In Everyone's Backyard: Assessing Proximity of Fracking to Communities At-Risk in West Virginia's Marcellus Shale

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Executive Summary

In the past decade, natural gas drilling and extraction from the Marcellus Shale in West Virginia has grown rapidly. The technique of hydraulic fracturing, or "fracking," has allowed for the extraction of gas from areas that were previously uneconomic. Further, in comparison with conventional gas wells, the impacts of fracking are also potentially much greater. Fracking requires the construction of large wellpads—often home to multiple wells drilled over a few years—and produces large amounts of solid and liquid waste containing toxic chemicals. In recent years, the public health and medical communities have expressed concerns about environmental issues and the potential for adverse human health impacts in communities located near fracking activities.

In this study, we explore whether gas production has become more common near places essential for everyday life in West Virginia, increasing the potential for human exposure to contaminants associated with drilling and natural gas extraction. First, we map and measure the footprint of Marcellus Shale gas development in West Virginia between 2007 and 2014 to evaluate the extent to which drilling has expanded near sensitive land uses such as homes and schools. Most prior studies of the growth of unconventional gas extraction have utilized point location information from permit data rather than polygons. Our approach using aerial imagery more accurately reflects the actual timing and aerial extent of wellpad development. Second, we characterize the toxicity of a set of chemicals used to frack wells near sensitive populations to better understand the potential for harmful exposures.

Marcellus Shale development in West Virginia

The footprint of gas extraction in West Virginia's Marcellus Shale has grown substantially. The average size of wellpads grew from 1.6 to 2.4 acres between 2007 and 2014, and the average size of wastewater impoundments—structures for storing liquid waste—grew from 0.1 to 1.3 acres. The total land area covered by wellpads and impoundments grew from 12 to 1,286 acres. Compared with other West Virginia counties, wellpads occupy the most land in Marshall, Wetzel, and Doddridge counties.

Proximity of Marcellus Shale development to sensitive areas

Over time, an increasing amount of Marcellus Shale fracking-related infrastructure has been located near sensitive areas, including homes, schools, public drinking water intakes, public lands, and health care facilities.

- **Homes.** 7,235 homes were located within one-half mile of at least one wellpad in 2014. West Virginia State Code specifies a setback distance of 625 feet between the center of wellpads and homes; however, homeowners may waive this setback, and several homes are located closer than this distance to wellpads.
- **Schools.** In 2007, the closest wellpad was 0.9 miles from a school. By 2014, seven schools had at least one wellpad within one-half mile, 36 schools had at least one wellpad within one mile, and six schools had two or more wellpads within one mile. West Virginia State Code does not specify a setback distance for construction of wellpads near schools, nor does it specify setback distances for public lands or health care facilities.
- **Public drinking water intakes.** West Virginia State Code specifies that wellpads must be more than 1,000 feet from a public drinking water intake; however, the Code does not restrict the construction of wellpads within drinking water protection areas such as zones of critical concern or zones of peripheral concern. In 2014, 30 wellpads and seven impoundments were located

within zones of critical concern, and 532 wellpads and 17 impoundments were located within zones of peripheral concern.

- **Public lands.** In 2007, no wellpads or impoundments existed within two miles of public land boundaries. By 2014, 21 wellpads and five impoundments had been developed within this distance of public lands.
- **Health care facilities.** In 2007, only three wellpads and three impoundments were located within two miles of a health care facility; by 2014, 81 wellpads and 21 impoundments were located less than two miles from at least one health care facility.

Chemicals used at fracking sites in close proximity to sensitive sites

Our ability to characterize the potential health threats posed by fracking in West Virginia is limited by the lack of disclosure and monitoring related to the chemicals used at fracking sites, as well as limited data on the health effects of many of the chemicals being used. Nevertheless, a systematic, screening-level evaluation of the toxicity of chemicals self-reported to the FracFocus Chemical Disclosure Registry revealed that several hazardous substances have been used in West Virginia to frack wells near schools and within zones of critical concern for surface public drinking water intakes.

- **Schools.** Thirty percent of wellpads located within one kilometer of a school reported their chemical usage to the FracFocus database, and 59 different chemicals were used between July 2013 and March 2016. Twenty percent of these 59 chemicals have been identified as possible reproductive and/or developmental toxicants, and one has been identified as a probable human carcinogen.
- **Public drinking water intakes.** Twenty percent of the 177 wellpads located within zones of critical concern for drinking water supplies reported their chemical usage to the FracFocus database, and 98 different chemicals were used between May 2013 and March 2016. Nineteen percent of these chemicals could be identified as possible reproductive and/or developmental toxicants, and two are probable or likely human carcinogens.

Conclusion

As the extent of fracking has grown since 2007, fracking infrastructure—wellpads and impoundments—has encroached on places essential for everyday life in West Virginia. Roughly one-fifth of the chemicals being used to frack Marcellus Shale wells close to schools and public drinking water intakes are possible reproductive and/or developmental toxicants or human carcinogens. Most operators are not voluntarily disclosing the chemicals they use, and toxicity information is unavailable for many of the chemicals used at fracking sites, limiting our ability to evaluate the potential health threats posed by fracking in the area.

West Virginia State Code requires setbacks to keep wellpads from being developed too close to homes and public drinking water intakes. However, the other types of sensitive areas assessed in this report are not protected from nearby Marcellus Shale development. Setback distances for schools, health care facilities, and public lands—and restrictions in zones of critical concern and zones of peripheral concern above drinking water intakes—would help protect vulnerable populations and recreational opportunities as fracking development continues.

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Introduction

In the past decade, natural gas drilling and extraction from the Marcellus Shale in West Virginia has grown rapidly; 60 horizontal well permits were issued by the West Virginia Department of Environmental Protection (WVDEP) in 2007, and growth peaked in 2013 when 706 permits were issued (WVDEP 2017a). The technique of hydraulic fracturing, or "fracking," has allowed for the extraction of gas from areas that were previously uneconomic.

In comparison with conventional gas wells, the impacts of fracking are also potentially much greater. Fracking requires the construction of large wellpads—often home to multiple wells drilled over a few years—and produces large amounts of solid and liquid waste containing toxic chemicals, which must be transported for disposal. In this study, we explore whether gas production has become more common near places essential to everyday life in West Virginia, increasing the potential for human exposure to contaminants associated with drilling and natural gas extraction.

In recent years, the public health and medical communities have expressed concerns about environmental issues and the potential for adverse human health impacts in communities located near fracking activities. Recent research suggests that living near fracking sites may negatively impact human health (Whitworth et al. 2017, Yao et al. 2015, Casey et al. 2015, Stacy et al. 2015, and McKenzie et al. 2014); however, research in this area to-date is limited—especially regarding long-term health impacts, such as cancer (Werner et al. 2015).

Potential pathways through which communities may be impacted include: water quality, air quality, noise and light from infrastructure, increased truck traffic, and related stress.

Further, fracking fluids and waste generated during the gas extraction process contain hundreds of substances, many of which are known to be toxic (Shonkoff et al. 2014, Yao et al. 2015, Elliot et al. 2016). These waste fluids are often stored in large pits or impoundments near wellpads. As the fracking boom has progressed, wellpads and impoundments have encroached on homes, communities, and sensitive areas such as schools, healthcare facilities, and public recreational spaces and, thus, the risks to human health may be intensifying.

The goal of this study is twofold. First, we map and measure the footprint of Marcellus Shale gas development in West Virginia between 2007 and 2014, in order to evaluate the extent to which drilling has expanded near sensitive land uses such as homes and schools. Most prior studies of the growth of

unconventional gas extraction have utilized point location information from permit data rather than polygons. Our approach using aerial imagery more accurately reflects the actual timing and aerial extent of wellpad development. Second, we characterize the toxicity of a set of chemicals used to frack wells near sensitive populations to better understand the potential for harmful exposures that may place people at risk.

Methods

Delineation of fracking impacts

Wellpad and impoundment identification

We downloaded well permit data from WVDEP's Oil and Gas database (WVDEP 2017b). We then filtered the permit data to include only wells with a designation of "Horizontal Well" or "Horizontal 6A Well." To identify wellpad locations, we developed an algorithm that grouped all well permits within 100 meters of each other into a set of approximated wellpad locations. A team of analysts visually examined each of the approximated wellpad locations in United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) imagery, for each year that imagery was available (2007, 2009, 2011, and 2014). If analysts detected the presence of a wellpad or impoundment, these features were delineated to create two distinct datasets: delineated wellpads and delineated impoundments. Because impoundments were only identified when they were observed near wellpads, it is likely that the total area covered by impoundments is underestimated in this study. An example of the user interface of the delineation application is shown in Figure 1.

Figure 1. Application utilized in wellpad and impoundment delineation

Home identification

A Pybossa[1] application was developed to enable a group of SkyTruth analysts, interns, and experienced community volunteers to locate and identify homes within one-half mile of the center of delineated wellpads. Users were given access to SkyTruth's guidelines for differentiating between homes and other structures. Using the Pybossa application, users were presented with 2014 NAIP imagery and asked to place points on structures they believed to be homes. A subset of the homes dataset was then examined by the SkyTruth team to gauge the accuracy of the identification process; results were found to be 96% accurate.

Proximity to sensitive land uses

Geographic information system (GIS) tools were utilized to measure the distances between wellpads and impoundments and sensitive areas. We define sensitive areas as places where people and vulnerable populations spend significant amounts of time, places that may impact public drinking water, and places that have recreational and environmental significance. Table 1 identifies the sensitive areas and spatial data sources included in our analysis.

Table 1. Sensitive areas included in this analysis

Sensitive area	Description	Data source
Homes	Homes located within one-half mile of an identified wellpad. The dataset was developed for this project using 2014 USDA NAIP aerial imagery.	SkyTruth (2017)
Schools	Kindergarten through 12th grade schools	WVDE (2015)
Public drinking water intakes	Areas designated to protect public drinking water sources, including zones of critical concern, zones of peripheral concern, and wellhead protection areas	WVBPH (2017a)
Public lands	State and national forests and parks and national wildlife refuges	USFS (2005), USNPS (2003), USFWS (2006), WVDOF (2015), and WVDNR (2011)
Health care facilities	Hospitals, community health care providers, nursing homes, and United States Department of Veterans Affairs facilities	WVHCA (2008), Homeland Security Infrastructure Project Freedom Program (2010), WVOVA (2005)

[1] Pybossa is an open-source platform for managing crowdsourced citizen projects such as collaborative image analysis projects.

Chemical use and toxicity

We downloaded a list of chemicals used at fracking sites in West Virginia from the FracFocus Chemicals Disclosure Registry[2] on February 28, 2017. Disclosure of chemicals used in the fracking process is mandatory in West Virginia,[3] although information is limited in that companies can withhold information by claiming chemical usage as a confidential trade secret.[4] Chemical usage information was joined to our dataset of delineated wellpads based on well American Petroleum Institute (API) number using the R software package (R Core Team 2016).

We further characterized chemicals that were reported to FracFocus with a Chemical Abstracts Service (CAS) registry number according to their potential for reproductive or developmental toxicity and carcinogenicity. We focused this analysis on wellpads located 1) within one kilometer of a school,[5] or 2) within a zone of critical concern (ZCC) for public drinking water sources from surface water. ZCCs include the land area adjacent to streams within a five-hour travel time to a surface water intake.

We extracted a list of chemicals contained in fracking fluids and wastewater that are possible reproductive or developmental toxins from a previous analysis (Elliot et al. 2016). We extracted a list of chemicals that have been evaluated for their potential to cause cancer from the Integrated Risk Information System (IRIS) database maintained by the United States Environmental Protection Agency (USEPA 2017). We then compared these chemicals to those that had been used near schools or within ZCCs based on their CAS numbers.

[2] FracFocus is a national hydraulic fracturing chemical registry managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission (https://fracfocus.org/).
[3] W.Va. Code of State Rules §35-8-10.1a and §35-8-10.1b.
[4] W.Va. Code of State Rules §35-8-10.1a.
[5] The one-kilometer search distance was chosen arbitrarily because it provided a sufficient number of chemicals to research.

Extent and growth of Marcellus Shale infrastructure in West Virginia

West Virginia's Marcellus Shale footprint has grown substantially. Our analysis of aerial imagery showed that the number of wellpads grew from eight in 2007 to 532 in 2014. Aerial imagery indicated a lag in the time between when a drilling permit was issued and when construction took place, and that multiple wells were typically drilled on a single wellpad. The number of unconventional natural gas drilling permits issued by WVDEP rose from 60 in 2007 to 685 in 2014 (WVDEP 2017a).

Unlike conventional wells, which require a minimal amount of land, shale gas wells are developed on large wellpads. The average area occupied by unconventional wellpads grew from 1.6 to 2.4 acres between 2007 and 2014, and the area occupied by impoundments grew from 0.1 to 1.3 acres (Table 2). The footprint of unconventional gas-related wellpads and impoundments grew over this period from 12 to 1,286 acres.

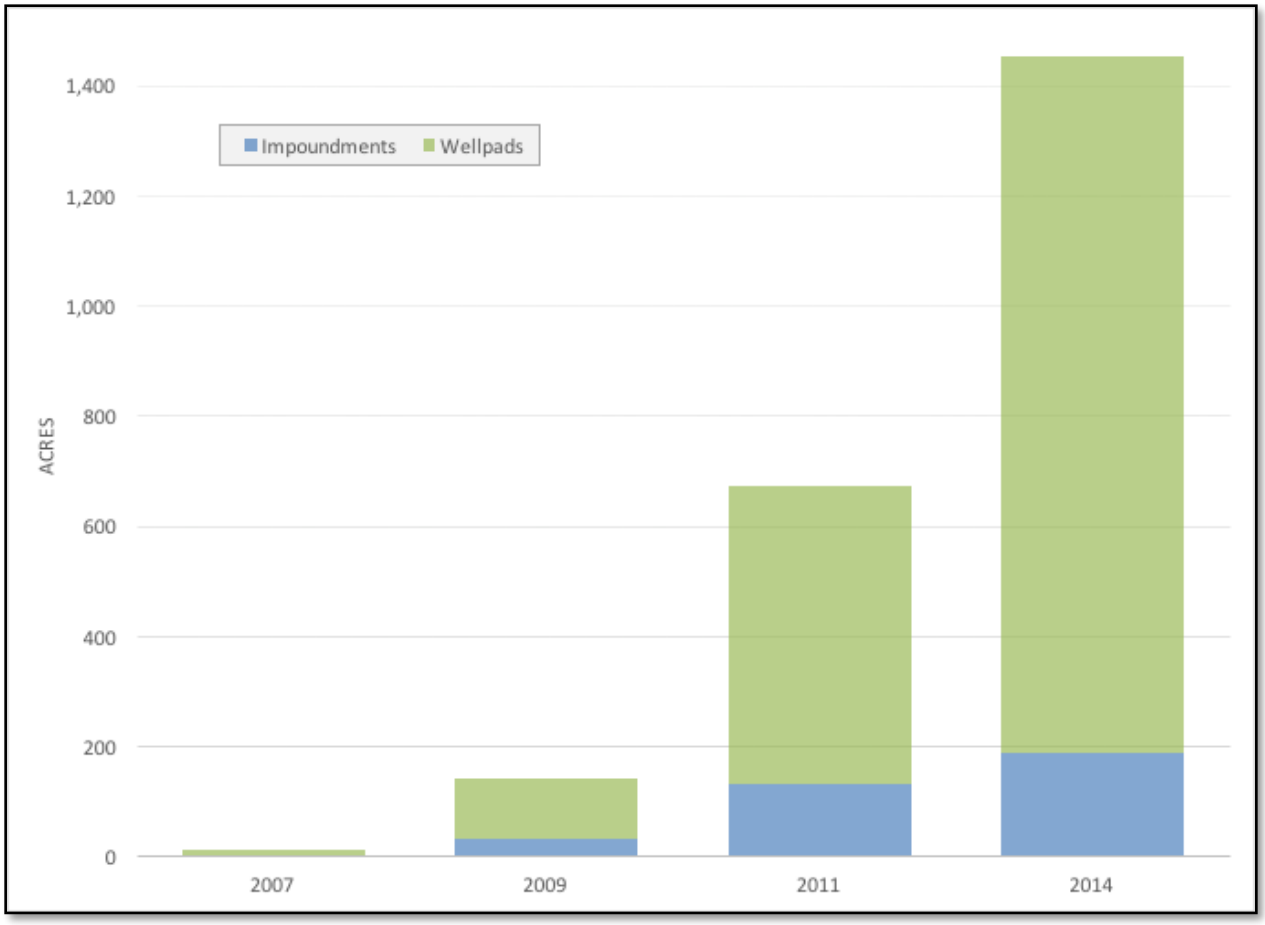
Multiple wells are typically drilled on a single wellpad, and, as mentioned above there is often a delay in construction of wells and wellpad after permits are issued. This study assessed actual wellpad development rather than the number of permits issued.

In 2007, eight wellpads had been developed, and in 2014, land had been cleared for 532 wellpads. Only wellpads with visible barren ground were counted in our analysis; wellpads that appeared to be reclaimed were only identified during the years in which barren land was observed.

Figure 2 displays the area utilized for wellpads and impoundments over time. An example of development over time at a wellpad is displayed in Figure 3.

Infrastructure—such as roads, impoundments, pipelines, and staging areas—supporting these wellpads requires additional space. Impoundments used to store fresh water and wastewater required 22 total acres for 17 impoundments in 2014. Between 2007 and 2014, an average impoundment covered 1.1 acres of land.

Figure 2. Area occupied by Marcellus Shale wellpads and impoundments, 2007-2014



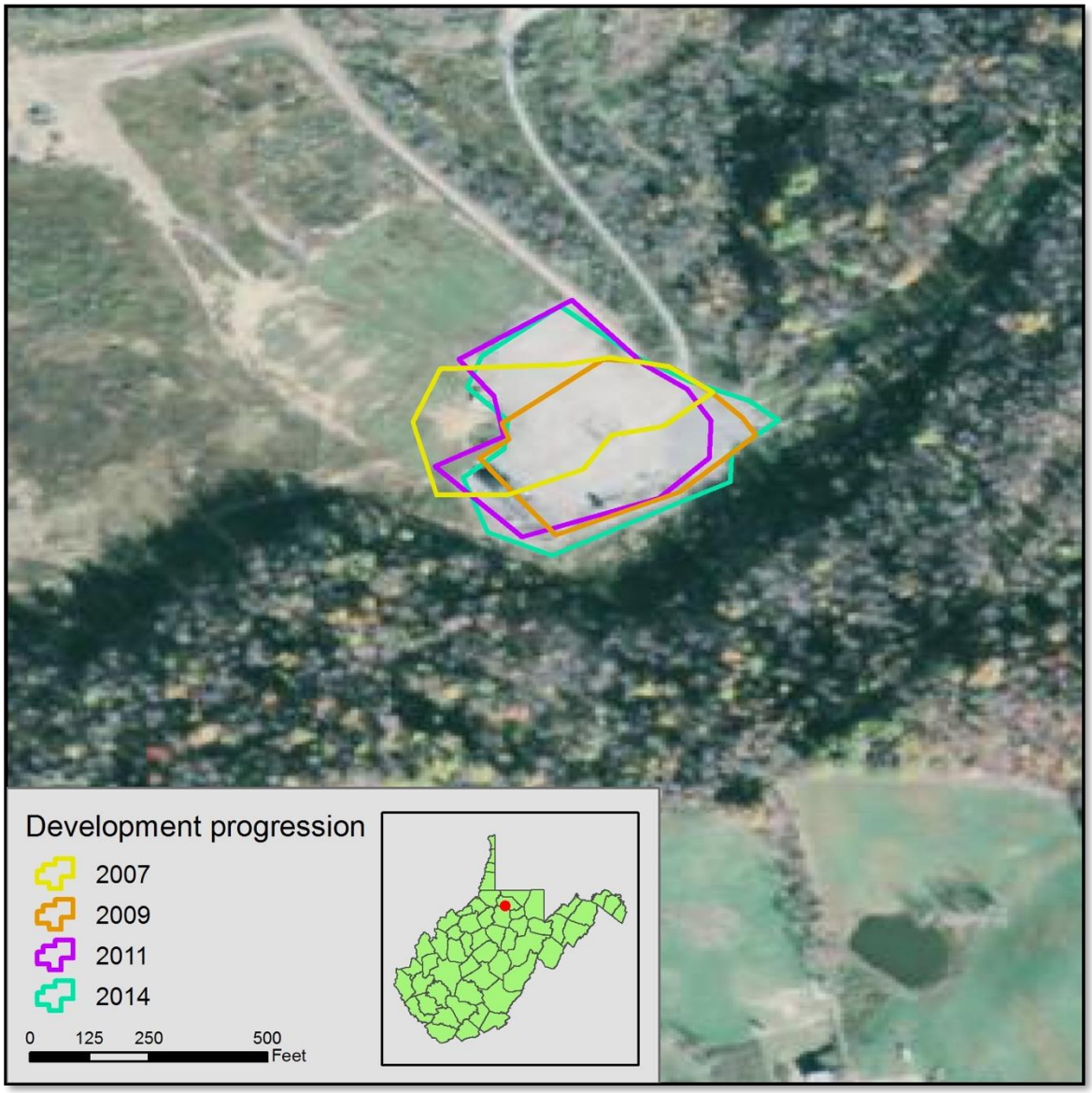
Note: The area covered by impoundments is likely underestimated in this study because they were only delineated when located close to wellpad permits.

Table 2. Average Marcellus Shale wellpad and impoundment size over time (acres)

Year	Wellpads	Impoundments
2007	1.6	0.1
2009	1.8	0.9
2011	2.5	1.3
2014	2.4	1.3

Note: The area covered by impoundments is likely underestimated in this study because they were only delineated when located close to wellpad permits.

Figure 3. Progression of development at a Marcellus Shale wellpad



Note: Aerial imagery in this figure is from USDA NAIP collected in 2014. Thus, delineations for earlier years do not align with the extent of wellpad development visible in this image.

The majority of fracking development has occurred in the north-central portion of West Virginia, as shown in Figure 4 and Figure 5. Marshall County, Doddridge County, Wetzel County, and Harrison County have experienced the greatest impacts of the fracking boom in West Virginia (See Table 3 and Table 4).

Figure 4. Marcellus Shale wellpads across West Virginia

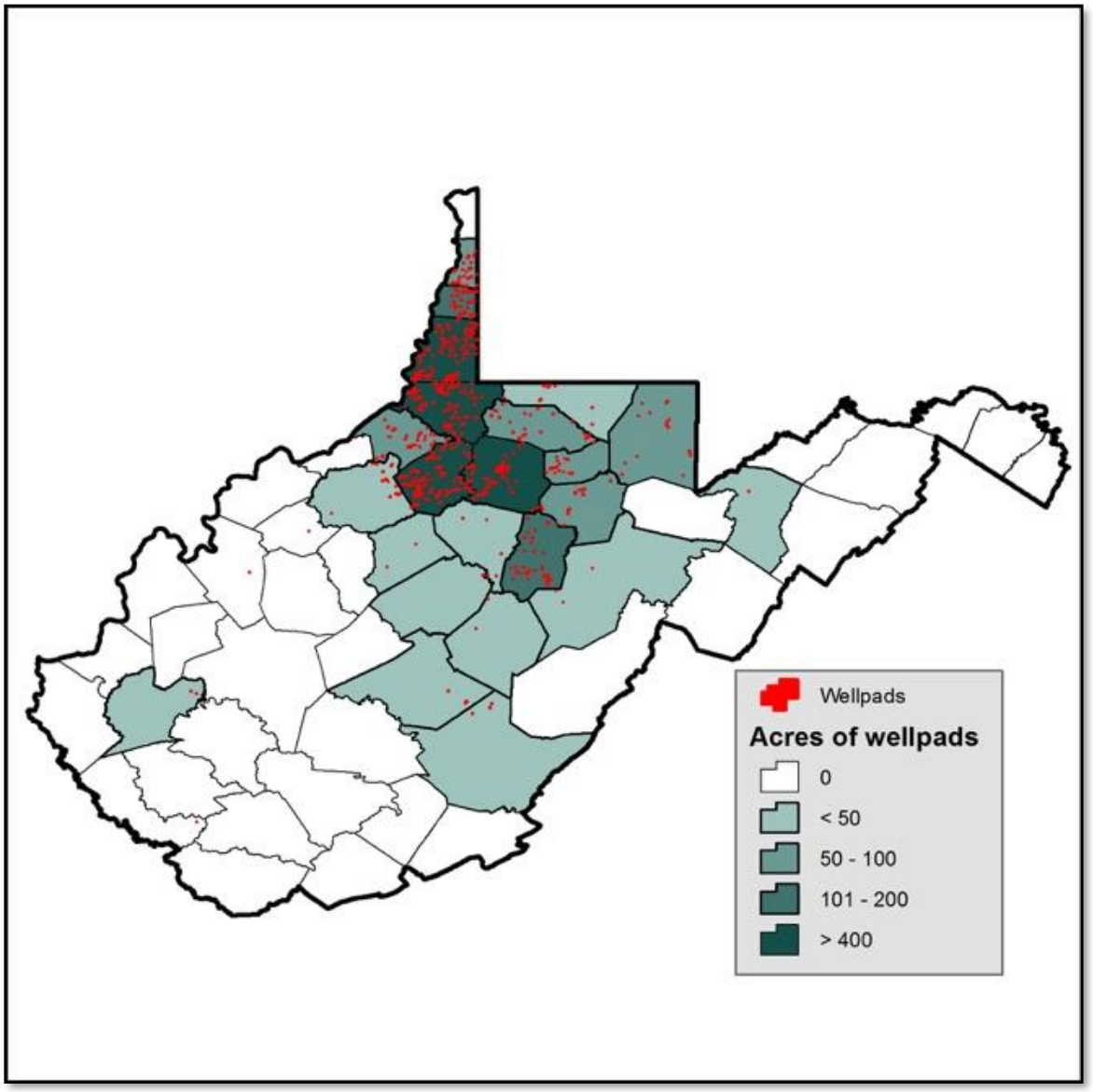


Figure 5. Marcellus Shale impoundments across West Virginia

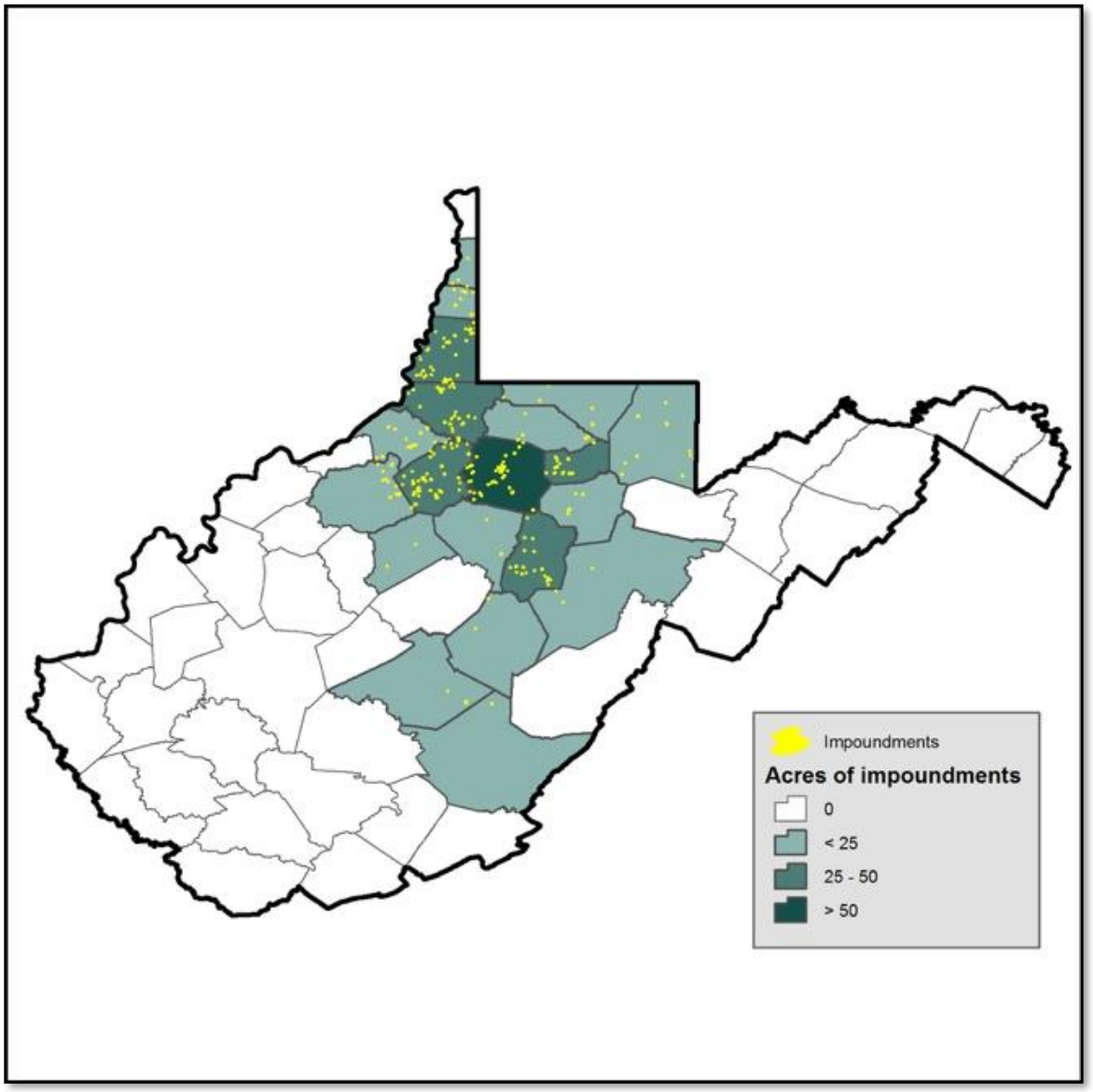


Table 3. Counties most heavily impacted by wellpads

	2007		2009		2011		2014	
County	Area (acres)	Number of wellpads	Area (acres)	Number of wellpads	Area (acres)	Number of wellpads	Area (acres)	Number of wellpads
Marshall	2.3	1	24.1	13	104.8	39	230.4	89
Wetzel	3.3	2	27.1	16	56.4	29	166.9	74
Doddridge	0	0	7.5	5	36.5	21	187.2	87
Harrison	0.9	1	10.7	5	78.8	33	127.2	58
Upshur	0.6	1	13.3	7	68.0	26	52.2	26
Ohio	0	0	0	0	47.4	15	83.9	30
Brooke	0	0	0	0	16.8	6	74.1	26
Tyler	0	0	0	0	5.7	1	79.4	30
Marion	2.1	1	4.3	2	20.8	8	53.8	22
Preston	2.6	1	12.6	5	21.7	11	28.4	14

Table 4. Counties most heavily impacted by impoundments

	2007		2009		2011		2014	
County	Area (acres)	Number of impound-ments	Area (acres)	Number of impound-ments	Area (acres)	Number of impound-ments	Area (acres)	Number of impound-ments
Harrison	0.2	1	5.5	6	33.8	31	27.6	24
Doddridge	0	0	1.1	2	7.0	14	38.4	28
Marshall	0	0	7.4	12	24.0	20	13.2	19
Wetzel	0.1	1	6.3	10	8.0	7	27.9	19
Upshur	0	0	5.6	5	16.7	15	4.6	4
Taylor	0	0	2.8	3	10.3	9	13.1	8
Preston	0	0	0.4	2	8.3	5	6.8	5
Marion	0	0	3.5	2	7.4	4	4.3	2
Tyler	0	0	0	0	0.7	1	14.0	14
Ritchie	0	0	0	0	0	0	14.0	13

Proximity to sensitive land uses

As the number of wellpads has expanded, many have been located close to places where people spend significant amounts of time. Although more research is needed, scientific studies have suggested that living near fracking may adversely impact human health (Werner et al. 2015). Routes of exposure may occur through contamination of drinking water sources, with surface water contamination being the more likely pathway (Harkness et al. 2017), or through air pollution (Werner et al. 2015). Additionally, noise and light associated with the increased industrial activity necessary for well development may negatively impact human well-being and stress levels (Werner et al. 2015). In this section, we assess the location of wellpads and impoundments in relation to homes, schools, public drinking water intakes, public lands, and health care facilities.

Homes

As described above, we created a database of homes for use in this analysis; this database included only those homes located within one-half mile of the center point of a wellpad in 2014. In total, we identified 7,235 homes.

West Virginia State Code provides a setback distance of 625 feet from the center of a wellpad to an occupied dwelling.[6] In addition to disturbing a quiet lifestyle associated with rural living, fracking infrastructure may impact drinking water and air quality. In rural areas, most homes utilize private wells or springs for drinking water.

While the 625-foot setback requirement offers some protection for nearby homes, many wellpads have still been built in very close proximity to homes. Our analysis identified five wellpads located less than 300 feet

[6] W.Va. Code §22-6A-12.

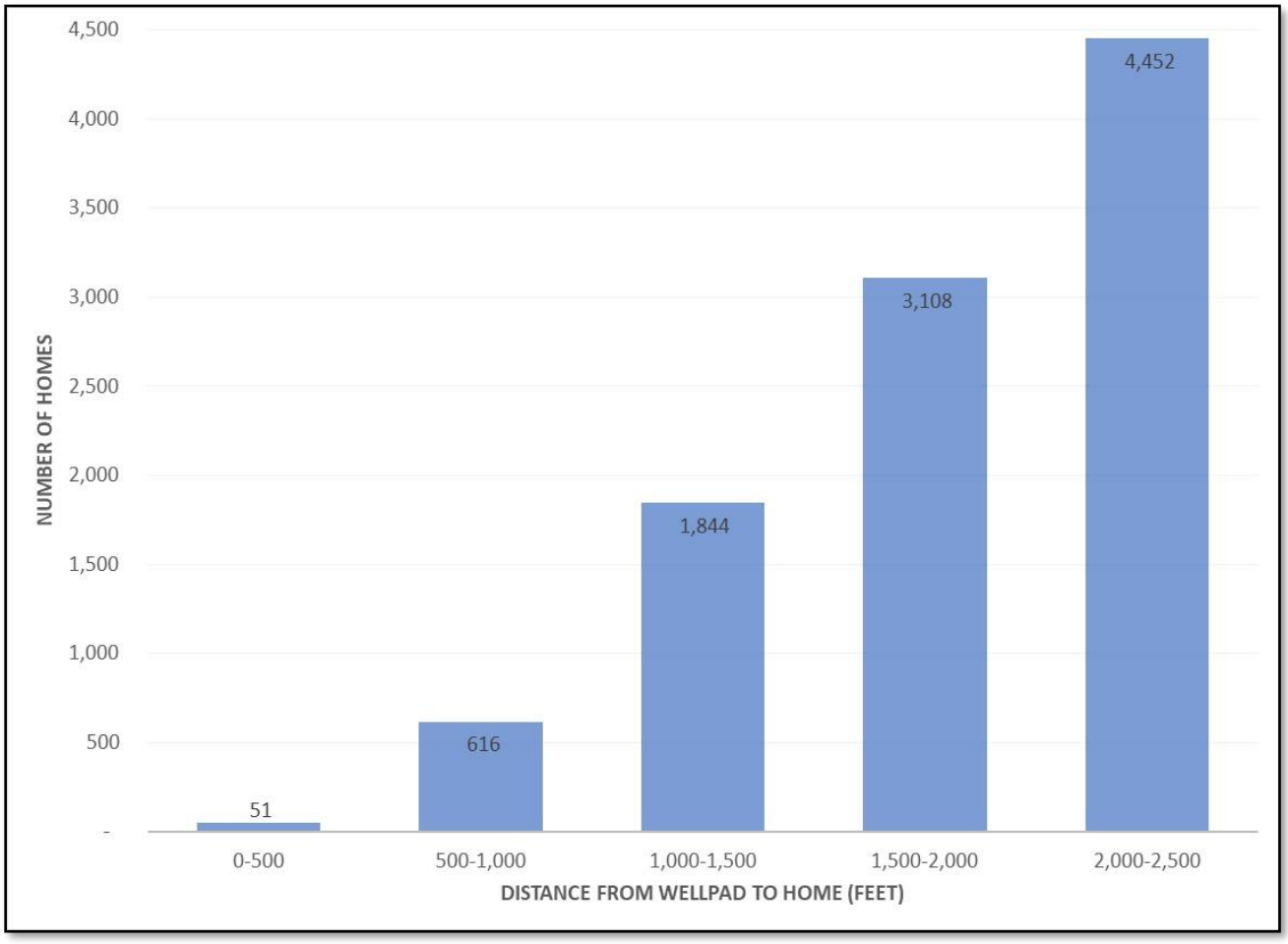
from at least one home and forty homes within 625 feet of a wellpad. Although these homes are located within the setback distance, they may not be in violation of the law. All except seven of these homes were permitted prior to the effective date of the Horizontal Well Control Act.[7] Additionally, homeowners may waive this setback distance requirement if they choose, allowing a wellpad to be developed less than 625 feet from their homes.

We investigated the proximity of homes and wellpads in two ways. First, we assessed the distance from each home in our database to wellpads. We found that thousands of homes have at least one wellpad located less than 2,500 feet away, and more than 600 homes have at least one wellpad located within 1,000 feet (See Figure 6).

Next, we assessed the distance from all wellpads to homes and found that the majority of wellpads (401) have fewer than ten homes located less than one-half mile away (Figure 7). Thirteen wellpads were constructed less than one-half mile from greater than 100 homes. Some wellpads have been built in close proximity to neighborhoods that include large numbers of homes. For example, over 200 homes are located within one-half mile of the center point of a wellpad in Middlebourne in Tyler County, and two other wellpads in the area are located within one-half mile of 150 homes (shown in Figure 8, below).

[7] The Horizontal Well Control Act was effective on December 14, 2011.

Figure 6. Number of homes located near at least one Marcellus Shale wellpad in 2014



Note: Homes are counted multiple times if they are located within a given distance to more than one wellpad. Therefore, the total number of homes displayed in this chart is greater than the total number of homes identified.

Figure 7. Marcellus Shale wellpads with homes located less than one-half mile away in 2014

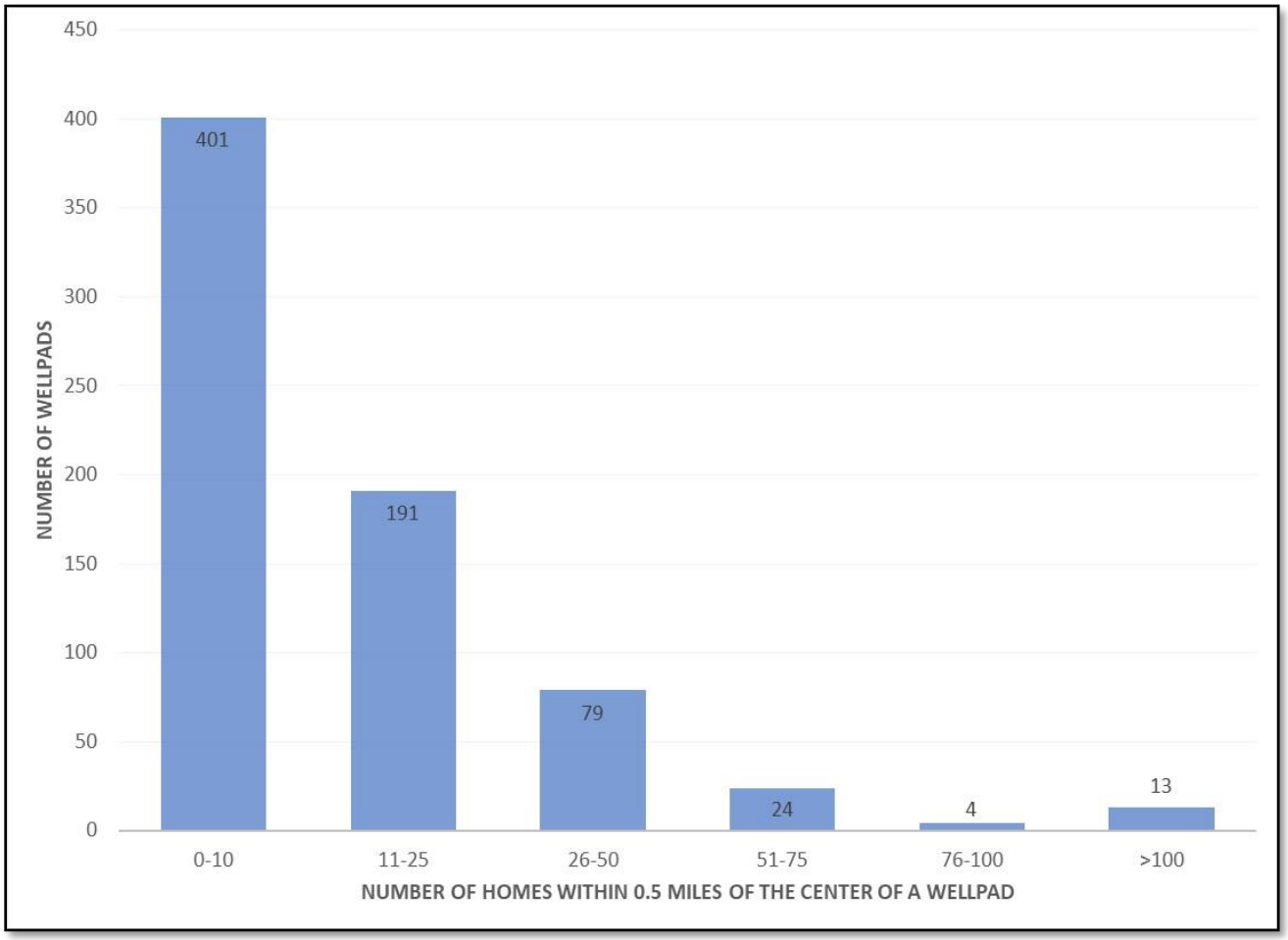
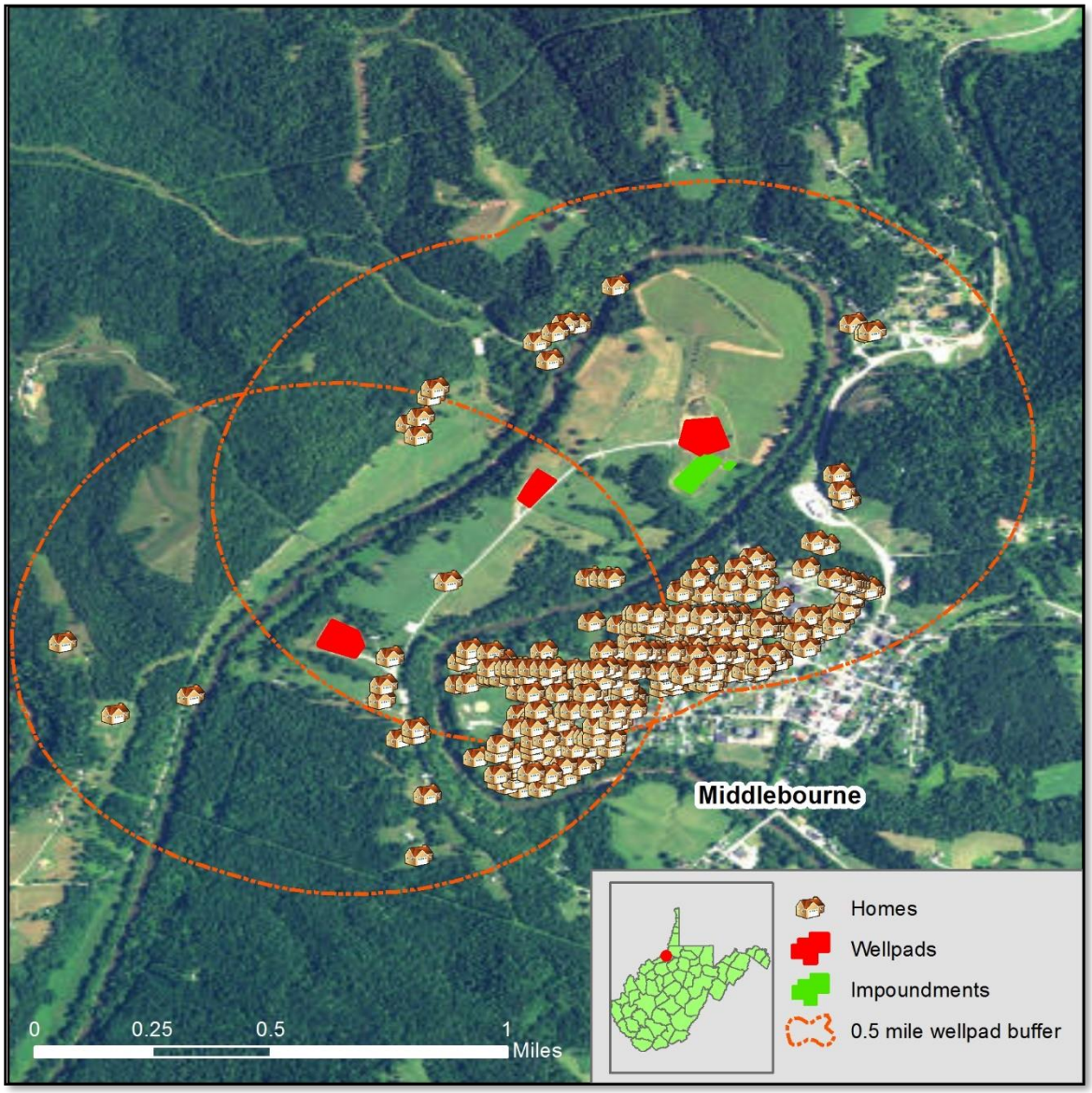


Figure 8. Marcellus Shale wellpads near numerous homes in Middlebourne, Tyler County



Schools

Most children spend significant amounts of time at school, from kindergarten through high school. Children are more vulnerable to the health effects of toxic chemicals because they breathe, eat, and drink more relative to their body weight—and because their bodies are still developing. Our analysis considers kindergarten through 12th-grade schools.

As the fracking boom progressed in West Virginia, more wellpads were developed near schools. In 2007, the closest wellpad was 0.9 miles from a school. By 2014, seven schools had at least one wellpad within one-half mile, 36 schools had at least one well located within one mile, and six schools had two or more schools within one mile (Figure 9).

Mountaineer Middle School in Clarksburg is located closest to a wellpad—only 0.3 miles. Wilsonburg Elementary School in Clarksburg had the most wellpads located in close proximity, with five wellpads within one mile and twelve within two miles (Figure 10). West Taylor Elementary School in Flemington had three wellpads within one mile in 2014.

West Virginia State Code[8] specifies setback distances, which restrict wellpad development near sensitive features such as homes and drinking water intakes; however, the Code does not include a setback distance for schools. This study demonstrates that a significant number of wellpads have been developed close enough to schools to potentially impact students. As the fracking boom has progressed, the number of schools in close proximity to fracking has increased. If this trend continues, setback distances for wellpad development near schools may be warranted to keep children safe.

[8] W.Va. Code §22-6A-12

Figure 9. Number of schools located near Marcellus Shale wellpads

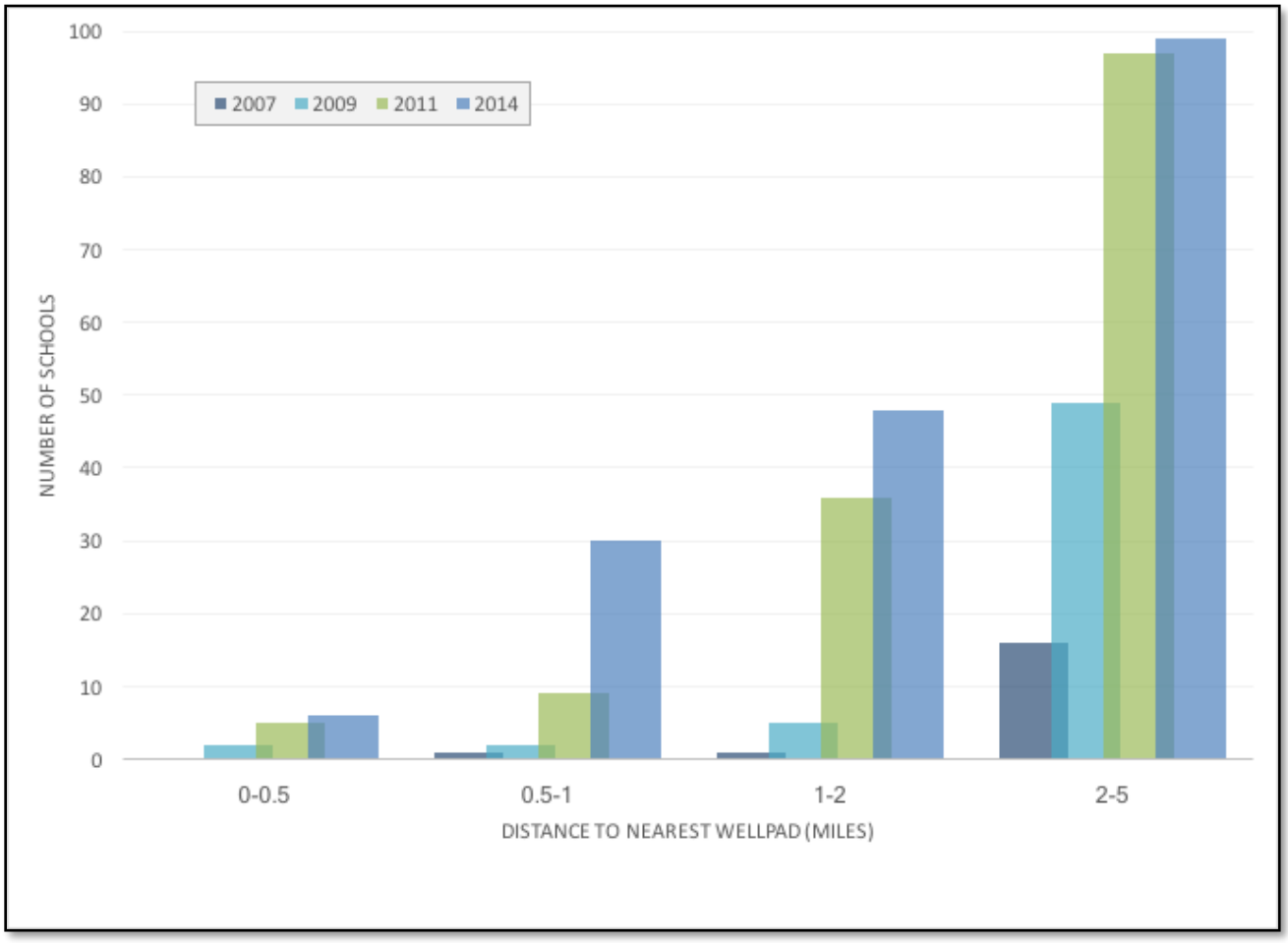
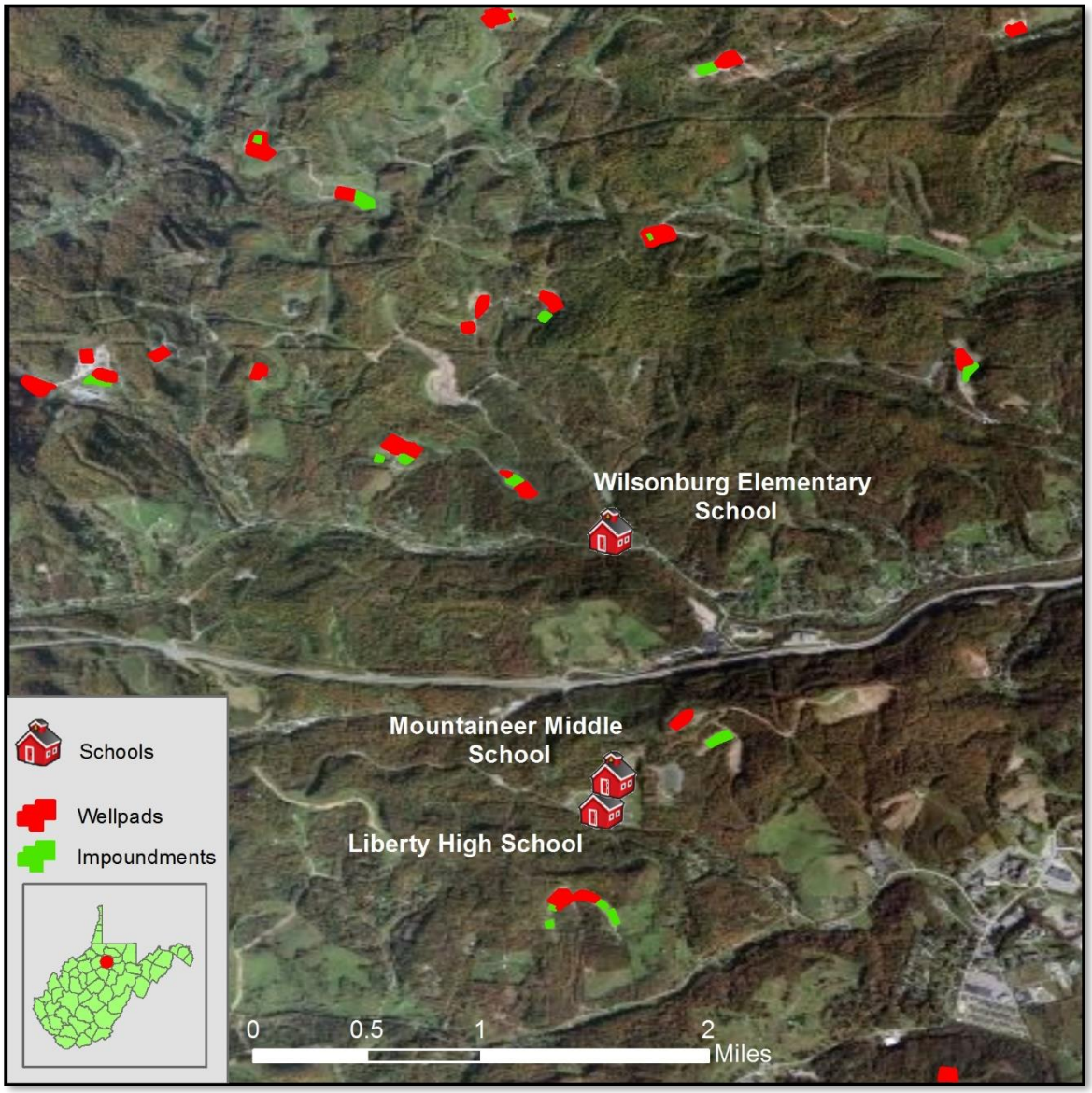


Figure 10. Marcellus Shale wellpads and impoundments near schools in Harrison County



Public drinking water intakes

More than 1.5 million West Virginians—approximately 83% of the population—rely on public utilities for drinking water (WVBPH 2017b). WVDEP and the West Virginia Bureau for Public Health (WVBPH) have identified protection areas for public water supply sources. These zones represent areas in which additional precautions must be taken to prevent contamination of water supplies. ZCCs and zones of peripheral concern (ZPCs) are designed to protect surface water and groundwater influenced by surface water used as sources of public drinking water.

A ZCC is based on a five-hour travel time in streams to a public drinking water intake and extends 1,000 feet from the banks of the principal stream and 500 feet from the banks of tributaries (WVDEP 2017c). In 2014, 30 wellpads and seven impoundments were located within ZCCs (See Figure 11 and Figure 12).

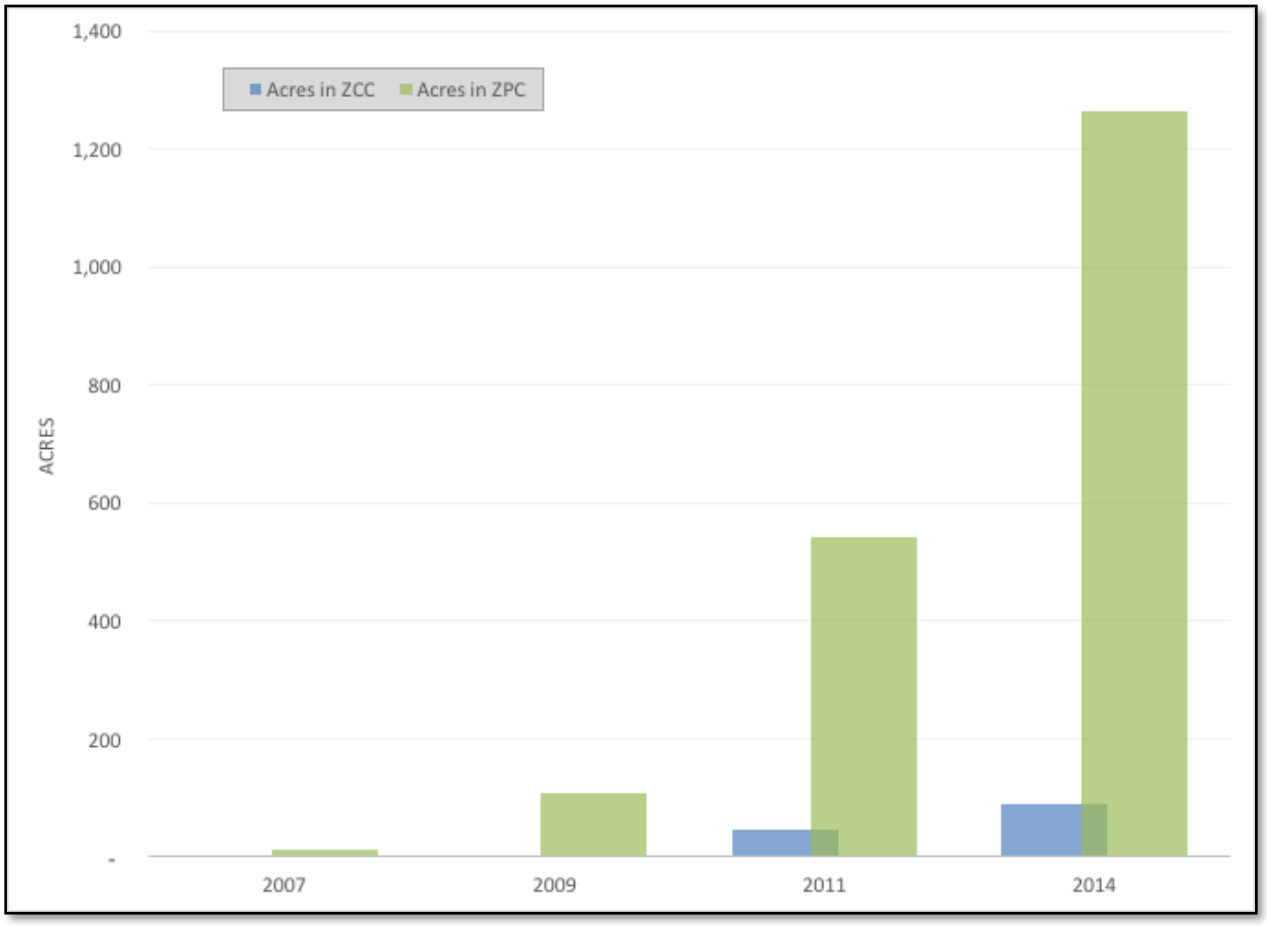
A ZPC extends beyond the ZCC and represents a five-to-ten-hour travel time in streams to a public drinking water intake. It also includes areas 1,000 feet from the banks of the principal stream and 500 feet from the banks of tributaries (WVDEP 2017c). In 2014, 532 wellpads and 17 impoundments were located within ZPCs (See Figure 11 and Figure 12).

Spills of chemical-laden fluids generated during fracking have the potential to enter surface waters and could contaminate public drinking water sources drawn from rivers and streams. West Virginia State Code[9] specifies that a wellpad must be located greater than 1,000 feet from a public water supply intake; however, it does not restrict the construction of wellpads within drinking water protection areas. Results of this study indicate that the oil and gas footprint within drinking water protection areas is growing. Restrictions on development within these protection areas would add another layer of protection from contamination for public drinking water customers.

Figure 13 depicts a portion of the ZCC and ZPC for the Clarksburg Water Board drinking water source, the West Fork River. It illustrates one location where wellpads and impoundments are located within and near drinking water protection areas.

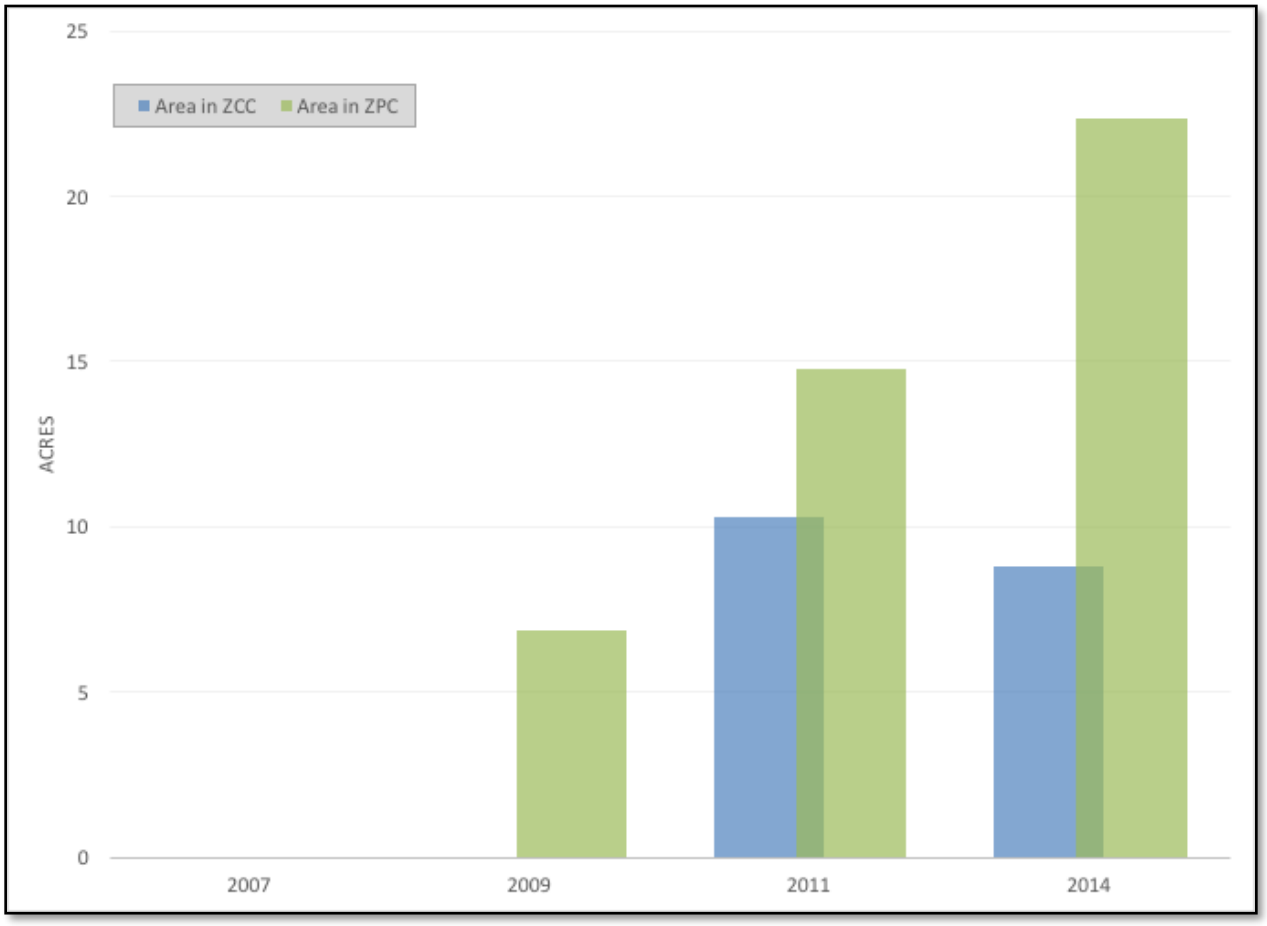
[9] W.Va. Code §22-6A-12.

Figure 11. Acres of Marcellus Shale wellpads within drinking water protection areas



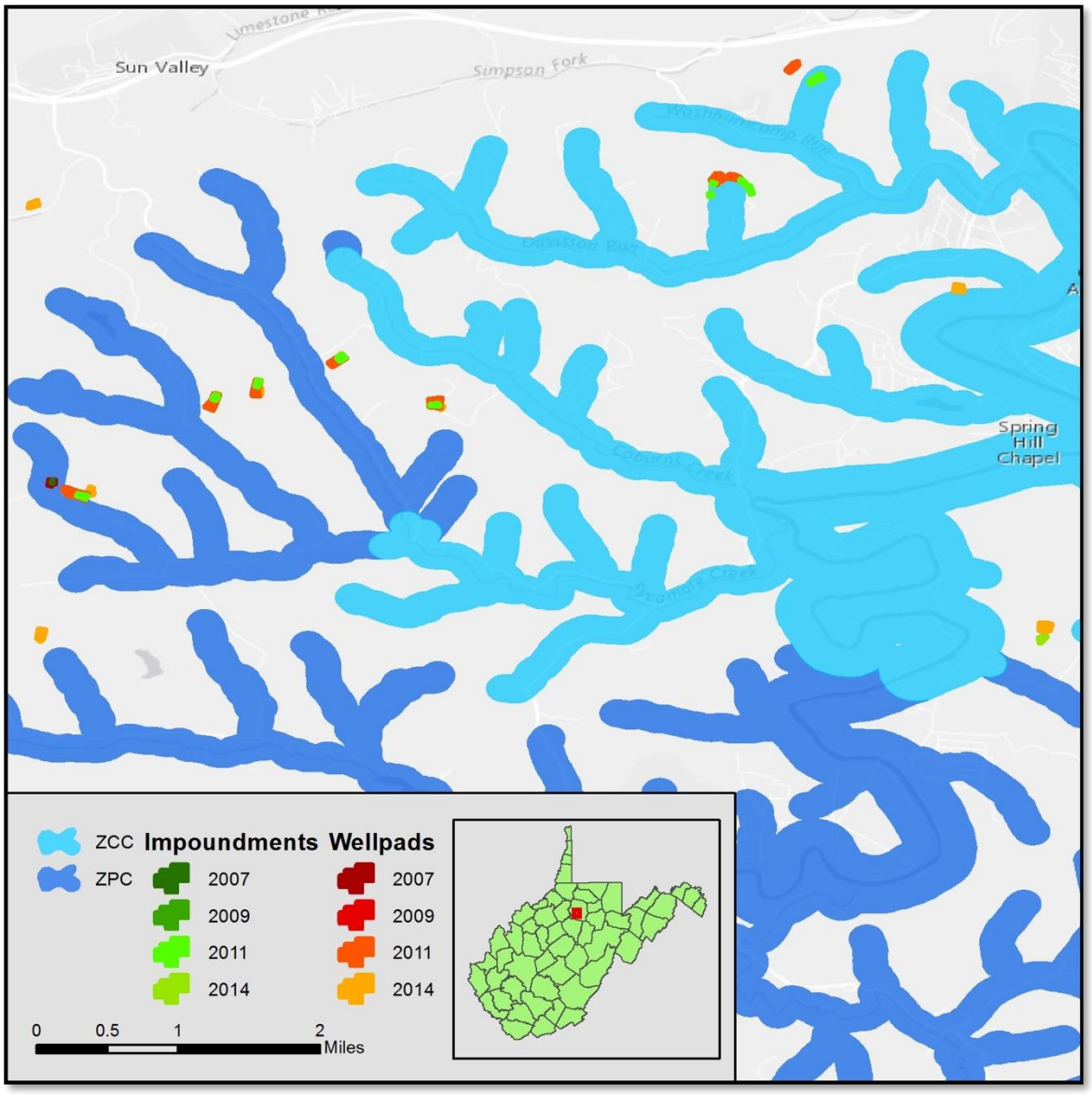
Note: No wellpads were identified within ZCCs in 2007 or 2009.

Figure 12. Acres of impoundments within drinking water protection areas



Note: No impoundments were identified within ZCCs in 2007 or 2009, and no impoundments were identified within ZPCs in 2007.

Figure 13. Marcellus Shale wellpads and impoundments in and near drinking water protection areas in Harrison County



Public lands

Many West Virginians and visitors utilize the state's public lands for recreation and relaxation; development of oil and gas infrastructure in their vicinity may diminish their recreational quality by decreasing scenic and relaxing qualities often enjoyed by visitors. Additionally, industrial development within natural areas could negatively impact wildlife populations residing within these protected lands. We assessed the development of wellpads and impoundments within and in proximity to public lands, including:

- national forests[10] (USFS 2005),
- state forests (WVDOF 2015),
- state parks (WVDNR 2011),
- national wildlife refuges (USFWS 2006), and
- national parks (NPS 2003).

West Virginia State Code[11] does not include setback distances for development of oil and gas infrastructure in or near public lands. This study demonstrates that an increasing number of wellpads and impoundments have been developed in the vicinity of public lands over time. As shown in Table 5, 21 wellpads and five impoundments had been developed within two miles of public lands boundaries by 2014. Restricting development of industrial activities within recreational areas would preserve the aspects of these lands valued for recreation and relaxation.

The Monongahela National Forest has had the largest amount of oil and gas development within its vicinity: five wellpads within its boundary and one on the boundary. The Ohio River Islands National Wildlife Refuge has one wellpad within one mile, ten wellpads within two miles, and five impoundments within two miles. Coopers Rock State Forest, Valley Falls State Park, Audra State Park, Kumbrabow State Forest, and Pricketts Fort State Park each have one wellpad located within two miles of their boundaries.

Table 5. Wellpads and impoundments within two miles of public lands over time

Year	Wellpads	Impoundments
2007	0	0
2009	1	0
2011	11	7
2014	21	5

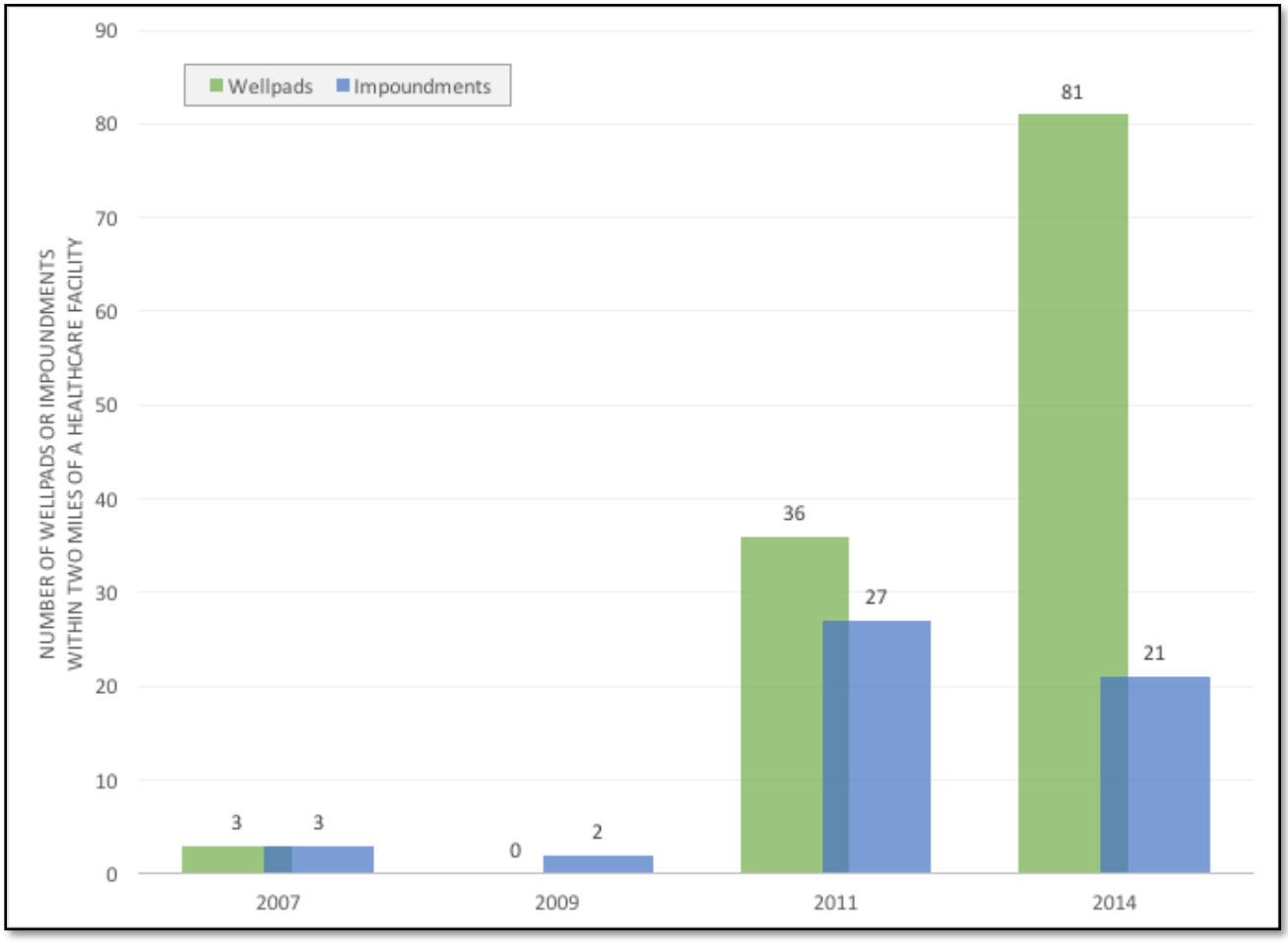
[10] The United States Forest Service (USFS) proclamation boundary was used in this analysis. The proclamation boundary is the forest boundary contained within the presidential proclamation that established the Monongahela National Forest. Not all land within this boundary is currently owned by USFS.
[11] W.Va. Code §22-6A-12.

Health care facilities

Finally, we analyzed the proximity of wellpads and impoundments to healthcare facilities: hospitals, community health care providers, nursing homes, and United States Department of Veterans Affairs facilities. These facilities serve populations whose health is compromised and who may be less able to tolerate additional environmental health stressors. Figure 14 demonstrates that over time, the number of wellpads and impoundments within two miles of healthcare facilities generally increased. In 2007, only three wellpads and three impoundments were located within two miles of a health care facility; by 2014, 81 wellpads and 21 impoundments were located less than two miles from at least one health care facility.

Two different health care facilities had five wellpads located within two miles from each facility in 2014. West Virginia State Code does not specify setback distances for oil and gas infrastructure development to protect vulnerable populations served by healthcare facilities.

Figure 14. Marcellus Shale wellpads and impoundments within two miles of healthcare facilities, 2007-2014



Chemicals used at fracking sites in sensitive areas

Our ability to characterize the potential health threats posed by fracking in West Virginia is limited by data availability. We relied on information on the chemicals used to frack wells that was self-reported to the FracFocus Chemical Disclosure Registry. We do not attempt to characterize the potential toxicity of wastewater generated from these wells and stored nearby, or the extent to which contaminants have moved into ground or surface water.

Importantly, wastewater produced at fracking sites is likely to be more hazardous than the injected fracking fluids because the wastewater can contain naturally occurring underground compounds such as heavy metals and radioactive materials that are mobilized by the fracking process. For example, a previous study analyzed 13 samples of flowback water from West Virginia and found levels of benzene, selenium, and toluene in excess of drinking water standards in ten (77%), three (23%), and three (23%) samples, respectively (Ziemkiewicz et al. 2014).

Direct measurements of air and water contaminants at fracking sites would allow for a more thorough assessment of the potential health risks, but was beyond the scope of this study. As with other studies, our analysis is also limited by the fact that toxicity information is lacking for the vast majority of chemicals used to frack wells.

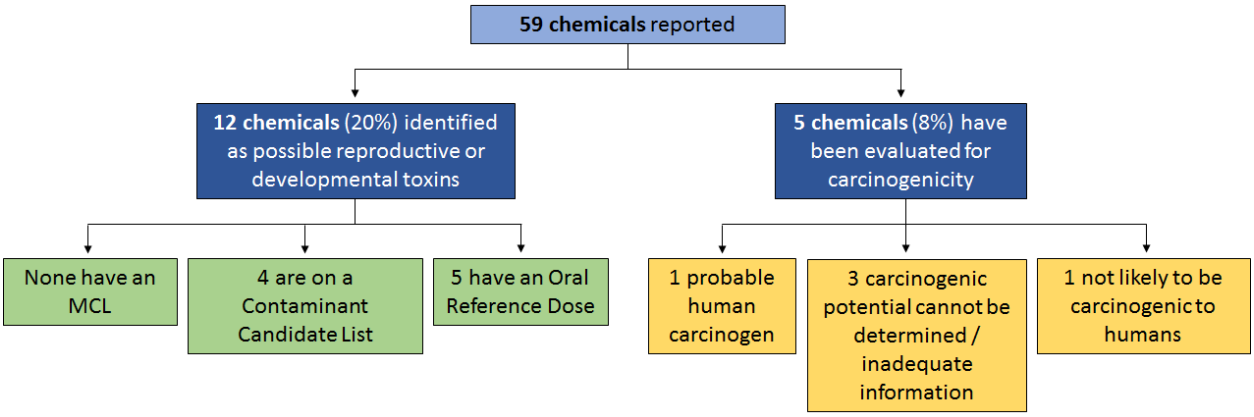
Nonetheless, our systematic, screening-level evaluation of the toxicity of chemicals used at fracking sites in West Virginia revealed that many hazardous substances have been used to frack wells near schools and within ZCCs for surface public drinking water intakes. A total of 54 wellpads were located within one kilometer of a school,[12] and 16 (30%) of them reported using at least one of 59 chemicals between July 2013 and March 2016. Twelve (20%) of these 59 chemicals have been identified as possible reproductive and/or developmental toxicants, and one has been identified as a probable human carcinogen (Figure 15A).

A total of 35 (20%) of the 177 wellpads located within ZCCs reported using at least one of 98 chemicals between May 2013 and March 2016. Nineteen (19%) of these chemicals were identified as possible reproductive and/or developmental toxicants, and two are probable or likely human carcinogens (Figure 15B). Table 6 summarizes the chemicals for which toxicity information is available. Again, it is important to note that for most of the chemicals used, little or no data on their potential toxicity is available.

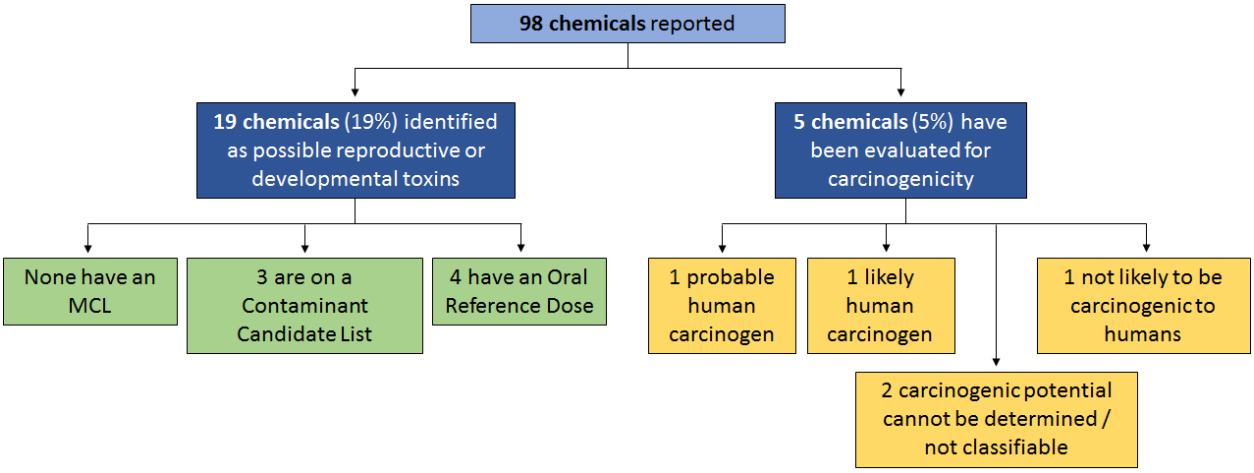
[12] The one-kilometer search distance was chosen arbitrarily because it provided a sufficient number of chemicals to research.

Figure 15: Chemicals used at Marcellus Shale fracking sites A. within one kilometer of a school and B. within zones of critical concern

A



B



A. Sample size is 54 wellpads. B. Sample size is 177 wellpads. MCL refers to the Maximum Contaminant Level, a legally enforceable public drinking water standard. Chemicals on a Contaminant Candidate List have been proposed for regulation in drinking water due to widespread occurrence or hazard information, but do not currently have a legally enforceable limit. The existence of an established Oral Reference Dose (RfD) indicates that enough scientific evidence of harm is available to determine the amount of a chemical that can be safely ingested.

Table 6. Potentially hazardous chemicals used at Marcellus Shale fracking sites within one kilometer of schools or within zones of critical concern

Chemical name	Toxicity for which information is available	Studies	Chemical Contaminant List	Oral RfD for reproductive or developmental effects (mg/kg/day)	Most recent weight-of-evidence characterization (year)
1,2,4-Trimethylbenzene	C	--	--	--	Inadequate information to assess carcinogenic potential (2005)
1,2-Propanediol	D	A, H	--	--	--
1,4-Dioxane	C	--	--	--	Likely to be carcinogenic to humans (2005)
2-Butoxyethanol	R, C	A	--	--	Not likely to be carcinogenic to humans (2005)
Ammonium acetate	C	--	--	--	Not classifiable as to human carcinogenicity (1986)
Ammonium chloride	D	A	--	--	--
Carbonic acid calcium salt	D	A	--	--	--
Chlorite (sodium salt)	C, D	A, H	--	0.03	Carcinogenic potential cannot be determined (1996)
Dibromoacetonitrile	D	A	--	--	--
Didecyldimethylammonium chloride	R	A	--	--	--
Diethanolamine	R	A	--	--	--
Diethylene glycol	R	A	--	--	--
Ethanol	R, D	H	--	--	--
Ethylene glycol	R, D	A	2009	2	--

Chemical name	Toxicity for which information is available	Studies	Chemical Contaminant List	Oral RfD for reproductive or developmental effects (mg/kg/day)	Most recent weight-of-evidence characterization (year)
Formaldehyde	R, D, C	A, H	2009	0.2	Probable human carcinogen - based on limited evidence of carcinogenicity in humans (1986)
Isopropanole	D	A	--	--	--
Methanol	D	A	2009	2	--
N,N-Dimethylformamide	D	A	--	--	--
Naphthalene	D, C	A	2015 (draft)	0.02	Carcinogenic potential cannot be determined (1996)
Potassium chloride	R, D	A, H	--	--	--
Quartz	R	A	--	--	--
Sodium hypochlorite	R, D	A, H	--	--	--
Sodium nitrate	R	A	--	--	--
Strontium chloride	R, D	H	--	--	--
Titanium dioxide	R	A	--	--	--

Note: R=reproductive; D=developmental; C=cancer. A=animal; H=human. Chemicals on a Contaminant Candidate List have been proposed for regulation in drinking water due to widespread occurrence or hazard information, but do not currently have a legally enforceable limit. The existence of an established Oral Reference Dose (RfD) indicates enough scientific evidence of harm is available to determine the amount of a chemical that can be safely ingested.

Summary

As the extent of fracking has grown since 2007, fracking infrastructure—wellpads and impoundments—has encroached on places essential for everyday life in West Virginia. Roughly one-fifth of the chemicals being used to frack Marcellus Shale wells close to schools and public drinking water intakes are possible reproductive and/or developmental toxicants or human carcinogens. Most operators are not voluntarily disclosing the chemicals they use, and toxicity information is unavailable for many of the chemicals used at fracking sites, limiting our ability to evaluate the potential health threats posed by fracking in the area.

West Virginia State Code requires setbacks to keep wellpads from being developed too close to homes and public drinking water intakes. However, the other types of sensitive areas assessed in this report are not protected from nearby Marcellus Shale development. Setback distances for schools, health care facilities, and public lands—and restrictions in zones of critical concern and zones of peripheral concern above drinking water intakes—would help protect vulnerable populations and recreational opportunities as fracking development continues.

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Appendix A: Future crowdsourced technical assessment

A set of two applications were developed to create the delineated wellpads, delineated impoundments, and homes datasets used in this research project. Due to the time constraints associated with crowdsourced projects, we did not open the projects to the wider public. Both applications can be used for future crowdsourced data collection efforts to update the existing datasets or to create similar datasets for other regions.