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Critical Review of Risks to Water Resources from Hydraulic Fracturing

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Abstract: Since the early 2000s, oil and natural gas production in the United States have been transformed through technological innovation. Hydraulic fracturing, combined with advanced directional drilling techniques, made it possible to economically extract oil and gas resources previously inaccessible. The resulting surge in production increased domestic energy supplies and brought economic benefits to many areas of the United States. The growth in domestic oil and gas production also raised concerns about potential impacts to human health and the environment, including potential effects on the quality and quantity of drinking water resources. Some residents living close to oil and gas production wells have investigated changes in the quality of drinking water and assert that hydraulic fracturing is responsible for these changes. Other concerns include competition for water between hydraulic fracturing activities and other water users, especially in areas of the country experiencing drought, and the disposal of wastewater generated from hydraulic fracturing. This investigation synthesizes available scientific literature and data to assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources, and identifies factors affecting the frequency or severity of potential changes. This investigation can be used by federal, tribal, state, and local officials; industry; and the public to better understand and address any vulnerabilities of drinking water resources to hydraulic fracturing activities.

Keywords: Hydraulic Fracturing, Drinking Water Resources, Oil, Gas

I. INTRODUCTION

Hydraulic fracturing is a stimulation technique used to increase oil and gas production from underground rock formations. Hydraulic fracturing involves the injection of fluids under pressures great enough to fracture the oil- and gas-producing formations. The fluid generally consists of water, chemicals, and proppant (commonly sand). The proppant holds open the newly created fractures after the injection pressure is released. Oil and gas flow through the fractures and up the production well to the surface. Hydraulic fracturing has been used since the late 1940s and, for the first 50 years, was mostly used in vertical wells in conventional formations.1 Hydraulic fracturing is still used in these settings, but the process has evolved; technological developments (including horizontal and directional drilling) have led to the use of hydraulic fracturing in unconventional hydrocarbon formations that could not otherwise be profitably produced. These formations include:

Shales: Organic-rich, black shales are the source rocks in which oil and gas form on geological timescales. Oil and gas are contained in the pore space of the shale. Some shales contain predominantly gas or oil; many shale formations contain both.

Tight Formations: "Tight" formations are relatively low permeability, non-shale, sedimentary formations that can contain oil and gas. Like in shales, oil and gas are contained in the pore space of the formation. Tight formations can include sandstones, siltstone, and carbonates, among others.

Coalbeds: In coalbeds, methane (the primary component of natural gas) is generally adsorbed to the coal rather than contained in the pore space or structurally trapped in the formation. Pumping the injected and native water out of the coalbeds after fracturing serves to depressurize the coal, thereby allowing the methane to desorb and flow into the well and to the surface.

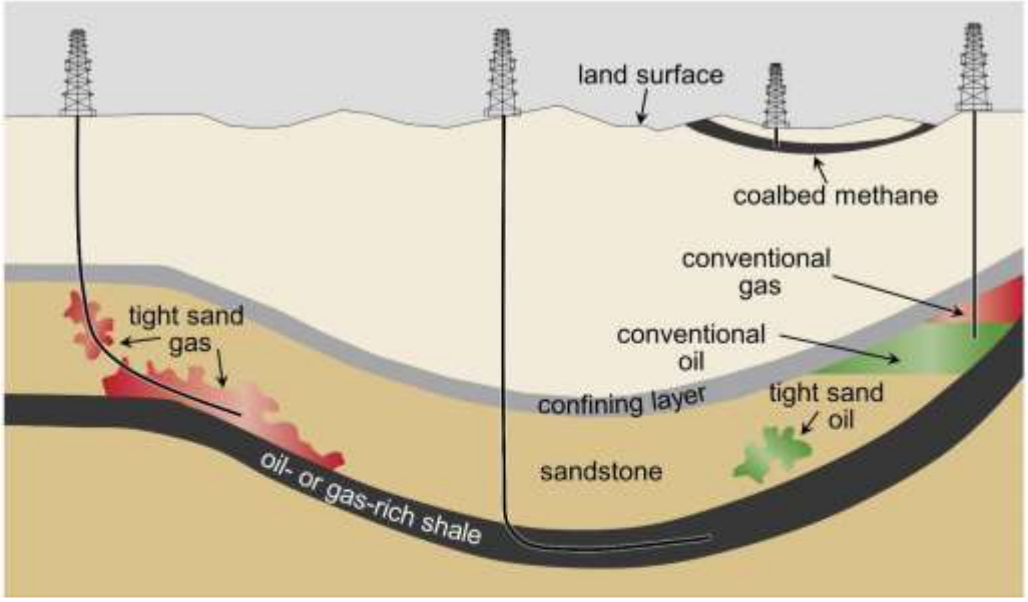

Figure: Schematic Cross-Section of General Types of Oil and Gas Resources and the Orientations of Production Wells Used in Hydraulic Fracturing

Hydraulic fracturing requires hundreds of thousands of gallons of freshwater per day, per well, to extract oil from the rock formations. A portion of the water is recycled, however, a large amount of water is instead discarded into disposal wells and ponds, both lined and unlined.

Except in cases where diesel fuel is injected underground, the Environmental Protection Agency (EPA) has never had jurisdiction over hydraulic fracturing. At first this was because it was never specified, but it was made clear in 2005 with an amendment to the Safe Drinking Water Act (SDWA) put forth in the Energy Policy Act of 2005 that hydraulic fracturing is exempt from any applicable regulation of the Underground Injection Control Program enforced by the EPA (Energy Policy Act, 2005, p. 102). Ground and surface water withdrawals for use during hydraulic fracturing may have adverse impacts on water basins in some areas, while withdrawals in different areas may be insignificant. Any adverse impacts to groundwater quality and/or freshwater reserves are to be mitigated by the state in which the activity occurs with the enactment of state and local legislation and ordinances.

II. LITERATURE REVIEW

Ground Water Quality

From an industry stance, hydraulic fracturing is safe, controlled, and has not been widely proven to cause any groundwater contamination of aquifers or groundwater wells. FracFocus, a national hydraulic fracturing chemical registry, asserts the casing, cementing, and tubing processes accompanied by regulations of the State in which the well is constructed is sufficient in protecting groundwater resources from contamination from fracking chemicals and fluids (Hydraulic Fracturing Water, 2012). With proper management and regulation, "generally, there is a 'very low' risk of any gas or fracking fluids seeping into aquifers due to the fracking itself, as this would require them to travel through several hundred – if not thousands – of meters of rock" and more likely, the risk lies with "the operators [rather] than the process itself" (Fracking Safe, 2012). Cracks in a layer of black shale remain more than one thousand feet underneath the surface where wells and aquifers are found (Wile, 2012). It is also important to note, groundwater contamination can result from "wells [sinking] into sandstone that has already filled with gas" and this could be confused as contamination from nearby hydraulic fracturing operations (Wile, 2012). An EPA enforcement action in 2010 provided evidence of groundwater contamination from hydraulic fracturing practices when "two residential drinking-water wells near two of [Range Resources gas company's] gas wells [were found to be] contaminated with methane of deep, 'thermogenic' origin, [which] originates [from] shale layers, unlike biogenic' methane, [which is found] where aquifers typically are" (Mooney, 2011). Groundwater contamination from gases and toxic chemicals used in hydraulic fracturing operations is more likely to result from faulty cementing, casing failure, and/or the instance of the connection of multiple fractures of adjacent wells rather than from the hydraulic fracturing procedure itself (Mooney, 2011).

Withdrawals from Freshwater Resources

It is necessary to use water free from impurities during a hydraulic fracturing operation so as not to hinder the effectiveness of the added chemical compounds (Hydraulic Fracturing Water, 2012). Sources of water withdrawals for hydraulic fracturing include rivers, lakes, municipal supplies, and groundwater sources depending on the area in which the operation occurs (Hydraulic Fracturing Water, 2012).

The amount of water needed to fracture a well for oil extraction varies from site to site. According to the EPA, "Fifty thousand to 350,000 gallons of water may be required to fracture one well in a coalbed formation while two to five million gallons of water may be necessary to fracture one horizontal well in a shale formation" (Hydraulic Fracturing Research, 2010, p. 2). In the most recent United States Geological Survey of Estimated Water Use in the United States, oil and mining operations combined made up one percent of total water usage in the United States (Kenny, 2009).

Oil and mining constituted the use of 174 million gallons of freshwater per day in Ohio, 195 million gallons of freshwater per day in Florida, and 426 million gallons of freshwater per day in Minnesota (Kenny, 2009, p. 36). A 2010 report on water usage of hydraulic fracturing operations in Colorado showed only 0.08% of water resources within the state, which translates to 13, 900 acre-feet – approximately 5 billion gallons – of water per year, was allocated to hydraulic fracturing (Water Sources and Demand, 2011). Conversely, in South Texas where approximately 4.9 million gallons of water are required to complete each well used in hydraulic fracturing, a potentially "greater strain is placed on the regional water supply, and this is a concern for local residents, farmers, and ranchers 'as they face growing competition for scarce water' due to worsening drought conditions" (Allen, 2013).

Studies have not been conclusive as to whether hydraulic fracturing poses a risk to ground and surface water resources. This may be attributed to the variance between the geology of each region and the procedures performed at each site. Additionally, groundwater contamination from hydraulic fracturing operations may be stronger linked to the disposal of fracking fluids rather than the fracturing of a well itself. Similarly, the degree to which levels of ground and surface water is affected by withdrawals for use in hydraulic fracturing operations depends on the region. In Colorado, the use of water for hydraulic fracturing has a minute impact on the water supply while in Texas it is causing concern during times of drought. Although the EPA does not have jurisdiction over hydraulic fracturing as it is enumerated in the amended SDWA, states are permitted to regulate hydraulic fracturing operations within their borders. Currently, the EPA is conducting research on the risks of hydraulic fracturing to freshwater resources. It is yet to be determined if the findings of these studies will trigger legal actions in the assertion of their discretion and jurisdiction over the activity or if policies will remain the same.

Hydraulic Fracturing Background

Today, hydraulic fracturing operations can be found across the United States and all around the world. As the need for energy and fossil fuels increases with the human population, oil companies continue to look for new ways and places to provide the desired energy source while making a significant profit. Floyd Farris of Stanolind Oil and Gas Corporation first introduced hydraulic fracturing in a treatment pressure and well performance study conducted in the 1940's (Montgomery, 2010, p. 27). This study led to the first "hydrofrac" of an oil well. Stanolind Oil and Gas Corporation performed the first hydraulic fracturing operation in Grant County, Kansas in 1947 and two years later, Halliburton Oil Well Cementing Company obtained the patent with the exclusive license to perform hydraulic fracturing on oil wells (Montgomery, 2010, p. 27). Since then, the procedure has dramatically expanded across the country to recover petroleum and natural gas to be sold and used domestically and abroad. Over the span of about sixty-five years, over one million natural gas and oil wells have been used in hydraulic fracturing to recover the fluids for production (Fuller, 2012). With the expansion of the exploration and recovery of oil and natural gas has come to the creation of jobs, increase in energy production, and economic growth. Hydraulic fracturing is not a drilling process per se; rather it is the process of creating or restoring fractures in rock formations deep underground to stimulate the movement of natural gas through a pipeline and up a well. In order to prevent contamination of the aquifer in which an oil well is drilled through, a steel pipe referred to as surface casing is lowered into the well past the depth of the aquifer (Halliburton, 2013).

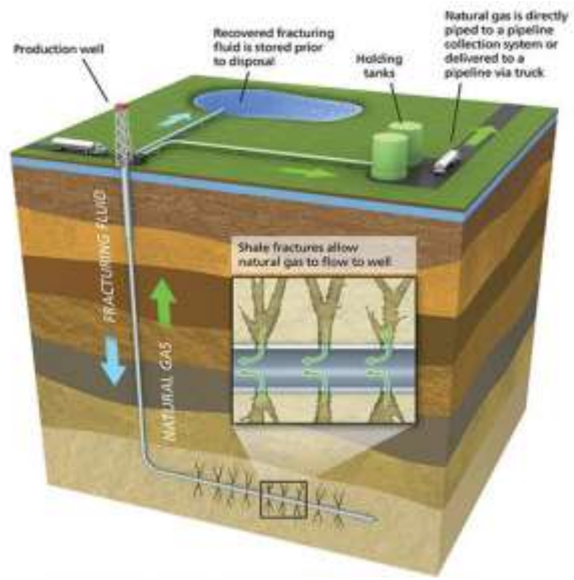

Figure: Illustration of a Typical Hydraulic Fracturing Wellbore and Process (Earth Energy Attitude, 2011)

Policy and Regulation

Numerous laws have been passed in recent decades regarding water quality and regulations on activities that may pose adverse impacts to water resources. Congress passed the Safe Drinking Water Act in 1974 to establish regulations and standards regarding water quality and the health of American citizens. Although hydraulic fracturing had been in operation across the country for almost three decades at the time of the original drafting of the SDWA, the practice was not specifically mentioned in the act until the establishment of the Energy Policy Act of 2005. Before the 2005 amendments to the SDWA, underground injection had only been addressed in regards to state and federal regulation of underground injections under the Underground Injection Control Program. In 2005, the Energy Policy Act provided an amendment to the SDWA to define underground injection and explicitly exclude hydraulic fracturing from the meaning. Section 322 of the Energy Policy Act of 2005 reads. The Clean Water Act was passed in 1972 as a series of amendments to the 1948 Federal Water Pollution Control Act (FWPCA) to provide a structure and reference for the regulation of the discharge of point source pollutants into the ground and surface water sources of the United States (EPA – Clean Water Act, 2012). Hydraulic fracturing is not explicitly mentioned in the FWPCA or the Clean Water Act. However, underground injection is addressed in section 502 of the FWPCA, as amended by the Clean Water Act, where "pollutant" is defined to exclude, "water, gas, or other material which is injected into a well to facilitate production of oil or gas…if [the] state determines that such injection or disposal will not result in the degradation of ground or surface water resources", giving the discretion of the state over the regulation of the injection and disposal of fluids and material injected underground within its jurisdiction (Federal Water Pollution Control Act, 1977).

Impact on Groundwater Quality

As more and more wells are being utilized for oil production by hydraulic fracturing practices, public attention and concern continue to grow. If a landowner or resident of a nearby hydraulic fracturing operation becomes sick or notices a change in his or her water supply after the activity has commenced, of course, he or she will assume the water contamination and/or depletion of the water supply was caused by the neighbouring oil production. This may or may not be the case, but unless the individual possesses a legitimate water sample taken prior to the start of production or the resulting water sample has traces of specific compounds known to be used by the oil production company responsible for the nearby operation as additives in the fracking fluid, it is very difficult to make the connection. The 2010 documentary Gasland, directed by Josh Fox, takes the audience into the homes of communities surrounded by hydraulic fracturing operations. Emotionally charged scenes of individuals lighting faucet water on the fire, and blaming it on neighbouring hydraulic fracturing operations, have received growing public attention, but the claims may or may not be factual. Because pinpointing the source of water pollution is often problematic and questionable, this difficulty stands in the way making definitive conclusions regarding the correlation of groundwater contamination and hydraulic fracturing operations. This controversy continues to attract both private and government funded research regarding the risk of hydraulic fracturing to water quality.

When trying to connect groundwater contamination to hydraulic fracturing one may assume the cause to be the creation of fractures within rock formations deep underground. However, the potential for groundwater contamination is more likely to be caused from cracks in the concrete casing, man-made fractures connecting to natural fractures or old wells within the rock formation, or leakage of wastewater at disposal sites (Mooney, 2011). The danger of these issues occurring is the seepage of methane or chemical additives found in the fracking fluid into public or private groundwater sources making them unsafe for humans to drink from or use. For example, Encana Corporation lists ammonium peroxidisulphate as the chemical compound with the highest percent of volume at 29% of the 11,800 gallons of chemical additives used in Wyoming during hydraulic fracturing (Crane-Murdoch, 2011).

As discussed, fracking fluid is made up of approximately 90% water, 9.5% sand, and 0.5% chemical additives. Figure two shows a visual representation of the fracking fluid composition by weight as reported in an Environmental Impact Statement produced by the Department of Environmental Conservation Division of Mineral Resources in New York. The EPA reports the amount of water required to fracture one well in a shale formation to be between two million to five million gallons, which results in the average amount of water being 3.5 million gallons with the total average volume of fracking fluid being approximately 3.86 million gallons, according to Figure two (Hydraulic Fracturing Research, 2010, p. 2). While the 0.44% chemical additive content of the fracking fluid is a small fraction compared to the water and sand proportion, approximately 17,000 gallons of the fluid is composed of chemicals. This equates to about 340 standard bathtubs full of chemicals. When that amount of fluid containing chemicals known to pose risks to human and environmental health is injected underground or disposed of near someone's home or even open space, the public is sure to have objections. The question is what the likelihood of groundwater contamination from hydraulic fracturing activities actually is on a small and large scale.

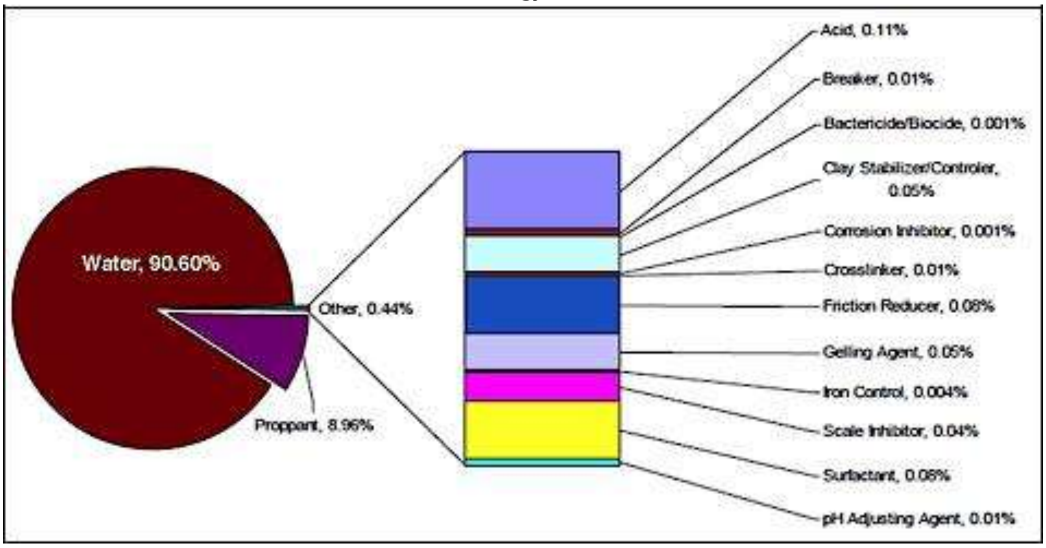

Figure 2. "Sample Fracture Fluid by weight Composition" As Reported in an Environmental Impact Statement Drafted by the New York State Department of Environmental Conservation Division of Mineral Resources (Lustgarten, Oct. 2009).

III. RESULTS & DISCUSSIONS

Variability between geologic basins, watersheds, and hydraulic fracturing procedures among operators makes it especially difficult to generalize conclusions on whether or not the activity is connected to groundwater contamination and/or the depletion of freshwater resources. This difficulty is increased when a legitimate water sample from before the start of oil extraction does not exist. Hydraulic fracturing is a consumptive use as the water is acquired and diverted for use. The majority of used water comes back as toxic wastewater to be stored in disposal ponds and wells rather than to be recycled and purified for future uses. When evaluating the impact the activity has on water table levels, it must, therefore, be considered cumulatively over the span of time in which the activity takes place in each region. Oil and gas corporations can take advantage of recycling water for future use for hydraulic fracturing or other purposes to save time and money in the way of water acquisition and reduce any adverse impacts the large freshwater withdrawals may have to riparian habitats and groundwater table levels.

Much like the difficulty of generalizing conclusions about the activity with respect to ground and surface water resources, a difficulty in implementing regulation at the federal level exists, stemming from the same variability. Additionally, regulation at the federal level that is too stringent may negatively impact economic growth, as the expansion of hydraulic fracturing is promising increases in jobs and real gross domestic product. Hydraulic fracturing regulations are best enforced at a state or local level because of the inconsistencies between geologic regions and watersheds, recycling of wastewater should be encouraged for the benefit of both industry and the environment, and in cases of widespread complaints of water contamination, it is necessary for the EPA to be able to legally assert jurisdiction. Potential impacts to drinking water resources may occur if hydraulic fracturing wastewater is inadequately treated and discharged to surface water. Inadequately treated hydraulic fracturing wastewater may increase concentrations of TDS, bromide, chloride, and iodide in receiving waters. In particular, bromide and iodide are precursors of disinfection by products (DBPs) that can form in the presence of organic carbon in drinking water treatment plants or wastewater treatment plants. Drinking water treatment plants are required to monitor for certain types of DBPs, because some are toxic and can cause cancer.

IV. CONCLUSIONS

Through this investigation, we have identified potential mechanisms by which hydraulic fracturing could affect drinking water resources. Above ground mechanisms can affect surface and ground water resources and include water withdrawals at times or in locations of low water availability, spills of hydraulic fracturing fluid and chemicals or produced water, and inadequate treatment and discharge of hydraulic fracturing wastewater. Below ground mechanisms include movement of liquids and gases via the production well into underground drinking water resources and movement of liquids and gases from the fracture zone to these resources via pathways in subsurface rock formations. We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States. Of the potential mechanisms identified in this report, we found specific instances where one or more of these mechanisms led to impacts on drinking water resources, including contamination of drinking water wells. The cases occurred during both routine activities and accidents and have resulted in impacts to surface or ground water. Spills of hydraulic fracturing fluid and produced water in certain cases have reached drinking water resources, both surface, and ground water. Discharge of treated hydraulic fracturing wastewater has increased contaminant concentrations in receiving surface waters. Below ground movement of fluids, including gas, most likely via the production well, has contaminated drinking water resources. In some cases, hydraulic fracturing fluids have also been directly injected into drinking water resources, as defined in this assessment, to produce oil or gas that co-exists in those formations. The number of identified cases where drinking water resources were impacted are small relative to the number of hydraulically fractured wells. This could reflect a rarity of effects on drinking water resources, or may be an underestimate as a result of several factors. There is insufficient pre- and Post-hydraulic fracturing data on the quality of drinking water resources. This inhibits a Determination of the frequency of impacts.

Other limiting factors include the presence of other Causes of contamination, the short duration of existing studies, and inaccessible information related to hydraulic fracturing activities. This state-of-the-science assessment contributes to the understanding of the potential impacts of Hydraulic fracturing on drinking water resources and the factors that may influence those impacts. The findings in this assessment can be used by federal, state, tribal, and local officials; industry; and the public to better understand and address any vulnerabilities of drinking water resources to Hydraulic fracturing activities. This investigation can also be used to help facilitate and inform Dialogue among interested stakeholders, and support future efforts, including: providing context to Site-specific exposure or risk assessments, local and regional public health assessments, and Assessments of cumulative impacts of hydraulic fracturing on drinking water resources over time or over defined geographic areas of interest. Finally, and most importantly, this investigation Advances the scientific basis for decisions by federal, state, tribal, and local officials, industry, and The public, on how best to protect drinking water resources now and in the future.

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