

# Executive Summary

Unconventional natural gas development using hydraulic fracturing has spurred a rapid expansion of natural gas extraction in Pennsylvania especially in the Marcellus Shale formation. Through the almost nine years of unconventional gas development in Pennsylvania, the Commonwealth has witnessed significant changes to energy costs, employment, communities, and the environment. While the price of natural gas has led to fluctuations in the rate of development, the significant quantity of gas reserves in the Marcellus Shale could support significantly more gas development in coming years.

The activities associated with unconventional natural gas development including drilling, land disturbance, water withdrawals, material handling and waste management, and operation of equipment have clear potential impacts to environmental resources and human health. The actual impacts and outcomes of these activities can vary considerably depending on industry practices, technology changes, and regulation, but in general they are proportional to the level of development. Improved practices, regulation, and monitoring can assist in managing impacts as they are occurring, but the overall level of impact will depend on the total amount of development that will occur. While many studies have investigated environmental impacts of gas development as it happens, relatively few consider the long range impacts of what might happen as development continues. In this study, we ask:

What would be the potential environmental impacts from natural gas development activities in Pennsylvania if the Interior Marcellus Shale resources were fully developed?

To answer this question, we developed a geospatial analysis methodology to identify the most likely future well locations based on the locations of existing wells relative to spatial data layers describing the shale characteristics, terrain, infrastructure, and hydrology of the region. We combined the probability surface generated from this analysis with recent estimates of total recoverable reserves and average production per well to determine how many wells could be developed and their most likely locations. We computed potential impacts based on the well (or well pad) numbers in a given geographic unit, and we derived impacts per well or well pad from published literature or data sets. With information on well locations and level of impact per well, we analyzed the spatial characteristics of impacts of natural gas development.

The scope of this study is limited to investigating potential impacts of additional well development in Pennsylvania in the Interior Marcellus<sup>1</sup> shale play. It does not consider other shale plays such as the Utica Shale. This study does not examine the full range of potential impacts from all activities associated with the natural gas sector<sup>2</sup>, does not consider all potential impact pathways (e.g. accidental wastewater discharges), and it does not project possible environmental and human health *outcomes* based on the impacts.

For the Commonwealth of Pennsylvania, we estimated the following potential impacts associated with this study's projections of well development of the Marcellus Interior Shale formation:

- **Well development** - We estimated that 47,600 additional wells could be developed on 5,950 well pads over the next 30 years *if* the Interior Marcellus's technically recoverable resources were fully developed.
- **Land use change** - The construction of natural gas infrastructure (well pads, gathering pipelines, and access roads) to support projected well development would result in about 94,000 acres of land disturbance. Over half (about 51,000 acres) of the land disturbance would impact agricultural land, while about 28,000 acres would constitute the clearing of forest cover.
- **Forest change** - Of the 28,000 acres of forest that would be cleared, we found that 12,700 acres were core forest areas (over 100 meters from the nearest forest edge). Additionally, over 88,000 acres of core forest would be fragmented by road and pipeline development and converted to edge forest. Thus, over 100,000 acres of core forest would be lost due to the combined effect of clearing and fragmentation.
- **Population in proximity to well pads** - We estimated that the current population in Pennsylvania living within one-half mile of a well pad is about 100,000, and, based on our projections, this number could increase to 639,000. Similarly, we estimate that the population living within one mile of a well pad could increase from about 311,000 today to over 1.8 million at full build-out.

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<sup>1</sup> The Interior Marcellus is the primary gas-producing portion of the Marcellus formation, with over 95 percent of its gas reserves.

<sup>2</sup> For example, this study does not consider the impacts associated with construction and operation of interstate gas transmission pipelines. Other potential impacts such as road traffic or groundwater contamination are not well suited to analysis using the methods employed for this study.

- **Air emissions** - The additional well development would result in greater emissions of NO<sub>x</sub>, VOCs, and CH<sub>4</sub> from activities related to well pre-production and production, and compressor stations for moving gas through gathering lines. When the play nears full development (i.e., ongoing emissions from producing wells reach their peak), the annual average air emissions could reach 37,000 tons per year for NO<sub>x</sub>, 22,500 tons per year for VOCs, and 388,000 tons per year for methane.
- **Water use, withdrawal, and consumptive use** - We determined that the projected natural gas development in the Marcellus would require 242 billion gallons of water in total, in order to mix frac fluid for the hydraulic fracturing process. Averaged over 30 years, this is a water use rate of 34 cubic feet per second or 22 million gallons per day. We found that roughly 200 billion gallons of fresh surface water would be withdrawn to support this development, and that 167 billion gallons would be used consumptively and would not re-join the hydrologic cycle after hydraulic fracturing injection.
- **Wastewater generated** - We estimated that 84 billion gallons of wastewater would be generated from projected natural gas development in Pennsylvania. Wastewater includes drilling fluid waste, plus flowback and produced water/brine recovered from the shale after frac fluid injection and during gas production.

These metrics offer a sense of the scale of the total statewide impacts of natural gas development through full development of the Interior Marcellus Shale. But these aggregated metrics do not tell the full story of the impacts, which have important geographic variations. Thus, the primary output of this research is an *atlas*: a set of maps that puts the impacts of the projected natural gas development into useful spatial context. These maps, and the data developed to generate them, present useful information to policy-makers, decision-makers, and other researchers concerned about managing the range of impacts of shale gas extraction in Pennsylvania.

The maps can be downloaded in sets corresponding to each chapter of this report at: [www.cna.org/PA-Marcellus](http://www.cna.org/PA-Marcellus)