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Oil and gas development footprint in the Piceance Basin, western Colorado

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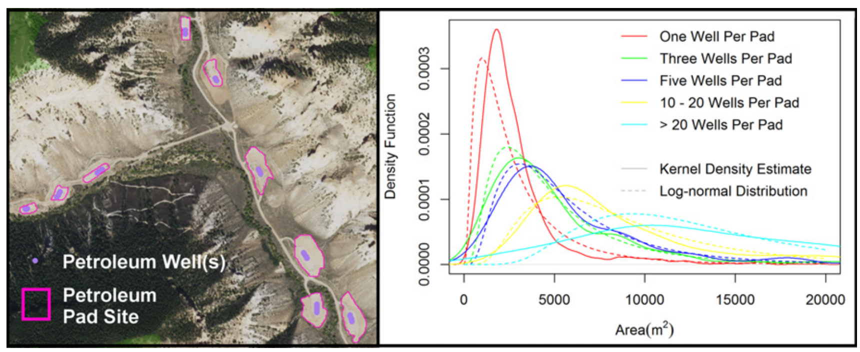
HIGHLIGHTS

- Over 21 million square meters of land used for petroleum energy development in the Piceance Basin of western Colorado
- The number of wells drilled at a single pad site has increased from an average of 2.5 prior to 2002 to 9.1 in 2016.
- A lognormal distribution approximates the relationship between the number of wells per pad and pad area.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding long-term implications of energy development on ecosystem function requires establishing regional datasets to quantify past development and determine relationships to predict future development. The Piceance Basin in western Colorado has a history of energy production and development is expected to continue into the foreseeable future due to abundant natural gas resources. To facilitate analyses of regional energy development we digitized all well pads in the Colorado portion of the basin, determined the previous land cover of areas converted to well pads over three time periods (2002–2006, 2007–2011, and 2012–2016), and explored the relationship between number of wells per pad and pad area to model future development. We also calculated the area of pads constructed prior to 2002. Over 21 million m^2 has been converted to well pads with approximately 13 million m^2 converted since 2002. The largest land conversion since 2002 occurred in shrub/scrub (7.9 million m^2), evergreen (2.1 million m^2), and deciduous (1.3 million m^2) forest environments based on National Land Cover Database classifications. Operational practices have transitioned from single well pads to multi-well pads, increasing the average number of wells per pad from 2.5 prior to 2002, to 9.1 between 2012 and 2016. During the same time period the pad area per well has increased from 2030 m^2 to 3504 m^2. Kernel density estimation was used to model the relationship between the number of wells per pad and pad area, with these curves exhibiting a lognormal distribution. Therefore, either kernel density estimation or lognormal probability distributions may potentially be used to model land use requirements for future development. Digitized well pad locations in the Piceance Basin contribute to a growing body of spatial data on energy infrastructure and, coupled with study results, will facilitate future regional and national studies assessing the spatial and temporal effects of energy development on ecosystem function.

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1. Introduction

The ability to quantify impacts of oil and gas (energy hereafter) development requires analysis of current and past petroleum production practices. The physical footprint of development varies by energy play in response to environmental characteristics of the area and geological constraints of the oil or gas reservoir. The lack of regional footprint data and analysis is a notable data gap, limiting the ability to forecast landscape level impacts of future energy development on a national scale.

The Piceance Basin of western Colorado (Fig. 1) is one area of historic energy production lacking a region-specific analysis of the footprint associated with development of energy resources. Energy development in the Piceance Basin began in the early 1900's and the basin still contains abundant natural gas resources. The Mancos Shale, which is estimated to contain on average 66.3 trillion cubic feet of undiscovered technically recoverable natural gas (Hawkins et al., 2016), is the second largest assessment of natural gas resources in the country behind the Marcellus Shale. Energy development from the Mancos Shale and other oil and gas bearing formations is anticipated to continue into the foreseeable future within the region (BLM Colorado River Valley Field Office, 2016; BLM Little Snake Field Office, 2011).

Mapping the footprint of well pad sites associated with energy development provides data to facilitate analysis of land use and land cover (LULC) change. Efforts have been made to develop and identify methods to quickly or automatically map the footprint of well pad sites with Germaine et al. (2012) providing an assessment of three methods. Tools such as the disturbance automated reference toolset (Nauman et al., 2017) have been developed to quickly estimate and remotely map reclamation and recovery efforts. Studies of the LULC change requirements for energy development highlight the need for additional regional studies in order to link the local footprints of development to ecological endpoints of regional concern. For instance, Preston and Kim (2016) identified an average pad footprint of 1.7 *ha* (17 thousand m^2) associated with the Williston Basin and an ecological endpoint of interest in limiting conversion of grassland. In Pennsylvania, Slonecker and Milheim (2015) identified an average pad footprint of 2.5 *ha* (25 thousand m^2) associated with the Marcellus shale and an aquatic ecological endpoint of interest.

In order to understand LULC changes from energy development, it is necessary to quantify both current and past development (Allred et al., 2015) as well as future impacts (Clancy et al., 2017; Jones et al., 2015). Often, the average area of an oil or gas well pad is used to represent the disturbance area of development in order to predict the future land conversion potential (Preston and Kim, 2016; Slonecker and Milheim, 2015; Buto et al., 2010; Copeland et al., 2009). However, recent technological advances in petroleum production operations, such as methods for hydraulically fracturing petroleum bearing formations and drilling multiple wells from a single pad, can make simple extrapolation of the trends observed in historical data to future predictions problematic (Maloney et al., 2018). For example, in the Williston Basin, it was found that the pad size is often larger for modern hydraulically fractured horizontal wells relative to traditional vertical wells, and that pads with a single well are often smaller than multi-well pads (Preston and Kim, 2016). As a result, it is necessary to understand the relationship between development and LULC change from historic data prior to modeling future scenario planning. One way this can be done is to assess the dependence of pad site area on the number of wells through time as a mechanism for accounting for changes in development practices.

The purpose of this work is to use the spatial and temporal trends observed in historical development to identify a relationship that can be used as the basis for modeling potential future impacts of energy development in the Piceance Basin. Specifically, we examine LULC change from the construction of oil and gas well pads, which are defined as the final area required for production from either single- or multi-well sites. Achieving this goal necessitates a twofold analysis. We first explore how the footprint of energy development has varied historically by associating a specific time with the area converted to an oil or gas pad. Next, we use these temporal trends in LULC changes from pad construction to develop analytical relationships between the number of wells per pad and pad area to allow for the prediction of future land requirements for energy development.

2. Methods

We first describe the approach used to digitize well pads in the Piceance Basin and associate each pad with a point in time to ascribe

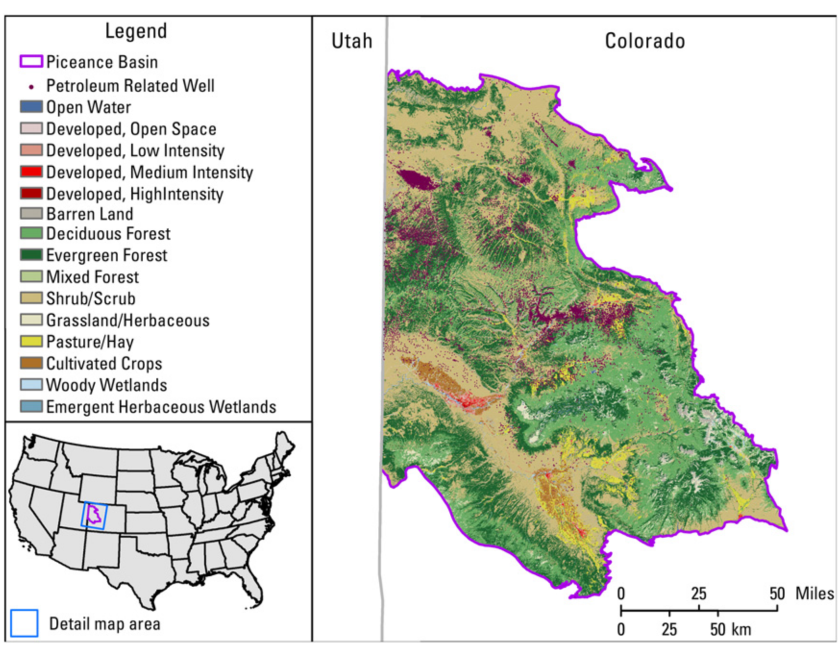

Fig. 1. Map showing location of the Colorado portion of the Piceance Basin. 2011 National Land Cover Database classifications are displayed within the Colorado portion of the Piceance Basin. Petroleum well locations are overlaid as purple dots.