Air Quality and Home Heating Analysis
KEENE, NH

KEENE STATE GEOGRAPHY DEPARTMENT

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Fall 2013

Keene
STATE COLLEGE

Acknowledgements

We would like to express deep gratitude to our professor, Dr. Christopher Brehme, for his valuable and constructive suggestions throughout the planning and development of our research project. Dr. Brehme has encouraged and helped us grow as geographers and students. We would also like to thank Dr. Nora Traviss for her assistance on planning and collecting research throughout the city of Keene. Mr. Michael Faber is owed a great thanks as well for his hospitality in allowing us to conduct research at the Monadnock Food Co-op. These three people have shown great dedication to our project and for that we thank them. We would not have been able to conduct this research without their help.

Abstract

This study analyzes the spatial distribution of woodstoves as a home heating method in Keene, New Hampshire, and forms the basis for future study of air pollution. The city sits in a glacial valley and is therefore prone to temperature inversions. Temperature inversions prevent the mixing of air and trap particulates within the city, of which Particulate Matter 2.5 ($PM_{2.5}$) is a primary concern. Three data collection methods were utilized: a woodpile and chimney survey, a home heating survey and a weather balloon experiment. Using this data and Geographic Information Systems, maps were created isolating potential $PM_{2.5}$ sources and neighborhoods at risk of this air pollutant. Statistical analysis showed that chimney types and the use of wood were variable between study regions, but there were trends within neighborhoods. The surveys showed that distribution of heating methods were consistent with past Census data, and had no correlation to household income or other demographic variables.

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Chapter 1: Introduction

Keene Air Quality and $PM_{2.5}$

People can go days without food and hours without water, but a person can only survive a few minutes without air. On average, a person breathes over 3,000 gallons of air each day, and that being said, air pollution is a significant threat to human health. In 1970, the United States created the Environmental Protection Agency, EPA, and passed the Clean Air Act, which gave the federal government authority to clean up air pollution. Since then, the EPA, environmental groups and state and local governments have worked to reduce air pollution across the United States. The Clean Air Act and the efforts that followed have had a positive effect on peoples' lives, yet there are still many air quality issues that need to be addressed.

There are many sources of air pollution in the United States. These include stationary sources like power plants, mobile sources such as vehicles and trains, and naturally occurring sources such as wildfires. The combination of these sources mean that many people encounter air quality issues in their daily lives, which can lead to health problems. The Western U.S. has the largest naturally occurring air pollution problem, due to forest fires. Recent examples of these were the Colorado forest fires in 2002 and 2013. The immediate damage to people and the landscape from these fires is visually apparent, but the invisible atmospheric damage might be even greater. During the Hayman, Colorado Wildfire in 2002, carbon monoxide emissions totaled 76,000 metric tons over the course of three months. This is equivalent to 24% of all human-caused carbon monoxide released per year in the United States (Kohler 2012). People over 100 miles away can smell the smoke from a forest fire. If the smell is significant, then the damage being done to the lungs will eventually become serious due to the various pollutants released.

In the Midwest, a major source of air pollution is sulfur emissions, which is the most harmful and environmentally damaging pollutant (Kohler 2012). These emissions include sulfur dioxide, sulfuric acid, and sulfate particulate matter which can pollute communities hundreds of miles away through the process of acid rain. Most of this pollution is carried eastward by the westerly winds and the jet stream, across the United States. This pollution is linked to asthma attacks, heart attacks, and thousands of premature deaths each year.

New studies have found lung cancer can be caused by air pollution. According to the Danish Cancer Society Research Center in the United Kingdom, studies have demonstrated that there is a link to lung cancer and heart failure due to the quality of the air. Raaschou-Nielsen examined 313,000 people after their long term-exposure to nitrogen oxides and $PM_{2.5}$ of these, 2,095 people developed lung cancer over 13 years. Through this research, it was discovered that for every five mg/m3 increase of $PM_{2.5}$ pollution, there was an 18% rise in the risk of lung cancer. This research refers to air pollution formed from diesel fumes, industrial sources, and household heating. With lung cancer and other health effects linked to air quality, the United States has tried to control pollution through government acts.

Due to a loophole in the Clean Air Act, power plants in the Midwest are exempt from current policy, and can continue to release sulfur dioxide. The loophole exists in a grandfather clause, which is “a provision in a statute that exempts those already involved in a regulated activity or business from the new regulations established by the statute” (Diction 2013). As a result, power plants release double the amount of sulfur into the air than vehicles and factories combined. Another growing issue in the Midwest is drilling and hydraulic fracturing, which involves heavy equipment powered by diesel fuel. Due to demand for natural gas, there is an increase in drilling, and a corresponding release of chemicals into the air. This creates a disturbingly large amount of air pollution which can travel to the eastern United States.

The most populated places within the Northeastern region of the United States are hundreds of miles away from the Midwest, yet industrial pollutants reach these cities through the process of long-range transport. Through this process some of the most toxic and corrosive chemicals can be carried long distances, and can interact with water droplets in the air and on the ground. This creates potent acids in a process known as acid deposition. Damage to forests and water resources from acid rain has occurred in the major mountain ranges of the eastern U.S. The Adirondack Mountains and Northern Appalachians have suffered extensive damage in regards to seedling production and tree density. Air pollution is prominent across the region of the Northeast. Particulate $matter_{2.5}$ is a rising problem in the city of Keene, New Hampshire and is the focus of this research.

Keene, New Hampshire Demographics

The population of Keene, New Hampshire is 23,409 people but it has a higher day time population than suggested. This is because it serves as a regional center of commerce that attracts residents of surrounding towns and nearby states. It also is home to two colleges, which create a seasonal change in population. The majority of the population in Keene is identified as white (95.3%), and the remainder of the population consists of Asian (2%), Black

(0.6%) and Native American (0.2%), (US Census Bureau 2010). It was reported that 53.1% of the general population is female. 3.9% of Keene residents are under 5 years old, 16.6% are under 18 years old and 14.7% are over 65 years old (Figure 1). Both young and elderly populations are more susceptible to the effects of $PM_{2.5}$, so this is an important consideration when looking at the overall population characteristics of Keene.

76.5% of the population of Keene has lived in the same house for one year or more within the years of 2007-2011. People who have established a permanent residence have a higher risk of being affected by $PM_{2.5}$ exposure because they reside in the area year-round compared to the large college population who live in the area for less time. For this reason, the residents of Keene should be made aware of the current dilemma with air pollution. In Keene, there are 9,719 housing units with an average of 2.25 people living in each household. Educational attainment of residents ages 25 years or older is 90.2% high school graduates and 35.6% with a bachelor's degree or higher (US Census Bureau. 2010).

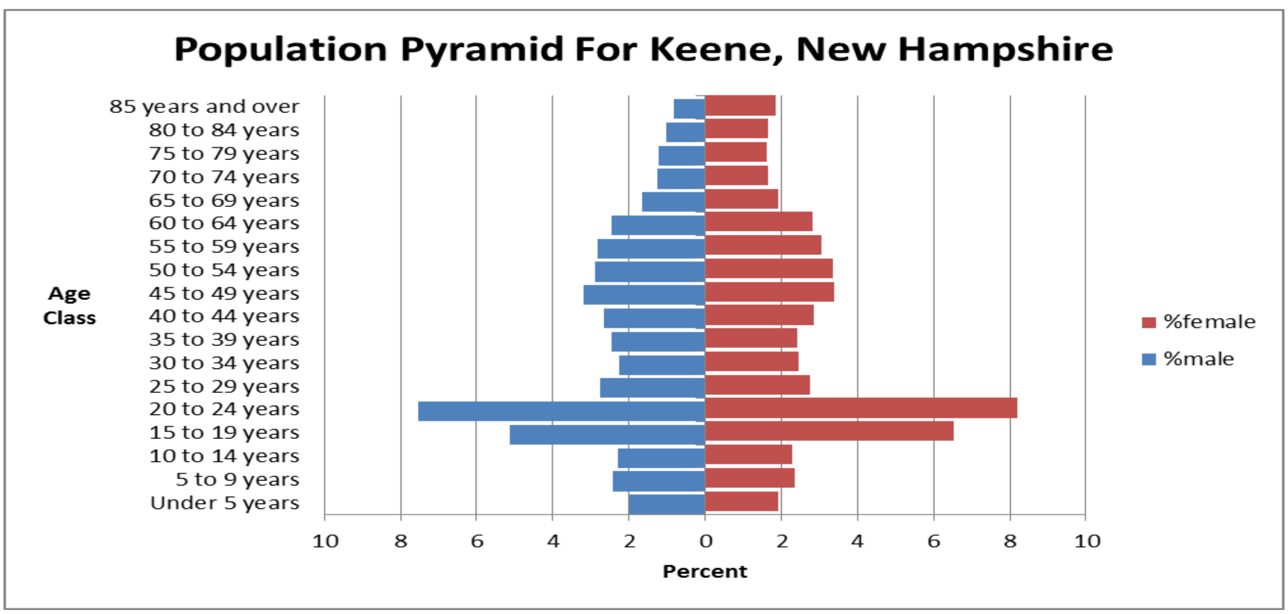


Figure 1. Population Pyramid for Keene, New Hampshire (Data Source: U.S. Census Bureau.)

Overview of Keene Neighborhoods

Several neighborhoods throughout Keene, New Hampshire were chosen to be surveyed for this research project. These neighborhoods were selected with the goal of surveying a diverse range of socioeconomic conditions. The research is focused on two regions of Keene: the area around Keene Middle School and the area in the vicinity of Keene High School. After defining these two regions, seven neighborhoods were derived (Figure 2). These neighborhoods include two neighborhoods in the Maple Acres section, one neighborhood in Tanglewood Estates, and four neighborhoods in West Keene. The neighborhoods within the Maple Acres and Tanglewood sections are grouped together as the Middle School region. All of the neighborhoods in West Keene comprise the High School region.

Maple Acres has an area of 0.679 square miles and a population of 591 people. The population density of this neighborhood is 826 people per square mile (City-Data.com. 2013 and US Census Bureau. 2010). The Tanglewood Estates neighborhood is 0.295 square miles with a population of 281 and a population density of 954 people per square mile. Lastly, West Keene is 5.475 square miles in area and has a population of 3,058 with a population density of 559 people per square mile. There are 310 housing units in the Maple Acres region, 316 housing units in Tanglewood Estates, and 307 housing units in the four neighborhoods of the West Keene region (City-Data.com. 2013 and US Census Bureau. 2010). The majority of the neighborhoods in each region are composed of family households. The median age of males in Maple Acres is 40.6 years and 44.9 years for females. In the West Keene neighborhood, the median age for males is 39.9 years and 54.1 years for females. In the last area, Tanglewood Estates neighborhood has a median age of 40.6 and 44.9 for females. The median house income in 2010 was $66,142 in Maple Acres, $59,587 in West Keene, and $61,617 in Tanglewood Estates. The overall median household income for the city of Keene median is $47,075. These neighborhoods were chosen as a focus because they are in high risk sections of the city for $PM_{2.5}$ exposures. Due to the geographic layout of the city, there were a number of neighborhoods that could have been studied. Among these are the neighborhoods of East Keene, and the region between Court and Washington Streets (Figure 2). Although these were not included in our study, they are available for future studies, as discussed in Chapter 6.

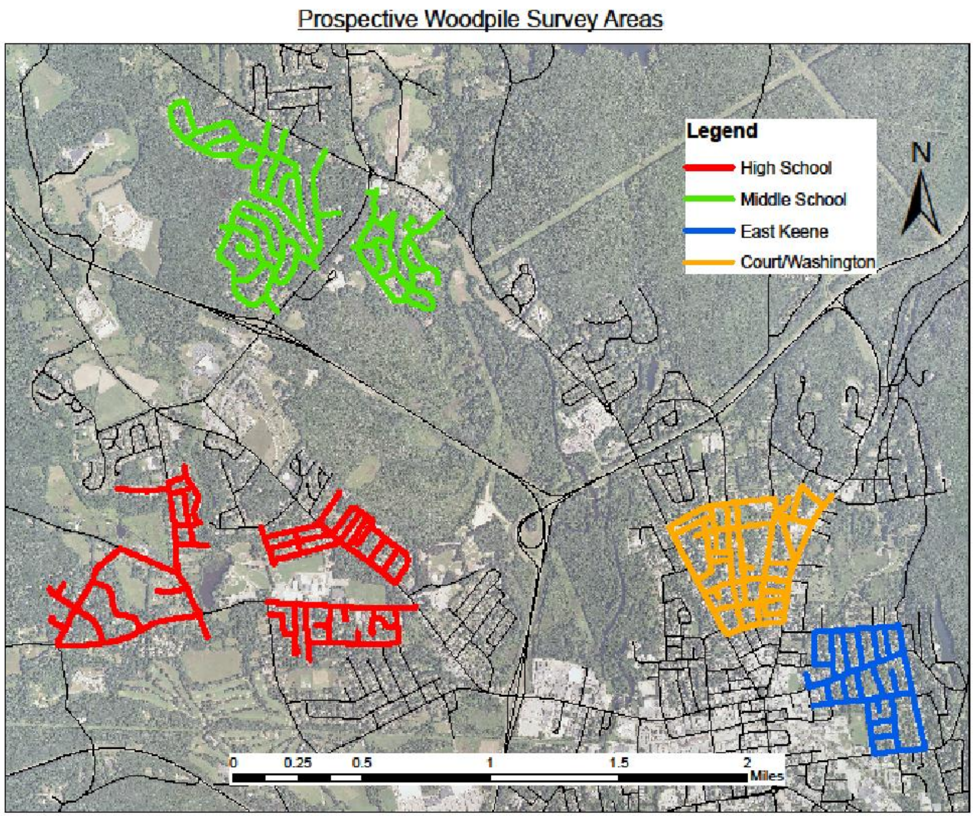


Figure 2: Woodpile Survey Neighborhoods.

Keene is located in a glacial valley which can frequently lead to the creation of air inversions. Pollution becomes trapped in the valley and lead to higher risk of exposure to those in the surrounding area. This is a recurring dilemma and is important to address to understand the current air quality issues in Keene.

Air Inversions

An important meteorological factor in the dispersion and concentration of pollutants is the occurrence of air inversions. This phenomenon occurs when a layer of air is overlain by another air mass of considerably different temperature. These layers are generally stable and constrain the vertical motion of air, effectively preventing the mixing and transport necessary to mitigate the buildup of harmful pollutants. There are several types of inversions, and each requires unique topological and meteorological conditions to form.

Radiation inversions occur very close to the surface on cold nights, when the ground rapidly transmits heat to low-lying air, creating a blanket that is significantly warmer than the local atmosphere. This can be further enhanced in a valley or basin as cold air flows downslope, collecting under the inversion and fortifying the presence of distinct layers (Wallace, Corr, and Kanaroglou 2010). Advective inversions form when cool air travels horizontally, sliding underneath warmer air and effectively reversing the local temperature gradient. These often occur in the presence of a large body of water, which warms more slowly than the adjacent land (Wallace, Corr, and Kanaroglou 2010). The third type is a subsidence inversion, when a high-pressure air mass moves to a lower elevation. The air mass becomes compressed, and as a result increases in temperature. If a cold air mass is situated over the area in question, an inversion may form (Wallace, Corr, and Kanaroglou 2010). Air inversion depth can vary widely in size, from a thousand or more feet in altitude to near ground level (Baumbach and Vogt 2003).

Air inversions are a powerful means of increasing concentrations of $PM_{2.5}$ and other suspended pollutants like ozone, NO_2, and various volatile organic compounds, VOC's (Baumbach and Vogt 2003; Wallace, Corr, and Kanaroglou 2010). There are distinct layers within an inversion, each having a different role in the containment of pollutants. In a single inversion, the cold air acts as the upper barrier for trapped pollutants. The lower edge of this cold air can range in altitude from near ground level in the winter to 2,500 meters in the summer (Baumbach and Vogt 2003). The concentration of pollutants is dependent on the rate of emission and the altitude of the barrier layer, meaning that pollution hazards from inversions are most intense in the winter, when the inversions are right near the ground. The barrier layer is usually dispersed as it is warmed during the day, rising and expanding until it dissipates into the atmosphere entirely.

In some cases, there can be dual inversions. A subsidence inversion can form at relatively high altitude, moving up and down due to diurnal temperature flux and containing a large mixing layer underneath it. This can be accompanied by a nighttime radiation inversion at the surface, which segregates the pollutants. $PM_{2.5}$, VOC's, NO_2, and other pollutants are contained by the barrier layer near the surface. Without the presence of NO_2 to deplete it, ozone collects in the mixing layer and persists until the lower barrier layer is burned off by the sun (Baumbach and Vogt 2003). Without a ground level barrier, the mixing layer traps the pollutants, but a low-lying inversion can trap the pollutants very low to the ground. These effects are particularly obvious in cities with smog problems, where the photochemical smog and particulates can be seen sitting on cities, with the area above the barrier layer remaining very clear.

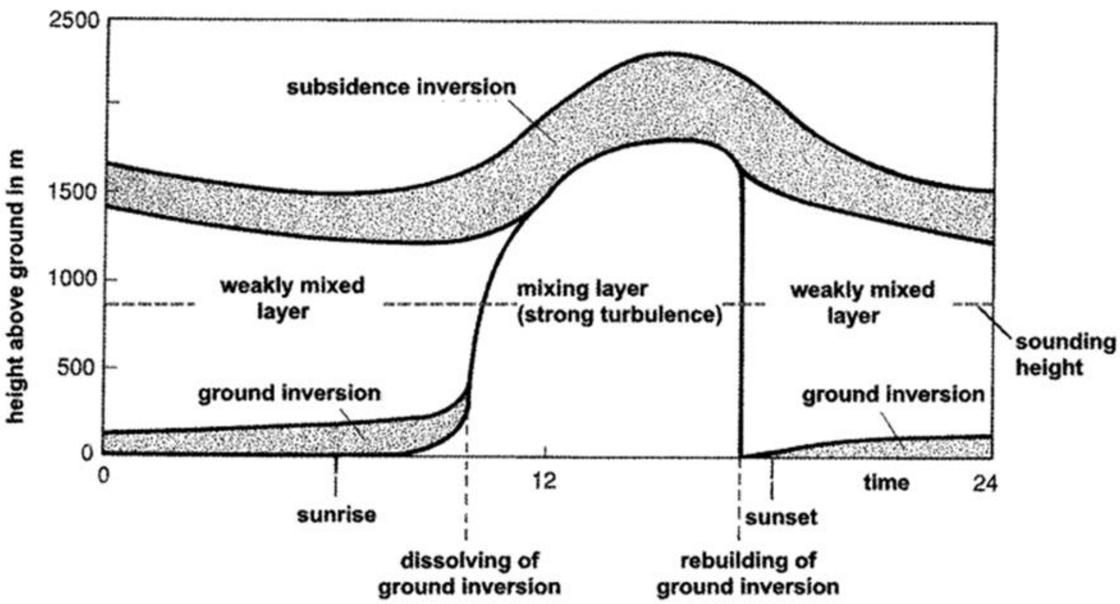


Figure 3: Air inversions in the summer, with altitude and composition changing throughout the day after. (Baumbach and Vogt 2003).

The relationships between air inversions and pollutant concentration in Keene, New Hampshire have been a topic of study for several years. $PM_{2.5}$ levels have been steadily rising in recent years, approaching and occasionally passing the National Ambient Air Quality Standards (NAAQS). The standards set a maximum annual average of 15 micrograms per cubic meter, and a 24-hour maximum of 35 micrograms per cubic meter. The young and the elderly are particularly susceptible to $PM_{2.5}$ pollution, and both demographics exist in the city in large numbers. The $PM_{2.5}$ levels in surrounding towns have been much lower over the same period, indicating that the problem lies within the city itself, as opposed to long range transport from industry in the Midwest.

Keene sits in a valley, which can affect the creation of air inversions and the subsequent increase in air pollution in at least two ways. First is the containment of particulate pollution and heat. Various buildings and pavement surfaces create an urban heat island which could help to stimulate the temperature difference that leads to an inversion. This is compounded by dewfall and frostfall, which release additional heat into the local atmosphere, mitigating the cooling that would naturally occur on a dry night (Whiteman, Wekker, and Haiden 2007). The valley walls trap heat along with the various airborne pollutants. The cooling of the ground following sunset creates a layer of cold air underneath the warm layer leading to the low lying inversions common during the winter. The second effect is katabatic flow from the valley walls. Cold air is denser than warm air, so it naturally sinks due to gravity. The cold air from the surrounding area flows down the sloped walls of the valley, slipping underneath the air warmed during the day.

These atmospheric factors enhance the buildup of $PM_{2.5}$, which is further influenced by the socioeconomic situation in the city. Since the economic downturn in 2008, local residents have increasingly turned to burning wood as a cost effective way to heat their homes. This has caused an expected increase in the amount of $PM_{2.5}$ released into the valley. In an attempt to mitigate the problem, the City of Keene, the United States Environmental Protection Agency, EPA, and the NH Department of Environmental Sciences, DES, planned and implemented a "Woodstove Change Out" campaign. This program encouraged members of the community to switch from inefficient woodstoves to more efficient pellet stoves. Using a $35,000 subsidy from Air Program funds and a $106,000 settlement with American Electric Power, the city aimed to trade 100 woodstoves. Organizers expected a large response, and implemented an application process, to determine priority. However there were only 40 initial applicants, and by January of 2010, the city had issued only 78 vouchers. The city also offered several incentives to the program, including tax incentives up to $1500 for the installation of Energy Star products, and one free ton of pellets for those who purchased pellet stoves. Phase 2 of the program increased the value of the vouchers to $3,000 dollars, which could be used to purchase approved heating equipment and pay for the modifications necessary for their installation. In the end, all of the money was distributed in vouchers, and 86 stoves were replaced. At the same time, the city performed various outreach campaigns, going door to door and hanging door tags informing citizens of the program, and educating them about $PM_{2.5}$. Unfortunately, $PM_{2.5}$ levels in Keene continue to exceed federal standards on a yearly basis, and investigation into the factors affecting particulate pollution and inversions is ongoing.

Chapter 2: Literature Review

Particulate Matter 2.5, $PM_{2.5}$, accumulates in the Earth's atmosphere due to air pollution caused by a variety of activities. $PM_{2.5}$ has an aerodynamic diameter of less than 2.5 mm (EPA 2013). Concentrations of this pollution have been exacerbated by human behavior. Particulate pollution levels can rise rapidly in the presence of industries and residences where combustion of coal and wood is utilized. $PM_{2.5}$ has been listed as an important and dangerous air pollutant due to its potential to collect in the lungs and cause damage to the human body. The amount of PM in the air humans breathe has been the focus of intense discussion in the medical community in recent decades (EPA 2013). High levels of $PM_{2.5}$ have been shown to correlate with increased risk of cardiovascular and respiratory deaths in humans (Vallejo et al. 2006; Haley, Talbot, and Felton 2009). An increase in cardiopulmonary morbidity and mortality has been associated with acute and chronic exposure to high levels of $PM_{2.5}$. The most severe cases have been linked with childhood asthma and cardiac and pulmonary issues in elderly.

Health Effects

A study done in the Mexico City metropolitan area from April to August 2002 looked at the levels of ambient fine particles and whether they modified heart rate variability (HRV) in healthy young adults (Vallejo et al. 2006). HRV is a measurement used to quantify and stratify risk of arrhythmic death. Low HRV is associated with an increased mortality rate in people with heart disease. This study monitored the health of 44 individuals with electrocardiogram and HRV monitors, in parallel with PM levels surrounding the test subjects. It was concluded that high PM levels were correlated with lower HRV levels (Vallejo, et al. 2006). This implies that high PM levels negatively affect those who are already at a high risk for cardiovascular disease, as well as the respiratory health of healthy individuals.

Another study conducted in the United States monitored the effects of particulate pollution on New York hospital patients with cardiovascular illnesses (Haley, Talbot and Felton 2009). The study involved air quality tests within and around major hospitals to determine how the air affects these patients. The results of the study suggest that high PM levels have a stronger impact on heart failure than other diagnoses. 3.1% of heart failure admissions to hospitals were attributed to short-term effects of high PM levels. This was especially true for the elderly, who proved to be more susceptible to heart failure after short-term exposure to high concentrations of $PM_{2.5}$ (Haley, Talbot, and Felton 2009).

Cardiovascular illnesses are just one health concern related to high PM levels. A 2013 study in Beijing, China focused on chronic respiratory diseases and induced oxidative stress (Deng, et al. 2013). Oxidative stress refers to a critical imbalance between the production of destructive oxygen species and antioxidant defenses. This study looked specifically at A549 live cells, which are lab grown human lung cells, with nitrocellulose filters in people with respiratory illness. Autophagy is a self-digestion process that regulates the degradation and recycling of unnecessary proteins and dysfunctional organelles, which helps the human lung cells repair themselves. Scientists concluded that autophagy may protect cells against cell death under oxidative stress (Deng, et al. 2013). This contributes to the efficient removal of oxidized proteins and reduces oxidative damage. However, the results of the test suggest that high PM levels induce oxidative stress, which probably plays a key role in autophagy in A549 cells.

Essentially, this study suggests that PM levels may induce an impairment of pulmonary function in those with chronic respiratory diseases.

Another respiratory condition that is affected by high PM levels is asthma. A study conducted on rats in Utah tested to see if high levels of PM would induce asthma or increase symptoms of those with asthma (Gavett and Koren 2001). Airway inflammation and obstruction did occur in rats when PM levels were raised. However, when a second testing was done on humans, the results varied. This result proves that at least one animal is affected by high PM levels in the form of asthma. $PM_{2.5}$ is known to be dangerous to animals and humans, although the mechanism at work is still unclear (Gavett and Koren 2001).

Another health concern that involves high PM levels centers on the correlation of low birth weights and high levels of air pollution. Different studies have produced different results on the topic but this may be because the composition of PMs can vary greatly with the frame of reference, which could contribute to discrepancies (Ebisu and Bell. 2012; Janssen et al. 2013). This is a debated topic, which is still being researched by the medical community. Even though there is no definitive correlation between the two variables, this is important to mention, as it could be an important health effect of PM air pollution.

Meteorological Factors

The most important meteorological factor in the dispersion and concentration of $PM_{2.5}$ is air inversions. An inversion is a phenomenon where a layer of air is overlain by another air mass of considerably different temperature. These layers are generally fairly stable and constrain vertical motion of air, effectively preventing the mixing and transport necessary to mitigate the buildup of various chemicals and particulates. While it is logical that areas with above average amounts of industrial and residential combustion would see an increase in particulate pollution, air inversions are a powerful factor in the concentration of $PM_{2.5}$ and other suspended pollutants like ozone, NO_2, and various volatile organic compounds (VOC's) (Baumbach and Vogt 2003; Wallace, Corr, and Kanaroglou 2010).

Tai (2011) compared $PM_{2.5}$ levels with meteorological variables around the United States and discovered that not every weather event has a strong correlation with PM levels, but there were a few that do, like temperature variations.

Dew and frost climactic factors can play a large role in the formation of inversions. Especially with radiative inversions, low-lying events can be greatly influenced by the humidity and precipitation of dew (Whiteman, De Wekker, and Haiden 2007). The energy contained and released by water vapor has several implications. The normal heat gradient of near surface warmth and cooling as you travel upwards becomes amplified as the latent heat is released from the formation of dew and frost (Whiteman, De Wekker, and Haiden 2007). This phenomenon is even stronger in basins and valleys, where advection is impeded. The combination of higher heat difference and large variation in humidity within the vertical profile can create strong inversions. In studies performed in the Gruenloch basin in the Swiss Alps, it was shown that latent heat released constituted between 33% and 55%. Given dry conditions, the amount of cooling within the basin would have been substantially larger (Whiteman, De Wekker, and Haiden 2007).

Effects of Physical Geography

Local geography can play a key role in the formation of inversions. Wallace, Corr and Kanaroglou (2010) found that the Niagara escarpment along the southern shore of Lake Ontario is a key factor in the formation of inversions in the city of Hamilton. Its proximity to Lake Ontario means that there are regular intrusions of cold air into the lower portion of Hamilton which are contained by the face of the escarpment. The upper portion of the escarpment would warm the air much more quickly, and this would easily slide on top of the low-lying cool air. This is a documented example of orographic lifting playing a role in the formation of inversions.

Topographic influence on air inversions has had deadly effects in the past. Before the implementation of air quality standards, Donora Pennsylvania experienced severe industrial pollution buildup. The horseshoe-shaped valley experienced such high levels that twenty people died (Wallace, Corr, and Kanaroglou 2010). In 1930, 60 deaths were attributed to buildup due to inversions in the Meuse Valley in Belgium. In Salt Lake City, Utah, Beard et al. (2012) performed a study correlating the length of inversions to respiratory ER visits. Salt Lake City sits in a valley, and is known for the number and longevity of its inversions. Given a three-day lag window from events, there was a strong statistical correlation between inversions and ER visits, which was strongest for asthma and related respiratory emergencies. As such, it seems pertinent to include inversion in meteorological forecasting, especially for urban areas where particulate matter may be an issue.

Environmental Justice

Socioeconomic issues play a substantial role when considering the spatial differences of air pollution exposure. Throughout history, heavy industrialization has taken place within close proximity to low-income housing. This trend likely exists because of the convenience of having lower paid factory workers live near the factories where they work. Since the industrial revolution, socioeconomic spatial distribution has become much more complex due to exponential population growth.

Segregating cities by race and socioeconomics is poor urban planning and, in the past, has led to poverty and environmental injustice. Research on environmental injustice has led to analogous discoveries on the correlation between socioeconomic patterns and air pollution in cities. This is now a serious environmental health issue across the world.

Jerret et al. (2001), used GIS to explore potential connections between socioeconomic factors and air pollution exposure. The authors established that environmental justice was heavily influenced by both the location of the polluting facilities and the distribution of racial and socioeconomic groups. Other contributing factors such as political power, externalities and land use institutions also exist. Land use and urban planning techniques from years past have unfortunately set up this unjust distribution of people, due to the ever-changing nature of urban life. Politics and market failure also relate to this urban phenomenon. Many urban areas that were once politically and financially successful are now run down, polluted and poverty-ridden. Planning for redevelopment or gentrification of urban areas past their prime is a common urban planning tactic.

The physical geography of cities varies substantially around the world. The physical landscape of cities is associated with the movement of particulates and air quality. The industrial activity in and around cities also plays a role. Hamilton, Ontario is a major industrial area and home to Canada's two largest steel makers. This high industrial activity results in areas with high levels of pollution (Jarret et al. 2001).

Although Keene, NH has not had any major industrial business in recent years, it is important to understand that $PM_{2.5}$ pollution was once an apparent issue caused by industrial activity. The Hamilton, Ontario study used air pollution data form 23 monitors operated by the Ontario Ministry of the Environment (MOE) in the surrounding area, as well as socioeconomic data from the 1991 Canada Census. Two methods were used to measure pollution exposure. Monitors measured chronic average exposure as well the probability of extreme exposure events. The authors concluded that; "groups with lower socioeconomic status are exposed to higher levels of ambient particulate air pollution in Hamilton than are groups with higher socioeconomic status" (Jarret et al. 2001).

A nationwide study focused on air quality impacts of transportation and their correlation with the racial and social economic status of people living in urban areas with reduced air quality. (Wernette and Nieves 1992) The researchers discovered that 437 of the 3,109 counties in the U.S. failed to meet one of the Environmental Protection Agency's air quality standards. Bullard (2005) states, "Specifically, 57 percent of whites, 65 percent of African Americans, and 80 percent of Hispanics live in 437 counties with substandard air quality. Nationwide, 33 percent of whites, 50 percent of African Americans, and 60 percent of Hispanics live in the 136 counties in which two or more air pollutants exceed standard." Other studies have found similar correlation, which lends support to the concept of environmental injustice, a spatial environmental health issue created over time during urban development all across the globe.

$PM_{2.5}$ Pollution Management

Many U.S. metropolitan areas began to invest in air quality management in the latter 20th century. In 1990, the South Coast Air Quality Management District instituted an air quality management program. The program applied to four counties in southern California. This air quality management program has had positive economic impacts. There was no negative correlation between GDP and pollutant levels, or employment and pollutant levels. In fact, economic numbers showed a slow growth as the amount of $PM_{2.5}$ and ozone dropped (AQMD 2012). The agency's 2012 report stated that control of airborne pollutants should help to create new jobs and increase revenue that will offset the average annual cost of the program. The report suggests that there are myriad financial benefits from controlling the level of airborne pollutants. For a $448 million annual investment, they project that there will be a reduction in morbidity and mortality, improved visibility and improved tourism, reduced materials use from lowered environmental degradation to buildings, and a reduction in traffic congestion, which combined should result in $10.6 billion dollars of decreased spending (AMQD 2012).

There are many health benefits from decreased pollution levels. Reductions in health emergencies related to declining pollutant numbers are classified and predicted in the

Socioeconomic Report. The most drastic classification; Minor Restricted Activity Days (MRAD), is where residents are told to stay inside to avoid negative health effects. It is predicted that, in 2014, 287,447 fewer people will be affected than control populations. Lost workdays would be reduced by about 40,000, and there would be almost 27,000 fewer asthma attacks. Adult and infant mortality would also be reduced by almost 700 (AMQD 2012).

Unfortunately, the program does not necessarily benefit lower income households in the immediate future. During this study, the people of the area were put into five groups based on median income and job type. The increase in jobs resulting in the implementation of clean air programs was greatest for the lowest income tier (those earning $352-517 per week), while the two highest earning groups received the second and third largest increase for 2014 (AMQD 2012).

Particulate air pollution leaves negative impacts on human health and can create environmental injustice. Physical geography and weather patterns exacerbate these issues in many geographic locations. The physical and cultural landscape of Keene, New Hampshire lends itself to these issues. New trends in home heating methods and winter time air inversions have made Keene a focus area for air quality improvement. In the next section we outline our study of how $PM_{2.5}$ is affecting Keene, NH followed by our results, analysis and conclusions.

Chapter 3: Woodpile Survey

Methods

In an effort to understand the spatial patterns of air quality in the city of Keene it was necessary to survey houses for evidence that they use wood as a fuel source. We targeted residential neighborhoods where high levels of $PM_{2.5}$ were previously recorded. Two regions were chosen for investigation, one surrounding the high school and the other near the middle school. These neighborhoods were selected for their variety of housing densities, altitudes, and income levels. These characteristics will facilitate comparison and analysis of the results. Each region was split into neighborhoods delineated by and nearby the school (HS1-HS4). There were four neighborhoods in the Keene High School area and three adjacent to Keene Middle School (MS1-MS3).

Data collection sheets were created for the purpose of the survey. We also created maps of the chosen neighborhoods using ArcGIS 10.2 (Esri 2013). Using a roads layer with street names obtained from the University of New Hampshire GRANIT GIS database, neighborhoods were selected and used to separate each into its own map (Appendix A1). Each neighborhood is less than 2,000 square feet. An aerial image was used as a base map to accentuate the layout of the neighborhoods, and provide the ability to recognize rooftops, driveways, and other features.

The maps of each neighborhood were accompanied by a table (Appendix B). The table contained columns for each house's address, the presence or absence of woodpiles, number and type of chimneys, and the number of chimney caps. The chimneys received one of four classifications based on the most prevalent types: metal, metal with siding, brick chimney with flue and brick chimney without flue.

Chimney Types

From the outside of a house, a metal rooftop chimney is the easiest of all types to identify. The metal chimney comes out of the roof in the form of a very large, round pipe. This pipe has a cover on the top, which regulates the amount and temperature of fireplace exhaust. The typical metal rooftop chimney has piping that extends a few feet out of the roof (Figure 4). There are four main brands for this type of chimney cap: the Vacustack cap, the Weather Shield cap, the Home Saver cap, and the Chimney Surround (Woodland Direct 2013).

Figure 4: Image of a metal rooftop chimney. (Source: Francis).

Prefabricated, or prefab, is a metal chimney with siding (Figure 5). These chimneys are covered by siding or shingles that usually matches the rest of the house. These are easily recognizable because of the conspicuous lack of masonry. Prefab chimneys surround the stove pipe and provide protection similar to that of a masonry chimney. Along with the four types of chimney caps, the prefab chimney can also use a decorative shroud, which can hide the metal piping entirely (Woodland Direct 2013).

A brick chimney with a flue is very common style in New England. This type of chimney can be very wide, allowing it to vent multiple stoves or fireplaces. This allows for more than one chimney cap to be placed on top. In a brick chimney with no cap, the clay flue can sometimes be seen from the ground, protruding above the chimney crown (Figure 6).

Figure 5: Image of prefabricated chimney. (Source: Woodland Direct).

Chimneys with removable caps can also have flues, as the caps can be taken off for regular cleanings. Like metal and prefab chimneys, the brick chimneys with flues have different options for chimney caps including; clay or copper tops, single flue caps, multi-flue caps, decorative shrouds, or no cap at all (Woodland Direct 2013).

Figure 6: Image of masonry chimney with flue. (Source: Woodland Direct).

The last type is a brick chimney without flue (Figure 7). This chimney looks the same as other masonry chimneys, except for the lack of a flue. As our survey could only be done while viewing chimneys from the street or sidewalk, it was very difficult to distinguish chimney types in some cases. It can also be difficult to tell if there is a flue or not, especially when there are multiple outlets in the same chimney. One clue as to whether or not a chimney has a flue is how the cement chimney

crown is formed. A chimney without a flue has a flat cement chimney crown, whereas a chimney with a flue has a rounded or angled crown molded over the protruding flue. Masonry chimneys without flues can use no cap, a multi outlet cap, a single cap, or a cap and damper combination (Woodland Direct 2013).

Figure 7: Image of masonry chimney without a flue. (Source: Woodland Direct).

Survey Data Collection

All seven neighborhoods were surveyed over four weeks during October. Each survey was conducted by a minimum of two team members. We walked the streets of each area, recording the house number and street name for each entry. Every chimney that was visible from the street was recorded by its house number and street. The total number of houses on each street was pulled from Keene's tax records for comparison.

For the woodpile column, each house was assigned a "y" or an "n". Houses received a "y" if there was definitely a woodpile, which includes the woodpiles obvious from the road. We also used a series of additional visual cues that indicated the presence of a woodpile. This included piles of bark at the entrance of a shed, open fronted sheds with wood visible through slats, and rectangular shaped piles that were covered, but too irregular to be building materials. An "n" was assigned to a house if there was no woodpile present, or if the view of the yard was obstructed. In a very small number of cases the entire property could not be seen and this was noted on our maps and data sheets. Though there are different types of structures in some of these neighborhoods, we only surveyed residential buildings and associated structures. Our neighborhoods are primarily residential; however there are also a number of churches and a large research farm. These properties were not included in our final analysis. Each survey took approximately two hours, and this timeframe varied given different building density. The middle school neighborhoods had higher housing densities than the high school neighborhoods.

The woodpile survey was executed to explore significant correlations between the presence of wood as a heating fuel, chimney types, and other factors. The data from the survey was entered in a spreadsheet in Excel, and then imported into ArcGIS 10.2 (Esri 2013).

Figure 8: Image of Dr. Brehme and Charles Babcock surveying chimneys.

The houses were geocoded to locations along address delineated TIGER/Line files released by the US Census Bureau in August of 2013. A number of errors and omissions are present in these files, so extensive measures were taken to improve the accuracy of geocoding. This involved editing the attribute table of the TIGER/Line files on a street by street basis. The original numbering was haphazard, sometimes putting values as high as 299 on roads that had less than ten houses. Luckily, the hand drawn reference maps we created during the data collection process had very detailed address information, so each street segment TIGER/Line in the neighborhoods we studied could be corrected with reasonable accuracy.

Following the corrections, geocoding was a simple matter of running the tools included in the Spatial Analyst toolset of ArcGIS. First, an address locator was created from the corrected files from the Census Bureau. The output was a dual range address locator, which has evenly spaced sockets running the length of each segment with odd numbers placed on one side and even on the other. The Excel sheets had to be modified, with a field for house number and address, and a second field for zip code. After the data was correctly organized the spreadsheet was imported into ArcGIS, and was geocoded into a series of points. These points could then be exported into their own shapefile, which contained all of the survey data.

Following the successful geocoding process, there were many options for analysis. First, a neighborhood field was added, and neighborhood subdivisions were extracted. By choosing the areas that we delineated on the data collection maps, the field could then be calculated with relative ease. The benefit of using Arc as a tool for analysis is the ease with which spatial trends can be explored. From the shapefiles, it was possible to repeatedly change the symbology to view different aspects of the data. From this, a series of maps was produced to show the distribution of the data we collected, including linear woodpile concentration, point density of woodpiles, and chimney type.

To preserve anonymity of the residents, the maps produced with specific points have no numerical data displayed. Any maps that have numbers have been aggregated to the level of street segments or larger so that individual houses cannot be identified.

Results

The different areas, illustrated in Figures 5 and 6, had fairly specific characteristics, both in comparison to each other and between the areas contained within them. The High School neighborhoods represent the higher of the two in terms of household income, and the various factors that entails. Anecdotally, these houses and plots tended to be larger, though there was a mix of housing types in both regions. The housing density in the middle school region was much higher. The neighborhoods were all of comparable size, but the topographical relief of the middle school neighborhoods was much greater.

The four high school neighborhoods had a total of 556 houses. There was an average of 139 houses, 113 of which had chimneys. Houses with chimneys were referred to as cases. The range of houses ran from 107 to 191, but the range of cases was about equal, ranging from 83 to 167. Neighborhood two had the greatest number of total residences and houses with chimneys, at 191 and 167 respectively, but neighborhood four had the highest overall percentage of cases at 89%. These are relatively high numbers, meaning that a large percentage of the residents have the capacity to burn wood, even if they do not.

High School	Houses	Cases	Percent
HS1	107	83	77.6
HS2	191	167	87.4
HS3	137	92	67.2
HS4	121	108	89.3
total	556	450	80.9
Middle School	**Houses**	**Cases**	**Percent**
MS1	260	244	93.8
MS2	196	181	92.3
MS3	328	190	57.9
total	784	615	78.4

Table 1: High School and Middle School Raw Numbers

The middle school region, on the other hand, had a much different range of values. There were a total of 784 houses, which we did not know when we developed the survey. We had drastically underestimated the size of the trailer park that makes up neighborhood three, so these numbers were not comparable to the others. The large number of houses was surprising, considering that these neighborhoods are about the same size as the high school neighborhoods. Neighborhood three (328) has almost seventy more houses than neighborhood one (260), and twice that of neighborhood 2 (196). The most notable initial finding is that MS3 is the outlier of the group. In MS1 and MS2, more than 90% of the houses have chimneys, but MS3 has only 57.8%, which is nearly ten percent lower than the lowest neighborhood in the study. It is this very low value pulls the middle school average down to a number comparable to the high school. Approximately 79% of residences in both regions have a chimney of some sort.

Neighborhood	Woodpiles	Cases	% Cases	Houses	% Houses
HS1	29	83	34.9	107	27.1
HS2	19	167	11.4	191	9.9
HS3	26	92	28.3	137	19.0
HS4	23	108	21.3	121	19.0
total	91	450	20.2	556	16.4
MS1	60	244	24.6	260	23.1
MS2	21	181	11.6	196	10.7
MS3	4	190	2.1	328	1.2
total	85	615	13.8	784	10.8

Table 2: Woodpile Data

The woodpile data suggests some fairly interesting trends regarding home heating. If a residence has a woodpile and some way to burn it, it can be assumed that they light a fire at least occasionally. The high school area has 91 woodpiles in total, of which the HS1 neighborhood had 29. This neighborhood had the least number of total houses, and the least number of cases. As a result, that neighborhood has the highest percentage of cases in the entire survey, with 34% of cases and 27% percent of houses having a woodpile.

Similar to the high school region, the middle school neighborhoods varied considerably in the ratio of houses to cases. MS1 had 60 woodpiles, accounting for 24.6% of cases and

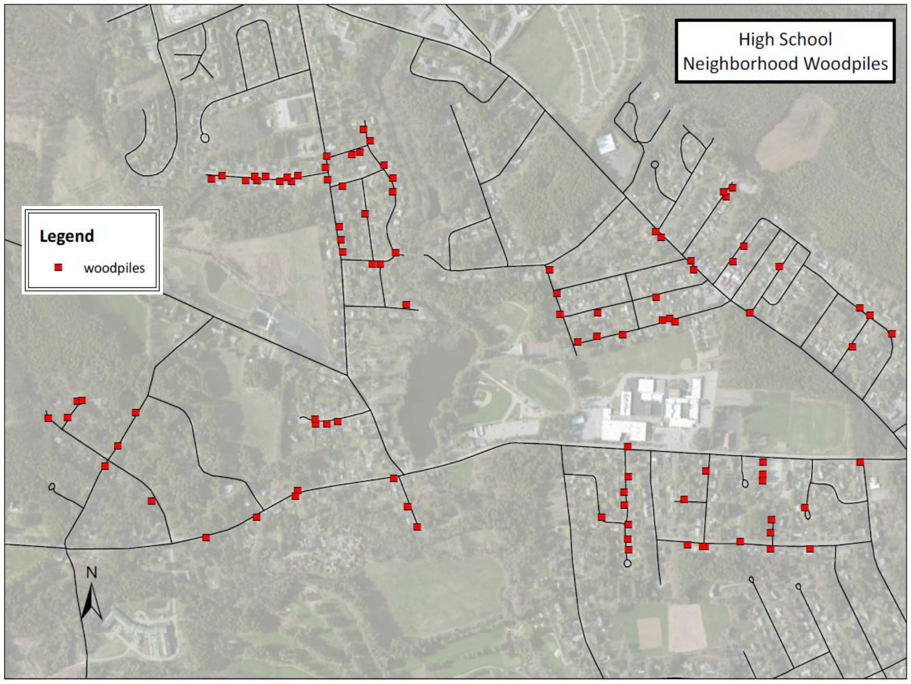


Figure 9: High School Woodpiles

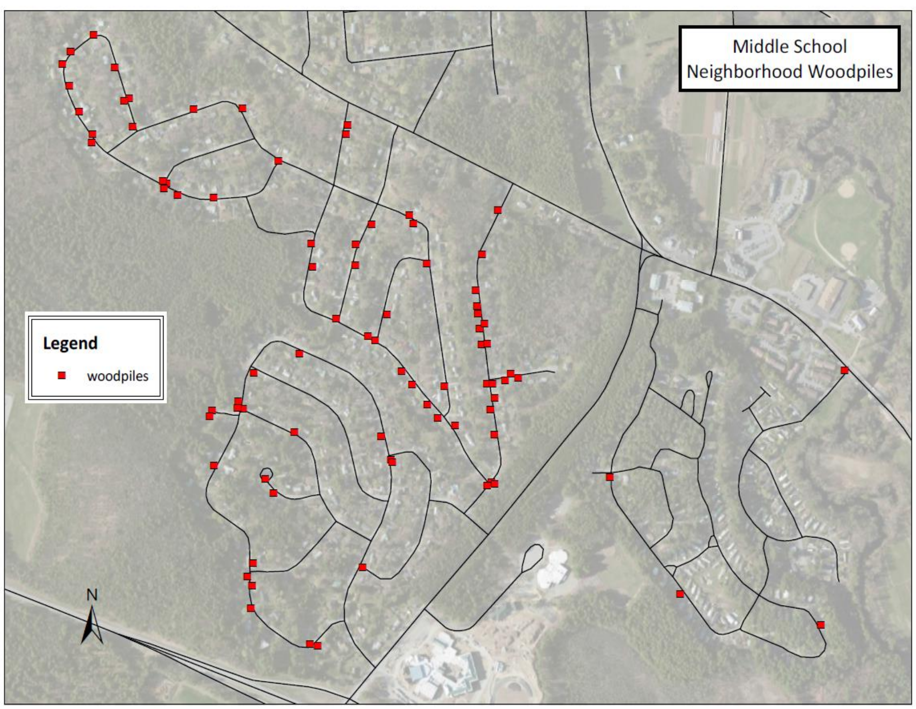


Figure 10: Middle School Woodpiles

23.1% of houses in that neighborhood. The next neighborhood, MS2, had 21 woodpiles, for 11.6% of cases and 10.7% of houses. This is similar to HS2, the neighborhood with the lowest number in the high school region. Neighborhood MS3 was far below the rest of the field. It was the largest area that we surveyed, but had just 4 woodpiles. This means that barely 1% of the houses in MS3 had a woodpile. In total, the area near the middle school had 85 piles, which account for 13.8% of cases and 10% of the houses there.

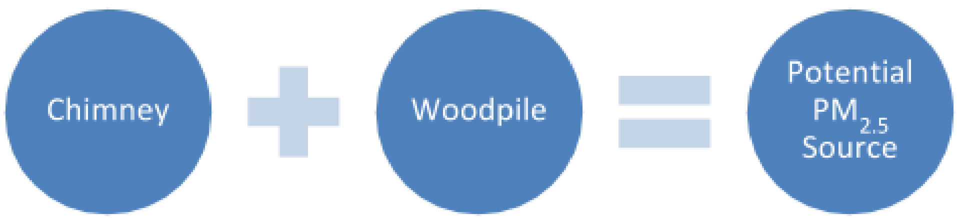


Figure 11: Visual Overview of Research

The collection of woodpile data was performed to quantify those areas at risk of experiencing elevated $PM_{2.5}$. Houses with chimneys and woodpiles represent the potential presence of combustion, which leads to the release of particulates into the air. As such, it seemed important to study proximity to woodpiles as a possible factor in the buildup of $PM_{2.5.}$ This was done using two representative methods: linear distance and point density.

First is linear distance. After the length of each line segment was calculated using the calculate geometry command, the segments were buffered and joined with the woodpile points. The calculate field tool divided the length by 100 feet, and divided the number of points by that value. The maps were divided into line segments at road intersections, but the math normalized the values in a reasonable manner. In the middle school region, MS1 has long stretches that are 0.3 woodpiles per 100 feet or more. This means that there is roughly 1 woodpile for every 300 feet traveled. There are several roads in the high school neighborhoods that are above 0.75 woodpiles per 100 feet. This could contribute greatly to the ambient $PM_{2.5}$ levels.

The second means of showing spatial distribution was through a point density map, created in ArcGIS. In looking at the quality assured data from the monitoring station in Keene, the minimum wind speed at the time of the recording was 0.1 miles per hour. This is the result of cold air flowing down the surface of the hills surrounding the town, creating the inversion and pulling the polluted air with it. The range of values for this data during times of high $PM_{2.5}$ (greater than $35 \mu g/m^3$) was an average of 0.36 miles per hour, ignoring outlier. We decided to use the minimum value to determine the minimum range affected, so 528 feet was used as the value for the number of pixels involved in the calculation of the point density map. The value of the pixels was the number of woodpiles per square acre.

In the middle school region, there seemed to be a middling point density throughout most of MS1 and MS2. MS3, with its noted lack of woodpiles, was completely clear. The area at the Butternut Drive loop is known to be a problem area from previous mobile monitoring, and it had fairly high values. The intersection of Liberty Lane and Kennedy and their proximity to Sesame Street made it a noticeable hot spot. Given widespread use of woodstoves during a short time period, those would appear to be the most at risk for the first hour. The proximity to the northern edge of the basin would most likely push the particulates to the south, so both the Butternut and Liberty/Kennedy/Sesame pollution would most likely spill into the nearby neighborhoods.

In the high school neighborhood, there were pockets of concentrations. HS2 had a large are between 0.26 and 0.5 woodpiles per square acre, but HS1 and HS4 appear to be the problem areas here. HS4 has elevated levels from Bradford Street to Hamden Drive, and between Arch Street and Robbins Road. HS1 is the highest, which is logical considering it had the highest ratio of woodpiles to houses. Near the corner of Hastings and Trowbridge was a pocket of high woodpile concentration. Again, the cold air sliding under the inversion would carry these potential pockets of high particulate air into nearby neighborhoods, most likely to the east.

The last type of analysis was studying the effects of chimney type. In total, there were 1065 houses with some sort of chimney, with 450 in the high school region and 615 in the middle school region. Of these, we have created five classes for the chimney cases. These are metal, masonry with a flue, masonry without a flue, a mix of metal and masonry, and mixed types of masonry. Due to the lack of prefabricated chimneys recorded, it was combined with the total metal chimney category.

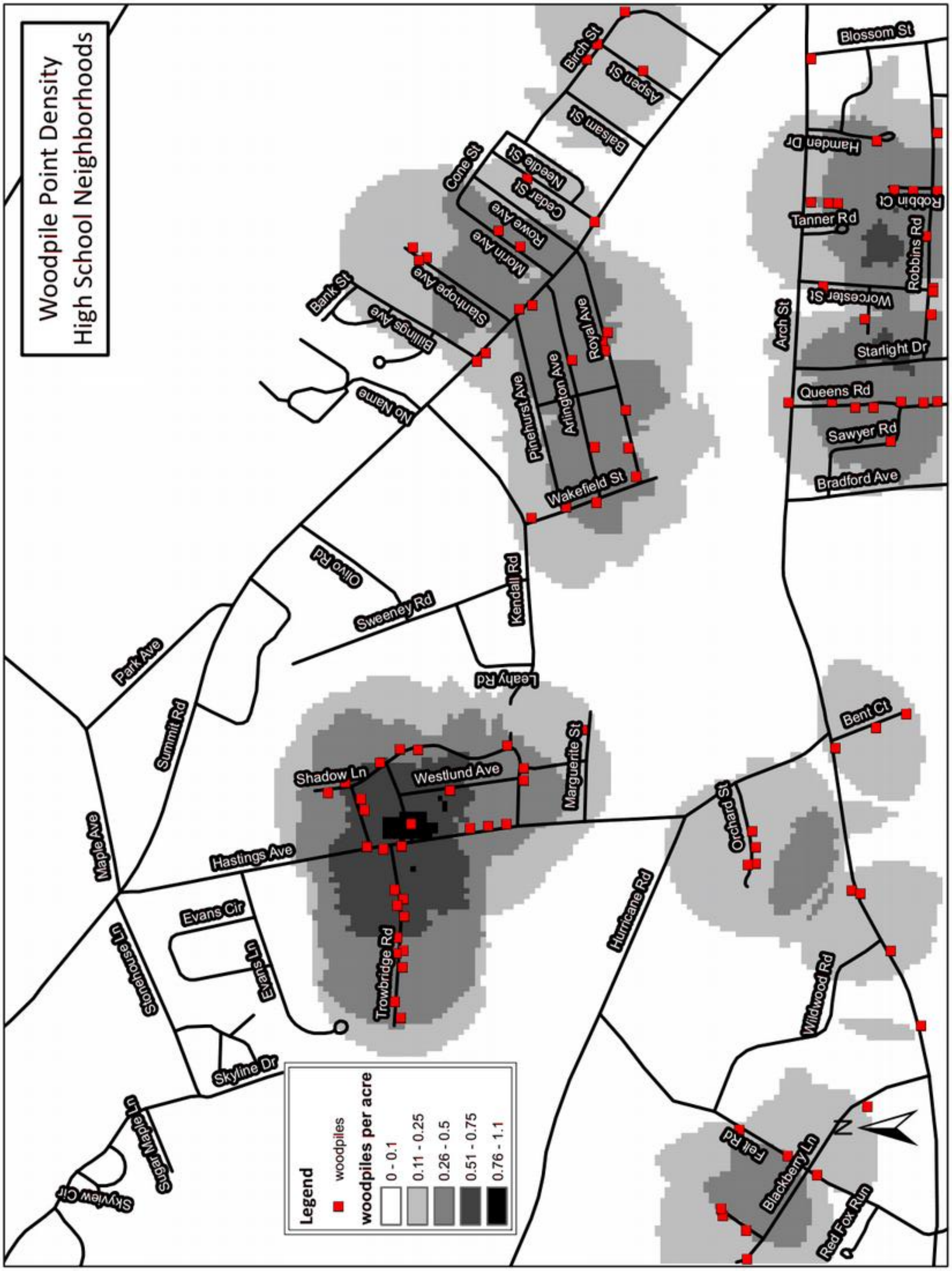


Figure 12. High School Point Density Map

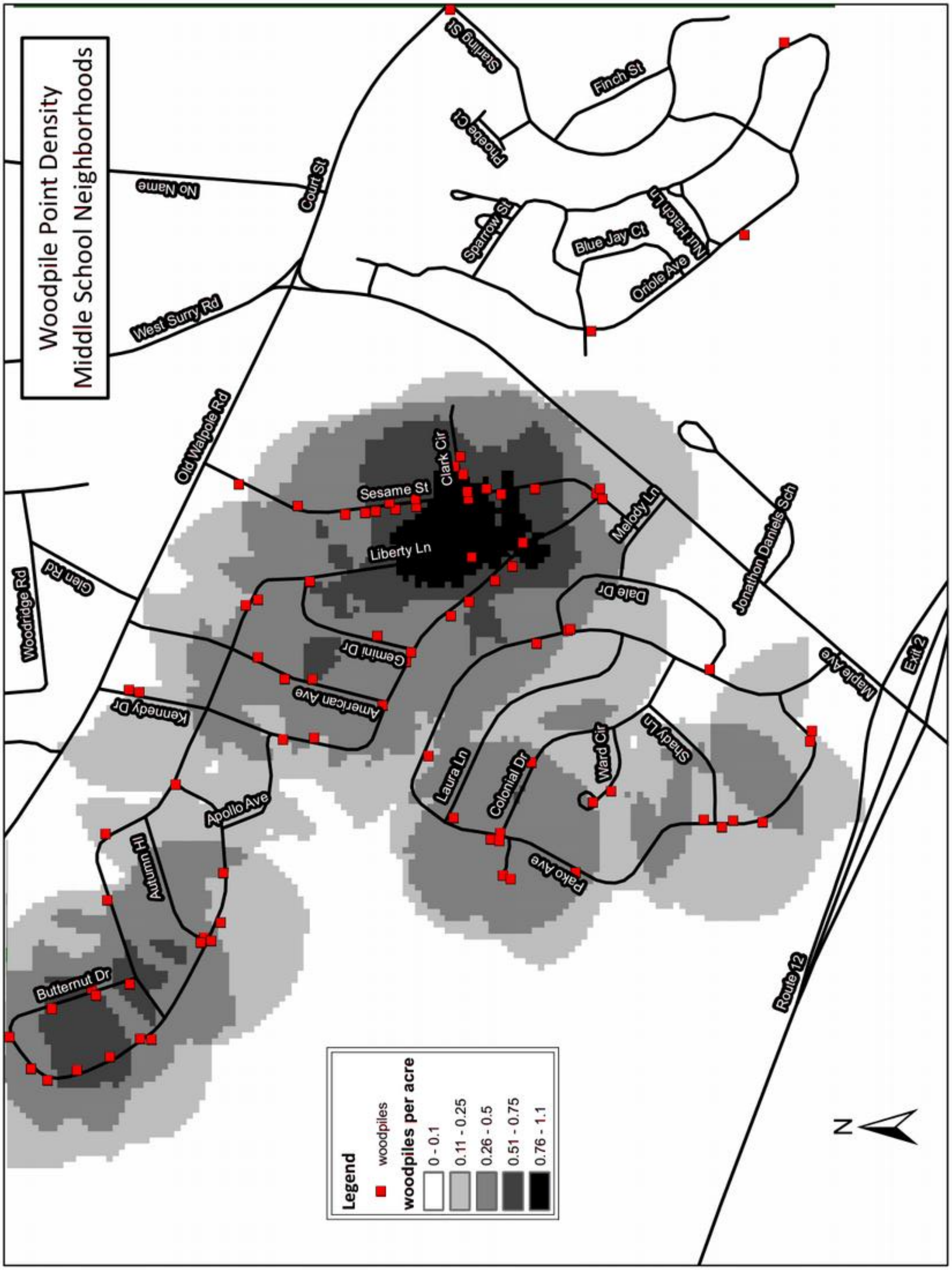


Figure 13. Middle School Point Density Map

In the high school neighborhood, the most common chimney was masonry with a flue, and second most common was masonry without a flue. These represent approximately three quarters of the case houses, and over fifty percent of the total houses. The least common is mixed masonry, with only fourteen houses having this combination. These results differ greatly from the middle school neighborhood, where metal chimneys are installed in over 40% of the cases. Masonry with a flue and mixed metal and masonry are second and a close third. As previously mentioned, the percentage of houses with chimneys is very similar between the two

High School	Number	% of Cases	% of Houses
metal	20	4.4	3.6
Masonry with flue	187	41.6	33.6
Masonry no flue	136	30.2	24.5
mixed metal + masonry	89	19.8	16.0
mixed masonry	18	4	3.2
total	450		80.9
Middle School	**Number**	**% of Cases**	**% of Houses**
metal	270	43.9	34.4
Masonry with flue	167	27.2	21.3
Masonry no flue	15	2.4	1.9
mixed metal + masonry	155	25.2	19.8
mixed masonry	8	1.3	1.0
total	615		78.4

Table 3: Middle School Neighborhood Chimney Types Counts.

study regions, but the compositions are very different. Masonry with a flue was the most common type, in 187 of the cases. The lowest, being mixed masonry, was found in only 18 cases. The range of values was even larger in the middle school region, ranging from 270 for metal to 8 for mixed masonry. This could be the result of the developments going up at

The distribution of chimney type throughout the surveyed neighborhoods is depicted in Figures 14 and 15. Each figure helps to visually display what chimney type is most prevalent and most scarce within each region.

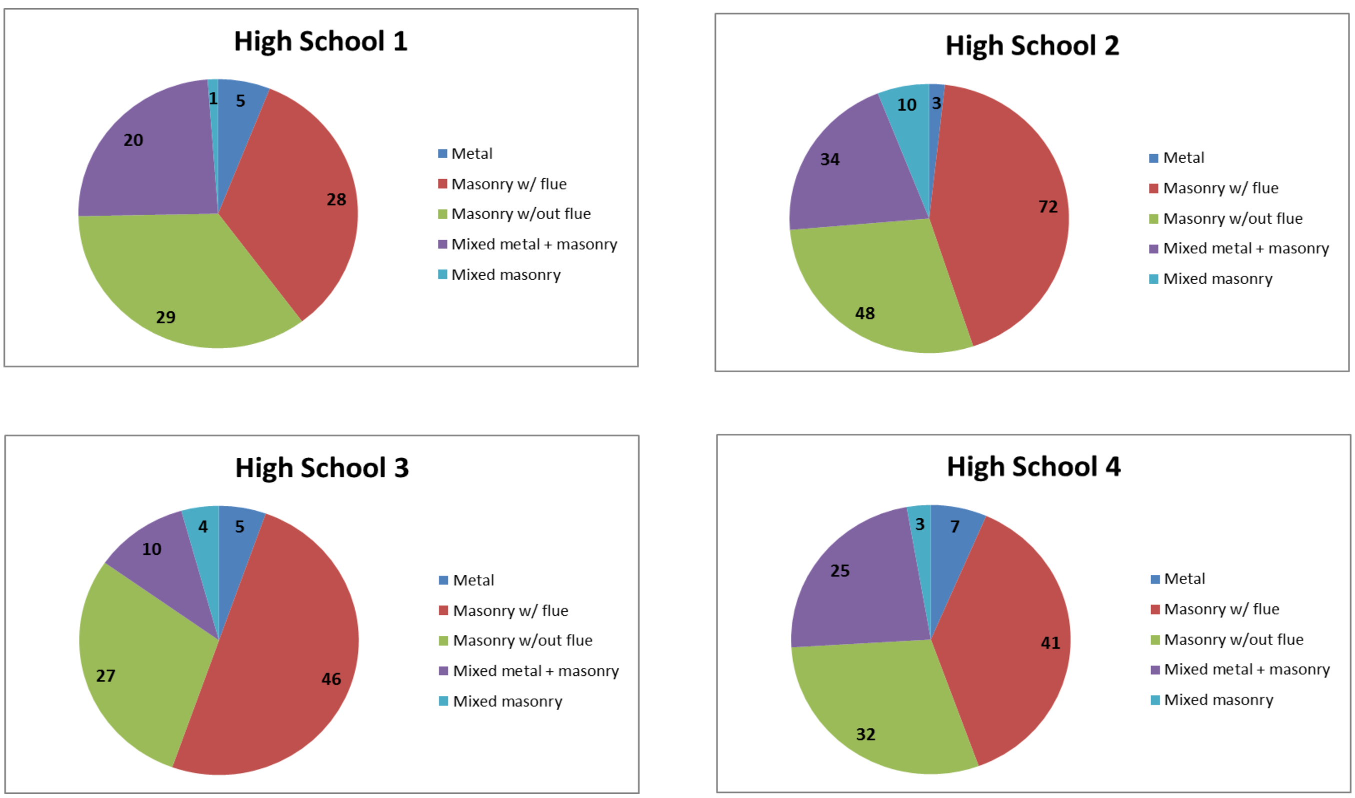
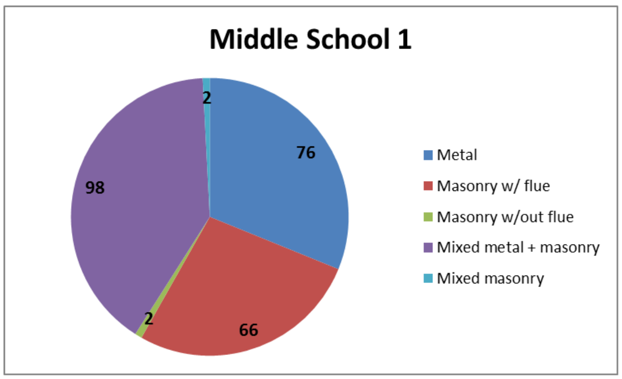
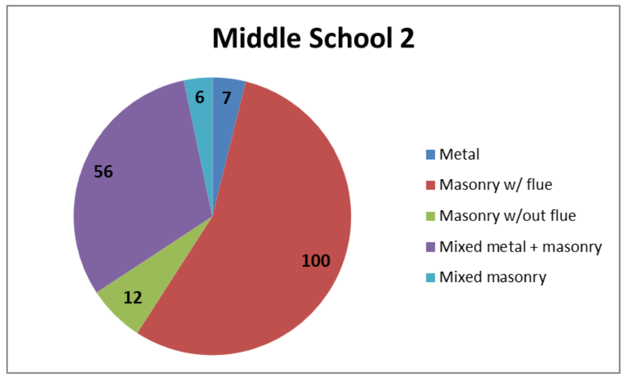


Figure 14: Chimney types in each High School neighborhood.

Though the number of houses varies between the high school neighborhoods, the pie graphs show that the two most common chimney types are masonry with flue and masonry without flue. These are often connected to a traditional fireplace and are likely used as a secondary source of heat. These chimney types have two general uses; heating small sections of a home, as well as seasonal and traditional aesthetic value. Houses that had metal chimneys, as well as metal and masonry take up about 25% of each neighborhood. Metal chimneys are usually connected to woodstoves and prefabricated fireplaces. Further statistical analysis will compare chimney type to the presence of wood piles, searching for a correlation between the two.





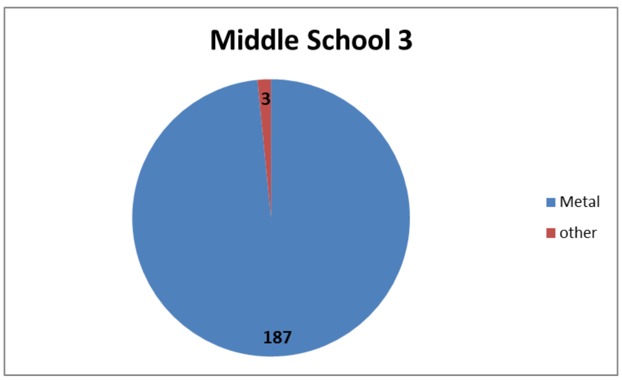


Figure 15: Chimney types in each Middle School neighborhood.

These graphs depict the chimney type distribution in neighborhoods of the middle school region. These neighborhoods vary in values substantially more than those in the High School region. Data acquired from MS3 neighborhood is an obvious outlier, most likely related to the fact that all the cases are mobile homes. Metal chimneys are much lighter than masonry and are clearly the obvious choice for mobile homes. MS1 has the most metal chimneys for any neighborhood in both regions. This could possibly be a problem area for excessive wood burning and $PM_{2.5}$ emissions, as discussed later in this section. Across the region, masonry chimneys are predominantly without flues, a trend not found in the high school region.

A greater understanding of the two regions can be gained from looking at the map of the chimney types, which are located in the appendix. Clusters are fairly easy to see, especially in neighborhood MS3. The high school neighborhood has some fairly distinct linear groups, where cases along a section of a road will have the same chimney type. This may be interrupted by a mixed house or two, but many seem to be of similar type, all masonry, or masonry and mixed. There are occasional pockets of seemingly random distribution, but it seems that there are neither giant groups, nor too many completely isolated designs.

The middle school is a completely different story. Immediately apparent is the trailer park, or MS3, where only three houses have a chimney that isn't metal, as previously mentioned. There may be a few anomalous points, but a house with a specific chimney configuration is in or near a cluster of similar houses. Streets are generally consistent along segments, and usually there is a single type or an evenly distributed mix of two chimney types.

We wanted to test the potential for relationships between chimney variables and the presence of woodpiles. This is only a test of the houses with chimneys, so the results are only indicative within the subset of cases.

We first tested whether there is a relationship between the number of chimneys per house and the presence of a woodpile. The inquiry tested the null hypothesis that the number of chimneys is independent from the presence of a woodpile. The rows had 3 different classes, one chimney, two chimneys, and three or more. This was crossed with presence of woodpiles, either yes or no (Appendix, 91).

For the high school, the test indicated that there was no meaningful relationship between the two. The Pearson value for chi square was 1.556, which was inside the critical value of 5.99, but the significance was 0.212, far outside the acceptable range for a test with 95% significance. This indicates that the result cannot be used, and that there is little significance to the test. The middle school had different results. The significance was 0.000, which definitively shows that the results are significant. The Pearson value was 24.126, well outside the critical value for two degrees of freedom. We rejected the null hypothesis, and demonstrated that there is a relationship between the number of chimneys and the presence of woodpiles in the middle school region. The data indicates that the more chimneys present, the more likely there is a woodpile.

In looking at the numbers, about 10% of the houses with one chimney had a woodpile. Of houses that had two, 21% had a woodpile. For three or more chimneys, 66% had a woodpile. It is clear that the number of chimneys generally reflects the likelihood of the presence of a woodpile. Chimneys are a significant installation to a house, so multiple chimneys probably means that there is a higher likelihood that the houses are designed to use wood primary heat source. More study into their relative location within the house and the architectural goals may be useful in future studies.

Next we investigated the relationship between the number of chimney caps and the presence of a woodpile. We tested the null hypothesis that the number of chimney caps is independent from the number of woodpiles. The three rows were no caps, one cap, and two or more caps. This was crossed with the same columns as the test of the number of chimneys (Appendix, 91).

The high school had a value inside the critical value, but the significance was outside of the 95% required for accepting the results. The Pearson value for the middle school was 0.37, and the Pearson value was 6.596. This is barely above the critical value for three degrees of freedom, but the significance indicates that the results are valid. As a result, we reject the null hypothesis for the middle school data set.

For no caps, only 10% of the cases had a woodpile. For one cap, only 14% had a woodpile. For two or more caps, 29% of the cases had a woodpile. As far as this result goes, it is a little less cut and dry than the number of chimneys. Our data reveal that more chimney caps indicate greater odds of the presence of a woodpile. We had hypothesized that caps on masonry would mean a greater likelihood of more frequent use, and thus be related to the presence of a woodpile. However, all metal chimneys have a cap, and the vast majority of those with caps and woodpiles are either metal or mixed metal. Therefore it is hard to make any serious assertions regarding the specifics of the relationship between chimney caps and woodpiles.

Next we explored the relationship between chimney types and the number of woodpiles. The null hypothesis was that the chimney type was independent from the presence of woodpiles. There were five classes: metal, masonry with flue, masonry without flue, mixed types of masonry, and a mix of metal and masonry (Appendix, 92).

Following the trend of the last two tests, the high school region had an acceptable Pearson value, but the significance was outside the acceptable range. For the middle school, there was a significance of 0.000, showing that the results were definitive. The Pearson value was 42.351, far outside the critical value of 9.49. We therefore reject the null hypothesis for the middle school region.

The percentages for the different classes were 6% for metal, 14 % for masonry with flue, 0% for masonry without a flue, 14% for mixed masonry, and 28% for mixed metal and masonry. If the 187 cases from the outlier MS3 are dropped, the percentage of metal chimneys with a woodpile jumps to just about 20% with no effect on the other classes. This shows that there is certainly some sort of relationship between metal and mixed masonry and metal chimney configuration and whether residents burn wood in two of the neighborhoods.

Chapter 4: Home Heating Survey

Methods

We used a survey to gain a better understanding of the home heating habits and demographic characteristics of Keene residents. The Mondanock Food Co-op in Keene allowed us to administer surveys to interested patrons. In addition to providing a venue for data collection, our time at the Co-op allowed us to perform outreach and education regarding $PM_{2.5}$ and healthier wood burning practices. We distributed literature provided by the Southwest Region Planning Commission and the outreach letter used in the Keene Woodstove Change-out campaign. We also answered questions regarding health and policy issues connected to $PM_{2.5}$. The survey was administered to 45 residents on Friday, November 9th and Saturday, November 10th, 2013.

The survey addresses several key goals of our study. The first section pertains to home heating habits, and asks about the type and amount of fuel used, and the estimated frequency of use. Considering the year-to-year variability of the weather and the cost of home heating fuel, we determined that asking for data from multiple years would result in inaccurate data. As such we opted to ask for data from only last year.

The second section of the survey focuses on demographic data. It asks about the number of residents in the household, the number of residents who control heat, as well as basic socioeconomic data. Monitoring station data from Keene shows that there is an upswing in $PM_{2.5}$ concentrations at the end of the workday. We are attempting to explain this phenomenon by surveying Keene residents about home heating practices.

For the location data, the survey requested only the street name of the residence, rather than the specific address. This will allow us to spatially reference the survey results without divulging the specific location of the subject. Each survey is accompanied by an informed consent form outlining the purpose of the survey. This included a clause outlining that the results would not tie any information to a specific person or the location of their home. We had planned on creating maps of these results, but could not for lack of time.

The third section of the survey pertains to the outreach goals of the Keene Air Quality Working Group. Questions in this section ask if residents are aware of $PM_{2.5}$ as a pollutant, and of air quality issues related to $PM_{2.5}$ in Keene. One question asks if the subject is aware of Air Quality Action Days, which are those days when health warnings regarding air quality are broadcast. Answers to these questions will be used to provide a broader perspective on the subject, and to inform recommendations for further action.

Upon the completion of data collection and collation into Excel spreadsheets, we were ready for further statistical analysis. We present the results in two parts: one addressing descriptive statistics and the other addressing inferential statistics. The descriptive statistics provide context from which hypotheses can be drawn. They also provide information about the use of various types of heating fuels, the most commonly used heating devices, whether the majority of woodstoves are manufactured after 1990 and if they are EPA certified. Through graphs and tables we compare demographic variables such as family size, home ownership, home heating habits, and awareness of $PM_{2.5}$ and air quality issues in Keene. We use GIS to further explore the relationship of home location and the many types of data gathered in our survey.

A question of interest is whether there is a relationship between income and home heating fuel. The test that we use is called a chi square test. We test the variable, income, against the types of fuels that people use. This test will tell us if income and heating fuels are related. Our null hypothesis: the amount of yearly income has no effect on what types of fuel people use to heat their homes.

Results

With the permission of the owner, we distributed our survey at the Monadnock Food Co-op in Keene, New Hampshire. We were able to stand at a table near the exit behind the cash registers. Our survey had 48 respondents, and five surveys were discarded as they were missing key of information. As described above, our survey consisted of 17 questions divided into two parts. Part one discussed residential home heating. In this section we addressed the types of fuel people use, type of heating devices, when their woodstove was manufactured, and whether or not the stove is EPA-certified. Part two addressed questions regarding demographics of the respondents and their air quality issues. We asked where the respondents live, the number of people in their home, their yearly income, and their knowledge of Air Quality Action Days.

Question one, asked whether respondents used a number of fuel types to heat their homes, (Survey Appendix, page 83). The division of fuel types can be seen in Figure 16. Oil or kerosene ranked as the highest fuel type, with electricity second and natural gas or propane ranked third. These results were not surprising to us because of data we found from the 2010 Census, which will be explained later.

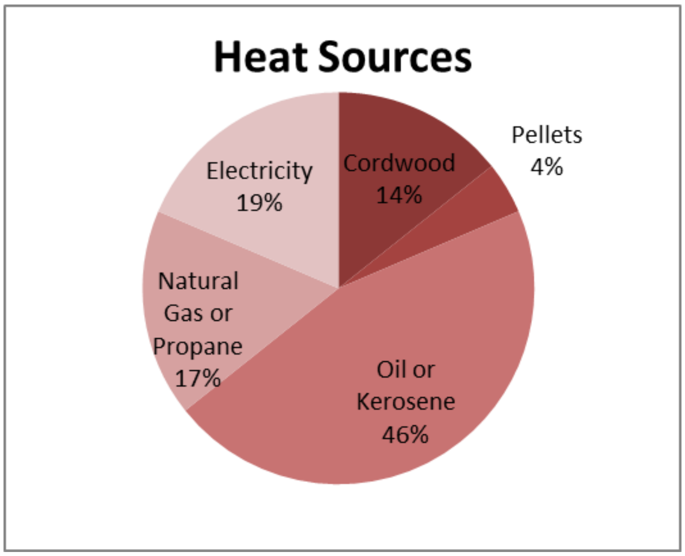


Figure 16: Percentage of fuel types illustrated in a pie chart.

The second question asks what the primary heating fuel each respondent uses during the winter, (Survey Appendix, 83). It is clear that oil is the highest used fuel type, followed by electric and then wood (Figure 16). This is not very surprising because of the relationship to question one, which showed that oil or kerosene is the most commonly occurring fuel types and that electricity was the second highest. However, now we know that not only do many people have it available to use, but it is also their primary source of fuel. There were also three respondents that said they use wood and oil equally.

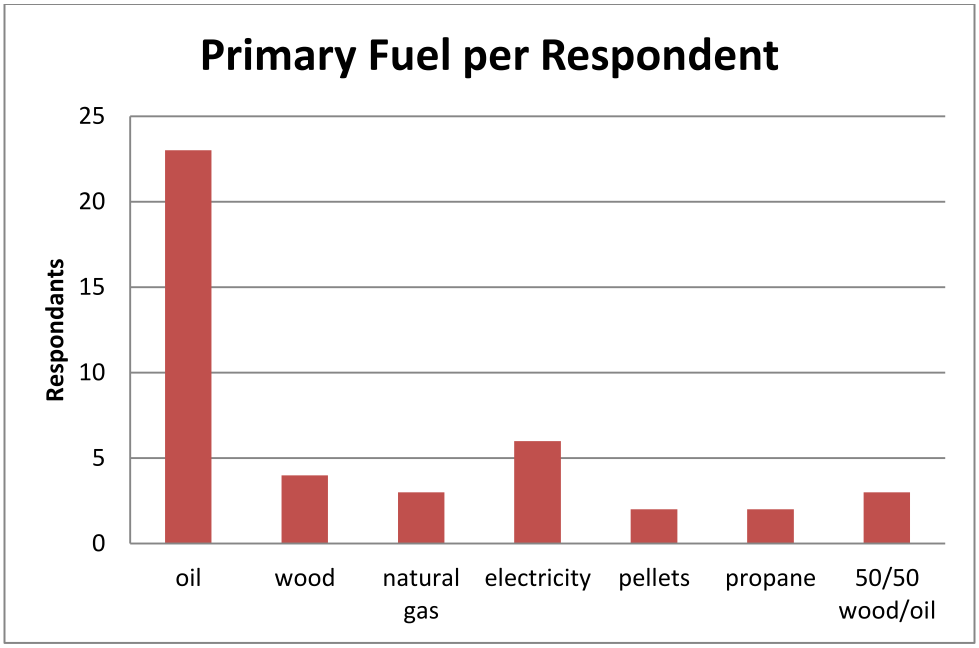


Figure 17: Primary heating fuel per respondent.

The next question that must be addressed is question seven (Survey Appendix, 83). This question asks what type of heating devices the respondent uses, and these are illustrated in Figure 17. Of the six types of heating devices we provided, woodstoves ranked the highest percentage, followed by the fireplace insert, the fireplace and lastly the coal stove (Figure 17). There were no responses for the outdoor wood boiler or the wood-fired furnace. We were not surprised by the lack of responses for the outdoor wood boiler and the wood-fired furnace. This is because the city has ordinances banning these types of heating devices.

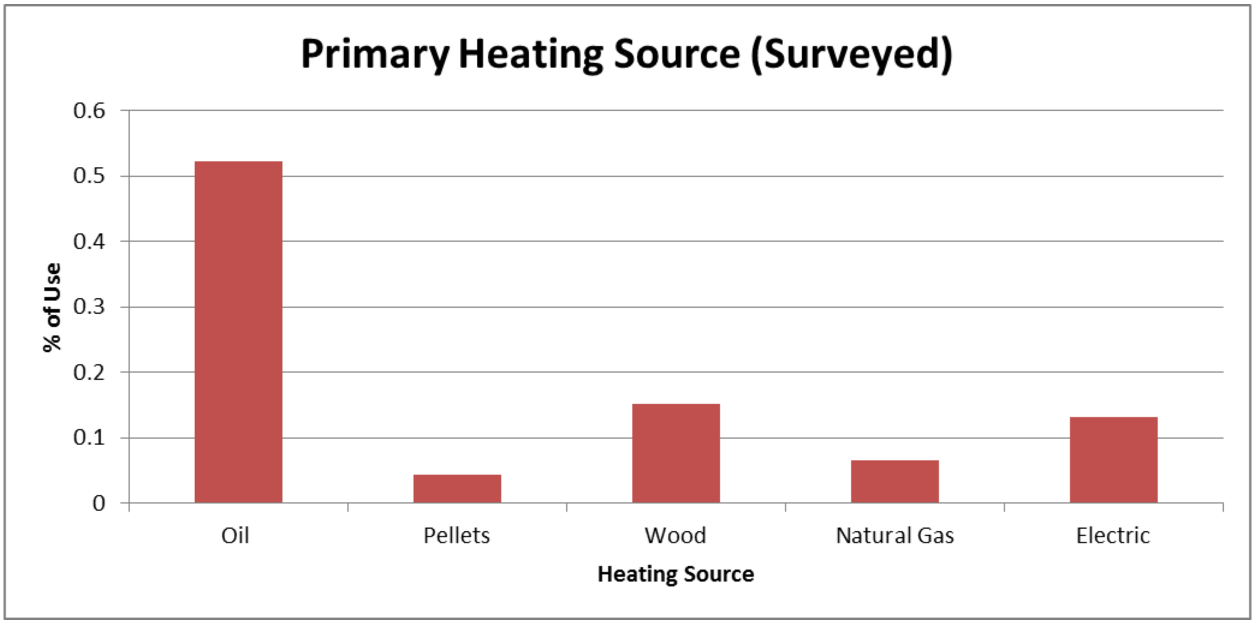


Figure 18: Percentages of primary heating devices.

Question fourteen, asks the respondent's yearly household income (Survey Appendix, 83). As seen in Figure 20, the most common income category was less than 20,000 dollars, the second was between 60,000 and 80,000 and the third was 100,000 and above. This was a little bit surprising for us as we thought that there would be far more respondents in the 60,000 and above categories. However, due to the proximity of Keene State College to the Co-op, the store is frequented by college students who are likely to comprise those who make less than 20,000 dollars a year.

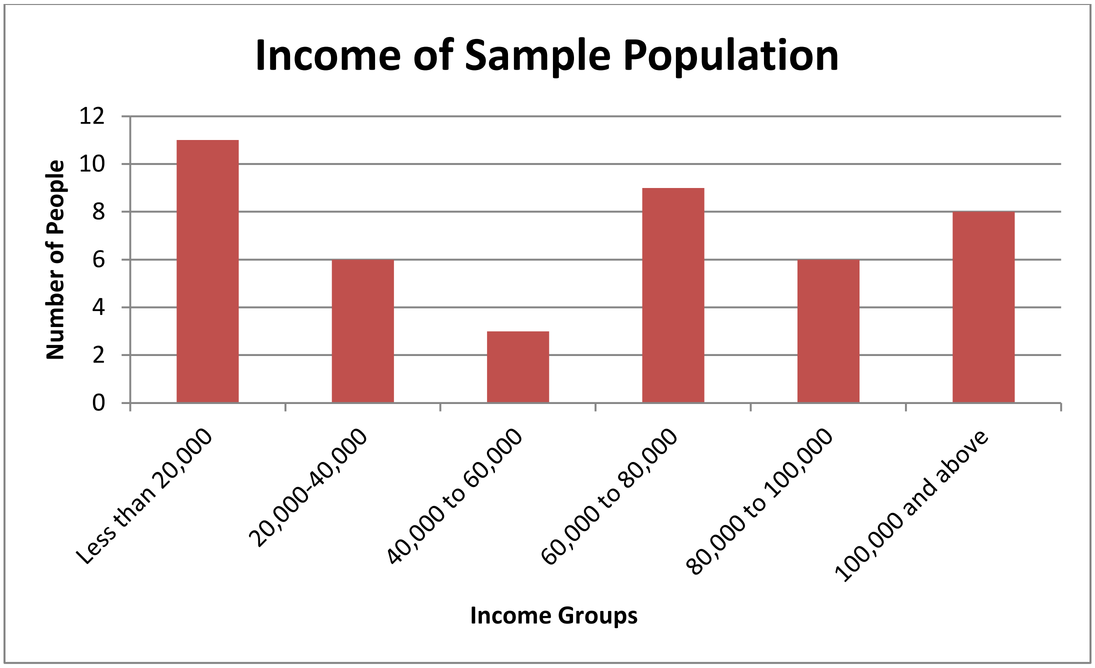


Figure 19: Yearly income of the sample population by number of respondents.

In order to gauge the diversity of our survey sample we ran a chi square test, looking for a relationship between the data we acquired, and expected data for the entire city of Keene. The survey question that we tested asked what the resident used as a primary fuel source to heat their home. The expected home heating values were acquired from the U.S. Census Bureau percentages from 2010.

Null Hypothesis: There is no relationship between the primary heating source of the observed sample and the expected population of Keene.

As the graph below depicts, our observed data is closely related to the expected values from the census. The Chi Square test output a value of .797 which rejects the null hypothesis, and also suggests that our sample was a relatively accurate representation of reality.

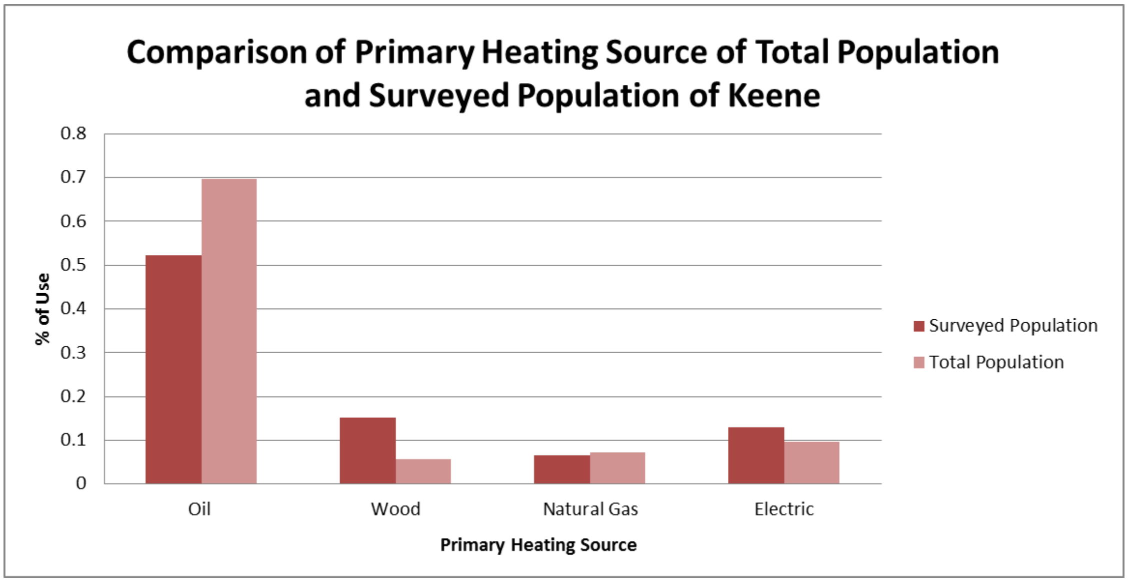


Figure 20: Primary home heating source.

Limitations

Due to the nature of our survey and the timeframe of our research, we were unable to send our Home Heating survey to people residing in the neighborhoods where we conducted our visual surveys of woodpiles and chimneys. Therefore, we tried to identify a public location or private business where we could ask local residents to take our survey. We administered our survey at the Mondanock Food Co-op, which is centrally located, just off Main Street. The Food Co-op sells organic, local fair trade food and health products. Like any specialty store, its customers may tend to have higher incomes and less diverse political views than Keene residents as a whole. The results of our income question would indicate otherwise, (see Figure 20). We expected our results to reflect the responses of this socio-economic background. From our data, this proved not to be the case. However, as our sample size is only

43 people, and we only surveyed in one place over the course of two afternoons, there could be bias that we are not aware of.

Chapter 5: Weather Balloon Inversion Experiment

Methods

Air inversions are a contributing factor to $PM_{2.5}$ concentrations. Understanding the altitude of an air inversion could contribute to understanding the spatial distribution of these events. A tethered weather balloon experiment was conducted to accurately determine the height and intensity of an air inversion in Keene. We requested access to high school and middle school athletic fields for use as test sites in this experiment. The schools' proximity to neighborhoods known to have serious $PM_{2.5}$ events make these an ideal location, as well as the large open areas that are available when launching the balloon. The experiment took place early in the morning before regular school hours and when meteorological records indicate these events may occur.

This experiment used a 12 foot weather balloon inflated to approximately six feet in diameter, 500 feet of parachute cord marked at two meter intervals, a USB Easylog LCD 2+ temperature and humidity sensor, and a stopwatch. The data logger was attached directly below the weather balloon, and set to record at ten second intervals. A GPS was used in distinguishing the exact location and the goal altitude is 500 feet, which is the approximate relief from the valley floor of Keene to the top of the surrounding ridges.

The location of the experiment would be logged using the GPS. The data logger and stopwatch would be started simultaneously, recording the first data point at ground level. We then have ten seconds to release two meters of line, and at the tenth second the logger would record the measurements. This is repeated until there is no more line to release. Any issues or discrepancies, like needing more than ten seconds to release the line, would be recorded with a timestamp so the results could be updated accordingly.

After retrieving the weather balloon, the temperature data was then uploaded into the computer, and indexed in regards to height and time. Finally, using a previously made map with DEM information, the GPS coordinates were used to find the height of the location. Using the height, all data collections were transformed to reference a single altitude in height above sea level. From this it should be possible to determine the height of the inversion within two meters/12.6 feet.

Results

We performed the experiment in the center of the Keene High School football field starting at 1:00 am on November 16th, 2013. The altitude of that area is 154 meters above sea level. We had 76 data points, meaning we released 152 meters/498 feet of line, which was nearly the whole spool. This puts the altitude measurements every two feet from 154 meters to 306 meters. The temperature ranged from 34 degrees Fahrenheit on the ground to 33 degrees at the highest altitude.

Had there been an inversion on this date, there would have been an abrupt increase in temperature at some point during rise of the balloon. We did not find this, and therefore did not capture an air inversion in our weather balloon experiment.

Limitations

We closely monitored the weather conditions in the city of Keene in preparation of this experiment. There were specific conditions for the creation of a temperature inversion, including a drop of at least ten degrees, no wind, high humidity, and clear skies. These conditions did not occur at the same time during the course of our study. We had been monitored the air quality alerts reported by the Southwest Regional Planning Commission, but there were very few monitored days where models predicted the potential for inversions and air quality events. While this is good news for the health of the residents of Keene, we were unable to capture a profile of air inversions during our study. Had we had our seminar class during the spring semester (January to May) the likelihood of capturing an air inversion would have been higher, as they are far more common during this time period.

Chapter 6: Conclusion and Discussions

Conclusions

Air quality is a great concern all around the world, but the political and physical landscape make $PM_{2.5}$ a particular concern in Keene, New Hampshire. High $PM_{2.5}$ concentrations even in short term events have been directly attributed to cardiovascular and cardiopulmonary emergencies in major metropolitan areas. Topographic and meteorologic factors can affect the concentration of $PM_{2.5}$ in Keene. Keene is in a valley, which can trap the pollutants within its rim. The valley walls can also create temperature inversions, trapping the pollution near the ground, drastically increasing the concentration of $PM_{2.5}$. Federal funding for public works projects and subsidies for local businesses are tied to EPA policies, so a better understanding of $PM_{2.5}$'s sources and effects is important. Our research was developed in order to understand the spatial distribution and demographic factors influencing sources of $PM_{2.5}$ in Keene, NH.

For the woodpile survey, Dr. Nora Traviss suggested that we study the regions near Keene High School and Keene Middle School, as they represent two areas that are known to have $PM_{2.5}$ problems. They also have variable housing density and median income, so they would represent multiple demographic groups. The middle school region was subdivided into three neighborhoods, and the high school region into four. The woodpile survey recorded the number of chimneys, number of chimney caps, type(s) of chimney, whether there was a woodpile, and the address of the house. The data showed that the neighborhoods were very different. There was no statistical relationship between any of the factors and the presence of a woodpile in the high school region. In the middle school region houses with more chimneys, more caps, and two specific chimney configurations were statistically more likely to have a woodpile. Armed with this knowledge, a complete census of the town could be done, and representative subsets of the city could be developed. These could then be surveyed to predict the use of wood in Keene on a year to year basis. Also, additional study of demographic information could aid in the creation of future woodstove replacement campaigns.

Maps were created from the woodpile survey data by geocoding addresses using TIGER/Line data from the US Census Bureau. Linear segment and point density maps were created, showing the areas where there were high numbers of woodpiles. These show areas that have the potential to be the greatest sources of $PM_{2.5}$, and potentially areas most at risk of exposure to high concentrations of the pollutant. These maps could also be used to perform targeted outreach regarding woodstoves and $PM_{2.5}$.

We administered a home heating survey to Keene residents at the Monadnock Food Co-op. This survey collected data regarding home heating fuel, home heating device, and home heating habits. It also asked about demographic information, like awareness of air quality issues, number of residents, and income. We initially thought there would be skewed results due to the survey being administered at an environmentally conscious business, but the survey results were fairly wide ranging. Of the 50 surveys we collected, 43 were usable, each coming from a mix of income levels. The distribution of home heating fuel use was consistent with the percentages from the 2010 census. We had hypothesized that income would be a factor in home heating fuel, but after conducting several tests, there was no statistical relationship. This could be the result of residents moving into homes, and simply using the existing heating systems.

The third part of our project was the weather balloon experiment. We used a tethered weather balloon in an attempt to measure the altitude of the temperature inversions. There were no inversions present during the course of our study, so we have no usable result. However, our methods seem very efficient, and could be used in future study of inversions and $PM_{2.5}$.

Discussions

Due to the time constrains of completing this project in one semester, we feel that our conclusions are only half of the story. Therefore, we have suggestions about further steps that could be taken. Regarding the woodpile and chimney survey, we feel that there should be a way to classify the woodpile size. When surveying the high school and middle school neighborhoods we strictly looked for the presence of woodpiles, but did not take into account the number or size of the piles. Throughout the survey, we saw houses with varying size woodpiles, some very small and other with many cords of wood. There were also lots with more than one pile, which would be useful. By having knowledge of which houses have more than one pile and the size of the piles, we would be able to statistically comment on the likelihood of houses that burn wood. There would be a way to rank homes with the likelihood of burning.

We also feel that the woodpile survey would be better suited for a full city census, rather than just the neighborhoods we chose. The Environmental Studies department's Junior Seminar class has continued this work with our methodology. They will have completed two more neighborhoods by the end of this semester. For the most comprehensive analysis of woodpiles and wood burning in the city of Keene, we believe this should be a city wide census.

The home heating survey also has components that we think could be continued. Most importantly, we believe that the survey we created has untapped potential in the questions that we did not analyze. Specifically, questions regarding air quality awareness. This information could be tied to street data, which would give us the ability to assess the knowledge of each neighborhood. Other questions we think would be worth investigating further would be ones regarding who lives in each house and the ages of those people. This would create the ability to make conjectures about those who are likely to use more heat, like the elderly, and those with children. Also, if given the chance we would want to add a question to the survey about the number and types of pets that people own. We would like to see if people are likely to increase their use of heat during the day for the comfort of their pets.

Another avenue that would be worth pursuing in the future would be to obtain the tax records of home values and home age for the neighborhoods that we surveyed. From this information, which is public, we would like to correlate the value of homes with the types of devices used and the primary heating fuels used. This would allow us to make correlations between similar homes in different neighborhoods. By adding the ages of the houses into our statistical analysis we could categorize the age of the homes with the types of devices and fuels used. This would also allow us to pinpoint what types of houses, by value, age, heating device, and primary fuel types, are in neighborhoods with the high levels of $PM_{2.5}$.

As with the woodpile survey, we feel that the home heating survey would be best distributed to the whole city. As this survey contained questions of a private nature, like the yearly income question, we avoided going door to door with our survey. However, this is still a possibility for the future. We also felt that the survey could be distributed by the city or by mail. Our group attempted to send the survey to the classrooms of the local schools for students to bring home to their parents. However, our survey was not approved by the Superintendent, even though it had a privacy consent form attached, (see survey appendix). One other way the survey could get attention would be to have it highlighted in the local papers.

Our weather balloon experiment was only a small part of a much larger set of experiments that could be attempted regarding $PM_{2.5}$ and air quality in Keene. As air inversions have very specific environmental parameters it was difficult for our group to monitor them. For one, the types of inversions we were looking for occur in early winter, which was as our semester was ending. We felt that to collect the best data for inversions would be to create one or more transect lines through the city. By collecting data about the inversions over a large area we would be able to create a model of where the inversions are and the altitudes of the inversion over the city. This would also be linked to the neighborhoods that affect the $PM_{2.5}$ pollution the most.

Another way to test temperatures across the city would be to create a pseudo vertical profile experiment. This would entail buying more of the thermometers we used for the weather balloon experiment, and attaching them to stakes. These stakes would then be placed on a transect line through the city, and would be at different altitudes, so as to record the varying temperatures through a winter night with inversions present.

The last part we feel is essential to monitoring the conditions for PM 2.5, is to perfect the mobile monitoring. As of the time of our study, the only monitoring that has taken place so far is the monitoring required by the state. The methods provided required that the mobile monitoring drive in a large circle around the city. However, when this data was put in front of us, as geographers, we felt this data was useless to us. Only a few runs had been done and there was no way for us to analyze the data properly in GIS. However, there is no reason that this methodology should not be improved upon because this data will be useful in the future. Therefore, we think that a more comprehensive methodology should be created that collects data from a spatial design that would allow for more thorough coverage and a spatial pattern conducive spatial statistics, like Inverse Distance Weighted and Kriging. Overall, this would give us the best picture of the city as a whole.

The last avenue that we feel can by investigated in this project is to use the data we have from the Census in connection with the location of $PM_{2.5}$ data. Essentially, we have the ability to statistically analyze neighborhoods by their socioeconomic level, by income, housing age, housing value, and location along with chimney types, presence of woodpiles, inversion locations and potential PM2.5 presence. This section could be a whole study by itself, but we think that the data we have and could potentially collect would allow for this analysis.

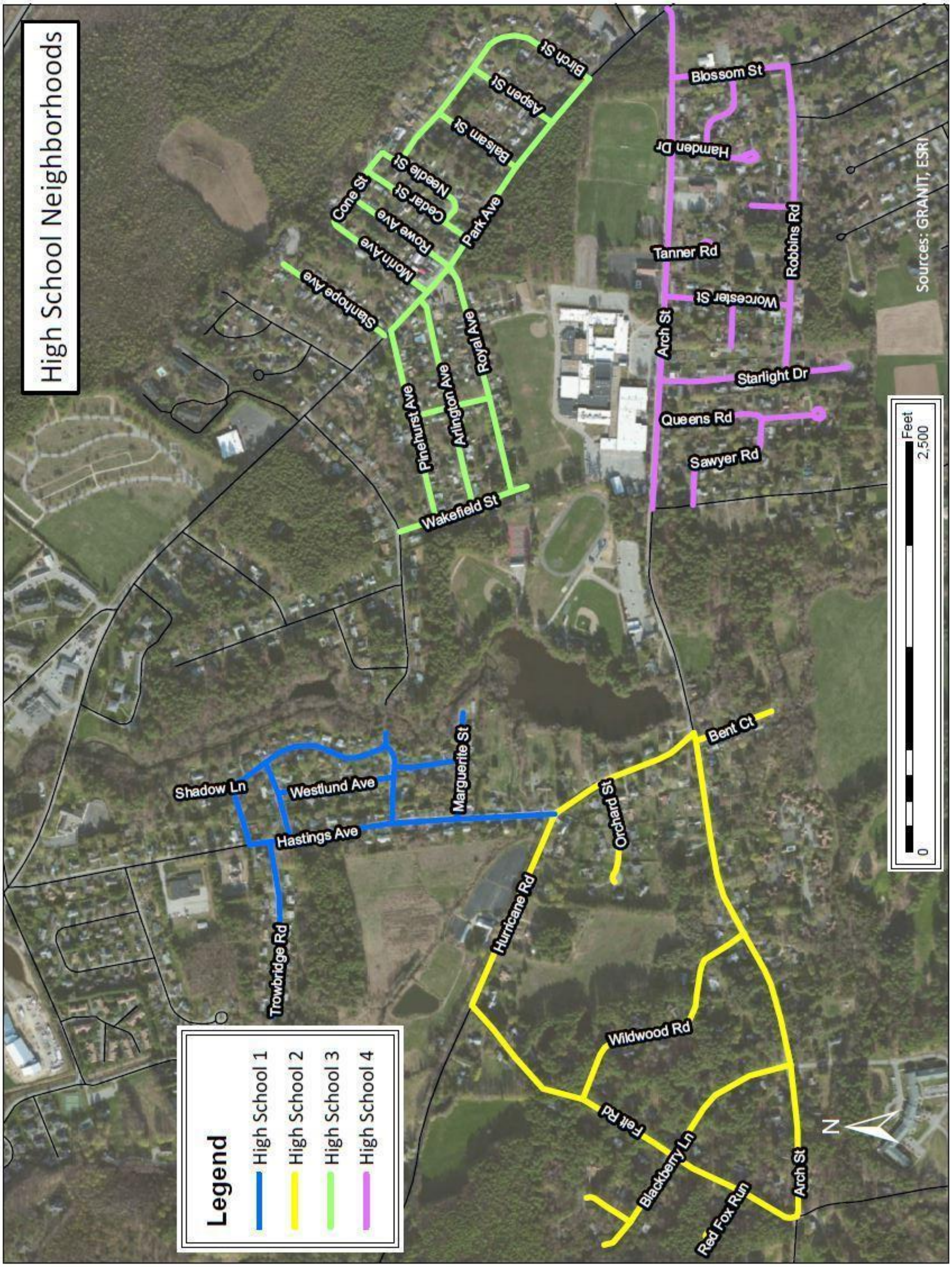
Our study of the air quality in the city of Keene, NH has created an excellent setup for future studies, which we believe is a benefit to our work. We hope that this is a project that the departments of Keene State College and the local authorities wish to pursue further.

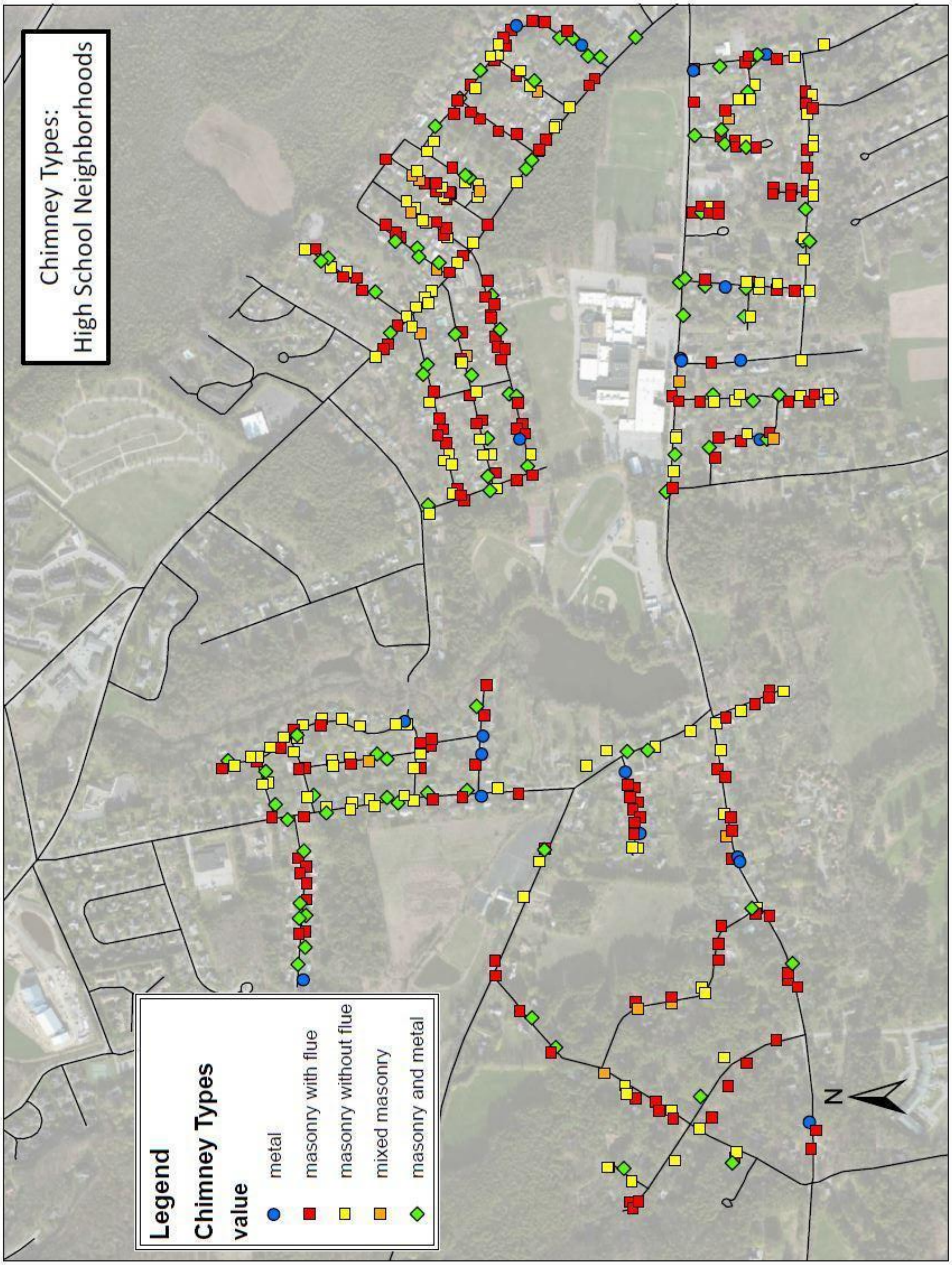
Appendix: Maps

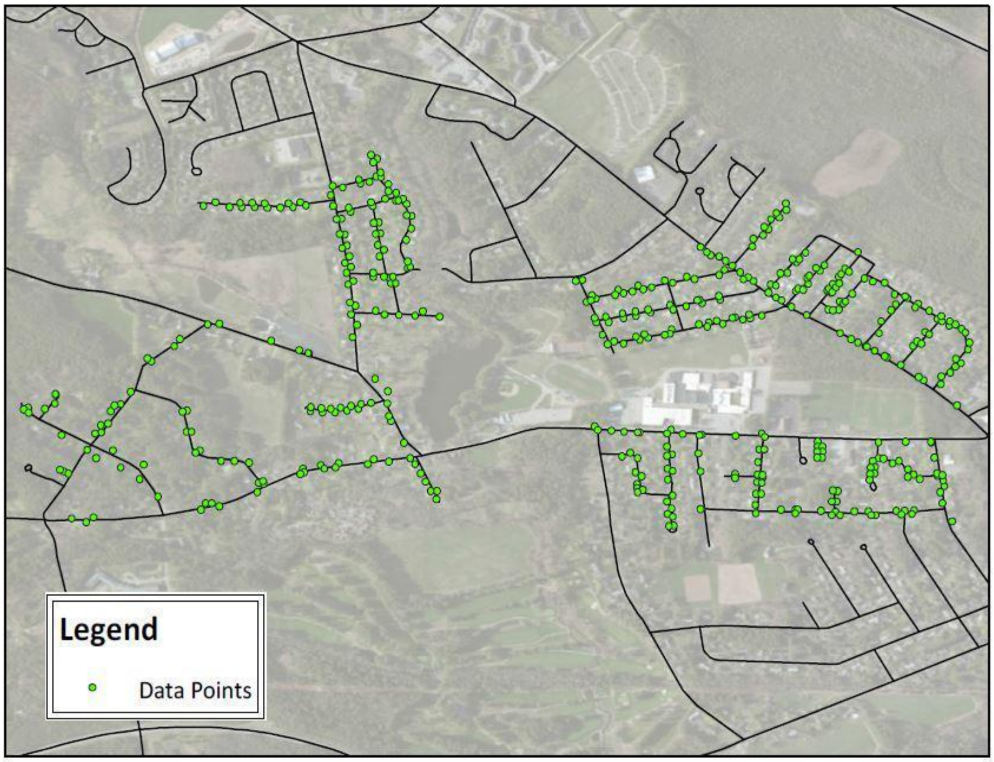
Appendix: Surveys

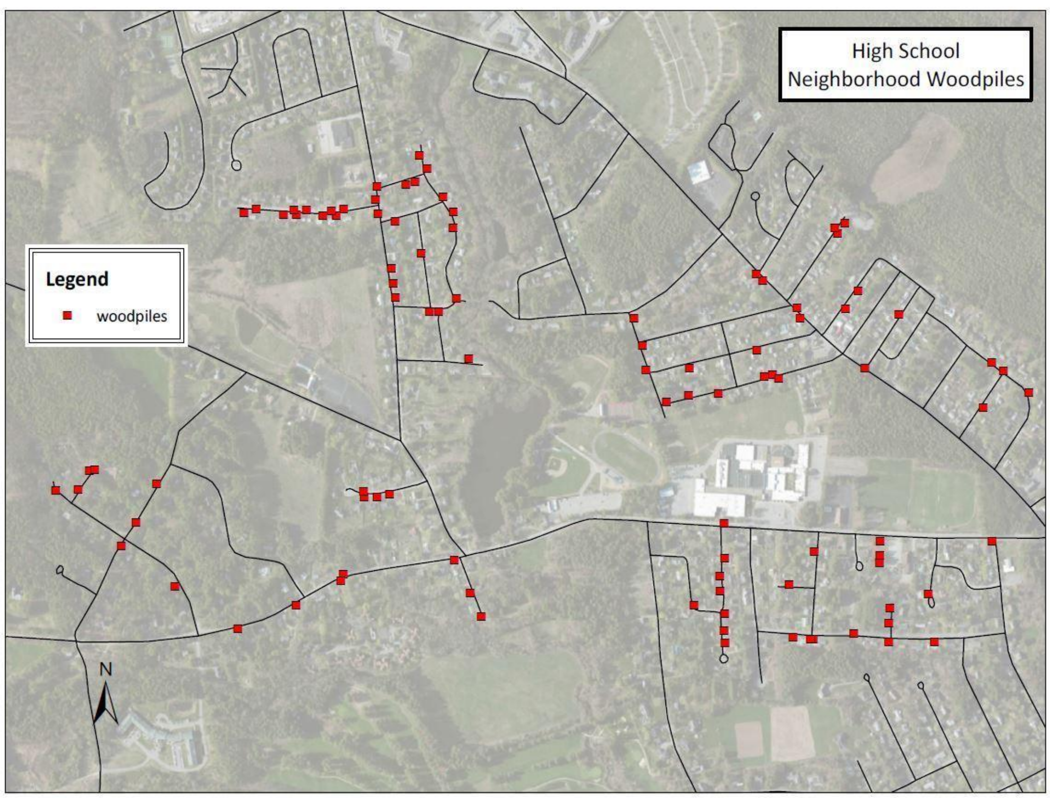
Appendix: Figures

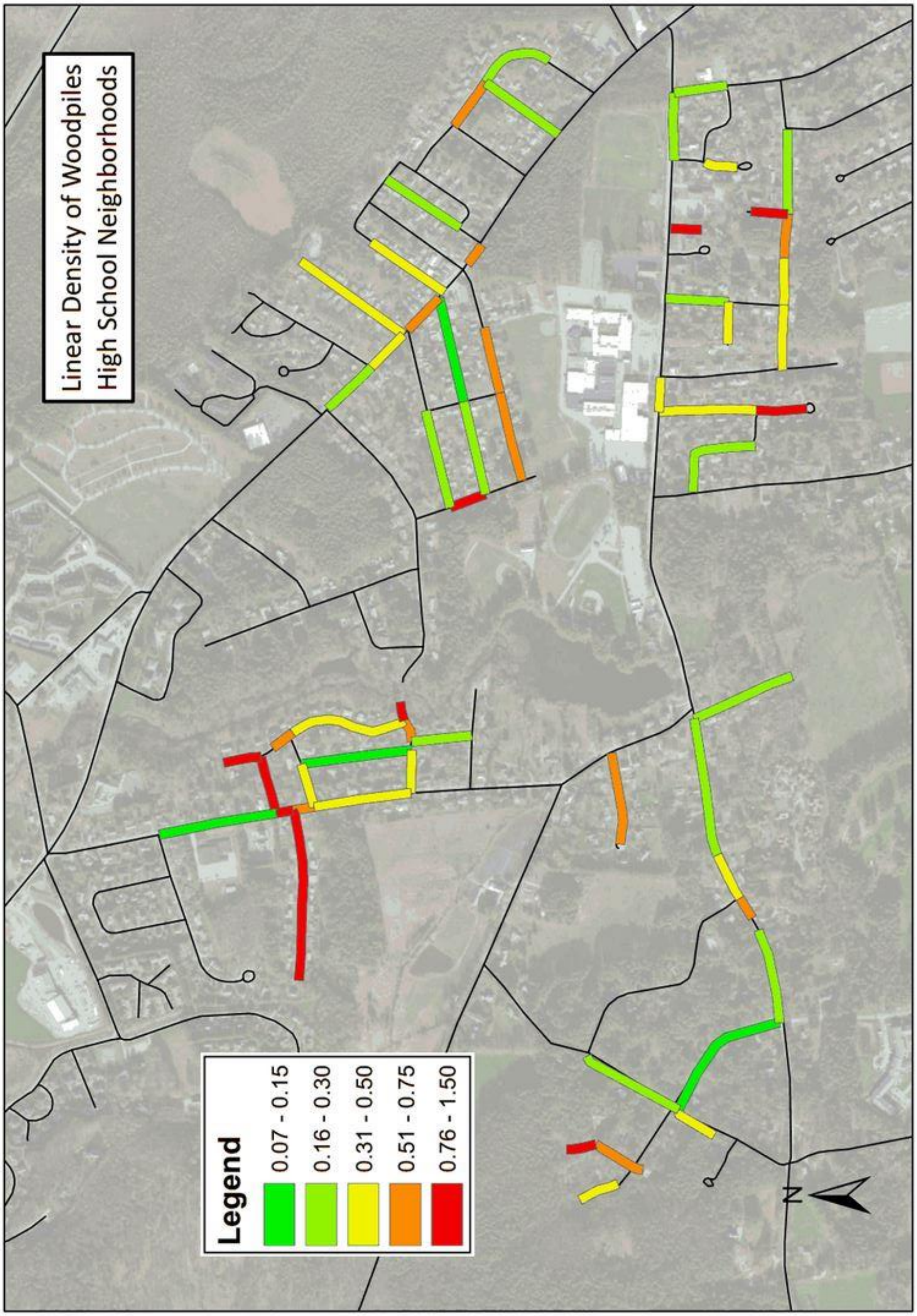
Appendix: Tables

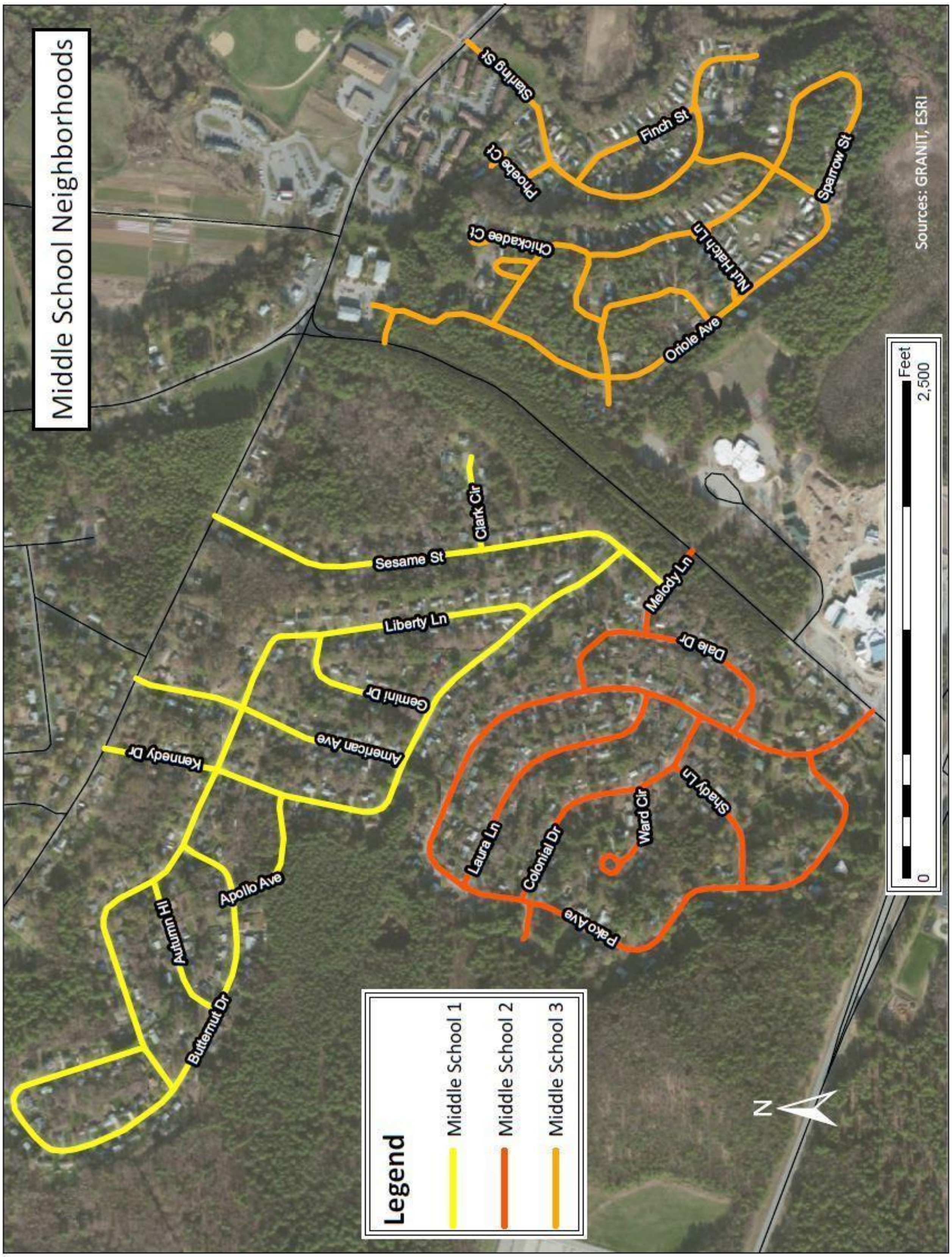

High School Neighborhoods
Legend
High School 1
High School 2
High School 3
High School 4
Birch St
Aspen St
Balsam St
Needle St
Cedar St
Cone St
Rowe Ave
Morin Ave
Park Ave
Stanhope Ave
Royal Ave
Arlington Ave
Pinehurst Ave
Wakefield St
Blossom St
Hamden Dr
Robbins Rd
Tanner Rd
Worcester St
Arch St
Starlight Dr
Queens Rd
Sawyer Rd
Bent Ct
Orchard St
Marguerite St
Westlund Ave
Shadow Ln
Hastings Ave
Trowbridge Rd
Hurricane Rd
Wildwood Rd
Felt Rd
Blackberry Ln
Red Fox Run
Arch St
Feet
0
2,500
N
Sources: GRANIT, ESRI

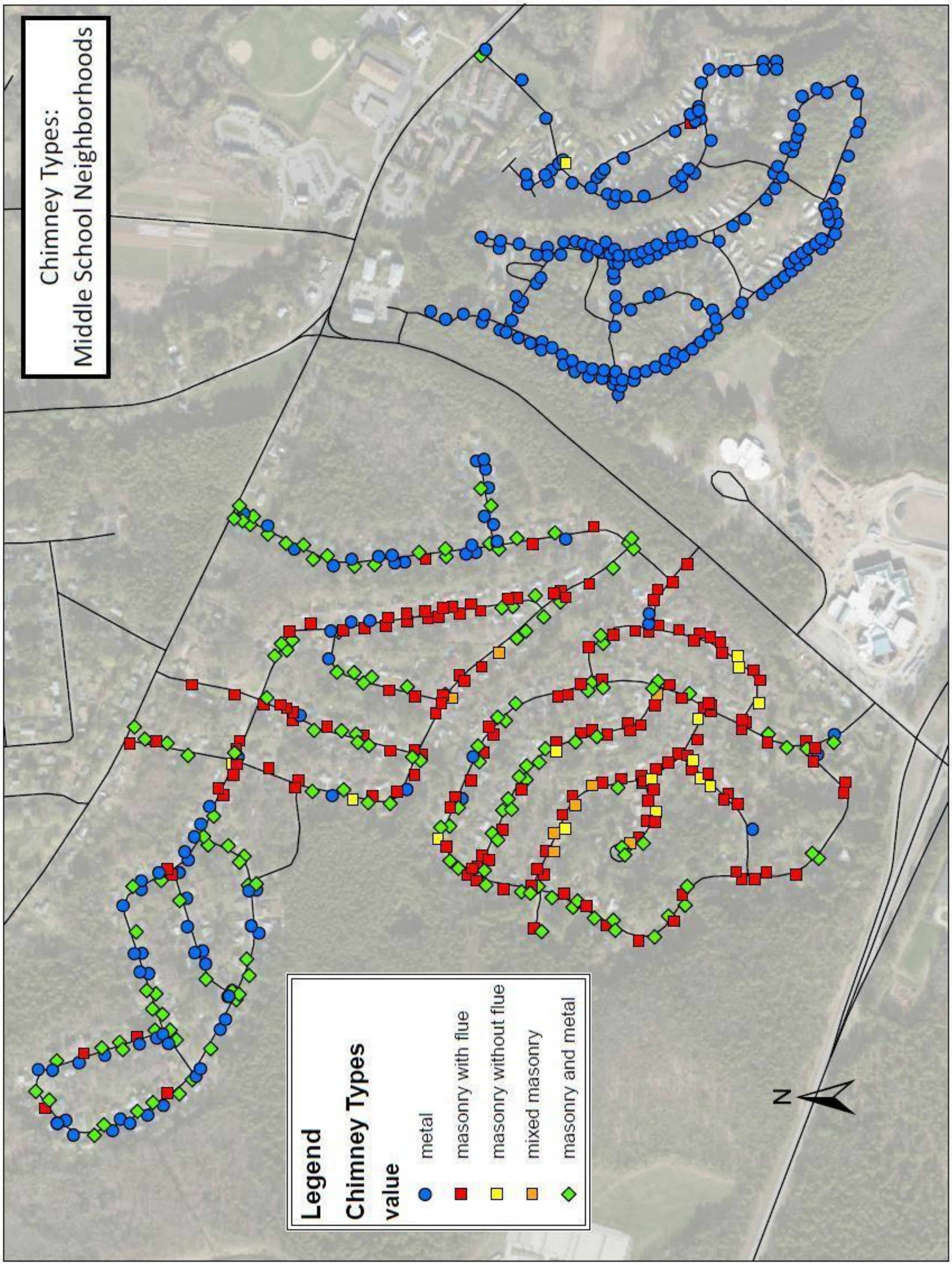

Chimney Types:
High School Neighborhoods
Legend
Chimney Types
value
metal
masonry with flue
masonry without flue
mixed masonry
masonry and metal
N

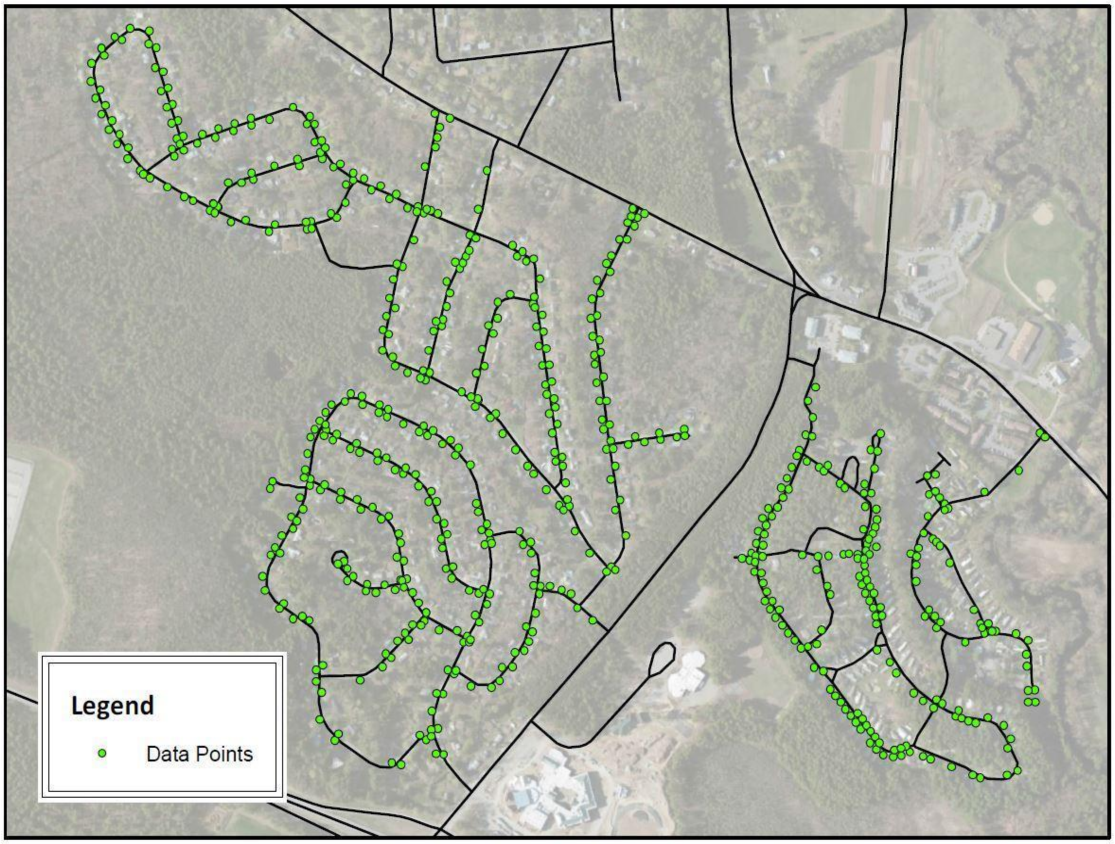

Legend
Data Points

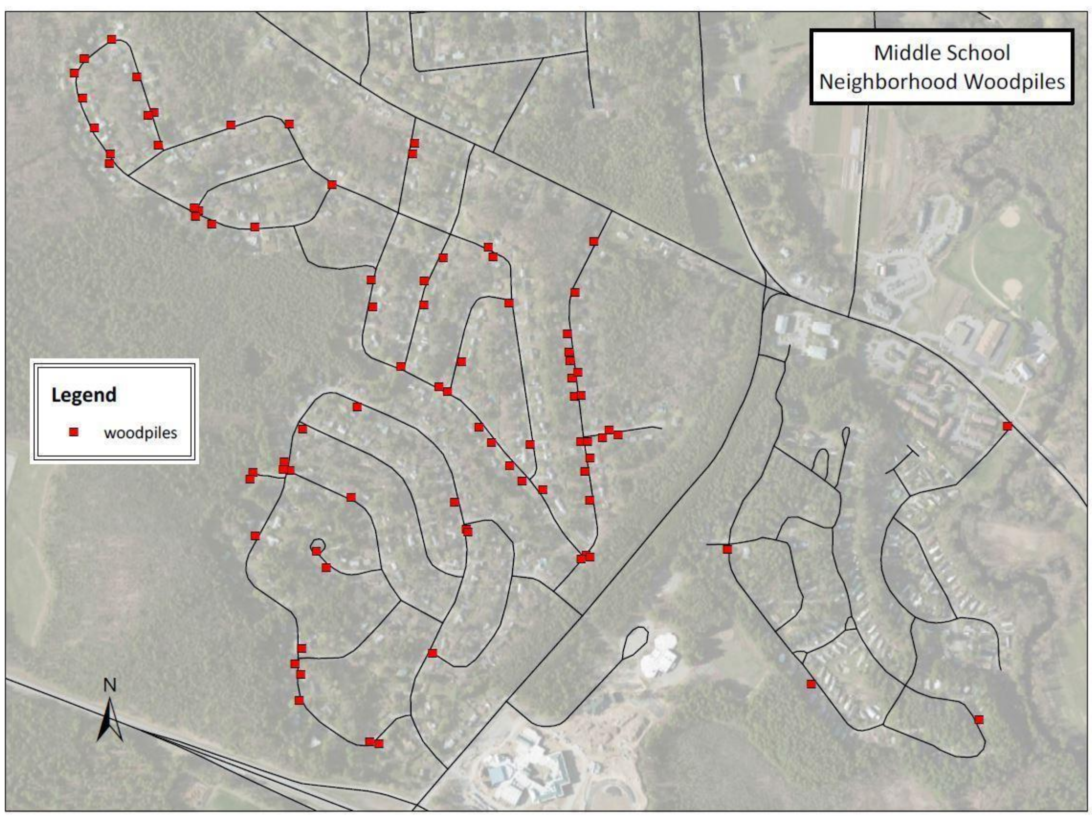

High School
Neighborhood Woodpiles
Legend
woodpiles
N

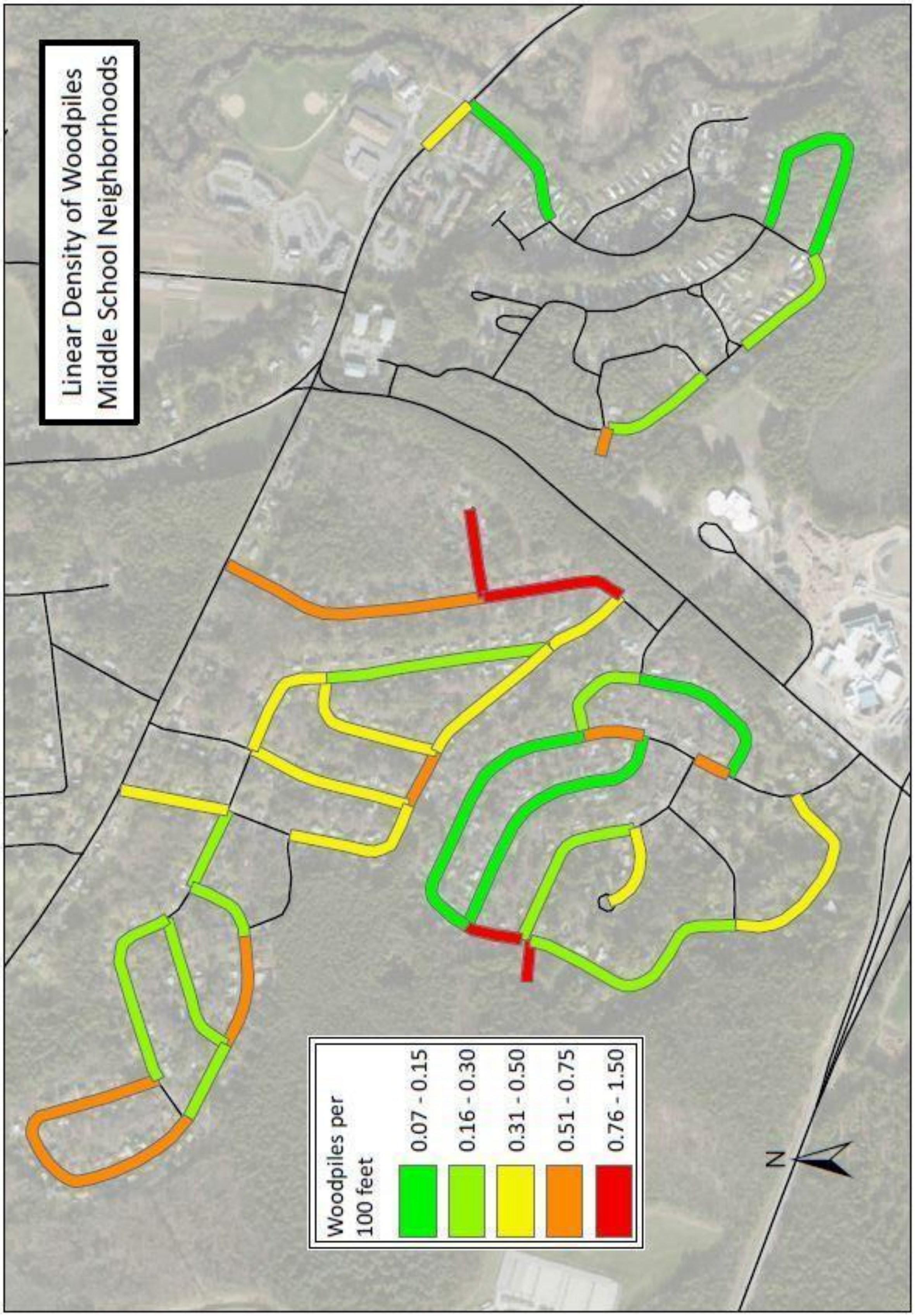

Linear Density of Woodpiles
High School Neighborhoods
Legend
0.07 - 0.15
0.16 - 0.30
0.31 - 0.50
0.51 - 0.75
0.76 - 1.50
N


Middle School Neighborhoods
Legend
Middle School 1
Middle School 2
Middle School 3
Sesame St
Clark Cir
Liberty Ln
Gemini Dr
American Ave
Kennedy Dr
Apollo Ave
Autumn Hl
Butternut Dr
Melody Ln
Dale Dr
Laura Ln
Colonial Dr
Ward Cir
Shady Ln
Pako Ave
Starling St
Finch St
Phoebe Ct
Chickadee Ct
Nut Hatch Ln
Sparrow St
Oriole Ave
N
Feet
0
2,500
Sources: GRANIT, ESRI


Chimney Types:
Middle School Neighborhoods
Legend
Chimney Types
value
metal
masonry with flue
masonry without flue
mixed masonry
masonry and metal
N


Legend
Data Points


Middle School
Neighborhood Woodpiles
Legend
woodpiles
N


Linear Density of Woodpiles
Middle School Neighborhoods
Woodpiles per
100 feet
0.07 - 0.15
0.16 - 0.30
0.31 - 0.50
0.51 - 0.75
0.76 - 1.50
N

INFORMED CONSENT FORM

1. NATURE AND PURPOSE OF THE PROJECT:

Our study focuses on air quality and pollution in Keene. We are studying local variations of Particulate Matter 2.5 (PM 2.5), which is mainly the result of burning wood. The general purpose of this survey is to inquire how the people of Keene heat their homes. This school's proximity to neighborhoods that are known to have significant PM 2.5 events make it an ideal location to survey the residents of these neighborhoods.

2. OF PROCEDURES:

This study will take approximately 7 minutes of your time. You will be asked to answer questions about how you heat your home during the winter months. Also, there will be a few basic demographic questions.

3. RISKS AND DISCOMFORTS:

There are no risks to taking this survey. If at anytime you feel uncomfortable with the questions presented, we ask that you return the survey with your student. However, please answer as many questions as you can.

4. BENEFITS:

This survey will benefit not only the education and understanding of air inversions and air quality of the City of Keene, NH, but also the Keene State College Geography Seminar II Group, which is using this project as their Capstone course.

5. CONFIDENTIALITY:

As the surveys are collected, this Consent Form will be removed from each survey and there will be no way to distinguish surveys. This data will be used solely for scientific purposes. There will be no way to identify individuals or their answers.

6. REFUSAL/WITHDRAWAL:

There will be no penalty for refusal or withdrawal.

7. DEBRIEFING:

Once data has been collected you will have the opportunity to obtain further information on this project. At any time, if you find that you have additional questions about this study, you may contact the Air Quality Geography Seminar II group at kscgeoaq@gmail.com or their advisor Dr. Chris Brehme at cbrehme@keene.edu.

8. SIGNATURES:

I acknowledge that I have read and understood the statement set forth above and agree to participate in this study.

____________________________ ____________________________

Signature of Subject **Date** **Signature of Researcher** **Date**

Keene
STATE COLLEGE

Air Quality & Home Heating Assessment:

Keene, NH   *Keene State College Geography Department*

Part 1: Residential House Heating

*Please answer yes or no (Y/N) to whether you use any of these to heat your home in the winter:

	Y	*N*
Cordwood		
Pellets		
Coal		
Oil or Kerosene		
Natural Gas or Propane		
Electricity		

*Of the fuels you use, which is your primary heat source over the past year? ____________________

*How many *days a week* do you use your primary source during the winter? ____________________

*Do you use a fireplace? ________________________

- if so, how many days a week do you use the fire place? ______________________________

*Approximately how many cords of wood did you burn this past winter season? ________________

*Please answer yes or no to whether you use any of these devices to heat your home in the winter:

	Y	*N*
Woodstove		
Coal Stove		
Outdoor Wood Boiler		
Fireplace		
Fireplace Insert		
Wood-fired Furnace		

*Please answer yes, no or I don't know to the following statements:

	Y	N	I don't know
Was your woodstove manufactured before 1990?			
Is your woodstove EPA-certified?			

Part 2: Demographics & Air Quality Awareness

*What street do you live on? ______________________

*Do you own or rent the house you live in? ______________________

-If you rent, are you a student? ______________________

*How many people live in your home? ______________________

-How many are under age 18? ______________________

*What is your yearly household income?

Less than 20,000	
20,000-40,000	
40,000 to 60,000	
60,000 to 80,000	
80,000 to 100,000	
100,000 and above	

*How many people have control of the heating apparatus in your house? ______________

*Are you aware on certain cold, calm nights, wood smoke from homes may contribute to elevated small particle pollution in Keene? Yes/No ______________________

*Are you aware elevated pollution may lead to Air Quality Action Days *(days when air pollution is unhealthy for children or people with certain health conditions) Yes/No* __________________

If you would like to learn how to be notified when AQAD's are predicted for the Keene area,

please contact Nora Traviss at ***ntraviss@keene.edu***

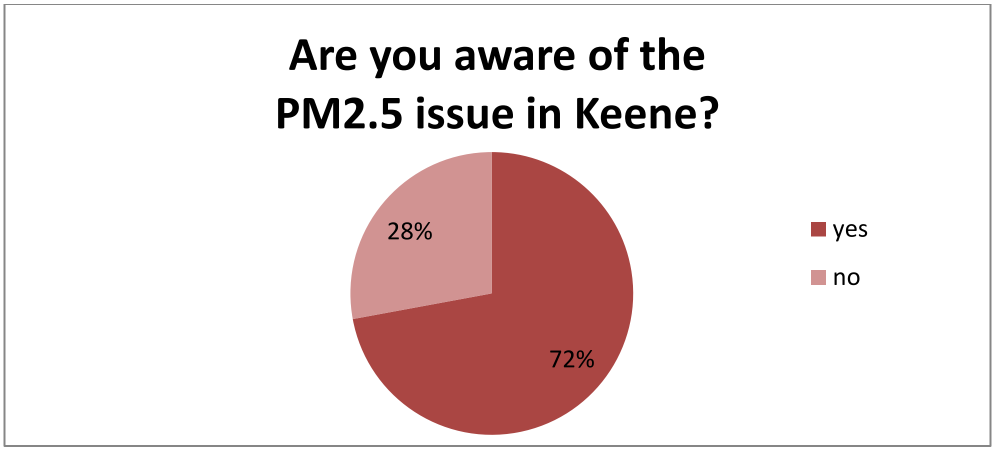
Additional Comments:

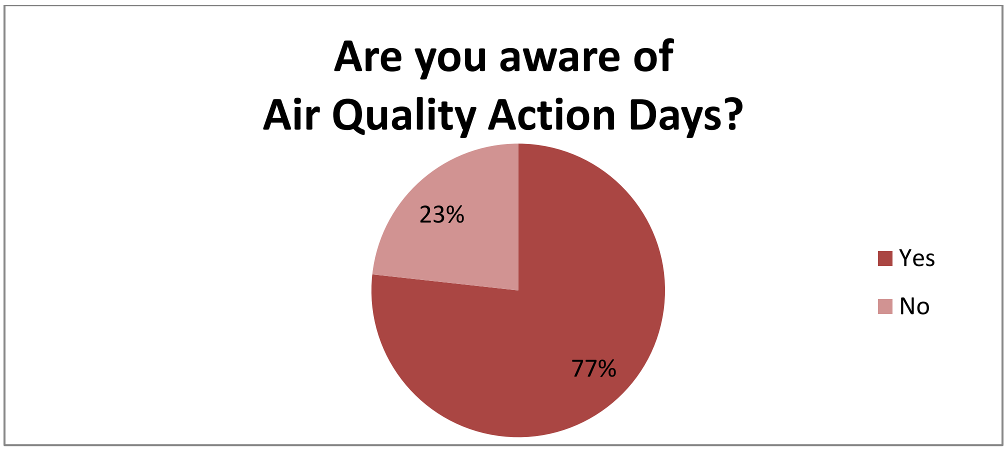
Air Quality Group: Woodpile and Chimney Survey

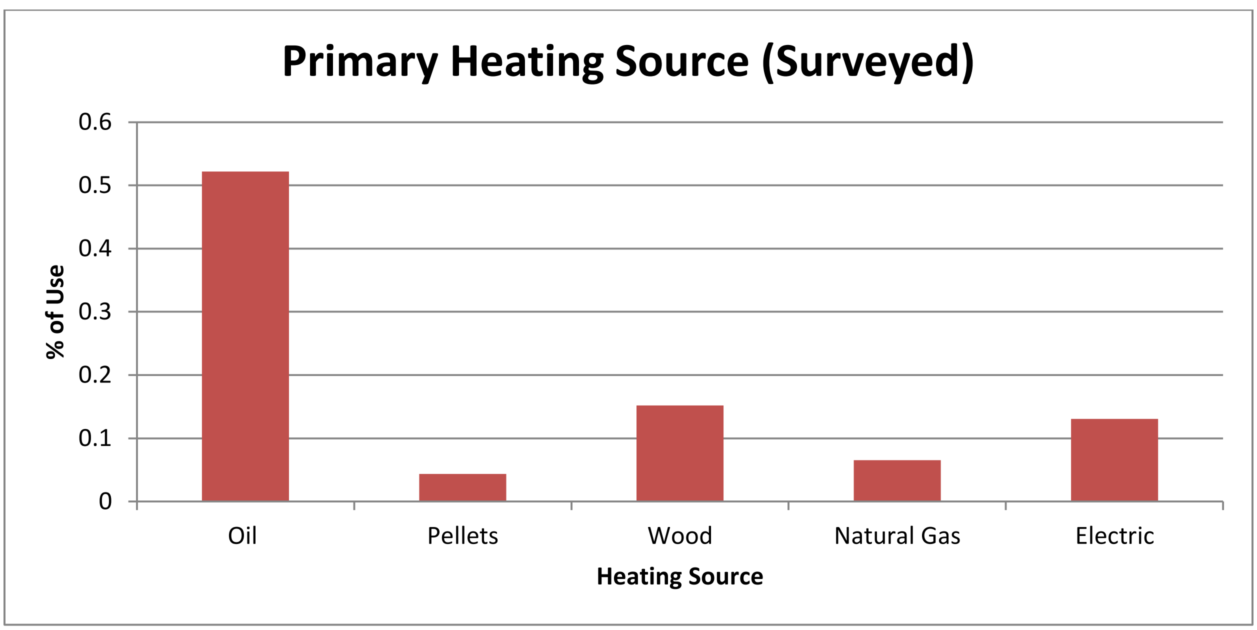
House Address	Woodpile (y/n)	# of Chimneys	Type of Chimney/s	# of Chimney Caps

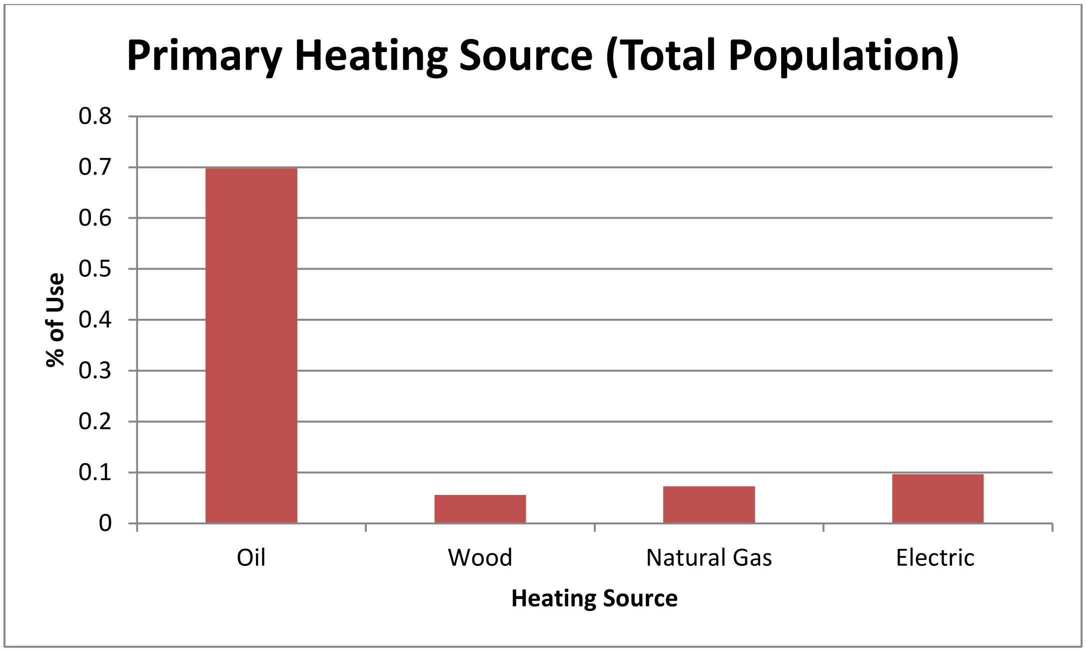
CHIMNEY TYPES M: Metal Top Chim. PF: Metal Siding Chim. MF: Brick Chim. WITH Flue

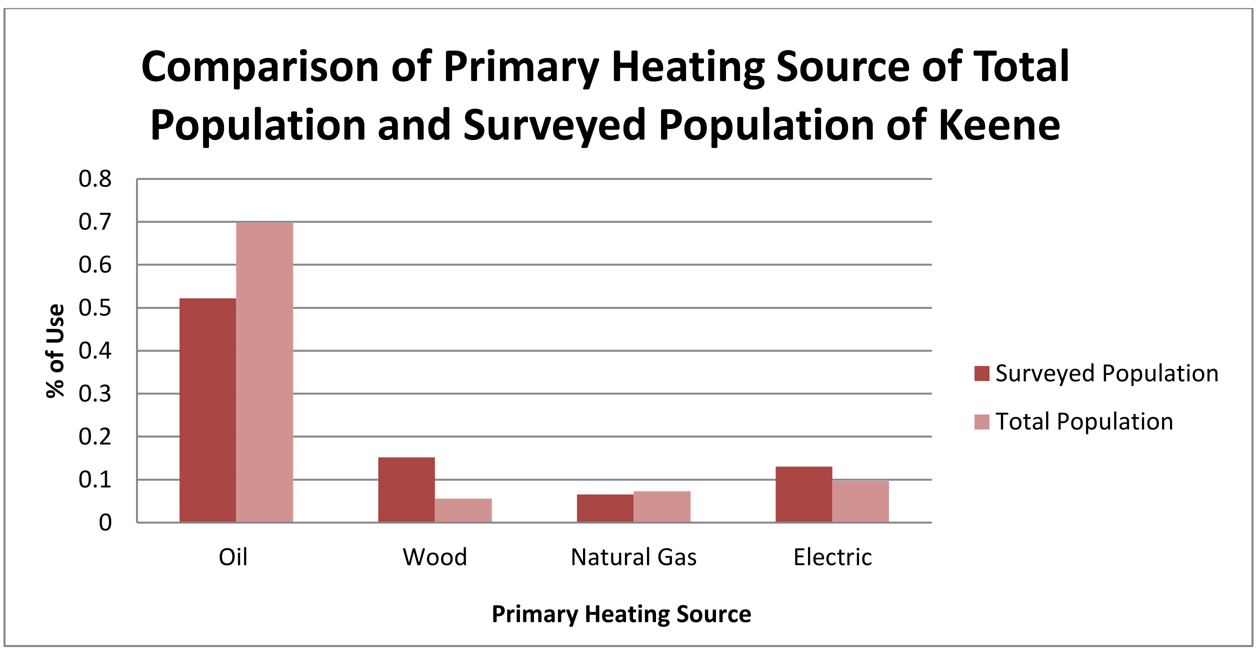
MNF: Brick Chim. NO Flue

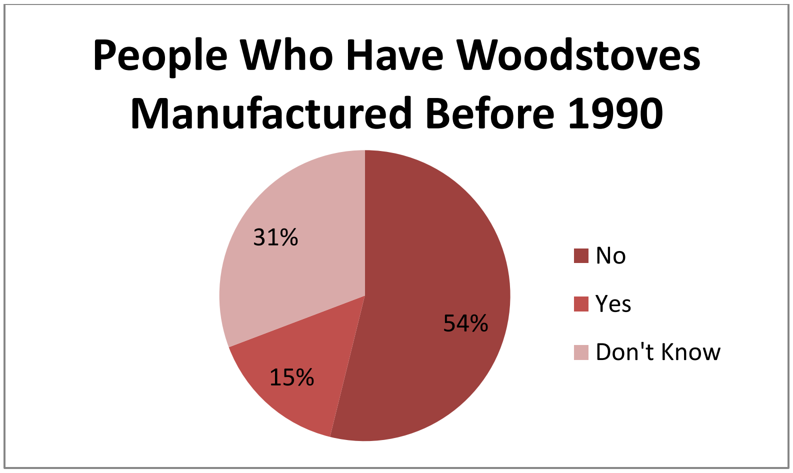

Are you aware of the
PM2.5 issue in Keene?
28%
72%
yes
no

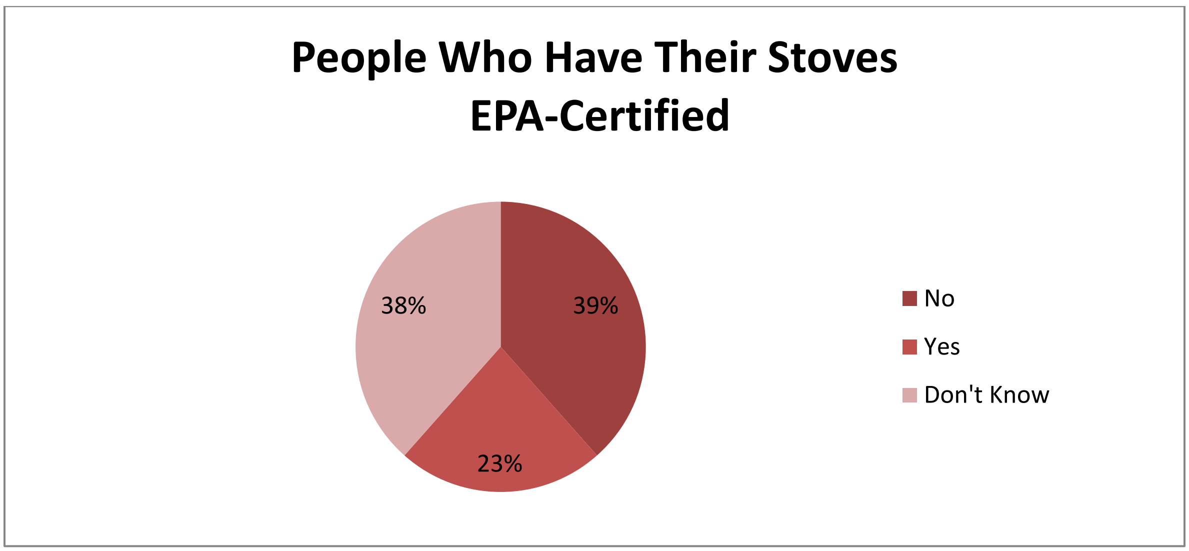

Are you aware of
Air Quality Action Days?
23%
77%
Yes
No

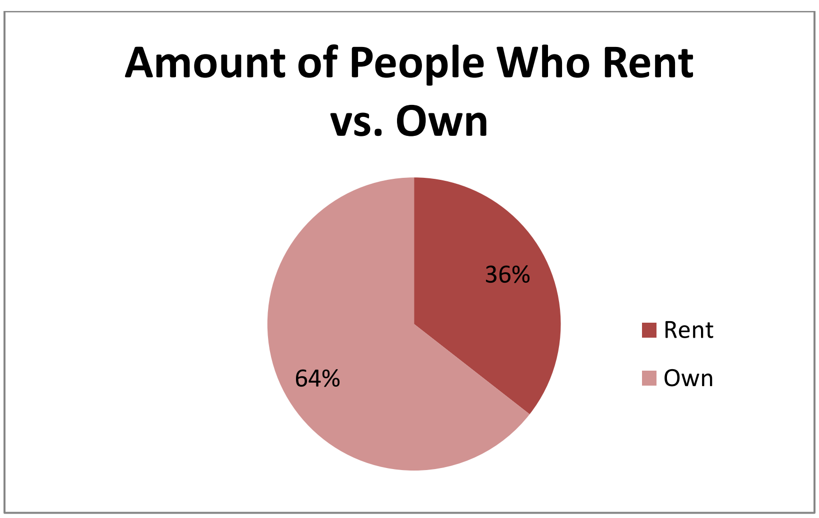

Primary Heating Source (Surveyed)
0.6
0.5
0.4
0.3
0.2
0.1
0
% of Use
Oil
Pellets
Wood
Natural Gas
Electric
Heating Source

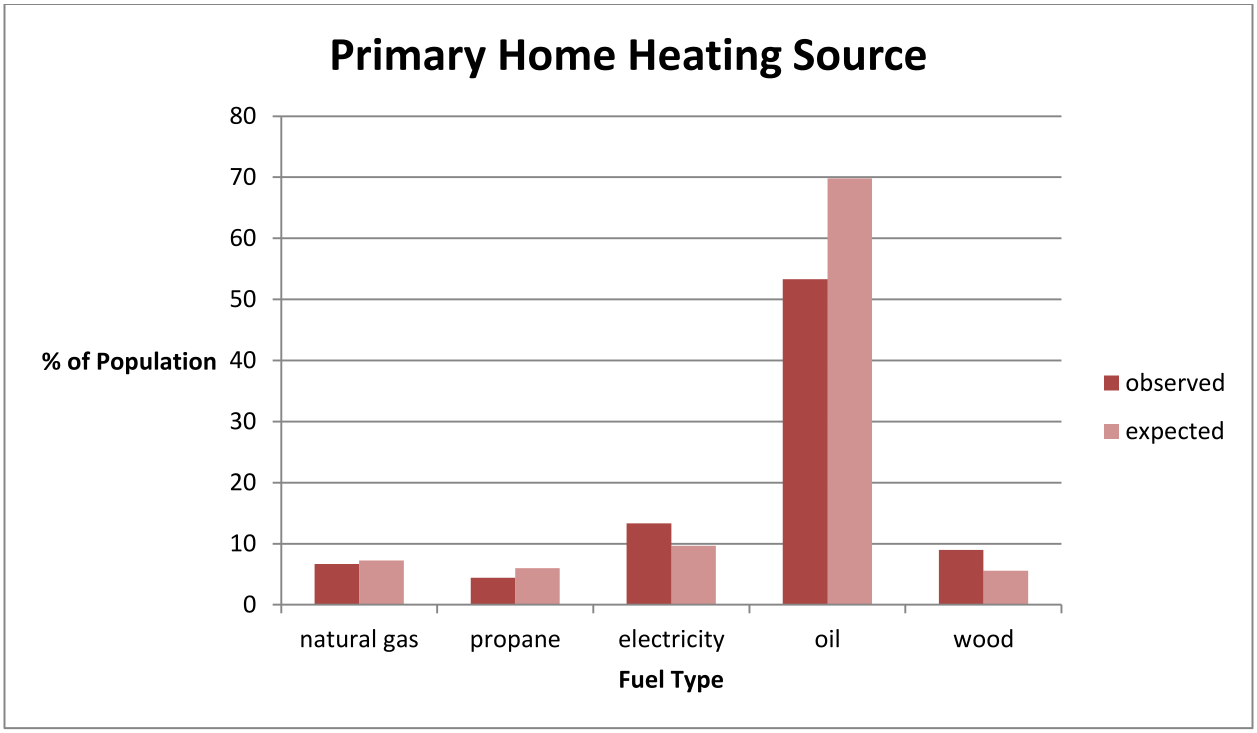

Primary Heating Source (Total Population)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
% of Use
Oil
Wood
Natural Gas
Electric
Heating Source


Comparison of Primary Heating Source of Total Population and Surveyed Population of Keene
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
% of Use
Oil
Wood
Natural Gas
Electric
Primary Heating Source
Surveyed Population
Total Population


People Who Have Woodstoves Manufactured Before 1990
31%
54%
15%
No
Yes
Don't Know


People Who Have Their Stoves EPA-Certified
38%
39%
23%
No
Yes
Don't Know


Amount of People Who Rent vs. Own
36%
64%
Rent
Own



Primary Home Heating Source
% of Population
80
70
60
50
40
30
20
10
0
natural gas
propane
electricity
oil
wood
Fuel Type
observed
expected

HS caps				
Crosstabulation		Woodpiles		
Count		0.00	1.00	Total
HSCAPS	0	207	49	256
	1	121	34	155
	2+	29	10	39
Total		357	93	450
Chi-Square Tests				
	Value	df	Asymp. Sig. (2-sided)	
Pearson Chi-Square	**1.104**	2	**0.576**	
Likelihood Ratio	1.078	2	0.583	
Linear-byLinenar Association	1.093	1	0.296	
N of Valid Cases	450.000			

Results of High School chimney caps count verses woodpiles Chi-square Crosstabs test.

MS caps				
Crosstabulation		Woodpiles		
Count		0.00	1.00	Total
HSCAPS	0	151	17	168
	1	320	51	371
	2+	59	17	76
Total		530	85	615
Chi-Square Tests				
	Value	df	Asymp. Sig. (2-sided)	
Pearson Chi-Square	**6.598**	2	**0.037**	
Likelihood Ratio	6.148	2	0.046	
Linear-byLinenar Association	5.886	1	0.015	
N of Valid Cases	615.000			

Results of Middle School chimney caps count verses woodpiles Chi-square Crosstabs test.

HS Chimney Types				
Crosstabulation		Woodpiles		
Count		0.00	1.00	Total
HSCAPS	1	368	38	406
	2	153	41	194
	3+	9	6	15
Total		357	85	615
Chi-Square Tests				
	Value	df	Asymp. Sig. (2-sided)	
Pearson Chi-Square	**24.126**	2	**0.000**	
Likelihood Ratio	21.449	2	0.000	
Linear-byLinenar Association	23.617	1	0.000	
N of Valid Cases	615.000			

Results of High School's number of chimneys verses woodpiles Chi-square Crosstabs test.

MS Chimney Types

Crosstabulation		Woodpiles		
Count		0.00	65.00	Total
HSCAPS	1	272	23	337
	2	80	5	103
	3+	5	93	10
Total		357	85	450

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	**5.813**	2	**0.055**
Likelihood Ratio	4.787	2	0.091
Linear-byLinenar Association	3.197	1	0.074
N of Valid Cases	450.000		

Results of Middle School's number of chimneys verses woodpiles Chi-square Crosstabs test.

HS Chimney Types

Crosstabulation		Woodpiles		
Count		0.00	1.00	Total
HSCAPS	Metal	13	7	20
	Masonry w/ flue	152	36	188
	Masonry w/out flue	110	25	135
	Mixed masonry	65	24	89
	Mixed Metal/Masonry	17	1	18
Total		357	93	450

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	**7.811**	4	**0.099**
Likelihood Ratio	8.170	4	0.086
Linear-byLinenar Association	0.111	1	0.740
N of Valid Cases	450.000		

Results of the second High School chimney types verses woodpiles Chi-square Crosstabs test.

MS Chimney Types

Crosstabulation		Woodpiles		
Count		0.00	1.00	Total
HSCAPS	Metal	253	17	270
	Masonry w/ flue	143	23	166
	Masonry w/out flue	15	0	15
	Mixed masonry	7	1	8
	Mixed Metal/Masonry	112	44	156
Total		530	85	615

Chi-Square Tests	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	**42.351**	4	**0.000**
Likelihood Ratio	41.967	4	0.000
Linear-byLinenar Association	37.328	1	0.000
N of Valid Cases	615.000		

Results of the second Middle School chimney types verses woodpiles Chi-square Crosstabs test.

Works Cited

AQMD. 2012. Socioeconomic Report 2012, Air Quality Management Plan. South Coast Air Quality Management District.

Baumbach, G. and U. Voght. 2003. Influence of inversion layers on the distribution of air pollutants in urban areas. Water, Air, and Soil Pollution: Focus, 3: 65-76.

Bullard, R. D. 2005. Environmental Justice of the 21st Century. The Quest for Environmental Justice, 19-42

City-Data.com. Keene, New Hampshire. http://www.city-data.com/city/Keene-New-Hampshire.html. (Last accessed 9th of December 2013).

Deng, X., F. Zhang, W. Rui, F. Long, L. Wang, Z. Feng, D. Chen, and W. Ding. 2013. PM2.5-induces oxidative stress triggers autophagy in human lung epithelial A549 cells. Toxicology in Vitro, 27: 1762-1770.

D.R. Wernette and L.A. Nieves, "Breathing Polluted Air: Minorities are Disproportionately Exposed," EPA Journal 18 (March 1992): 16-17.

Ebisu, K., and M. Bell. 2012. Airborne PM2.5 chemical components and low birth weight on the northeastern and mid-Atlantic regions of the United States. Environmental Health Perspectives, 120 (12): 1746-1752.

EPA. 2013. Fine Particle ($PM_{2.5}$) Designations: Frequent Questions. United States Environmental Protection Agency. (Last accessed 21st of November 2013).

Gavett, S. H., and H. S. Koren. 2001. The role of particulate matter in exacerbation of atopic asthma. International Archives of Allergy and Immunology, 124: 109-112.

Haley, V. B., T. O. Talbot, and H. D. Felton. 2009. Surveillance of the short-term impact of fine particle air pollution on cardiovascular disease hospitalizations in New York state. Environmental Health, 8 (42).

Health. 2013. Air Pollution Linked to Higher Risk of Lung Cancer and Heart Failure. http://www.nbcnews.com/health/air-pollution-causes-lung-cancer-worsens-heart-failure-studies-find-6C10584685 (Last accessed 28th of October 2013).

Hill, B. and E. Baum. 2001. Sulfur Emissions: Sulfur Emissions and Midwest Power Plants: Focus, 1: 3-8.

Janssen, N. A. H., P. Fischer, M. Marra, C. Ameling, and F. R. Cassee. 2013. Short-term effect of PM2.5, PM10 and PM2.5-10 on daily mortality in the Netherlands. Science of the Total Environment, 463-464: 20-26.

Jerrett, M., R. T. Burnett, P. Kanaroglou, and J. Eyles. 2001. A GIS – environmental justice analysis of particulate air pollution in Hamilton, Canada. Environment and Planning 33; 955-973.

Kohler. J. 2012. Burning Concern: Drought Driven Wildfires Generating Pollution. http://blog.nwf.org /2012/09/burning-concern-drought-driven-wildfires-generating-pollution/. (Last accessed 4th of October 2013).

Lee, S., M. L. Serre, A. van Donkelaar, R. V. Martin, R. T. Burnett, and M. Jerrett. 2012. Comparison of geostatistical interpolation and remote sensing techniques for estimating long-term exposure to ambient PM2.5 concentrations across the continental United States. Environmental Health Perspectives, 120 (12): 1727-1732.

Lydersen. K. 2013. Midwest Energy: Pollution http://www.midwestenergynews.com /tag/pollution/. (Last accessed 4th of October 2013).

Tai, A. P. K., L. J. Mickley, D. J. Jacob, E. M. Leibensperger, L. Zhang, J. A. Fisher and H. O. T. Pye. 2011. Meteorological modes of variability for fine particulate matter (PM2.5) air quality in the

United States: implications for PM2.5 sensitivity to climate change. Atmospheric Chemistry and Physics Discussions, 11: 31031-31066.

Urban Mapping. 2011. Keene, New Hampshire Neighborhood Map. http://www.city-data.com/nbmaps/neigh-Keene-New-Hampshire.html#N5 (Last accessed 6th of October 2013).

U.S Census Bureau. 2010. Keene, NH Census. US Census Bureau. Census.gov (Last accessed 25th of September 2013).

Vallejo, M., S. Ruiz, A. G. Hermosillo, V. H. Borja-Aburto, M. Cardenas. 2006. Ambient fine particles modify heart rate variability in young adults. Journal of Exposure Science and Environmental Epidemiology, 16 (2): 125-130.

Wallace, J., D. Corr, and P. Kanaroglou. 2010. Topographic and spatial impacts of temperature inversions on air quality using mobile air pollution surveys. Science of the Total Environment, 408: 5086-5096.

Whiteman, C.D., S. F. J. De Wekker, and T. Haiden. 2007. Effect of dewfall and frostfall on nighttime cooling in a small, closed basin. Journal of Applied Meteorology and Climatology, 46: 3-13.

Woodland Direct. Learn More: Chimneys and Their Caps. http://www.woodlanddirect.com/Chimney/Chimney-Information/Chimney-Types-and-their-Caps. (Last accessed 8th of December 2013).