Hydraulic fracturing (fracking)

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Key Concepts

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- Oil and gas operators use hydraulic fracturing (fracking) to develop unconventional wells by creating openings in the tiny pore spaces of reservoir rock. Unconventional wells are low-permeability, low-porosity oil and gas reservoirs, such as shales, tight sandstones, and coalbeds.
- During fracking, operators inject a treatment fluid into a well at high pressure to fracture the host rock to stimulate or increase production of oil or gas.
- Fracturing fluids contain additives (such as proppant carriers, friction reducers, and gelling and foaming agents) and propping agents (such as sand).
- Any water produced during fracking must be separated from the oil and gas, stored, and treated, disposed of, or recycled.
- Environmental concerns related to fracking include water consumption, migration of contaminated fluids or stray gases from the wellbore, induced seismicity from the injection of large volumes of water into formations, and spills of hydraulic fracturing fluids or wastewaters.

A well stimulation technique, commonly referred to as "fracking," that is part of a larger process of the development of unconventional oil and gas wells. During hydraulic fracturing, oil and gas operators inject a treatment fluid into an oil or gas well at a pressure high enough to fracture the host rock so as to stimulate or increase the production of oil or gas from a low-permeability reservoir (**Fig. 1**). The coupling of hydraulic fracturing and horizontal drilling has increased oil and gas production in the United States in recent years. Between 2000 and 2015, the proportion of U.S. natural-gas production from hydraulically fractured wells increased from 7% to 67%, while the proportion of U.S. crude oil production from hydraulically fractured wells increased from 2% to 50%. Hydraulic fracturing, however, has also led to environmental concerns such as high water consumption, migration of contaminated fluids or stray gases from the wellbore, induced seismicity related to the perturbation of preexisting faults by the injection of large volumes of water into formations, and spills of hydraulic fracturing fluids or wastewaters. Because hydraulic fracturing applications, chemicals used, amounts of water used, types of geological formations targeted, and methods of hydraulic fracturing have changed over time and vary depending on the basin, the potential for both oil and gas production and environmental impacts varies across the United States. *See also:* **Aquifer (/content/aquifer/045600)**; **Natural gas (/content/natural-gas/444800)**; **Petroleum (/content/petroleum/502600)**; **Petroleum engineering (/content/petroleum-engineering/502700)**

Fig. 1 Hydraulic fracturing operation. [Credit: Mark Engle, U.S. Geological Survey, in Gallegos and Varela, 2015 (https://pubs-usgs-gov.ezproxy.snhu.edu/sir/2014/5131/) (open access)]

Reservoirs

Hydraulic fracturing is generally applied in various oil and gas basins across the United States (**Fig. 2**). Hydraulic fracturing has been used in the United States, since about 1947, initially to fracture vertical wells drilled in "conventional" carbonate reservoirs to increase the production of oil. Hydraulic fracturing has boomed in recent years due to its application in horizontally and directionally drilled wells completed in “continuous” or “unconventional” low-permeability, low-porosity reservoirs, notably shales, tight sandstones, and coalbeds. Directional wellbores deviate from the vertical orientation to intercept a target formation, whereas horizontal wellbores deviate by more than 80% from vertical to follow a near-horizontal path along a formation. **Figure 3** shows an example of the differences between continuous and conventional reservoirs along with horizontal, directional, and vertical wells. Simply stated, continuous oil or gas resources are found in small pores over a large areal expanse of low-permeability, low-porosity reservoir rock. The small pore spaces and their poor connection to each other limit the free flow of oil or gas, but over geologic time, some of the oil or gas is released and travels out of the formation until it becomes trapped and sealed by a geological formation. The discrete accumulations of the trapped oil and gas are considered “conventional” reservoirs and are generally produced using vertical wells without the use of hydraulic fracturing, although it is sometimes implemented to increase production when the flow of oil or gas diminishes in later years. Because the oil or gas is trapped in the tiny pore spaces of the unconventional reservoirs (such as coalbeds, shales, and tight sandstones), hydraulic fracturing is required to create openings in the reservoir rock, allowing for enhanced oil and gas production. *See also:* **Coalbed methane (/content/coalbed-methane/757500)**; **Oil and gas field exploitation (/content/oil-and-gas-field-exploitation/466400)**; **Petroleum geology (/content/petroleum-geology/502900)**; **Sandstone (/content/sandstone/600900)**; **Shale (/content/shale/618400)**

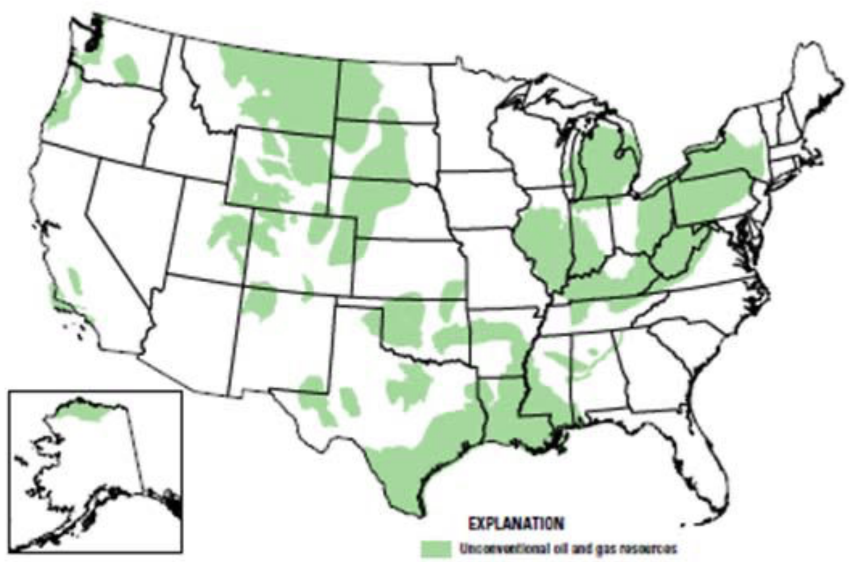

Fig. 2 Areas of unconventional oil and gas resources. [Credit: USGS/Susong et al., 2012 (https://pubs-usgs-gov.ezproxy.snhu.edu/fs/2012/3049/) (open access)]

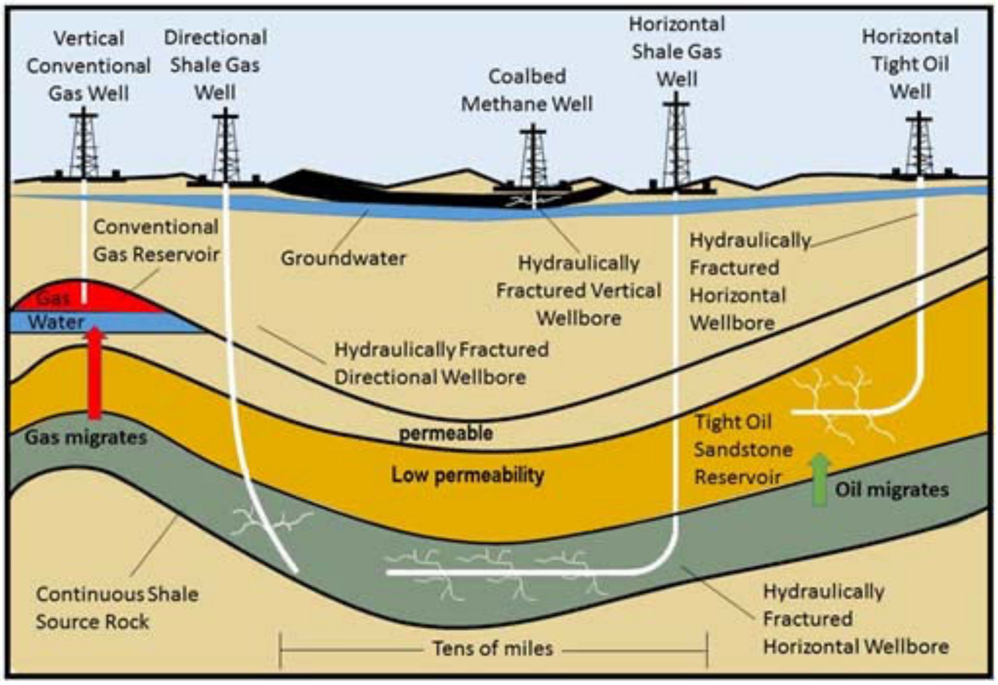

Fig. 3 Unconventional and continuous oil and gas resources. [Modified from Schenk and Pollastro, 2002 (https://pubs-usgs-gov.ezproxy.snhu.edu/fs/fs-0113-01/) (open access)]

Hydraulic fracturing process

Figure 4 is a schematic of the hydraulic fracturing process. Hydraulic fracturing is preceded by drilling, casing, and cementing of a vertical, horizontal, or directional well into the oil or gas reservoir. Hydraulic fracturing can take place in multiple stages consisting of perforating the casing along the target interval of the formation and injecting hydraulic-fracturing treatment fluids containing a proppant (a small, solid particle such as sand that can help keep a fracture open) under high pressure into the well to fracture the reservoir rock. The newly created fractures provide pathways for oil, gas, and water to move out of the formation and into wellbore. Following hydraulic fracturing, production of water, proppant, oil, and (or) gas is produced from the well at the surface. *See also:* **Oil and gas well completion (/content/oil-and-gas-well-completion/466600)**; **Sand (/content/sand/600600)**

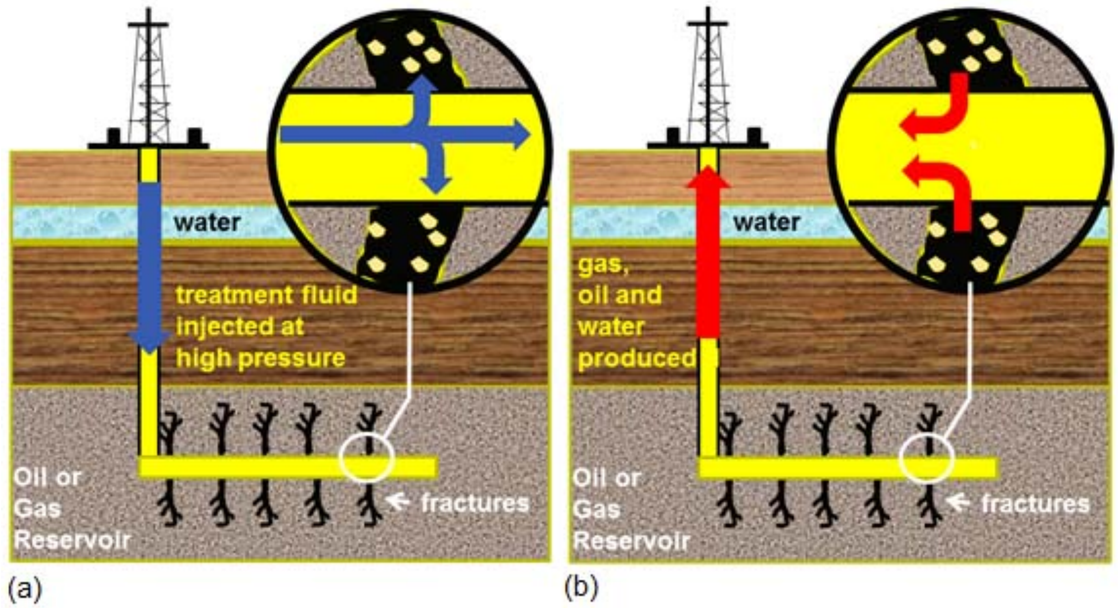

Fig. 4 Hydraulic fracturing. (a) Injection of hydraulic fracturing fluids at high pressure to create fractures in the reservoir rock. (b) The newly opened fractures allow the flow and production of oil, gas, and water once trapped in small pores within the reservoir rock.

Hydraulic fracturing fluids

The amount and composition of water injected for hydraulic fracturing is variable. The source of water used in hydraulic fracturing also differs by location. For example, about 79% of water used to hydraulically fracture the Marcellus Shale in the northeastern United States comes from surface water sources, whereas water used to hydraulically fracture the Barnett Shale in north-central Texas comes from both surface (48%) and groundwater (48%). Generally, more water is used to hydraulically fracture horizontal wells than vertical or directionally drilled wells. Horizontal oil wells drilled between 2011 and 2014 used, on average, about 15,000 m^3, whereas horizontal gas wells used an average of 19,000 m^3. Furthermore, the average water volumes injected per well during hydraulic fracturing vary across the oil- and gas-producing regions in the United States, as shown in **Fig. 5**. The injected hydraulic fracturing fluids are composed of a “base” fluid to which additives and propping agents are mixed; this base fluid is typically water and sometimes oil, foam, or acid. The types of base fluid, additives, and even proppants vary depending on the reservoir properties, such as the hydrocarbon type, pressure, and temperature, as well as the reservoir rock and the desired fracture geometry. Typical additives include chemicals to control microbial activity and reduce friction; carry proppant or control iron precipitation, rust, or scale; dissolve minerals to improve flow; or create specific hydraulic-fracturing treatment-fluid base types, such as foam, slickwater (low-viscosity fluids), or gels. Hydraulic-fracturing base fluids vary across the United States. For example, typically, gels or cross-linked gels (high-viscosity fluids) are used to hydraulically fracture tight-oil formations in the Williston Basin Basin (Montana, the Dakotas, and Saskatchewan), whereas slickwater compositions are typically injected into shale-gas reservoirs in the Appalachian Basin. A recent evaluation of the historical attributes of hydraulic fracturing has shown that injected fluids have varied over time, reflecting the different applications of hydraulic fracturing as shown in **Fig. 6**. Changes in the regulations for reporting of the fluids used in hydraulic fracturing have led to publically available data repositories on websites, such as fracfocus.org (http://fracfocus.org/), operated by the Groundwater Protection Council. *See also:* **Foam (/content/foam/265200)**; **Gel (/content/gel/283800)**

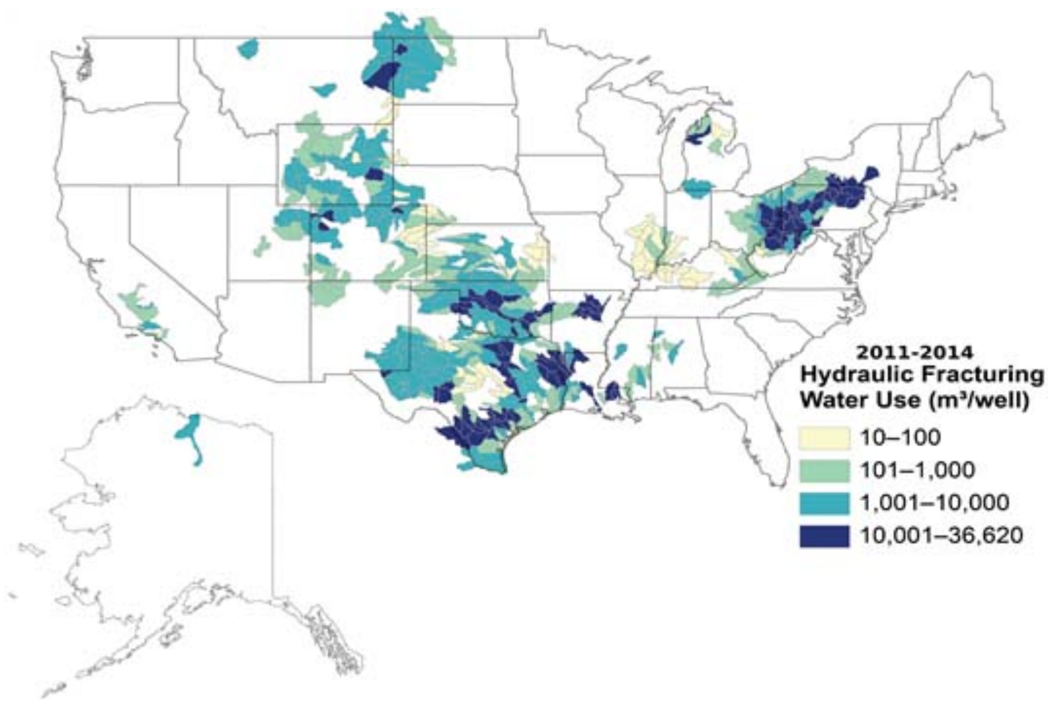

Fig. 5 Average volume of water injected for hydraulic fracturing per hydrologic unit. (From Gallegos et al., 2015 (http://onlinelibrary.wiley.com.ezproxy.snhu.edu/doi/10.1002/2015WR017278/abstract) (open access)]

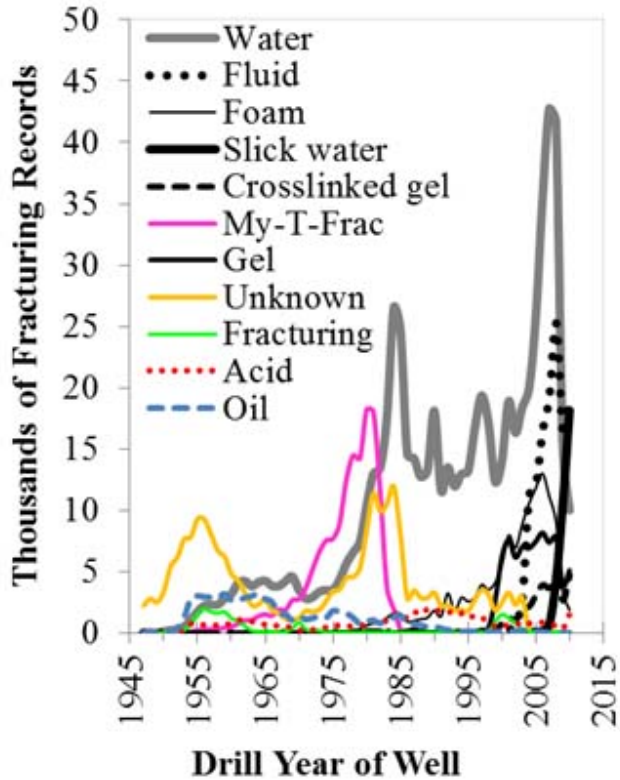

Fig. 6 Number of records of hydraulic fracturing fluid types reported in the IHS Oil Gas Database (IHS, 2011) in the United States from 1947 to 2010. [From Gallegos and Varela, 2015 (https://pubs-usgs-gov.ezproxy.snhu.edu/sir/2014/5131/) (open access)]

Produced water

Water is often produced, along with oil and gas. It is estimated that, in 2012, onshore conventional and unconventional oil and gas wells generated over 20 billion barrels of produced water. The composition and volume of water produced in oil and gas wells and the proportion of injected fluids that flow back to the surface, vary as a function of well age, well location, and the type of reservoir that is being hydraulically fractured. During a period following hydraulic fracturing (known as "flowback"), a portion of the treatment fluid that was injected flows back to the surface. Eventually, the volume of water produced from a fractured well becomes greatly reduced. It is generally accepted that only a portion (5–10%) of the hydraulic fracturing fluids actually flow back to the surface, as the fluids can be "lost" into the formation due to imbibition (absorption) or preferential flow paths. Flowback fluids are generally thought to contain a mixture of the injected hydraulic fracturing fluids and the natural formation water found in the reservoir prior to hydraulic fracturing. The flowback fluids and the natural formation water are referred to collectively as produced waters. Over time, the composition of the produced waters transitions from mostly flowback fluids to that of the natural formation waters. The water continues to be produced along with the oil or gas long after hydraulic fracturing is complete and continues over the life of the well. It should be noted that water can be produced from all oil and gas wells, regardless of whether the well was hydraulically fractured. Produced water is sometimes called "co-produced water" or simply "brine," because it often contains total dissolved solids in excess of seawater. Aside from high total dissolved solids, produced water has been found to contain many other constituents depending on the geological formation, such as:

- Naturally occurring inorganic chemicals, such as those containing barium, manganese, iron, strontium, chloride, bromide, sulfate, sodium, magnesium, calcium, and sometimes ammonium
- Naturally occurring organic compounds, including benzene, toluene, ethylbenzene, xylenes (BTEX), as well as oil and grease
- Naturally occurring radioactive materials (often called NORM), including radium
- Hydraulic fracturing chemicals and their chemical transformation products
- Suspended particles, including a portion of the injected proppant.

More information on the composition of produced waters from both conventional and unconventional wells can be found in the USGS National Produced Waters Geochemical Database (https://eerscmap-usgs-gov.ezproxy.snhu.edu/pwapp). *See also:* **Oil-field waters (/content/oil-field-waters/467000)**; **Radioactive minerals (/content/radioactive-minerals/568700)**

Once the waters are produced from the oil or gas well, they have to be separated from the oil or gas, stored, and treated, disposed, or recycled in another hydraulic fracturing operation. The degree of recycling and reuse in the hydraulic fracturing life cycle is affected by the disposal options, the treatment options, and the costs of treatment, which in turn are affected by the quality of the produced waters and the reuse requirements. In some regions, such as in areas of the Barnett Shale play (formation) in Texas, nearly 95% of the water is disposed of into Class II Underground Injection Control (UIC) disposal wells. Class II UIC wells are those regulated by the U.S. Environmental Protection Agency (EPA) and permitted for the disposal of oil- and gas-related waste fluids. On the other hand, in areas where permitted Class II wells are scarce, such as in areas of the Marcellus Shale play, about 90% of the water is reused in hydraulic fracturing.

Environmental impact

Some concerns about the environmental impacts of hydraulic fracturing are related to both the injected fluids and the produced waters. A 2016 evaluation by the EPA indicated that the following activities were the most likely to affect drinking water: (1) water withdrawals, (2) spills of hydraulic fracturing fluids, chemicals, or produced waters, (3) injection of hydraulic fracturing fluids into groundwater either directly or via leaky wells, (4) escaping of produced waters, gases, or hydraulic fracturing fluids from the wellbore, (5) discharge of inadequately treated wastewater into surface water, and (6) leakage of hydraulic fracturing wastewaters from unlined pits. Additionally, researchers have found that felt earthquakes can be induced as part of the disposal of wastewater process or less commonly from hydraulically fracturing of tight shale formations. It should be noted, however, that there have been hundreds of thousands of injection and extraction activities related to energy resource development, and yet only a small fraction have resulted in noticeable levels of induced seismic events. *See also:* **Induced earthquakes (/content/induced-earthquakes/BR0501151)**; **Seismology (/content/seismology/613300)**

While there is concern over environmental impacts, the EPA noted in a 2016 study on hydraulic fracturing that, because of significant data gaps and uncertainties in the available data, it was not possible to characterize fully the severity of impacts, nor was it possible to calculate or estimate the national frequency of impacts on drinking-water resources from activities in the hydraulic fracturing water cycle. Because hydraulic fracturing often takes place in areas of conventional oil and gas production, it is challenging to discern whether potential changing concentrations of constituents associated with oil and gas production stem from hydraulic fracturing or from conventional oil and gas production or other processes. *See also:* **Water pollution (/content/water-pollution/738900)**

Hydraulic fracturing has greatly improved oil and gas production in the United States. However, like many other energy-production processes, it has prompted concern about potential environmental impacts. Hydraulic fracturing is not a one-size-fits-all technology, and as such, neither is the potential for environmental impacts, which are likely to vary by region, based on specifics of each oil and gas basin. As with all energy resources, there are costs and benefits in the production of oil and gas by hydraulic fracturing, which must be weighed to determine the best course forward for energy resource security and environmental protection. Education regarding the nuances of hydraulic fracturing is essential to improve dialogue among oil and gas production companies, environmental regulators, researchers, and the public, so that the best solutions for our future can be identified.

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Tanya J. Gallegos

Test Your Understanding

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1. Why do petroleum companies perform hydraulic fracking?
2. How does fracking work?
3. Describe the controversies associated with fracking.
4. Critical Thinking: Scientists have linked the disposal of hydraulic-fracturing wastewater to some small earthquakes and tremors. However, the evidence that fracking causes earthquakes is not conclusive. How might scientists increase their understanding of the effect of fracking on seismic events? What difficulties might scientists encounter in doing so?

Related Primary Literature

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Additional Reading

U.S. Environmental Protection Agency, Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States (Final Report), U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/236F, 2016

FracFocus Chemical Disclosure Registry (http://fracfocus.org)

National Academies of Sciences, Engineering, and Medicine: Unconventional Hydrocarbon Roundtable (http://nas-sites.org/uhroundtable)

U.S. Environmental Protection Agency: EPA’s Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources (https://www.epa.gov/hfstudy)

U.S. Geological Survey: Hydraulic Fracturing and Induced Seismicity (https://energy-usgs-gov.ezproxy.snhu.edu/OilGas/UnconventionalOilGas/HydraulicFracturing.aspx)

U.S. Geological Survey: Map of Produced Water Sample Locations (https://eerscmap-usgs-gov.ezproxy.snhu.edu/pwapp)

U.S. Geological Survey: Produced Waters (https://energy-usgs-gov.ezproxy.snhu.edu/EnvironmentalAspects/EnvironmentalAspectsofEnergyProductionandUse/ProducedWaters.aspx)

U.S. Geological Survey: Water-Quality Topics: Hydraulic Fracturing (https://water-usgs-gov.ezproxy.snhu.edu/owq/topics/hydraulic-fracturing)