CHAPTER 4

Hydraulic Fracturing and Water Resources

What Do We Know and Need to Know?

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According to some energy analysts, natural gas is "poised to enter a golden age" as a result of the availability and development of large volumes of new sources of unconventional natural gas, including coal bed methane, tight gas, and shale gas. Historically, natural gas production from unconventional reserves has been limited. In 2010, unconventional natural gas accounted for about 14 percent of total global natural gas production. The International Energy Agency (IEA) projects that by 2013 annual production from unconventional sources will triple and will represent about one-third of all natural gas production (IEA 2012). While North America, especially the United States and Canada, dominated unconventional gas production in 2010, growth in unconventional gas production is expected widely around the world (IEA 2012). China, in particular, is projected to experience major increases in production, becoming the second-largest producer after the United States. While shale gas accounts for the vast majority of growth in natural gas production, some growth is also projected for tight gas.

Natural gas is typically classified as conventional or unconventional. Conventional natural gas is generally held as a pocket of gas *beneath* a rock layer with low permeability and flows freely to the surface once the well is drilled. By contrast, unconventional natural gas is more difficult to extract because it is trapped *in* rock with very low permeability. Extracting natural gas from unconventional sources is more complex and costly than conventional natural gas recovery. Technological improvements, however, have made extraction from unconventional sources more economically viable in recent years. In particular, the combination of horizontal drilling and hydraulic fracturing has greatly increased the productivity of natural gas wells. These new techniques have also raised concerns about the adverse environmental and social consequences of these practices, especially effects on water resources.

To date, much of the debate about hydraulic fracturing has centered on the use of chemicals and concerns that these chemicals could contaminate drinking water. In response, numerous states have passed or are considering regulations requiring natural gas operators to disclose the chemicals used during well injection. Additionally, the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission have established a public website that allows companies to voluntarily disclose water and chemical usage for wells since January 2011 that have been hydraulically fractured, although it is of note that these data are not subject to third-party verification and are not in a format that can be searched or aggregated.

The debate has been particularly controversial in the United States, where the majority of unconventional natural gas development has been concentrated. To better identify and understand the key issues, the Pacific Institute conducted extensive interviews with a diverse group of stakeholders, including representatives from state and federal agencies, academia, industry, environmental groups, and community-based organizations from across the United States. This chapter provides a short summary of the key issues identified in the interviews and in an initial assessment and synthesis of existing research. It especially examines the impacts of hydraulic fracturing and unconventional natural gas extraction on water resources and identifies areas in which more information is needed. More detail is available in the full report (Cooley and Donnelly 2012).

Overview of Hydraulic Fracturing

Hydraulic fracturing, or fracking, refers to the process by which fluid is injected into wells under high pressure to create cracks and fissures in rock formations that improve the production of these wells. These fissures can extend more than 300 meters (1,000 feet) from the well (Veil 2010). The fracturing fluid consists of water, chemical additives, and a propping agent. The propping agent—typically sand, ceramic beads, or another incompressible material—holds open the newly created fissures to allow the natural gas to flow more freely. In the first few days to weeks after completion of the fracturing process, the well pressure is released and some of the fracturing fluid (referred to as flowback) flows back to the surface through the well bore. Some unknown volume of fracturing fluid, along with its chemical additives, remains underground. Over longer time periods, any water naturally present in the ground (referred to as produced water) continues to flow through the well to the surface. The flowback and produced water, which can be considerably saltier than seawater and contain a variety of other contaminants (IOGCC and ALL Consulting 2006), are typically stored on-site in tanks or pits before reuse, treatment, or disposal. There are varying and conflicting reports on whether and to what extent wells will be fracked multiple times over their productive life (Nicot et al. 2011), although this will likely depend on local geology, spacing of wells, and natural gas prices.

Hydraulic fracturing was first developed in the early twentieth century but was not commercially applied until the mid- to late 1940s. Although initially developed to improve the production of oil and gas wells, hydraulic fracturing has been used in other applications, including development of drinking water wells (NHDES 2010), disposal of wastes, and enhancement of electricity production from geothermal energy sources. Hydraulic fracturing is standard practice for extracting natural gas from unconventional sources, including coal beds, shale, and tight sands, and is increasingly being applied to conventional sources to improve their productivity. While the process is the same, the various applications of hydraulic fracturing differ in their water requirements, the amount and types of chemicals employed, and the quantity and quality of wastewater generated.

We note that there is no single definition of "hydraulic fracturing." Some, including industry representatives, define hydraulic fracturing narrowly, referring only to the process by which fluids are injected into a well bore. They argue that some of the challenges, such as wastewater disposal, spills, and leaks, are common to all oil and gas operations and therefore are not specifically associated with hydraulic fracturing. Others, however, define the issue more broadly to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure (US EPA 2011c; ProPublica 2012). For these groups, hydraulic fracturing and unconventional natural gas production are synonymous because hydraulic fracturing has allowed for the development of these unconventional natural gas resources. Without hydraulic fracturing, shale gas production would be far more limited. For the purposes of this analysis, we use a broader definition of hydraulic fracturing to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure (Cooley and Donnelly 2012).

Concerns Associated with Hydraulic Fracturing Operations

Hydraulic fracturing has generated a tremendous amount of controversy. There are daily media reports from outlets across the United States, Canada, South Africa, Australia, France, England, and elsewhere about environmental, social, economic, and community impacts. In an effort to identify the key issues, the Pacific Institute interviewed sixteen representatives of state and federal agencies, academia, industry, environmental groups, and community-based organizations in the United States. Their responses are summarized in figure 4.1. Although the sample size was relatively small, the interviews were extensive, and the detailed responses from these diverse stakeholders are similar across the spectrum and indicative of the broad range of concerns associated with hydraulic fracturing raised in other forums.

All of the interviewees indicated that impacts on the availability and quality of water resources were among the primary concerns associated with hydraulic fracturing operations. Water-related findings of the interviews include the following:

- Spills and leaks were the most commonly cited concern, with fourteen of the sixteen people interviewed expressing concern.
- Thirteen of the interviewees considered wastewater treatment and disposal to be key challenges. One industry representative noted that wastewater management was perhaps a larger issue than chemical usage.
- Three-quarters of the interviewees were concerned about the water requirements of hydraulic fracturing. This concern was not limited to interviewees in the most arid regions; rather, it was expressed by people working in various regions across the United States. In some cases, the concern was directly related to the effects of large water withdrawals on the availability of water for other uses. In other cases, concern was related to how large withdrawals would affect water quality.

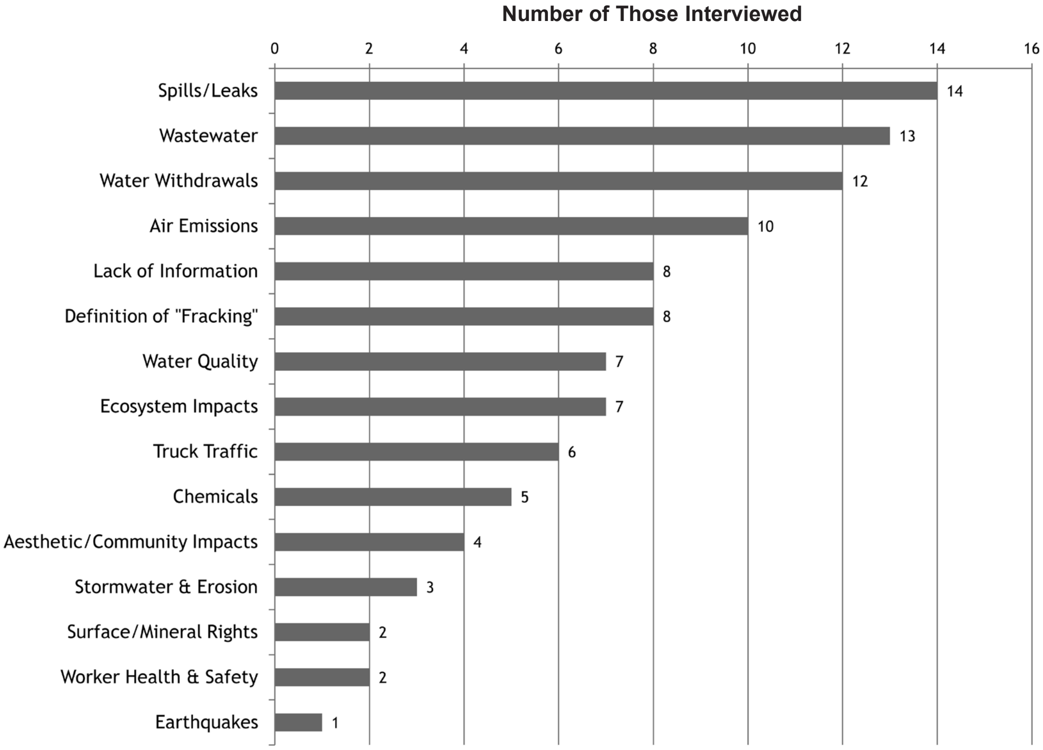

FIGURE 4.1 KEY CONCERNS IDENTIFIED BY INTERVIEWEES
Note: Results are based on interviews with sixteen representatives of state and federal agencies, academia, industry, environmental groups, and community-based organizations.

- Nearly half of the interviewees explicitly identified water quality as a key issue. Many of the other concerns mentioned, such as spills, leaks, and wastewater management, also imply concern about water quality. One interviewee expressed concern about surface water contamination associated with air emissions.
- Less than one-third of those interviewed specifically identified chemical usage and the associated risk of groundwater contamination as key issues, although many more expressed concern about groundwater contamination more broadly. Some of the interviewees thought that with so much attention given to chemical usage, inadequate attention is given to some of the other issues, such as wastewater disposal and methane migration, which may ultimately pose more serious risks.
- One issue identified in our interviews that was not directly related to environmental impacts was the overall lack of information, with half of those interviewed describing it as a key problem. Several commented on the complexity of the issues and the difficulty of explaining the technology to the general public.

Water Challenges

In this section, we summarize the available information on the following key water-related concerns identified by those interviewed: (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management. This information is largely drawn from a review of the academic and gray literature and from media reports. Our focus throughout this chapter is on shale gas, although we discuss other unconventional natural gas sources for which information is readily available. Here, we evaluate the impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure.

Water Withdrawals

The drilling and fracking of a horizontal shale gas well uses large volumes of water, although the amount of water required is both variable and uncertain. The US Environmental Protection Agency (EPA) reports that fracturing of shale gas wells requires between 2.3 million and 3.8 million gallons of water per well (US EPA 2011c).[1] An additional 40,000–1,000,000 gallons is required to drill the well (GWPC and ALL Consulting 2009). This is considerably more water than is required for conventional gas wells and even for coal bed methane because the wells to access shale gas are deeper. Water requirements for hydraulic fracturing of coal bed methane, for example, range from 50,000 to 350,000 gallons per well (US EPA 2011c), although we note that these estimates may be outdated and may not include the application of more recent water-intensive processes.

New data, however, suggest that the water requirements for fracking of shale gas wells might be both much larger and more variable than is reported by the EPA (table 4.1). For example, Thomas Beauduy (2011) of the Susquehanna River Basin Commission finds that fracking in the Marcellus Shale region requires, on average, about 4.5 million gallons per well. Water requirements can be even greater within Texas's Eagle Ford Shale area, where fracking can use up to 13 million gallons of water per well (Nicot et al. 2011), with additional water required to drill the wells. These data highlight the significant variation among shale formations, driven in part by differences in the depth to the target formation, even among wells within close proximity of one another (Nicot et al. 2011). Estimation of water requirements is further complicated by uncertainty about how many times a single well will be fracked over the course of its productive life and by limited publicly available data.

Water for hydraulic fracturing is typically withdrawn from one location or watershed over several days (Veil 2010). Additionally, in some cases, the water is taken from "remote, often environmentally sensitive headwater areas" (Beauduy 2011, 34), where even small withdrawals can significantly affect the flow regime. As a result, while fracking may account for a small fraction of a state's or even a basin's water supply, there can be more severe local impacts. Additionally, much of the water injected underground either is not

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[1] While *The World's Water* volumes prefer to consistently use metric units, much of the research on water and fracking discussed here is based on work done in the United States, so we have opted to report the original units. For reference, one cubic meter contains 264.2 gallons. Additional conversion factors can be found in the Water Units, Data Conversions, and Constants section near the end of this book.

Table 4.1 Water Requirements for Hydraulic Fracturing by Shale Plays in Texas

Shale Play	Water Requirements (Gallons per Well)		
	Low Value	Median Value	High Value
Barnett Shale	< 1 million	2.6 million	> 8 million
Haynesville and Bossier Shales	< 1 million	5.5–6 million	> 10 million
Eagle Ford Shale	1 million	6–6.5 million	13 million
Woodford, Pearsall, and Barnett-PB Shales	< 1 million	0.75–1 million	< 5 million

Source: Estimated on the basis of data in Nicot et al. (2011).

recovered or is unfit for further use once it is returned to the surface, usually requiring disposal in an underground injection well. This water use represents a consumptive use if it is not available for subsequent use within the basin from which it was extracted. In some cases, water is treated and reused for subsequent fracking jobs, although this is still fairly uncommon, and no national estimate on the prevalence of this practice is available (US GAO 2012).

There is some evidence that the water requirements for hydraulic fracturing are already creating conflicts with other uses and could constrain future natural gas production in some areas. For example, in Texas, a major drought in 2011 prompted water agencies in the region to impose mandatory reductions in water use. Water agencies, some of which sold water to natural gas companies, indicated they might have to reconsider these sales if the drought persisted. Natural gas companies also tried to purchase water from local farmers, offering $9,500 to nearly $17,000 per million gallons of water (Carroll 2011). Likewise, at an auction of unallocated water in Colorado during the spring of 2012, natural gas companies successfully bid for water that had previously been largely claimed by farmers, raising concerns among some about the impacts on agriculture in the region and on ecosystems dependent on return flows (Finley 2012).

Concerns over water availability are not limited to drier climates. Pennsylvania is generally considered a relatively water-rich state. However, in August 2011, thirteen previously approved water withdrawal permits in Pennsylvania's Susquehanna River basin were temporarily suspended because of low stream levels; eleven of these permits were for natural gas projects (Susquehanna River Basin Commission 2011). While parts of the state were abnormally dry, the basin was not experiencing a drought at the time, suggesting that natural gas operations are already creating conflict with other water uses under normal conditions. In many basins, the application of fracking is still in its infancy and continued development could dramatically increase future water requirements and further intensify conflicts with other uses.

While water withdrawals directly affect the availability of water for other uses, water withdrawals can also affect water quality. For example, withdrawals of large volumes of water can adversely affect groundwater quality through a variety of means, such as mobilizing naturally occurring substances, promoting bacterial growth, causing land subsidence, and mobilizing lower-quality water from surrounding areas. Similarly, withdrawals from surface water can affect the hydrology and hydrodynamics of the source water (US EPA 2011c), and reductions in the volume of water in a surface water body can reduce the ability to dilute municipal or industrial wastewater discharges.

Given the proposed expansion of drilling in many regions, conflicts between natural gas companies and other users are likely to intensify. More and better data are needed on the volume of water required for hydraulic fracturing and the major factors that determine the volume, such as well depth and the nature of the geologic formation. Additional analysis is needed on the cumulative impacts of water withdrawals on local water availability, especially given that water for hydraulic fracturing can be a consumptive use of water. Finally, more research is needed to identify and address the impacts of these large water withdrawals on local water quality. This work must be done on a basin-by-basin level.

Groundwater Contamination Associated with Well Drilling and Production

Groundwater contamination from shale gas operations can occur through a variety of mechanisms. Natural gas is located at various depths, often (but not always) far below underground sources of drinking water. A well bore, however, must sometimes be drilled through these drinking water sources in order to access the gas. Chemicals and natural gas can escape the well bore if it is not properly sealed and cased. While there are state requirements for well casing and integrity, accidents and failures still occur, as was demonstrated by an explosion in Dimock Township, Pennsylvania (see box 4.1 for more information). Old, abandoned wells can also potentially serve as migration pathways (US EPA 2011b) for contaminants to enter groundwater systems. States have estimated that there are roughly 150,000 undocumented and abandoned oil and gas wells in the United States (IOGCC 2008). Natural underground fractures, as well as those potentially created during the fracturing process, could also serve as conduits for groundwater contamination (Myers 2012). Finally, coal bed methane is generally found at shallower depths and in closer proximity to underground sources of drinking water, and therefore accessing natural gas from this source might pose a greater risk of contamination.

Much of the debate about groundwater contamination—and some of the most striking visual images showing water and burning natural gas coming out of home faucets—is related to reports of methane contamination in drinking water. Nearly 90 percent of shale gas is composed of methane. A study in New York and Pennsylvania found that methane levels in drinking water wells in active gas production areas (less than 1 kilometer, or about five-eighths of a mile, from wells) were seventeen times higher than in those outside of active gas production areas. An isotopic analysis of the methane suggests that the methane in the active gas production areas originated from deep underground (Osborn et al. 2011).

Methane is not currently regulated in drinking water, although it can pose a public health risk. Robert B. Jackson of Duke University and his colleagues (2011) note that methane is not regulated in drinking water because it is not known to affect water's potability and does not affect its color, taste, or odor. Methane, however, is released from water into the atmosphere, where it can cause explosions, fires, asphyxiation, and other health or safety problems. The 2009 New Year's Day drinking water well explosion in Dimock, Pennsylvania, for example, was due to methane buildup associated with natural gas production. The US Department of the Interior recommends taking mitigative action when methane is present in water at concentrations exceeding 10 milligrams per liter (mg/l) (Eltschlager et al. 2001). A recent study, however, notes that research on the health effects is limited and recommends that "an independent medical review be initiated to evaluate the health effects of methane in drinking water and households" (Jackson et al. 2011, 5).

BOX 4.1 Dimock Township, Pennsylvania

Dimock Township is located in northeastern Pennsylvania's Susquehanna County, the heart of some of the most productive drilling areas in the Marcellus Shale play. On New Year's Day in 2009, a residential water well in Dimock exploded as a result of methane buildup in the well. Further investigation found methane gas in drinking water wells and in the headspaces of drinking water wells that provide water to local residents. These water wells were located near drilling wells owned and operated by Cabot Oil & Gas Corporation, and in February 2009 the Pennsylvania Department of Environmental Protection (DEP) issued a notice of violation against the company, which stated that Cabot had discharged natural gas, failed to properly cement casings, and failed to prevent natural gas from entering fresh groundwater (PA DEP 2009). Pennsylvania has what is called a "rebuttable presumption" for drinking water pollution, whereby the oil and gas operator is assumed to be responsible for drinking water pollution that occurs within 1,000 feet and within six months of a drilling operation, unless the company can provide baseline data to refute the claim. In the absence of baseline data, the company is required to replace the water that has reportedly been lost or degraded (025 Pa. Code §78.51). Cabot was ordered to install methane detectors in nine homes and provide drinking water to four homes in the affected area (Lobins 2009).

The DEP conducted an investigation into the methane contamination and determined that Cabot was responsible for polluting thirteen drinking water wells, which was later revised to include an additional five wells (PA DEP 2010). Other violations were found, including several cases of improper or insufficient casings and excessive borehole pressure. In November 2009, the DEP entered into a consent order and settlement agreement with Cabot that required the company to permanently restore or replace water supplies for the affected homes and fix any wells identified to have improper or insufficient casing (PA DEP 2009). Cabot was also ordered to cease drilling in the area, and the company was later completely banned from fracking new or existing wells until authorized by the DEP.

Six well owners signed agreements with Cabot and had water treatment systems installed, including methane venting systems, although most were still using bottled water because they lacked confidence in the treatment systems. Twelve well owners refused to sign agreements with Cabot and took part in a civil suit. Cabot continued to provide temporary water service to these twelve homes. In October 2011, however, the DEP formally stated that Cabot had fully complied with the consent order and was no longer required to provide drinking water to Dimock residents (Legere 2011). The DEP allowed Cabot to stop providing water to the twelve homes that had not installed the water treatment systems because Cabot had provided a solution and the well owners had been given sufficient time to sign the agreement (US EPA 2011a).

Despite a subsequent announcement in December 2011 from the US Environmental Protection Agency (EPA) that Dimock water was safe to drink, local residents submitted results from their own testing, which indicated that the water was polluted (McAllister and Gardner 2012). In January 2012, the EPA began sampling water at sixty-four homes in the area and supplying drinking water to four households that had shown elevated levels of contaminants that pose a health concern (US EPA 2012a). Results of the testing indicated that although five homes showed elevated levels of arsenic, barium, and manganese—all naturally occurring substances not necessarily linked to fracking—the private wells did not have contaminant levels that posed a health concern or exceeded the safe range for drinking water (US EPA 2012b). The EPA's testing also concluded that elevated levels of methane were present in some of the wells, although Cabot disputes whether the methane resulted directly from the drilling.

There is also significant concern about groundwater contamination from hydraulic fracturing fluids, although limited data are available. According to draft reports released in December 2011 and September 2012, however, EPA testing detected the presence of chemicals commonly associated with hydraulic fracturing in drinking water wells in Pavillion, Wyoming (US EPA 2011b, 2012c). Encana Oil and Gas Inc., the company responsible for the natural gas wells, disputed the findings of the study, criticizing the EPA's testing methods and assumptions as well as the processes used to construct the monitoring wells and analyze the results (see box 4.2 for additional information).

Real analysis of the likelihood and extent of groundwater contamination is hindered by a lack of baseline data and confusion about definitions. Without baseline data, it is difficult to confirm or deny reports of groundwater contamination. In 2009, regulatory officials submitted signed statements to the United States Congress asserting that there were no confirmed cases of groundwater contamination associated with the hydraulic fracturing process (NYSDEC 2011). Likewise, an American Petroleum Institute report states that "there are zero confirmed cases of groundwater contamination connected to the fracturing operation in one million wells hydraulically fractured over the last 60 years" (American Petroleum Institute 2010). Yet documented cases in Dimock, Pennsylvania; possibly in Pavillion, Wyoming; and elsewhere provide evidence of groundwater contamination. In these cases, however, the contamination was associated with well casing integrity and wastewater disposal, not the process of injecting fluids underground per se—and so the issue is clouded by definitions.

Wastewater Management

Natural gas drilling also produces liquid waste. After completion of the fracturing process, well pressure is released and some of the fracturing fluid, along with naturally occurring substances, returns to the surface through the well bore. This mixture, commonly referred to as flowback, returns to the surface over the course of several hours to weeks after the fracturing process is completed (GWPC and ALL Consulting 2009). The amount of fracturing fluid that is actually recovered has not been well quantified and is likely to be highly variable, depending on local formation characteristics. While various sources quote estimates for the fracture fluid recovery rate (Beauduy 2011; Hoffman 2010; US EPA 2011c), a report by the Groundwater Protection Council (GWPC) and ALL Consulting (2009, 67) notes that "it is not possible . . . to differentiate flow back water from natural formation water." Thus, these estimates are likely based on assumptions rather than on actual data.

In addition to flowback, natural gas operations may generate produced water. Produced water "is any water that is present in a reservoir with the hydrocarbon resource and is produced to the surface with the crude oil or natural gas" (Veil et al. 2004, 1). Produced water can consist of natural formation water, that is, groundwater; naturally occurring substances, such as radioactive materials, metals, and salts; and even some residual fracturing fluid. The physical and chemical properties of produced water depend on the local geology (Veil et al. 2004). Flowback and produced water often have very high levels of total dissolved solids (TDS), in some cases exceeding 200,000 mg/l (Kargbo et al. 2010), nearly three times higher than seawater. In a recent report, the US Government Accountability Office (US GAO 2012) found that the volume of produced water generated by a given well varies depending on the type of hydrocarbon produced, the geographic location of the well, and the method of production.

Wastewater resulting from natural gas production is temporarily stored in pits, embankments, or tanks at the well site and then transported, usually via pipeline or truck, to a disposal site. Pits can lead to groundwater contamination, particularly if the pits are unlined or if the integrity of the lining is compromised. In Pavillion, Wyoming, for example, high concentrations of benzene, xylenes, and other organic compounds associated with gasoline and diesel were found in groundwater samples from shallow monitoring wells near pits (US EPA 2011b) (see box 4.2 for additional information on Pavillion, Wyoming).

Wastewater from natural gas operations can be disposed of using a variety of methods. In most areas, the primary way to dispose of wastewater from natural gas operations is by injection into a Class II well.[2] In 1988, the EPA made a determination that oil and gas waste is exempt from hazardous waste regulations under the Resource Conservation and Recovery Act of 1976. As a result, oil and gas wastes can be disposed of in Class II wells rather than in Class I hazardous waste wells.[3] Class II wells are subject to less stringent requirements than are Class I wells, and therefore disposal in Class II wells presents a greater risk of contaminating groundwater and triggering earthquakes than in Class I wells (Hammer and VanBriesen 2012).

The EPA estimates that there are about 144,000 Class II wells in operation in the United States, about 20 percent of which are disposal wells for brine and other fluids from oil and natural gas production. A Class II well might be an on-site well operated by the natural gas company or, more commonly, an off-site well operated by a commercial third

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[2] An injection well is a site where fluids, such as water, wastewater, brine, or water mixed with chemicals, are injected deep underground into porous rock formations, such as sandstone or limestone, or into or below the shallow soil layer. Injection wells are used for long-term storage, waste disposal, enhancement of oil production, mining, and prevention of saltwater intrusion.

[3] States can adopt more stringent regulations if desired.

BOX 4.2 Pavillion, Wyoming

The Pavillion gas field is located in central Wyoming in the Wind River basin, the upper portion of which serves as the primary source of drinking water for the area. Oil and gas exploration began in the area in the 1950s and increased dramatically between 1997 and 2006. The Pavillion gas field is composed of a mix of sandstone and shale; at the time of this writing, the field had 169 vertical gas production wells. Encana Oil and Gas Inc. owns the rights to the Pavillion field and began drilling in the area in 2004 after acquiring another drilling company. Encana has not drilled any new wells since 2007 (US EPA 2011b).

In 2008, domestic well owners began complaining about taste and odor problems, and residents believed these issues to be linked to nearby natural gas activities. In response to complaints from local residents, the EPA initiated an investigation, collecting four rounds of water samples from thirty-five domestic wells and two municipal wells between 2009 and 2011. The EPA also installed two deep monitoring wells in 2010 and took two rounds of samples from each of these wells. According to a draft report released in December 2011, EPA testing found chemicals commonly associated with hydraulic fracturing in drinking water wells in the area (US EPA 2011b). The EPA also found that concentrations of dissolved methane in the domestic wells were higher near the gas production wells. The report concluded that nearby drilling activities had “likely enhanced gas migration” (US EPA 2011b).

Encana is disputing the EPA’s preliminary findings. According to Encana, methane is “commonly known” to occur in the shallow groundwater aquifers in the area (Encana Oil and Gas Inc. 2011b) and is expected, given that the Pavillion gas field is also quite shallow (Encana Oil and Gas Inc. 2011a). Furthermore, Encana argues that Pavillion has always had poor water quality, referencing historical reports that levels of sulfate, total dissolved solids, and pH “commonly exceed state and federal drinking water standards” (Encana Oil and Gas Inc. 2011b). A 2011 report from the Wyoming Water Development Commission confirms that Pavillion’s water is generally of poor quality and has often had taste and odor problems. However, the Commission states that nearly all of the private wells meet federal and state drinking water standards (James Gores & Associates 2011). One of the challenges associated with the EPA’s analysis is that baseline data are not available to support claims about impacts on groundwater quality.

Encana continues to dispute the findings of the study, criticizing the EPA’s testing methods and assumptions as well as the processes used to construct the monitoring wells and analyze the results (Gardner 2012). Although the EPA has indicated its intention to submit the report to scientific review, the comment period on the draft report has been extended several times, most recently until September 2013, while the EPA collects and distributes new information and meets with stakeholders (*Federal Register* 2013).

party (Veil 2010). In some cases, wastewater receives partial treatment prior to disposal to avoid clogging the well (Hammer and VanBriesen 2012).

With the proper safeguards, disposing of wastewater by underground injection reduces the risk of releasing wastewater contaminants into the environment; however, it increases the risk of earthquakes and can require the transport of wastewater over long distances (Hammer and VanBriesen 2012; Keranen et al. 2013). Some states do not have sufficient injection well capacity to handle the volume of wastewater generated from expanding hydraulic fracturing operations, so wastewater is transported to neighboring states for disposal (Veil 2010). For example, as of late 2010, Pennsylvania had only seven active disposal wells, and some wastewater had been hauled to Ohio, West Virginia, and other states for disposal (STRONGER 2010; Veil 2010).[4]

Flowback and produced water have been treated at municipal wastewater treatment plants (GWPC and ALL Consulting 2009), although this practice is both uncommon and controversial. Municipal systems are not typically designed to handle this type of wastewater, which can potentially disrupt the treatment process and discharge salts and other contaminants into the environment. In 2008 and 2009, TDS levels exceeded drinking water standards along Pennsylvania's Monongahela River, a major source of drinking water that receives discharges from facilities handing wastewater from natural gas production (STRONGER 2010). In 2009, excess TDS, primarily from mining discharges, "wiped out 26 miles of stream" in Greene County, Pennsylvania (STRONGER 2010, 22). In response, regulations for new or expanded facilities that accept oil and gas wastewater, including municipal wastewater treatment plants and centralized treatment plants, were passed in 2010 that set strict monthly discharge limits for TDS, chlorides, barium, and strontium (STRONGER 2010). Municipal wastewater treatment plants in Pennsylvania can still receive wastewater from "grandfathered" natural gas operations, although this has now been virtually eliminated (Hammer and VanBriesen 2012).

Wastewater reuse is becoming more common, driven in large part by the challenges associated with wastewater disposal and in part by the growing difficulty of finding new sources of water for fracking operations. Reusing wastewater for new fracking activities reduces the total volume of water required, helping to minimize impacts associated with water withdrawals. Wastewater can also be reused for irrigation, dust control on unpaved roads, and deicing of roads (US EPA 2011c; Hammer and VanBriesen 2012). In most cases, the wastewater must be treated prior to reuse, but in others it is simply blended with freshwater to bring the levels of TDS and other constituents down to an acceptable range (Veil 2010). Treatment for reuse can occur at the well site using a mobile plant or at a centralized industrial facility. Some downsides of reuse include the need for more on-site storage, energy requirements for the treatment processes, and additional transportation needed to haul wastewater to the treatment plant and among sites. Additionally, concentrated treatment residuals, including brine, must be disposed of in some manner and may require dilution (NYSDEC 2011).

Wastewater treatment and disposal associated with hydraulic fracturing may prove to be a larger issue than some of the other water-related risks. Yet to date there has been little discussion about the risks that wastewater treatment and disposal pose. In some areas, they may physically or economically constrain natural gas operations. Additional work is needed

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[4] Applications for at least twenty additional disposal wells are presently before the EPA (STRONGER 2010).

to understand the nature of the risk of wastewater treatment and disposal to human health and the environment and to identify where it may constrain natural gas operations.

Truck Traffic

Hydraulic fracturing operations generate a large amount of truck traffic. All of the materials and equipment needed for activities associated with hydraulic fracturing, including water and chemicals, are typically transported to the site by trucks (US EPA 2011c). Additionally, wastewater from natural gas operations is usually removed by tanker truck to the disposal site or to another well for reuse. Using information from the natural gas industry, the New York State Department of Environmental Conservation estimates that high-pressure hydraulic fracturing in a horizontal well would require 3,950 truck trips per well during early development of the well field (NYSDEC 2011), two to three times more than is required for conventional vertical wells (see table 4.2). Much of the truck traffic is concentrated over the first fifty days following well development. Truck traffic could be reduced by nearly 30 percent if pipelines were used to move water between sites, although pipelines can create other concerns, such as leaks, spills, and right-of-way controversies.

Truck traffic raises a variety of other water-related social and environmental concerns. Trucks increase wear and erosion on local roads and increase the risk of spills, both of which can pollute local surface water and groundwater. In addition, because so much of new drilling is occurring in rural locations, new roads must be built to accommodate the truck traffic, increasing habitat fragmentation and ecological disturbances.

TABLE 4.2 Truck Traffic Estimates for Vertical and Horizontal Wells

	Horizontal Well		Vertical Well	
Well Pad Activity	**Heavy Truck**	**Light Truck**	**Heavy Truck**	**Light Truck**
Drill pad construction	45	90	32	90
Rig mobilization	95	140	50	140
Drilling fluids	45		15	
Non-rig drilling equipment	45		10	
Drilling (rig crew, etc.)	50	140	30	70
Completion chemicals	20	326	10	72
Completion equipment	5		5	
Hydraulic fracturing equipment	175		75	
Hydraulic fracturing water hauling	500		90	
Hydraulic fracturing sand	23		5	
Produced water disposal	100		42	
Final pad preparation	45	50	34	50
Miscellaneous	—	85	—	85
Total one-way, loaded trips per well	1,148	831	398	507
Total vehicle round trips per well	**3,950**		**1,810**	

Source: NYSDEC (2011).

Note: Light trucks have a gross vehicle weight rating that ranges from 0 to 14,000 pounds. Heavy trucks have a gross vehicle weight rating in excess of 26,000 pounds. The gross vehicle weight is the maximum operating weight of the vehicle, including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers, and cargo but excluding any trailers.

Surface Spills and Leaks

All fossil-fuel extraction activities come with some risk of surface water or groundwater contamination from the accidental or intentional release of waste. In the case of hydraulic fracturing, common wastes of concern include fracking fluid, additives, flowback, and produced water. Fluids released onto the ground from spills or leaks can run off into surface water and seep into groundwater.

Spills can occur at any stage during the drilling life cycle. Chemicals are hauled to the site, where they are mixed to form the fracturing fluid. Accidents and equipment failure during on-site mixing of the fracturing fluid can release chemicals into the environment. Above ground storage pits, tanks, or embankments can fail. Vandalism and other illegal activities can also result in spills and improper wastewater disposal. For example, in Canton Township, Pennsylvania, a January 2012 spill of 20,000 gallons of hydraulic fracturing wastewater is being investigated as "criminal mischief" (Clarke 2012). In a larger incident in March 2012, criminal charges were filed against a waste-hauling company and its owner for illegally dumping millions of gallons of produced water into streams and mine shafts and on properties across southwestern Pennsylvania (Pennsylvania Attorney General 2012). Given the large volume of truck traffic associated with hydraulic fracturing, truck accidents can also lead to chemical and wastewater spills. In December 2011, a truck accident in Mifflin Township, Pennsylvania, released fracking wastewater into a nearby creek (Reppert 2011).

While there are reports of spills and leaks associated with hydraulic fracturing operations, the national extent of the problem is not yet well understood. A recent report from Pennsylvania documented a string of violations in the Marcellus Shale region, many of which could result in surface spills and leaks, including 155 industrial waste discharges, 162 violations of wastewater impoundment construction regulations, and 212 faulty pollution prevention practices (Pennsylvania Land Trust Association 2010), during the thirty-two-month period from January 2008 to August 2010. New research provides documentation of twenty-four cases in six states of adverse health effects on humans, companion animals, livestock, horses, and wildlife associated with natural gas operations, including spills and leaks (Bamberger and Oswald 2012). Additional research is needed on the frequency, severity, cause, and impact of spills associated with hydraulic fracturing.

Stormwater Management

Stormwater runoff carries substances from the land surface that can be detrimental to water quality and ecosystem health and deposits them into local waterways. While runoff is a natural occurrence, human disturbances to the land surface have increased the timing, volume, and composition of runoff. According to the EPA, a 0.4-hectare (one-acre) construction site with no runoff controls can contribute thirty to forty metric tons of sediment each year, comparable to the runoff from six and one-half hectares (sixteen acres) of natural vegetated meadow (US EPA 2007a; Schueler 1994). Drilling for natural gas contributes to this problem, as the process requires disturbances to the land surface. Modern natural gas drilling requires the clearing of three or more hectares (typically seven to eight acres) per well pad, which includes area for the pad itself plus additional land for access roads, waste pits, truck parking, equipment, and more (Johnson 2010). Runoff can also contain pollutants from contact with drilling and construction equipment as well as with storage facilities for fracking fluid and produced water.

Stormwater discharges are regulated by state and local governments. The National Pollutant Discharge Elimination System (NPDES) program regulates stormwater runoff at the federal level, although states can receive primacy to administer their own permitting program. At the federal level, oil and gas operations have been afforded special protections and are exempt from provisions in the Clean Water Act. Consequently, oil and gas operators are not required to obtain a stormwater permit unless, over the course of operation, the facility generates stormwater discharge containing a reportable quantity of oil or hazardous substances or the facility violates a water quality standard (40 CFR 122.26(c)(1)(iii)).[5] In 2005, the definition of oil and gas exploration and production was broadened to include construction and related activities, although regulations still require well pads larger than one acre to apply for an NPDES stormwater permit (Wiseman 2012).[6] A 2005 study of the surface water impacts of natural gas drilling noted the difficulty of monitoring and suggested that few facilities were monitoring in a way that would allow them to determine whether they even required an NPDES permit (US EPA 2007b).

Conclusions

Energy analysts project massive increases in domestic natural gas production over the next twenty-five years. This increase is expected to be largely supplied by unconventional sources, especially shale gas. Although previously too expensive to develop, unconventional natural gas resources have become more economically viable in recent years as a result of the application of horizontal drilling and hydraulic fracturing. These technological advances have allowed for a rapid expansion of natural gas development both in areas accustomed to natural gas operations and in new areas.

Hydraulic fracturing has generated a tremendous amount of controversy in recent years. Hydraulic fracturing is hailed by some as a game changer that promises increased energy independence, job creation, and lower energy prices. Others have called for a temporary moratorium or a complete ban on hydraulic fracturing because of concern over environmental, social, and public health concerns. There are daily media reports on this topic from outlets across the United States and in a host of other countries, including Canada, South Africa, Australia, France, and England.

In an effort to identify the key issues, the Pacific Institute interviewed a diverse set of representatives of state and federal agencies, academia, industry, environmental groups, and community-based organizations in the United States. Despite the diversity of viewpoints, there was surprising agreement about the range of concerns and issues associated with hydraulic fracturing. Interviewees identified a broad set of social, economic, and environmental concerns, foremost among which are impacts of hydraulic fracturing on the availability and quality of water resources. In particular, key water-related concerns identified by the interviewees included (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management (Cooley and Donnelly 2012).

Much of the media attention on hydraulic fracturing and its risk to water resources has centered on the use of chemicals in the fracturing fluids and the risk of groundwater

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[5] This requirement will not be met by sediment discharges alone.

[6] States can implement stronger requirements if desired.

contamination. The mitigation strategies identified to address this concern have centered on disclosure and, to some extent, the use of less toxic chemicals. Risks associated with fracking chemicals, however, are not the only issues that must be addressed. Indeed, interviewees more frequently identified as key issues the overall water requirements of hydraulic fracturing and the quantity and quality of wastewater generated.

Most significantly, a lack of credible and comprehensive data and information is a major impediment to identifying or clearly assessing the key water-related risks associated with hydraulic fracturing and to developing sound policies to minimize those risks. Given the nature of the business, industry has an incentive to keep the specifics of its operations secret in order to gain a competitive advantage, avoid litigation, and so forth. Additionally, there are few peer-reviewed scientific studies on the process and its environmental impacts. While much has been written about the interaction of hydraulic fracturing and water resources, the majority of this writing is either industry or advocacy reports that have not been peer-reviewed. As a result, the discourse around the issue is largely driven by opinion. This hinders a comprehensive analysis of the potential environmental and public health risks and identification of strategies to minimize these risks.

Finally, the dialogue about hydraulic fracturing has been marked by confusion and obfuscation because of a lack of clarity about the terms used to characterize the process. For example, the American Petroleum Institute and other industry groups, using a narrow definition of fracking, argue that there is no link between their activities and groundwater contamination (American Petroleum Institute 2010), despite observational evidence of groundwater contamination in Dimock, Pennsylvania, and Pavillion, Wyoming, that appears to be linked to the integrity of the well casings and of wastewater storage. Additional work is needed to clarify terms and definitions associated with hydraulic fracturing to support more fruitful and informed dialogue and to develop appropriate energy, water, and environmental policy.

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