LAND USE EFFECTS OF NATURAL GAS WELLS: A COMPARISON OF CONVENTIONAL WELLS IN NEW YORK TO UNCONVENTIONAL WELLS IN PENNSYLVANIA

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ABSTRACT Hydraulic fracturing has revolutionized the natural gas industry with its application to drilling in shale formations and has been combined with horizontal drilling technology to create a novel and unconventional process for extracting natural gas from places once thought inaccessible. The opening of new areas to natural gas drilling created a boom in the mid-2000s with the Marcellus Shale play in Pennsylvania. Thousands of new wells were drilled every year using the unconventional technique. The land use changes of natural gas wells have not been thoroughly investigated. With new drilling techniques being used on a large scale, the question of how these new drilling methods affect the land is being asked. Conventional gas drilling in New York State was compared to the unconventional drilling techniques being used in Pennsylvania regarding the land use effects of natural gas well pads. Spatial analysis was done using ArcGIS software to determine the quantitative effects of individual well pads on land use changes and new road construction. It was found that both conventional and unconventional wells require similar demands on the landscape with both involving the clearing of forests. Further, wells that had been hydraulically fractured required more forest to be cleared, had larger well pads, and required more new road construction. The clearing of forested land combined with the construction of permanent and semi-permanent structures is important in understanding the larger effects of natural gas development on local land use changes.

Keywords: *GIS, land use, land cover, hydraulic fracturing, natural gas*

INTRODUCTION

Though the unconventional drilling techniques of high volume hydraulic fracturing and horizontal well formation are not new, their combination and the subsequent boom in gas drilling in the past fifteen years have brought changes to the land at a scale that is still beginning to be understood (Blohm et al., 2012). These effects go beyond the actual well formation and include the construction of necessary infrastructure like roads, pipelines, and collection centers for on-site operation. The effects are not isolated either with 8,030 wells inspected in Pennsylvania alone between 2005 and 2013, 7,317 of which being reported as unconventional wells drilled in this time period (Davies et al., 2014; Manda et al., 2014). These landscape changes are also occurring at the national level with Texas, Colorado, the Dakotas, and other states using shale drilling technology. The primary differences between the hydraulic fracturing process and conventional well development is that hydraulic fracturing wells require millions of gallons of water to break up the shale along the horizontal drilling path while conventional wells require far less water because they are drilled vertically and only contact the formation along the vertical path (Davies et al, 2014).

Unconventional wells that use high volume hydraulic fracturing and horizontal drilling have one other unique factor: the increased tendency for the well pad to house multiple wells. The majority of wells drilled with fracturing in the Marcellus shale have had multi-well pads because it increases the economic viability of the production to have many wells in one place as opposed to separate wells spaced out from one another on individual well pads (Manda et al., 2014). The tendency for multi-well pads is a more recent phenomena with a majority of pads developed from 2009-2013 being reported as multi-well pads (Manda et al., 2014). This practice has a direct effect on the land similar to conventional well drilling and has been explored by some researchers including the tendency for wells to be located on private land, land use patterns as they relate to watershed location, and examining how close wells are located to freshwater sources (Drohan et al., 2012; Slonecker et al., 2012; Slonecker et al., 2015). The specific effects of well pads on land use patterns are of interest because the changes are measurable using spatial analysis and important in contemporary discussion of future shale gas plays where new wells appear in high numbers and are multi-well pads. In addition a comparison of unconventional drilling to conventional drilling will offer insight as to similarities and differences between them on how the land is affected.

As noted by other authors, the effects of conventional drilling on the landscape has received less attention in the literature than unconventional drilling making its presence in this paper important in determining landscape changes (Slonecker et al., 2015). Natural gas wells have directly impact the land starting with site identification and begin changing the landscape with well pad and infrastructure construction, well drilling, high volume hydraulic fracturing for unconventional wells, and then production (Brittingham et al., 2014).

The questions this project is intending to answer are: (1) How does land use change as a result of unconventional drilling, and (2) how does this compare to conventional drilling? The hypotheses are: (1) wells that have been fracked (unconventional) will use more land area and have a greater impact on the land use changes than conventional wells; and (2) fracked wells will require a greater amount of new road construction. It is predicted that if a natural gas well is fracked it will require a greater amount of infrastructure than other conventional wells because the process involved requires among other things greater road construction to facilitate increased tanker truck traffic carrying water for fracking fluid and well pads are larger because many are multi-well pads (Slonecker et al., 2012). The water demands have been noted by other research projects as requiring importation of water by many vehicles which creates a demand for solid and extensive infrastructure (Brittingham et al., 2014).

METHODS AND MATERIALS

Selection of States to Examine and Well Sites

This study seeks to learn the effects of conventional and unconventional drilling on the landscape. To compare these two processes, wells were selected from the states of Pennsylvania and New York. Both states have a long history of drilling conventionally and it may have been possible to locate the study entirely within PA; however, it was decided that two different states would be studied for a few reasons. One is that NY has had no unconventional drilling within its borders and will not have any for the foreseeable future due to recent law changes. This gave the researcher a state where only one kind of drilling is occurring and thus the state acts as a control. PA continues to have extensive unconventional drilling but most recent drilling activity has been unconventional as noted above. Thus, the majorities of new wells being drilled are unconventional and will likely be going forward, it seemed logical to locate the unconventional wells studied in PA and focus on those changes.

There are challenges to organizing research project like this including the external variables of varying state and local regulations on land use patterns which may account for some differences found in this study. It is important to note though that the original regulatory ban on fracking in NY was caused by a lack of up to date laws to handle the new regulatory challenge which this drilling practice brought with it, specifically the lack of a Generic Environmental Impact Statement (New York State Department of Environmental Conservatio, 2015). Thus the widespread environmental effects of drilling were largely unknown at the time. Since then, extensive studies have been done to examine the effects of drilling on the landscape today. By selecting wells drilled in the last ten years, the researcher avoids major problems with regulatory changes that may have altered the way drilling is done today as opposed to in the past.

Data Collection: Well Sites

Selection of sites for analysis was the first task to complete. The most recent land cover data for study were the data for the years 2006 and 2011 which led to selection of well sites that were established within these years. With most unconventional drilling having occurred in large numbers in PA after 2005, selection of sites for both conventional and unconventional drilling was done for wells drilled after 2007 and before 2010 to fall within the available land cover data for 2006 and 2011 and to provide a diverse amount of locations in both states.

PA well locations were difficult to find as no single comprehensive and complete database was available for PA. That is, no one database contained all the relevant material for this research project in an easily searchable form. Thus, links found on Natural Gas Forums were used for maps of specific counties where hydraulic fracturing was occurring (Natural Gas Forum for Landowners, 2015). These wells were identified on the Google map links and then selected for dates between January 1st, 2007 and January 1st, 2010. To learn the name of the well and other relevant information, their Facility IDs which were noted on the Google map links were searched in the PA Department of Environmental Protection permit application searchable database (Pennsylvania Department of Environmental Protection, 2015). Wells were found in five PA county maps from the forums page, including Bradford, Tioga, Wayne, Sullivan, and Susquehanna. Various counties were selected to give the project a more broad perspective of state averages for the effects of wells. These counties were selected because of the availability of the data and individual sites were selected for their location as at the time being distanced from other wells to avoid cumulative effects being measured. This project was focused on the effect of individual well pads not many well pads close together. Twenty wells meeting the criteria were selected for analysis as indicated in Figure 1. Well sites were verified as being horizontal by cross referencing the well's name with environmental watch groups' websites specifically the FracTracker Alliance (2015) and the Natural Resources Defense Council (2014). Horizontal wells were required because they require the amount of water and drilling techniques that are considered unconventional to distinguish from the conventional drilling practices.

NY well locations and information were obtained from the NY DEC Oil and Gas searchable database (New York State Department of Environmental Conservation, 2014). Search criteria for the sites were: well type gas development, permit application date after 01/01/2007, permit application date before 01/01/2010, and well status active. The active well status was preferred because it ensured that the well itself had been drilled. The results provided over 800 wells of which 20 wells meeting the criteria were selected for analysis. Wells were selected from several counties; different counties were preferred to give statewide estimates on the effects of drilling. Their locations are noted in Figure 1 in western and southern NY.

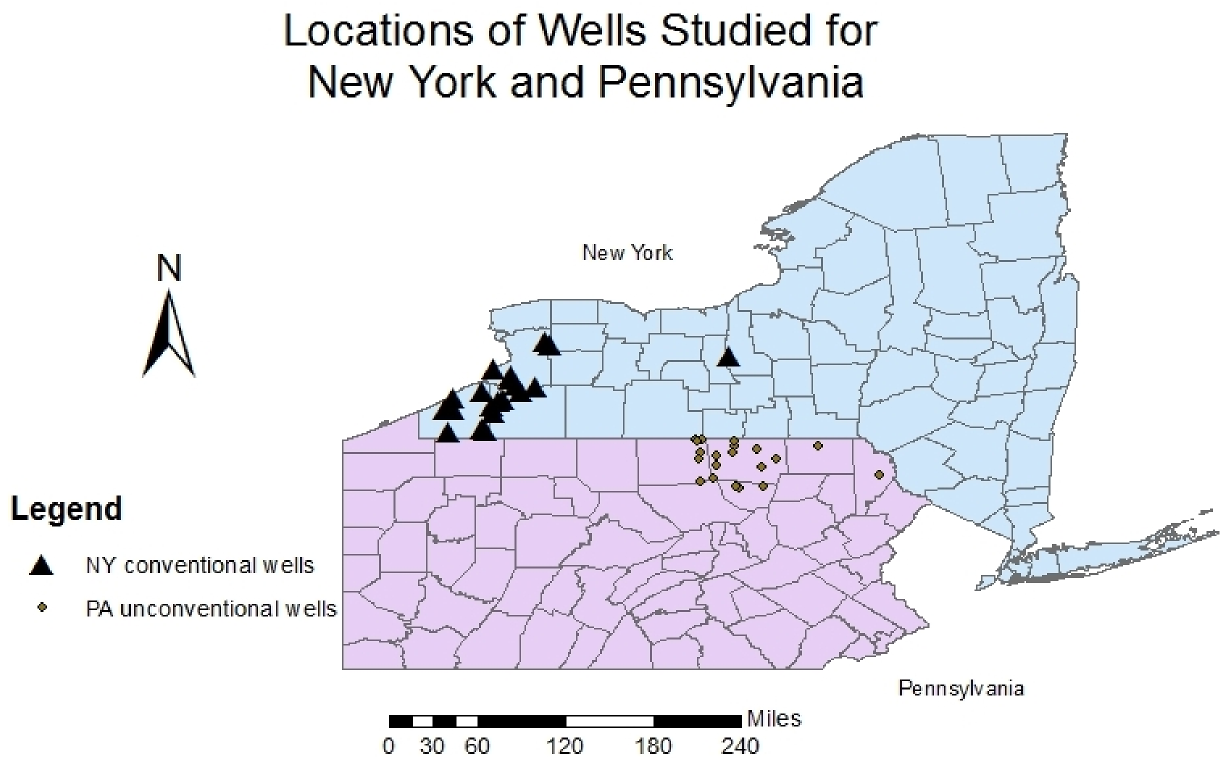

Figure 1: New York and Pennsylvania states with the points indicating the geographic location of the wells examined.

Data Collection: Maps

To approach the question of changes in land use, spatial analysis was done on map data in ArcGIS 10.2.2. Land cover files were the primary data source obtained from the National Map Viewer (United States Geological Survey, 2015). National Land Cover Database files were obtained for the years of 2006 and 2011 for both NY and PA. The 2006 data was compared to the 2011 data for conventional NY wells and unconventional wells in PA that were drilled from 2007 to 2010.

Road data was downloaded from the US Census Tiger/Line database (United States Census Bureau, 2015). For NY the line data which contains the spatial information on roads was downloaded for the counties of Cattaraugus, Chataqua, Cayuga, and Erie for the years of 2006 and 2011. For PA the same data was downloaded for the counties of Bradford, Tioga, Wayne, Sullivan, and Susquehanna. All wells analyzed for all tests were from one of these counties as seen in Figure 1.

Data Analysis: Geospatial

PA wells were examined first with well coordinates put into an Excel file and then opened in ArcMap. The coordinates were then converted into a points file and projected using the geographic coordinate system North America 1983. Then the 2006 land cover file for PA was loaded as a raster image in ArcMap. Next, a buffer of 1 kilometer was added for each data point. A distance of 1 kilometer was used because it captured all relevant information around the well, changes beyond the well pad itself like roads, accounted for imprecise data coordinates, and because each well's size and impact was unknown. The land cover file was clipped for each point's buffer leaving one km radii circles for each point. The new land cover file with the buffers was then converted to a polygon for measurement. After this the intersect tool was used to combine the data points from the original points file to the new land cover polygon file so each set of polygons could be matched up to the relevant well pad. The new layer containing the landcover polygons was projected to Albers Equal Area from North America 1983 to match the projection of the coordinates. The area in square meters was calculated for each polygon. Next, each layer was separated by land cover grid-code so that each new layer represented all the polygons for each land cover characteristic. For example, all the developed open space polygons were in one file for calculation. Then each database file was brought into Excel and the total area for the land cover type for each was calculated. This process was done a total of fifteen times for each land cover year representing the fifteen different land cover characteristics listed in Table 1.

In Excel, the total area for each well's respective land cover was calculated for each characteristic. Land cover characteristics were recoded from the map to new categories by combining similar land characteristics which can be examined in Table 1. This allowed for certain important land areas to have their changes more easily measured against the land areas where changes were expected to be minimal.

Table 1: Recoded Land Cover Characteristics

Land cover characteristic	**Recoded characteristic**
Open water	Open water
Developed open space	Developed open space
Barren	Barren
Deciduous, evergreen, mixed forest	Forest
Shrub / scrub, herbaceous	Shrub / herbaceous
Hay / pasture, cultivated crops	Pasture / cultivated crops
Woody, emergent herbaceous wetlands	Wetlands

The above steps were then repeated for the land cover data of PA in 2011 and NY in 2006 and 2011 respectively.

Road data in 2006 and 2011 were extracted respectively from the Tiger/Line shapefiles for the four counties in NY and five counties in PA. The road layers were ten clipped with a 1 km buffer using the coordinates of the well sites for each buffer. New roads that were observed in the 2011 file but not in the 2006 file were measured and recorded.

Data Analysis: Calculations

Averages for the twenty PA wells and the twenty NY wells were then calculated for each land cover type from Table 1 and are represented in Figure 2. Figure 2 displays the average land cover change for PA and NY for the years of 2006 to 2011. For roads, PA new road length was measured for each well and an average was calculated across the twenty wells. The same was done for NY and the data is represented in Figure 3. Figure 3 displays the cumulative average new road length for the wells examined for PA and NY from 2006 to 2011. For all calculations zero values or no change values were included with the positive and negative change values to represent all wells equally.

RESULTS

Classification of Wells

The United States Geological Survey which produces the National Land Cover data sets classifies natural gas wells as developed open space. Through correspondence with the USGS office, it was also learned that some natural gas wells do not get properly coded into these datasets for various reasons including the wells being un-flagged for geographers. These un-flagged wells then get classified as barren land in the dataset. Therefore, this project took careful note of the changes in developed open space and the changes in barren land.

In an exploratory look at natural gas wells in both NY and PA, it was found that developed open space was not the best category for studying wells in this project. Though some locations showed changes in this characteristic, most did not. There were; however, significantly greater changes for barren land changes. Thus, this project focused its attention on the changes in barren land as the best indicator of the presence of the well pad after its construction. It is important to note that the researcher did do a comparison including both developed open space changes and barren land changes in a test of the average and compared it to the results of just the barren land. The results showed that inclusion of the developed open space characteristic had a negligible impact on the values gathered and described here.

PA Unconventional Wells

The presence of the well pad is best represented by the barren land characteristic as can be seen in Figure 2 with a significant increase being noted. The average change as noted in Figure 2 for PA was an increase in coverage of over 10,000 m^2. This would account for wells of an average size of about one hectare. The other notable increase was of shrub-land and grassland which for PA rose also by over 10,000 m^2.

Notable decreases in PA were of forest land of which over 15,000m^2 of forest was lost. Also, crop pasture land decreased almost 18,000 m^2 as seen in Figure 2.

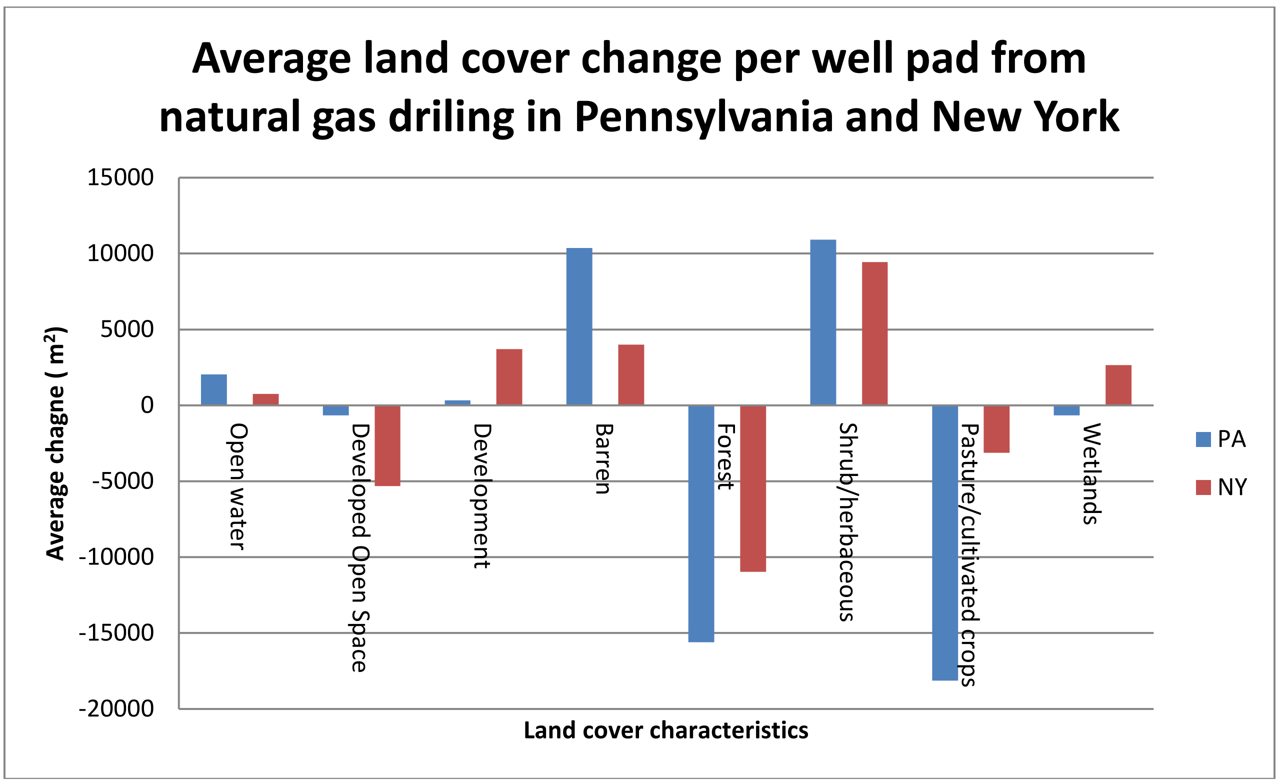

Figure 2: Average change in land cover for PA and NY per well. Averages were calculated from twenty wells for each state. Negative values indicate a decrease in that land cover type while positive values indicate an increase.

NY Conventional Wells

NY well sites also changed considerably. Similarly to PA, NY saw decreases in developed open space characteristics. Barren land did increase for NY for an average of about 4,000 m^2 per well. Shrub and herbaceous land also increased about 9,500 m^2.

Decreases as can be seen in Figure 2 were largest for forest land of a little over 10,000 m^2. Crop and pasture land did not decrease nearly as much as PA with only about 3000 m^2 of land lost.

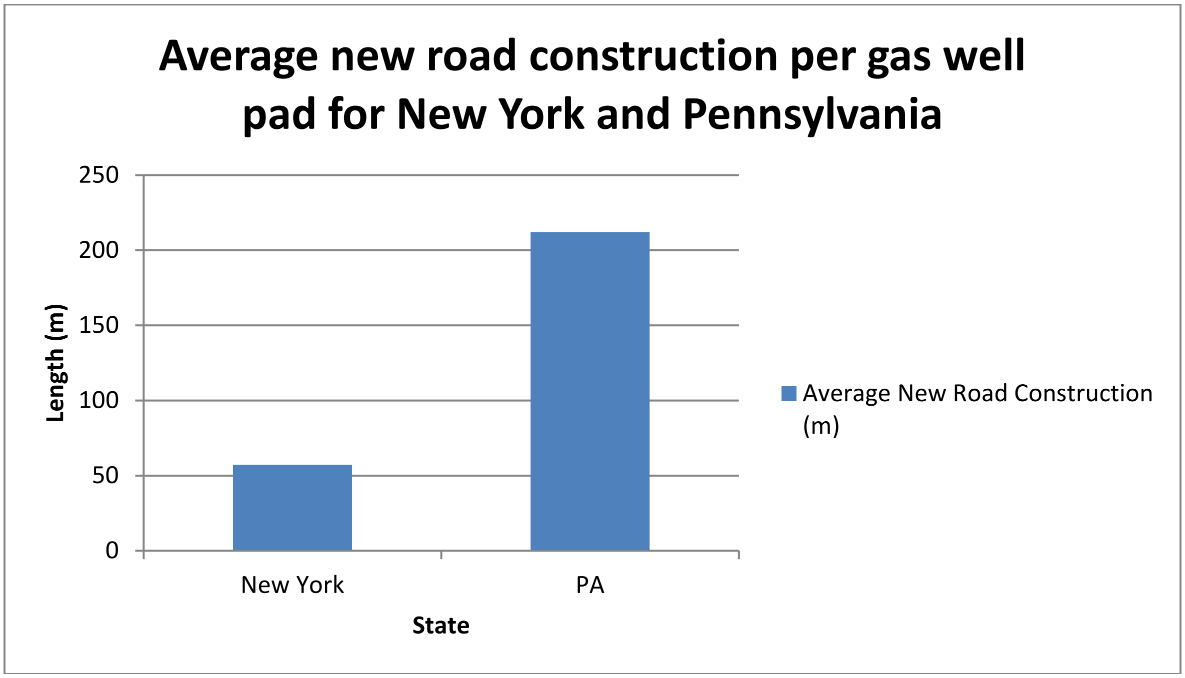

Figure 3: Average length of new roads built for PA and NY per well.

PA and NY New Road Construction

PA new road construction was over twice that of NY as seen in Figure 3. For PA new road construction averaged just over 200 m per well and for NY just over 50 m per well of new roads was created.

DISCUSSION

Conventional v. Unconventional Wells Land Use Changes

An overall increase in barren land which represents the well pads was found with more than double the area for PA wells than NY. This is likely because the unconventional PA well pads are larger as many are likely to be multi well pads. The average decrease in developed open space suggests a lack of a compiled database which allows for correct coding of well pads. This variability may also result from the fact that the land cover files themselves are only accurate to 30 m. Thus, the resolution may have affected the results.

Forest land and former crop or pasture land were primarily replaced by barren land, which is the well pad, and grassland. The overall loss of forest for both drilling processes indicates an important environmental point made by other authors. Habitat loss and forest fragmentation occur because of drilling, road construction, and well pad establishment (Brittingham et al., 2014). Gas drilling often occurs in rural areas and thus these areas usually have more forest land to lose (Brittingham et al., 2014; Slonecker et al., 2012). The increases in shrub-land and herbaceous land are indicative of primary successor species beginning to fill in previously forested land in the early stages of reclamation which suggests that more land is cleared than needed. The above results indicate that the unconventional drilling resulted in more grassland afterward than conventional drilling. This implies that more land is cleared in the hydraulic fracturing process. Also much of that land may not be used for the well pad or other construction. It may be done to set back the forest line from the well pad itself in forested areas.

In addition to high losses of forest land, there was also a large loss in cropland and pasture land in PA compared to NY, 18,000 m^2 to 3000 m^2 respectively. An explanation of this greater loss in farmland is that many fracking wells yield high royalties for landowners with high expectations of profit from drilling who previously made an income from farming chose no longer to do so. Also, landowners may be hesitant to grow crops or keep livestock so close to the well pad for various reasons. In addition, a similar study looking at land cover change in Pennsylvania noted a tendency for wells to be located on land once farmed and suggested that drilling may be competing with farm production (Drohan et al., 2012). Further, the study noted that forty-eight percent of drilling in PA was occurring non-forest land (Drohan et al., 2012). The results of this paper also found that most of the land changes from well-pads were conversion of non-forest land and was usually agricultural land before.

In addition, drilling operators have argued that multi-well pads tend to impact the environment less than single well pads. The results of this paper would suggest that this claim is questionable particularly as the PA well data suggests that the effect of unconventional wells on land clearing is greater than conventional. Even if the well is a single pad, it is on average greater; the multi-well pads have even greater demands of water, resources, pipelines, and space for the pad itself to accommodate the multiple wells. As noted earlier, most new wells being drilled in shale regions are multi-well pads (Manda et al., 2014).

New Road Construction

The data in Figure 3 demonstrate that new road construction is one area where the fractured wells far surpassed the conventional wells. With more than doubled in average length of new roads constructed for fracked wells, the permanent impact of unconventional wells is greater than conventional. The major reason is that fracked wells require millions of gallons of water which is usually imported by tanker trucks. It has been estimated that one fracked well requires 3,300 one way truck trips (Brittingham et al., 2014). This amount of traffic requires roads that are stable; paved roads are most likely used and are much more permanent.

The USGS produced a study recently that went into some detail on the changes to forests in PA as a result of the construction of well pads and the associated road construction with that and the affects this has on fragmenting the landscape (Slonecker et al., 2015). The report by Slonecker et al. (2015) goes into great detail about the effects on the land and forests but is focused on two counties within PA which gives an idea of the effects of shale in PA but does not offer the comparison to conventional drilling or to other states in the region.

CONCLUSIONS

Summary of Significant Points

This study quantified the land use effects of conventional wells in NY and of unconventional drilling practice in PA respectively. The results show significant forest fragmentation in both processes and greater permanent land change effects from unconventional drilling due to larger well pads and greater road length construction. Forest land area in NY and PA and replaced by barren land (well pads), grassland, and shrub land. The amount of forest land removed was greater in unconventional wells. Further, PA witnessed drastic reductions in land once used for farming or pasture with high proximity to the well pads. Road construction was far greater for PA unconventional wells with over twice the average amount of construction at unconventional well sites than conventional.

Habitat and Forest Changes

The changes that are highlighted in this paper reflect significant altercations to the landscape including the removal of forest habitats and the general clearing of space to accommodate the well pads. As noted by other authors, well pads are not considered habitats and thus the lost habitats are almost certainly gone for good (Brittingham et al., 2014). The division of forested land by roads is a concern related to this.

The report by Slonecker et al. (2012) highlights how some drilling occurs in very dense quantities with several hundred wells are requiring roads, pads, and infrastructure that fragments the forests. Though not all well pads are in forested regions, this paper found that individual well pads remove about 15,000 m^2 of forest per well. Further, the roads that are constructed are not continuous like one long length of a highway, but individual, small road lengths per well which cut up the forest regions. Slonecker et al. (2012) report significant rises in new forest edges and provide information on how many forest areas once contiguous are now divided into smaller sections representing this fragmentation.

State Wide Change Estimates

This data can be used to compare the overall state wide effects of natural gas drilling in PA and NY. In PA as mentioned earlier 7,317 horizontal wells have been drilled (Manda et al., 2014). Taking the numbers from Figure 2 this is equivalent to 109,755,000 m^2 of forest being removed or 10,975.5 ha. Also in PA and estimation of 1,463.4 km of new roads were built to accommodate these wells using the average new road length per well from Figure 3. This estimate is greater than found in other studies; on report had the estimate of new road coverage at 649 km (Drohan et al., 2012). The study did note that they were working with less accurate road data but both numbers are considerable. The USGS study mentioned earlier also looked at road changes and noted that the lengths of new roads tend to be small per shale well, 0.2 km on average which corresponds to the results found in the paper by this author of 200m per unconventional well or .2 km (Slonecker et al., 2012). The volume of change occurring is due in part to the number of wells being drilled. In NY only 900 wells have been drilled since 2005 (Wells data search, 2014). This results in about 900 ha of forest lost total and using the average of 50 m per well about 45 km of new roads across the state.

These changes are not small; it is true that with more drilling more forest and cropland will be replaced by grassland and barren land but the degree of change is greater for the horizontally drilled and hydraulically fractured wells than the vertical conventional wells.

Suggestions for Further Research

Orphaned or abandoned wells are an issue around the US today. Over a million conventionally drilled wells that are unused have not been reported as sealed or capped (Davies et al, 2014). Thus, one must consider the number of wells drilled unconventionally in the past eight years over a landscape where the exact amount of retrievable gas is unknown and abandoning of wells can be expected to rise with more wells becoming inactive over time (Blohm et al., 2012). Abandoning of these wells may be greater than past wells because of this overestimation. A study looking at the success of fracking could be beneficial in the future as well as research into land reclamation efforts of current drilling operators to account for orphaned and abandoned wells.

This study answered the question of how much the land has changed; however, the larger implications of this study are not yet determined. Looking into the combined effect of carbon sink removal with forests being replaced by barren land, grassland, and the co-occurrence of emission of methane from wells could yield large implications of natural gas drilling on climate change in the Appalachian region which contains many forested regions. Methane gas escape during drilling is an occurrence that happens in both conventional wells and unconventional wells and researchers report that leaks from one to five percent can negate the advantages of natural gas compared to other fossil fuels (Allen, 2014). This may be unrelated to land cover change but when examined in tandem with changes like forest removal, the drilling of unconventional wells has a large carbon footprint in the Northeastern US where drilling is likely to occur on forest land. This footprint is worth being examined as drilling activity in the US accelerated in the middle 2000s with hundreds of wells drilled a year and in some cases thousands across multiple states removing thousands of hectares of forest land and leaking methane.

It is important to note that this study looked at the land use of natural gas well pads and road construction in the vicinity of new wells without examine other drilling related changes in the landscape like pipeline construction and other infrastructure like pumping stations and collection centers. The study mentioned earlier by the USGS authored by Slonecker et al. (2012) does go into depth examining the more cumulative effect of external buildings and pipelines along with landscape changes but this information is for PA only. A look at cumulative conventional well drilling effects in other states would allow for interstate comparisons.

It is clear that the environment is affected by the drilling of natural gas wells. With new and more efficient drilling methods being used, we must continue to study the effects of drilling on a changing landscape. New drilling techniques mean new effects on the land and on habitats and wildlife.

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