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Factors Influencing the Location of Gathering Pipelines in Utica and Marcellus Shale Gas Development

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Abstract

The extraction of natural gas from shale plays, such as the Marcellus and Utica in the Eastern United States, is forecast to continue to grow in the coming decades. Infrastructure in these areas must be located in rural but populated areas that are naturally forested and are predominantly in private ownership. Land change from gathering pipelines is greater in extent than the combined land-change impact of other development-related features and persists for long time periods. The route of these pipelines must be negotiated on a household-by-household basis across the landscape and is not well understood. This research uses GIS to quantitatively assess the role of ownership patterns, topography, roads, and existing land cover in the location of gathering pipelines in two study areas in Ohio and Pennsylvania using GIS and spatial analysis methods. Results show that the pattern of land ownership has a strong influence on gathering pipeline location in both the Ohio and Pennsylvania study areas with pipelines frequently located near parcel boundaries. Roads, topography, and existing land cover have identifiable but weaker influence on the location of gathering pipelines. These results are important for future efforts at modeling and mitigating land change impacts from shale gas development.

Keywords: shale gas, land change, pipelines, land ownership patterns

1. Introduction

The extraction of natural gas from shale plays has increased greatly over the past decade in the United States (EIA 2017) and abroad (EIA 2013) and forecasts suggest that unconventional gas production will double by 2040 (EIA 2017).Development of shale gas plays in the Eastern United States, such as the Marcellus and Utica, is expected to be the main driver of U.S. shale gas production through 2050 (EIA 2017). Impacts and tradeoffs from shale gas development include issues of water quantity use Gottshalk et al. 2012; Nicot and Scanlon 2012),water quality degradation (Johnson et al. 2010; Olmstead et al. 2013; Warner et al. 2013), air quality (Annevelink et al. 2016), deforestation (Brittingham et al. 2012; Drohan et al. 2012; Drohan and Brittingham 2012; Slonecker et al. 2012; Slonecker and Milheim 2015), loss of habitat (Brittingham et al. 2014; Jones and Pejchar 2013; Ludlow et al. 2015; Abrahams et al 2015), biodiversity (Kiviat 2013), and other ecosystem services (Allred et al. 2015).

The land change impacts from "energy sprawl" have far outpaced land change from urban and residential sprawl but are not well understood (Trainor et al. 2016). Development of shale gas production in the Marcellus and Utica shale plays results in land change and fragmentation due to locating wells in rural but populated areas that are naturally forested and are dominated by private land ownership (Donnelly et al. 2017; Brittingham et al. 2012; Drohan et al. 2012). Land change associated with pipelines that connect wells to the processing and distribution network is greater in extent than the combined land change impact of the well pads, access roads, and retention ponds (Donnelly et al. 2017; Brittingham et al. 2012; Drohan et al. 2012).

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Comprising the majority of the pipeline network in these regions, gathering pipelines are much less regulated than transmission pipelines and aggregate maps of their location are often not maintained thereby making any overall estimation of their impact on the landscape difficult. Unlike in the case of interstate transmission pipelines, eminent domain is not applicable to routing gathering pipelines (Schmid and Company 2012) and so the routing process happens via a parcel-by-parcel negotiation. Landowners can choose whether or not they wish to have gathering pipelines on their land and, if so, where on their land they prefer the gathering lines to be located. The aggregate pattern resulting from the many individual decisions is important to understanding and predicting the environmental impacts of shale gas development but has received very little attention in the land-change literature. Therefore, the broad goal of this research is to assess factors that influence the many parcel-scale decisions that in aggregate shape the path of gathering pipelines across the landscape. Along with the system-level factors, such as well pad and processing facility location, influences on the route of pipeline location include geology and topography, waterways including wetlands, habitat for threatened and endangered species, and existing and planned infrastructure (Henderson 2012; Leuttinger and Clark 2005; Schmid and Company 2012; Schwartz et al. 2015).

2. Study Area

The area for which the influence of these factors will be examined is near the border between Ohio and Pennsylvania (Fig. 1) in the United States. This area is of interest due to the high level of shale gas development in a naturally forested landscape where most land is in small private holdings. The physical geography is generally constant across the area but there are important differences in the political geography and geology. More specifically, the land in the eastern part of the study area was divided according to a metes and bounds system of description while the land in the western part of the study area was divided according to the rectangular township and range systemof the "Seven Ranges" described in the Land Ordinance of 1785 (Onuf 1987). The system of land divisionimpacts a number of other landscape characteristics (Brown et al. 2000; Donnelly and Evans 2008; Donnelly 2011). In terms of the underlying geology, the wells in the eastern study area are drilled into the Marcellus shale (Carter et al. 2011)while the wells in the western study are drilled into the Utica shale (ODNR 2017). Because of the shape of the shale formations, the depth to these two plays is quite similar in the two areas (EIA 2016a; EIA 2016b) and so the drilling technology and techniques are not appreciably different. The characteristics of the gas and oil extracted from the two shale plays are different (Kowalski 2014), however, and this led to somewhat different timelines of development because of changing market forces.

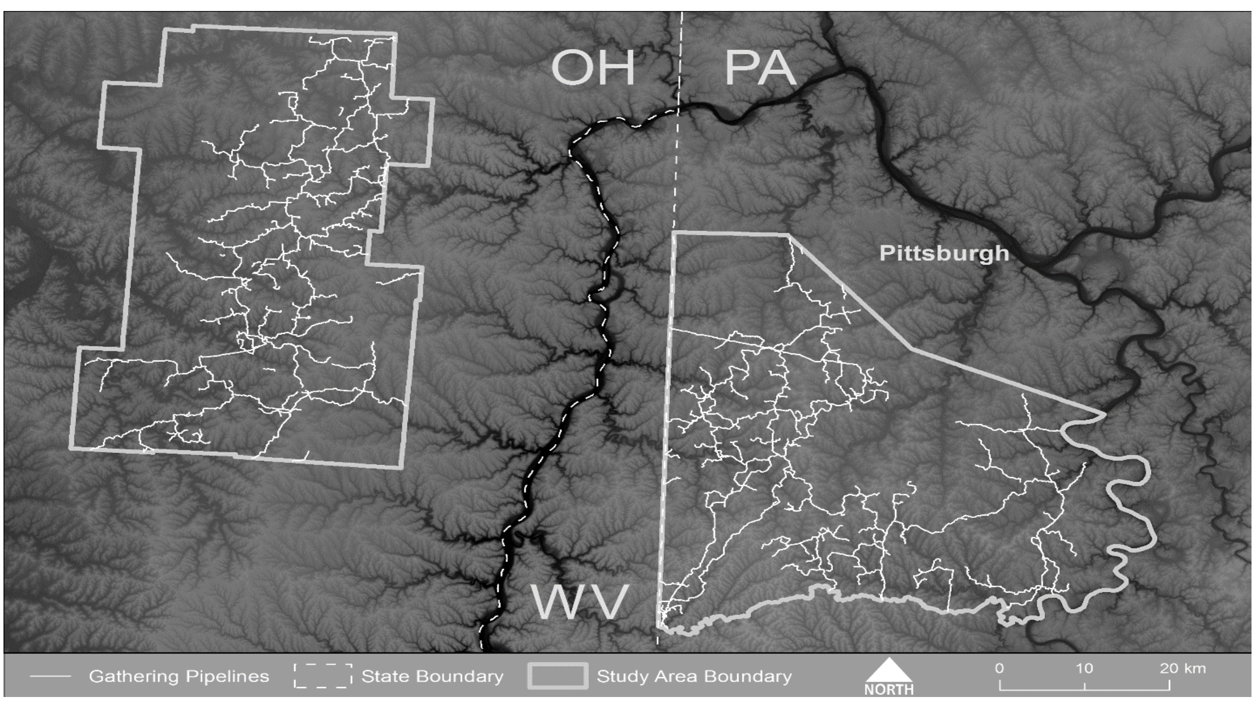


Fig. 1. Study areas with gathering pipelines in Ohio (611.12 km) and Pennsylvania (700.53 km)

The study area in Ohio is comprised of two counties, Carroll County and Harrison County, while Washington County is used at the study area in Pennsylvania. The two study areas are predominantly rural with similar topography and land cover composition other than the Pennsylvania study area has a larger population (USCB 2010a; USCB 2010b) due to a larger urbanized area in the north central portion of the county connected to the city of Pittsburgh, PA.

The general research objective of this study is to quantify the influence of factors affecting the route of shale gas gathering pipelines in two study areas in Ohio and Pennsylvania at the parcel scale. The influence of four specific factors, parcel boundaries, roads, slope, and existing land cover, are examined. The expected relationships between pipeline location and these landscape components are that pipelines will be routed near the edges of parcels, pipelines will be routed away from roads, pipelines will be routed on land with low slope, and pipelines will be routed through non-forested areas. Examples of these influences can be seen in Fig. 2.

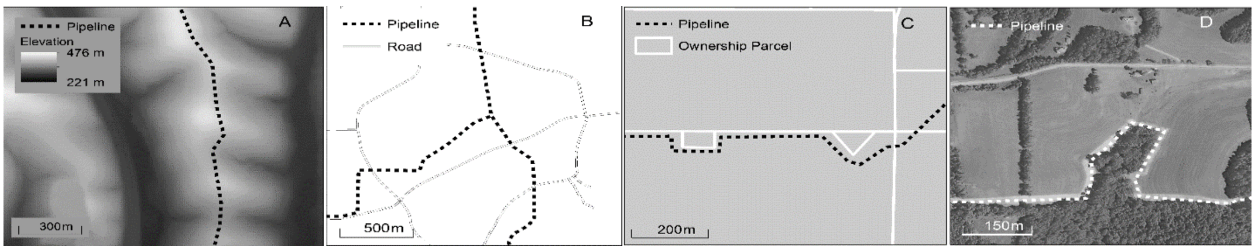


Fig. 2. Factors influencing the location of gathering pipelines include slope (A), roads (B), ownership boundaries (C), and existing land cover (D)

3. Materials and Methods

Gathering pipelines were digitized by visually examining color orthorectified aerial imagery for several time points between 2005 and 2015. The spatial resolution of the aerial imagery ranged from 0.2 to 3 meters. Lines were used to represent the gathering pipeline by identifying areas cleared for pipeline ROWs in the imagery and creating lines in the center of the visible ROW. To ensure that visible pipeline ROW was for gas gathering pipelines rather than transmission pipelines, which are subject to different siting processes, digitized lines were compared against maps of transmission pipelines whose locations must be reported to state and/or federal agencies (PHMSA 2017). If the cleared ROW led to water impoundment features, the pipeline was removed from the dataset under the expectation that it likely transported water rather than natural gas liquids. While nearly all of the existing shale gas wells in the study areas were connected to gathering pipelines at the time of the most recent imagery, both well construction and pipeline construction are an ongoing processes. The density of pipelines in the two study areas is very similar with 0.370 km/km^2 in Ohio and 0.374 km/km^2 in Pennsylvania.

Current land ownership parcel datasets were obtained from each of the three county governments in the study area. Any polygons representing road or infrastructure ROWs were selected based on their linear shape and removed from the datasets. Parcels containing pipelines were selected based upon intersection with the dataset of digitized pipelines. Summary statistics for the ownership parcels are presented (Table 1). The shape index (McGarigal et al. 2012) compares the perimeter of each polygon to a square of the same area and has a minimum value of 1 when the polygon is a square.

	N	Total area (ha)	Mean area (ha)	Area SD (ha)	Mean shape index	Shape index SD
Ohio						
All parcels	45195	207155.51	4.58	15.10	1.19	0.28
Parcels on pipeline	1442	34980.65	24.34	35.42	1.20	0.24
Pennsylvania						
All parcels	113150	213306.27	1.89	9.84	1.18	0.25
Parcels on pipeline	1768	36788.81	20.81	23.07	1.28	0.32

Table 1. Descriptive statistics for ownership parcels in the Ohio and Pennsylvania study areas

Concentric buffers were created every 20 meters from the boundaries of the parcels that contained pipelines to test the hypothesis that ownership patterns influence the siting of gathering lines because landowners prefer to locate pipelines near the edge of their parcels. The length of pipeline in each buffer polygon was then tabulated by intersecting the digitized pipelines with the concentric buffers. A 20 m buffer size was chosen because this is the approximate minimum size of gathering line ROWs (Donnelly et al. 2017).

Lines representing road centerlines were obtained from the TIGER Lines database created by the U.S. Census Bureau (UCSB 2015). To remove small roads, such as driveways and private lanes, features with blank or null type were selected and deleted from each dataset.

Slope data was derived from 1/3 arc second elevation data (USGS 2017)that has a spatial resolution of 10 m. Elevation data was first projected and then resampled using bilinear interpolation prior to calculating slope values. To compare the slope of cells within the pipeline ROW to the rest of the parcels with pipelines and the entire study areas, the lines representing the pipelines were converted to raster data sets with 10 m by 10 m cells by assigning a unique value to all cells that intersected the pipelines. One cell was added to each side of the cells that intersected lines to create a three cell, or 30 m, raster representation of the pipeline ROW. The mean slope values of the cells representing the pipeline ROW were compared to the slope values of the cells that comprised the parcels containing pipelines and the entire study areas. A single sample Z score was calculated to test for statistically significant difference of means.

To further examine the relationship of slope along the pipeline, on parcels with pipelines, and for the entire study area over the range of existing slopes, the slope raster datasets were classified into categories. These classified slope datasets were then converted to polygon datasets. To tabulate the percentage of the length of pipeline and the percentages of areas in each slope class, the polygon slope classes were intersected with these datasets.

Land cover data was derived from the National Land Cover Dataset (NLCD) from 2011 (Homer et al. 2015) for the Ohio study area and from 2006 (Fry et al. 2011)for the Pennsylvania study area. These datasets have a spatial resolution of 30 m by 30 m. To align with previous studies (Donnelly et al. 2017), different time points were used to best match the beginning of shale gas development in the study areas. The NLCD data were reclassified into four classes of water/wetlands, developed, forest/shrub, and herbaceous/hay/crop. The classified land cover data was converted to polygons and intersected with pipelines, parcels containing pipelines, and the entire study area. All spatial data were projected into the appropriate state plane coordinate systems for each study area and processing of spatial data was done in ArcGIS 10.4 (ESRI 2016).

4. Results

The study area in Pennsylvania has a much larger population and much of that population lives on smaller parcels in urban areas. The differences in the summary statistics for all parcels in the two study areas (Table 1.) are largely driven by this disparity where there are many more parcels that are smaller and less variable in size in the Pennsylvania study area. The number and total area of parcels that contain pipelines in each study area is similar, but the parcels with pipeline in the Ohio study area are larger and more variable in size while the parcels in the Pennsylvania study area are less compact in shape and have more variability in their shape.

The proportion of pipeline in both study areas is greater near parcel boundaries (Fig. 3) with about half of all pipelines occurring within the approximately 30% of the landscape that is within 40 m of a parcel boundary. At distances greater than 40 m from the parcel boundary, the proportion of pipeline is very similar to the total amount of area indicating a weak relationship with distance to parcel boundary. Both the proportion of pipeline and the proportion of area near the parcel boundary are greater in the Pennsylvania study area because of the less compact shape of parcels that results from metes and bounds land division.

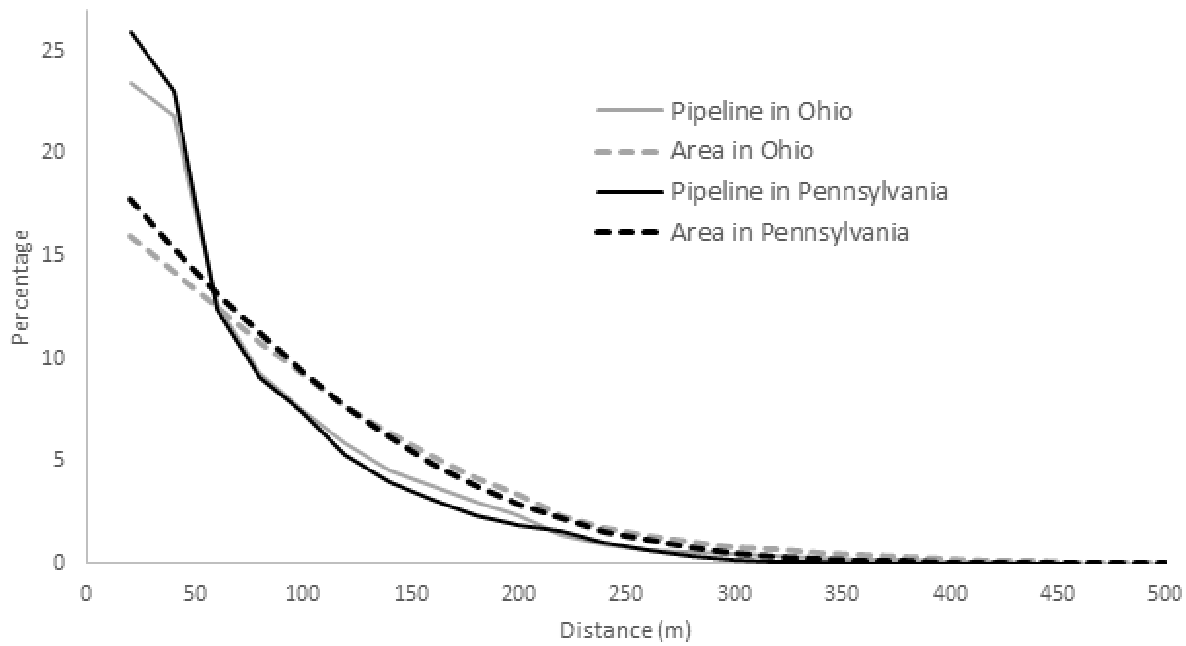


Fig. 3. The percentage of pipeline (solid lines) and percentage of total area (dashed line) at distances from the edge of parcels that contain pipelines in the Ohio and Pennsylvania study areas.

The relationship between roads and pipelines is characterized by a general lack of influence of roads on pipeline location. This is indicated by the constant relationship between the proportion of pipeline and the proportion of area across the range of distances from roads in both study areas (Fig. 4). The notable exception is a small spike in the proportion of pipelines between 20 m and 40 m in both study areas. The more gradual slope of both the proportion of pipeline and proportion of area in Ohio is related to the location of roads along the rectangular land divisions of the township and range system. The decrease in the proportion of area within 20 m of roads in the Pennsylvania study area as compared to the Ohio study area is due to differences in production methods of the parcel datasets rather than any real difference in the landscape.

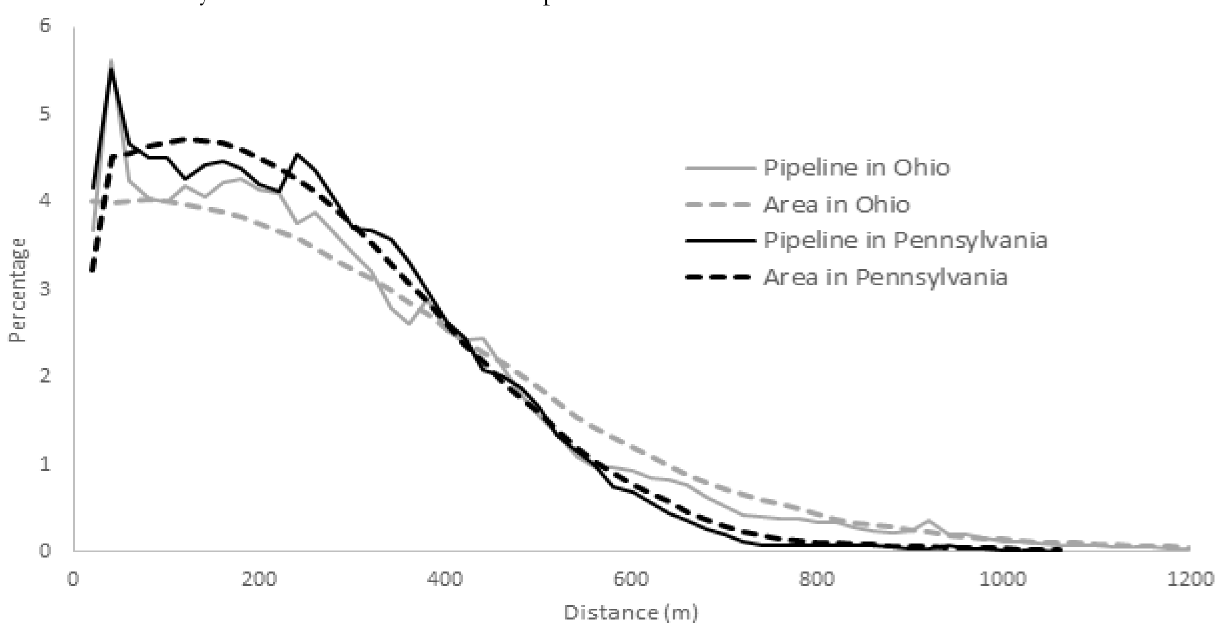


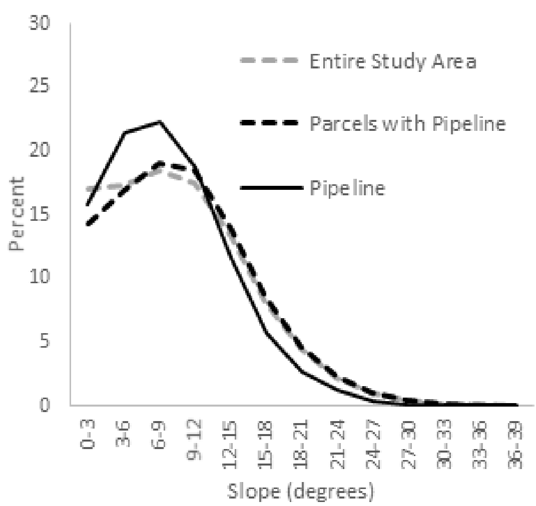
Fig. 4. The percentage of pipeline (solid lines) and percentage of total area (dashed line) at distance from roads (UCSB 2015) in the parcels that contain pipelines in the Ohio and Pennsylvania study areas.

In both the Ohio and Pennsylvania study areas, the mean slope of cells in the pipeline ROW was statistically significantly lower than in both the parcels with pipelines and the entire study areas (Table 2). In all cases, the mean slope in Ohio was less than in Pennsylvania but the variance was higher.

	Mean (deg)	Variance (deg)	Z score
Ohio			
All parcels	9.182	36.720	-60.890*
Parcels on pipeline	9.523	35.355	-90.193*
Pipeline ROW (n=240746)	8.430	27.040	
Pennsylvania			
All parcels	10.178	30.969	-53.163*
Parcels on pipeline	10.325	26.041	-73.249*
Pipeline ROW (n=281112)	9.620	22.000	

Table 2. Single sample Z-score used to compare mean slope value of cells comprising pipeline ROWs to the mean slope value of cells comprising all parcels and parcels containing pipelines. * indicates $p < 0.01$.

The shape of the distribution of slope values is very similar in Pennsylvania for the entire study area, the area of parcels with pipelines, and the pipeline (Fig.5). This suggests that the location of pipelines is not strongly influenced by slope in the Pennsylvania study area. The shape of the distribution of slope values in the three areas in Ohio, however, does show some difference between where pipelines are located versus the broader areas. The percentage of pipelines is higher at low slope values. The general shape of the distributions shows that while the Pennsylvania study area has a higher mean slope value (Table 2), the Ohio study area has a higher percentage of area of higher slopes.



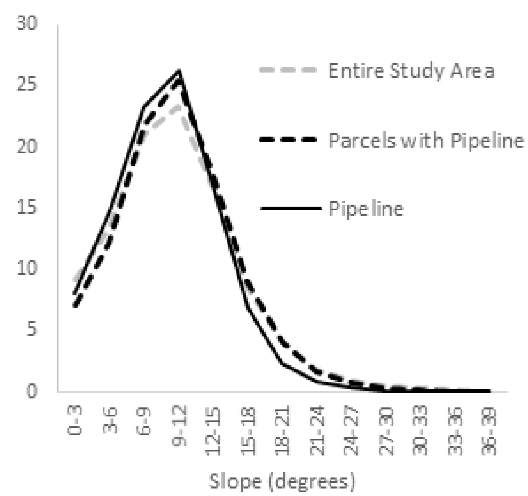


Fig. 5. The distribution of slope values (USGS 2017) for the entire study area (gray dashed lines), the area of parcels that contain pipelines (black dashed lines), and along the pipeline (black line)for the Ohio (panel A) and Pennsylvania (panel B) study areas.

As seen above in the population and parcel data, the Pennsylvania study area has nearly twice the proportion of land in development and more area of water/wetland as compared to the Ohio study area (Table 3). The Ohio study area is slightly more forested and agricultural. In Ohio, the percentage of pipeline in forested land is lower than the overall percentage of forested land in the study area while these values are nearly identical in Pennsylvania. In both Ohio and Pennsylvania, the percentage of pipeline occurring in agricultural land is substantially higher than the percentage of land in agriculture in the study area. The analysis of land cover suggests that pipelines are most frequently located in forested areas in both study areas but may preferentially be located in agricultural areas in Ohio.

	Water	Developed	Forest	Agriculture
Ohio				
Entire Study Area	2.01%	7.64%	59.09%	31.26%
Parcels with Pipeline	1.26%	4.83%	57.56%	36.35%
Pipeline	0.00%	5.10%	50.13%	44.74%
Pennsylvania				
Entire Study Area	6.47%	14.84%	56.02%	28.49%
Parcels with Pipeline	0.00%	4.03%	56.83%	38.74%
Pipeline	0.00%	4.26%	56.35%	39.36%

Table 3. Land cover composition of the entire study areas, the parcels that contain pipelines, and along the pipeline (Homer et al. 2015; Fry et al. 2011).

The mean and standard deviation of slope values in each land cover class (Table 4) show very similar values for forest land but a higher mean slope value for agricultural land. Very few pipelines occur on land classified as water/wetland or developed.

	Water	Developed	Forest	Agriculture
Ohio	2.52 (5.89)	7.94 (5.53)	11.64 (5.93)	6.64 (4.34)
Pennsylvania	2.21 (5.17)	9.78 (6.04)	11.73 (5.28)	8.40 (3.86)

Table 4. Mean and standard deviation of slope in each land-cover class on parcels containing pipelines. Units are degrees.

5. Discussion

From the above results, the greatest influence on gathering pipeline location identified in this analysis is a strong preference to locate pipelines near parcel boundaries in both the Ohio and Pennsylvania study areas. This preference is an important factor in creating the complicated route that emerges from many individual negotiations in a landscape composed of small, privately owned parcels. The mean size of parcels on which pipelines are located is similar in the two study areas but the shape of the parcels is somewhat different due to the historical systems of land division. It is conceivable that if the preference to locate pipelines along parcel boundaries were strong enough, the length of the pipeline would approach the "Manhattan distance" in a landscape divided by rectangular survey while the pipeline length would be shorter in a landscape divided by metes and bounds where ownership boundaries are more likely to follow topographic or other physical landscape features. Given that the emergent pipeline pattern in the two counties is approximately equally dense, the preference to locate pipelines along parcel boundaries appears to be mediated by other influences.

As roads tend to be located near parcel boundaries in the rectangular land division system used in Ohio and less so in the metes and bounds system used in Pennsylvania, it is somewhat surprising that there is not a stronger relationship, be it direct or indirect, between the location of roads and the location of gathering pipelines in Ohio. The exception to this lack of apparent relationship is a small spike in the amount of pipelines between 20 and 40 meters from roads. One possible explanation of this pattern comes from the fact that pipelines must pass underneath existing roads by way of tunneling. Tunneling under roads is more costly and so would logically be minimized by pipeline construction companies. The combination of the increased cost with the preference to locate pipelines near parcel boundaries could result in pipelines running along roads until a more optimal location for tunneling is reached.

In both study areas, the mean slope along the pipelines is less than on the parcels with pipelines or in the entire study area. The pipeline appears be built on somewhat different topography when looking at the distribution of slope values in the two study areas, however. The distribution of slope values along the pipeline in the Pennsylvania study area is very similar to the distribution of slope values in the broader study areas. In Ohio, however, more of the landscape is flatter and there is a more pronounced preference to locate gathering pipelines in flatter areas. In the Pennsylvania study area, there is less land area in the lower slope categories and there appears to be less preference for locating pipelines in the flatter areas.

While a causal relationship cannot be verified from the current spatial analysis, the relationship between lower slope areas and agricultural land cover provides a possible interpretation of this pattern. The land cover composition of the parcels on which pipelines occur is very similar in the two study areas. The land cover in which the pipelines were actually constructed, however, is more agricultural in the Ohio study area. If pipelines are preferentially built on agricultural land in Ohio and agricultural land is flatter, then this relationship could explain the difference in the distribution of slopes along pipelines in the two study areas. Possible reasons for the preference of building pipelines on agricultural land versus forested land might come from either the landowner or the pipeline company. For instance, preference by a landowner for the revenue from selling the timber cleared from a pipeline ROW or preference by the pipeline company for the shortest route might lead to the routing of a ROW through the forest. On the other hand, the preference against sustained land alteration might influence a landowner to route a pipeline through agricultural land that can continue to be used in this way once the pipeline is installed. Likewise, pipeline companies may prefer to establish ROWs in agricultural land because of ease of development.

In the few efforts at modeling the impact from shale gas development in the Marcellus and Utica, the approach has either not been spatially explicit (Johnson et al. 2010)or made the simplification that the length of pipelines will be minimized(Racitot et al. 2014). Especially for gathering pipelines in landscapes dominated by small private ownership, this assumption is clearly false and could create a substantial underestimate of land change given that pipelines are the largest contributor. The findings presented here can improve estimates of the impact of pipelines by better understanding some of the factors that are related to the complex pipeline routes and aid in future efforts at minimizing those impacts (Abrahams et al. 2015; Klaiber et al. 2017).An important next step toward a better understanding of the influences on gathering pipeline location is to survey the preferences of land owners and land agents that negotiate pipeline ROW leases. These stakeholders have fundamental information necessary to better model the decision making process involved in these potentially contentious negotiations. The findings presented here both provide insight into some possible influences on those negotiations and quantify the actual outcomes of those negotiations.

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