Impact of Hydraulic Fracturing on Ground and Surface Water Resources

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by

Reyna Schenck

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Abstract

The following study examines hydraulic fracturing operations in the United States in relation to groundwater contamination, withdrawals of freshwater resources, and jurisdictional authority over the activity with the purpose of producing objective analysis of research findings. With a growing population and increasing energy needs, hydraulic fracturing is expanding across the nation, as is public concern over the risks to freshwater resources. Because of the difficulty in identifying non-point sources of water pollution, a lack of legitimate water samples representing baseline conditions, and incomplete lists of chemical additives used, study results are often inconclusive as to the correlation between hydraulic fracturing and groundwater contamination. However, there is a higher likelihood of groundwater contamination caused by poor wastewater disposal and management practices. The impact of large withdrawals of water from a watershed varies between regions and while millions of gallons of freshwater per day used in hydraulic fracturing may not affect a watershed in a region with relatively high rates of annual precipitation, these withdrawals can have an adverse impact on remote and sensitive areas. The Environmental Protection Agency has never had jurisdiction over hydraulic fracturing except when diesel fuel is used; however, further research may prompt new legislation allowing the agency to oversee the activity.

Table of Contents

List of Figures

List of Tables

Chapter 1: *Introduction*

Hydraulic fracturing, also known as fracking, is the practice of injecting fluid underground at a high pressure for the purpose of extracting heavy oil. This procedure was invented by Halliburton Oilfield Services in the 1940's and has been utilized for oil production ever since (Hydraulic Fracturing Water, 2012). Over the years, neighboring citizens of hydraulic fracturing operations have claimed their groundwater has been contaminated as a result. Claims range from negative changes in tastes and smells of tap water to entire fields of crops destroyed as a result of irrigating with water from a groundwater well close to wastewater disposal ponds. Determining the source of pollution beyond a reasonable doubt is often difficult because studies on the impact of hydraulic fracturing in relation to contaminated groundwater sources tend to generate inconclusive results as the source of contaminants is non-point whether it originates from hydraulic fracturing operations, natural causes, or others.

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.

Purpose

The purpose of this paper is to provide objective research findings concerning hydraulic fracturing in respect to groundwater contamination, depletion of freshwater resources, and jurisdictional authority. Existing conclusions on the topic fall within a wide spectrum. On one end of the spectrum, opinions suggest hydraulic fracturing has no connection to groundwater contamination or depletion of freshwater resources and that regulations are too strict. On the opposite end, opinions propose a definite correlation of hydraulic fracturing to groundwater contamination and depletion of freshwater resources and that regulations are not strict enough. This paper seeks to examine research and conclusions across the spectrum and outline the reality of the circumstances.

Research Objectives

1. Examine the scientific, political, and social aspects of hydraulic fracturing operations.
2. Summarize research findings concerning the impact of hydraulic fracturing operations on groundwater quality.
3. Summarize research findings concerning the impact of hydraulic fracturing operations on freshwater reserves.
4. Summarize research findings regarding laws, regulations, and state and federal jurisdiction in relation to hydraulic fracturing operations.

Chapter 2: *Literature Review*

The literature review provides findings and opinions on hydraulic fracturing in respect to groundwater quality, withdrawals from freshwater resources, and jurisdiction. The review of literature utilizes academic articles, websites, and government publications to convey objective information on hydraulic fracturing in respect to these topics.

Groundwater 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 hundreds – 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).

Numerous claims and lawsuits have been made and filed against oil companies in assertion of groundwater contamination. A lawsuit filed in 2007, *Starh and Starh Cotton Growers v. Aera Energy LLC* was decided in favor of farmer Fred Starrh who claimed his application of groundwater destroyed his entire almond crop as a result of contaminants in the unlined pits seeping into his groundwater source ("Starrh and Starrh", 2007). Improper disposal is one thing, but groundwater contamination from operation of hydraulic fracturing is another. 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, p. 5). The report also provides a breakdown of oil and mining water usage by State in which the top three states are listed as Ohio, Florida, and Minnesota (Kenny, 2009, p. 36).

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).

Jurisdiction

The Environmental Protection Agency does not have jurisdictional authority over hydraulic fracturing activities, except in instances in which diesel fuel is used (Tiemann, 2013, p. 2). In fact, the EPA has never had jurisdiction over hydraulic fracturing (Fuller, 2012). When the SDWA was signed into law in 1974, hydraulic fracturing had been developed as an oil extraction practice almost three decades prior and was not mentioned in the act for regulation (Fuller, 2012). In 2005, Congress passed the Energy Policy Act, which explicitly indicates in Section 322 as an amendment to the SDWA that hydraulic fracturing and any associated propping agents pursuant to the operations, except diesel fuels, are excluded from the meaning of 'underground injection' (Energy Policy Act, 2005, p. 102).

The Federal Water Pollution Control Act as amended by the Clean Water Act of 1977 makes it clear in Section 502, "the term 'pollutant'…does not mean… (B) water, gas , or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil or gas production and disposed of in a well" which further excludes hydraulic fracturing operations from being subject to the authority of the EPA (Federal Water Pollution Control Act, 1977). However, authority is given to the states to approve or deny wells used for hydraulic fracturing or disposal of wastewater with the determination of potential impacts to water quality and freshwater resources (Federal Water Pollution Control Act, 1977).

In May of 2012, the EPA put forth a document titled "Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels – Draft: Underground Injection Control Program Guidance #84" in which the agency attempts to explain requirements for the use of diesel fuels in hydraulic fracturing operations (Permitting Guidance, 2012, p. 2). As the SDWA gives authority to the EPA over hydraulic fracturing only in cases where diesel fuel is used, the purpose of the 2012 document is to "provide regulatory certainty, improve compliance with the SDWA requirements and strengthen environmental protections consistent with existing law" (Permitting Guidance, 2012, p. 2). Five U.S. Senators expressed their concern at the release of this draft document, as they believed it overly expands the authority of the EPA in regards to hydraulic fracturing because four out of the six specified diesel fuels are not formally considered as such (Lammi, 2012).

The Fracturing Responsibility and Awareness of Chemicals Act of 2011 (FRAC Act) was created in response to the Energy Policy Act to reverse the amendment made to the SDWA that exempts hydraulic fracturing from authority of the EPA. If the FRAC Act were to pass, Section 1421 (b) of the SDWA would be amended to read, "the term 'underground injection' includes the underground injection of fluids or propping agents pursuant to hydraulic fracturing operations relating to oil or gas production activities" (Fracturing Responsibility and Awareness, 2011). The Act would also require hydraulic fracturing operators to disclose the chemical constituents used, minus trade secrets, to the state and from the disclosure, the state shall provide the information to the public (Fracturing Responsibility and Awareness, 2011).

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 assertion of their discretion and jurisdiction over the activity or if policies will remain the same.

Chapter 3: Analysis of *Research Findings*

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 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). The well extends beneath the surface at a depth of 6,000 to 10,000 feet before reaching the "kick-off point" where it starts to turn horizontally and continues into the shale rock layer (Halliburton 2013). The horizontal section of the well lies within the shale formation that is to be fractured. A proliferating gun is lowered into the horizontal section of the well where it creates holes in the steel pipe and the fracturing fluid composed of water, sand, and a mixture of chemicals is pumped into the well at a high pressure to create fractures within the shale rock formation (Halliburton, 2013). With that, the fossil fuels within the layer of shale are free to flow through the well and up to the surface where they can be collected for production. The figure below provides an illustration of a typical hydraulic fracturing operation.

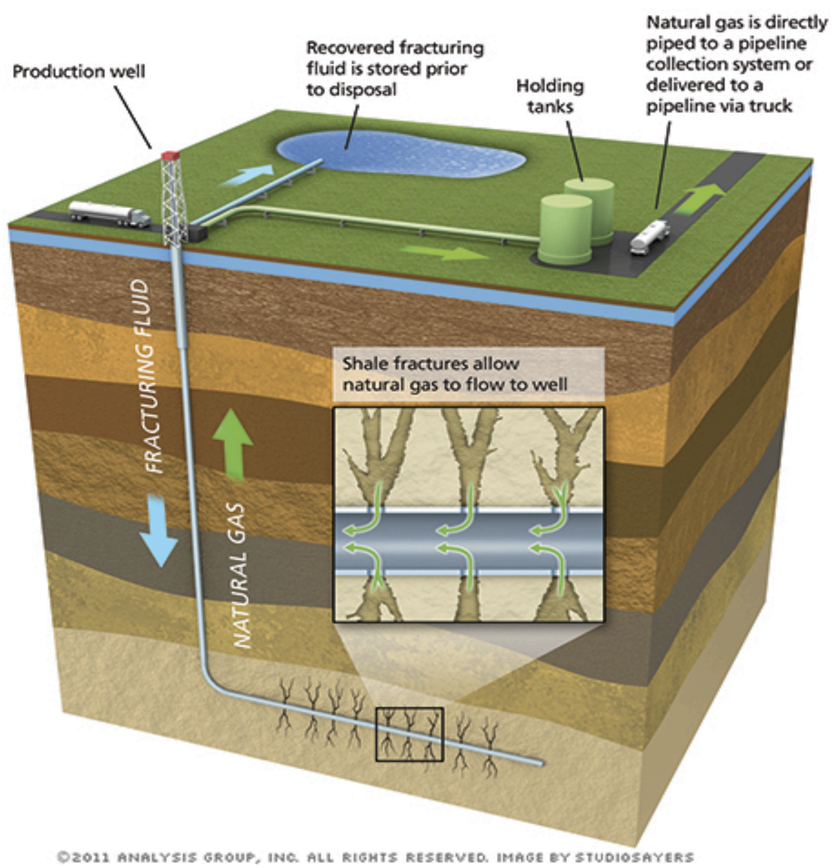

Figure 1. Illustration of a typical hydraulic fracturing wellbore and process (Earth Energy Attitude, 2011).

The composition of the fracking fluid mixture differs among production companies performing the hydraulic fracturing operation and the make-up of the geologic basin at the site, but is generally the same in terms of the percentages of water, sand and chemical compounds used. Typically, the fluid is composed of 90% freshwater, 9.5% sand, and 0.5% chemical additives (Chemical Use, 2012). The ground and surface water injected underground should be free from impurities, such as salt, natural and synthetic contaminants, to prevent interference with the effectiveness of the chemical additives in the fracturing fluid. Depending on the location of the well, the geology of the region, and the company recovering the oil, tens of thousands to millions of gallons of fresh water may be required to fracture one well. According to the EPA, fifty thousand to 350,000 gallons of fresh water are used to fracture one well in a coalbed formation while two to five million gallons are necessary to fracture a well in a shale rock formation (Hydraulic Fracturing Research, 2010, p. 2). As environmental and public concerns have been raised about the use of freshwater for purposes of oil extraction, oil and gas corporations have made efforts to recycle and/or purify the wastewater generated during hydraulic fracturing operations. Any water that is not recycled is transferred to disposal ponds or wells.

Fifty-nine chemicals are listed on the FracFocus Chemical Disclosure Registry website as the additives most frequently used in fracturing fluid during hydraulic fracturing operations. This list does not include the chemicals undisclosed by oil and gas corporations in order to maintain confidentiality of trade secrets. These chemicals are used for purposes of reducing friction, inhibiting corrosion, controlling iron, adjusting pH, stabilizing clays, or used to act as an acid, biocide, gelling agent, scale inhibitor, breaker, surfactant, non-emulsifier, or crosslinker (Chemical Use, 2012). A list of chemicals and their significance in the operation of hydraulic fracturing practices can be found in Appendix A. Ten chemicals in particular have received public attention as they are especially carcinogenic and/or toxic when consumed. Methanol, BTEX compounds, naphthalene, sulfuric acid, diesel fuel, crystalline silica formaldehyde, hydrogen fluoride, lead, and those chemicals undisclosed by hydraulic fracturing operators are among the chemicals of highest concern (Kelley, 2012). The human and environmental health risks associated with these chemical compounds are a driving force behind those pushing for more strict federal regulation of hydraulic fracturing activities.

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 term underground injection – (A) means the subsurface emplacement of fluids by well injection; and (B) excludes – (i) the underground injection of natural gas for purposes of storage; and (ii) the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas ,or geothermal production

activities" (Energy Policy Act, 2005).

Former Vice President, Richard Cheney, was chairman of the Energy Task Force responsible for creating the national energy policy now known as the Energy Policy Act of 2005. Because Cheney is a former Chief Executive Officer of Halliburton Oilfield Services, section 322 of the Act has become known as the "Halliburton Loophole". This informal name for this particular section of the act alleges the exclusion of hydraulic fracturing from being considered an "underground injection" activity was drafted to benefit the oil and gas industry and furthermore, disregards the purpose of the SDWA which promotes public health through the protection of drinking water sources. Speculation continues on whether or not the "Halliburton Loophole" controversy is based on truth.

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 states discretion over the regulation of the injection and disposal of fluids and material injected underground within its jurisdiction (Federal Water Pollution Control Act, 1977). An amendment to the FWPCA put forth by the Clean Water Act specifies that an Administrator of the Environmental Protection Agency should not require stormwater discharge permits from operations involving oil and gas exploration or production

(Federal Water Pollution Control Act, 1977). This amendment has drawn attention from environmental groups as it exempts hydraulic fracturing operations from the National Pollutant Discharge Elimination System (NPDES) authorized by the Clean Water Act, which acts as the permitting program regulating point source and discharge pollutants to ground and surface waters.

Although the EPA does not have authority over hydraulic fracturing activities, a state has the power to regulate hydraulic fracturing operations within its jurisdiction as it sees fit. As of May 2012, nine states had enacted legislation addressing hydraulic fracturing and in total, nineteen states had introduced at least 119 bills regarding the activity (Pless, 2012, p. 4). Wyoming became the first state, in 2010, to require full disclosure of chemicals injected underground during hydraulic fracturing, the proposed concentrations of the chemical compounds, and reporting of the compounds and concentrations after well treatments (Wyoming Promulgates New Rules, 2010). Following Wyoming's lead, Michigan's Department of Environmental Quality recently instated a policy requiring chemical and volume of chemical disclosure by oil and gas corporations involved in hydraulic fracturing to the Department of Environmental Quality and similarly, Texas enacted a law requiring public disclosure of chemicals (Pless, 2011). There are a number of oil and gas corporations participating in voluntary chemical disclosure of additives used during hydraulic fracturing operations through FracFocus Chemical Disclosure Registry and other reporting mediums. As environmental and public concerns over groundwater contamination from hydraulic fracturing practices persist, it is expected the number of state regulations on hydraulic fracturing will increase.

Numerous bills are currently pending or being drafted in various states to impose regulations on hydraulic fracturing operations. In California for example, Assembly Bill 591 is pending approval from legislative officials and if approved, would require the person responsible for the activity to disclose “the chemical constituents used in the hydraulic fracturing fluid and the amount of water and [fracturing] fluid recovered from the well” to the owner of the well and furthermore, the owner would then be responsible for making this information available to the public (Assembly Bill No. 591, 2011, p. 2). The majority of passed, pending, and withdrawn state legislation regarding hydraulic fracturing has to do with chemical disclosure while fewer bills relate to well regulation and inspection, limiting withdrawal of freshwater reserves, and temporary prohibition of the activity. Legislators and the public in Massachusetts, New Jersey, and Pennsylvania are considering drafting legislation that would address the exemption of hydraulic fracturing in the SDWA (Pless, 2011). These pieces of legislation would encourage the enactment of the Fracturing Responsibility and Awareness of Chemicals (FRAC) Act.

The most well known pending federal legislation regarding hydraulic fracturing and groundwater resources is the FRAC Act, introduced to both houses in 2009 and reintroduced in 2011. If passed, the Act would amend section 1421 of the SDWA, which was previously amended by the Energy Policy Act in 2005. Section 1421 would be amended to read, “[underground injection] includes the underground injection of fluids or propping agents pursuant to hydraulic fracturing” and would add requirements of chemical compound disclosure as well as chemical volume disclosure to the state (Fracturing Responsibility and Awareness, 2011). This bill has yet to be passed, but has received attention from both environmental groups and the oil and gas industry. Earthjustice, the National Wildlife Federation, and the Food and Water Watch Fund are a few of the organizations endorsing this bill while the opposing side includes the America’s Natural Gas Alliance and the Independent Petroleum Association of America (What’s Your Position, 2011). This should come as no surprise as the environmental groups will likely always push for more stringent regulation of oil and gas production for protection of natural resources while the oil and gas industry prefers regulation of the activity to be as little as possible so as to encourage higher profits.

Increased regulation of the oil and gas industry is sure to be felt economically. According to the Independent Petroleum Association of America, federal oversight as opposed to the current state oversight of hydraulic fracturing operations would increase the cost of new natural gas wells by $100,000 each (Lustgarten, 2009). This additional cost could discourage exploration and production of natural gas in the United States, which would be counterproductive to the nation's energy goals. IHS Global Insight predicts that by 2015 hydraulic fracturing will be responsible for 870,000 U.S. jobs and impact the economy by 118 billion dollars and in a 2009 study, it was forecasted that if hydraulic fracturing was required to comply with the underground injection control program, by 2014 real gross domestic product would decrease by eighty-four billion dollars and 635,000 jobs would be eliminated (Measuring the Economic, 2009, p.2). The oil and gas industry in the United States is expanding with the development of hydraulic fracturing and with this expansion comes great economic potential at federal, state, and local levels. With that said, the economic potential of hydraulic fracturing for energy production must be taken into consideration with the preservation of the earth's natural resources in a maintainable manner for the benefit of future human populations and the environment.

Impact on Groundwater Quality

As more and more wells are being utilized for oil production by hydraulic fracturing practices, public attention and concern continues 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 neighboring 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 fire, and blaming it on neighboring 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 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 fracking fluid into public or private groundwater sources making them unsafe for humans to drink from or use. For example, Encana Corporation lists diammonium 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). This particular chemical is known to cause health hazards such as respiratory, liver, immune, cardiovascular, and reproductive problems when consumed (Crane-Murdoch, 2011). The list of disclosed chemicals provided by the Wyoming Oil and Gas Conservation Commission is composed of twenty-seven other chemical compounds known to cause sensory organ, nervous system, kidney, carcinogenic, mutagenic, endocrine, and developmental health hazards when exposed to or consumed in addition to those also caused by diammonium peroxidisulphate (Crane-Murdoch, 2011). The EPA is currently conducting studies in multiple states to evaluate whether or not these toxic substances have already contaminated groundwater resources in particular regions.

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.

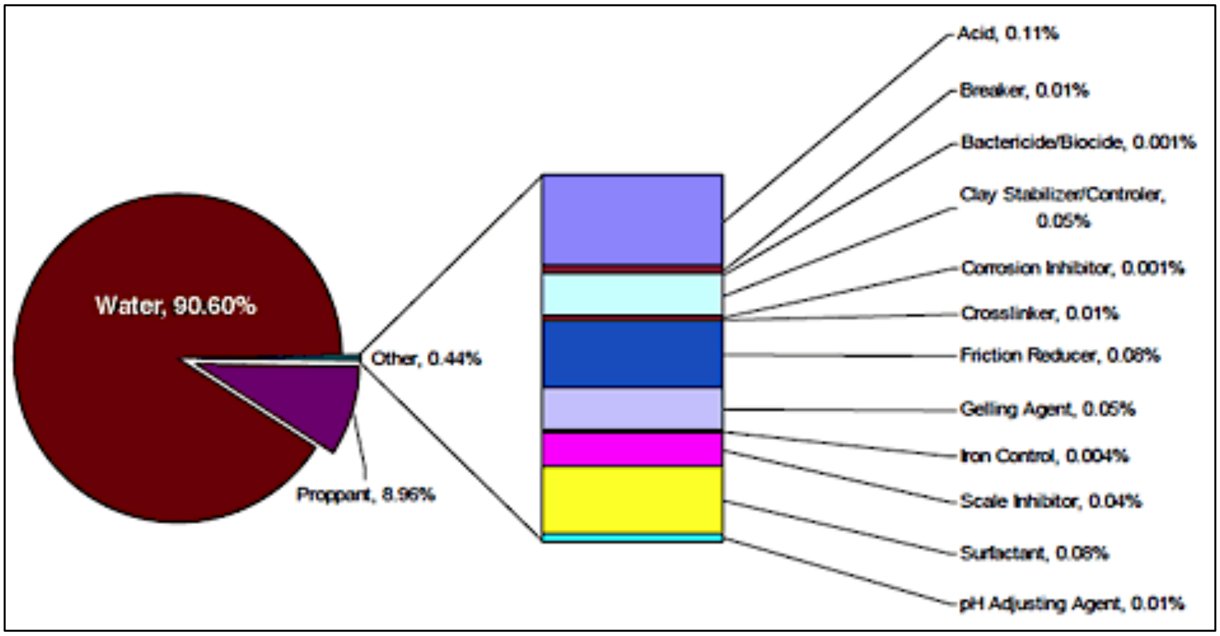

Figure 2. "Sample Fracture Fluid by Weight Composition" as reported in an Environmental Impact Statement drafted by the New York State Department of Environmental Conservation Division of Mineral Resources (Lustgarten, Oct. 2009).

Of the three probable causes of groundwater contamination from hydraulic fracturing operations, the formation of cracks in the concrete casing surrounding the vertical pipes extending through the aquifer is an issue that oil and gas producers want to be sure to prevent. In a discussion at Cal Poly State University, San Luis Obispo, Ken Daraiae, President of Continental Industries and Vice President of Operations at World Oil Properties Inc. explained that bad cement jobs can cause problems and one of the last things an oil producer wants is for the casing to crack and oil to escape, even if the corporations do not care about the impacts to the environment because they do not want to lose any money or pay for the cleanup of an oil spill (Daraiae, 2013). Even so, the risk remains. Dr. Anthony Ingraffea, Civil and Environmental Engineering Professor at Cornell University with a research focus in simulation and testing of complex fracturing processes, explains, "a significant percentage of cement jobs will fail…it will always be that way. It just goes with the territory" and if a cement job does fail, there is potential for a pathway to be opened up for the fracturing fluid to flow out and leak into the surrounding aquifer (Mooney, 2011). However, by industry definition cementing is not officially part of hydraulic fracturing, but nevertheless is a key component in the extraction of oil from deep underground.

Another common worry associated with hydraulic fracturing is the connection of fractures created during hydraulic fracturing to preexisting natural fissures in the rock formation that extend far enough to reach the aquifer. Engineer and former Chief Executive Officer at Pinnacle technologies – a Halliburton service firm – Kevin Fisher, found the most extensive natural fractures in the Marcellus Shale formations reached a vertical length of two thousand feet (Mooney, 2011). With horizontal drilling occurring six thousand to ten thousand feet below the surface, a connection of man-made and naturally occurring fractures would not pose a threat to groundwater sources, as a buffer of four thousand to eight thousand feet would remain to protect aquifers from contamination. Ingraffea, among most scientist who study hydraulic fracturing processes, doubts the likelihood of a single fracture extending from the depth at which horizontal drilling occurs all the way up to the depth of the aquifer (Mooney, 2011). In theory, the possibility of man-made fractures connecting to natural fissures in the rock extending up to the aquifer exists; however, this is unlikely to occur and out of the three most probable causes of groundwater contamination, it is of the least concern.

When a hydraulic fracturing operation has been completed and the fracking fluid flows back up through the well, the wastewater must be either disposed of at a disposal site or recycled for future use. In a risk analysis study conducted by Stony Brook University scientists, Daniel Rozell P.E., and Sheldon Reaven, Ph.D., the probability of groundwater contamination from wastewater disposal sites was found to be “several orders of magnitude larger” than potential pathways such as cement casing leaks, transportation spills, leaks through natural rock fractures, and drilling site discharge (Rozell, 2012). Disposal of wastewater into lined and unlined pits can pose threats to groundwater if done carelessly as the ground is a natural sponge and, depending on the soil type and condition, will soak up any fluid it comes in contact with. A tropical storm that hit Pennsylvania in 2011 caused multiple disposal ponds full of fracking fluid laden with chemicals to overflow onto the surrounding grounds (Mooney, 2011). If hydraulic fracturing is defined as the process in its entirety including the drilling of wells and disposal of wastewater, contamination and the potential for future contamination of groundwater is apparent and is currently being addressed by environmental groups, private individuals, federal and state governments, and the EPA.

Case Studies

A study conduced by the EPA regarding groundwater contamination from hydraulic fracturing in Pavillion, Wyoming was released in December of 2011 and is being held open for public comment until September of 2013. Adverse changes to the tastes and smells of the water in domestic wells of the residents of Pavillion prompted the EPA to begin the study and sample thirty-nine individual wells to assess the water for any potential health hazards (DiGuilio, 2011 p. 1). Results of the groundwater testing revealed both public and private drinking water sources in the region had been contaminated with synthetic chemicals such as alcohols, glycols, and benzene compounds consistent with those used during nearby hydraulic fracturing operations and found the concentrations of these chemicals to be higher than the standards outlined in the Safe Drinking Water Act (DiGuilio, 2011, p. 1). It was concluded the wastewater disposal pits in the area of investigation represented a source of potential contamination of shallow groundwater sources and in effect, the operator of the disposal sites was ordered to implement further investigation and begin remediating the sites (DiGuilio, 2011, p. 33). Disposal sites, as they are above ground, can be more easily identified as a point source for water pollution, but a factor such as the migration of fracking fluid, oil or gasoline upward into aquifers and groundwater wells is more of a non-point source, which is not as easily identified. A number of synthetic organic compounds were detected in the water samples taken by the EPA, some of which were not listed on the data sheets as chemical additives used at the Pavillion hydraulic fracturing sites; however, it is known that chemicals considered "trade secrets" are not disclosed so as to keep them confidential (DiGuilio, 2011, p. 35). These compounds were found in higher concentrations at higher depths of the monitoring wells and were also present at shallower depths, which suggest the upward migration of the substances and the EPA attributed this to potential variability in cement bonds and the permeability of the layered sandstone and shale formations of the region (DiGuilio, 2011, p. 35). These complaints from citizens of a relatively small population prompted the expansion of similar research and studies across the United States.

The Pavillion study findings influenced Congress to request similar studies to be conducted in additional areas around the country to assess hydraulic fracturing operations' relation to adverse impacts on groundwater resources. One study looks at hydraulic fracturing in its entirety, starting from water acquisition to chemical mixing, well injection, flowback and produced water, and ends with the examination of wastewater treatment and disposal in seven counties – Dunn County, North Dakota, Wise County, Texas, Bradford and Sesquehanna Counties, Pennsylvania, Washington County, Pennsylvania, and Las Animas and Huerfano Counties, Colorado (EPA's Study of Hydraulic Fracturing, 2012). Conclusions have not yet been made as to the extent at which hydraulic fracturing is impacting groundwater resources in these regions. The Draft Report outlining this study and the findings will be released for peer review and public comment in 2014.

Several independent and class action lawsuits have been filed in the past decade alleging groundwater contamination from nearby hydraulic fracturing operations. A notable case brought before the Supreme Court of California is *Starrh and Starrh Cotton Growers v. Aera Energy LLC* in which farmer, Fred Starrh filed a lawsuit against Aera Energy, an oil producer of which disposed of wastewater in unlined pits near his property allegedly causing groundwater contamination that led to the loss of his entire almond crop (Starrh and Starrh, 2007). The court ruled in favor of Starrh as chemicals used by Aera Energy as chemical additives in the fracking fluid and subsequently present in the wastewater were found in his private well during water quality testing (Starrh and Starrh, 2007). Of course, not all suits brought against oil corporations are awarded in favor of the opposing party. Many cases prove to be inconclusive as to the origin of groundwater contamination and/or the facts presented to the court turn out to favor the company responsible for the hydraulic fracturing operation in question.

More often than not, lawsuits brought by individuals claiming contamination of groundwater from hydraulic fracturing are resolved with a holding in favor of the oil producer because of inconclusive results regarding the source of water contamination. This was the case in *Harris v. Devon Energy Production Co.* in which Doug and Diana Harris, residents to a nearby hydraulic fracturing site operated by Devon Energy Production Company, alleged their well water had been contaminated as a result of the oil production (King, 2012). When Devon Energy filed a case summary claiming the plaintiff, Harris, had no evidence for such contamination the lawsuit was dropped as the claims of contamination were sure to be found inconclusive (King, 2012). Unless a party bringing suit against an oil corporation alleging water contamination has a legitimate water sample from before the activity began or strong evidence can be brought before the court that supports the claim of contamination beyond a reasonable doubt, the findings of the source of contaminants will remain inconclusive in a court of law.

Researchers at Duke University performed a study concerning methane contamination of groundwater in relation to neighboring hydraulic fracturing operations in Pennsylvania and New York. Water samples were taken from sixty-eight wells and of those samples, eighty-five percent were contaminated with methane regardless of their proximity to active natural gas wells; however, methane concentrations were found to be seventeen-times higher in shallow wells in areas of active oil extraction than in non-active areas (Osborn, 2011, p. 1). Figure three displays the findings of the methane concentrations in the water samples taken in relation to the distance to the nearest gas well. As indicated on the chart, methane concentrations in the water increase with a decrease in distance to an active gas well, while a trend of lower methane concentrations was apparent in samples taken in non-active extraction areas. When the researchers looked at the carbon isotopes of the contaminants in the samples, values indicated the methane found near the active extraction areas was thermogenic and of deeper geological origins suggesting the upward migration of the fluid into the neighboring water wells (Osborn, 2011, p. 2). Because the source of this water pollution cannot surely be determined without concrete data representing the baseline conditions before oil extraction began, it is difficult to come to strong conclusions on whether or not the methane in the water samples was truly caused by hydraulic fracturing operations.

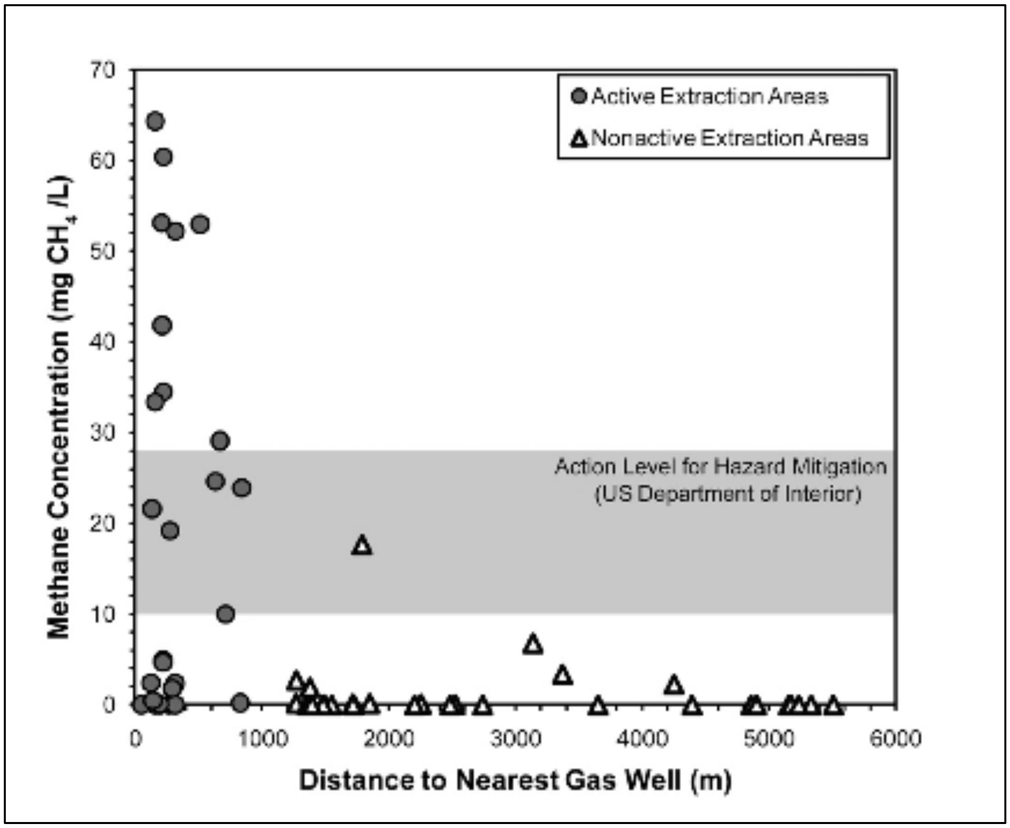

Figure 3. Methane concentrations of water samples compared to distance to nearest gas well in Pennsylvania and New York (Osborn, 2011, p. 2).

Case studies assessing the impact of hydraulic fracturing on groundwater resources in respect to ground and drinking water contamination offer a wide variety of conclusions. This is because the geology of the study region and management of oil extraction and disposal practices differs from site to site. Senior Research Analyst, Sarah Fletcher, at IHS Unconventional Energy Blog explains, "even if some case studies are able to properly identify the source of contamination, they will likely not yield conclusions that could be generalized to other areas", and stresses the importance of separating fact from fiction when evaluating the risk of hydraulic fracturing to groundwater resources (Fletcher, 2013). The difficulty this poses from an environmental and human health and safety perspective is if hydraulic fracturing is in fact conducive to polluting ground and drinking water in some areas, this may not be the case in others and in effect, doubt could prevent the implementation of stronger regulations, which would be necessary to protect environmental and human health in certain regions.

Impact on Freshwater Reserves

An issue seemingly on the backburner to groundwater contamination is the depletion of groundwater reserves. Although the operation of hydraulic fracturing uses much less water than agricultural and public supply uses across the country, the practice acquires millions to billions of gallons of freshwater of which most is left as wastewater not to be recycled or purified. Ken Daraiae, President of Continental Industries, made clear during the discussion, “Debating the New Era of Hydraulic Fracturing” that because hydraulic fracturing uses such enormous amounts of freshwater, “[the industry] is on a very unsustainable trend, recycling of water only happens when it can be economically justified, and this is [what the public and industry] should be concerned about” (Daraiae, 2013). The difference between the large water usage for irrigation and public supply and the use of freshwater for hydraulic fracturing is a large percentage of water used for irrigation and public supply is recycled and purified for future use while much of the water used to extract oil during hydraulic fracturing becomes waste.

Use of water in the United States varies from state to state depending on factors such as population, development, and land uses. The most recent United States Geological Survey, reporting the water usage of each state, ground and surface water in gallons per type of use, and the usage of the country as a whole, reports thermoelectric power as the greatest user of water at 201 billion gallons per day (gpd), irrigation at 128 billion gpd, public supply at 44.2 billion gpd, industrial purposes at 18.2 billion gpd, aquaculture at 8.78 billion gpd, mining and oil extraction at 4.02 billion gpd, domestic purposes at 3.83 billion gpd, and livestock at 2.14 billion gpd (Kenny, 2009, p. 5). Figure four displays the water use in the United States in percent.

Water use for the category of mining, oil, and gas operations is significantly smaller than the majority of water uses in the country. Also, oil extraction only accounts for a fraction of the water use in its category. Even so, withdrawing millions of gallons of fresh water for a single natural gas well can have significant impacts on a watershed depending on the location of withdrawals. When assessing environmental impacts of an activity it is important to look at how the action is affecting the environment locally rather than only focusing on the broader picture. This is true for hydraulic fracturing as it uses a small percentage of the total water used in the United States annually, but when examining the water withdrawals on a local level, it is more obvious how the activity is impacting specific areas of the country.

[redacted]

Figure 4. Usage of water by type in the United States as reported in the most recent United States Geological Survey, "Estimated Use of Water in the United States in 2005" (Kenny, 2009).

Withdrawing millions of gallons of freshwater to hydraulically fracture rock formations for oil extraction may not have a significant impact on groundwater reserves of a country, state or even watershed as a whole, but if taken from a remote area, the withdrawals can adversely affect the flow patterns and riparian habitat of a sensitive environment. A report released by the

Pacific Institute explains, "[hydraulic fracturing] represents a 'consumptive' use if it is not available for subsequent use within the basin from which it was extracted" (Cooley, 2012, p. 16). A rapid consumptive use of water resources in remote areas may better represent the direct impact hydraulic fracturing has on freshwater resources. Deputy Executive Director of the Sesquehanna River Basin Commission, Thomas Beauduy, in a hearing concerning water use of shale gas production in the Eastern United States, recognized that although the cumulative impact of water withdrawals throughout the region for hydraulic fracturing is significant, mitigation measures may be used to manage the activity so as not to deplete water resources (Beauduy, 2011, p. 10). Some areas of the country may approach this issue of water consumption much like Beauduy to monitor and manage water resources, but others may choose to be more lax or strict depending on if the area has access to an abundance of water or if it is going through a drought period.

Colorado has an abundance of water for use within the State and represents a region in which hydraulic fracturing is growing. In a 2011 report on Colorado water use prepared by the Colorado Water Division, only an eighth of a percent – about 5 billion gallons – of freshwater in the state was dedicated to hydraulic fracturing in 2010 (Water Sources and Demand, 2011, p. 2). However, since the majority of that water is used in a purely consumptive manner rather than recycled, it must be looked at cumulatively over the years of use. Colorado water law indicates the use of a water right may be changed by an amendment to the existing water right to allow for it to be used for hydraulic fracturing and the state has not expressed that such uses are having an adverse impact to the water table levels as the annual use is relatively minimal (Water Sources and Demand, 2011, p. 9). Less controversy is likely to occur over freshwater use for oil extraction in areas not experiencing drought.

In Texas, the United States' largest producer of oil and gas, a drought occurred in 2011 and put strain on water allocation for various uses (Allen, 2013). When there is a lack of water available for farmers and a large amount of water is being used by hydraulic fracturing operators or even for environmental purposes, conflict emerges. Approximately 4.9 million gallons of water are necessary to complete a well for hydraulic fracturing in the Eagle Ford Shale formation in South Texas, and although this only represents about 0.4% of the water used annually in the entire State, this amount is significant to neighboring farmers and ranchers who must compete with oil and gas corporations to buy and use water at rising prices as it becomes more scarce (Allen, 2013). The question then arises for policy makers and state departments of water resources, which purposes and how much water for each purpose constitutes a reasonable and/or beneficial use in the interest of the state and its citizens.

Acquisition of water to be used for hydraulic fracturing varies from state to state and region to region depending on state water laws and policies. Most states require the water right to be put to a beneficial and reasonable use and some allow the transferring of appropriative water rights for alternative uses than for which the right was originally granted. Part of the EPA's current study regarding the impact of hydraulic fracturing on water resources is devoted to determining if the withdrawal of large amounts of water from certain basins will adversely impact the environment and surrounding communities. Potential sources of water for hydraulic fracturing include, but are not limited to, water transported from inside or outside of the state in which it is used, irrigation water leased or purchased from a landowner, diverted water from surface or groundwater sources, treated water leased or purchased from a water provider, and produced, reused, or recycled water used in previous operations or well construction (Water Sources and Demand, 2011). Ideally for conservation of fresh water, water is recycled for multiple hydraulic fracturing operations to ease the consumptive nature of the process.

The potential for the recycling of water used and turned into wastewater during hydraulic fracturing operations presents opportunities for preservation of groundwater and surface water resources and for economic growth. Bear Creek Services in Louisiana offers portable forward osmosis systems that can be utilized at oil production sites for wastewater reclamation, Hydration Technology Innovations in Arizona offers a purification system for wastewater held in pits to be purified and recycled, and although these systems require money for set up and operation, this is balanced with a decrease in costs for securing and transporting water for use and disposal purposes (Schultz, 2010, p.1). As the industry continues to grow, competitors are looking to decrease costs while expanding production. The technology for the recycling of "frac water" is still developing and expanding and during this transition period some companies are finding it less expensive to dispose of water at disposal sites and acquire new water for use rather than utilize a wastewater recycling operation on or off site. However, Vice President of well-production services, Salvador Ayala, asserts, "reducing freshwater use 'is no longer just an environmental issue – it has to be an issue of strategic importance'" (Sider, 2012). The purifying and recycling of wastewater produced from hydraulic fracturing can be taken advantage of in the interests of both the environment and economic growth.

Jurisdiction

The issue of who has and who should have jurisdiction over hydraulic fracturing activities across the United States has gained attention in recent years. Environmental groups and some members of the public and law making bodies believe jurisdiction should belong to the EPA and regulations should be increased while the oil and gas industry and other members of the public and law making bodies believe the current state-held jurisdiction is appropriate and there is no need for increased regulation. The EPA has never had jurisdiction over hydraulic fracturing except in instances in which diesel fuels are injected underground as explicitly stated in the 2005 amendments to the SDWA (Energy Policy Act, 2005, p.102). While the more local approach to regulating an activity is beneficial in some instances, it is also beneficial to have a comprehensive standard for local agencies to use as a reference. As more and more states across the country are drafting legislation concerning the regulation of hydraulic fracturing in regards to groundwater reserves, the EPA is concurrently investigating the need behind these regulations.

One reason for state regulation of hydraulic fracturing is it is very inefficient for the federal government to enforce laws. Each state has separate, but often-similar laws and regulations governing how hydraulic fracturing may be operated within the state. The SDWA exempts hydraulic fracturing from regulation by the Underground Injection Control (UIC) Program, which is approved for primary state regulation in thirty-three states (Permitting Guidance, 2012). Therefore, hydraulic fracturing is not subject to the regulation of construction, operation, permitting, and closure of injection wells required by the UIC Program, but the states may still enforce laws and regulations on the operations within their jurisdiction as they please. Most often, these state regulations involve the disclosure of chemicals, while others have to do with well inspection procedures and limitation of water withdrawals, but it is up to the state to determine how heavy of a hand to impose on the activity within its borders.

Although it is more efficient for states and local governments to enforce laws and regulations, creation of laws is more effective if done at a higher level of government. If hydraulic fracturing was not exempt from being considered “underground injection” in the SDWA and fracturing fluid was not exempt from being considered a “pollutant” in the Clean Water Act, the United States EPA would be responsible for setting the standard of regulation for the states to meet or surpass. To improve compliance with the regulation of diesel fuels injected underground, the EPA drafted the document, "Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels – Underground Injection Control Program Guidance #84" as the SDWA grants authority to the agency to regulate hydraulic fracturing operations through the UIC Program in cases where diesel fuels are injected underground (Permitting Guidance, 2012). Other than hydraulic fracturing operations involving the underground injection of diesel fuels, federal regulation of the activity as a whole will only occur if new amendments to the SDWA and Clean Water Act were implemented or a new piece of federal legislature was passed to do so.

Chapter 4: *Discussion and Conclusion*

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 in respect to ground and surface water resources, a difficulty in implementing regulation at the federal level exists, stemming from the same variabilities. Additionally, regulation at the federal level that is too stringent may negatively impact economic growth, as 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 be able to legally assert jurisdiction.

The academic community is in agreement, for the most part, that the idea of man-made fractures six to ten thousand feet underground connecting to natural fissures in the layers of rock, extending all the way up to the aquifer and in effect, exposing the water source to toxic chemical laden fluids is unrealistic. The more probable cause of groundwater contamination is negligence on the part of the hydraulic fracturing operator. This negligence includes factors such as hydraulic fracturing wells with cement casing susceptible to leaks, oil and wastewater spills during transportation, and improper disposal practices. Of these factors, improper disposal of wastewater is the most likely to pose risks to ground and surface water quality, especially if the waste is disposed of in unlined pits (Rozell, 2012). This risk may be mitigated with the adoption of local, state, or federal legislation outlining disposal policies and penalties for violation. In effect, attentive regulation and enforcement at a local level paired with sampling of nearby groundwater wells before and after hydraulic fracturing operations begin is likely to increase the safety of drinking water sources as well as the confidence in pinpointing sources of water pollution.

As mentioned, the most effective way to prove groundwater contamination of private and public wells from nearby hydraulic fracturing operations is to perform water quality sampling prior to the start of the activity so baseline conditions can be set and referenced in an instance of alleged contamination. Companies such as Independent Water Testing, based in Pennsylvania, offer baseline testing of water quality in groundwater wells with the mission of "[providing] court admissible baseline water quality data" for landowners (Independent Water Testing, 2011). The company offers three tiers of increasingly extensive water quality testing. The first tier service offers water quality testing for detection of methane, ethane and other more commonly found substances related to oil extraction while the second and third tier services additionally test for common chemicals used in fracking fluids (Independent Water Testing, 2011). Once baseline conditions are established, the landowner or oil producer can reference the results of the baseline conditions and compare them to current conditions to prove or disprove groundwater contamination from hydraulic fracturing. Otherwise, alleged groundwater contamination evaluated in a court of law would have to be based solely on water samples representing the current conditions. Findings of chemicals in the sample known to be used in a nearby hydraulic fracturing operation or disposed of at a nearby disposal site, or lack thereof, may hold up in court to prove a connection or lack of connection between groundwater contamination and the activity; however, without a water sample representing baseline conditions, it is more difficult to draw conclusions beyond a reasonable doubt.

Consumptive water use depletes a water source at the point of diversion with no intention of later contributing to the regeneration of the source through the addition of water back into the hydrologic cycle. Hydraulic fracturing largely represents a consumptive use since the majority of water acquired and used during the process is disposed of rather than recycled back into the water table for future uses. Technically speaking, any use of water that takes water from a water source such as a groundwater well, stream or reservoir is considered a consumptive use as the water is being removed from the source and used and non-consumptive uses are considered to be activities such as recreational purposes or hydroelectric power generation because no water is being diverted from the source for use. Cumulative impacts must be taken into account to assess the affect withdrawals for particular uses have on freshwater resources. Thermoelectric power generation, for example, uses a closed-loop system, in which water is withdrawn, used in a cooling process, and then recycled for future uses (Kenny, 2009, p. 38). Hydraulic fracturing on the other hand, does not “close the loop” the majority of the time as recycling of water is still rare for most operations while millions to billions of gallons of freshwater are withdrawn from groundwater wells, rivers, and reservoirs, not to be recycled back into the water cycle for future use. The cumulative impacts to at least sensitive areas are likely to be adverse and apparent with the likelihood rising over time if there continues to be an increasing amount of water converted to wastewater and disposed of not to be put to beneficial uses in the future.

The feasibility of recycling larger percentages of produced “frac water” is becoming more realistic with developments in technology. Forward osmosis units can be established at hydraulic fracturing sites to purify water to a very high quality to be used in future operations as eighty percent of the wastewater can be recycled to provide twenty percent of the water necessary for hydraulic fracturing (Schultz, 2010, p.1). With eighty percent of the wastewater offering the promise of only twenty percent of the necessary water to be used for hydraulic fracturing, this may not seem worth the money and effort; however, twenty percent of the water required for an average operation equates to an average of 700,000 gallons of freshwater that would not need to be taken from a watershed, appropriated, and bought by the oil company. This can work to lower production costs and reduce adverse impacts to the freshwater supply and riparian habitats. During times of drought, the conservation of a relatively small amount of water can make a big difference and can help ease conflicts between oil companies, farmers, and environmental groups.

It is most efficient for laws to be enforced at a state or local level of government while it is more effective for the creation of laws to occur at the federal level to set the standard necessary for the states to meet or surpass in the interest of preserving the country’s natural resources. The benefit of allowing states to create and enforce policies on hydraulic fracturing within their jurisdiction is it can be done so to address the unique geological and environmental conditions of the region while the disadvantage is the political climate of a state may not be sensitive to resource conservation and maintainability, which in effect would prevent necessary legislation from being passed to address these issues. Federal oversight by the EPA is necessary in these instances.

Increased regulation of a business activity has potential to negatively impact economic growth when it results in an increase in fixed and/or production costs and expansion is discouraged in the marketplace. Hundreds of thousands of jobs and billions of dollars in profit are expected to come from the expansion and development of hydraulic fracturing across the country, but with increased regulation in the form of federal oversight by the EPA, the cost of each well would increase and potentially discourage future production (Lustgarten, 2009). A contraction in hydraulic fracturing operations caused by increased regulation would decrease potential economic growth and be counterproductive to the nation's energy goals. Although in the interests of preventing potential groundwater contamination and conserving freshwater resources it may be necessary to enforce more stringent regulations at the federal level, these interests must be balanced with the economic well-being of the country.

Hydraulic fracturing is expanding in range and number of sites across the country and with this expansion comes increased public attention and concern. Claims of groundwater contamination caused by the activity may or may not be true as the correlation cannot be generalized and each case or region needs to be assessed individually to pinpoint the pollutant source if possible. However, the current study being conducted by the EPA in seven counties that examines the activity in it's entirety from water acquisition to wastewater disposal could lead to recognition of risks to ground and surface water quality and reserves that would ultimately trigger the adoption of federal regulations on hydraulic fracturing. The results may turn out to be the opposite, but it will not be determined until the report is released in 2014 for public comment. In the meantime, case studies such as the Pavillion, Wyoming study and *Starh and Starh Cotton Growers* have revealed the potential for a connection between groundwater contamination and hydraulic fracturing and it is known that large withdrawals of water from remote sensitive areas can be detrimental to riparian habitats. Therefore, the need for assessment of environmental and social impacts exists, even if it turns out that only a percentage of hydraulic fracturing operations have and will have adverse effects.

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Appendix A: *Chemicals Used in Hydraulic Fracturing*

Table 1. List of chemicals used as additives in fracking fluid and their function (Chemical Use, 2012).

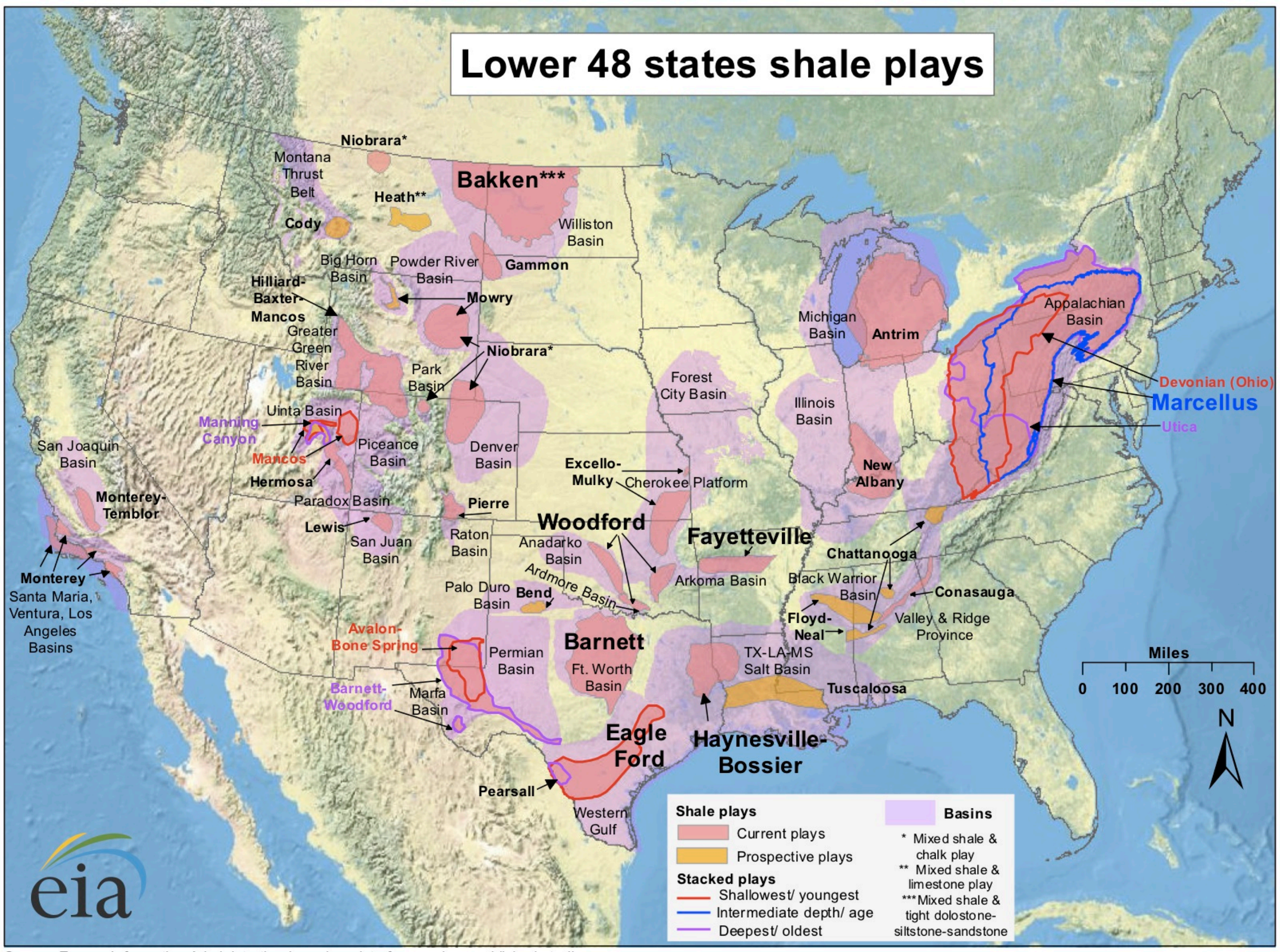
Chemical Name	CAS	Chemical Purpose	Product Function
Hydrochloric Acid	007647-01-0	Helps dissolve minerals and initiate cracks in the rock	Acid
Glutaraldehyde	000111-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	012125-02-9	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	061789-71-1	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Tetrakis Hydroxymethyl-Phosphonium Sulfate	055566-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Ammonium Persulfate	007727-54-0	Allows a delayed break down of the gel	Breaker
Sodium Chloride	007647-14-5	Product Stabilizer	Breaker
Magnesium Peroxide	014452-57-4	Allows a delayed break down the gel	Breaker
Magnesium Oxide	001309-48-4	Allows a delayed break down the gel	Breaker
Calcium Chloride	010043-52-4	Product Stabilizer	Breaker
Choline Chloride	000067-48-1	Prevents clays from swelling or shifting	Clay Stabilizer
Tetramethyl ammonium chloride	000075-57-0	Prevents clays from swelling or shifting	Clay Stabilizer
Sodium Chloride	007647-14-5	Prevents clays from swelling or shifting	Clay Stabilizer
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Methanol	000067-56-1	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Formic Acid	000064-18-6	Prevents the corrosion of the pipe	Corrosion Inhibitor
Acetaldehyde	000075-07-0	Prevents the corrosion of the pipe	Corrosion Inhibitor
Petroleum Distillate	064741-85-1	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Potassium Metaborate	013709-94-9	Maintains fluid viscosity as temperature increases	Crosslinker
Triethanolamine Zirconate	101033-44-7	Maintains fluid viscosity as temperature increases	Crosslinker
Sodium Tetraborate	001303-96-4	Maintains fluid viscosity as temperature increases	Crosslinker
Boric Acid	001333-73-9	Maintains fluid viscosity as temperature increases	Crosslinker
Zirconium Complex	113184-20-6	Maintains fluid viscosity as temperature increases	Crosslinker
Borate Salts	N/A	Maintains fluid viscosity as temperature increases	Crosslinker
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Crosslinker
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Crosslinker

Polyacrylamide	009003-05-8	"Slicks" the water to minimize friction	Friction Reducer
Petroleum Distillate	064741-85-1	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Guar Gum	009000-30-0	Thickens the water in order to suspend the sand	Gelling Agent
Petroleum Distillate	064741-85-1	Carrier fluid for guar gum in liquid gels	Gelling Agent
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for guar gum in liquid gels	Gelling Agent
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Polysaccharide Blend	068130-15-4	Thickens the water in order to suspend the sand	Gelling Agent
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Citric Acid	000077-92-9	Prevents precipitation of metal oxides	Iron Control
Acetic Acid	000064-19-7	Prevents precipitation of metal oxides	Iron Control
Thioglycolic Acid	000068-11-1	Prevents precipitation of metal oxides	Iron Control
Sodium Erythorbate	006381-77-7	Prevents precipitation of metal oxides	Iron Control
Lauryl Sulfate	000151-21-3	Used to prevent the formation of emulsions in the fracture fluid	Non-Emulsifier
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Sodium Hydroxide	001310-73-2	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Hydroxide	001310-58-3	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Acetic Acid	000064-19-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Sodium Carbonate	000497-19-8	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Carbonate	000584-08-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Copolymer of Acrylamide and Sodium Acrylate	025987-30-8	Prevents scale deposits in the pipe	Scale Inhibitor
Sodium Polycarboxylate	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Phosphonic Acid Salt	N/A	Prevents scale deposits in the pipe	Scale Inhibitor

Lauryl Sulfate	000151-21-3	Used to increase the viscosity of the fracture fluid	Surfactant
Ethanol	000064-17-5	Product stabilizer and / or winterizing agent.	Surfactant
Naphthalene	000091-20-3	Carrier fluid for the active surfactant ingredients	Surfactant
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Surfactant
Isopropyl Alcohol	000067-63-0	Product stabilizer and / or winterizing agent.	Surfactant
2-Butoxyethanol	000111-76-2	Product stabilizer	Surfactant

Appendix B: ***Map of Shale Plays in the United States***

The following map displays the shale plays in the United States (excluding Alaska and Hawaii). A shale play is a geographic region targeted for exploration of oil and gas resources. These areas have been determined to have the potential for oil exploration based on geoseismic studies and survey results. As seen in the image, the majority of shale plays are designated as current plays or basins and fewer are designated as prospective plays.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Figure 5. Map of shale plays in the lower forty-eight states of the United States (Lower, 2011).

Appendix C: *Health Effects Associated with Fracking Fluid*

Table 2. Health effects associated with chemicals in fracking fluid as provided by the Wyoming Oil and Gas Conservation Commission and the Endocrine Exchange (Crane-Murdoch, 2011).

Health effects associated with chemicals in fracking fluid*

Chemical	Percent of volume	Skin, eye & sensory organs	Respiratory	Gastrointestinal & liver	Brain & nervous system	Immune	Kidney	Cardiovascular & blood	Carcinogen	Mutagen	Developmental	Reproductive	Endocrine disruptor	Other uses
Diammonium peroxidisulphate	29	■	■	■		■		■						bleach, laboratory cleaning
Distillates (petroleum), hydrotreated light	17	■	■	■	■							■		kerosene
Guar gum	15	■	■			■								food additive
Tetramethylammonium chloride	9	■	■	■	■			■						chemical catalyst
Vinylidene chloride/methylacrylate copolymer	6	Not available												plastic wrap
Methanol	5	■	■	■	■	■	■	■		■	■	■	■	fuel & chemical synthesis (formaldehyde)
1, 2, 3 - Propanetriol	4	■	■	■	■		■	■						sweetener & preservative
2,2`,2"-nitrilotriethanol	2	■	■	■	■	■	■	■	■	■		■	■	chemical manufacturing
Sorbitol	2	■	■	■				■						sweetener & laxative
Sodium tetraborate decahydrate	2	■	■	■	■		■	■			■		■	cleaning products & insecticides
Sodium borate (borax)	1	■	■	■	■		■	■			■		■	cleaning products & insecticides
Acrylamide-sodium 2-acrylamido-2-methyl-1-propanesulfonate	0.9	No health effects												drilling
Ethoxylated branched C7-9, C8-rich alcohols	0.8	■	■											industrial cleaning
Ethoxylated branched C9-11, C10-rich alcohols	0.8	■	■											industrial cleaning
Sodium hydroxide (lye)	0.8	■	■	■										soap & textiles
Bis(hydrogenated tallow alkyl)dimethylammonium bentonite	0.6	■	■			■								various industrial uses
Ethoxylated propoxylated 4-nonylphenol-formaldehyde resin	0.6	■	■	■	■	■	■	■	■	■	■	■		circuit board manufacturing
Heavy aromatic naphtha	0.4	■	■	■	■									gasoline & paint thinner production
Alcohols, C11-14-isoalcs., C13-rich, ethoxylated	0.4	■	■	■										chemical catalyst
Alkylbenzyldimethylammonium chlorides, benzyl-C10-16-	0.4	Not available												various industrial uses
Magnesium silicate hydrate (talc)	0.3	■	■	■	■			■	■					baby powder
Poly(oxy-1,2-ethanediyl)	0.2	■	■	■		■	■							pesticides
Alcohols, C12-13-alkyl, ethoxylated	0.2	■	■	■										chemical catalyst
Alcohol ethoxylate C-10/16 with 6.5 EO	0.2	■	■	■										industrial cleaning
Sodium chloride	0.1	■	■	■	■		■	■	■			■		table salt
Tetrakis(hydroxymethyl)phosphonium sulfate	0.1	■	■	■	■	■	■	■	■	■	■		■	pesticides
Non-crystalline silica	0.1	■	■	■		■								electronics
Boric acid	0.0042	■	■	■	■	■	■	■			■	■	■	insecticides
	100.0%													

*Dependent upon degree and route of exposure.

SOURCES: WYOMING OIL AND GAS CONSERVATION COMMISSION; THE ENDOCRINE DISRUPTION EXCHANGE