ABSTRACT

Title of Document: MONITORING AND ASSESSMENT OF RESIDENTIAL EXPOSURE TO NOISE ASSOCIATED WITH NATURAL GAS COMPRESSOR STATIONS IN WEST VIRGINIA

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Noise is a growing concern for residents living near natural gas compressor stations. This study monitored and evaluated residential noise exposure associated with living near natural gas compressor stations in West Virginia. Short-term outdoor measurements (20 min) and medium-term (24-hour) indoor and outdoor measurements were collected at homes located near compressor stations. The average sound equivalent was calculated using logarithmic averages and stratified by distance from compressor station, time of day, and location. Average short-term noise levels were 61.43 dBA (45.3 to 76.1 dBA); average 24-hour noise levels were 60.20 dBA (35.3 to 94.8 dBA). Average noise levels at control homes were 51.40 dBA, with 45.02 dBA indoors and 54.03 dBA outdoors. Average noise levels at homes near compressor stations were 8.7 dBA higher, with a 16.25 dBA difference indoors and a

4.3 dBA difference outdoors. Results indicate that living near a natural gas compressor station may increase environmental noise exposure.

MONITORING AND ASSESSMENT OF RESIDENTIAL EXPOSURE TO NOISE ASSOCIATED WITH NATURAL GAS COMPRESSOR STATIONS IN WEST VIRGINIA

By

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Dedication

For my partner and son, John and Jacob, who have provided unwavering support and encouragement as I pursued my dreams.

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Chapter 1: Introduction

U.S. Energy Use

In 2013 total U.S. energy production was 81.7 quadrillion British thermal units (BTUs) and total consumption was 97.5 quadrillion BTUs. The major sources of this energy include petroleum (36%), natural gas (27%), coal (19%), renewables (10%), and nuclear power (8%) (U.S. Energy Information Administration, 2014a, 2014b). Energy from these sources is used in four sectors: 1) electricity generation, 2) transportation, 3) industrial, and 4) residential and commercial. Each sector uses a mix of energy sources. For example, 92% of the energy for the transportation industry comes from petroleum, while 43% of electric power is generated by coal and 22% is generated by natural gas (U.S. Energy Information Administration, 2014a). Natural gas production is increasing. From 2000 to 2013, natural gas production increased 26% from 19.7 trillion cubic feet to 24.9 trillion cubic feet (U.S. Energy Information Administration, 2014b). The U.S. Energy Information Administration (EIA) projects that natural gas production will continue to increase to 33.1 trillion cubic feet by 2040 (U.S. Energy Information Administration, 2012). The rapid growth of the natural gas sector is due to shale gas, recently made accessible by new technologies, allowing the ability to tap into natural gas resources that were once deemed unreachable. Production from shale gas deposits, which measured only 0.32 trillion cubic feet in 2000 grew to 8.6 trillion cubic feet in 2013—an astounding 2,588% increase—and is expected to reach 16.7 trillion cubic feet by 2040 (U.S. Energy Information

Administration, 2012). The major shales at play in the U.S. include the Bakken in North Dakota, Eagle Ford and Barnett in Texas, and the Marcellus in the Northeast. The Marcellus underlies Pennsylvania, West Virginia, New York, Ohio, and western Maryland, and is the largest shale at play in the U.S. It is estimated to contain enough natural gas to supply the U.S. for the next 45 years (Finkel & Law, 2011).

Unconventional Natural Gas Development

Unconventional natural gas development, also known as hydraulic fracturing or "fracking," refers to a method of extraction that combines vertical and horizontal drilling with hydraulic fracturing. Hydraulic fracturing is a well stimulation process that involves the injection of millions of gallons of water, chemicals, and proppant deep into underground shale in order to release trapped natural gas. These new technologies are a small part of the overall development and production process. Other steps include the transportation of water, chemicals, and wastewater, well pad construction, vertical and horizontal drilling, well completion, and the development of the infrastructure necessary to clean and transport the natural gas from the well to the end user. Tracking the number of unconventional well pads in the U.S. seems to be a challenge due to the lack of a national reporting system. However, in 2014 FracTracker estimated that there were nearly 1.1 million active wells in 36 states (Kelso, 2014; Magill, 2014).

Following extraction, the natural gas travels from the well through a network of gathering lines to field compressor and processing stations. Compressors are used to increase pressure in the pipeline to move natural gas from the well pad to the processing facility and then to the end user. The compressor and processing facility is necessary to remove impurities such as hydrogen sulfide, helium, carbon dioxide, hydrocarbons, and water vapor that was not removed at the well head (Paleontological Research Institution, 2012). Once these impurities are removed, the gas is pumped into large high-pressure interstate pipelines. Compressors operate twenty-four hours a day and seven days a week and are placed in 50-60 mile intervals along the Interstate pipeline (American Gas Association, n.d.). Field compressor stations are concentrated in areas where natural gas development is occurring. It is not clear how many field compressor stations are needed per well, but one report suggests that one compressor station is needed for every 100 wells (Shaleshock, n.d.). The continued growth and spread of this industry has the potential to negatively impact millions of people, and there are many aspects of the development and production process that pose environmental health risks.

Hazards Associated with Unconventional Natural Gas Development

The public health community has expressed concern that the quick spread of unconventional natural gas development has left little time for a thorough evaluation of the health impacts (Adgate, Goldstein, & McKenzie, 2014; Finkel & Law, 2011; Shonkoff, Hays, & Finkel, 2014). While there are few epidemiologic studies on the health impacts associated with natural gas development, recently published studies and state-funded health assessments have begun to illuminate the major hazards and exposure pathways that potentially lead to adverse health effects. The hazards of concern include air, water, and soil quality, environmental noise, earthquakes, exposure to toxic chemicals, occupational health, and secondary impacts including mental health and disruption of the social fabric in impact communities (Adgate et al., 2014; Brown, Weinberger, Lewis, & Bonaparte, 2014; Food and Water Watch, 2013; McKenzie, Witter, Newman, & Adgate, 2012; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010).

Noise is a hazard mentioned in many studies and reports, however, little monitoring has been conducted. One study collected noise data associated with various stages of unconventional natural gas development and two studies have estimated noise levels based on equipment used during well pad development (Mccawley, 2013; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010). Accumulating anecdotal evidence is showing that natural gas compressor stations may be a major source of environmental noise for nearby communities. In addition, noise related to natural gas compressor stations is anticipated to be the "most litigated issue in the coming decades" (Bombatch, 2013, p. 19). Before states can effectively propose regulations to protect public health, there needs to be a clear understanding of the hazards.

Public Health Significance

The purpose of this study is to monitor and evaluate residential exposure to noise associated with natural gas compressor stations in West Virginia. The currently available data and literature on noise impacts associated with natural gas development focuses on well construction and hydraulic fracturing. This study is the first to monitor and evaluate the noise levels residents are exposed to as a result of their proximity to natural gas compressor stations. As natural gas development and production continues to spread across the U.S., the construction of natural gas processing and compressor stations to clean and transport natural gas through the pipeline will continue to impact communities. It is important that environmental noise standards and setbacks are adequate to protect communities from the health hazards associated with noise pollution. State and local governments could use the results of this study in the regulatory decision-making process to identify appropriate setback regulations and noise standards. In addition, the monitoring data could be used to inform future epidemiological studies that evaluate noise levels and health outcomes.

Research Rationale

Research regarding noise associated with natural gas development and production is sorely lacking. There are a few studies that have evaluated noise levels associated with construction and development of a well pad, but none have evaluated noise associated with compressor stations. The purpose of this thesis was to conduct a pilot study to understand the noise levels associated with living near a natural gas compressor station. For the purpose of this study, the following questions were addressed:

1. Are residents exposed to higher noise levels during the nighttime as compared to the daytime?
2. At what proximity to a compressor station do residential noise exposure levels exceed 55 dBA, the EPA recommended 24-hour outdoor standard (U.S. Environmental Protection Agency, 1974)?
3. What setback is necessary to adequately protect residents from the adverse health effects associated with excessive noise exposure levels?

The investigation included one research hypothesis:

1. Living in close proximity to natural gas compressor stations will increase exposure to noise levels greater than 55 dBA.

The primary objectives were:

1. To evaluate noise levels inside and outside individual residences located at varying distances from a natural gas compressor station.
2. To investigate whether significant differences in noise levels exist with regard to the time of day (daytime versus nighttime), distance, and location (indoor versus outdoor).
3. To determine an appropriate setback to protect residents from the adverse health effects associated with high noise levels.

Chapter 2: Background

Introduction

Unconventional natural gas development is spreading across the United States, putting millions of Americans at risk of adverse environmental exposures. Noise associated with natural gas development is a major concern for nearby residents and communities, yet this is an under-researched area. Noise is considered a major physical hazard, potentially leading to a myriad of adverse health effects, such as hearing impairment, cardiovascular disease, hypertension, annoyance, and sleep disruption (Halonen et al., 2012; Kawada, 2011; Miedema & Oudshoorn, 2001; Münzel, Gori, Babisch, & Basner, 2014; National Institue on Deafness and Other Communication Disorders, 2014). The industrial activity associated with natural gas development—including increased diesel truck traffic and the use of diesel engines and compressors—contributes to higher noise levels in impacted communities. Noise can be controlled through a combination of methods. However, due to a lack of federal regulations and standards, these methods are used at the discretion of each state and local government. Only a few studies have evaluated noise associated with these processes and to date there have not been any studies to monitor and assess noise associated with living near natural gas compressor stations (Mccawley, 2013; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010).

Environmental Noise

In the early twentieth century Nobel Prize winning bacteriologist Robert Koch wrote, "The day will come when man will have to fight noise as inexorably as cholera and the plague" (Münzel et al., 2014; Todd, 2012). He was right. Noise, defined by the EPA as "an unwanted or disturbing sound," has become the norm in developed countries around the world (U.S. Environmental Protection Agency, 2012, 1974). Noise can come from a variety of sources. Indoor noise sources include appliances, radio, televisions, humans, and animals, while major outdoor noise sources include transportation, industry, and construction (U.S. Environmental Protection Agency, 1974). Urban areas typically have higher noise levels compared to rural areas. Most of the increase is due to traffic. According to the World Health Organization (WHO), 40% of individuals living in the European Union (EU) are exposed to daytime noise levels greater than 55 dBA, and 30% are exposed to nighttime noise levels greater than 55 dBA (World Health Organization (WHO), n.d.). A 1974 EPA report on urban environmental noise found that the day-night average sound level (L_{dn}) at twenty-four sites in seven major cities across the U.S. ranged from 50.8 to 72.8 dBA (U.S. Environmental Protection Agency, 1977). A more recent study conducted in 2012 found that average noise levels (L_{eq}) at 56 monitoring locations in New York City ranged from 59.1 to 80.7 dBA (Kheirbek et al., 2014). Noise in rural communities is much lower than the levels found in urban areas. The EPA estimates that noise levels are less than 50 dBA in rural areas (U.S. Environmental Protection Agency, 1974).

Noise is considered a major stressor because it is associated with numerous negative health outcomes. Adverse health effects from noise are dependent on the duration of exposure and the intensity of the noise. The amount of time an individual spends in various indoor and outdoor locations and the level of noise in each of those locations determine daily noise exposure (U.S. Environmental Protection Agency, 1974). The contribution of outdoor noise to indoor noise is usually small, however, it depends on the intensity of the noise, the noise reduction capability of the building, and whether the windows are opened or closed (U.S. Environmental Protection Agency, 1974). The EPA classified a home's sound reduction capabilities into two categories: warm climate and cold climate. Warm climate homes are estimated to reduce outdoor noise by 12 to 24 dB, while cold climate homes are estimated to reduce outdoor noise by 17 to 27 dB (U.S. Environmental Protection Agency, 1974).

Noise-Related Health Effects

Noise can have both psychosocial and physiological impacts. The most common health effects associated with chronic noise exposure are hearing impairment, hypertension, cardiovascular disease, annoyance, sleep disturbances, and decreased school function in children (Passchier-Vermeer & Passchier, 2000). As discussed above, adverse health effects from noise are dependent on the duration of exposure and the intensity of the noise.

Hearing Impairment

Noise-induced hearing loss can occur as a result of exposure to noise levels that are too loud, even if exposure lasts for a short amount of time (National Institue on Deafness and Other Communication Disorders, 2014). Long-term exposure to noise levels greater than 85 dBA and short-term exposure to noise levels greater than 100 dBA can lead to hearing loss (National Institue on Deafness and Other Communication Disorders, 2014). Hearing loss is a pervasive occupational problem and has been characterized by the Centers for Disease Control and Prevention (CDC) as the most common work-related illness in the US (Centers for Disease Control and Prevention, 2013; Occupational Safety and Health Administration (OSHA), n.d.-b). Excessive and/or continuous noise, such as that typically experienced in the natural gas industry, is associated with documented health impacts such as permanent tinnitus or hearing loss (Occupational Safety and Health Administration (OSHA), n.d.-a, n.d.-b). NIOSH sets occupational noise standards at 85 dBA over 8 hours while OSHA's standards are a bit higher at 90 dBA over 8 hours (Centers for Disease Control and Prevention, 2013; Occupational Safety and Health Administration (OSHA), n.d.-b). Even at these exposure levels over a lifetime of work, a 5-10 decibel hearing impairment is expected for most workers (Passchier-Vermeer & Passchier, 2000).

As a protective standard, in 1974 the EPA recommended a 24-hour yearly hearing level of 70 dBA to protect against hearing loss and damage for 96% of the population (U.S. Environmental Protection Agency, 1974). While this standard has become universal, there have not been any large-scale epidemiological studies to support the standard (Passchier-Vermeer & Passchier, 2000). Hearing loss as a result of daily environmental noise exposure is less common among the general population than other health effects, such as annoyance and sleep disturbances.

Psychosocial Impacts

Psychosocial health impacts related to noise exposure include stress, anxiety, aggression, irritability, and annoyance (Golmohammadi, Mohammadi, Bayat, Habibi Mohraz, & Soltanian, 2013). Noise annoyance can be described as a subjective discomfort or reaction to noise which can be influenced by personal traits and opinions of the noise source (Babisch et al., 2013; Schrenckenberg, Griefahn, & Meis, 2010; U.S. Environmental Protection Agency, 1974). Golmohammadi and colleagues (2013) found average noise levels near construction sites in Iran were 74.57 dBA with a standard deviation of 7.12 dBA. Residents living near the sites expressed a high level of annoyance due to its disruption of activities such as sleep, reading, and overall distraction. The level of annoyance seemed to correlate with the sound levels (Golmohammadi et al., 2013). In a meta-analysis, Fields (1993), found some indication that noise annoyance was associated with day-night noise levels (DNL) below 55 dBA. It is difficult to determine a noise level at which annoyance would be diminished because it is subjective and varies person to person. Miedema and Oudshoorn (2001) developed a model to show the relationship between annoyance and DNL related to transportation noise sources (air, road, and rail). Their data provide evidence of a dose-response relationship between annoyance and DNL.

Sleep Disruption

Uninterrupted sleep is important for overall physiological and mental functioning. There is accumulating evidence that shows that exposure to noise levels as low as 32 dBA during sleep can cause a reduction in sleep period, arousals, awakenings, sleep stage modifications and autonomic responses, as well as other secondary impacts (Münzel et al., 2014; Murphy & King, 2014; Passchier-Vermeer & Passchier, 2000; World Health Organization, 2009). Secondary impacts appear the next day and include fatigue, low work capacity, reduced cognitive performance, changes in behavior, mood, and negative emotions (Murphy & King, 2014; Stansfeld & Matheson, 2003). A Finnish study found an association between nighttime traffic noise greater than 55 dBA (OR: 1.32) and symptoms of insomnia. The association was stronger for individuals with anxiety traits exposed to noise levels greater than 50 dBA (OR: 1.61) (Halonen et al., 2012). There is some evidence that nighttime noise exposure may be more likely to affect cardiovascular health than daytime noise. Children, pregnant women, elderly, sick individuals, and shift workers are more vulnerable to sleep disruption associated with noise (World Health Organization, 2009). The WHO recommends that outdoor nighttime noise levels not exceed 40 dBA in order to protect public health (World Health Organization, 2009).

Cardiovascular Disease

Babisch and colleagues (2013) outline two pathways to describe the development of adverse health effects due to noise exposure – 1) noise levels directly impact health; and 2) an individual's subjective perception of noise indirectly affects health (Münzel et al., 2014). Physiological responses to noise have been observed. These responses include increased heart rate and blood pressure, vasoconstriction, and vascular resistance (Stansfeld & Matheson, 2003). Dratva and colleagues (2012) found significant associations between daytime and nighttime railway noise with systolic and diastolic blood pressure, but did not find any association with transportation noise (Dratva et al., 2012). Recent research has shown that nighttime exposure to noise levels greater than 55 dBA may be more relevant for cardiovascular effects than daytime noise exposure (World Health Organization, 2009).

There is some indication that annoyance may be a modifier between noise and cardiovascular disease (Babisch et al., 2013). Babisch and colleagues (2013) found that both noise level and annoyance "may serve as explanatory variables for the assessment of cardiovascular diseases due to chronic noise exposure" in an analysis of airport and traffic noise from the Hypertension and Exposure to Noise Near Airports Study (HYENA) in Europe. The findings indicate that there may indeed be a modifier, however the results were not conclusive.

The World Health Organization provided estimates of the noise-related health burden in Europe by calculating the disability-adjusted life years (DALYs). The number of years lost include 61,000 for ischemic heart disease, 45,000 for children aged 7-19, due to cognitive impairment, 903,000 for sleep disturbances, 22,000 for tinnitus, and 654,000 as a result of noise-induced annoyance – a total of 1.6 million years lost each year due to environmental noise (World Health Organization, 2011). While there is not any lack of science indicating that noise is associated with numerous adverse health effects, choosing an adequately protective standard has proven more difficult.

Noise Regulation and Control

In 1974 the EPA published a "Levels Document" that outlined noise levels determined to protect public health with an adequate margin of safety. The document was created in response to the charge outlined in the Noise Control Act of 1972. The EPA identified a 55 dBA limit for outdoor areas and 45 dBA for indoor residential areas, hospitals, and schools (U.S. Environmental Protection Agency, 1974). In 1981, funding was cut and noise regulation, monitoring, and enforcement was delegated to the state and local governments (U.S. Environmental Protection Agency, 2012). This has led to a patchwork of regulation. There are at least 12 states and 75 cities, counties, and towns with noise regulations (Noise Pollution Clearinghouse Law Library, n.d.-a, n.d.-b). Noise standards vary by 10-15 dBA state to state, with daytime levels ranging from 50-65 dBA and nighttime levels from 45-55 dBA (Noise Pollution Clearinghouse Law Library, n.d.-b). In contrast, local noise standards can vary by as much as 35 decibels even within the same state. For example, Fayette County, Pennsylvania allows noise levels up to 90 dBA at 25 feet from the property line of the noise source, whereas the City of Altoona in nearby Blair County set the noise standard for residential areas at 55 dBA (City Council of the City of Altoona, 2007; Fayette County Board of Commissioners, 2006).

Europe is more advanced in their acknowledgement of noise as an environmental hazard, as well as their evaluation and assessment of noise (World Health Organization, 2009, 2011). In 1999 the World Health Organization (WHO) published community noise guidelines, which recommended that outdoor daytime noise levels not exceed 55 dBA and outdoor nighttime noise levels not exceed 45 dBA in order to protect public health. In addition to the noise standards, the WHO recommended noise management programs, including noise surveillance and monitoring to understand human exposure to noise (Berglund, Lindvall, & Schwela, 1999). This report led the European Union (EU) to adopt Environmental Noise Directive (END) 2002/49/EC. The Directive sets out several objectives designed to identify noise pollution through mapping and the development of local action plans to reduce noise ("Assessment and management of environmental noise," n.d.). It is important to note that the Directive did not set noise standards that had to be met; the focus was on surveillance and local action plans. As a result of the Directive, EU countries created large-scale surveillance programs that have allowed them to understand noise exposures and create policies to protect health. While emphasis on noise as a major threat to public health and uniform noise policy in Europe is likely to have positive health implications, the unregulated, patchwork nature of noise standards in the U.S. continues to contribute to unfettered development of industrial activity with little emphasis on noise mitigation.

Natural Gas Development Noise Regulation

Noise associated with natural gas development comes from a variety of sources, including truck traffic, well pad construction, hydraulic fracturing, and compressor stations. The Federal Energy Regulatory Commission (FERC) regulates interstate natural gas compressor stations. FERC outlines specific standards for interstate compressor stations. For example, noise levels cannot be more than 55 dBA at a "pre-existing noise-sensitive area, such as schools, hospitals, and residences" (Federal Energy Regulatory Commission, 2013). However, natural gas compressor stations used by producers in gathering facilities are not subject to the same standards. States use a combination of setback regulations, noise standards, and noise-reduction technologies to minimize environmental impacts and protect public health from natural gas development. A setback is a minimum distance required between a structure and another designated line or location, for example, the center of a well pad and an occupied dwelling. Setback regulations vary by state, from 100 to 1,500 feet for a well pad, and from 300 to 1,500 feet for compressor stations (City of Dish, 2009; Maryland Department of the Environment & Maryland Department of Natural Resources, 2013; Pennsylvania General Assembly, 2012; Richardson, Gottlieb, Krupnick, & Wiseman, 2013). Some areas require very restrictive setbacks. Recently the Dallas City Council passed an ordinance that would require a 1,500 minimum setback between protected areas, such as homes, and compressor stations and drill rigs (Malewitz, 2013). To control noise associated with natural gas development, Maryland is proposing a setback of 1,000 feet between a compressor station and “any occupied dwelling” as well as enforcement of the state noise standards (Maryland Department of the Environment & Maryland Department of Natural Resources, 2013). Pennsylvania requires a minimum setback distance of 750 feet from the “nearest existing building” and stipulates that noise levels may not exceed 60 dBA (Pennsylvania General Assembly, 2012). Meanwhile, Dish, Texas requires a 300 foot setback between compressor stations and residential areas and pre-development noise levels must be met (City of Dish, 2009).

Currently technologies do exist to reduce noise levels, such as use of sound barrier fences, insulation, and enclosures/buildings to house the compressors (Acoustical Solutions, n.d.; Ecology and Environment Incorporated, 1992; Southwestern Energy, n.d.). These technologies are regularly employed around natural gas operations in urban locations such as Fort Worth, TX (personal communication, American Petroleum Institute). But because of the cost associated with them, such technologies are not typically used in rural areas. There is a lack of clear and consistent regulations designed to protect the public's health from noise in the U.S.; natural gas is no exception. Without federal and state regulations, local communities are left to fend for themselves against this multi-billion dollar industry.

Noise Associated with Natural Gas Development

There is limited information on noise associated with natural gas. Three reports have begun to assess noise associated with natural gas development and production, however they have focused on well pad development and hydraulic fracturing (Mccawley, 2013; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010). To date there have not been any studies to monitor and evaluate noise associated with natural gas compressor stations. Yet there is some anecdotal evidence that noise from compressor stations is a concern for nearby residents.

McCawley (2013) monitored and recorded the average dBA in West Virginia at 9 sites located around 5 well pads at different stages of natural gas development, including site preparation, vertical drilling, horizontal drilling, hydraulic fracturing, and flowback. He found that the average noise levels across the sites were lower than 70 dBA, but the levels were frequently over 55 dBA (Mccawley, 2013). The Colorado School of Public Health conducted a health impact assessment (HIA) to assess the potential health impacts associated with natural gas drilling in Battlement Mesa (Witter et al., 2010). They determined that the significant sources of noise would be heavy truck traffic, construction equipment, diesel engines used throughout drilling and hydraulic fracturing, and drill rig brakes (Witter et al., 2010). Based on these sources and the estimated baseline noise levels in the community, they determined that noise associated with natural gas extraction would produce negative health effects (Witter et al., 2010). Similarly, New York evaluated the noise impact associated with natural gas development in their draft supplemental Environmental Impact Assessment (EIA) using a model to estimate the noise levels at varying distances associated with each stage of well pad construction and drilling. Noise levels were estimated based on data obtained from the industry for the construction equipment. They found that noise levels at a distance of 50 to 2,000 feet would range from 52-75 dBA during well pad construction, 44-68 dBA during drilling, and 72-102 dBA during high-volume hydraulic fracturing (New York State Department of Environmental Conservation (NYSDEC), 2011). Noise associated with construction, drilling, and hydraulic fracturing would last approximately 60 days per well pad.

Table 1. Noise Associated with Natural Gas Development

Phase/Activity	Distance (feet)	Average dBA	Source
Well Development			
Access road construction	50-500	69-89	NYSDEC, 2011
Access road construction	1,000-2,000	57-63	NYSDEC, 2011
Truck traffic, construction	625	56-73	McCawley, 2013
Truck traffic[1]	< 500	65-85	Witter et al, 2010
Site preparation	625	58-69	McCawley, 2013
Well pad preparation	50-500	64-84	NYSDEC, 2011
Well pad preparation	1,000-2,000	52-58	NYSDEC, 2011
Drilling			
Vertical drilling	625	54	McCawley, 2013
Rotary air well drilling	50-500	58-79	NYSDEC, 2011
Rotary air well drilling	1,000-2,000	45-52	NYSDEC, 2011
Horizontal drilling	50-500	56-76	NYSDEC, 2011
Horizontal drilling	1,000-2,000	44-50	NYSDEC, 2011
Well Completion			
Hydraulic fracturing	625	47-60	McCawley, 2013

[1] This is an estimate based on anticipated noise associated with diesel truck traffic and residential proximity to truck routes (New York State Department of Environmental Conservation (NYSDEC), 2011).

Phase/Activity	Distance (feet)	Average dBA	Source
Hydraulic fracturing[2]	50-500	82-102	NYSDEC, 2011
Hydraulic fracturing	1,000-2,000	70-76	NYSDEC, 2011
Hydraulic fracturing & flowback	625	55-61	McCawley, 2013

Objectives of Thesis

To better understand the noise exposure levels associated with compressor stations, we conducted a pilot study to monitor and evaluate residential exposure to noise associated with natural gas compressor stations in West Virginia.

[2] Average dBA for pumper truckers with a sound pressure level of 110 and 115.

Chapter 3: Monitoring and Assessment of Residential Noise Exposure Associated with Natural Gas Compressor Stations

Abstract

Introduction: Noise is a growing concern for residents living near natural gas compressor stations. This study monitored and evaluated residential noise exposure associated with living near natural gas compressor stations in Doddridge County, West Virginia.

Methods: Short-term measurements (20 min) were collected at increasing distances from the compressor stations and indoor and outdoor medium-term (24-hour) measurements were collected at 8 test homes located within 2,500 feet of a compressor station and 3 control homes located more than 3,500 feet away from a compressor station. The average sound equivalent was calculated using logarithmic averages and stratified by distance from compressor station, time of day, and location.

Results: Average short-term noise levels were 61.43 dBA (45.3 to 76.1 dBA), while average 24-hour noise levels were 60.20 dBA (35.3 to 94.8 dBA). Both the average short-term and average 24-hour measurements significantly decreased with distance from the compressor stations, 63.15 dBA at less than 1,000 feet to 54.09 dBA at 2,000 to 2,500 feet for 24-hour measurements and 63.34 dBA at less than 1,000 feet to 54.10 dBA at 2,000-2,500 feet for short-term measurements. Outdoor average noise levels were 58.33 dBA (35.3 to 85.0 dBA) compared to 61.27 dBA (35.3 to 95.8 dBA) indoors. Average noise levels were generally higher during daytime hours

compared to nighttime hours, 61.44 dBA and 56.38 dBA, respectively. Average noise levels at the control homes were 51.40 dBA; 45.02 dBA indoors and 54.03 dBA outdoors. Noise levels at homes near compressor stations were on average 8.7 dBA higher than that of control homes, with a 16.25 dBA average difference indoors and a 4.3 dBA average difference outdoors with regard to the levels observed at the control homes.

Conclusions: Living near a natural gas compressor station increases environmental noise exposure and subsequently may lead to adverse health effects among exposed individuals.

Introduction and Objectives

Unconventional natural gas development is spreading across the United States, putting millions of Americans at risk of adverse environmental exposures. From 2000 to 2013, natural gas production increased 26% from 19.7 trillion cubic feet to 24.9 trillion cubic feet, and is expected to continue to increase to 33.1 trillion cubic feet by 2040 (U.S. Energy Information Administration, 2012, 2014b). Much of this growth is due to technological advances in horizontal drilling and high-volume hydraulic fracturing that have allowed access to shale gas deposits. Production from shale gas deposits increased 2,588% from 2000 to 2013 and is expected to nearly double by 2040 (U.S. Energy Information Administration, 2012).

There is a great deal of concern among the public health community that the rapid spread of unconventional natural gas development has left little time for a thorough evaluation of the health impacts (Adgate et al., 2014; Finkel & Law, 2011; Shonkoff et al., 2014). Since 2005 several published studies and reports have begun to identify the major hazards and exposure pathways associated with natural gas development that have the potential to lead to adverse health effects. The hazards of concern include air pollution, water pollution, soil pollution, environmental noise, earthquakes, adverse occupational health impacts, and secondary impacts including mental health and disruption of the social fabric in impacted communities (Adgate et al., 2014; Brown et al., 2014; Food and Water Watch, 2013; McKenzie et al., 2012; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010). Noise associated with natural gas development is a major concern for nearby residents and communities, yet this is an under-researched area.

Major sources of environmental noise are transportation, including vehicular traffic, aircrafts, and railroads, as well as industrial operations. Urban areas typically have higher noise levels compared to rural areas. Most of the higher noise levels in urban areas is due to traffic-related noise. Noise is considered a major stressor because of its ability to lead to a number of adverse health effects. Most of the literature on noise and health effects has focused on transportation (traffic, airplanes, and trains) sources. Adverse health effects from noise are dependent on the duration of exposure and the intensity of the noise. Long-term exposure to A-weighted decibels ranging from 32-75 have been associated with a myriad of health effects, from disruption of sleep and school performance to hypertension (Passchier-Vermeer & Passchier, 2000). Children, elderly, chronically ill, and hearing impaired individuals have been found to be more susceptible to environmental noise (van Kamp & Davies, 2013).

Reports have shown that noise levels associated with natural gas development, including truck traffic, well pad construction, and hydraulic fracturing are likely to be higher than 55 dBA (Mccawley, 2013; New York State Department of Environmental Conservation (NYSDEC), 2011; Witter et al., 2010). While increased noise levels are associated with both natural gas development and production, development is temporary. There have not been any studies to evaluate noise levels associated with natural gas compressor stations, which are actually a more permanent source of noise in the community.

To better understand the noise exposure levels associated with compressor stations, we conducted a pilot study to monitor and evaluate residential exposure to noise associated with natural gas compressor stations in West Virginia. This study had three main objectives: 1) to evaluate noise levels inside and outside individual residences located at varying distances from a natural gas compressor station; 2) to investigate whether significant differences in noise levels exist with regard to the time of day (daytime versus nighttime), distance, and location (indoor versus outdoor); and 3) to determine an appropriate setback to protect residents from the adverse health effects associated with high noise levels.

Methods

Noise monitoring was conducted around natural gas compressor stations in Doddridge County, West Virginia between April 11-17, 2014, using 3M Quest SoundPro noise monitors (3M Personal Safety Division, St. Paul, MN). All monitors were set to collect slow, A-weighted decibel levels (dBA) L_{eq}, L_{min}, L_{max}, L_{peak}, L_5, and L_{95} and C-weighted decibel levels L_{eq}, L_{min}, L_{max}, L_{peak} in 1-minute intervals.

Site Selection and Noise Monitoring

Short-term Measurements: Short-term measurements (20 min) were collected at increasing distances from compressor stations in Doddridge County, WV. The monitors were placed in a safe outdoor location using a tripod. The exact geographical coordinates of the monitor locations were recorded.

Medium-term (24 hr) Measurements: 24-hour noise measurements were collected inside and outside homes that were near compressor stations in Doddridge County, WV. A total of three homes were located less than 1,000 feet from the compressor stations, three homes were located between 1,000 and 2,000 feet away, and two homes were located between 2,000 and 2,500 feet away from the compressor stations. An additional 3 homes were recruited as controls, located beyond 3,500 feet from the compressor stations. Noise monitors (Quest SoundPro SE/DL Series**)** were placed inside and outside each home for 24 hours. Indoor monitors were typically placed in a bedroom and outdoor monitors were placed in the yard facing the natural gas compressor stations. Outdoor monitors were encased in an environmental protection kit (3M SoundPro Outdoor Measuring System (SP-OMS)). Outdoor measurements for the two homes located 2,000 to 2,500 feet away were not for a full 24-hours, due to battery failure. Monitors were factory calibrated prior to use and then were pre-calibrated using a Quest QC-10/QC-20 Calibrator onsite prior to each measurement. Following each measurement, the monitor was post-calibrated and the data were downloaded using Quest Suite Professional. The University of Maryland, College Park's Internal Review Board (IRB) approved this study.

Statistical Analysis

Summary noise measures were calculated using logarithmic averages and were stratified by distance from compressor station (less than 1,000 feet, 1,000 to 2,000 feet, 2,000 to 2,500 feet, and more than 3,500 feet), time of day (daytime 7:00 am -10:00 pm and nighttime 10:00 pm - 7:00 am), and location (indoor, outdoor, and short-term). The logarithmic averages were calculated as follows:

$$L_{eq,t} = 10log_{10}\left(\frac{1}{N_t}\right)\sum 10^{\frac{L_{eq}}{10}}$$

Where $L_{eq,t}$ is the average equivalent sound level for the time period of interest, N_t is the number of 1-minute interval L_{eq} sound levels taken during the time period of interest, and L_{eq} is the 1-minute interval sound levels during the period. T-tests were used to determine significant differences in noise levels associated with temporal and spatial factors, including proximity to compressor station, indoor versus outdoor, and daytime versus nighttime, as well as comparisons of the test homes to control homes.

Following the method used by Murphy and King (2014), we evaluated the difference between the C-weighted dB and the A-weighted dB to determine the presence of low-frequency noise. A difference greater than 15 dB indicates the potential for low frequency noise and would require further spectral analysis. Statistical significance was assumed at a level of $p<0.05$. All statistical analyses were performed using Stata/IC 13.1 for Mac (StataCorp LP, College Station, TX).

Results

Noise levels associated with compressor stations were dependent on the distance from the compressor station, location (indoor vs. outdoor), and time of day.

Overall the average noise level for the combined compressor stations was 60.20 dBA (range 35.3 to 94.8 dBA), and the average short-term noise level was 61.43 (range 45.3 to 76.1 dBA). The control homes in West Virginia were located in a semi-rural/rural community more than 3,500 feet from a compressor station. Overall, the average noise level at the control homes was 51.50 dBA (range: 35.3 to 74.1 dBA) (**Table 2**).

A significant difference of 8.7 dBA ($p<0.001$) was observed at sites located less than 2,500 feet from a compressor station (mean: 60.20, range: 35.3 to 94.8 dBA) compared to control homes located more than 3,500 feet from a compressor station (mean: 51.50, range: 35.3-74.1). Both short-term and 24-hour measurements decreased with distance from the compressor station (**Figure 3**). Compared to noise levels observed at the control sites, a significant difference of 11.65 dBA was found at sites located less than 1,000 feet from a compressor station, 3.98 dBA was found at sites between 1,000 and 2,000 feet, and 2.59 dBA was found at sites between 2,000 and 2,500 feet, $p<0.001$. Short-term measurements showed similar results, with an average noise level of 63.34 dBA (range: 50.0 to 76.1) at sites located less than 1,000 feet, 55.40 dBA (range: 46.2 to 67.8) at sites located 1,000 to 2,000 feet, and 52.10 dBA (range: 45.3 to 57.1) at sites located 2,000 to 2,500 feet (**Table 2**).

At sites located near compressor stations, average indoor noise levels (mean: 61.27, range: 35.3 to 95.8 dBA) were significantly higher compared to outdoor noise levels (mean: 58.33, range: 35.3 to 85.0 dBA), $p<0.001$. The contribution of outdoor noise to indoor noise varies depending on the type of home and whether the windows are opened or closed. A 17 dB reduction in noise levels would be expected in a cold-climate home with windows open and a 27 dB reduction with windows closed (U.S. Environmental Protection Agency, n.d.). We observed a 3-7 dB difference in indoor versus outdoor noise levels, much lower than would be expected. There were significant differences between indoor and outdoor noise levels at sites located less than 2,500 feet from a compressor station compared to the control homes, 16.25 dBA and 4.3 dBA respectively. Differences also varied by distance from compressor station. At sites less than 1,000 feet from a compressor station, indoor noise levels were 64.59 dBA (range: 35.3 to 94.8) and outdoor noise levels were 60.97 dBA (range: 55.3 to 73.3). Indoor noise levels at sites 1,000 to 2,000 feet were 57.28 dBA (range: 35.3 to 75.7) and 52.36 dBA (range: 35.3 to 77.6) outdoor. Meanwhile, indoor noise levels at sites 2,000 to 2,500 feet were 53.75 dBA (range 35.3 to 80.3) and 55.33 dBA (range: 35.3 to 76.5) outdoor. There was a wide amount of variation across all monitoring sites, however, indoor noise levels at sites located less than 1,000 feet from compressor stations varied the most, from 35.3-94.8 dBA (**Figure 1**).

Noise levels were significantly higher at sites located near compressor stations during daytime hours (mean: 61.44 dBA, range: 35.3-94.8) compared to nighttime hours (mean: 56.39 dBA, range: 35.3-73.3), $p<0.001$. Differences between daytime and nighttime noise between the sites less than 2,500 feet from compressor stations and control homes were also significantly different, with a daytime difference of 9.65 dBA and a nighttime difference of 5.40. Both indoor and outdoor nighttime noise levels were regularly over 45 dBA (**Figure 4**). Outdoor noise levels show that sites less than 1,000 feet from a compressor station experience the highest noise levels, with a minimum noise level of 55.3 dBA (**Figure 2**).

There is little indication that low-frequency noise is present at sites located less than 2,500 feet from a natural gas compressor station. A difference between the 24-hour dBA and dBC greater than 15 dB was only observed at sites located less than 500 feet from the compressor station.

Discussion

Noise levels associated with natural gas compressor stations routinely exceed both the EPA's 1974 proposed noise standards (55 dBA outdoor and 45 dBA indoor) and the WHO's community noise standards (55 dBA daytime and 45 dBA nighttime), which are standards deemed to adequately protect public health. This highlights that living in close proximity to a natural gas compressor station is likely to contribute to adverse health outcomes. The exceedance was less common at control homes located more than 3,500 feet from the compressor stations (**Figure 3**). This shows that residents living more than 3,500 feet away from natural gas activity are not expected to experience high levels of noise. The findings presented here are from compressor stations and are not related to development activities. As such, they represent chronic noise exposure that community members will have to encounter for years/decades, not transient exposures that go away after the completion of a well.

There have not been any epidemiologic studies to evaluate health outcomes associated with noise from living near natural gas compressor stations; however, numerous studies have evaluated the health impact of long-term exposure to environmental noise from other industries. The most common health effects associated with environmental noise exposure are annoyance, stress, sleeping disturbances, and cardiovascular problems (Babisch et al., 2013; Dratva et al., 2012;

Haralabidis et al., 2008; Murphy & King, 2014; Swiss Noise Database & Environment, 2009).

According to a model developed by Miedema and Oudshoorn (2001) there seems to be a dose-response relationship between annoyance and day-night noise levels associated with noise from air, road, and rail. There is also some indication that annoyance may be a modifier between noise and cardiovascular disease (Babisch et al., 2013).

A growing body of evidence shows that exposure to nighttime noise levels as low as 32 dBA can cause a reduction in sleep period, arousals, awakenings, sleep stage modifications and autonomic responses, as well as other secondary impacts (Münzel et al., 2014; Murphy & King, 2014; Passchier-Vermeer & Passchier, 2000; World Health Organization, 2009). Recent research has shown that nighttime noise exposure to levels greater than 55 dBA may be more relevant for cardiovascular effects than daytime noise exposure (World Health Organization, 2009). Children, elderly, and hearing impaired individuals are likely to be more susceptible to environmental noise (van Kamp & Davies, 2013).

These are serious health effects associated with regular noise exposure. In addition to noise-related health outcomes, there may be synergistic effects between noise and air pollution associated with unconventional natural gas development and production (Huang et al., 2013). This is especially a concern for compressor stations that have been found to emit nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs) (Rich, Grover, & Sattler, 2014; Roy, Adams, & Robinson, 2014). Several studies have evaluated the relationship between air quality and noise on health, but results have been inconsistent (Allen et al., 2009; Floud et al., 2013; Huang et al., 2013; Kheirbek et al., 2014). Huang and colleagues (2013) found that both air pollution and noise were associated with heart rate variability in a study on short-term exposure. They found that noise levels greater than 65 dBA seemed to amplify the effects of air pollution when compared with noise levels less than 65 dBA.

Strengths & Limitations

This was the first study to evaluate noise levels associated with natural gas compressor stations. There are several limitations: 1) the study consisted of a small, convenience sample with 8 test homes and 3 control homes; 2) only noise was measured; topography, weather, and wind direction were not considered; and 3) anecdotal evidence suggests that noise levels associated with natural gas compressor stations vary by season, yet this study was limited to one season. Finally, choosing appropriate control sites with similar characteristics to the test homes was challenging. The control homes selected for this study were located near a major roadway and also had some local traffic. Selecting controls located in an area with some local traffic potentially introduced additional noise that may not have been found in a completely rural location.

Public Health Implications

This study highlights the need for a more thorough evaluation of noise levels associated with natural gas development as well as an understanding of the health effects experienced by nearby residents as a result of noise exposure. This is an opportunity for surveillance and monitoring programs designed to understand the impact of noise, the combined effects of noise and air pollution, and the overall health hazards associated with natural gas development and production. Regular exposures to the decibel levels observed in this study are likely to cause adverse health effects. State and local governments should consider applying appropriate standards and setback regulations using the precautionary principal to mitigate noise exposure and protect impacted residents.

Future Research

This study highlights the need for a larger noise monitoring study to be conducted in areas near natural gas development to further evaluate noise levels, taking into consideration season, weather, topography, age of home, and whether windows are typically left open or closed. In addition, due to the potential synergistic effects between noise and air pollution, future research should include both air and noise exposure associated with living near compressor stations. Finally, to understand the health impacts potentially associated with noise due to natural gas development it is necessary to conduct an epidemiological study in impacted areas.

Conclusion

This pilot study indicates that noise levels may be of concern for residents living near a compressor station. In order to minimize noise exposure associated with living near a natural gas compressor station, states should consider increasing the setback distance to 2,000 feet. Alternatively, a setback of 1,000 feet could be adopted if noise mitigation technologies are employed. States should also consider taking a proactive approach by creating noise and health outcomes surveillance programs to monitor noise levels, as well as the health of residents living in close proximity to natural gas activity.

Table 2. Summary Statistics, Stratified by Distance, Location, and Time

Distance (feet)	**Location**	**Time of Day**	**N**	**Mean L_{eq} (dBA)**	**Range L_{eq} (dBA)**
All distances	All locations	All times	21205	60.20	35.3-94.8
	Indoor	All times	11520	61.27	35.3-94.8
	Outdoor	All times	9388	58.33	35.3-85
	Short	All times	297	61.43	45.3-76.1
	All locations	Daytime	13575	61.44	35.3-94.8
	All locations	Nighttime	7630	56.38	35.3-73.3
<1000	All locations	All times	8818	63.15	35.3-94.8
	Short	All times	178	63.34	50-76.1
	Indoor	All times	4320	64.59	35.3-94.8
		Daytime	2700	66.49	35.3-94.8
		Nighttime	1620	53.85	35.3-70.1
	Outdoor	All times	4320	60.97	55.3-85
		Daytime	2700	61.25	55.3-85
		Nighttime	1620	60.46	55.3-73.3
1000-2000	All locations	All times	8963	55.48	35.3-77.6
	Short	All times	53	55.40	46.2-67.8
	Indoor	All times	4320	57.28	35.3-75.7
		Daytime	2700	57.86	35.3-75.7
		Nighttime	1620	56.12	35.3-65.3
	Outdoor	All times	4320	52.36	35.3-77.6
		Daytime	2700	52.75	35.3-77.6
		Nighttime	1620	51.62	36.9-57.9
2000-2500	All locations	All times	3694	54.09	35.3-80.3
	Short	All times	66	52.10	45.3-57.1
	Indoor	All times	2880	53.75	35.3-80.3
		Daytime	1800	54.31	35.3-80.3
		Nighttime	1080	52.61	35.3-72.6
	Outdoor	All times	748	55.33	35.3-76.5
		Daytime	678	55.32	35.3-76.5
		Nighttime	70	55.41	50.9-69.6
>3500	All locations	All times	8704	51.50	35.3-74.1
	Indoor	All times	4384	45.02	35.3-69.3
		Daytime	2764	45.95	35.3-69.3
		Nighttime	1620	42.72	35.3-65.1
	Outdoor	All times	4320	54.03	35.3-74.1
		Daytime	2700	54.23	35.3-74.1
		Nighttime	1620	53.66	35.3-58.4

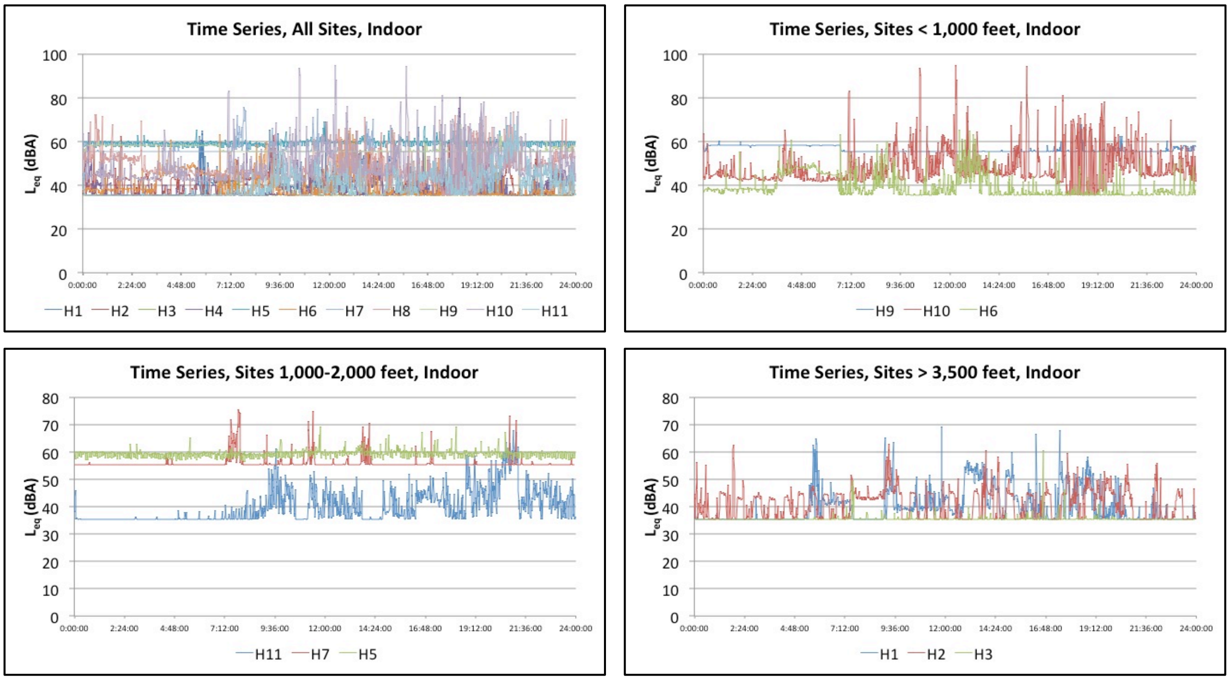

Figure 1. Time Series, Indoor Noise Level by Distance from Compressor Station

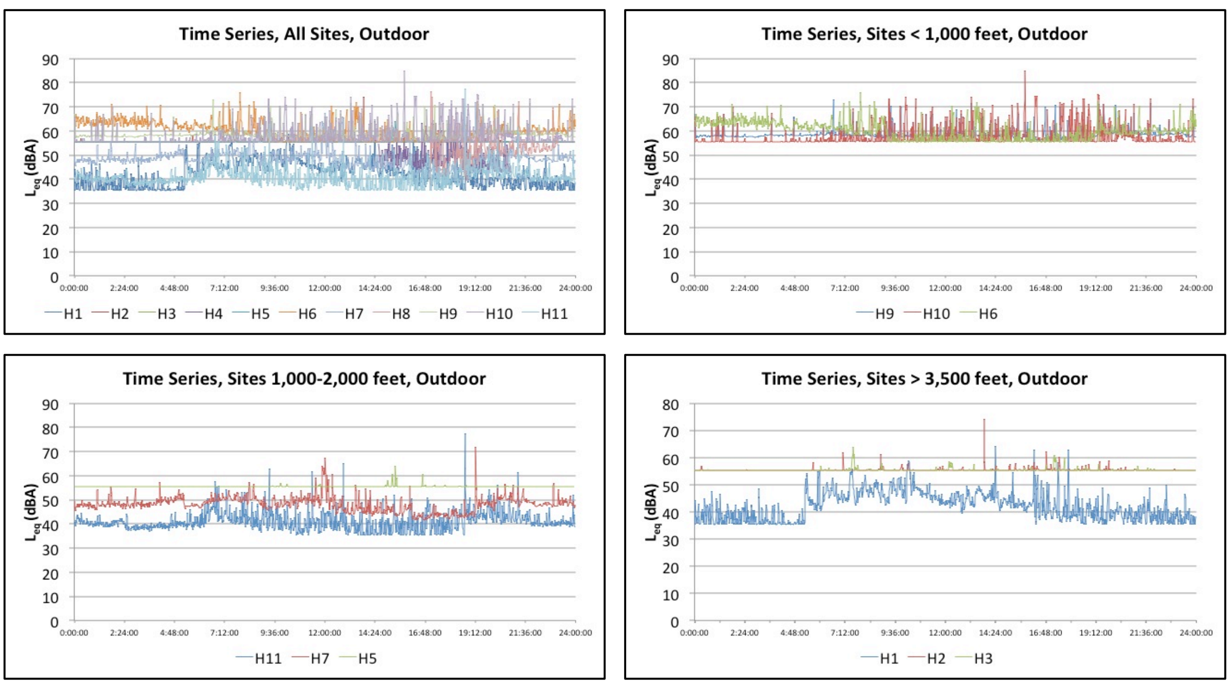

Figure 2. Time Series, Outdoor Noise Level by Distance from Compressor Station

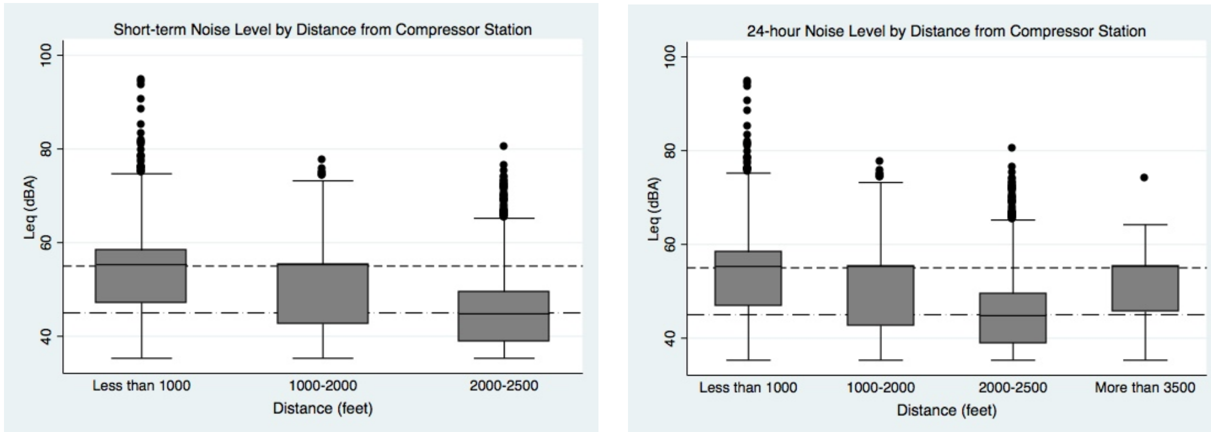

Figure 3. Boxplots, Noise Levels by Distance from Compressor Station

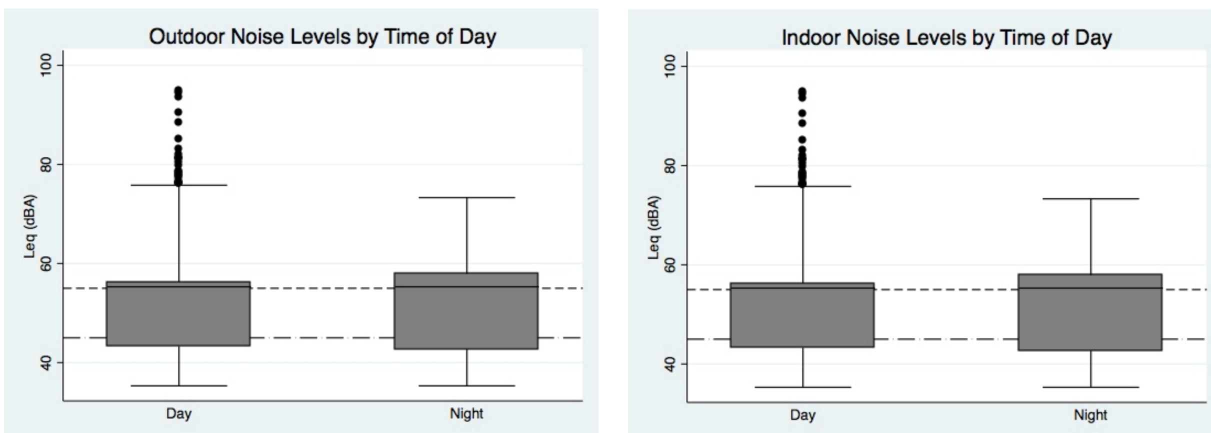

Figure 4. Boxplots, Noise Levels by Location and Time of Day

Chapter 4: Public Health Implications and Overall Conclusions

Public Health Implications

The public health implications of this thesis are two-fold. First, this study shows that noise levels associated with natural gas compressor stations are a major concern and may contribute to adverse health outcomes for nearby residents. An ever-growing body of literature indicates that long-term noise exposure to the decibel levels found in this study can lead to a number of adverse psychosocial and physiological health outcomes. This study opens the door for future research to explore noise levels associated with all aspects of natural gas development and the health of nearby residents. There is also an opportunity for state and local governments to take a proactive approach by 1) creating surveillance and monitoring programs designed to understand the impact of noise, the combined effects of noise and air pollution, and the overall health hazards associated with natural gas development and production; and 2) setting appropriate standards and setback regulations using the precautionary principal. Regular noise exposure to the decibel levels seen in this study is likely to cause adverse health effects, and there are methods available to reduce noise. These methods need to be implemented to protect the most vulnerable people in our community.

Second, and unexpectedly, it has become clear that U.S. noise standards are lacking. There is a patchwork system of state and local noise standards and zoning ordinances in place that do not provide adequate protection for the public's health.

The World Health Organization has shown that millions of years are potentially lost as a result of noise exposure each year and this demands immediate national attention.

Concluding Thoughts

The pilot study conducted as part of this thesis brushes the surface of a major environmental hazard and public health issue. As natural gas development continues to grow, so will the number of impacted communities and individuals. More studies are necessary to understand both noise exposure and health outcomes associated with living near natural gas development. The studies will likely highlight that stronger regulations are necessary to adequately protect public health.

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