Assessing Land Use Changes Due to Marcellus Gas Operations in Bradford County, PA

Abstract

Marcellus Shale gas drilling became of particular interest in the late 2000's, with gas fields and well pads becoming prominent fixtures throughout the Appalachian Basin region by 2010. Bradford County, Pennsylvania has the highest number of permitted and actively drilled Marcellus Shale wells in the state (DEP 2011). Because of the intensity and speed at which the natural gas industry has infiltrated Bradford County, there is little research available to provide insight on the implications of Marcellus Shale gas drilling, particularly in terms of the amount and types of land that have been altered for extraction purposes. Using high-resolution aerial photography, land cover data, and well point data, this research was able to quantify the amount of land that has been altered as of 2010 as a result of Marcellus Shale gas drilling. Approximately 2400 acres of land have already been cleared in order to develop well pads. This does not include any additional infrastructure such as pipelines of access roads. Using current data, forecasts have been made to quantify the potential acreage that could be converted to well pads, as well as the types of land cover currently converted, and how that translates into future land cover conversion.

Introduction

Marcellus Shale is an organically rich black-shale, which is currently being explored through drilling as a prominent source of natural gas. The Marcellus Shale Formation encompasses most of the Appalachian Basin, which stretches from Ontario, Canada, through New York, Pennsylvania, Ohio, Maryland, West Virginia, Virginia, and a very small portion of New Jersey. Much of the land within the Appalachian Basin region is forested, with agriculture interspersed, and small concentrations of low-density development. In order to viably extract the natural gas, a process called hydraulic fracturing is implemented within the drill sites. The incumbent process is less invasive than other natural resource extraction, such as coal or oil. The infrastructure is only a fraction of the size of a coal mine. However, the implications from establishing the well pads, as well as the influx in population to the rural regions has become a cause for concern among environmentalists, geographers, land owners, and economists alike. The commercial drilling and exploration for Marcellus Shale really began to take shape in the late 2000's, and has created a buzz throughout the energy sector, causing everyone to want a piece of the

proverbial pie. By 2010, gas fields and well pads became prominent fixtures in much of the Appalachian Basin region (DCNR 2011.)

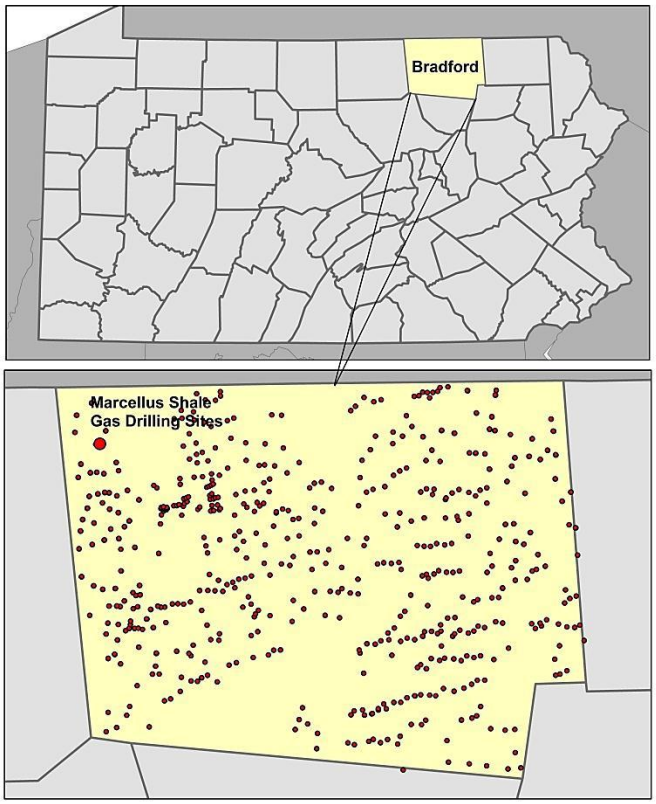

Figure 1: Location of Bradford County within the state of Pennsylvania. Currently permitted well sites also depicted.

Study Site – Bradford County, Pennsylvania

The number of permitted wells and active wells increases every day, with Pennsylvania leading the way in natural gas exploration. Marcellus Shale natural gas drilling became an integral part of Bradford County in 2008. Bradford County is located at the border between Pennsylvania and New York and encompasses 1,147.40 square miles (US Census Bureau 2010). It is largely agrarian, with large tracts of forest intermixed (Bradford CountyPA.org 2011). It is comprised of mostly low-density development, with the average being only 54 people per square mile (US Census Bureau 2010). The Pennsylvania Department of Environmental Protection (DEP) is responsible for the permit regulatory processes, and thus has the most current data for the state. Since drilling began in 2008, the number of wells has increased by more than twenty percent (BradfordCountyPA.org 2011). DEP reports that as of November 8, 2011, Bradford County, Pennsylvania has the highest number of permitted and actively drilled Marcellus Shale wells in the state. In fact, there are nearly three times as many permits issued and wells drilled in Bradford County than in any other county in Pennsylvania (DEP 2011). The Marcellus Shale is the deepest there, ranging from 75

feet to more than 250 feet of viable, gas producing Marcellus Shale (DCNR 2011). Because of the intensity at which the Marcellus rush has hit Bradford County, there are some questions as to the amount of land that has been altered in order to fit and maintain the extraction operations. In addition, drilling for Marcellus natural gas is a very recent endeavor, and there is a definite lack of research, data and quantification of the impacts pertaining to Marcellus Shale drilling. These provide a basis for new research, and this subsequent analysis of land change in Bradford County.

Objectives

We have several objectives which aim to detect and quantify land changes due to the emergence of Marcellus shale drilling in Bradford county.

- Delineate the average footprint (in square meters) for a well pad, based on currently developed well pads
- Determine how much area has been changed as a result of the installation of well pads
- Determine what type of land cover was converted by the installation of the well pads
- Quantify the amount of land cover that was converted per land cover type
- Determine the average number of permitted wells per developed well pad
- Forecast total potential amount of land cover change based on current number of permitted wells and average well pad size
- Forecast the potential amount of land cover per type that could be changed, based on the forecasted total land cover change and the amount of land cover already changed per type

Data

All data were derived from the Pennsylvania Spatial Data Access website (PASDA) which is available at www.pasda.psu.edu.

- **Oil & Gas Locations**

Pennsylvania Department of Environmental Protection. *Oil & Gas Locations.* Harrisburg, PA: Pennsylvania Department of Environmental Protection , 2011.

  - The Oil and Gas location layer shows individual points for permitted locations of Marcellus Shale well activity. The layer has been clipped to just include locations within the study area of Bradford County.

- **Pennsylvania County Boundaries**

Pennsylvania Department of Transportation, Bureau of Planning and Research, Cartographic Information Division. *PennDOT - Pennsylvania County Boundaries.* Harrisburg, PA: Pennsylvania Department of Transportation, 2010.

- The Pennsylvania County Boundaries layer shows all 67 county boundaries in Pennsylvania. The layer has been clipped to only include the study area.

- **NAIP Digital Ortho Photo Image 2010**

USDA-FSA Aerial Photography Field Office. NAIP Digital Ortho Photo Image 2010. Salt Lake City, Utah : USDA FSA Aerial Photography Field Office, 2010.

- The NAIP Image is a tiled remotely sensed image of the study area from 2010. The resolution of the imagery is $1m^2$

- **NAIP County Mosaics for Pennsylvania 2005**

U.S. Department of Agriculture. *USDA - NAIP County Mosaics for Pennsylvania 2005 .* Salt Lake City, Utah: USDA_FSA_APFO Aerial Photography Field Office , 2005.

- The NAIP Image is a tiled remotely sensed image of the study area from 2005. The resolution of the datum is $4m^2$

- **Chesapeake Bay Watershed Land Cover Data Series 2006**

U.S. Geological Survey. *Chesapeake Bay Watershed Land Cover Data Series .* Reston, VA: USGS, 2006.

- The CBLCD layer is derived from the National Land Cover Database (NLCD) to only include the area of the CBW. Each pixel defines a specific type of land use.

Methods

In order to accomplish our first objective of delineating the average footprint size for fully developed well pads, it was necessary to establish the amount and distribution of permitted wells currently in production. This was done using a “display-only” shapefile representing all permitted Marcellus Shale wells currently in production in Pennsylvania (as of October 11, 2011) obtained from the ESRI online database (ArcGIS.com 2011). The shapefile was derived from the same source as the total permitted wells in Pennsylvania shapefile compiled by DEP. A new shapefile was created that mimicked the “display-only” shapefile representing all producing wells in Bradford County. Assuming any well pad containing producing wells was a fully developed site, a polygon shapefile was created representing the footprint of each well pad containing producing wells. Well pad footprints did not include roads leading

to and from well pads. The total area of the footprints was calculated to establish total amount of land cover change resulting from Marcellus Shale drilling well pads, then the *Tabulate Area* tool in ArcGIS 10 was used to derive land cover types from the CBLCD 2006 dataset within the developed well pad footprints. The resulting table was used to determine the type of land cover lost to Marcellus Shale development and to quantify the amount of each land cover type lost to development.

A series of equations were used in order to forecast what the potential land loss and land cover could be due to Marcellus Shale gas extraction. It was assumed that all permitted wells will eventually go into production. Because there are often multiple permitted wells per developed well pad, it was necessary to determine the average number of wells per developed well pad. The *Spatial Join* tool was used in ArcGIS 10 to attach a unique well pad identification number to each permitted well point (producing and non-producing wells) within developed well pads. The unique identifier field was *summarized* to obtain the count of total points within each unique well pad. Statistics were then obtained from the count field in the summary table to determine the average number of permitted wells within developed well pads (4.67).

The number of producing Marcellus Shale wells in Bradford County (322) was subtracted from the total number of permitted wells in Bradford County (1887), in order to determine the total number of permitted wells at undeveloped well pad sites (1565). This number was then divided by the average number of permitted wells in a developed well pad site (4.67) to forecast the number of well pads to be developed (335). This forecasted value was then multiplied by the average developed well pad size (7.18 ac) to obtain potential amount of future land cover change in the county based on the current number of non-producing permitted Marcellus Shale wells. The amount of each land cover type that will potentially become developed as a result of new well pads was forecasted using the current percentages of land cover change classes derived from the *Tabulate Area* analysis.

It is important to note that land cover area tabulations were calculated by using the well pad digitized polygons, and overlaying the CBLCD 2006 land cover data. If the polygon intersected the centroid of a land cover pixel, then the pixel was included in the tabulations. If the centroid was outside of the polygon, then the pixel was not included. This did cause some overestimation, but subsequently also caused some underestimation. These errors were considered to equal each other, creating the most accurate tabulation possible.

Results

Figure 2 shows the location of all permitted and producing wells in Bradford County, as of October 2011.

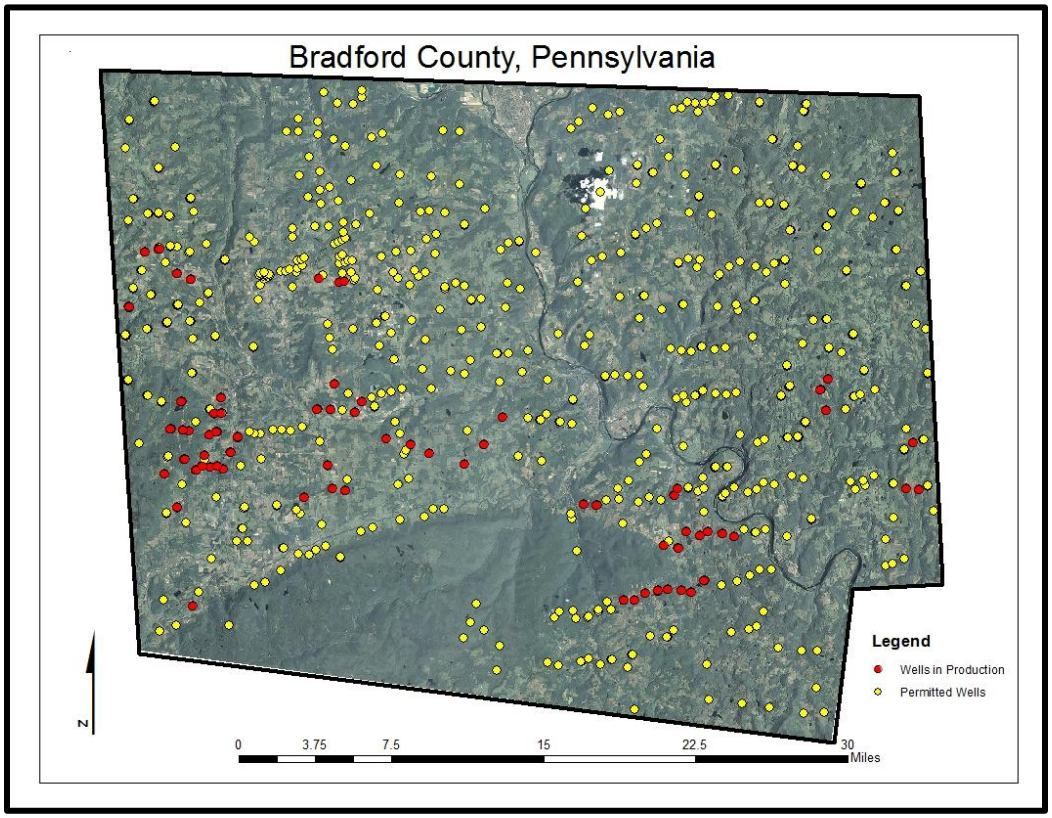

Figure 2: All permitted wells in Bradford County as of November 2011. Wells in production data is current as of October 2011. Data courtesy of DEP 2011.

Table 1 contains summary statistics for all of the wells which are contained within fully developed well pads. Table 2 contains summary statistics for all wells currently in production and contained within a fully developed well pad.

Table 1: Summary Statistics all wells contained in developed well pads. Data courtesy of DEP 2011.

Stats for all wells (producing and non-producing) contained in well pads (n=69) that have wells currently in production	# wells
Minimum:	1
Maximum:	13
Sum:	322
Mean:	4.67
Standard Deviation:	2.65

Table 2: Summary Statistics all wells currently in production contained in developed well pads. Data courtesy of DEP 2011.

Stats for all producing wells in well pads (n=69)	# wells
Minimum:	1
Maximum:	8
Sum:	169
Mean:	2.45
Standard Deviation:	1.47

Figure 3 is a land cover map of Bradford County. Visual interpretation alone reveals that the majority of the county is forested, with large tracts of agricultural land.

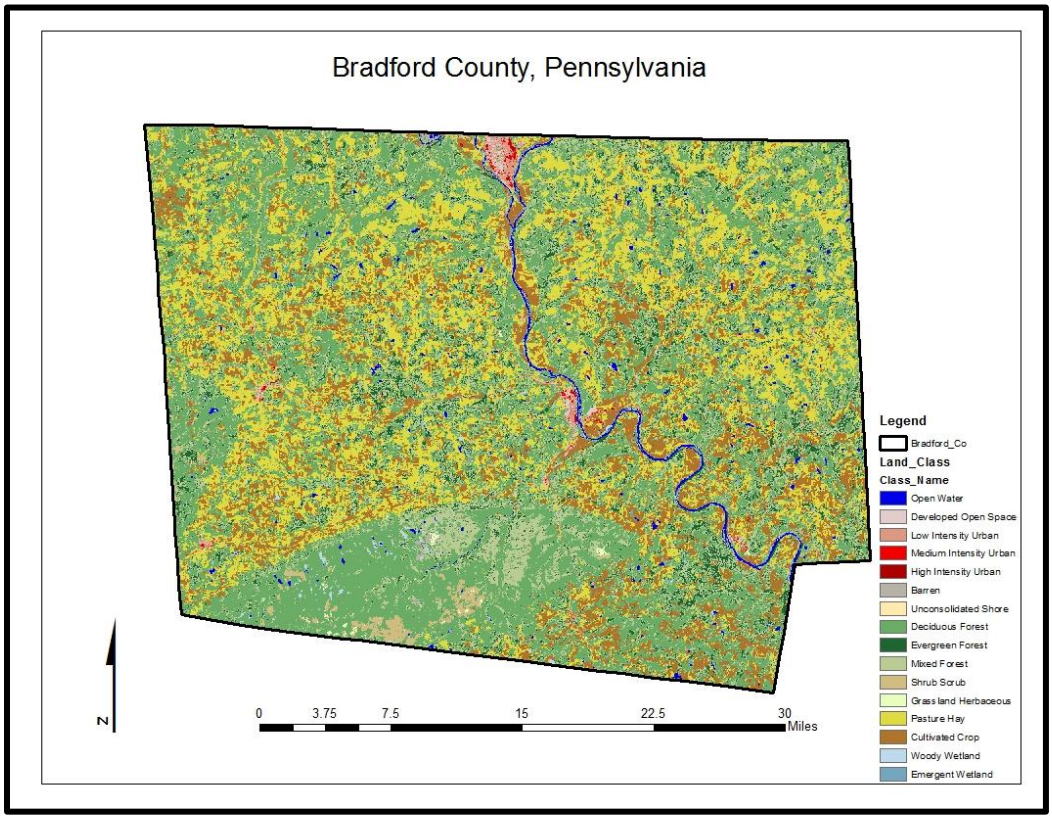

Figure 3: Land cover data for Bradford County, PA. Data courtesy of NLCD 2006.

Figure 4 and Figure 5 show well pad footprints at a 1mx1m resolution. Figure 5 also depicts an enlarged sample of how pixel centroids factored into the land cover quantification. Table 3 contains summary statistics for the developed well pads, including the average size along with standard deviation.

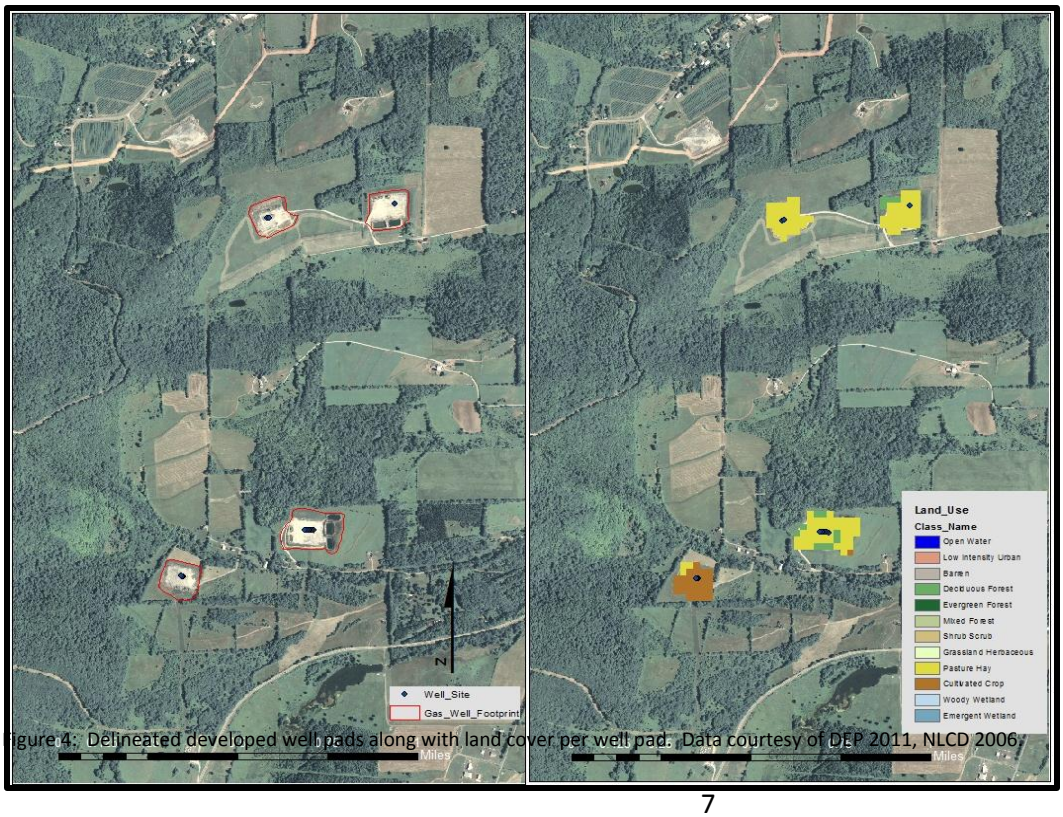

Figure 4: Delineated developed well pads along with land cover per well pad. Data courtesy of DEP 2011, NLCD 2006.

Figure 5: Zoomed delineation of a developed well pad with land cover per well pad as the overlay. Data courtesy of DEP 2011, NLCD 2006.

Table 3: Summary Statistics for developed well pads. Data courtesy of DEP 2011.

Well Pad Area Stats (n = 69)	Sq Meters	Sq Km	Acres
Minimum:	5311.20	0.01	1.31
Maximum:	78496.28	0.08	19.40
Sum:	2003954.81	2.00	495.17
Mean:	29042.82	0.03	7.18
Standard Deviation:	17549.44	0.02	4.34

Discussion

As discussed previously, the intensity at which the Marcellus Shale gas drilling rush has hit Bradford County has been very fast and very hard. Much of the research that has been conducted relative to Marcellus Shale drilling pertains to water usage and effects on water quality. There has not been a focus on land loss or land cover changes.

As of October 2011, the number of wells in production totaled 169. As depicted in Figure 5, there are often multiple wells per well pad site, with some in production and some permitted but not in production. Through analysis of all developed well pad sites, it was determined that the average number of permitted wells (not necessarily in production) per well pad was 4.67, with the average well pad being 7.18 acres in size. This acreage is inclusive of the actual well pad only, and not any of the pipeline or roadway infrastructure that has been installed. This determination was made based on the amount of subjectivity involved in delineating additional infrastructure with each well pad.

As of November 2011, there have been 1887 permits issued to energy companies. These permits allow for the companies to drill, assuming that the land has been leased or bought from the current land owners. Of those 1887 permitted wells, 169 are currently in production within Bradford County. Through the analysis, 69 developed well pads were found within the County, with most containing multiple wells (both in production and not in production, but permitted). There are 322 permitted wells within the developed well pads, with 169 of them currently in production.

In total, the 69 developed well pads were found to be just under 500 acres. This is less than one percent of the total acreage for Bradford County. However, please note that this study quantified only the land directly associated with the well pad, and was not inclusive of pipelines, access roads, compressor stations, laydown yards, or water storage impoundments, if they were located outside of the developed well pad.

Forecast – Land Loss

There are 1565 issued permits that have the potential to be developed within Bradford County. With the average number of wells per well pad being 4.67, this translates into the potential for 335 new well pads to be developed within the County. The average size of a developed well pad within Bradford County, as calculated using current digitized well pads, is 7.18 acres. The calculated estimate for the average amount of land cover to potentially be converted to a well pad is 2406.65 acres. Using a

standard deviation of 4.34 acres for average well pad size, our forecast was found to have a range of 952.41 to 3860.90 acres. Table 4 depicts these statistics.

Table 4: Forecasted data for Marcellus Shale well development in Bradford County.

Forecast for Land Loss	
Total Permits Issued	1887
Total Permits (producing&non-producing) Located w/in Developed Well Pads (n=69)	322
Total Permits (producing) Located w/in Developed Well Pads (n=69)	169
Permits Not Developed	1565
Potential Well Pads to Be Developed	335.36
Potential Land Loss to Well Pad Development (acres)	2406.65
Low (acres)	952.41
High (acres)	3860.90

This forecast is based on the number of permits that have been issued. However, new permits are still being issued by DEP, therefore, the amount is only an estimate based on current data.

Forecast – Land Cover

Examining the type of land cover converted to well pads reflected a trend: Agricultural land was the most converted land cover type, with about 360 acres having been converted as of the 2010 aerial imagery. Forest land cover was the second most highly converted, with just over 100 acres having been converted. Typically, gas companies prefer to secure land for well development in agricultural areas as a way to lower costs associated with well pad development. Agricultural

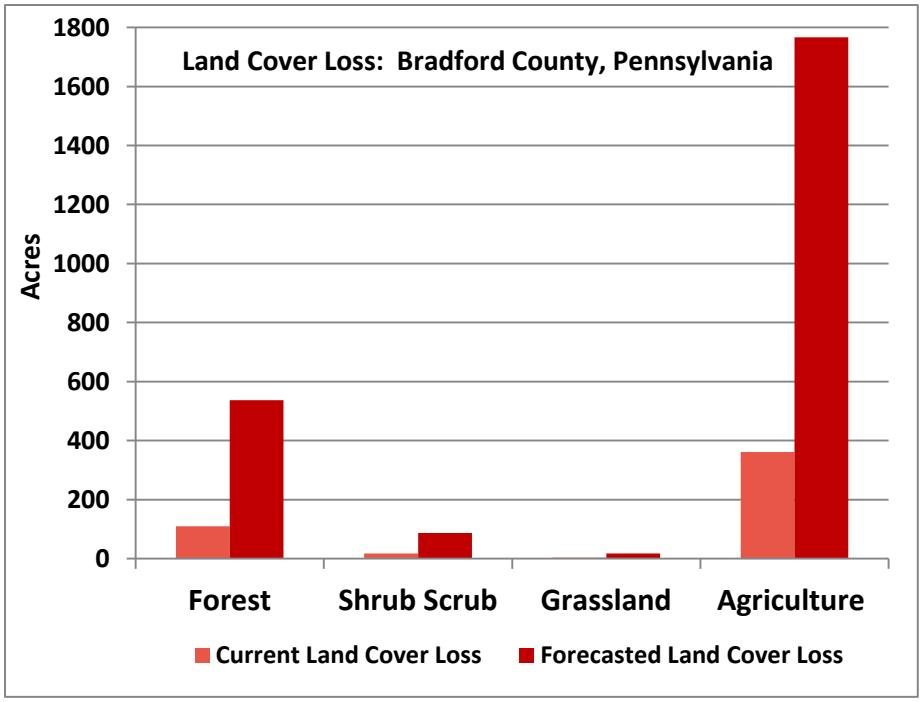

Figure 6: Current and forecasted land cover loss amounts in acres for Bradford County.

land is less expensive and invasive to clear for development. In addition, gas companies are required to do restoration and reclamation on the land post-drilling, and agricultural land is the most cost efficient to restore.

Based on total land cover amounts for the entire County, forested land cover comprises more than fifty percent of Bradford County, yet it is converted only about 22% of the time, versus agriculture which is nearly 75%. Figure 6 depicts the forecasted land cover loss on a per type basis. While it is true that the forecasted land change is less than 1% of the total land within Bradford County, it is very important to know and understand the implications and affects that the land loss could have.

Implications and Considerations

Marcellus Shale gas drilling is still in its formative and initial years of production, and without much research, leaving confounded questions, implications and considerations for researchers to answer. First, there are two types of drilling techniques used in natural gas extraction: horizontal and vertical. Horizontal drilling has an average footprint of 7 to 10 acres, while vertical drilling has a much smaller footprint at only 2 to 4 acres (Knapp Acquisitions and Productions 2011). The majority of the Marcellus Shale gas wells are drilled using the horizontal technique, and particularly the wells in Bradford County. Vertical drilling is not able to efficiently extract gas at deeper depths. Since Bradford County has Marcellus Shale reaching depths of 250 feet, horizontal drilling is the most viable option (DCNR 2011). This information is important to consider when forecasting the amount of land disturbances. The other discerning characteristics between horizontal and vertical drilling such as water consumption and development time are important factors to consult when developing and updating current regulations and legislation.

Secondly, this research only quantified the amount of converted land within the actual well pads. However, the other infrastructural components that are integral parts of gas extraction such as access roads, pipelines, compressor stations, laydown yards, water impoundments and water

withdrawal access, all have their own footprints associated with them. One producing well will oftentimes impact more than one farmer, as pipelines and access roads transverse their properties (Mark Madden, Penn State Extension, 2011).

Though these pipelines are usually reseeded, the impacts go beyond the land cover. Many of the farmers in Bradford County adhere to no-till farming, and have worked many years perfecting their soil to contain the necessary amount of organic matter. Excavation for the pipelines disturbs the soil, and often new topsoil is imported, leaving the land with a different soil composition. Most pipelines are installed in the dry months so as to alleviate excess storm water runoff from bare and exposed soil (Mark Madden, Penn State Extension, 2011). However, farmers have the potential to see soil compaction in their fields from repeated truck and equipment traffic along the access roads and pipelines. The soil compaction can have long term effects for farmers and crop production, as biological processes change with the structural change in the soil. Subsoil compaction in particular, has long term adverse effects, and can cause severe environmental degradation. The subsoil compaction causes prolonged periods of surface soil saturation and conversely surface runoff and erosion (Duiker and Micsky 2009).

Another consideration is the fragmentation of forested land by not only the installation of well pads, but also the installation of pipelines and access roads. With over 50% of Bradford County covered in forests, the probability that new well development will occur within a forested tract of land increases. This fragmentation could lead to decreased wildlife habitat, decreased diversity, and an increase in non-native species, as gas companies run the risk of introducing invasive species during the reclamation process (Rodgers et al 2008).

The impacts from Marcellus Shale gas drilling go far beyond just Bradford County. Forest fragmentation, drilling adjacent to waterways, water removal from the Susquehanna River and tributaries all affect the health of Pennsylvania waterways and eventually the Chesapeake Bay. These

forests are responsible for absorbing pollutants, stabilizing soil, and buffering waterways from surface runoff. It is not just the removal of the actual forests that could cause problems, but the proximity of drilling activities to forested areas. Many species of plants and animals are intolerant of habitat disturbance and excess noise. Large scale forest removal could have profound impacts for Pennsylvania in reaching its Total Maximum Daily Load requirements for discharge into the Chesapeake Bay. About 46% of Marcellus Shale gas drilling is projected to take place within the Chesapeake Bay watershed. Increasing the amount of bare soil, or restoring once forested land as agricultural land, could increase nutrient and sediment runoff by the following estimates: nitrogen—30,000-80,000 pounds/year, phosphorous—15,000-40,000 pounds/year, sediment—18 million-45 million pounds/year (The Chesapeake Bay Journal 2011).

The Pennsylvania Department of Environmental Protection (DEP) urges the usage of riparian buffer zones (particularly forested riparian buffer zones) and has prohibited the removal of them for extraction purposes.

Except as in accordance with subsection (d), persons proposing or conducting earth disturbance activities when the activity requires a permit under this chapter may not conduct earth disturbance activities within 150 feet of a perennial or intermittent river, stream, or creek, or lake, pond or reservoir when the project site is located in an exceptional value or high quality watershed attaining its designated use as listed by the Department at the time of application and shall protect any existing riparian buffer in accordance with this section.
--Title 25 Chapter 102, The Pennsylvania Code

DEP requires the use of “Best Management Practices” for drilling sites under 5 acres, while a more structured permit is required for drilling sites that exceed 5 acres, in terms of erosion and sediment control (DEP 2011). However, because of the increased intensity of well pad development, these codes and permitting regulations are being reviewed in order to determine if they appropriately protect waterways in accordance with The Clean Streams Law (DEP 2011).

Conclusion

The land impacts resulting from Marcellus Shale in Bradford County can only be estimated, yet even the estimates show that there is potential for high impacts. Some of the key points to consider are the types of land cover most affected—agriculture and forest. The impacts are often felt by multiple land owners, not just the ones who have leased their land. Land disturbances go beyond the actual well pad as additional infrastructure is installed. Forest fragmentation and soil compaction could lead to further degradation of Pennsylvania waterways as well as the Chesapeake Bay. Much further research is needed in order to fully understand the impacts and implications that Marcellus Shale gas drilling has on the landscape, people and environment. As more wells are permitted and subsequently developed, the impacts reach farther. Therefore, increased awareness, monitoring and research are the important aspects which should continue to be developed.

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