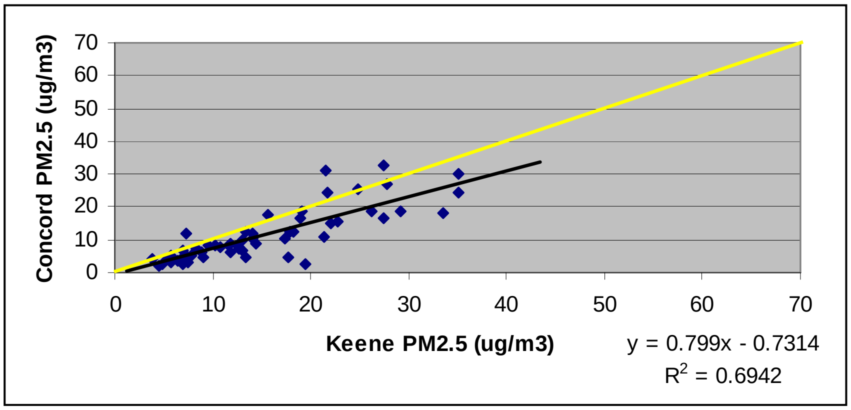
Figure 40: Hourly Correlation of Concord TSU and Keene $PM_{2.5}$ BAM Units (December 8, 2011 – February 21, 2012)



3.6.1.4.c FRM (Filters)

Figure 41 shows the filter-based FRM $PM_{2.5}$ data correlation between Concord and Keene. Concord FRM monitoring took place on the roof of the State Annex building from 1999 to 2003. Although closer to downtown than the TSU location on Hazen Drive, the rooftop monitor's position was high relative to recessed areas along the river valley.

Figure 41: 24-Hour Correlation of Concord and Keene FRM $PM_{2.5}$ (Winters January 1999 – December 2003)



Approximately five seasons of FRM data include only three 24-hour averages over 30 µg/m^3 in Keene and three in Concord during the 1999 to 2003 timeframe. Both locations exceeded 30 µg/m^3 on the same day, but neither actually exceeded the NAAQS threshold. The overall correlation between the Concord FRM and the Keene FRM is strong, with a near-zero intercept, a slope of 0.80, and an R^2 of 0.70.

FRM data support the general agreement between Concord and Keene suggested by the continuous TSU data in Part 1 despite differing locations of measurement within Concord.

3.6.1.5 Gorham

NHDES has no long-term $PM_{2.5}$ monitoring data from Gorham, but located the TSU there for more than a month from January 31 to March 2, 2011 for this study.

3.6.1.5.a TSU (January 31 – March 2, 2011)

Figure 42 compares BAM data from the Gorham TSU, Lebanon Airport station, and Keene station. Gorham $PM_{2.5}$ exhibited some stagnation peaks, but generally stayed in the good range, with only a few hours at the low-mid moderate $PM_{2.5}$ concentration level. Several moderate $PM_{2.5}$ events occurred in Keene and Lebanon during this time period, but not in Gorham.

The correlation shown in Figure 43 is weak. Gorham may not have topography to make it susceptible to acute inversions or a dense enough emission base to produce unhealthy $PM_{2.5}$ levels except on the rarest occasions.

Figure 42: Sample Data for Gorham, Lebanon and Keene $PM_{2.5}$ BAM Units (January 31 – March 2, 2011)

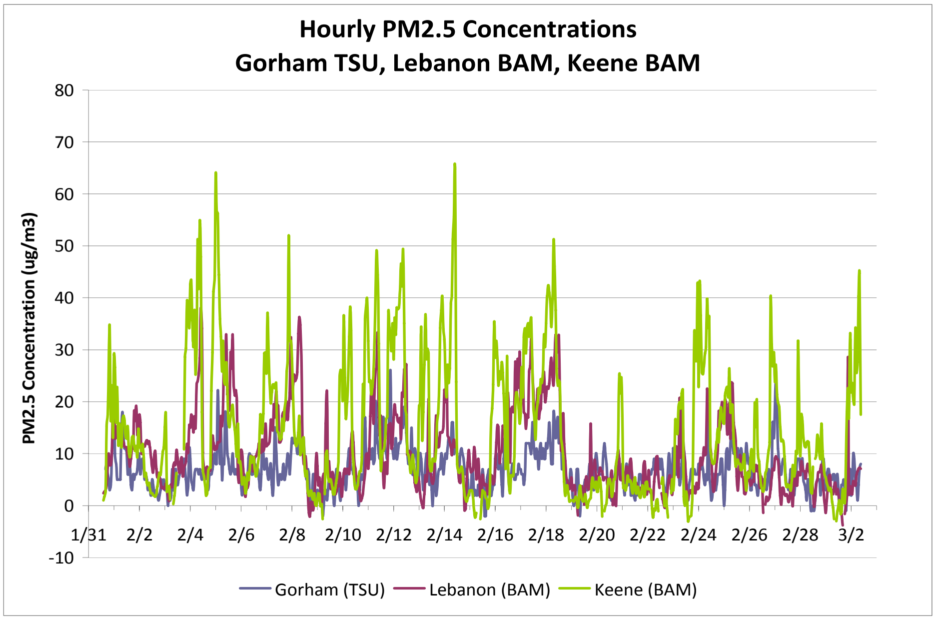
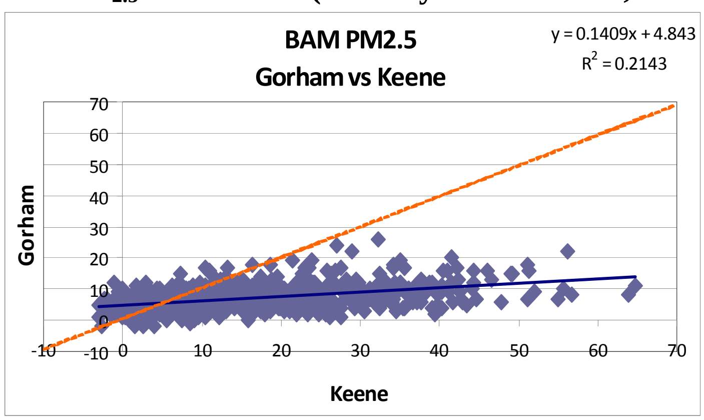


Figure 43: Hourly Correlation of Gorham TSU and Keene $PM_{2.5}$ BAM Units (January 31 – March 2, 2011)



3.6.1.6 Berlin

NHDES located the TSU in Berlin for about two weeks near the end of the 2010-11 winter season, March 2-14, 2011. NHDES also collected 1-in-6-day FRM filters in Berlin January 1999 to December 2006.

3.6.1.6.a TSU (March 2 – 14, 2011)

Figure 44 compares BAM data from the Berlin TSU, Lebanon Airport station, and Keene station. While usually lower, Berlin tracked the general $PM_{2.5}$ pattern of Keene and Lebanon and actually exceeded Lebanon several times. Keene experienced a few jumps in $PM_{2.5}$ not shared by the other two sites. For instance, on the 3rd-4th of March, Berlin $PM_{2.5}$ followed Keene's into the mid-20's µg/m^3, while Lebanon lagged in the good range until early morning.

Figure 44: Running Sample Data for Berlin, Lebanon and Keene $PM_{2.5}$ BAM Units (March 2-14, 2011)

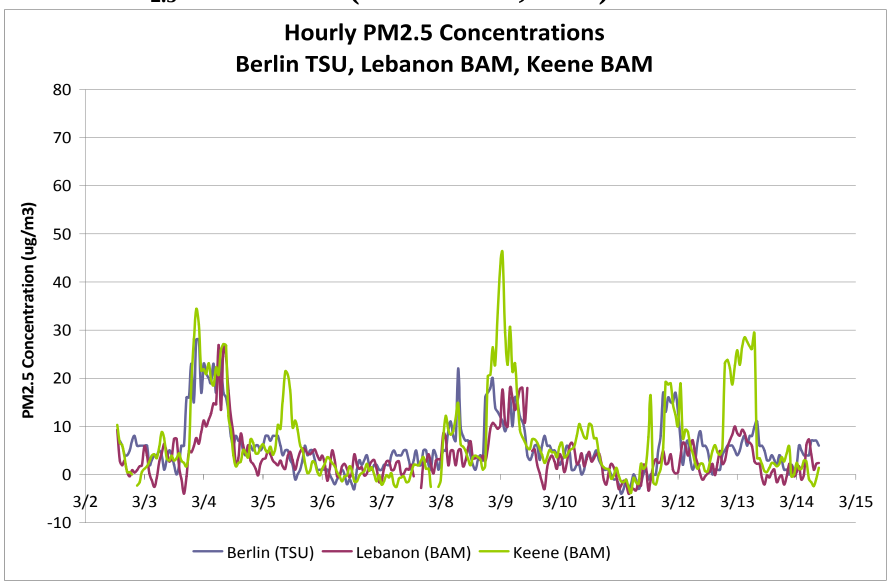
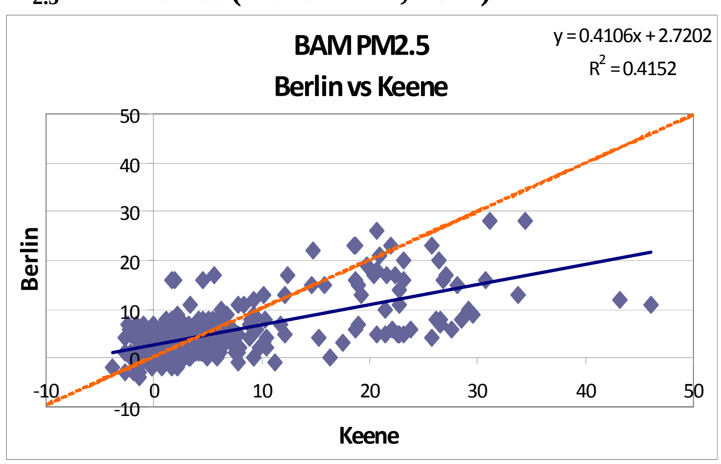


Figure 45 shows the correlation between Berlin and Keene. Berlin demonstrated greater risk for high $PM_{2.5}$ than its neighbor Gorham. The correlation slope for Berlin is 0.41 compared to 0.14 for Gorham, and the dataset includes several more hourly averages over 20 µg/m^3 despite a sampling period less than half as long and later in the season.

Figure 45: Hourly Correlation of Berlin TSU and Keene $PM_{2.5}$ BAM Units (March 2-14, 2011)



Although Berlin $PM_{2.5}$ occasionally climbed overnight, peak values tended to stay at good-to-moderate $PM_{2.5}$ concentration levels. However, because this dataset is short and at the tail end of winter, it may underestimate Berlin's potential $PM_{2.5}$ levels under conditions more suitable for inversions and stagnation.

3.6.1.6.b FRM (Filters)

Figure 46: 24-Hour Correlation of Berlin and Keene FRM $PM_{2.5}$ (Winters January 1999 – December 2006)

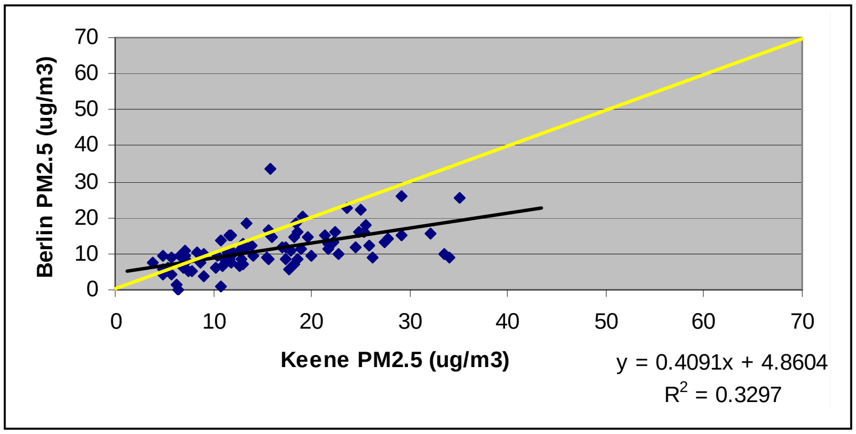


Figure 46 shows the correlation between Berlin and Keene filter-based FRM $PM_{2.5}$ data. The 24-hour $PM_{2.5}$ average in Berlin exceeded 30 µg/m^3 only once over the 1999-2006 period of FRM sampling. Based on days with data from both sites, Keene $PM_{2.5}$ went over this value four times, but never exceeded the NAAQS threshold. Although the FRM correlation slope of 0.41 is nearly the same as that derived from the two weeks of TSU data, neither dataset provides enough data on the upper end of concentrations to implicate Berlin as a community at significant risk for elevated $PM_{2.5}$ levels.

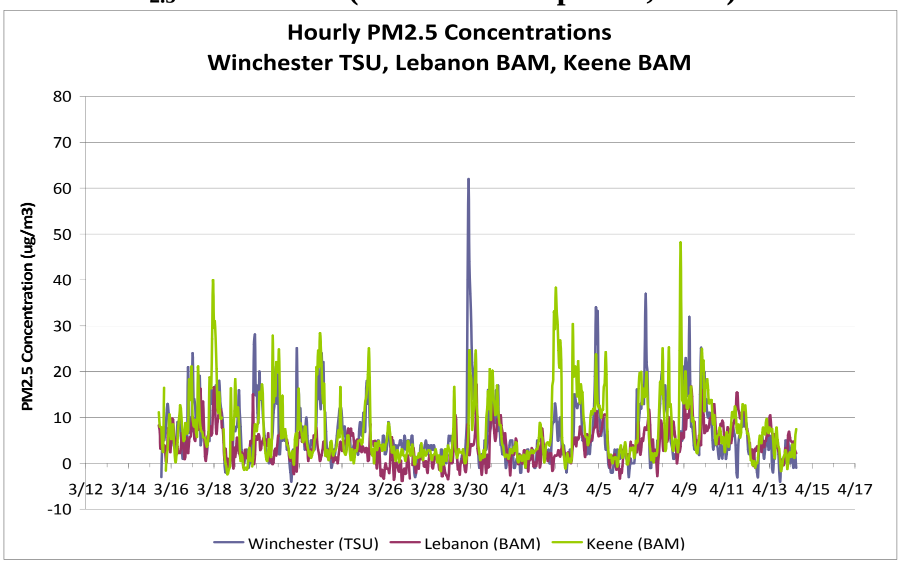
3.6.1.7 Winchester

There are no historical $PM_{2.5}$ monitoring data for Winchester, thus NHDES placed the TSU on Winchester school grounds for about a month from March 15 to April 14, 2011. The MMU also measured very high real-time concentrations as it passed through Winchester during the MAMS Southwestern Loop.

3.6.1.7.a TSU (March 15 – April 14, 2011)

During mobile sampling, the MMU recorded some of its highest real-time concentrations in Winchester. To investigate the town further, NHDES decided to place the TSU in Winchester for the remainder of the winter season after the last loop. Figure 47 displays the 31 days of Winchester TSU data with corresponding Lebanon Airport and Keene BAM data.

Figure 47: Running Sample Data for Winchester, Lebanon and Keene $PM_{2.5}$ BAM Units (March 15 to April 14, 2011)

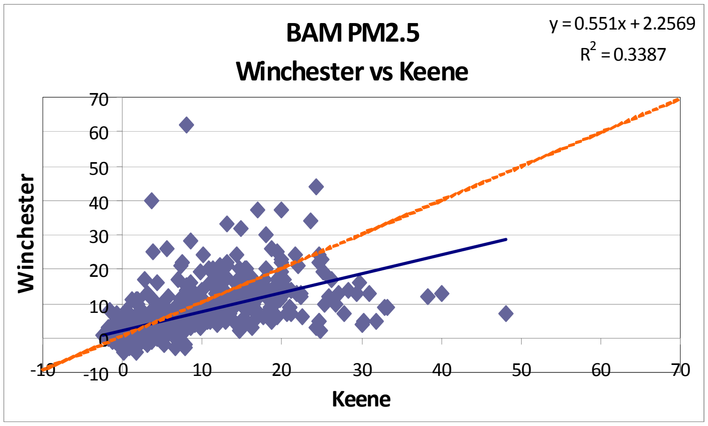


This sampling period took place late in the season when strong inversions are rare. Throughout this four-week period, Keene's hourly $PM_{2.5}$ remained almost exclusively in the good and moderate ranges, sporadically pushing into the category for unhealthy for sensitive populations only a handful of times. The absence of classic event scenarios prevents the use of this dataset to determine whether events in Keene would frequently be accompanied by similar events in Winchester. When Keene did reach its highest values, Winchester's concentrations stayed very low.

Nonetheless, Figure 47 shows several hours when Winchester's $PM_{2.5}$ concentrations climb to high moderate levels or greater without a corresponding rise in Keene. It is uncertain whether these $PM_{2.5}$ spikes were due to a single source located near the TSU or due to $PM_{2.5}$ accumulation throughout the town. However, the data are consistent with results from the 2009-2010 study, when a 24-hour filter sample taken March 19-20, 2010 measured higher $PM_{2.5}$ concentrations in Winchester than in Keene. This occurred only in the March sample; results from the January 13-14 and February 2-3 samples the same season showed slightly lower concentrations in Winchester than in Keene.

Correlation data in Figure 48 show that Winchester and Keene can both experience elevated $PM_{2.5}$ concentrations, but often at different times. The resulting weak correlation may imply that a few distinct sources may dominate Winchester $PM_{2.5}$ in contrast to Keene's community-wide events. Whether Winchester's winter $PM_{2.5}$ concentration depends more on near-monitor wind direction than stagnation is difficult to assess with the current dataset (without meteorological data).

Figure 48: Hourly Correlation of Winchester TSU and Keene $PM_{2.5}$ BAM Units (March 15 to April 14, 2011)



3.6.2 Other Supporting FRM Data

The following sites have historical filter-based FRM $PM_{2.5}$ data, but no continuous $PM_{2.5}$ monitoring data. Attachment J provides correlation plots and additional discussion on each of these sites. Pack Monadnock (Miller State Park in Peterborough) is left out of this group because the station's high elevation prohibits winter inversions from forming at that location.

The Claremont FRM site was located in the central portion of town and collected samples on a schedule of 1 in 6 days over nine complete and two partial winter seasons. Claremont's FRM concentrations averaged about 65% of the magnitude of Keene and correlated fairly strongly on an event-to-event basis.

Haverhill is located in a rural area on the upper Connecticut River valley along the northwest border of New Hampshire. It was a 1-in-6-day station that operated for two and a half seasons. Haverhill data averaged about 31% the magnitude of Keene and had only a fair correlation of data.

Laconia is located in the Lakes Region of the State and continues to build on its 13-year record of FRM $PM_{2.5}$ sampling. It is a 1-in-6-day station. Laconia's 24-hour averages tend to stay under 20 $\mu g/m^3$ and averages about 41% the magnitude of Keene $PM_{2.5}$. Correlation with Keene data is only fair.

Nashua has a 13-year sampling record and currently samples on a 1-in-3-day basis. The site is located in downtown Nashua along the Merrimack River near its intersection with the Nashua River. Nashua has exceeded the NAAQS threshold twice and averages 62% of the magnitude of Keene with a moderate correlation of data.

Pembroke station is located along the Merrimack River between Concord and Manchester and is located about 0.75 miles to the south of a power plant. The station has operated for just under eight years and collects filters on a 1-in-3-day basis. The Pembroke FRM averages about 58% of the Keene magnitude and has a moderate data correlation.

The Sunapee monitoring station was located on the summit of Mt. Sunapee in the southwestern portion of New Hampshire. It collected samples for about three years on a 1-in-6-day basis and averaged 24% of the Keene magnitude. Its poor data correlation is due to its remoteness from population centers and its high elevation above the stagnation-causing thermal inversions.

3.7 Comparisons and General Discussion

The MAM study's primary objective addresses the question: Do communities other than Keene often experience winter $PM_{2.5}$ buildup similar to Keene's? NHDES identified several isolated areas with high $PM_{2.5}$ concentrations, but brevity of sampling precludes conclusive answers. The challenge of inferring long-term exposure risk from short-term or sporadic sampling revolves around the following questions, which are discussed in Sections 3.7.1-3.7.4 below:

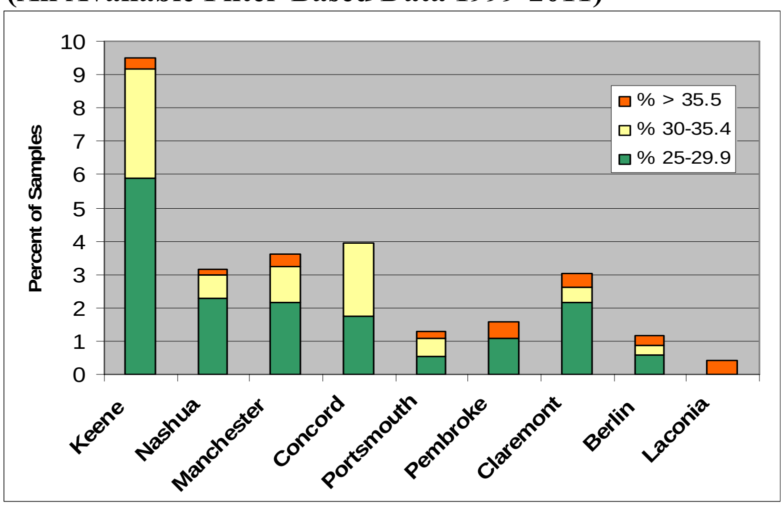
- What thresholds or other data attributes are the best indicators of potential $PM_{2.5}$ concentration buildup based on:
  - 24-hour data,
  - Hourly data, and
  - Instantaneous data?
- Do events in other communities tend to occur on the same nights as in Keene?

3.7.1 24-Hour $PM_{2.5}$ Averages at Permanent Monitoring Stations

Filter-based 24-hour FRM $PM_{2.5}$ sampling, performed once every three or six days, provides the longest-term datasets from the NHDES $PM_{2.5}$ monitoring network. The 1-in-3-day and 1-in-6-day sampling by definition omits 66% to 83% of the days between samples during the winter season and thus can inherently underestimate the number of NAAQS threshold exceedances. For example, the Keene FRM measures only one NAAQS threshold exceedance from 1999 to 2011, even though three seasons of continuous BAM monitoring show up to three midnight-to-midnight averages over the NAAQS threshold per season. Future monitoring may reveal an even greater number of exceedances as NHDES introduces more continuous monitors into the New Hampshire $PM_{2.5}$ monitoring network.

Because filter-based FRM $PM_{2.5}$ sampling is periodic, it can miss sporadic and infrequent $PM_{2.5}$ events. Thus, even one exceedance or near-exceedance of the NAAQS threshold could be a powerful indicator of a winter $PM_{2.5}$ episode. Figure 49 ranks each FRM site with at least one 24-hour $PM_{2.5}$ concentration equal to or greater than 30 μg/m^3. Table 6 presents these data in more detail.

Figure 49: Percent of FRM 24-Hour $PM_{2.5}$ ≥25ug/m^3 (All Available Filter-Based Data 1999-2011)



Implications of varying sampling durations and frequencies complicate comparisons among monitoring locations. NHDES has monitored $PM_{2.5}$ with FRM filters on the order of one every three days at some sites and one every six days at other sites, and this monitoring has taken place over periods from two years to over 10 years, depending on the site. Although presented as percentages of the total number of samples, each season's meteorology and other conditions differ; FRM sampling may have been more likely to capture high values at some sites simply due to timing of the samples, while high values may have been missed at other sites for the same reason. This should be considered before drawing conclusions.

Table 6: Number of Filter-Based FRM 24-Hour $PM_{2.5}$ Sample Days by Threshold for Sites with at Least One FRM 24-Hour Sample $\geq$30 µg/m^3 (All Available Data 1999-2011)

Site	25-29.9 µg/m^3	30-35.4 µg/m^3	≥35.5 µg/m^3	# Samples	% >30 µg/m^3
Keene	18	10	**1**	305	3.61%
Nashua	13	4	**1**	572	0.87%
Manchester	6	3	**1**	278	1.44%
Concord	4	5	0	229	2.18%
Portsmouth	3	3	**1**	546	0.73%
Claremont	5	1	**1**	231	0.87%
Pembroke	4	0	**2**	377	0.53%
Berlin	2	1	**1**	343	0.58%
Laconia	0	0	**1**	252	0.40%

Concord is the only site for which all filter-based FRM $PM_{2.5}$ samples fell below the NAAQS threshold of 35 µg/m^3. However, it also had the fewest number of samples. In spite of a lack of measured exceedances of the NAAQS threshold, Concord had the highest number of values 30-35.4 µg/m^3 and percentage of hours above 30 µg/m^3, after Keene.

Both Berlin and Claremont had one filter-based NAAQS threshold exceedance, each occurring on different days of November 1999. Since then, both sites have had only one 24-hour concentration over 30 µg/m^3.

Laconia had one 24-hour concentration greater than 35 µg/m^3, but no other values over 25 µg/m^3. This concentration of 53.3 µg/m^3 surpassed Keene's on the same day during 1999, but may be an outlier affected by an isolated or temporary source rather than representative of potential city-wide concentrations.

Pembroke's two values over 30 µg/m^3 also exceeded 35 µg/m^3. Portsmouth, Manchester, and Nashua each had one sample exceeding 35 µg/m^3 and at least three more 24-hour days over 30 µg/m^3. Nashua stands out with the greatest number of high moderates (25-29.9 µg/m^3).

By percentage of filter-based FRM $PM_{2.5}$ samples over 30 µg/m^3, the top five sites with potential to exceed the NAAQS threshold rank in the following order include: Keene, Concord, Manchester, Nashua, and Claremont.

3.7.2 Hourly $PM_{2.5}$ Averages from Permanent Continuous Monitoring Stations

Unlike continuous $PM_{2.5}$ monitoring data, the filter-based $PM_{2.5}$ FRM does not disclose short-term concentrations, nor their timing, over a winter night. Only when recent continuous monitoring began did data show that Keene hourly $PM_{2.5}$ concentrations often surpassed 35 µg/m^3 and might reach values approaching 80 µg/m^3.

Continuous monitoring data is only available in the most recent years. The available seasons of BAM data in Keene (2008-09, 2009-10, and 2010-11) reveal four 24-hour midnight-to-midnight NAAQS threshold exceedances at that location. During this same period, Manchester recorded one (adjusted TEOM), while the Lebanon (December 2009 to March 2011) and Portsmouth (January 2010 to March 2011) BAMs recorded zero exceedances of the NAAQS threshold.

During its four exceedance days, Keene reached maximum hourly concentrations ranging from 61.1 µg/m3 to 75.6 µg/m^3 and had periods lasting 8 to 19 hours where $PM_{2.5}$ concentrations were sustained at levels higher than 40 µg/m^3.

On the four dates when Keene exceeded the NAAQS threshold, Portsmouth and Lebanon BAMs each recorded only four one-hour periods where concentrations exceeded 40 µg/m^3, and Manchester (TEOM data adjusted to approximate the BAM) had several hourly concentrations in this range, but almost all occurred during a two-day episode January 1-2, 2011 when fireworks and late-night activities likely created spikes atypical of most winter nights.

For continuous $PM_{2.5}$ monitors, hourly concentrations greater than 40 µg/m^3 are of special interest because they often indicate an increased potential for a 24-hour NAAQS threshold exceedance.

Table 7 provides the number of one-hour periods with $PM_{2.5}$ concentrations greater than 40 µg/m^3at continuous $PM_{2.5}$ sites (Keene, Lebanon, Manchester, and Portsmouth) during the entire 2010-11 winter season. Keene had significantly more hourly $PM_{2.5}$ concentrations above 40 µg/m^3than any other continuous $PM_{2.5}$ monitoring site during this time frame. **It appears that Keene is unique among the larger communities in New Hampshire in that it tends to have more and higher hourly concentrations above the 30-40 µg/m^3 thresholds, suggesting it may be more likely to exceed the midnight-to-midnight 24-hour $PM_{2.5}$ NAAQS threshold.**

Table 7: Number of Hourly $PM_{2.5}$ Averages >30 µg/m^3 from BAM and TEOM Continuous Data (Winter 2010-11) (% of available data)

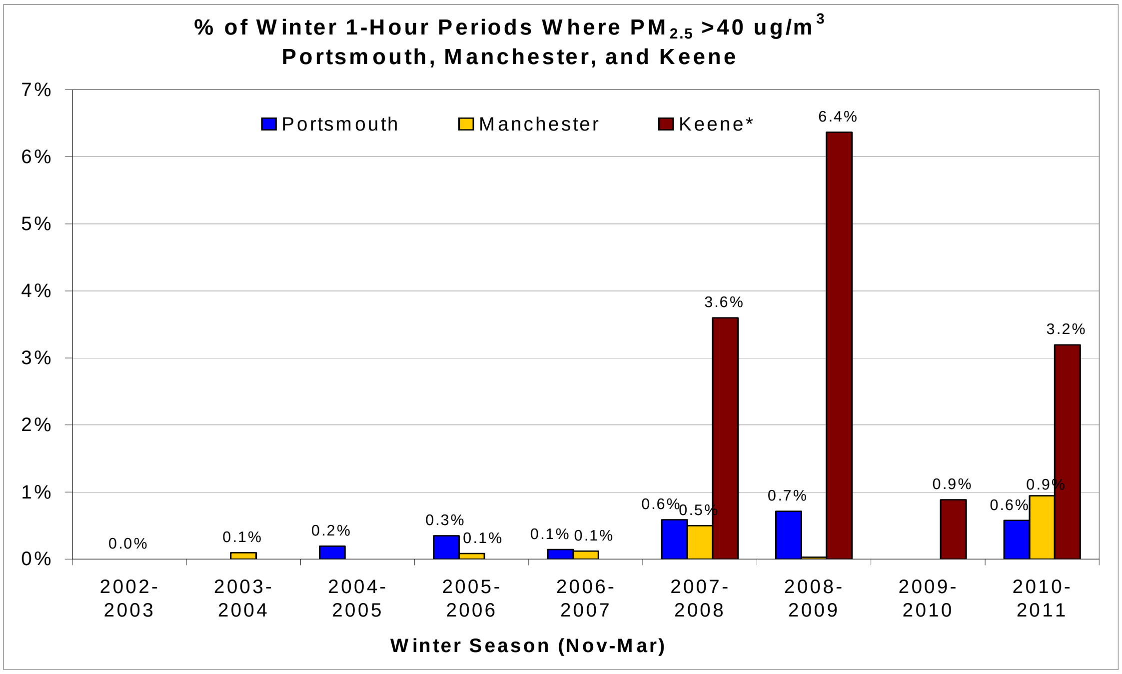
Threshold	Keene BAM	Portsmouth BAM	Lebanon BAM	Manchester "BAM"
>30 µg/m^3	357 (10.0%)	100 (3.0%)	56 (1.6%)	108 (3.0%)
>35 µg/m^3	205 (5.8%)	42 (1.3%)	17 (0.5%)	54 (1.5%)
>40 µg/m^3	114 (3.2%)	19 (0.6%)	2 (0.06%)	34 (0.9%)

NHDES also operated a version of the TEOM, the Filter Dynamic Measurement System (FDMS), in Portsmouth from 2004 to 2009. The FDMS unit was designed to better account for volatile materials than standard TEOM units. Though not an official Federal Equivalent Method (FEM), Portsmouth FDMS data expands the continuous $PM_{2.5}$ monitoring database and allows more extensive comparisons of winter concentrations.

Figure 50 compares hourly $PM_{2.5}$ averages greater than 40 µg/m^3 measured by the Portsmouth FDMS and compares it with available data 2002 through 2011 from other communities with continuous monitors (Keene and Manchester). This includes Keene 2007-2008 data from the TEOM, which preceded the BAM at that site and has been adjusted by the same best-fit equation applied to Manchester TEOM data. NHDES does not attempt to adjust the Portsmouth FDMS data because it is a distinct method.

Portsmouth's frequency of hourly values above 40 µg/m^3 was relatively consistent each season, but Keene had a much greater frequency of hourly concentrations above 40 µg/m^3 regardless of the monitoring method.

Figure 50: Percent of Winter Hourly $PM_{2.5}$ Concentrations >40 µg/m^3 in Portsmouth, Manchester, and Keene (2002-2011)



** Keene TEOM data for 2007-2008 is adjusted by the best-fit line based on a one-year co-location of the BAM and TEOM in Keene (October 2008 – November 2009).*

3.7.3 MAM Study: TSU (Stationary) Continuous $PM_{2.5}$ Monitoring (January 10 - April 14, 2011 and December 8, 2011 - February 21, 2012)

As part of the MAM Study, stationary continuous $PM_{2.5}$ monitoring was conducted for periods of days to weeks with a TSU-based BAM unit. Table 8 details the number of hourly $PM_{2.5}$ concentrations above 40 µg/m^3 recorded by the TSU in its different locations around the state. The table also details the percentage of hours the TSU and Keene BAM exceeded 40 µg/m^3 for each period. In Keene, BAM values above 40 µg/m^3 were most frequent during the months of December, January, and February (this is the same time period when the TSU was in Concord and Gorham). The Keene BAM recorded only three hours with $PM_{2.5}$ concentrations over 40 µg/m^3 while the TSU was in the Lebanon valley, two hours when it was in Berlin, and a single hour when it was in Winchester. The TSU BAM only exceeded 40 µg/m^3 while located in Concord (7 hours) and Winchester (2 hours).

Table 8: TSU BAM Hourly $PM_{2.5}$ Concentrations >40 µg/m^3 (2011, 2012)

TSU Location	Count # >40 µg/m^3		Percent >40 µg/m^3		Dates	Total # Hours (TSU)
	TSU BAM	Keene BAM	TSU BAM	Keene BAM		
Lebanon	0	3	0	0.9	Jan. 10 – 24, 2011	336
Concord Part 1	7	16	5.2	11.8	Jan. 25 – 31, 2011	134
Concord Part 2	0	94	0	5.3	Dec. 8, 2011 – Feb. 21, 2012	1,769
Gorham	0	34	0	4.8	Jan. 31 - Mar. 2, 2011	714
Berlin	0	2	0	0.7	Mar. 2 – 14, 2011	284
Winchester	2	1	0.3	0.1	Mar. 15 - Apr. 14, 2011	714

3.7.4 MAM Study: MMU (Mobile) Continuous $PM_{2.5}$ Monitoring (January 10 - April 14, 2011 and December 8, 2011 - February 21, 2012)

NHDES mobile monitoring over five event nights provides snapshots of continuous $PM_{2.5}$ concentrations too brief to draw firm conclusions as to how the locations would fare on a 24-hour basis if stagnation were to persist. However, it does offer a peek into how these locations behave, relative to others, at a time when conditions are favorable for stagnation.

The composite maps in Section 3.6 give a good overview of statewide MMU sampling. Figure 21 (Section 3.6 - "filtered" MMU $PM_{2.5}$ data) indicates that communities such as Concord, Hillsborough, Henniker, Hopkinton, Meredith, Newport, West Swanzey, and Winchester all had sustained peak instantaneous concentrations above 35 $\mu g/m^3$. The MMU measured one or more instantaneous $PM_{2.5}$ values over 60 $\mu g/m^3$ in Bennington, Concord, Hopkinton, Hillsborough, Meredith, West Swanzey, and Winchester. Except in Concord, West Swanzey, and Winchester, these were brief spikes in the data bounded by measurements below 35 $\mu g/m^3$. In order to exceed the 24-hour $PM_{2.5}$ NAAQS threshold, these levels would need to hold over a period of at least several hours.

During the MMU Southwestern Loop, West Swanzey and Winchester recorded the highest sustained (90 seconds or longer) MMU values during the entire MAM study, near or over 80 $\mu g/m^3$. This $PM_{2.5}$ episode was strong, and both the Concord MMU and TSU measurements also reached hourly concentrations of 60 to 90 $\mu g/m^3$ during the Southwestern Loop's co-location period. These extreme values provide the best evidence of potential for 24-hour exceedances of the NAAQS threshold given sufficient transport and prolonged stagnation.

On an instantaneous basis, the following communities measured the highest MMU $PM_{2.5}$ concentrations and are considered to have the greatest risk of NAAQS threshold exceedances (listed in alphabetical order): Concord, Keene, West Swanzey, and Winchester. All of these communities were sampled during the Southwestern Loop, one of the most pronounced events of the MAM study.

Other towns that measured high instantaneous concentrations during the Southwestern Loop, though none sustained levels over the NAAQS threshold, include: Charlestown, Jaffrey, Langdon, Marlow, South Acworth, and Westermoreland. Still other towns recorded high measured $PM_{2.5}$ concentrations relative to surrounding areas during the other loops, such as Belmont, Berlin, Epping, Farmington, Franklin, Lincoln, Pittsfield, Plymouth, Raymond, Rochester, and Somersworth. It is possible that some communities such as these could show even higher concentrations if they were sampled during a stronger episode.

3.7.5 Correlation with Keene

Because NHDES records the highest and most frequent wintertime $PM_{2.5}$ events in Keene, current forecasts focus on Keene and conservatively include surrounding valley towns. To accurately extend forecasts to areas without permanent continuous monitoring, it is important not only to identify which towns have the potential to exceed the 24-hour NAAQS threshold, but also to ascertain whether those exceedances would happen in the same timeframe as $PM_{2.5}$ events in Keene.

The datasets assembled for this study show that $PM_{2.5}$ levels in Keene correlate with $PM_{2.5}$ levels in other communities at least some of the time. The data further indicate that:

- Some communities correlate strongly with Keene, showing similar timing but at some percentage lower in $PM_{2.5}$ concentration (Concord);
- Some communities differ in timing (lower correlation) but experience $PM_{2.5}$ concentrations high enough at times to show some potential for NAAQS threshold exceedances (Winchester), and;
- Some communities demonstrate neither timing nor magnitude similarities to Keene (Gorham).

For the most part, however, the snapshot nature of this study's data leaves too many data gaps to permit conclusive statements about how each of the different communities specifically relates to conditions in Keene, the strength of those associations, and their predictive value. In addition, there are many communities not sampled in this study; therefore there cannot be a conclusion that "all" communities have been assessed for their risk of NAAQS threshold exceedances. Without sufficient data to identify with certainty all communities of interest, the question of how often events in other towns coincide with events in Keene is best saved for future analyses.

4.0 Summary and Conclusions

Continuous $PM_{2.5}$ monitoring in winter reveals that hourly $PM_{2.5}$ in the city of Keene frequently experiences concentrations surpassing 35 µg/m^3 on a one-hour basis, and once in a while such events are severe enough and last long enough to surpass the NAAQS threshold on a 24-hour basis. Based on these unexpectedly high wintertime $PM_{2.5}$ concentrations, NHDES sought to collect more air quality information in other New Hampshire communities to better determine whether similar conditions might exist in other areas. This was accomplished through continuous $PM_{2.5}$ monitoring by the MMU during drives through and between target communities and via strategic placement of the TSU.

The NHDES 2010-11 and 2011-12 MAM Study used a portable monitoring device (MMU) to cover hundreds of previously unmonitored miles in New Hampshire during events that were forecasted to have $PM_{2.5}$ stagnation buildup. NHDES technical staff collected these data with a pDR monitoring unit in a moving vehicle modified to house data-logging equipment. Data collected by TSU BAM equipment was added to the dataset to obtain days or weeks of additional hourly data in select locations. This new information builds on historical data from the permanent NHDES $PM_{2.5}$ network to provide a more comprehensive understanding of winter $PM_{2.5}$ patterns throughout New Hampshire.

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.

Based on this MAM Study, Keene appears to incur the highest wintertime $PM_{2.5}$ concentrations and the most frequent episodes of the larger communities in New Hampshire. Regarding other communities, there is some evidence that a few other locations 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 µg/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. Keene is also not currently violating the $PM_{2.5}$ NAAQS.

Background levels of $PM_{2.5}$ are Important

The contrast between the two most severe mobile monitoring events studied (January 25-26, 2011 and February 9-10, 2012) highlights the difference regionally transported background $PM_{2.5}$ (which adds to the locally produced $PM_{2.5}$) can make to NAAQS threshold exceedance potential. The Keene BAM recorded peaks 30% higher during the sampling period of the Southeastern Loop than the Southwestern Loop, but the maximum rolling 24-hour average was higher for the event monitored by the Southwestern Loop run (41.8 µg/m3 versus 35.3 µg/m^3). The profiles of the two events are very different, and the higher 24-hour average of the Southwestern Loop event resulted from levels remaining elevated over a greater number of hours.

One of the primary differences between these two events is that there was a higher degree of regionally transported background $PM_{2.5}$ during the Southwestern Loop. In this case, $PM_{2.5}$

transported into New Hampshire from sources hundreds of miles away stagnated for a prolonged period of time over the state, mixing with and adding to the locally produced $PM_{2.5}$ and creating higher local $PM_{2.5}$ concentrations.

While data from this study indicate that other communities in the state may periodically reach high $PM_{2.5}$ levels under stagnant conditions (particularly populated cities and valleys of the southwestern part of the state), considerably more continuous stationary data rather than instantaneous snapshot measurements are needed to solidify the degree of 24-hour risk associated with $PM_{2.5}$ exposure in these places. As demonstrated between the events during the Southeastern Loop and the Southwestern Loop, the likelihood of exceeding the NAAQS threshold increases when regionally transported $PM_{2.5}$ stagnates in the region before local thermal inversions develop to trap local emissions.

4.1 Communities of Interest

Data demonstrating 24-hour $PM_{2.5}$ concentrations near the NAAQS threshold of 35 $\mu g/m^3$ and hourly $PM_{2.5}$ concentration averages above 40 $\mu g/m^3$ suggest Concord, Nashua, Manchester, and Portsmouth show potential risk of winter $PM_{2.5}$ USG events similar to Keene's. However, the longer history of data presented by the TEOM units in Manchester and Portsmouth have thus far failed to substantiate this expectation. Neither location has experienced more than two 24-hour averages over the NAAQS threshold since 2004. While occasional exceedances of the NAAQS threshold are possible, events are rare and overall concentrations have been much lower than in Keene.

Concord filter-based $PM_{2.5}$ FRM data from the roof of the State House Annex and continuous BAM data from the TSU on Hazen Drive in January 2011 have shown some high 24-hour and hourly $PM_{2.5}$ concentrations in the city, respectively. While early FRM data seem to support the 2011 TSU data, with several filter-based samples over 30 $\mu g/m^3$ (though no exceedances), additional TSU BAM monitoring in Concord for about two months during the 2011-12 season do not necessarily support the 2011 measurements and lend to conflicting conclusions.

Concord's density of population, south-central location vulnerable to transport, and valley topography support the supposition that the high moderate $PM_{2.5}$ concentrations monitored at the filter-based FRM and TSU locations may be accompanied by $PM_{2.5}$ concentrations exceeding the NAAQS threshold at lower elevations within the city. Additional longer-term continuous $PM_{2.5}$ monitoring data for downtown Concord would be useful to better determine whether this location mimics $PM_{2.5}$ events in Keene.

The MMU portion of this study uncovered several communities where thermal inversions and $PM_{2.5}$ emissions from residential heating are likely to produce some level of $PM_{2.5}$ buildup. Recognizing that many spikes in the MMU data may be caused by single isolated sources, a data filter was applied and the list of communities was narrowed down (shown in Figures 21 and 23 in Section 3.5).

Combining all screening techniques highlights a few towns that may warrant further investigation. Of particular concern are those located in the southern part of the state where transport can also be a significant factor. It should be noted that without extended stationary $PM_{2.5}$ monitoring in each community of interest (presented in Table 9), there are currently insufficient data to pinpoint health risks. Even then, the selection of location to monitor within these communities could affect the outcome as risks are likely to vary based on location. Further such monitoring efforts for each community of interest are not planned at this time. On a more limited basis, NHDES is collaborating with Keene State College to obtain more mobile and stationary monitoring data for Winchester, West Swanzey, and other towns near Keene.

Table 9: Potential Communities of Interest:

Primary	**Secondary**	**Others to Watch**
Sustained >35 μg/m^3 and a normalized ratio >1.0	Sustained >35 μg/m^3 or a normalized ratio >1.0	Notably high local concentrations or 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 $PM_{2.5}$ concentrations from the Central, Southwest, North 1, North 2 MAM loops or at least two consecutive 60-second pDR $PM_{2.5}$ 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.*

4.1.1 Primary Communities of Interest

As discussed in Section 3.7.2, high hourly $PM_{2.5}$ concentrations (>35 μg/m^3) have surfaced as one of the most potent indicators of a potential 24-hour $PM_{2.5}$ event, particularly where only short-term data are available. Further, how a community compared to $PM_{2.5}$ concentrations measured in Keene (normalized ratios of >1.0) indicates that the location can experience concentrations higher than the benchmark community. Primary communities of interest were identified from mobile monitoring based on these criteria combined.

Hourly $PM_{2.5}$ concentrations of 60 μg/m^3 and higher observed in West Swanzey and Winchester are especially noteworthy and may be a significant indication of potential winter $PM_{2.5}$ event risk approaching that of Keene. No additional data exist for West Swanzey, but Winchester TSU data show that events may not always occur on the same nights as in Keene. Because these late-season data are inconclusive, NHDES has coordinated with Keene State College to perform additional mobile monitoring to further investigate these locations at future dates.

Concord has also exhibited some $PM_{2.5}$ concentrations over 40 μg/m^3. As explained above, other long-term monitoring does not strongly reinforce the $PM_{2.5}$ buildup potential at higher elevations in Concord. However, these data point to potential risk that is likely to be more significant deeper into the valley areas of the city, where more monitoring may be merited.

The towns of Henniker, Hillsborough, and Newport also showed signs of Winter $PM_{2.5}$ concentration build-up. All three are valley communities in southwestern New Hampshire where residential heating with wood, thermal inversions, and regional transport are fairly common.

The three adjacent towns of Hopkinton, Henniker, and Hillsborough located to the southwest of Concord appear in this list of primary or secondary communities of interest. The MAM passed through this stretch four times during the Southwestern Loop. Except for the first pass, before the inversion strengthened, each of these towns consistently exhibited moderate $PM_{2.5}$ concentrations. In some instances, multiple values exceeded the NAAQS.

During the Central Loop, Newport stood out with concentrations rising to around 20 $\mu g/m^3$, then to over 30 $\mu g/m^3$, with a singular peak over 40 $\mu g/m^3$. At the same time, the Keene BAM recorded an hourly average of 26.1 $\mu g/m^3$. $PM_{2.5}$ values measured in the area around Newport were much lower, in the good and low moderate ranges. Newport is situated in a valley near Lake Sunapee.

4.1.2 Secondary Communities of Interest

Secondary communities include most of the other communities highlighted in Figures 21 and 23 (Section 3.6) that were not included in the primary community list. These communities each recorded at least 90 seconds of instantaneous MMU-recorded $PM_{2.5}$ values 35 $\mu g/m^3$ or higher <u>or</u> experienced a normalized ratio (community to Keene) of at least 1.0. Although this data only reflects a snapshot in time, these locations are documented as having event $PM_{2.5}$ concentrations near or over the standard for at least a short time.

Southeast of Mount Monadnock, Jaffrey is a secondary community of interest measured during the Southwestern Loop. The MMU values rose steadily as the MMU passed through town, with a peak of 36 $\mu g/m^3$. The Keene BAM measured 38.1 $\mu g/m^3$ for that hour. While the concentrations were not extreme, the consistent measurement of values near the standard show that $PM_{2.5}$ can accumulate in the town of Jaffrey during winter events.

Meredith, a lakeside town, exhibited several concentrations 30-40 $\mu g/m^3$ and one value over 60 $\mu g/m^3$ during the first Northern Loop. This peak was short lived and appeared to affect a limited vicinity, but the concentrations were consecutive and similar to hourly averages recorded in Keene at the time. The MMU also went through Meredith during the second Northern Loop; this time there was only a slight increase in concentration. However, the Northern Loop event was unimpressive, and even Keene BAM values were only around 20 $\mu g/m^3$ when the MMU traveled into Meredith.

Two towns in northern New Hampshire also meet the criterion for secondary communities: Lincoln and Lancaster. Lincoln was traversed more than once between the first and second Northern Loop, but only during the first Northern Loop did concentrations rise to the high moderate range. The MMU recorded about five minutes of mobile sampling in the high 20's $\mu g/m^3$, compared to an hourly Keene average of 20.9 $\mu g/m^3$ over that period. Lancaster, in the far North, experienced concentrations in the low 20's $\mu g/m^3$ when the Keene BAM recorded an hourly average of 18.5 $\mu g/m^3$, and produced a normalized ratio higher than 1.0.

4.1.3 Others to Watch

While the remaining towns have mobile data well below the NAAQS threshold of 35 μg/m^3, some where concentrations were observed to increase relative to the surrounding area may still be worth noting. During each sampling period, the MMU tended to record background levels around 10 μg/m^3; for the Southwestern Loop, this was closer to 20 μg/m^3 because of greater transport. Therefore, concentrations over 20 μg/m^3 usually represented pockets of elevated background $PM_{2.5}$.

In these places, the MMU may not have recorded values near the NAAQS threshold or similar to Keene at the time, but it did respond to a localized increase. These communities are important to note because lack of high concentrations can be as much due to timing or event conditions as an overall low risk of buildup. These places are, at the least, local pockets where nearby sources and topography can produce elevated levels of $PM_{2.5}$. More data may be of interest to determine the degree of $PM_{2.5}$ buildup likely to occur under larger $PM_{2.5}$ event conditions in these areas.

Several of the communities on the "Others to Watch" list lie along a continuous stretch of the Southwestern Loop: Charlestown, Langdon, Acworth, and Marlow. The MAM recorded a steady increase in concentration beginning farther south in Westmoreland, but reached consistently higher levels, primarily in the 20's μg/m^3, in Charlestown and Langdon. Although lower overall, the MMU also detected momentary peaks in Acworth and Marlow as the MMU traveled east. This part of the route also produced a notable increase in $PM_{2.5}$, peaking around Charlestown. These towns lie along water bodies, and the road through them follows the valley areas.

The MMU also made more than one pass through Berlin over the two Northern Loops. Sampling during the second Northern Loop produced only low concentrations, around 10 μg/m^3, even during the hour-long co-location period. However, during the first Northern Loop, the MMU recorded a few minutes of concentrations in the 20's μg/m^3. Other towns also reached this level during this sampling period, but, other than Lincoln, the values were not sustained in the other towns for at least 90 consecutive seconds.

4.1.4 Isolated Risk

This study focused on identifying communities with a mix of wood-burning demographics and topography conducive to trapping local smoke emissions such that $PM_{2.5}$ concentrations could concentrate to levels of potential health concern. Single-instant spikes in concentration were not used to assign communities of interest because they were likely caused by the MMU passing through smoke plumes of a single source. Though not the focus of this study, these areas could represent isolated areas of concern if conditions were persistent and repeatedly affected nearby residences or businesses. While epidemiological studies have increasingly implicated short-term spikes in $PM_{2.5}$ in adverse cardiac and respiratory outcomes, a firm declaration of health risks cannot be made with regard to isolated concentration spikes recorded in this study.

Isolated risk areas can be located anywhere near sources of smoke. Such areas are not highlighted in this report but are evident in the data. Such areas appear to be dominated by single sources. These may be neighborhood nuisances, and concerns should be raised to local officials.

Community-wide risk areas are areas where more than one or two city blocks are at risk for wood smoke events. These areas generally have several or more sources contributing to routine stagnation buildups that can affect a larger population.

4.2 Forecasting Ramifications

NHDES provides daily air quality forecasts to advise citizens of any potential health risk in their communities. Wintertime air pollution forecasts have historically been challenging, but have improved since NHDES began employing continuous $PM_{2.5}$ monitoring at several sites, including Keene. To broaden public protection during winter wood smoke stagnation to other locations, community-to-community relationships need to be better understood so that coverage of air quality advisories can be sufficiently inclusive.

Keene is the only community with a documented susceptibility toward winter $PM_{2.5}$ inversion events that also has real-time $PM_{2.5}$ monitoring as part of the current network. Comparing data from other communities to Keene can be useful so that when concerns arise for wood smoke events in Keene, public health officials can be better advised on the likelihood that wood smoke events may be occurring elsewhere in the state as well. Mobile monitoring has highlighted several communities of interest where these situations may periodically develop.

Winchester and West Swanzey exhibited very high short-term concentrations during the strong wintertime $PM_{2.5}$ event of the Southwestern Loop sampling period. Additional FRM and TSU monitoring in Winchester gave some cause for concern but did not exceed the NAAQS threshold. Further, this data unexpectedly showed that the event timing in Winchester is inconsistent compared to Keene. It is unknown whether Winchester often experiences $PM_{2.5}$ buildup when Keene does not, or vice versa. This makes it difficult to routinely extend forecasts to conservatively cover Winchester and other towns located to the south of Keene, based on forecasted conditions in Keene.

At this time, these data are insufficient to significantly alter forecasting methodologies and messages, but they provide insight into areas that have some potential for short periods of elevated health risk, though likely to a lesser degree than Keene. While the data do not demonstrate actual exceedances of the 24-hour NAAQS threshold beyond what is found in Keene, it may be reasonable to extend advisories to include primary communities of interest as potentially having elevated health risks when unhealthy conditions are forecasted for Keene. Additional work exploring the content of the $PM_{2.5}$ during unhealthy periods could be useful in understanding the role of various local sources and allow for more refined forecasting and outreach messages.

Attachment A

MMU - Mobile Monitoring Unit (2008 Chevrolet HHR)
Dell laptop, GPS unit with Delorme mapping software, Thermo pDR (continuous $PM_{1.0-1.87}$ 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.

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

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

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

Attachment B

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 following directory: H:\Air Monitoring\Keene Site Info\2010-2011_$PM_{2.5}$ Special Study\ 2011-01-05_Special Study Log_Template

*****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

Attachment C

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

Attachment D

TSU - Temporary Stationary Unit (16' Wells Cargo)

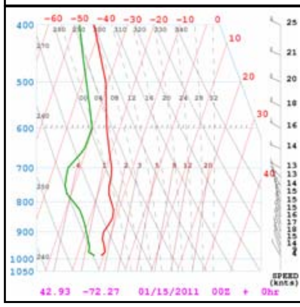
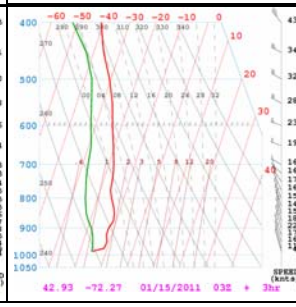
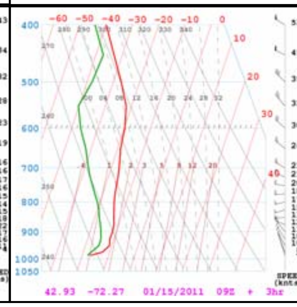
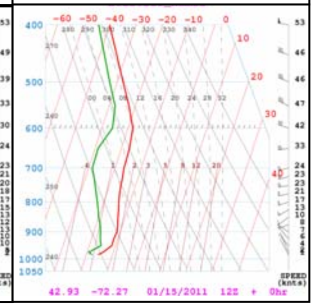
Met One Beta Attenuation Monitor (continuous BAM $PM_{2.5}$ monitor), heater, light. While the TSU is equipped with a generator for power, it was decided that establishing a local host for the TSU with plug-in power was desirable to avoid generator emissions impacting the sampling process. The planning team specifically asked hosts if they could provide a 120V outlet to operate along with an overestimated electrical usage of 1000 watts, based on full use of all possible electrical units.

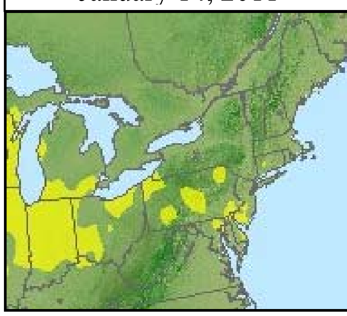
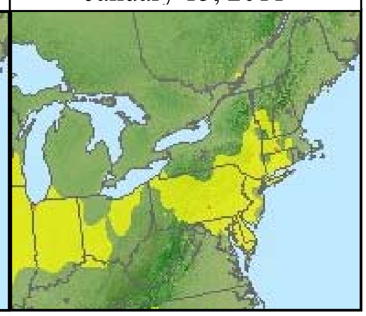
TSU – TSU during co-location (left, green) and TSU BAM installation (right)

TSU – Electrical in TSU (left) and TSU ready for deployment (right)

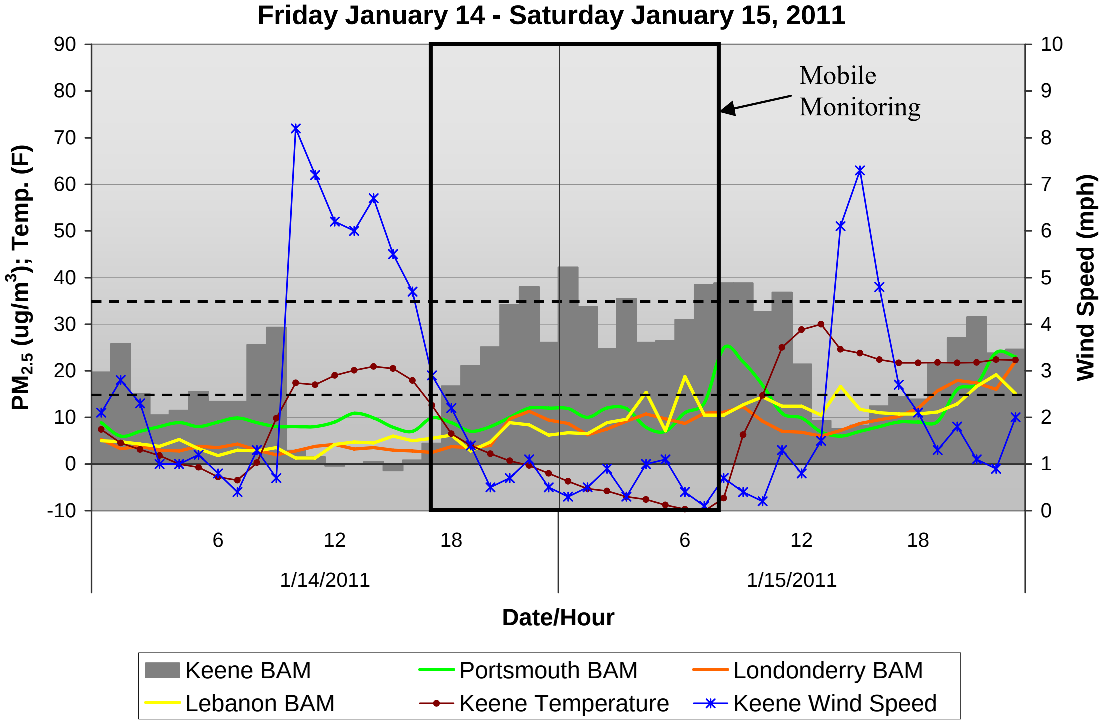
Attachment E

Central Loop Event Graphics and Recorded $PM_{2.5}$ Data

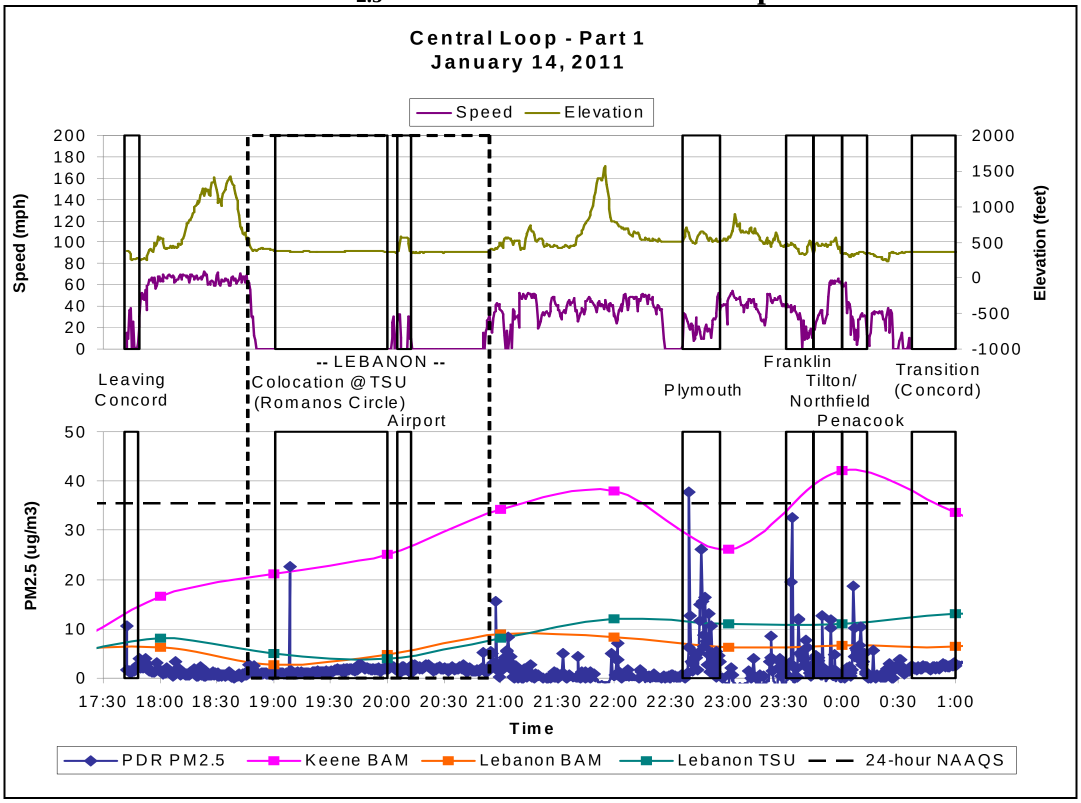
HYSPLIT Model NAM12k Soundings			
7pm Jan. 14, 2011	10pm Jan. 14, 2011	4am Jan. 15, 2011	7am Jan. 15, 2011
			

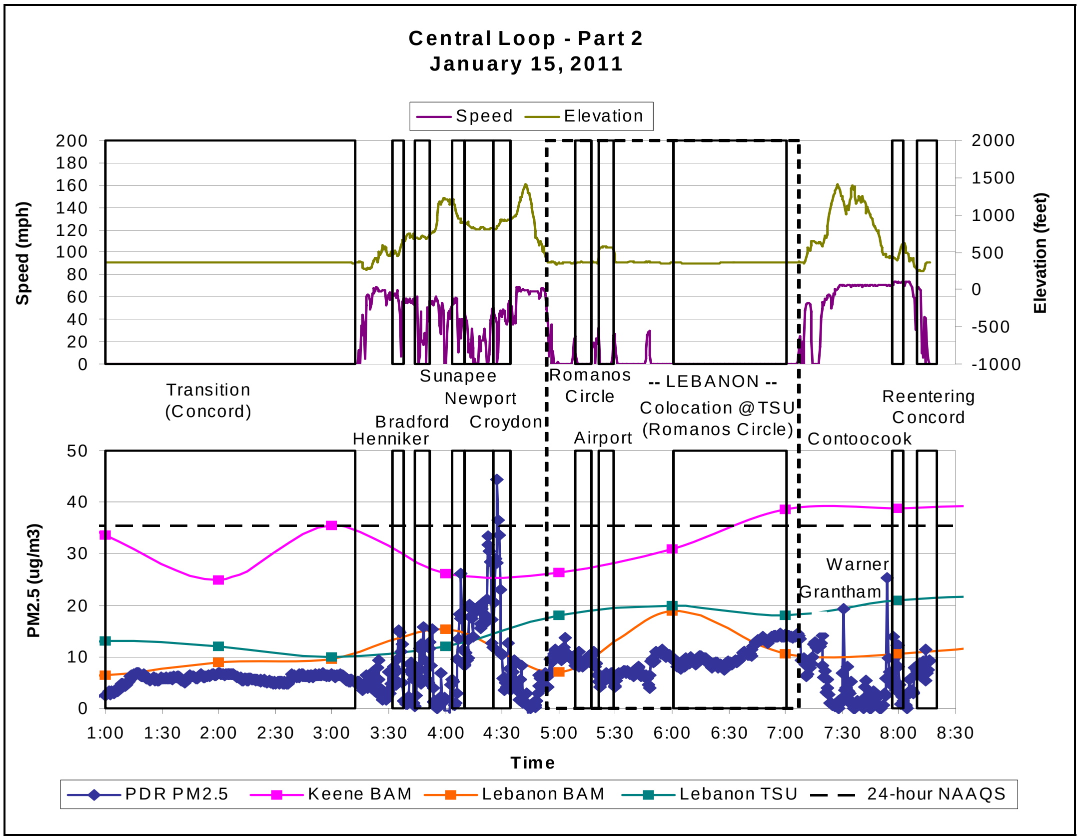
AIRNow Daily Average $PM_{2.5}$ AQI Maps	
January 14, 2011	January 15, 2011
	

Hourly Average $PM_{2.5}$, Wind Speed, and Temperature
Friday January 14 - Saturday January 15, 2011



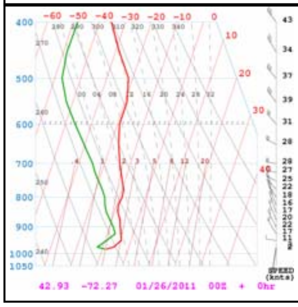
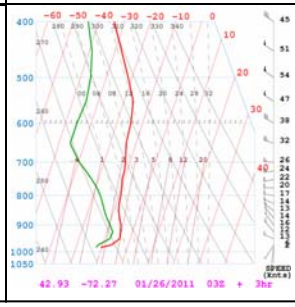
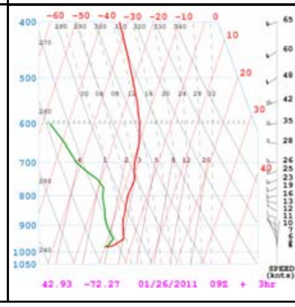
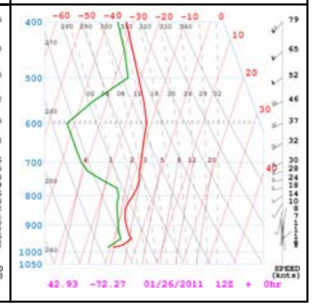
$PM_{2.5}$ Data from the Central Loop

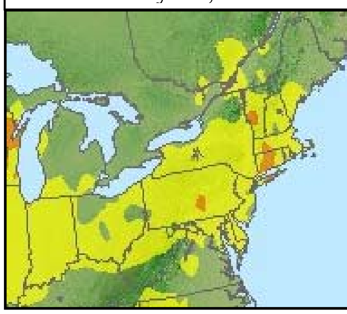
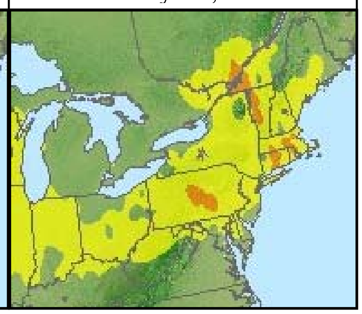




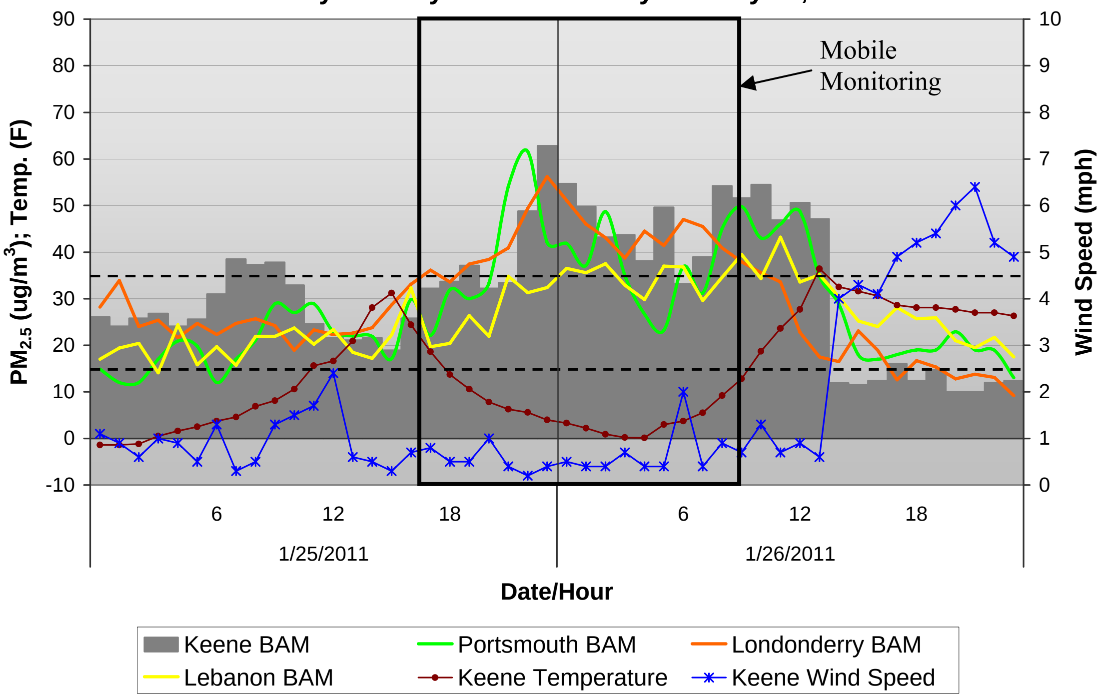
Attachment F

Southwestern Loop Event Graphics and Recorded $PM_{2.5}$ Data

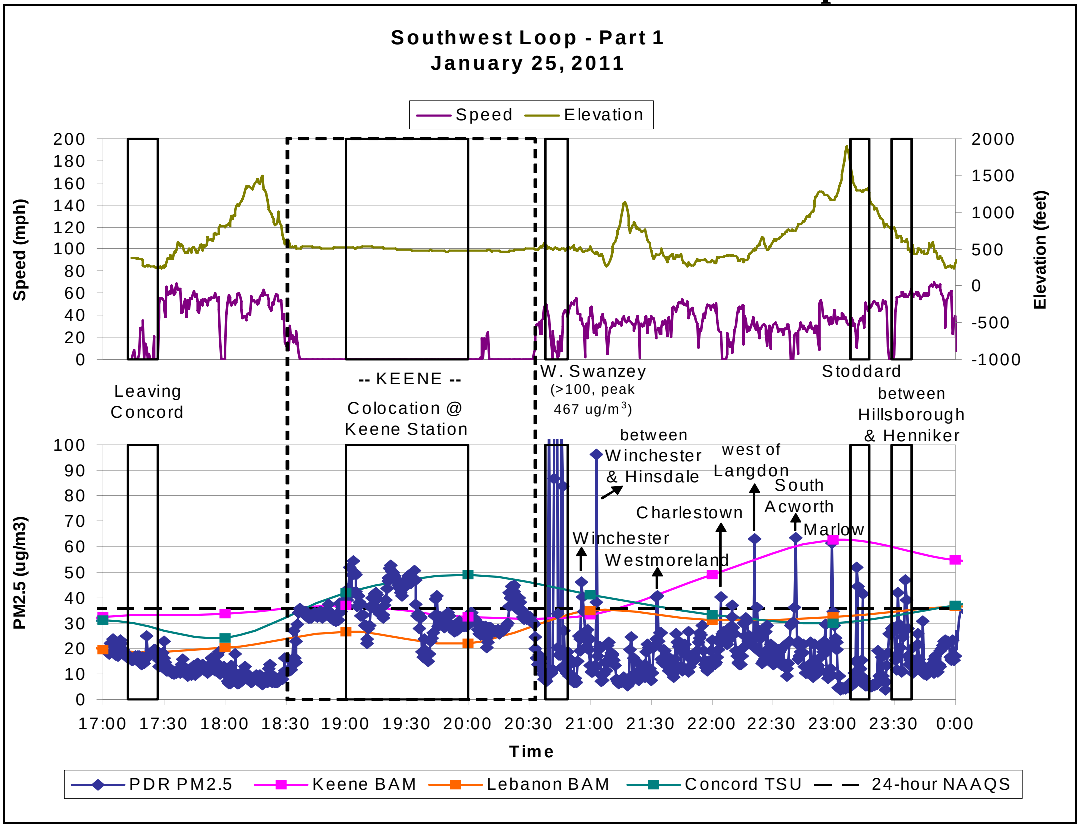
HYSPLIT Model NAM12k Soundings			
7pm Jan. 25, 2011	10pm Jan. 25, 2011	4am Jan. 26, 2011	7am Jan. 26, 2011
			

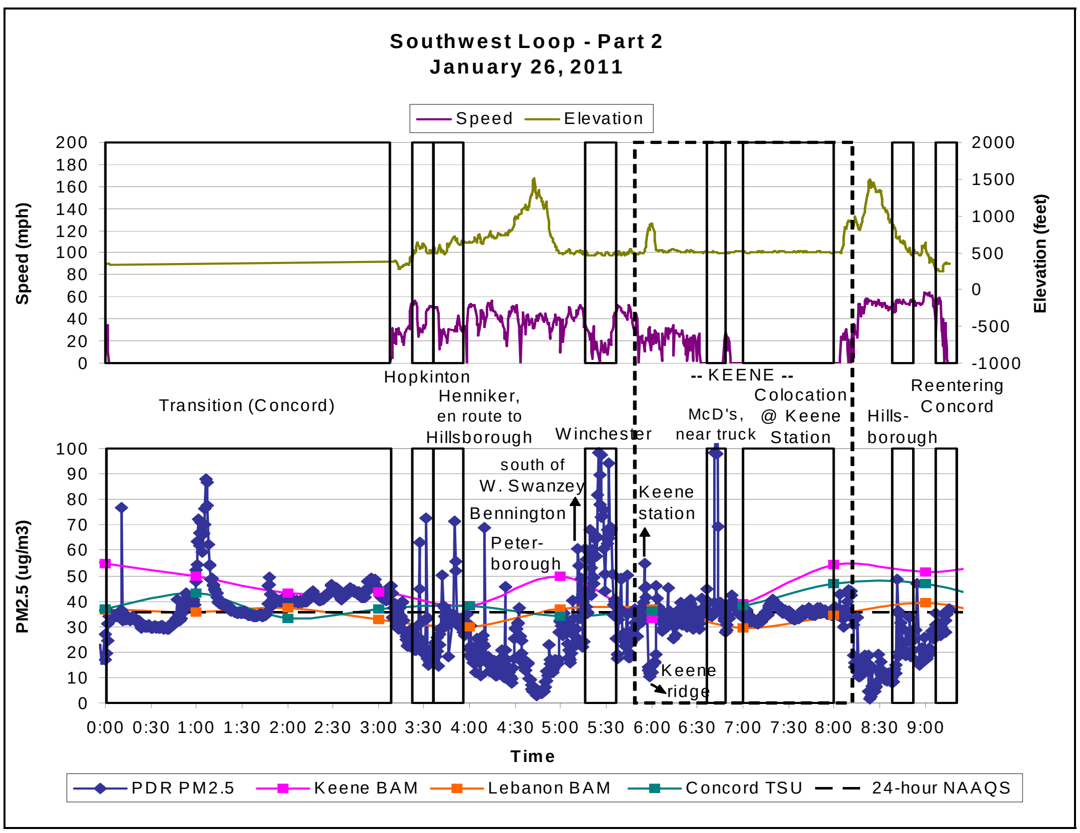
AIRNow Daily Average $PM_{2.5}$ AQI Maps	
January 25, 2011	January 26, 2011
	

Hourly Average $PM_{2.5}$, Wind Speed, and Temperature
Tuesday January 25 - Wednesday January 26, 2011



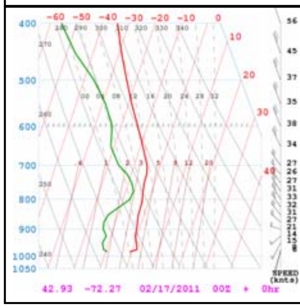
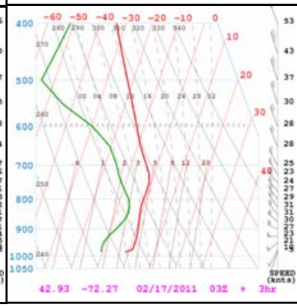
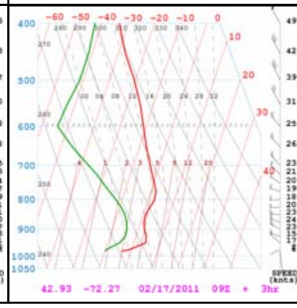
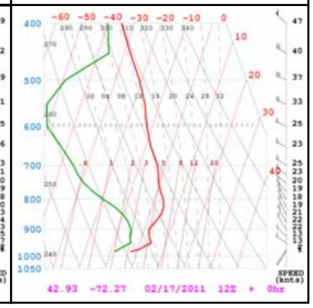
$PM_{2.5}$ Data from the Southwestern Loop

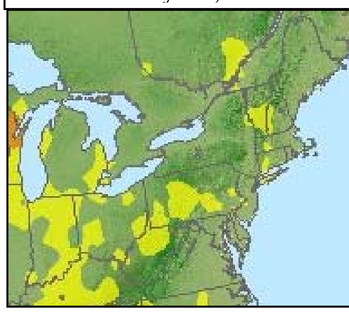
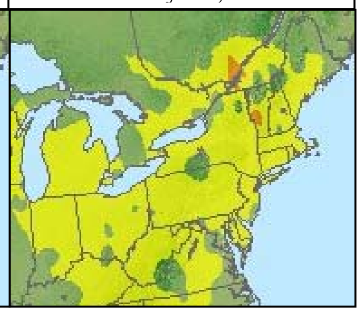




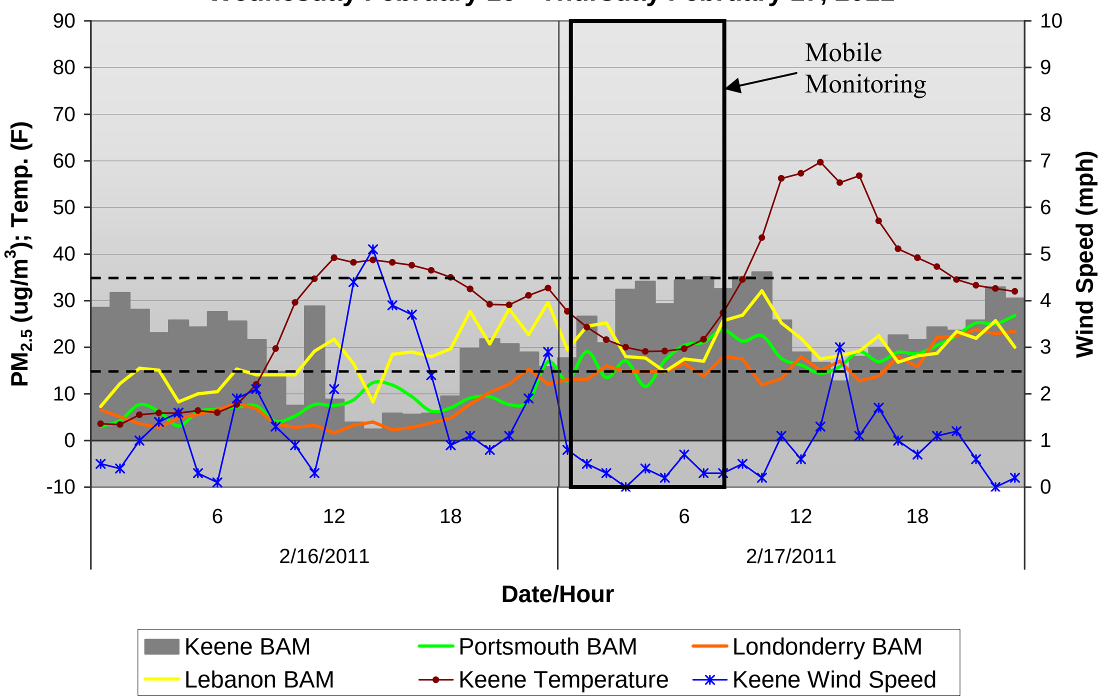
Attachment G

Northern Loop Run 1 Event Graphics and Recorded $PM_{2.5}$ Data

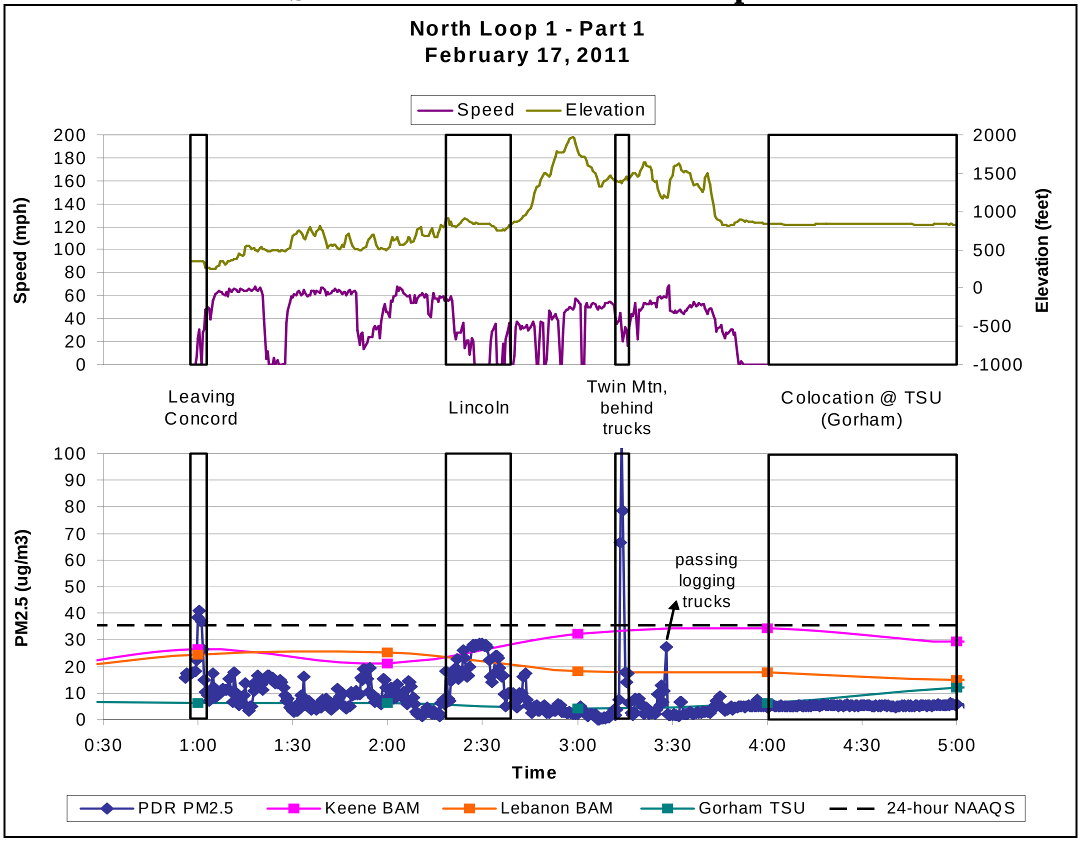
HYSPLIT Model NAM12k Soundings			
7pm Feb. 16, 2011	10pm Feb. 16, 2011	4am Feb. 17, 2011	7am Feb. 17, 2011
			

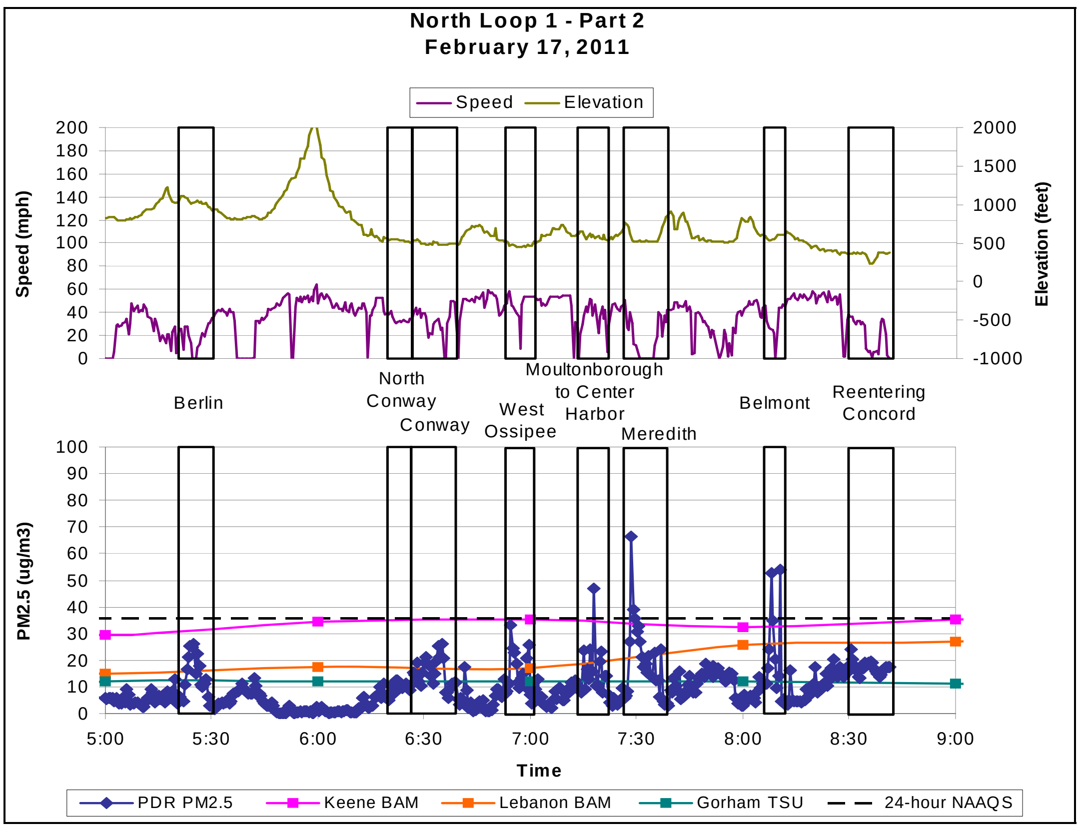
AIRNow Daily Average $PM_{2.5}$ AQI Maps	
February 16, 2011	February 17, 2011
	

Hourly Average $PM_{2.5}$, Wind Speed, and Temperature
Wednesday February 16 - Thursday February 17, 2011



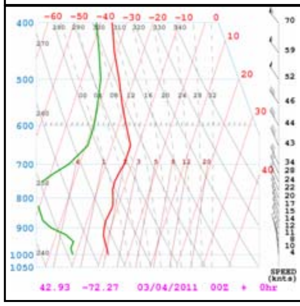
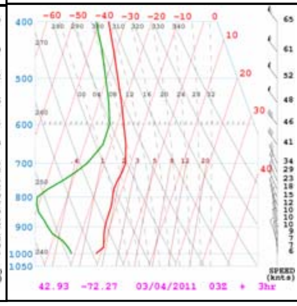
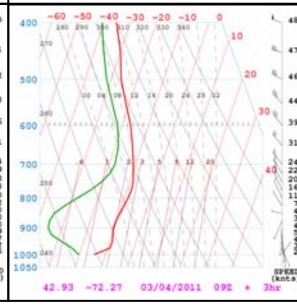
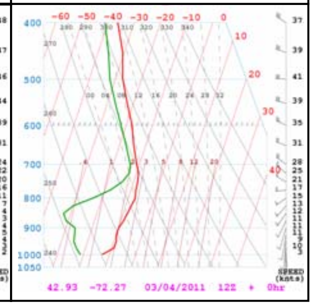
$PM_{2.5}$ Data from the Northern Loop Run 1

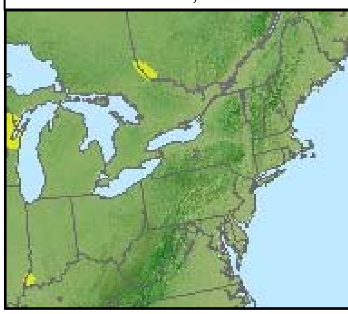
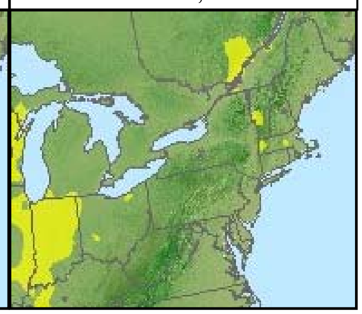




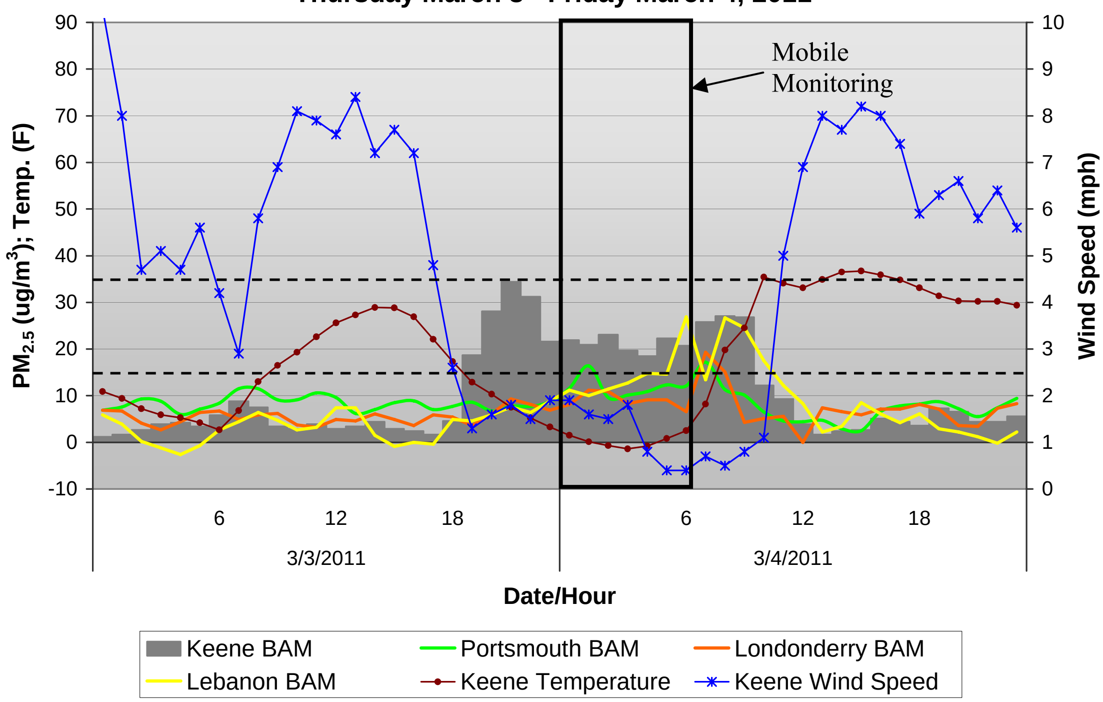
Attachment H

Northern Loop Run 2 Event Graphics and Recorded $PM_{2.5}$ Data

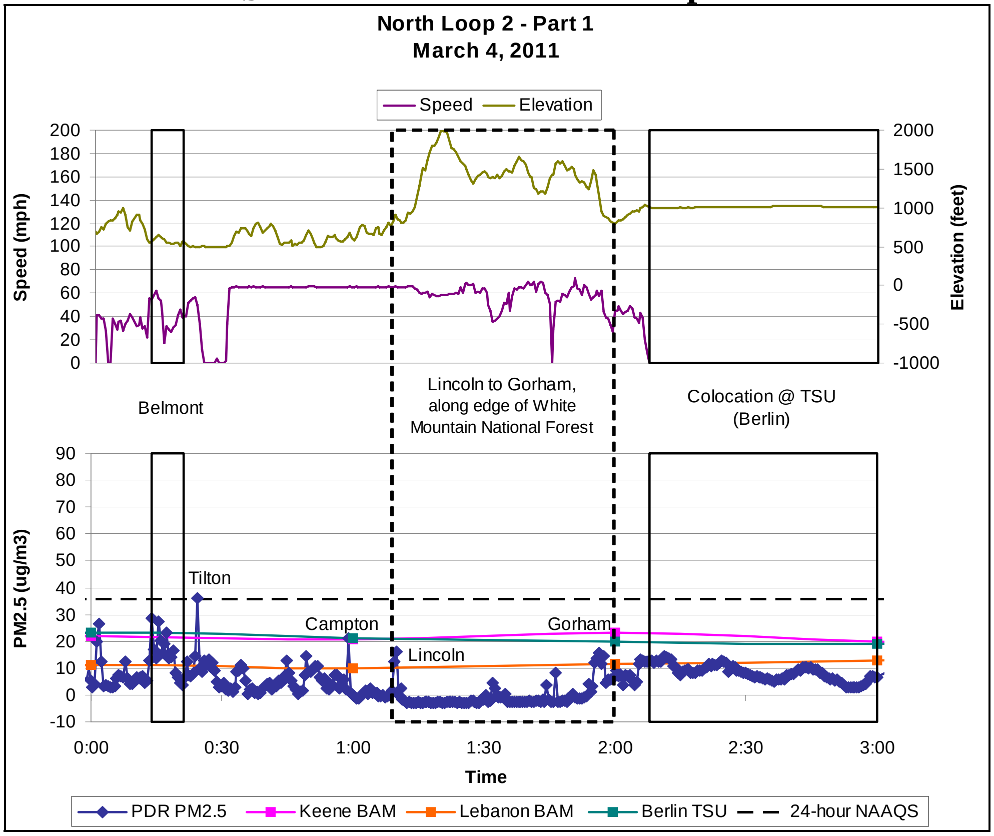
HYSPLIT Model NAM12k Soundings			
7pm Mar. 3, 2011	10pm Mar. 3, 2011	4am Mar. 4, 2011	7am Mar. 4, 2011
			

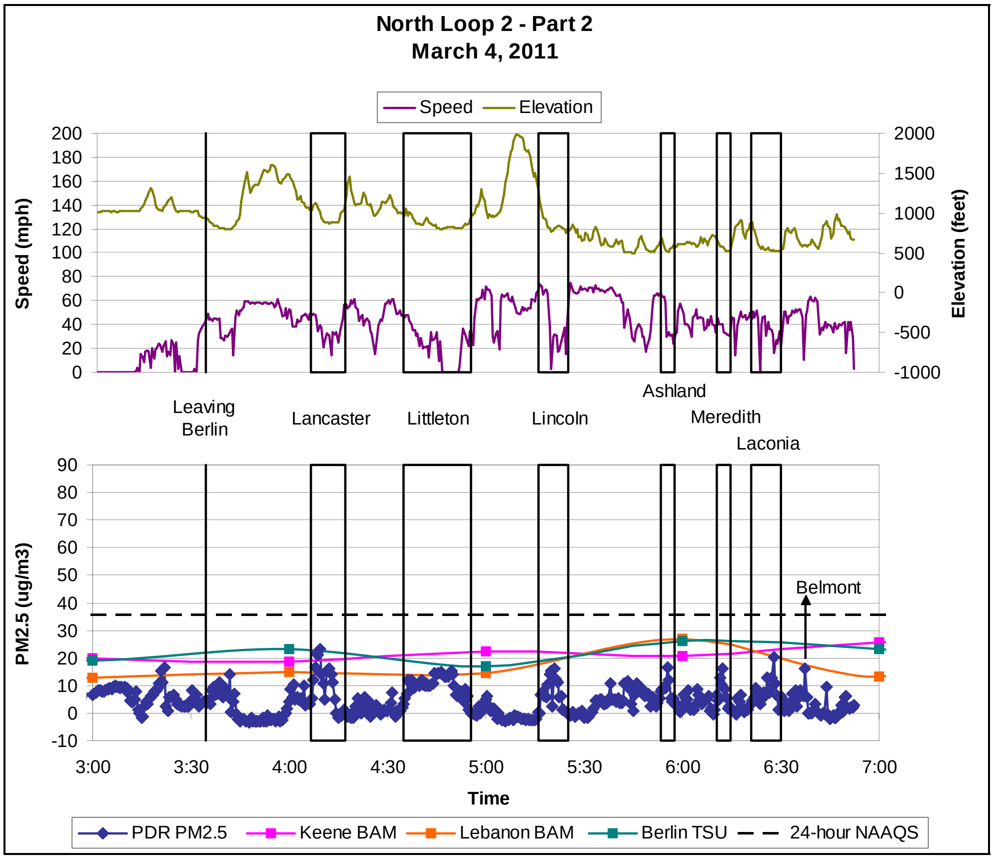
AIRNow Daily Average $PM_{2.5}$ AQI Maps	
March 3, 2011	March 4, 2011
	

Hourly Average $PM_{2.5}$, Wind Speed, and Temperature
Thursday March 3 - Friday March 4, 2011



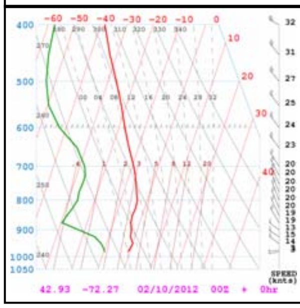
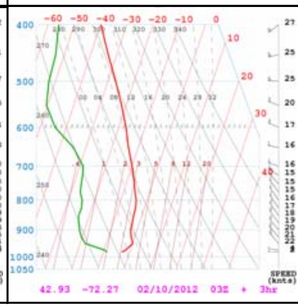
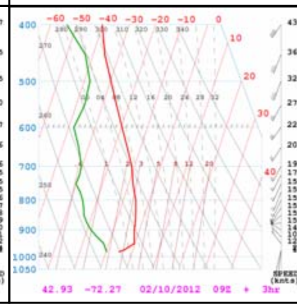
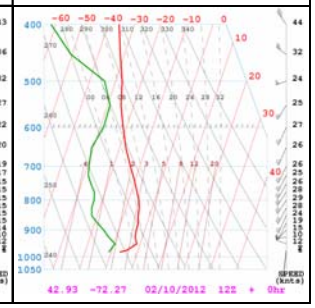
$PM_{2.5}$ Data from the Northern Loop Run 2

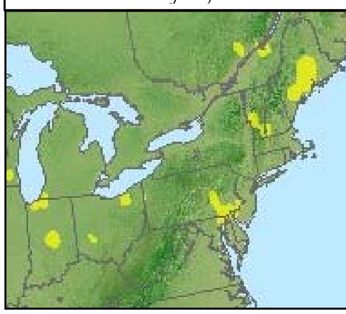
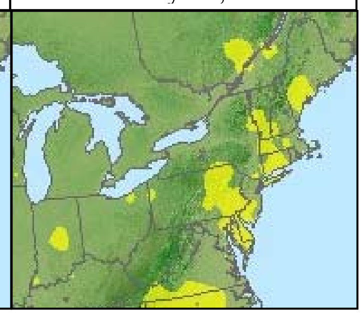




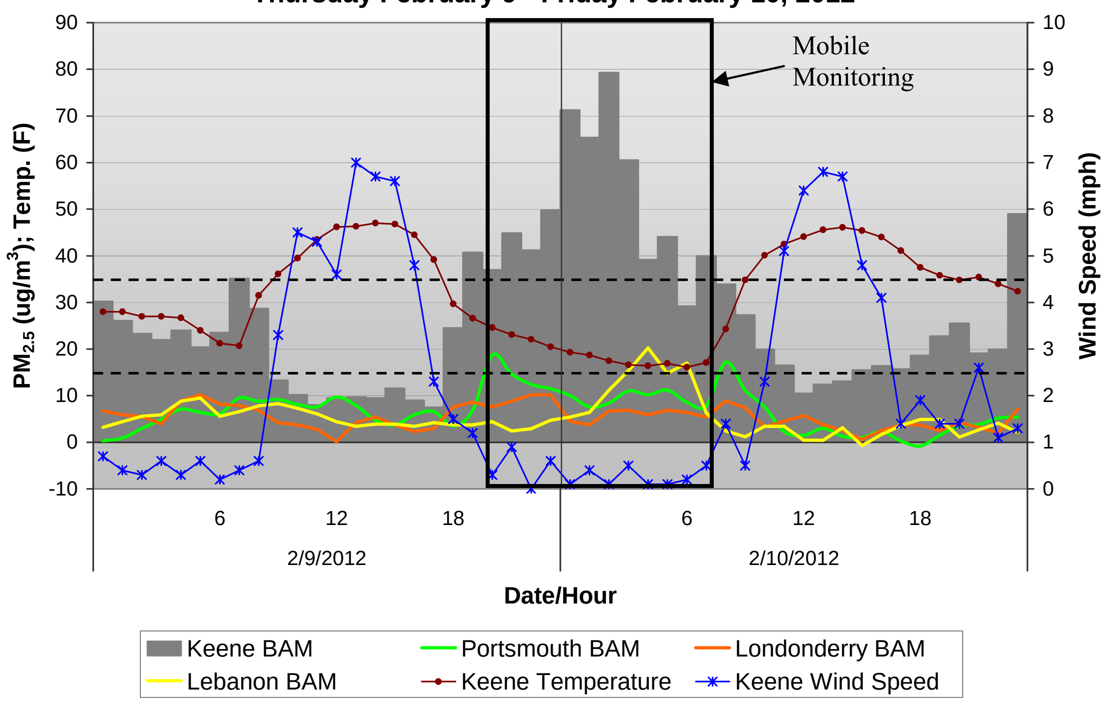
Attachment I

Southeastern Loop Event Graphics and Recorded $PM_{2.5}$ Data

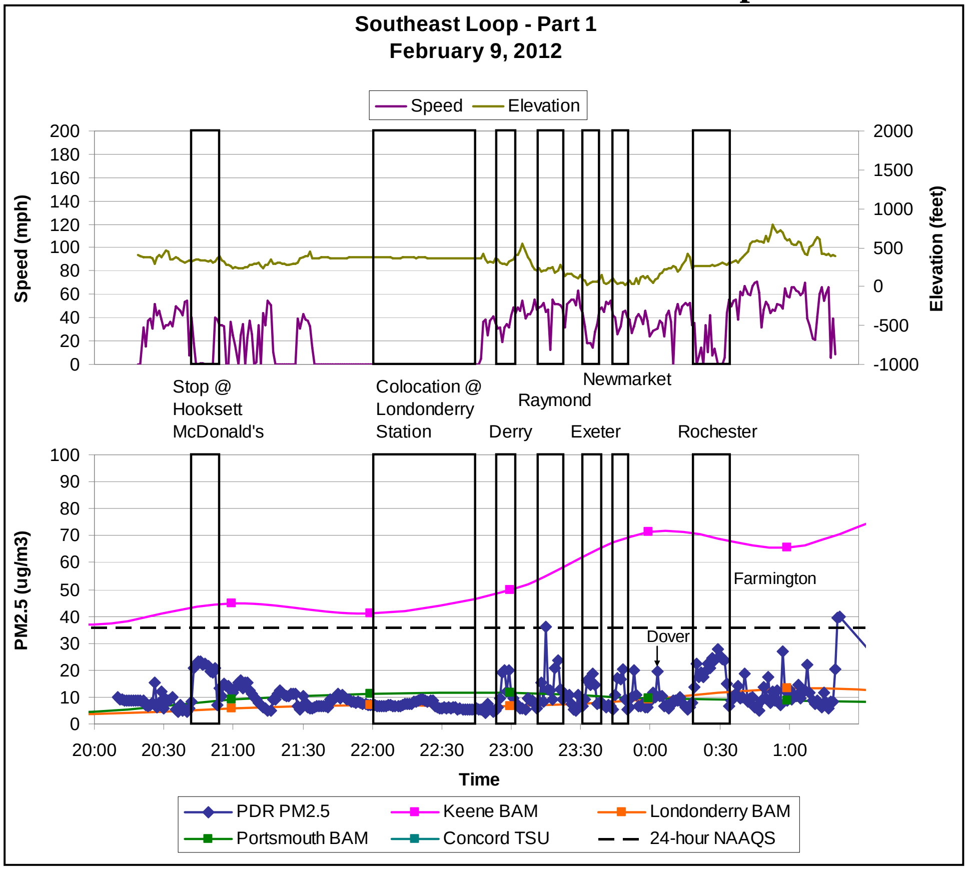
HYSPLIT Model NAM12k Soundings			
7pm Feb. 9, 2012	10pm Feb. 9, 2012	4am Feb. 10, 2012	7am Feb. 10, 2012
			

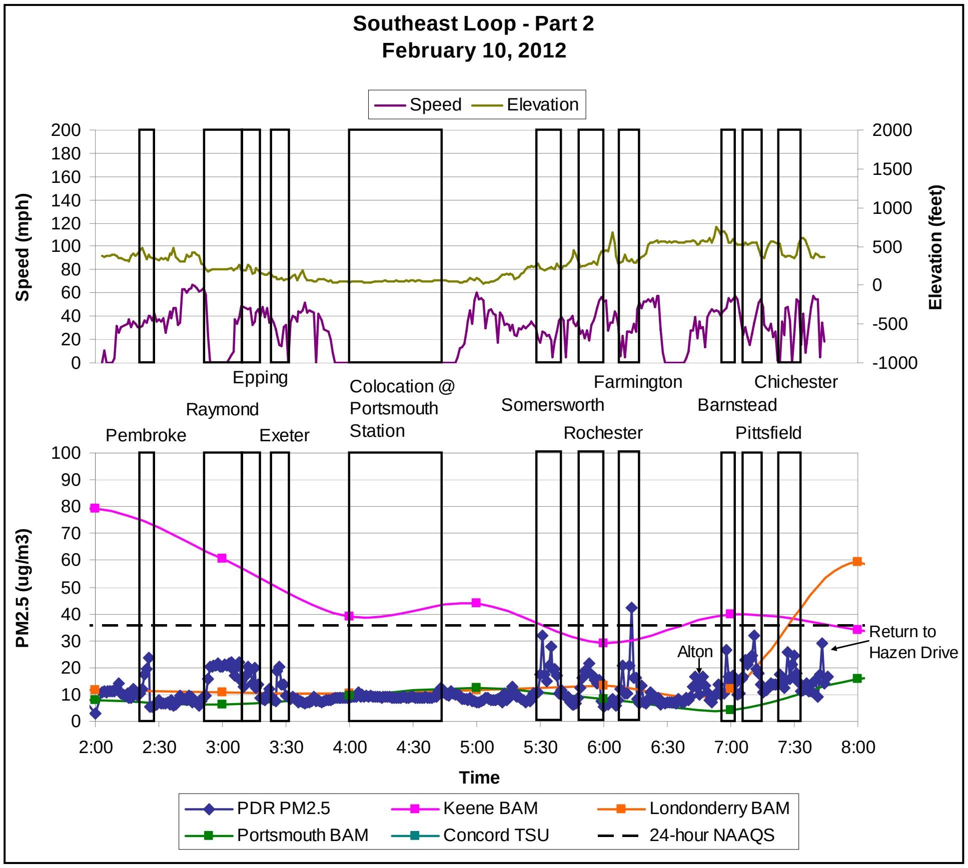
AIRNow Daily Average $PM_{2.5}$ AQI Maps	
February 9, 2012	February 10, 2012
	

Hourly Average $PM_{2.5}$, Wind Speed, and Temperature
Thursday February 9 - Friday February 10, 2012



$PM_{2.5}$ Data from the Southeastern Loop





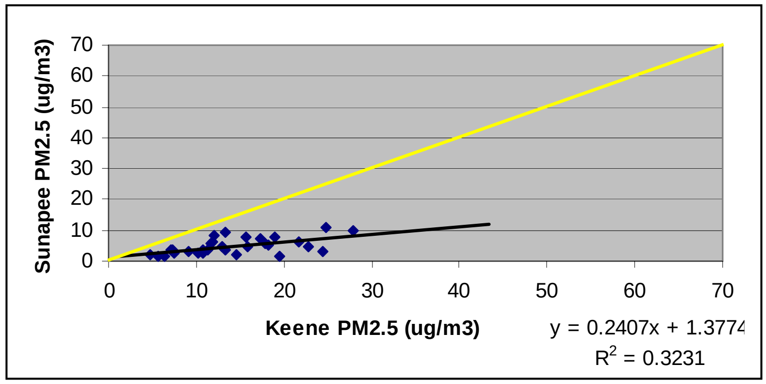
Attachment J
Other Supporting FRM Data

The following sites have filter-based $PM_{2.5}$ FRM data, but no continuous $PM_{2.5}$ monitoring data.

Sunapee

From three seasons of 1 day-in-6 filter-based $PM_{2.5}$ FRM data, the maximum in Sunapee is about 10 μg/m^3, and the slope of 0.24 for the correlation to Keene is very low (Figure 49). However, the Sunapee monitor is on the top of Mount Sunapee and does not reflect $PM_{2.5}$ buildup potential at lower elevations. During the Central loop of the mobile monitoring study, the MMU did see values in this area around 20 μg/m^3, relatively high for that event.

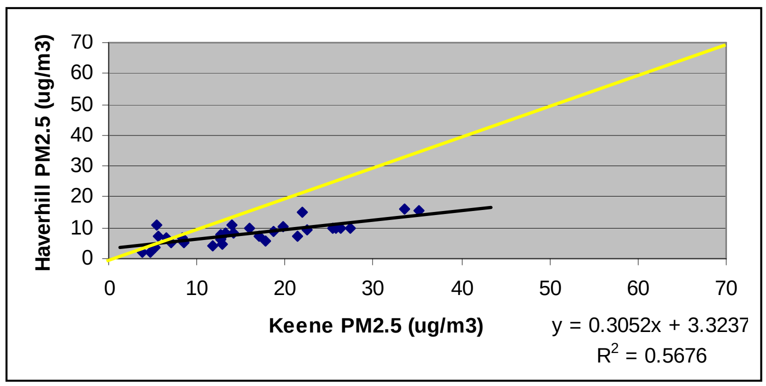
Figure 49: 24-Hour Correlation of Sunapee and Keene FRM $PM_{2.5}$ (Winters January 1999 – March 2002)



Haverhill

There are only two and a half seasons of 1 day-in-6 filter-based $PM_{2.5}$ FRM data from Haverhill. Keene has several 24-hour averages in the high moderates, and two in the mid 30's μg/m^3, but Haverhill's maximum is under 20 μg/m^3. Haverhill's correlation slope, 0.31, is only slightly higher than Sunapee's, and this limited dataset provides no indication of a risk of high $PM_{2.5}$ (Figure 50).

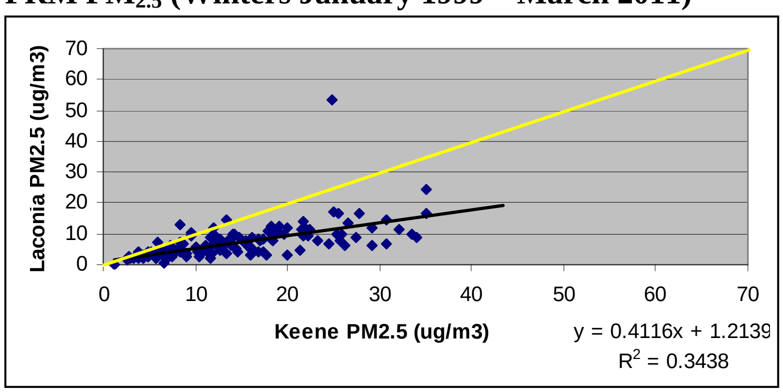
Figure 50: 24-Hour Correlation of Haverhill and Keene FRM $PM_{2.5}$ (Winters November 2002 – December 2004)



Laconia

Laconia's 1 day-in-6 filter-based $PM_{2.5}$ FRM dataset spans just under 13 winter seasons over which Keene experiences several high moderate 24-hour averages, but none over the NAAQS threshold. Laconia's averages tends to stay under 20 μg/m^3, with one exception: on January 12, 1999, Laconia $PM_{2.5}$ reaches 53.3 μg/m^3, even though Keene's $PM_{2.5}$ averages just 23.8 μg/m^3. The correlation slope is fairly low at 0.41 (Figure 51).

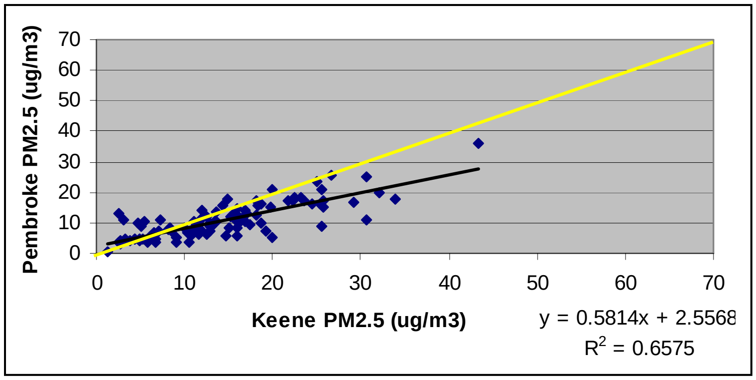
Figure 51: 24-Hour Correlation of Laconia and Keene FRM $PM_{2.5}$ (Winters January 1999 – March 2011)



Pembroke

Just under eight full seasons of 1 day-in-3 filter-based $PM_{2.5}$ FRM data capture one concurrent exceedance of the NAAQS threshold in Pembroke and Keene: 36.0 μg/m^3 and 43.4 μg/m^3, respectively. Keene's 24-hour averages go slightly over 30 μg/m^3 four more times, but Pembroke's next high is only 25.6 μg/m^3. Pembroke also records 44.4 μg/m^3 on December 31, 2010; there are no FRM data from Keene on this day, but the BAM averages 25.3 μg/m^3. Pembroke has a correlation slope of 0.58 (Figure 52).

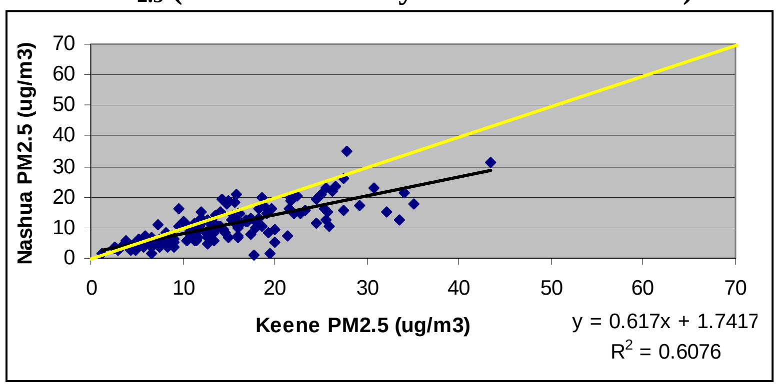
Figure 52: 24-Hour Correlation of Pembroke and Keene FRM $PM_{2.5}$ (Winters January 2004 – March 2011)



Nashua

Nashua has a 1 day-in-3 filter-based $PM_{2.5}$ FRM dataset just under 13 winter seasons. On days with data at both sites, Keene experiences six, and Nashua two, $PM_{2.5}$ 24-hour averages over 30 μg/m^3. Nashua has a high of 35.0 μg/m^3 in 2002, when Keene averages 27.8 μg/m^3. Keene's high is 43.4 μg/m^3 in 2008, when Nashua averages 31.5 μg/m^3. On days without Keene FRM data, Nashua $PM_{2.5}$ concentrations also come close to and exceeds the NAAQS threshold twice with values of 35.4 and 35.8 μg/m^3, respectively. Nashua's correlation slope of 0.62 is just higher than Pembroke's (Figure 53).

Figure 53: 24-Hour Correlation of Nashua and Keene FRM $PM_{2.5}$ (Winters January 1999 – March 2011)



Nashua exhibits the potential to approach or exceed the NAAQS threshold and occasionally surpass Keene in $PM_{2.5}$ concentrations, but the number of high days is limited. Continuous data would be vital to determine how often $PM_{2.5}$ builds to unhealthy levels in Nashua.

Claremont

Claremont has 1 day-in-6 filter-based $PM_{2.5}$ FRM sampling over nine complete and two partial winter seasons. On days with data at both sites, Keene has five 24-hour $PM_{2.5}$ averages over 30 μg/m^3, including a high of 43.4 μg/m^3 when Claremont records its only value over this threshold: 32.1 μg/m^3. Claremont's correlation slope, 0.65, is one of the highest, but still considerably lower than Concord's 0.80 and Manchester's 0.88 (Figure 54).

Figure 54: 24-Hour Correlation of Claremont and Keene FRM $PM_{2.5}$ (Winters January 1999 – December 2008)