Groundwater Contamination and Health Consequences of Hydraulic Fracturing

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With the petroleum industry moving toward consensus that peak oil has passed [1], countries across the globe are starting to look at other sources of fuel to meet the demand for low cost energy. Among these sources is natural gas, occurring within bodies of rock such as shale, tight sands, or coalbeds. As of 2009, natural gas accounts for approximately 25 percent of the total U.S. energy use—out of that 25 percent, shale gas accounts for 14 percent alone [2]. The method of hydraulic fracturing involves extracting natural gas from shale plays; areas of land that contain an economically viable amount of natural gas existing within underground hydrocarbon-bearing formations. Extraction of gas requires drilling wells and pumping pressurized water, proppants, solvents, and other chemicals into the gas-containing formations, forcing the gas to surface.

Currently, activist groups and environmental scientists are focusing research on the chemicals used in the process of hydraulic fracturing, (a.k.a – “hydro fracking”, or “fracking”). Environmental groups, along with populations near fracking operations, are lobbying for energy companies involved in hydro fracking to disclose the list of chemical constituents used in the fracturing process. Knowing the amounts and concentrations of the various chemicals used throughout the fracking process would enable researchers to identify and track resulting toxicity levels in groundwater and aquifers, and in biological tissue, including humans [3].

The Hydraulic Fracturing Process

The process of hydraulic fracturing starts with a well drilled into the ground, extending down 5,000 to 12,000 feet [4], depending on the specific formation (see Figure 1 for a diagram outlining fracking operations). In the Marcellus formation, drinking water wells can extend down as far as 500 feet above the Marcellus shale play where fracking occurs [5]. Once a hole is drilled for the fracturing well, steel pipes called ‘casings’ are inserted into the ground [2]. Casings act to prevent the hole from caving in following drilling, and isolate the fluid injected to fracture the bedrock until the fluid reaches the stretch of bedrock prepared for fracturing. The casings are then secured into place by cement slurry poured into the well. Once the well is completed, water is transported to the pumping site and combined with chemicals called proppants, or propping agents; the most common proppant used is sand. Proppants are included to allow fractures to remain open after the fracturing process. Fluid is pumped into the well after a series of induced explosions occur in the casing at the targeted shale play; when the fluid reaches the fractured casing, it forces its way into the cracked bedrock under pressure, expanding the cracks and allowing the natural gas to release into the well. Water that returns to the surface of the well, called “flowback,” may contain either hydraulic fracturing fluid, natural formation water, or a combination of the two. Surfacing fluid is generally considered waste and is stored on site until it can be transported for treatment or disposal. Occasionally, flowback is used again as the fracturing fluid for another well [2].

Once the drilling of a well site is completed and the energy company is ready to extract natural gas, 3 to 5 million gallons of water are transported to the well site per “frack”, or extraction of natural gas [6]. Calculated by the depth, horizontal fracture zone, and frequency with which a well is fractured, the U.S. EPA estimates the average hydraulic fracturing well to require between 2 and 5 million gallons of water [4]. Moreover, the water necessary for the continuous operation of 35,000 hydraulic fracturing wells created annually equates to the yearly water consumption of 40 to 80 cities with population 50,000 people, or 1 to 2 cities of 2.5 million people [2]. With water volumes in the millions as well as anecdotal reports of methane contamination in drinking water, scientists have been prompted to conduct more research on the hydrological effects of pumping water into bedrock.

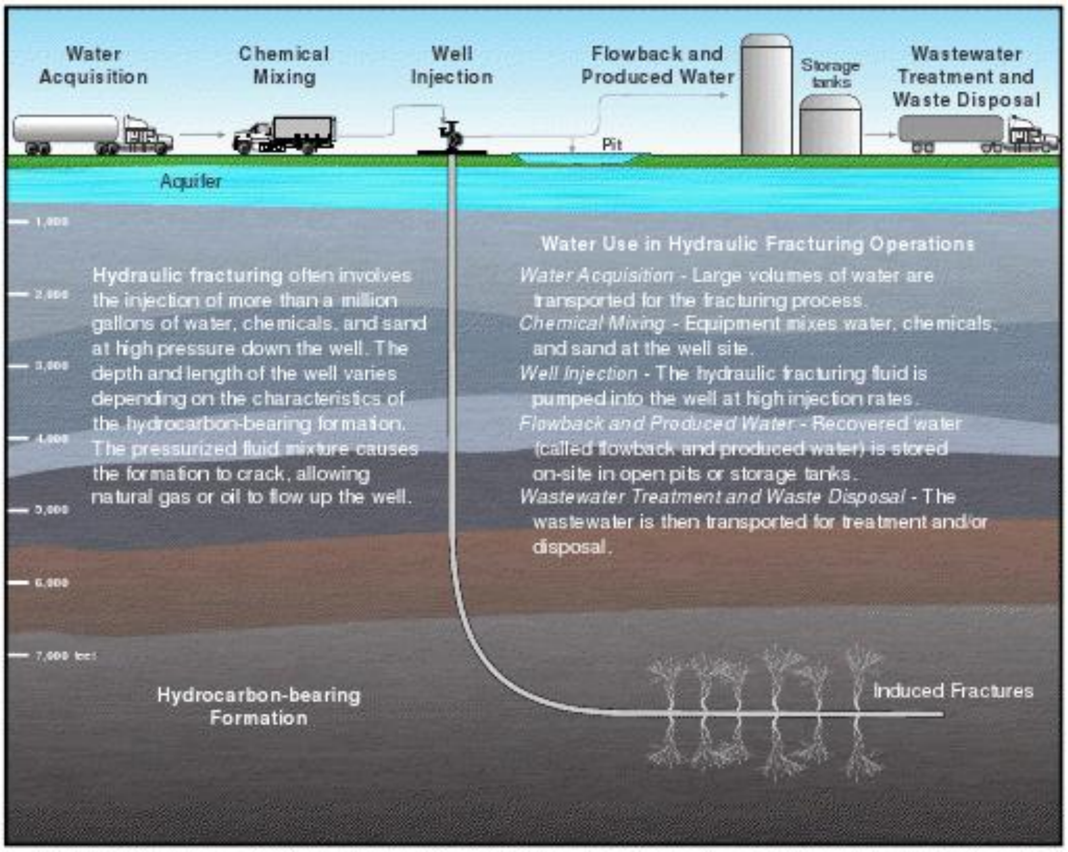

Figure 1. Lifecycle of water used in hydraulic fracturing. Note onsite storage of flowback and produced water from injection of wells can be stored in outdoor ponds, or in aboveground tanks. Water is then transported offsite to wastewater treatment facilities. Image courtesy of U.S. EPA [2].

According to 2009 data, the Energy Information Administration (EIA) estimates that 14% of domestically produced natural gas comes from shale deposits, and as much as 45% of the U.S. natural gas supply will be sourced from shale deposits by 2035, if current trends in governmental policies continue [2]. In 2011, Advanced Resources International estimated that there remains 1,930 tons per cubic foot (tcf) of recoverable natural gas in the U.S, and 860 tcf located solely in technically recoverable gas shales [7]. Also in 2011, the U.S. Geological Survey (USGS) released information regarding the Marcellus Shale formation —America's largest shale formation stretching from New York to Alabama. The USGS estimates the 45 percent calculated by the EIA to be an overestimate of the supply by a factor of five [8].

Hydrological Impacts of Hydraulic Fracturing

Factors for consideration in the hydrological impact of fracking include the surrounding bedrock composition, depth and location of the nearest aquifers, depth of fracking operation, and permeability of overlying bedrock. With methane gas composing greater than 90% of shale plays [9], current research is focusing on the composition of water returning to the surface of well operations and shallow aquifers in bedrock surrounding fracking operations. However, methane is not regulated by drinking water standards because it does not alter potability, taste, color, or the smell of water, and the petroleum industry cannot be held liable due to laws passed during the George W. Bush administration exempting fracking from the Safe Drinking Water Act [4]. The U.S. Department of the Interior suggests immediate action to ventilate wells when dissolved methane concentrations exceed 28 milligrams per liter [9]. Jackson et al. (2011) [9] also notes the Department of the Interior's recommendations to reduce methane concentrations to 10 mg/L by well ventilation and remediation efforts; methane concentrations above 10 mg/L pose the risk of asphyxiating workers as well as explosions at the well sites [9].

Reports regarding the presence of methane, surfactants and other chemicals in drinking water supplies are now increasing in relation with the number of new fracking operations each year [10]. Within the U.S., almost 44 million Americans depend on a private well drawing from a shallow aquifer for supplying their household and agricultural needs [9]. A study by Warner, et al. (2007) [11], conducted in Northeastern Pennsylvania, revealed that wells drawing from a shallow aquifer within 1 kilometer of a natural gas operation produced elevated concentrations of methane, ethane, and propane solely from geophysical and geochemical processes and pathways, unrelated to hydraulic fracturing [11]. However, another study in Pennsylvania by Howarth, et al. (2011) [8], utilizing isotopic fingerprinting, shows that 75 percent of wells within 1 kilometer of fracking operations had elevated amounts of methane from deep shale plays, beyond background concentrations of biologically derived methane [8].

Health Impacts of Hydraulic Fracturing

Although many of the chemicals used in hydraulic fracturing are unknown, those that are known pose health issues to the exposed individuals. Though methane in drinking water has obvious safety risks and documented health consequences [5], the solvents and surfactants used in the fracturing process also pose potential ecological impacts and human health risks. Beginning in 1999, residents in Pavillion, Wyoming reported to government officials incidents of miscarriages, rare cancers, and central nervous system disorders [4]. A decade later, the U.S. EPA identified wells that had been contaminated by 2-butoxyethanol, a common hydraulic fracturing component [4]. In Pennsylvania and New York, wastewater treatment plants were contaminating tributaries of the Ohio River after receiving flowback from fracking wells; contaminants included barium, strontium, and bromides that reacted with organic matter during the chlorination process [8]. These reactions in the water treatment process formed dangerous brominated hydrocarbons that tainted the municipal drinking water supply, exceeding action level standards [8].

Rahm (2011) [4] presents information on blood and urine samples from residents who drank water from contaminated wells near Barnett Shale gas operations in Dish, Texas; the data show 65 percent of the population had toluene in their system, while another 53 percent display the presence of xylene, both common fracking components. Furthermore, the U.S. EPA and the Texas Commission on Environmental Quality (TCEQ) have identified elevated toluene and xylene concentrations above toxicity standards in air samples from Dish, TX [4]. The state of Texas has also reported airborne benzene contamination from the Barnett Shale play that exceeds acute toxicity standards set by the U.S. EPA; acute toxicity refers to adverse effects from single to multiple exposure episodes within 24 hours, with adverse effects occurring within 14 days [8]. Chronic exposure to benzene is known to increase an individual's risk of cancer [3].

Other Impacts of Hydraulic Fracturing

Aside from direct human health impacts, secondary impacts posed on humans have also been researched. Within the Barnett Shale play alone, over 14,000 wells have been drilled as of 2010, with 1,200 located in the city limits of Fort Worth, Texas. In 2009, one of the older pipelines transporting the extracted natural gas ruptured in Amarillo, Texas after a magnitude 4.0 earthquake. The resulting explosion sent flames over 60 meters high, burning at temperatures of 3,871 °C, (over 7000 degrees Fahrenheit) [4].

Another factor for consideration is the effect of fracking operations on the vegetation surrounding the drilling locations; spray and discharge of fluids from drilling affects plant survivability. Researchers at the 17th Central Hardwood Forest Conference (2011) [13] presented a study on vegetation affected by flowback from drilling wells. Results showed immediate browning of trees, shrubs, and understory plants and up to 45 percent premature leaf drop from trees indirectly impacted by the fluid; more than 50 percent of trees lost all foliage, with mortality most evident in American Beeches [13].

Public Response to Hydraulic Fracturing

The range of effects from hydraulic fracturing is raising the demand for public disclosure of fracking solvents. On September 9, 2010, the U.S. EPA sent nine prominent hydraulic fracturing companies voluntary information requests to release data on the chemical composition of fluids used, sites where fracking fluids have been applied, and the impacts of such fluids on the environment and human health. As of May 2011, no requests have been returned [4]. Opponents to disclosing the chemical composition of fracking fluids argue that adequate information about the effects of the chemicals was released in the Material Safety Data Sheets (MSDS) required by the Occupational Safety and Health Administration in 2009 [4]. MSDS regarding hydraulic fracturing chemicals are available to the public through internet databases. Drilling companies resist full disclosure of the chemical composition of fracking fluid, claiming the chemicals to be proprietary. Since the actual chemical composition of fracking fluid is unavailable, scientists are forced to speculate the components based on based on chemical properties; estimates include: potassium chloride, guar gum, ethylene glycol, sodium carbonate, potassium carbonate, sodium chloride, borate salts, citric acid, glutaraldehyde, acid, petroleum distillate, and isopropanol [4].

Currently, scientists are focused on formulating appropriate paths of remediation and prevention of fracking operations. In 2011, Jackson et al. (2011) [9] laid out six main points to focus future research on hydraulic fracturing to increase comprehension of the full range of effects: 1) initiating medical review of methane health effects; 2) construction of a national database of chemical concentrations and chemical attributes present in drinking water; 3) evaluation of mechanisms for water contamination from methane; 4) refined estimates for greenhouse gas emissions of methane from fracking practices; 5) systematic sampling of drinking water wells and deep water formations; and 6), studies in disposal methods of fracking wastewater.

Jackson et al. (2011) [9] furthered their intent by recommending policy actions, including consideration to regulate hydraulic fracturing under the Safe Drinking Water Act

(SDWA), and full disclosure of the chemicals used in hydraulic fracturing [4]. However, under the George W. Bush administration, Dick Cheney's Energy Task Force recommended that Congress exempt fracking from regulation under the SDWA; this goal was accomplished with the passing of the National Energy Policy Act in 2005. Then in 2009, the Fractured Responsibility and Awareness of Chemicals (FRAC) Act was created to amend the SDWA and allow the U.S. EPA the ability to regulate fracking, requiring companies to fully disclose the chemicals involved in the process. Yet, the bill never passed. The congressional session expired before any action was taken on the bills [4].

With the continuing increase in demand for fossil fuels and unconventional methods developed for extracting both new and old natural gas reserves, ongoing research will be required to give direction to policies and legislation. Estimation of the environmental and anthropological risks remains necessary, no matter the energy source under scrutiny—hydraulic fracturing, tidal power, geothermal, wind, or solar thermal. In turn, the need for a comprehensive approach to furthering energy technologies and research remains a point for consideration. Closer examination of the issues that reports have raised to this point indicate a need for further discussion and research before the safety of hydraulic fracturing can be properly concluded.

References

[1] Deffeyes, K.S. (2001). Hubbert's Peak: The Impending World Oil Shortage, Princeton University Press, Princeton, NJ. 2001.

[2] EPA Science Advisory Board. (2011). Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: 1-140.

[3] Colborn, T., C. Kwiatkowski, K. Schultz, and M. Bachran. (2011). Natural Gas Operations from a Public Health Perspective, Human and Ecological Risk Assessment: An International Journal, 17(5): 1039-1056.

[4] Rahm, D. (2011). Regulating Hydraulic Fracturing in Shale Gas Plays: The Case of Texas, Energy Policy, 39(5): 2974-2981.

[5] Halliburton. (2012). Drilling through Groundwater Aquifers; General Definitions, Practices and Environmental Considerations.

[6] Brzycki, Elaine. "Public Media for Public Understanding: Explore Shale." *Explore Shale*. Penn State Public Broadcasting, n.d. Web. 10 Dec 2012. <exploreshale.org>.

[7] Medlock, K.B., III. (2012). Modeling the Implications of Expanded US Shale Gas Production, Energy Strategy Reviews, 1(1): 33-41.

[8] Howarth, R.W., A. Ingraffea, and T. Engelder. (2011). Natural Gas: Should Fracking Stop?, Nature, 477(7364): 271-275.

[9] Jackson, R.B., B.R. Pearson, S.G. Osborn, N.R. Warner, and A. Vengosh. (2011). Research and Policy Recommendations for Hydraulic Fracturing and Shale-Gas Extraction, Center on Global Climate Change, Duke University, Durham, NC: 1-12.

[10] Ehrenberg, Rachel. (2012). "The Facts Behind the Frack: Scientists Weigh in on the Hydraulic Fracturing Debate." *ScienceNews*. 182(5): 20.

[11] Warner, N.R., R.B. Jackson, T.H. Darrah, S.G. Osborn, A. Down, K. Zhao, A. White, and A. Vengosh. (2012). Geochemical Evidence for Possible Natural Migration of Marcellus Formation Brine to Shallow Aquifers in Pennsylvania, Proceedings of the National Academy of Sciences, 109(30): 11961-11966.

[12] IUPAC. Compendium of Chemical Terminology, 2nd ed. (the "Gold Book"). Compiled by A. D. McNaught and A. Wilkinson. Blackwell Scientific Publications, Oxford (1997). XML on-line corrected version: http://goldbook.iupac.org (2006-) created by M. Nic, J. Jirat, B. Kosata; updates compiled by A. Jenkins. ISBN 0-9678550-9-8. doi:10.1351/goldbook.

[13] Adams, M.B., W.M. Ford, T.M. Schuler, and M.T.V. Gundy. (2011). Effects of Natural Gas Development on Forest Ecosystems, Proceedings of the 17th Central Hardwood Forest Conference, 2010 April 5-7: 219-226.