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Fracking in Pennsylvania: A Spatial Analysis of Impacts on Land Cover and Land Use, the Viewshed, and the Audioshed

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Hydraulic fracturing is the process of extracting natural gas from layers of shale rock beneath the surface of the Earth. The largest source of natural gas in the US is the Marcellus Shale, largely located in Pennsylvania, and it is believed to hold about 141 trillion cubic feet of natural gas in its shale deposits. My study examined the impacts of well sites on land cover and land use, the viewshed, and the audioshed. To study the effect of wellpads on land use and land cover, we overlaid a layer of wellpads over land cover data as well as a layer of Pennsylvania natural resources. To study the visual and sound impacts of wellpads and compressor stations, we generated viewsheds and audiosheds and then calculated the percent of land, road, and trails impacted within different environment types. We found that the majority of producing wells are currently found in forested areas and within 1320 feet of a stream or wetland. However, we found that there is also seemingly a bias against placing wellpads near wetland areas. Additionally, rural land cover areas were found to have a disproportionate number of wellpads in relation to their area within the Marcellus shale region. Rural environments were also found to be impacted the highest in regards to the viewshed, having over 20% of the tile within the fracking viewshed for tiles with at least 2 wellpads. In regards to noise impacts, high road density areas and state forest areas were found to have similar percentages within the audioshed for tiles with at least one compressor station. So overall, in areas with at least 2 wellpads, rural areas have the most potential impacts due to fracking for both land cover and land use as well as the viewshed.

Keywords

Fracking, audioshed, viewshed, land cover, land use

Disciplines

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Comments

Environmental Studies Senior Honors Thesis

FRACKING IN PENNSYLVANIA: A SPATIAL ANALYSIS OF IMPACTS ON LAND COVER AND LAND USE, THE VIEWSHED, AND THE AUDIOSHED.

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Abstract

Hydraulic fracturing is the process of extracting natural gas from layers of shale rock beneath the surface of the Earth. The largest source of natural gas in the US is the Marcellus Shale, largely located in Pennsylvania, and it is believed to hold about 141 trillion cubic feet of natural gas in its shale deposits. My study examined the impacts of well sites on land cover and land use, the viewshed, and the audioshed. To study the effect of wellpads on land use and land cover, we overlaid a layer of wellpads over land cover data as well as a layer of Pennsylvania natural resources. To study the visual and sound impacts of wellpads and compressor stations, we generated viewsheds and audiosheds and then calculated the percent of land, road, and trails impacted within different environment types. We found that the majority of producing wells are currently found in forested areas and within 1320 feet of a stream or wetland. However, we found that there is also seemingly a bias against placing wellpads near wetland areas. Additionally, rural land cover areas were found to have a disproportionate number of wellpads in relation to their area within the Marcellus shale region. Rural environments were also found to be impacted the highest in regards to the viewshed, having over 20% of the tile within the fracking viewshed for tiles with at least 2 wellpads. In regards to noise impacts, high road density areas and state forest areas were found to have similar percentages within the audioshed for tiles with at least one compressor station. So overall, in areas with at least 2 wellpads, rural areas have the most potential impacts due to fracking for both land cover and land use as well as the viewshed.

Introduction

Hydraulic Fracturing, fracking, is known as the process of extracting natural gas from layers of shale rock beneath the surface of the Earth (Qingmin & Ashby, 2014). This process is completed by drilling down into the layers of shale and pumping in highly pressurized fluids to break apart the rock and quickly release the natural gas (Quinmin & Ashby, 2014). The desire for natural gas is substantial since natural gas is a cleaner burning energy than most other fossil fuels today (Slonecker et al., 2011-2014). The largest source of natural gas in the US is the Marcellus Shale, largely located in Pennsylvania, and it is believed to hold about 141 trillion cubic feet of natural gas in its shale deposits (Quingmin, 2012). There are many concerns about the process of hydraulic fracturing. These concerns are large in scope, and include environmental impacts such as changes in air quality, human health risks, and ground water pollution (Qingman & Ashby, 2014).

Despite all the heavy research on water quality, air pollution, and human health, little research has been done on other impacts of fracking on the surrounding environment. Land use and land cover, the viewshed, and the audioshed are three areas that have not been addressed nearly enough.

Previous research on spatial effects of fracking points out that hydraulic fracturing directly changes the local environment and landscape characteristics around well sites (Quingmin & Ashby, 2014), as well as the overall ecosystem (Quingmin, 2012). In fact, changes in land use, such as the clearing of forests to input well-sites, a process which drastically affects forest ecosystems, often occur so quickly that the changes to land cover and ecology become nearly impossible to properly track (Davis and Robinson, 2012). Land cover is also affected through the infrastructure required to create well sites, such as roads to the site, retention ponds, and power sources. This infrastructure results in about 17-23 acres of land cover disturbance per well pad (Habicht et al. 2015). A study on the Delaware River Basin found that in watersheds, this disruption of land cover could decrease forest cover by 1-2%, and cause a 5-10% drop in core forest ecosystems (Habicht et al. 2015).

Additionally, while wellpads are generally small in size, compressor stations, where the natural gas is processed and transported through pipelines, are significantly larger. Compressor stations are mandatory about every 40 miles between wellpads in order to maintain required pressures for pumping natural gas and oil (Gillespie & Clark, 1979). One station may be anywhere from 20 to 40 total acres with from 5 to 10 acres of above ground structures. The compressor cab enclosures are the largest infrastructure on any fracking site, which means a much larger impact on the surrounding land and ecosystems (Gillespie & Clark, 1979).

In Pennsylvania, specifically Bradford and Washington County, forests and land cover have been significantly impacted as a result of the replacement of forest ecosystems with well-sites and necessary infrastructure for fracking (Slonecker et al., 2011-2014). It has also been discovered that fracking sites are not placed at random and in fact can be predicted. There is a distinct spatial distribution to their locations based on landscape, elevation, slope, and distance to rivers (Quingmin, 2012). In fact, if even half of the potential well sites had been exploited just in New York before the ban on fracking was passed, we could have seen a 6% increase in core forest degradation, a 17% increase in stream degradation, and a 7.5% increase in grassland bird habitat degradation, and there are far more potential sites in Pennsylvania than there were in New York (Davis & Robinson, 2012)

Additionally, during peak well development, up to 70% of water could be removed if taken from local small streams at low-flow conditions (Habicht et al. 2015). Erosion as a result of fracking implementation increases at rates up to 150% at the start of development to around 15% post-development (Habicht et al. 2015). This even furthers the initial impact on land cover, and thus increases the potential to degrade ecosystems.

There are also economic impacts due to the placement of wellpads. Property value can decrease with the presence of wellpads and compressor stations in the area (Upadhyay and Bu, 2010). Additionally, under the Clean and Green Act, agricultural land is assessed at its agricultural value rather than the fair market rate (Bamberger and Oswald 2014). This gives farmers a decreased property tax bill, but the placement of a wellpad on their land changes the classification to industrial, and thus removes the Clean and Green assessment for the whole farm (Bamberger and Oswald 2014). Doing this results in an increase in property taxes on the farmers that may not balance out with the revenue they receive for the placement of the well, particularly if it is a test well and not a functional well.

These impacts have not yet been fully evaluated though, since to date, most land cover change studies have been in smaller areas of Pennsylvania rather than state-wide.

There is very little regulation for the impacts of fracking on the viewshed, or the total area visually compromised by the placement of wellpads and compressor stations, which causes changes in both the aesthetics of an area and the property values. In a study done by

Cornell, it was determined that well pad visual impacts were small in radius, but indirect visual impacts, such as site related vehicles, were much more significant (Upadhyay, 2010). It was also determined that site restoration is the best viewshed mitigation technique, but the timeline for this process varies significantly from site to site (Upadhyay, 2010). Site restoration is the landscaping the existing drilling pad so that it looks as similar as possible to the predrilling landscape. This includes restoring vegetation and previous land us, and it must be completed by the company within 9 months of drilling the well (Upadhyay, 2010)("Restored Marcellus Gas Well Sites," 2009-2015). Making the process more difficult, viewshed impact mitigation is often not even *considered* until after siting, due to its perceived lesser importance (Upadhyay, 2010). Thus far, however, there have been no spatial analysis of the total impacts of fracking on the audioshed and viewshed in Pennsylvania.

Fracking has also had an impact on the audioshed, the total area pervaded by the noise which originates from the well-sites. The fracking industry is not a quiet one. From the setup of the well site, to the pumping of millions of tons of water into the ground there is a significant amount of sound being emitted from the site (Cusik, 2014). Then, after the well is producing gas, the construction workers and the fracking stop, and the well site is a reasonably quiet space (Cusik, 2014). However, there are other sites called "compression stations," where the natural gas is processed and transported through pipelines, and these create much more noise at all hours of the day for *years* (Cusik, 2014).

Under current Department of Conservation and Natural Resources (DCNR) guidelines, compressor stations on state forest land can't exceed 55 decibels, 300 feet from the site (Cusik, 2014)("Compressor Noise on State Forest Land,"n.d.). Currently, however, there are no statewide noise regulations on the issue, though there are new draft regulations being processed that would require site-specific noise management plans for each well-site (Cusik, 2015). Studies have shown that noise levels produced by compressor stations have the ability to disrupt the surrounding ecosystem. One study conducted in the Boreal Forest found that many bird types were significantly less dense in noisy areas vs. non-noisy areas, and that removing this excessive sound could help conserve high-quality habitat for birds in the region (Bayne et al., 2008). Other studies on periodic but intense noise disturbances have concurred with this assessment, finding that animals tend to abandon areas where anthropogenic noise is occurring and return only after the noise is dissipated (Bayne et al., 2008). In addition to these effects on wildlife, humans are also impacted by the noise in a more aesthetic manner.

No formal studies of compressor station noise in Pennsylvania have been conducted. Thus, we want to determine the approximate area that is impacted by the audioshed to estimate what those regulations should consist of in order to reduce the impact of the audioshed both on humans and in natural ecosystems.

This study will examine the impacts of well sites and compressor stations on land cover, the audioshed, and the viewshed. It will also compare the spatial distribution of land cover change, well audioshed, and well viewshed to the location of important natural resources in Pennsylvania, which includes hiking trails, wetlands, protected areas, streams, and roadless areas.

- **Land cover and land use:** We want to determine what land cover type existed in areas that now contain wellpads or compressor stations. In addition we will determine what the land use for these areas are and what natural resources are in close proximity to these areas.

- **Audioshed:** This study will determine the total area impacted by noise from compressor stations in different environment types in Pennsylvania. Determining impacts in different environments is important since noise travels differently in different areas and conditions, and ecosystems vary significantly. Birds, for example, are one of the most impacted species to noise pollution, and thus fracking in forested areas could impact them significantly. Additionally, we find the total anthropogenic impact by evaluating the percentages of roads and trails in the audioshed for each environment.
- **Viewshed:** We will determine the total area visually impacted by wells and compressor stations in Pennsylvania, as well as impacts on roads and trails in order to assess impacts within developed, rural and forested areas.

Methods

To get an understanding of the locations of wellpads in Pennsylvania, we first overlaid a map of wellpads onto the locations of several state resources: national forests, state forests, and state gamelands. To do this, we first had to derive a layer of wellpads from the layer of wells created by the Carnegie Museum of Natural History's Pennsylvania Unconventional Natural Gas Wells Geodatabase. This is a compilation of 8 other datasets created by the PA Department of Environmental Protection that has been updated quarterly. Wellpads are approximately 3.5 acres in size prior to rehabilitation and 1.5 acres in size after the mandatory partial reclamation (“The Basics-Operations”, 2012). Each well pad can contain up to 6 wells (“The Basics-Operations”, 2012). We aggregated individual wells into well polygons, where any well within 100 feet of another well was considered to be in the same wellpad.

Analysis of Land Cover & Land Use

We evaluated the presence of wellpads in relation to land cover and land use by comparing the location of wellpads to state resources and land cover type. First, we classified each wellpad as producing, permitted, or drilled. We defined producing pads as wellpads that have at least one well on them that is actively producing. Permitted wellpads were defined as wellpads that were licensed, but contain no producing wells and have no recorded drilling date. Drilled wellpads were defined as those that contain at least one well that are drilled, or under construction, but do not contain any active wells.

We compared the location of wellpads to the following natural resources: trails, roadless areas, state forest, national forest, state gamelands, wetlands, and streams. State and nationally owned resources are important, but we also wanted to natural resources, such as the wetlands, streams, and roadless areas to see more of the ecological impact on non-regulated areas. To do this, we measured the number of wellpads both within each resource, and then within a buffer zone of a quarter mile from each resource. How we defined wells to be “within” a resource varied by legality of wells in relation to each particular resource (Table 1).

Table 1. PA natural resources/land use legal boundaries and input boundaries used for this study

Resource	**Restriction:** **Legal buffer/Generalized buffer**
Trails	<100 ft. for State <200 ft. for National Scenic
	< 1320 ft.
State Forest	Within
	< 1320 ft.
National Forest	Within
	< 1320 ft.
Game Lands	Within
	< 1320 ft.
Wetlands	<300 ft.
	< 1320 ft.
Streams	<300 ft.
	< 1320 ft.
Roadless Areas (>656 ft. from road)	Within
(>2625 ft. from road)	Within

For the legal boundaries, state forest, national forest, and gamelands have clearly defined boundaries from which to measure. By law in Pennsylvania, wells cannot be within 300 feet of streams or wetlands, so we created a 300 ft. buffer around both these resources and measured the number of wells contained within it. For the trails, we made individual buffers for both trail types and then merged them together. Finally, in a study on the estimate of area impacted ecologically by the US road system, it was found that for secondary (local, public) roads, road effects are estimated to extend about 656 feet from the road. For primary, or state-maintained roads, the maximum believed road effects is 2625 feet (Forman 2001). So for the legal boundaries measurement, we calculated the number of wellpads within all areas greater than 656 feet from a road. Then, contrastingly to the other resource measurements, instead of using a 1320 foot buffer for the general potential impact zone for roadless areas, we used the estimate of 2625 feet given from the study. Using these buffers, we calculated the number of producing, permitted, and drilled wellpads for each zone and buffer zone.

To calculate the wellpads within each land cover type, we first did a reclassification of the land cover types, generalizing forested land and developed areas. The 2006 NLCD classification, created by the U.S. Geological Survey, has the following legend:

Land Cover Type	Value
Open Water	11
Developed, Open Space	21
Developed, Low Intensity	22
Developed, Medium Intensity	23
Developed, High Intensity	24
Barren Land (Rock/Sand/Clay)	31
Deciduous Forest	41
Evergreen Forest	42
Mixed Forest	43
Shrub/Scrub	52
Grassland/Herbaceous	71
Pasture/Hay	81
Cultivated Crops	82

My condensed, reclassification of the dataset based on the land cover types present in my data was as follows:

Land Cover Type	Value
Open Water	11
Developed	21, 22, 23
Barren Land (Rock/Sand/Clay)	31
Forest	41, 42, 43
Rural	52, 71, 81, 82

We then measured the number of producing, permitted, and drilled pads within each land cover type and the total number of wellpads in each land cover type.

Analysis of Viewshed

The viewshed analysis defined areas where the wellpads and compressor stations were visually impacting the environment. This allowed us to calculate the percentages of land, roads, and trails that were within the viewshed, showing us both the anthropogenic impact of the wells and compressor stations as well as the ecological impact. To do this, we first selected LiDAR tiles in four different types of environments (Figure 1). The LiDAR data was created by the PAMAP Program, PA Dept. of Conservation and Natural Resources, and each tile represents 10,000 x 10,000 feet on the ground. We took a random sampling, using a random number generator, of ten LiDAR tiles that contained at least 2 wellpads for each type of environment.

We defined four types of environments in Pennsylvania where wellpads could be located: state forest, rural, high road density, and other. The first three areas were chosen because they have high road or trail traffic, they are appreciated for their aesthetic appeal, or both. These aspects contribute to a more significant visual impact. We defined a LiDAR tile , a 10,000 x 10,000 foot square of LiDAR data, to be in state forest if its centroid intersected the State Forest shapefile. We reclassified the NLCD dataset to determine which tiles were rural. We calculated road density for each tile by using zonal statistics on the PA roads dataset. Tiles were classified as ‘high road density’ if they were within the top 20% of road density, where road density was greater than 2.69678 roads per km^2. All other tiles were classified as ‘other’.

We generated LiDAR “panels” for each selected tile, by creating an LAS dataset out of that tile and the 8 tiles surrounding it, creating 30,000 x 30,000 ft. panels. Then, we created elevation rasters for each panel with which to create the viewsheds in ArcGIS. Generally, viewsheds are created using Digital Elevation models, or DEMs, which represent the elevation of the Earth’s surface. However, these models only represent the elevation of the Earth itself (Miller, 2011). LiDAR, or Light Detection and Ranging, uses an airborne laser to scan the terrain (Miller, 2011). Not only does this imply higher accuracy than the typical DEMs, but LiDAR digital surface models (DSMs) include surface features as well, such as tree canopy, which would be significant in determining the viewshed for objects as small as wellpads (Miller, 2011). Therefore, LiDAR allows us be much more precise when completing out viewshed analysis. For our viewsheds, observation points were defined as all wellpads and compressor stations within the panels. Wellpads were given a height of 7 feet and compressor stations were given a height of 50 feet (Citations).

We then calculated the percent area of our selected tiles contained in the viewshed, and the percent of roads within the center tile contained in the viewshed. To do this, we intersected the 40 selected tiles with the PA roads shapefile, and used calculate geometry to get the length of each road within each tile. A spatial join with the tiles shapefile was used to determine the sum of road lengths within in each selected tile, and then we were able to use zonal statistics to calculate the percent of roads in the viewshed for each tile. We used a similar process to determine the percent of trails in the viewshed, for those tiles that contained trails. Following these calculations, we ran an ANOVA test on the data to determine if the environments were significantly different.

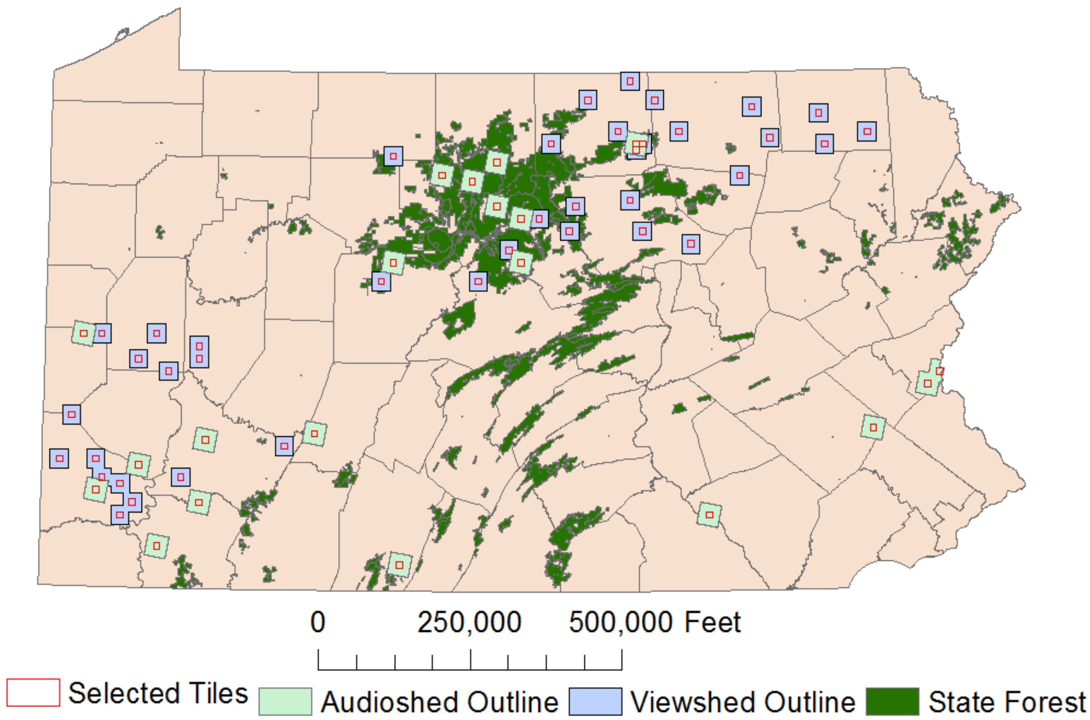


Figure 1. LiDAR panels for viewshed and audioshed analyses.

We also ran a verification study at a compressor site in Adams County, taking pictures at 6 intersections around the compressor station to see if the site was visible or not.

Analysis of Audioshed

We completed a stratified random selection of 10 LiDAR tiles for High Road Density and State Forest environments that contained at least one compressor station (Figure 1). We chose the high road density and state forest environments to get an idea of audioshed impacts in areas both anthropogenically and ecologically critical. We again created LiDAR “panels” by taking the selected tiles and the 8 surrounding tiles.

We created an audioshed of the total sound propagated in relation to each compressor station for each panel using the Spread-GIS tool from Colorado State University. This tool takes in sound source locations, elevation, land cover, and weather condition data to generate a noise propagation model. Each panel was used to generate an extent for the tool to run within, and we used a Pennsylvania DEM for elevation data as opposed to the LiDAR data due to program restrictions. We chose settings for our audioshed such that the wind speed and wind direction would not play a role in the sound propagation:

- Temperature – 83 degrees
- Humidity – 26%
- Wind Speed– 0 mph
- Wind Direction – 285
- Day – clear, calm summer day

For tiles with more than one compressor station, it was necessary to get the sum-total sound for each panel using a summing tool within the Spread-GIS toolset. As a cut off for human hearing, we considered 40 dB and louder audible. We then calculated the percent land in a tile and the percent of roads in the tile that were contained within the audioshed. To verify that the data was significantly different between environment types, we ran an ANOVA test. Following this study, we conducted a validation study at a compressor station in Adams County, PA. At 6 intersections around the compressor station, I measured the number of decibels and noted if I could identify noise generated from the compressor station with my own ears.

Results

Overall wellpads are concentrated most heavily in the northeast and southwest areas of Pennsylvania (Figure 2). There were approximately 4746 wellpads total in Pennsylvania at the start of this study in late 2015 (Figure 2).

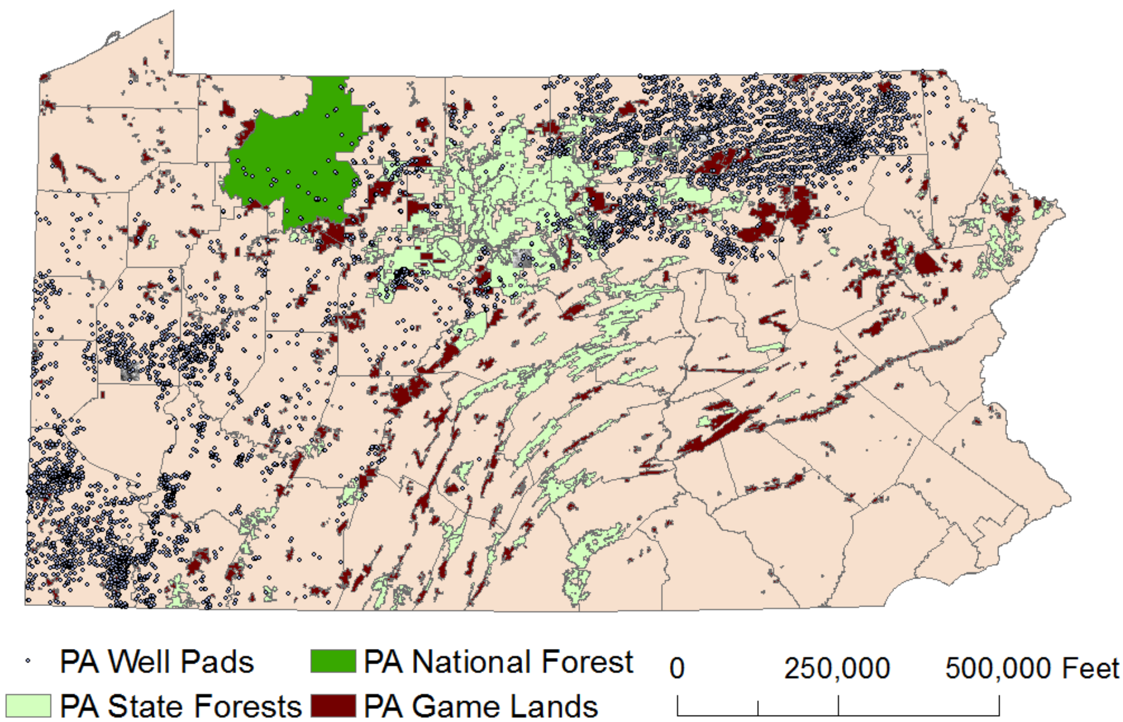


Figure 2. Wellpads in Relation to state-owned land

From 2005 to 2011 the number of drilled wellpads each year increased from less than 100 drilled prior to 2005 to approximately 650 between 2009 and 2011 (Figure 3). However, after 2011, the number of wellpads drilled each year decreased significantly (Figure 3).

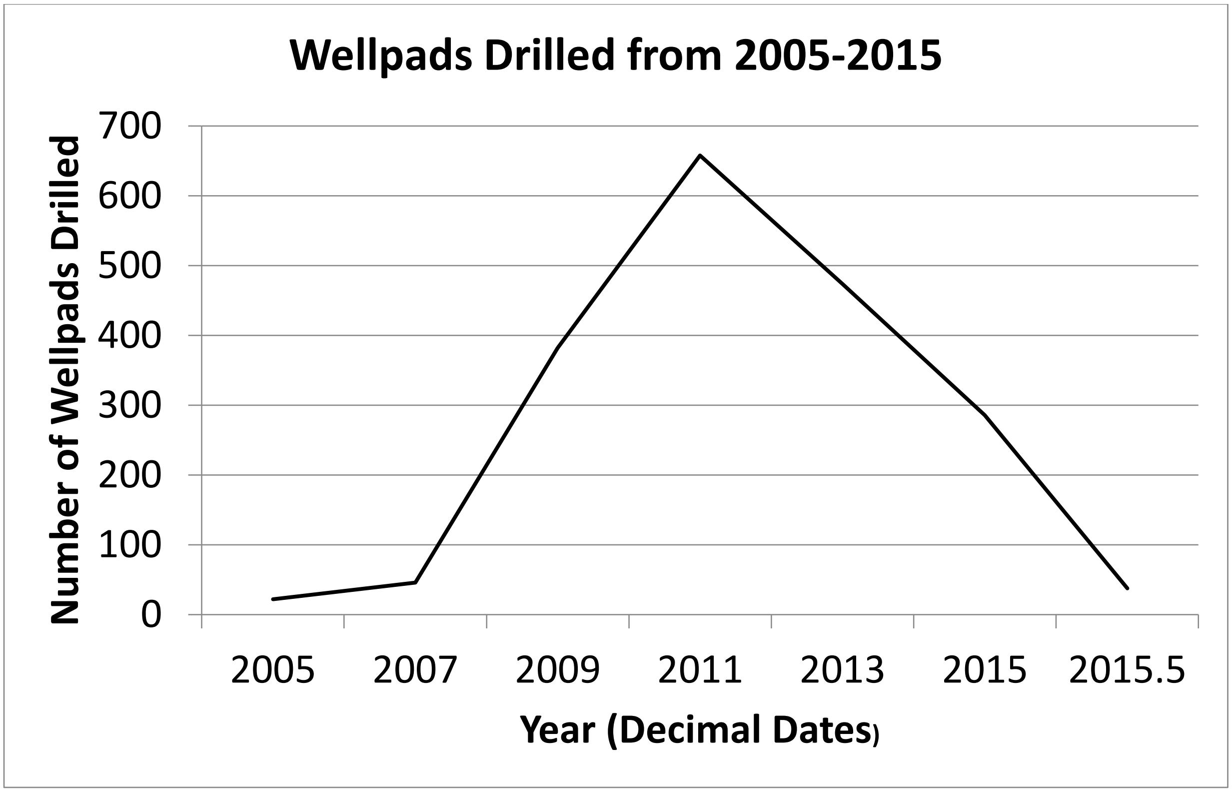


Figure 3. Wellpads drilled in Pennsylvania up to 2005 and every two years following.

Land Cover & Land Use

This study indicated that 43.7% of wellpads were built on forested land cover. This is the largest overall number of wellpads, followed by rural areas, with 30.8% in Pasture/Hay land cover and 20.7% in Cultivated Crop land cover (Table 2). The largest percentage of producing wells were contained within these three land cover types as well at 41.2%, 32.6%, and 22.2% respectively (Table 2). This is a disproportionately large quantity of producing wells located in pasture and cultivated crop land cover areas compared to total area within the Marcellus Shale region. Pasture/Hay land makes up 12.55% of the Marcellus shale, and cultivated crop land makes up 6.08% of the Marcellus shale (Table 2). This trend continues with the permitted wells, a disproportionate quantity of permitted wells also being in these locations at 28.2% and 18.8% (Table 2).

Table 2. Wellpads in relation to 2006 NLCD land cover classes.

Land Cover	% of Marcellus Shale Region	Producing (% of Total)	Permitted (% of Total)	Drilled (% of Total)	Non-Producing (% of Total)	Sum (% of Total)
Developed (21, 22, 23, 24)	8.85	22 (<1%)	2 (<1%)	1 (<1%)	19 (1.3%)	44 (<1%)
Barren Land (31)	.46	17 (<1%)	1 (<1%)	0 (<1%)	14 (1.0%)	32 (<1%)
Forest (41, 42, 43)	67.30	1060 (41.2%)	156 (45.9%)	179 (44.3%)	718 (48.9%)	2075 (43.7%)
Shrub (52)	1.22	29 (1.1%)	11 (3.2%)	10 (2.3%)	32 (2.2%)	82 (1.7%)
Grassland/ Herbaceous (71)	.64	36 (1.4%)	10 (2.9%)	4 (<1%)	17 (1.2%)	66 (1.4%)
Pasture/Hay (81)	12.55	839 (32.6%)	96 (28.2%)	128 (31.2%)	409 (27.9%)	1462 (30.8%)
Cultivated Crops (82)	6.08	572 (22.2%)	64 (18.8%)	82 (20.3%)	277 (18.9%)	983 (20.7%)
		2575	**340**	**404**	**1468**	**4746**

In relation to land use and land cover within Pennsylvania, this study found that although 94% of the Marcellus Shale region is within 1320 feet from a wetland, percentages of producing and permitted wells are relatively small at 45.0% and 33.8% (Table 3). This trend follows similarly with areas within 300 feet from streams, national forest areas, trails, and state forest, although areas within ¾miles of streams have the highest percentage of wellpads overall with 71.7% (Table 3).

Table 3. Wellpads in relation to natural resources.

Natural Resource	% of Marcellus Shale	Restriction	Producing (% of Total)	Permitted (% of Total)	Drilled (% of Total)	Non-Producing (% of Total)	Sum (% of Total)
Trails	1.21	<150 ft.	1 (<1%)	0 (<1%)	0 (<1%)	1 (<1%)	2 (<1%)
	10.62	< 1320 ft.	58 (2.3%)	6 (1.8%)	18 (4.5%)	38 (2.6%)	120 (2.5%)
State Forest	7.63	Within	112 (4.3%)	14 (4.1%)	27 (6.7%)	79 (5.4%)	232 (4.5%)
	11.16	< 1320 ft.	125 (4.9%)	23 (6.8%)	32 (7.9%)	99 (6.7%)	279 (5.9%)
National Forest	3.48	Within	14 (<1%)	5 (1.5%)	15 (3.7%)	9 (<1%)	43 (<1%)
	3.66	< 1320 ft.	14 (<1%)	5 (1.5%)	15 (3.7%)	9 (<1%)	43 (<1%)
Game Lands	5.95	Within	25 (1.0%)	21 (6.2%)	15 (3.7%)	33 (2.2%)	94 (2.0%)
	9.82	< 1320 ft.	77 (2.3%)	34 (10%)	21 (5.2%)	66 (4.5%)	198 (4.2%)
Wetlands	12.45	<300 ft.	45 (1.7%)	2 (<1%)	6 (1.5%)	26 (1.8%)	74 (1.6%)
	94.13	< 1320 ft.	1160 (45.0%)	115 (33.8%)	184 (45.5%)	600 (40.9%)	2059 (43.4%)
Streams	24.29	<300 ft.	64 (2.5%)	0 (<1%)	5 (1.2%)	37 (2.5%)	106 (2.2%)
	77.21	< 1320 ft.	1868 (72.5%)	228 (67.1%)	250 (61.9%)	1057 (72.0%)	3403 (71.7%)
Roadless Areas (>656 ft. from road)	52.14	Within	1486 (57.7%)	224 (65.9%)	224 (55.4%)	893 (61.0%)	2827 (59.6%)
(>2625 ft. from road)	9.92	Within	107 (4.2%)	24 (7.1%)	34 (8.4%)	99 (6.7%)	264 (5.6%)
TOTAL			**2575**	**340**	**404**	**1468**	**4746**

Results: Viewshed

We determined that LiDAR data was more accurate for viewshed analysis than regular DEM data in the verification study of two compressor stations in Adams County, PA. The total area of the South Compressor DEM generated viewshed was 375,174,482 ft^2, which is about 95% larger than the LiDAR generated viewshed (Figure 4). Additionally, the total area of the North Compressor DEM generated viewshed was 432,078,258 ft^2, which is about 95% larger than the LiDAR generated viewshed (Figure 4).

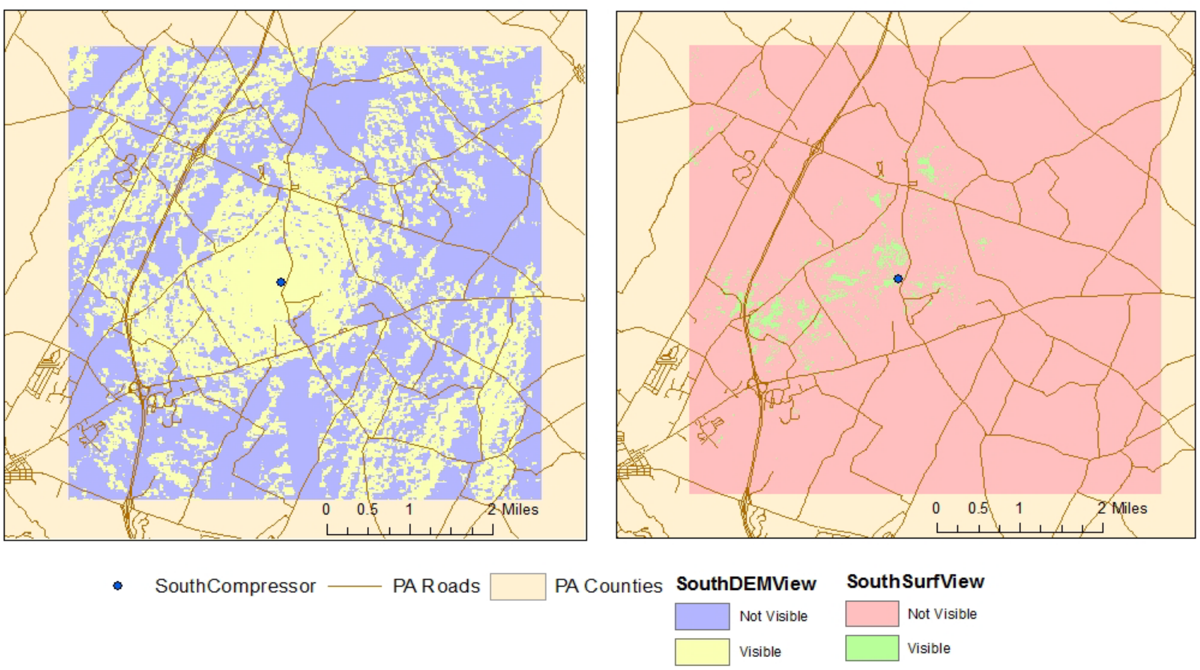
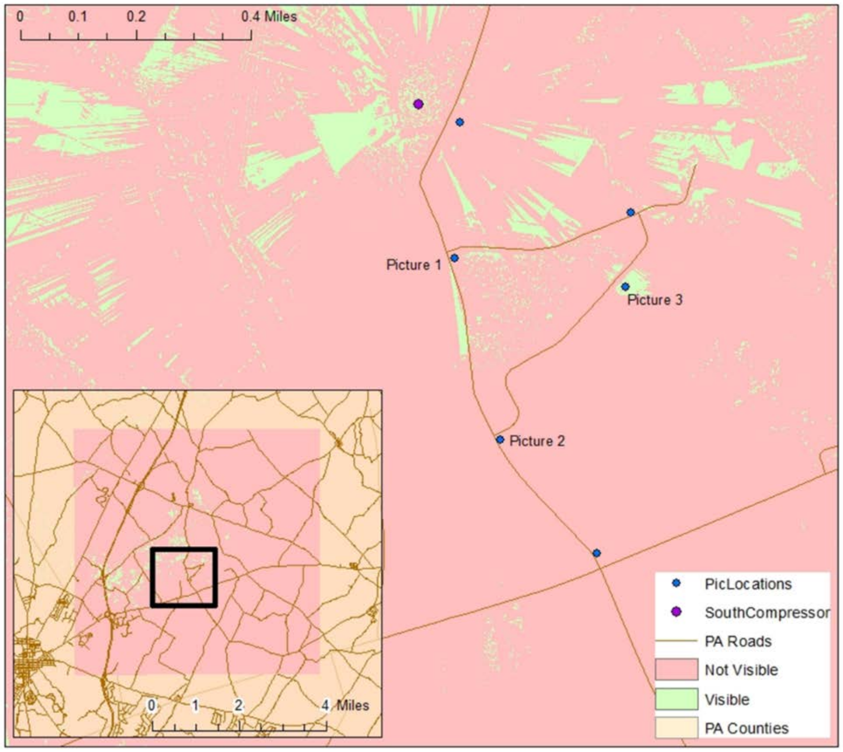


Figure 4. Viewshed of Compressor Station in Adams County, PA using both DEM and LiDAR data.

Ground truth images were taken at 6 sites around the South Compressor station (Figure 5). Out of the 6 images taken, the compressor station site was only visible in two of them, pictures 1 and 3 (Figure 5). In the LiDAR viewshed, these two picture locations were in the visible as well, showing 100% accuracy for this site study (Figure 5).



1.  **2.**  **3.** 

Figure 5. Ground truth images for a compressor station in Adams County, PA using LiDAR data

Of the 13415 tiles in Pennsylvania, 11378 tiles have zero wellpads, and 921 tiles have one wellpad. Only 1116 have at least two wellpads, which is 8.3% of the total land area in PA. This analysis evaluates a sample of the tiles that meet this criteria.

The viewshed analysis found that rural areas are most heavily impacted by fracking wellpads and compressor stations, and that state forest areas are the least impacted overall within the tile areas (Tables 4 & 7). Differences in overall area percentages and road percentages between environment types were found to be significantly different ($p<.05$) (Tables 5 & 6).

Table 5. ANOVA Test for Viewshed % in Different Environment Types

% Viewshed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.204	3	.068	17.784	.000
Within Groups	.138	36	.004		
Total	.342	39			

Table 6. ANOVA Test for % of Road in Viewshed for Different Environment Types

% Road in Viewshed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.130	3	.043	18.323	.000
Within Groups	.085	36	.002		
Total	.215	39			

On average, 17.19% of roads are within the viewshed in rural areas, and only 1.56% are in the viewshed in State Forests (Tables 4 & 7). Only 2.41% of trails are in the viewsheds in State Forest, though they are much more common in State Forest areas than any other environment type (Tables 4 &7). Rural areas face the largest impact overall with an average of 24.14% of a tile present within the viewshed.

Table 7. Percent of total tile area, trails, and roads within viewshed for 4 site types.

Site Type	**Avg. % Tile in Viewshed**	**Avg. % Roads in Viewshed**	**Avg. % Trails in Viewshed (% Tiles with trails in test)**
High Road Density	14.63%	6.13%	14.97% (10%)
Rural	24.14%	17.19%	n/a
State Forest	4.57%	1.56%	2.41% (60%)
Other	18.61%	9.02%	0.00% (10%)

Results: Audioshed

Of the 13415 tiles in Pennsylvania, 13064 have zero compressor stations, and 351 have at least one compressor station. This is only 2.6% of the state of Pennsylvania, but these are the areas that will be most heavily impacted by the fracking audioshed.

High road density and state forest area audiosheds are impacted similarly. On average, 25.89% of a 10,000 x 10,000 ft. tile in a high road density environment is within the fracking audioshed (Table 8). In State Forest environments, 21.54% of the tiles in the sample were within the audioshed (Table 8). The average road percentages within the audioshed samples are also similar between the environment types with 28.96% in high road density and 30.06% in state forest (Table 8).

Table 8. Percent of total tile area, trails, and roads within audioshed for 2 site types

Site Type	**Avg % Tile in Audioshed**	**Avg. % Road in Audioshed**	**Avg % Trail in Audioshed (% Tiles with trails in test)**
High road density	25.89%	28.96%	8.89% (50%)
State Forest	21.54%	30.06%	0.00% (10%)

However, the average trails impacted by the audioshed were much higher in high road density areas with 50% of the tiles containing trails and an average percentage of 8.89%. State Forest had only 10% of tiles with trails at 0.00% in the audioshed (Table 8).

Conclusions and Implications:

Our study found that water sources are potentially being impacted in different ways as a result of fracking. We found that 94% of the Marcellus shale region was within a quarter mile of a wetland, but only 43% of all wellpads were located within this area. This shows a bias against the placement of wellpads around wetland areas. However, this is still a large percentage of wellpads in general, and thus, may have an impact on the watershed area in Pennsylvania. Additionally, we found that although about on par with placement percentage-wise, the most wellpads were placed within a quarter mile of a stream compared to all other resources. Not only does this pose a potential threat to water ways and ground water pollution, but the placement of these wells can also cause further negative impacts due to their biased placement in rural areas.

Rural areas are in danger of the most environmental degradation as a result of fracking according to the results of our study. We found that a disproportionate quantity of wellpads were placed within cultivated crop and pasture/hay land cover areas. Land cover change due to fracking causes erosion, and in rural areas like farms and fields this can lead to excess sediments in surrounding streams and wetlands, increased concentration of nutrients leading to eutrophication, decreased quality of aquatic life, and the overall degradation of water quality (Leh et al. 2013). These increased risks of water pollution could have significant impacts on agriculture and farming in Pennsylvania.

Our study also found that rural areas are more spatially impacted by fracking viewsheds than the other environment types. About 24% of the total tile area was within the viewshed for our study sites, and about 17% of roads were as well. The impact in these areas is significantly different than in the other environment types. According to the DCNR Shale-Gas Monitoring Report, since 2008, scenic "areas of special consideration" have been included in oil and gas leases to prevent the detriment of scenic viewsheds "whenever possible" (Shale-Gas Monitoring Report, 2014). Areas that have been protected must be in forest districts on roads or trails with high scenic value or streams with scenic river destinations (Shale-Gas Monitoring Report, 2014). This means that many areas in Pennsylvania that have a different aesthetic appeal, like rural fields, are not protected through this process.

Recent regulations from the Department of Environmental Protection (DEP) are on the verge of being passed that will further protect land from the impacts of fracking, despite our findings that the number of drilled wells has been decreasing in recent years. Applicants for well permits will be required to inform any relevant public resource agency, such as the DCNR, if a well site is within 200 feet of a public park, forest, game land, wildlife area, or any historical or archeological site. These regulations should help to decrease viewshed as well as natural resource impacts in all different environment types. Our study only concentrated on wellpads contained *within* state forests, national forests, and game lands as regulation. These new regulations would push put that buffer to better protect these resources. However, rural areas, which we have seen as being most heavily impacted by fracking viewsheds, seem to still be left out of the regulations unless a historical or archeological site.

A study on public attitudes toward fracking use and policies in Pennsylvania showed that people in rural areas are less likely to oppose fracking than people in urban areas (Davis and Fisk 2014). This seems contradictory to our findings that rural areas are impacted more heavily by fracking visually than any of the other environment types. This is likely because many Pennsylvania residents are more concerned with economic benefits of fracking as opposed to the environmental impacts (Davis and Fisk 2014). Up to this date, however, there have been no studies concerning public opinion of Pennsylvania residents in relation to the *visual* impacts of fracking.

Our study also looked at potential impacts on forested areas. Forested areas contain the most wellpads overall than any other land cover type with about 44% of all wellpads being placed in this land cover type. However, only 4.5% of all wellpads were placed in *state* forest. This shows a desire to maintain state owned areas preferentially. Additionally, we determined that near to 30% of roads in state forest lie within the fracking audioshed. Many compressor sites have an overnight policy in an attempt to cause less noise disturbance to surrounding trafficked areas (Goodman et al., 2016). However, during these hours, this policy ends up doubling the amount of sound pressure at roadside (Goodman et al., 2016). Thus, any persons or animals in this area would be doubly impacted by the audioshed of the compressor stations during these hours when a lot of other ambient noise will have died down, particularly in high road density and urban areas.

Our study also determined that on average 21% of a 10,000 x 10,000 ft. tile in state forest areas for our sample was impacted audibly by compressor stations for humans. It was found in the study in the Boreal forest that compressor noise was perceptible at distances well over 1 km, which is even higher than our study (Bayne et al., 2008). This means that audioshed impacts could be greater in some areas than our study determined. However, birds have the ability to hear 10-15 dB lower sound pressure than most humans, and thus we would have an even larger resulting impact. Bird density in the Boreal forest was significantly lower near compressor stations compared to other fracking infrastructure, such as wellpads (Bayne et al., 2008). This implies that noise generated by fracking processes does in fact have the capacity to influence habitat quality in surrounding ecosystems for some bird types, which could be detrimental to the rest of the ecosystem (Bayne et al., 2008). In fact, ecological processes such as decomposition, pollination, and seed dispersal would all decrease in areas impacted audibly by compressor stations (Çağan et al. 2004).

Currently, Pennsylvania only has the regulation that the noise level cannot exceed 60dbA at the nearest property line (Title 58, 2012). In a study at Rattlesnake Canyon Habitat Management Area (RCHMA), located in northwestern NM, USA, it was found that of 16 km^2 study area, 84.5% of that area was impacted by compressor station noise when measuring in C-weighted decibels with a baseline of 55dB (Francis et al. 2011). This is clearly a much larger impact than our study suggests, though this may relate to the land cover and environment types present at this site. However, due to the clear significant impact of fracking noise on habitats, it is clear that something must be done to further regulate the noise.

Since bird density and nest success rates are only two ecological processes out of many that could be impacted by compressor noise exposure, we see that reducing anthropogenic noise in relation to fracking should be a conservation priority (Francis et al. 2011). This study also determined that the use of sound barrier walls around these compressor stations could reduce the area affected by the noise by about 70% (Francis et al. 2011). Doing this could maintain bird density levels at much closer levels to areas not impacted by compressor station noise. This also shows that audiosheds can be effectively managed despite the lack of regulations in Pennsylvania currently. Our study suggests that areas within a minimum of about 2,000 feet of a compressor station are within the audio-impact zone, and thus will have ecological and anthropogenic consequences. Regulations should be set into place that ensure protection for the surrounding habitats as well as the natural resources in Pennsylvania.

Appendix

Table 4. Percentages of tiles in viewshed, roads in viewshed, and trails in viewshed within the 4 environment types.

TILEID	Viewshed Type	% of Tile in Viewshed	% Trails in Viewshed	% Road in Viewshed
22001380PAS	High Road Density	14.81%		3.29%
29001340PAS	High Road Density	12.39%		7.03%
33001290PAS	High Road Density	10.22%		5.91%
33001420PAS	High Road Density	27.43%		9.44%
36001280PAS	High Road Density	16.84%	14.97%	9.26%
42002180PAN	High Road Density	7.26%		1.23%
43001240PAS	High Road Density	12.61%		5.17%
50001400PAS	High Road Density	13.58%		5.25%
52001350PAS	High Road Density	20.51%		11.07%
56001380PAS	High Road Density	10.63%		3.65%
27001320PAS	Other	29.95%		18.12%
34001910PAN	Other	6.78%		0.00%
36001220PAS	Other	28.50%		9.51%
38001590PAS	Other	9.04%		8.08%
40002260PAN	Other	27.37%		9.75%
51002340PAN	Other	14.57%		8.09%
52001450PAS	Other	10.93%	0.00%	5.38%
54001450PAS	Other	14.97%		6.74%
58002140PAN	Other	27.16%		12.89%
58002550PAN	Other	16.83%		11.65%
32001320PAS	Rural	25.48%		9.62%
56001290PAS	Rural	16.49%		13.06%
56002480PAN	Rural	25.28%		25.79%
57002390PAN	Rural	20.53%		15.97%
58002240PAN	Rural	19.76%		12.50%

61002470PAN	Rural	21.67%		17.52%
62002360PAN	Rural	33.35%		31.65%
63002090PAN	Rural	30.21%		14.91%
63002200PAN	Rural	27.88%		23.65%
66002160PAN	Rural	20.72%		7.27%
34001750PAN	State Forest	0.78%	0.00%	0.15%
39001960PAN	State Forest	9.44%	8.79%	4.65%
42002060PAN	State Forest	1.12%	0.00%	0.41%
44002010PAN	State Forest	4.95%	5.70%	2.08%
46002070PAN	State Forest	0.15%	0.00%	0.00%
47002160PAN	State Forest	7.56%		0.38%
54001770PAN	State Forest	1.94%		0.06%
55002170PAN	State Forest	10.27%		0.51%
56002030PAN	State Forest	2.44%	0.00%	3.26%
56002180PAN	State Forest	7.10%		4.10%

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