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Hydraulic Fracturing and Water Resources

Lucija Muehlenbachs and Sheila Olmstead

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The potential for impacts on water resources is often recognized as an important issue when shale gas development is discussed. Potential and significant impacts on groundwater and surface water resources might arise by wellbores traversing drinking-water aquifers, the use of significant water inputs, and the generation of large wastewater streams. Water withdrawals for energy development could reduce instream flows in rivers and streams, or reduce groundwater levels, diminishing ecosystem services—such as species habitat, recreation, and pollution assimilation—and reducing water available for other diverted uses. Water pollution from shale gas development could reduce or degrade the quality of available resources for uncompensated downstream users who divert water from shared rivers and streams, or users of a common aquifer. Accidental releases are one avenue for these impacts. Liquid waste treatment and disposal is another. Recent research is beginning to shed more light to better inform public concerns.

What Does the Scientific Literature Say?

Water Quality Concerns

The potential for contamination of groundwater from hydraulic fracturing has received significant attention in the popular media. Case studies of isolated incidents of groundwater contamination do suggest links with shale gas activity. For example, in Pavilion, Wyo., studies by two federal agencies found contamination in groundwater wells from shale gas activities, though it is not clear whether the source was a leak from the well casing or seepage from surface fluid storage ponds (U.S. Environmental Protection Agency, 2011; and Wright et al., 2012). In Alberta, Canada, an energy developer inadvertently fractured a well above the targeted gas-bearing formation, contaminating groundwater in the process (Energy Resources Conservation Board, 2012).

Regions with plentiful methane in the sub-surface often have high methane levels in groundwater, thus it can be difficult to attribute groundwater quality impairment to energy development. There is evidence consistent with migration of methane from Marcellus Shale gas wells in Pennsylvania to overlying groundwater wells (Osborn et al., 2011; and Darrah et al., 2014). In the latter study, results are consistent with casing and cementing failures as the source of contamination. The occurrence of this phenomenon is likely to vary significantly; a study in Arkansas' Fayetteville Shale did not detect evidence in groundwater of stray gas contamination or contamination by brine (Warner et al., 2013b).

Much of the public attention regarding groundwater contamination focuses on the process of hydraulic fracturing itself. However, the potential for the movement of brines and fracking fluids from deep shale formations to overlying aquifers through natural or induced fractures is debated in the scientific literature (Vengosh et al., 2014). The migration of fracking fluids and other contaminants, if it is even possible, would likely unfold over a long time frame, making impacts from current, unconventional gas development undetectable in the short run.

Though much of the public discussion has centered on potential risks to groundwater aquifers, risks to surface water rivers and streams may be greater in scope and magnitude (Krupnick, Gordon, and Olmstead, 2013).

And emerging evidence suggests that surface water quality impacts from shale gas development may be significant. The most significant measured impacts thus far have to do with the release of partially treated wastewater to rivers and streams. In the Marcellus Shale, 10% to 70% of fracking fluid inputs may return as flowback, along with formation brine, sometimes called produced water, which contains naturally occurring contaminants such as heavy metals and radioactive material (Vidic, 2013). Most flowback in the Marcellus is now recycled for new well completions, with the remaining liquid waste either trucked to industrial wastewater treatment facilities or transported to deep injection wells in Ohio, West Virginia, and New York (Jiang, Hendrickson, and VanBriesen, 2014). In western shale plays, there is little recycling of water inputs and essentially no shipments to wastewater treatment facilities—deep injection is a widely-available, cost-effective disposal option. In many shale plays, the regional wastewater treatment and disposal burden has expanded significantly due to energy development. For example, in Pennsylvania, shale gas wastewater flows represent a 570% increase over baseline oil and gas wastewater flows in 2004 (Lutz, Lewis, and Doyle, 2013). This increase is important whether shale gas wastewater is shipped to wastewater treatment plants or injected deep underground; the injection of very large quantities of new fracking waste into deep injection wells has caused faults to slip, resulting in seismic activity in states such as Arkansas, Ohio, and Oklahoma (Ellsworth, 2013).

Regulators have focused on shipments of flowback and produced water from Marcellus Shale gas wells to municipal and industrial wastewater treatment plants as a public and environmental health concern. In 2011, Pennsylvania banned shipments to municipal sewage treatment plants, though industrial "centralized waste treatment" (CWT) facilities continue to treat shale gas waste (Pennsylvania General Code, 2010; and Zhang et al., 2014). Impacts on rivers and streams from the incomplete treatment of the salty wastewater have been demonstrated (Olmstead et al., 2013; and Wilson and VanBriesen, 2013). The increased concentration of dissolved solids may affect economically important species such as brook trout (Weltman-Fahs and Taylor, 2014) as well as the quality of downstream drinking water (Wilson and VanBriesen, 2013). Radioactive material from treated shale gas waste is also accumulating in stream sediments after partial removal by CWTs, suggesting potential long-run impacts on human and ecosystem health (Warner et al., 2013a; and Zhang et al., 2014).

The water pollution problems from partially treated flowback and produced water being released to rivers and streams are serious, but they are regional in nature. As discussed above, most U.S. regions with significant shale gas resources also have plentiful deep injection well capacity for liquid waste disposal. The Marcellus Shale region is an exception to this rule, though the limited deep injection capacity in this region may be a problem in other global shale plays. Two additional surface water quality risks are not region-specific and may cause damages more broadly.

First, the recent rapid increase in shale gas development has caused an infrastructure boom, including well pads, pipelines, and roads. The associated land clearing, construction, and installation of impervious surfaces may increase stormwater runoff, erosion, and sedimentation of local rivers and streams, particularly because oil and gas construction sites have been exempt from the Clean Water Act's stormwater control regulations for construction sites since 2005. Empirical evidence of increases in total suspended solids (TSS) downstream of shale gas well pads in Pennsylvania has been demonstrated (Olmstead et al., 2013).

Second, the specter of widespread accidental releases contaminating surface water has been a focus of public concern. The only empirical study to examine this possibility shows no statistical evidence of systematic pollution associated with gas wells in Pennsylvania through 2011 (Olmstead et al., 2013). However, individual spills can and do occur. For example, a 2007 accidental release of fracking fluids to a creek in Kentucky had toxic impacts on fish, including two federally protected species, lasting several months (Papoulias and Velasco, 2013).

Water Quantity Concerns

Water inputs to hydraulic fracturing vary with geology, the amount of recoverable gas, number and length of horizontal wellbores, and other factors. Approximately 2 to 4 million gallons are required for wells in the Marcellus Shale (Veil, 2010), and somewhat more – about 5 million gallons per well – in the Barnett Shale in Texas and Oklahoma (Nicot et al., 2014).

Empirical evidence for hydraulic fracturing impacts directly related to freshwater extraction is thin. In the Marcellus Shale region, surface water is generally plentiful, and withdrawals for shale gas development represent a very small fraction of total withdrawals (Mitchell, Small, and Casman, 2013). Withdrawals for hydraulic fracturing in Texas—which includes part or all of the Barnett, Fayetteville, Haynesville, and Eagle Ford shales—amount to less than 1% of statewide water withdrawals (Nicot and Scanlon, 2012). In addition, while shale gas production is somewhat more water-intensive than conventional gas, it is less water-intensive than the production of most other fossil fuels such as coal, and conventional and unconventional oil (Kuwayama, Krupnick, and Olmstead, 2014).

However, the risks associated with surface water consumption can be expected to vary both spatially and over time. Globally, 38% of shale resources are in areas that are arid (Reig, Luo, and Proctor, 2014), where water's marginal value in alternative uses could be high. In Texas' sparsely populated Eagle Ford Shale, water use for fracking may increase to 89% of total use in area counties during peak production (Nicot and Scanlon, 2012). Water rights structures and the regulation of water withdrawals will mitigate the impacts to varying degrees. Even within a river basin, small streams may be relatively more sensitive to changes in water quality and availability than larger river segments; these smaller water bodies support about 40% of surface water withdrawals in the Marcellus Shale (Mitchell, Small, and Casman, 2013). In addition, water withdrawals during low-flow periods, such as summers and droughts, may have more significant ecosystem impacts (Entrekin et al., 2011).

While the amount of groundwater used for fracking in the humid eastern United States is negligible, fracking in arid and semi-arid regions uses significant groundwater inputs. For example, groundwater use in Texas' Barnett Shale represented about 50% of total withdrawals for fracking in 2006, though Barnett operators have since increased the use of surface water, and this percentage has dropped (Nicot et al., 2014). Even in semi-arid states, however, groundwater withdrawals for fracking represent a small fraction of total statewide withdrawals (Murray, 2013; and Nicot and Scanlon, 2012). The extent to which the resulting groundwater depletion represents a negative effect depends on geologic as well as economic and institutional factors. The rates of recharge in some aquifers are so low that many would be considered non-renewable resources over our lifetimes, and the speed at which they are depleted should take into consideration the future foregone uses such as for municipal drinking water supplies. Compared to the case of groundwater pollution resulting from hydraulic fracturing, far less attention has been given to groundwater use, including its impacts on agricultural production.

What Does the Economics Literature Say?

There is a growing literature in economics examining various impacts from hydraulic fracturing, including impacts on employment, health, and electricity prices (see Mason, Muehlenbachs, and Olmstead, forthcoming, for a review). Of this literature, only a small handful of papers focuses on water resources and fracking. A survey of Pennsylvania residents in four counties on the Susquehanna River found that they would be willing to pay an average of $10.46 per month—in aggregate, about $9.3 million per year—for eliminating all risks to area waterways through the "implementation of public safety measures around gas wells (such as the installation of containment ditches)" (Bernstein, Kinnaman, and Wu, 2013). In a different survey (Siikamaki and Krupnick, 2014) of a random sample of households in Pennsylvania and Texas, Texas households may be willing to pay about $24 per year to eliminate pollution related to shale gas development in 1% of the state's surface water bodies. Pennsylvania residents' willingness to pay for reducing such surface water impacts was about $10 per year (Siikamaki and Krupnick, 2014).Siikamaki and Krupnick (2014) have also estimated households' willingness to pay, in Pennsylvania and Texas, for reducing the risk of groundwater contamination. On average, households in both states are willing to pay about $33 per year to reduce by 1,000 the number of groundwater wells with potential pollution problems related to shale gas development.

A study of the Pennsylvania real estate market suggests that groundwater contamination risk from fracking—real or perceived—has been capitalized in housing prices. Using transaction records of all properties sold in 36 counties in Pennsylvania between January 1995 and April 2012, Muehlenbachs, Spiller, and Timmins (2014) compare the difference in impacts from drilling across properties that have access to publicly supplied, piped water and properties that depend on their own private, drinking water well. They focused on properties that were sold more than once and calculated the change before and after drilling a well. The researchers then compared how this change differed by drinking water source. Groundwater-dependent homes within a mile of a shale gas well lost about 3.4% of their market value after the well was drilled. These negative impacts become more pronounced the closer the house was to the well, reaching -16.7% within .6 miles (1km). Properties with access to piped water from public water sources, conversely, experienced small net gains (6.6%) on average at a distance of a mile, likely because royalty payments made to homeowners for the mineral rights offset other costs of proximity (such as the loss of a preferred visual landscape, potential pollution, or traffic congestion). However, those benefits tend to disappear for homes within a .6-mile-distance of a well, likely because the negative effects of proximity outweigh any benefits from lease payments. With these numbers they identify the component of the negative impact specifically attributable to groundwater contamination risk and find that this can vary between 10% to 22% of the house value, depending on the distance to the top of the well. This implies very large local economic impacts from groundwater contamination risk, or the perceptions thereof.

Towards a Full Cost-Benefit Analysis

The majority of the scientific literature to date has focused on water quality impacts, with less research on the water quantity impacts. There is evidence that incomplete treatment of wastewater at treatment plants has impaired downstream water quality in rivers and streams. There is also some evidence linking groundwater contamination to shale gas activity, and significant public concern about these impacts, with surveys indicating that people are willing to pay to avoid risk. Furthermore, the potential risk of groundwater contamination—real or perceived—from hydraulic fracturing has already had real effects on the housing market. Many of the risks discussed have not yet been monetized, which would be a necessary next step to perform a cost-benefit analysis.

For More Information

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Lucija Muehlenbachs (lmuehlen@ucalgary.ca) is Assistant Professor, Department of Economics, University of Calgary, Alberta, Canada, and a Visiting Fellow at Resources for the Future, Washington, D.C. Sheila Olmstead (sheila.olmstead@austin.utexas.edu) is Associate Professor, LBJ School of Public Affairs, University of Texas at Austin and a Visiting Fellow at Resources for the Future, Washington, D.C.