Concerned Health Professionals of NY

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COMPENDIUM OF SCIENTIFIC, MEDICAL, AND MEDIA FINDINGS DEMONSTRATING RISKS AND HARMS OF FRACKING (UNCONVENTIONAL GAS AND OIL EXTRACTION)

The following excerpts from the Fifth Edition of the Compendium, focused on water contamination, are published in advance of the full report given timely and important consideration of the issue by state officials in Florida.

January 19, 2018

Fracking industry site near Greers Ferry Lake in Quitman, Arkansas in the Fayetteville Shale region.

excerpts from **About this Report**

The Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (the Compendium) is a fully referenced compilation of the evidence outlining the risks and harms of fracking. It is a public, open-access document that is housed on the websites of Concerned Health Professionals of New York (www.concernedhealthny.org) and Physicians for Social Responsibility (www.psr.org).

The four earlier editions of the Compendium have been used and referenced all over the world. The Compendium has been twice translated into Spanish: independently in 2014 by a Madrid-based environmental coalition, followed by an official translation of the third edition, which was funded by the Heinrich Böll Foundation and launched in Mexico City in May 2016.

The Compendium is organized to be accessible to public officials, researchers, journalists, and the public at large. The reader who wants to delve deeper can consult the reviews, studies, and articles referenced. In addition, the Compendium is complemented by a fully searchable, near-exhaustive citation database of peer-reviewed journal articles pertaining to shale gas and oil extraction, the Repository for Oil and Gas Energy Research, that was developed by PSE Healthy Energy and which is housed on its website (http://www.psehealthyenergy.org/site/view/1180).

For this fifth edition of the Compendium, as before, we collected and compiled findings from three sources: articles from peer-reviewed medical or scientific journals; investigative reports by journalists; and reports from or commissioned by government agencies. Peer-reviewed articles were identified through databases such as PubMed and Web of Science, and from within the PSE Healthy Energy database. The studies and investigations referenced in the dated entries catalogued in Compilation of Studies & Findings are current through December 2017.

About Concerned Health Professionals of New York

Concerned Health Professionals of New York (CHPNY) is an initiative by health professionals, scientists, and medical organizations for raising science-based concerns about the impacts of fracking on public health and safety. CHPNY provides educational resources and works to ensure that careful consideration of science and health impacts are at the forefront of the fracking debate. http://concernedhealthny.org

About Physicians for Social Responsibility

Working for more than 50 years to create a healthy, just, and peaceful world for both present and future generations, Physicians for Social Responsibility (PSR) uses medical and public health expertise to educate and advocate on urgent issues that threaten human health and survival, with the goals of reversing the trajectory towards climate change, protecting the public and the environment from toxic chemicals, and addressing the health consequences of fossil fuels. PSR was founded by physicians concerned about nuclear weapons, and the abolition of nuclear weapons remains central to its mission.

excerpts from **Emerging Trends**

Emerging Trend: **Fracking and the disposal of fracking waste threaten drinking water.**

Cases of drinking water sources contaminated by drilling and fracking activities, or by associated waste disposal, are now proven. The U.S. Environmental Protection Agency (EPA)'s assessment of fracking's impacts on drinking water resources confirmed specific instances of water contamination caused by drilling and fracking-related activities and identified the various pathways by which this contamination has occurred: spills; discharge of fracking waste into rivers and streams; and underground migration of chemicals, including gas, into drinking water wells. Independently, researchers working in Texas found 19 different fracking-related contaminants—including cancer-causing benzene—in hundreds of drinking water samples collected from the aquifer overlying the heavily drilled Barnett Shale, thereby documenting widespread water contamination. In Pennsylvania, a solvent used in fracking fluid was found in drinking water wells near drilling and fracking operations known to have well casing problems. In California, state regulators admitted that they had mistakenly allowed oil companies to inject drilling wastewater into aquifers containing clean, potable water. A 2017 study found that fracking wastewater discharged to rivers and streams through treatment plants created dozens of brominated and iodinated disinfection byproducts that are particularly toxic and "raise concerns regarding human health." As we go to press, researchers report on the discovery of opportunistic, pathogenic bacteria in fracking-impacted water wells in Texas and raise questions about fracking's effects on the microbial ecology of aquifers.

Emerging Trend: **Fracking in Florida presents many unknowns.**

Gas and oil drilling in Florida, now only a minor industry, is currently concentrated in two areas: the western Panhandle near Pensacola and the Everglades area of southwest Florida. So far, fracking has been used at least once—in 2013 at a test well located in the Corkscrew Swamp Sanctuary near Naples in Collier County. The Texas company that fracked this well, using high-pressure acid fracturing techniques to dissolve the bedrock, received a cease and desist order from the Florida Department of Environmental Protection. Renewed interest in oil and gas exploration in Florida has prompted public debate about fracking and whether to promulgate state regulations or prohibit it outright.

Florida has more available groundwater than any other state; it is the drinking water source for 93 percent of Florida's population. Groundwater is also pumped to irrigate crops and provide frost protection to winter crops. Most of this water is held in the Floridan Aquifer, which extends across the entire peninsula and into parts of Georgia, Alabama, and South Carolina. This aquifer provides drinking water to ten million people in both rural and urban communities, including residents of several major cities: Gainesville, Jacksonville, Orlando, Tallahassee, and Tampa. Overlain by smaller, shallower aquifers in southern Florida, it is a highly permeable, highly interconnected subterranean system, with water moving rapidly in multiple directions through massive shelves of limestone, which represent the dissolved shells and fossilized skeletons of prehistoric marine organisms. Honeycombed with pores, fissures, joints, and caves, the

underground terrain of the Floridan Aquifer resembles a vast, brittle, sponge partly covered with sand and clay. Springs and sinkholes are common.[1, 2]

It is not known whether fracking in Florida could induce sinkholes to open up or whether alterations in underground pressures could cause springs to go dry. Certainly, Florida's porous geology makes it vulnerable to groundwater contamination. Crumbly, soluble limestone offers pathways for contaminants spilled on the surface to travel deep into the aquifer, where they can be dispersed over great distances by the aquifer's river-like currents. A 2003 experiment with a dye tracer showed the special susceptibility of Florida's groundwater to potential contamination: within a few hours, the red dye traveled through the aquifer a distance (330 feet) that researchers had presumed would take days.[3]

Compounding these risks, Florida's exposure to hurricanes makes it vulnerable to spills of fracking-related chemicals. In August 2017, flooding from Hurricane Harvey shut down fracking sites in Texas and triggered 31 separate spills at wells, storage tanks and pipelines.

As of early 2018, it is unclear where Florida would send any potential fracking wastewater for treatment and/or for underground injection. Florida currently injects other types of liquid waste into disposal wells that are located above, rather than below, oil- and gas-producing zones. The injection of fracking waste in these same shallower layers may make earthquakes less likely than, for example, in Oklahoma (where it is injected into deep formations), but it would also locate that waste closer to the aquifers, which are poorly mapped. To undertake the necessary study to determine how securely Florida's geological formations could contain wastewater from drilling and fracking operations and protect drinking water would be, in the words of two geophysicists, "a monumental task requiring full-time work…for decades."[4] There are reasons to be concerned. In South Florida in the 1990s, 20 stringently regulated disposal wells failed and leaked sewage waste into the Upper Floridan Aquifer, a potential future source of drinking water for Miami.[5]

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[1] Johnson, R. H., & Bush, P. W. (2013, September 4). *Summary of the hydrology of the Floridan Aquifer System in Florida and in parts of Georgia, South Carolina, and Alabama.* U.S. Geological Survey Professional Paper 1403-A. Retrieved from https://sofia.usgs.gov/publications/papers/pp1403a/

[2] Tihansky, A. B., & Knochenmus, L. A. (2001, February 13). *Karst features and hydrogeology in west-central Florida. U.S.* Geological Survey Water-Resources Investigations Report 01-4011. Retrieved from https://water.usgs.gov/ogw/karst/kigconference/abt_karstfeatures.htm

[3] Miami-Dade County Wellfield Technical Work Group. (2017, July 31). *Final Report.* Retrieved from http://ecmrer.miamidade.gov:8080/reports/WellfieldTechnicalWorkgroupReportJuly2017.pdf

[4] Russo, R., & Screaton, E. (2016, May 9). Should Florida 'frack' its limestone for oil and gas? Two geophysicists weigh in. *University of Florida News.* Retrieved from http://news.ufl.edu/articles/2016/05/should-florida-frack-its-limestone-for-oil-and-gas-two-geophysicists-weigh-in.php

[5] Lustgarten, A. (2012, June 21). Injection wells: the poison beneath us. *ProPublica.* Retrieved from: https://www.propublica.org/article/injection-wells-the-poison-beneath-us

excerpt from **Compilation of Studies & Findings**

Water contamination

Substantial evidence shows that drilling and fracking activities, and associated wastewater disposal practices, inherently threaten groundwater and have polluted drinking water sources, as confirmed by the U.S. Environmental Protection Agency's 2016 final report on the impacts of fracking on the nation's drinking water. Repudiating industry claims of risk-free fracking, studies from across the United States present irrefutable evidence that groundwater contamination occurs as a result of fracking activities and is more likely to occur close to well pads. In Pennsylvania alone, the state has determined that more than 300 private drinking water wells have been contaminated or otherwise impacted as the result of drilling and fracking operations over an eight-year period. As determined by the U.S. Agency for Toxic Substances and Disease Registry, the chemical contamination of some private water wells in Dimock, Pennsylvania posed demonstrable health risks, rendering the water unsuitable for drinking.

Evidence on instances and pathways of water contamination exist even though scientific inquiry is impeded by industry secrecy and regulatory exemptions. The 2005 Energy Policy Act exempts hydraulic fracturing from key provisions of the Safe Drinking Water Act. As a result, fracking chemicals have been protected from public scrutiny as "trade secrets." The oil and gas sector is the only U.S. industry permitted to inject known hazardous materials near, or directly into, underground drinking water aquifers. At the same time, in most states where fracking occurs, routine monitoring of groundwater aquifers near drilling and fracking operations is not required, nor are companies compelled to fully disclose the identity of chemicals used in fracking fluid, their quantities, or their fate once injected underground.

Nevertheless, of the more 1,000 chemicals that are confirmed ingredients in fracking fluid, an estimated 100 are known endocrine disruptors, acting as reproductive and developmental toxicants. Adding to this mix are heavy metals, radioactive elements, brine, and volatile organic compounds, which occur naturally in deep geological formations and which can be carried up from the fracking zone with the flowback fluid. As components of the fracking waste stream, these toxic substances also pose threats to surface water and groundwater. A 2017 study found that spills of fracking fluids and fracking wastewater are common, documenting 6,678 significant spills occurring over a

period of nine years in four states alone. In these states, between 2 and 16 percent of wells report spills each year. About 5 percent of all fracking waste is lost to spills, often during transport. Spills and intentional discharges of fracking waste into surface water have profoundly altered the chemistry and ecology of streams throughout entire watersheds, increasing downstream levels of radioactive elements, heavy metals, endocrine disruptors, toxic disinfection byproducts, and acidity, and decreasing aquatic biodiversity and populations of sensitive fish species, such as brook trout. New studies documenting changes in the bacterial flora in groundwater following drilling and fracking operations represent an emerging area of concern.

- December 11, 2017 – A report by the *Texas Observer* investigated groundwater depletion by fracking operations in west Texas at the southern edge of the Ogallala Aquifer. Groundwater conservation districts lack legal financial resources to restrict groundwater pumping or even compel metering on water wells that would monitor exactly how much water is pumped. In Howard County alone, water used for fracking is now believed to constitute about 20 percent of average annual water use.[6]

- November 16, 2017 – The 2005 Energy Policy Act prohibited the U.S. Environmental Protection Agency from regulating fracking under the Safe Drinking Water Act and from requiring that operators disclose their chemicals. According to an investigation by *InsideClimate News,* the scientific study that justified this provision (which is widely known as the Halliburton loophole) was the subject of a whistleblower complaint. The study was also disavowed by its authors, who said the conclusion of the report—that fracking posed no risk to groundwater—was not supported by the evidence. These authors removed their names from the final document. Interviewed for the story, one of these authors said that the belief that fracking was safe for water was a foregone conclusion at the EPA under George W. Bush. "What we would have said in the conclusion is that there is some form of risk from hydraulic fracturing to groundwater. How you quantify it would require further analyses, but, in general, there is some risk."[7]

- November 9, 2017 – As part of a preliminary study, a Texas team assessed the groundwater microbiome in a rural area of southern Texas where farming and fracking co-exist. Each of the sampled water wells had a unique community of microorganisms living in the water. The dominant bacteria were denitrifying species that transform nitrates into gaseous nitrogen or those that break apart hydrocarbon molecules. Earlier studies have postulated that fracking can alter the chemical composition of groundwater and change the species composition of the microbial communities living within it. The results of this study "do not provide a definitive link between [fracking] or agricultural activities and the groundwater microbiome; however, they do provide a baseline

[6] Collins, C. (11 December, 2017). Big spring vs. big oil. *Texas Observer.* Retrieved from https://www.texasobserver.org/big-spring-vs-big-oil/

[7] Banerjee, N. (16 November, 2017). Industrial strength: How the U.S. government hid fracking's risks to drinking water. *Inside Climate News.* Retrieved from https://insideclimatenews.org/news/16112017/fracking-chemicals-safety-epa-health-risks-water-bush-cheney

measurement of bacterial diversity and quantity in groundwater located near these anthropogenic activities."[8]

- November 1, 2017 – In Oklahoma, horizontal wells can be fracked within 600 feet of older, vertical wells that do not use fracking. Oil companies in Oklahoma that extract oil using conventional, vertical wells alleged that hundreds of their wells have been inundated by fluids from nearby horizontal wells that use high-volume hydraulic fracturing, as documented by *E & E News*. Vertical well operators have raised questions about whether these "frack hits" from nearby horizontal wells that have flooded their own wells have also reached the groundwater. "Logic said it will impact [groundwater]," said one driller. "There was water coming up out of the ground. There was enough pressure to bring it to the surface." Small operators of vertical wells, organized as the Oklahoma Energy Producers Alliance (OEPA), released a study estimating that, in just one county alone, there were 400 cases of frack fluid from horizontal wells flooding nearby vertical wells.[9, 10]

- October 31, 2017 – A study of fracking wastewater disposed of in rivers and streams found that chemical contaminants in the waste were transformed into more toxic substances when they chemically reacted with chlorinated compounds discharged from downstream drinking water treatment plants. The result was dozens of different, brominated and iodinated disinfection byproducts (DBPs). A lab analysis found that all were highly toxic to mammalian cells. Conventional water treatment practices do not remove these chemicals. "It is likely that in oil- and gas-impacted drinking water sources, iodo-phenolic DBPs could form at significant levels, particularly in cases in which chloramination is used."[11]

- October 18, 2017 – Researchers concerned about reports of skin rashes, gastrointestinal distress and breathing problems among people who live near drilling and fracking operations found increased levels of certain harmful bacteria in private water wells impacted by fracking in the Barnett and Eagle Ford Shale areas in Texas. These results raise questions about whether drilling and fracking activities could alter the communities of microorganisms in groundwater in ways that pose health risks. According to one of the lead authors of the study, interviewed in the *Dallas News*, "the potential contribution of

[8] Santos, I. C., Martin, M. S., Reyes, M. L., Carlton Jr., D. D., Stigler-Granados, P., Valerio, M. A., … & Schug, K. A. (2017). Exploring the links between groundwater quality and bacterial communities near oil and gas extraction activities. *Science of the Total Environment. 618,* 165-173. doi: 10.1016/j.scitotenv.2017.10.264

[9] Soraghan, M. (1 November, 2017). Now it's oilmen who say fracking could harm groundwater. *E&E News.* Retrieved from https://www.eenews.net/stories/1060065209

[10] OEPA. (2017, September 14). Are vertical wells impacted by horizontal drilling? A study of Kingfisher County. Retrieved from https://www.eenews.net/assets/2017/10/27/document_pm_07.pdf

[11] Liberatore, H. K., Plewa, M. J., Wagner, E. D., VanBriesen, J. M., Burnett, D. B., Cizmas, L. H., & Richardson, S. D. (2017). Identification and comparative mammalian cell cytotoxicity of new iodo-phenolic disinfection byproducts in chloraminated oil and gas wastewaters. *Environmental Science & Technology Letters, 4*(11), 475–480. doi: 10.1021/acs.estlett.7b00468

these microbes to these health effects is probably understudied, underappreciated, unknown."[12, 13]

- August 3, 2017 – Due to permitting errors and a mix-up in records 30 years ago, wastewater from drilling operations in California was mistakenly injected directly into drinking water aquifers. Six years after the discovery of the problem, 175 wastewater wells that were illegally injecting into protected aquifers have been shut down, but hundreds more are still operating. An investigation by KQED Science revealed that California state water regulators know very little about the actual impact of those injections on the state's drinking water reserves. "State water regulators say they hope to figure out what the larger impacts have been in years ahead, but have no set timeline. The risk is that they've allowed oil companies to contaminate drinking water aquifers to such an extent that Californians may have permanently lost those sources of fresh water."[14] An earlier investigation by KQED Science revealed that illegal wastewater wells would still be allowed to operate while the necessary paperwork was filed.[15]

- July 12, 2017 – In western Pennsylvania, a team of researchers looked at sediments in the Conemaugh River watershed downstream of a treatment plant that was specially designed to treat fracking wastewater. The researchers found contamination for many miles downstream with fracking-related chemicals that included radium, barium, strontium, and chloride, as well as endocrine-disrupting and carcinogenic compounds. The peak concentrations were found in sediment layers that had been deposited during the years of peak fracking wastewater discharge. Elevated concentrations of radium were detected as far as 12 miles downstream of the treatment plant and were up to 200 times greater than background. Some stream sediment samples were so radioactive that they approached levels that would, in some U.S. states, classify them as radioactive waste and necessitate special disposal.[16, 17]

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[12] Martin, M. S., Santos, I. C., Carlton Jr. D. D., Stigler-Granados, P., Hildenbrand, Z. L., & Schug, K. A. (2017). Characterization of bacterial diversity in contaminated groundwater using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. *Science of the Total Environment.* Advance online publication. doi: 10.1016/j.scitotenv.2017.10.027

[13] Mosier, J. (2017, December 1). UTA research finds dangerous bacteria in groundwater near Texas gas drilling sites. *Dallas News.* Retrieved from https://www.dallasnews.com/business/energy/2017/12/01/uta-study-finds-dangerous-bacteria-groundwater-near-texas-gas-drilling-sites

[14] Sommer, L. (17 August, 2017). How much drinking water has California lost to oil industry waste? No one knows. *KQED Science.* Retrieved from https://ww2.kqed.org/science/2017/08/03/how-much-drinking-water-has-california-lost-to-oil-industry-waste-no-one-knows/

[15] Sommer, L. (17 January, 2017). California says oil companies can keep dumping wastewater during state review. *KQED Science.* Retrieved from https://ww2.kqed.org/science/2017/01/17/california-says-oil-companies-can-keep-dumping-wastewater-during-state-review/

[16] Burgos, W. D., Castillo-Meza, L., Tasker, T. L., Geeza, T. J., Drohan, P. J., Liu, X., … Warner, N. R. (2017). Watershed-scale impacts from surface water disposal of oil and gas wastewater in Western Pennsylvania. *Environmental Science & Technology, 51*(15), 8851–8860. doi: 10.1021/acs.est.7b01696

[17] Johnston, I., (2017, July 12). Fracking can contaminate rivers and lakes with radioactive material, study finds. *The Independent*. Retrieved from http://www.independent.co.uk/news/science/fracking-dangers-environment-water-damage-radiation-contamination-study-risks-a7837991.html

- May 31, 2017 – A U.S. Geological Survey team sampled drinking water wells near drilling and fracking sites in the Eagle Ford, Fayetteville, and Haynesville Shale basins and found detectable levels of methane and benzene. However, the sources of these contaminants were unclear, and, given the slow travel time of groundwater, "decades or longer may be needed to fully assess the effects of potential subsurface and surface releases of hydrocarbons on the wells."[18]

- May 1, 2017 –A study examining the impacts of drilling and fracking operations on public drinking water in Pennsylvania found evidence of contamination when drinking water source intakes were located within 1 kilometer (.62 miles) of a well pad. Noting that many Pennsylvanians living near well pads drink bottled water, the authors concluded, "our results suggest that these perceived risks may in fact be justified."[19] [See also entry below for October 13, 2016]

- April 19, 2017 – Using data from the South Coast Air Quality Monitoring District, a team of researchers in California compared chemicals used in fracking operations with those used in the routine maintenance of conventional oil and gas wells where chemicals are used to aid in drilling, for corrosion control, to clean the well bore, and to enhance oil recovery. They found significant overlap in both the types and amounts of chemicals used. "The results of this study indicate regulations and risk assessments focused exclusively on chemicals used in well-stimulation activities may underestimate potential hazard or risk from overall field chemical-use. . . . Our analysis shows that hydraulic fracturing is just one of many applications of hazardous chemicals on oil and gas fields."[20]

- April 5, 2017 – A three-year study in West Virginia led by scientists at Duke University assessed surface water and groundwater drawn from drinking water wells both before and after drilling and fracking began in the region. Using geochemical techniques, including a suite of tracers that help distinguish naturally occurring methane and salts from those contained in fracking fluid, the researchers found no evidence of groundwater contamination. They did, however, document threats to surface water from fracking wastewater spills.[21] In an accompanying statement, the researchers noted, "What we

[18] McMahon, P., Barlow, J. R. B., Engle, M. A., Belitz, K., Ging, P. B., Hunt, A. G., … & Kresse, T. M. (2017). Methane and benzene in drinking-water wells overlying the Eagle Ford, Fayetteville, and Haynesville Shale hydrocarbon production areas. *Environmental Science & Technology, 51*(12), 6727-6734. doi: 10.1021/acs.est.7b00746

[19] Hill, E., & Ma, L. (2017). Shale gas development and drinking water quality. *American Economic Review: Papers & Proceedings, 107*(5), 522–525. doi: 10.1257/aer.p20171133

[20] Stringfellow, W. T., Camarillo, M. K., Domen, J. K., & Shonkoff, S. B. C. (2017) Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development. *PLoS ONE, 12*(4), e0175344. doi: 10.1371/journal.pone.0175344

[21] Harkness, J. S., Darrah, T. H., Warner, N. R., Whyte, C. J., Moore, M. T., Millot, R., … Vengosh, A. (2017). The geochemistry of naturally occurring methane and saline groundwater in an area of unconventional shale gas development. *Geochimica et Cosmochimica Acta, 208,* 302–334. doi: 10.1016/j.gca.2017.03.039

found in the study area in West Virginia after three years may be different from what we see after 10 years because the impact on groundwater isn't necessarily immediate."[22]

- Feb 21, 2017 – Between 2005 and 2014, researchers surveyed spill record data from drilling and fracking operations in four states (Colorado, New Mexico, North Dakota, and Pennsylvania). During these nine years, they documented 6,678 total spills, or about five spills each year for every 100 wells. Between 2 and 16 percent of wells reported a spill each year. Half of all spills were related to storage and transport of fluids through flow lines. The authors also found that the chances of spills are highest during the first three years of a well's life and that spill reporting requirements differ markedly from state to state, making impossible the task of comparing states or creating a national picture.[23, 24]

- December 14, 2016 – To better understand the impact of fracking fluid spills on aquatic animals, scientists at the University of Alberta exposed rainbow trout in laboratory tanks to various dilutions of fracking fluids. Even at very low exposures, the fish experienced adverse effects, including alterations in liver functioning and disruption of hormonal pathways. [This study was partially funded by industry.][25]

- December 13, 2016 –The final version of the EPA's six-year, $29 million study on the impacts of hydraulic fracturing on the nation's drinking water confirmed that fracking activities have caused contamination of water resources in the United States, and it traces the various routes by which drinking water can be impacted by fracking. Documented cases of drinking water contamination have resulted from spills of fracking fluid and fracking wastewater; discharge of fracking waste into rivers and streams; and underground migration of fracking chemicals, including gas, into drinking water wells. Depletion of aquifers caused by water withdrawals has created other impacts.[26, 27, 28, 29]

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[22] Lucas, T. (2017, April 24). West Virginia groundwater not affected by fracking, but surface water is. Duke University press release. Retrieved from: https://nicholas.duke.edu/about/news/west-virginia-groundwater-not-affected-fracking-surface-water

[23] Patterson, L., Konschnik, K., Wiseman, H., Fargione, J., Maloney, K. O., Kiesecker, J., … Saiers, J. E. (2017). Unconventional oil and gas spills: Risks, mitigation priorities and states reporting requirements. *Environmental Science & Technology, 51*(5), 2563–2573. doi: 10.1021/acs.est.05749

[24] Kusnetz, N. (2017, February 21). Fracking well spills poorly reported in most top-producing states, study finds. *InsideClimate News.* Retrieved from: https://insideclimatenews.org/news/21022017/fracking-spills-north-dakota-colorado

[25] He, Y., Folkerts, E. J., Zhang, Y., Martin, J. W. Alessi, D. S., & Goss, G. G. (2017). Effects on biotransformation, oxidative stress, and endocrine disruption in rainbow trout (*Oncorhynchus mykiss*) exposed to hydraulic fracturing flowback and produced water. *Environmental Science & Technology, 51*(2), 940-947. doi: 10.1021/acs.est.6b04695

[26] U.S. EPA. (2016). *Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States.* U.S. Environmental Protection Agency, Washington, DC, EPA-600-R-16-236Fa. Retrieved from https://www.epa.gov/hfstudy

[27] U.S. EPA. (2016). *Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States* (Appendices). U.S. Environmental Protection Agency, Washington, DC, EPA-600-R-16-236Fb. Retrieved from https://www.epa.gov/hfstudy

[28] U.S. EPA. (2016). *Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States* (Executive Summary). U.S. Environmental Protection Agency, Washington, DC, EPA-600-R-16-236ES. Retrieved from https://www.epa.gov/hfstudy

The final EPA report details the problem of fracking-related drinking water contamination in three communities—Pavillion, Wyoming; Dimock, Pennsylvania; and Parker County, Texas.[30] Summing up the report, then-EPA Deputy Administrator Tom Burke said in a statement to *American Public Media*, "We found scientific evidence of impacts to drinking water resources at each stage of the hydraulic fracturing cycle."[31] [See also the entry for June 5, 2015, which describes the contents of the 2015 draft report.]

- December 1, 2016 – According to a review paper that examines the potential environmental impacts of oil and gas wastewater, about 5 percent of fracking waste is accidentally or illegally spilled. Almost all of the rest is transported off site and injected into disposal wells that are drilled into porous geological formations. In North Dakota's Bakken Shale, disposal wells are located within miles of the well pad, and the wastewater can travel there via pipeline. In Pennsylvania's Marcellus Shale, drilling activity exceeds the capacity for disposal of waste in local wells and must be trucked out of state.[32]

- November 4, 2016 – A critical review of potential routes of water contamination from drilling and fracking operations in the Bakken Shale noted that the high salinity of fracking wastewater minimizes its recycling options and thus contributes to the need for disposal wells. Transportation of large volumes of waste to these wells, via truck or pipeline, presents opportunities for large spills that can threaten groundwater.[33]

- October 16, 2016 – A team of scientists led by researchers at the Lawrence Berkeley National Laboratory evaluated chemicals used for fracking in California oil fields. Chemical additives included large amounts and a wide variety of solvents, as well as other toxic substances, including biocides and corrosion inhibitors.[34]

- October 14, 2016 – One of the first studies to investigate the impacts of fracking on the ecology of streams found that fracking "has the potential to alter aquatic biodiversity and

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[29] Tong, S., & Scheck, T. (30 November, 2016). EPA's late changes to fracking study downplay risk of drinking water pollution. *Marketplace.org.* Retrieved from https://www.marketplace.org/2016/11/29/world/epa-s-late-changes-fracking-study-portray-lower-pollution-risk

[30] U.S. Environmental Protection Agency Science Advisory Board. (2016, August 11). *SAB review of the EPA's draft assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources.* EPA-SAB-16-005. Retrieved from https://yosemite.epa.gov/sab/sabproduct.nsf/LookupWebReportsLastMonthBOARD/BB6910FEC10C01A18525800C00647104/$File/EPA-SAB-16-005+Unsigned.pdf

[31] Scheck, T. & Tong, S. (2016, December 13). EPA reverses course, highlights fracking contamination of drinking water. *APM Reports.* Retrieved from https://www.apmreports.org/story/2016/12/13/epa-fracking-contamination-drinking-water

[32] Konkel, L. (2016). Salting the earth: The environmental impact of oil and gas wastewater spills. *Environmental Health Perspectives, 124*(12), A230-A235. doi: 10.1289/ehp.124-A230

[33] Shrestha, N., Chilkoor, G., Wilder, J., Gadhamshetty, V., & Stone, J. J. (2016). Potential water resource impacts of hydraulic fracturing from unconventional oil production in the Bakken shale. *Water Research, 108,* 1-24. doi: 10.1016/j.watres.2016.11.006

[34] Stringfellow, W. T., Camarillo, M. K., Domen, J. K., Sandelin, W. L., Varadharajan, C., Jordan, P. D., & … Birkholzera, J. T. (2017). Identifying chemicals of concern in hydraulic fracturing fluids used for oil production *Environmental Pollution, 220,* Part A, 413-420. doi: 10.1016/j.envpol.2016.09.082

methyl mercury concentrations at the base of food webs." The researchers sampled 27 remotely-located streams in the Marcellus Shale basin of Pennsylvania where drilling and fracking is taking place. They showed that methyl mercury levels in stream sites where fracking occurs were driven upwards by higher acidity and lower numbers of macroinvertebrates. In streams with the highest numbers of fracking fluid spills, "fish diversity was nil," and in some cases, there were no fish at all, including in streams previously classified as high-quality brook trout habitat. "Fracking and flowback fluids can contain various highly acidic agents, organic and inorganic compounds, and even Hg [mercury]. The flowback fluids can reach nearby streams through leaking wastewater hoses, impoundments, and lateral seepage and blowouts, as well as by backflow into the wellhead. Flowback water reaching streams can…decrease aquatic biodiversity. . . .Lowered stream pH increases Hg solubility, leading to increased bioaccumulation in food webs."[35]

- October 13, 2016 – Researchers at Pennsylvania State University and Ohio State University combined GIS data on drilling and fracking activities in Pennsylvania and Ohio with household data on bottled water purchases. They found that yearly household purchases of bottled water increased as local drilling and fracking intensity increased. This "averting behavior" is a measure of perceived risk. In 2010, averting-behavior expenditures in the form of bottle water purchases by people living in Pennsylvania's shale counties totaled $19 million.[36] [A subsequent study suggests that those engaged in drinking-water averting behaviors in Pennsylvania have evidence-based reasons to be concerned. See entry above, for May 1, 2017.]

- September 22, 2016 – Using the agency's list of 1076 chemicals that have reported use as ingredients in hydraulic fracturing fluid, EPA scientists developed a framework to analyze and rank subsets of chemicals in order to better understand which fracking-related chemicals pose the greatest risk to drinking water. Their model collates multiple lines of evidence. For example, data on inherent toxicity are combined with data on occurrence and propensity for environmental transport. In the absence of local data on actual human exposures, this model can serve as a qualitative metric to "identify chemicals that may be more likely than others to impact drinking water resources."[37]

- September 16, 2017 – A reconnaissance analysis of groundwater in the Eagle Ford Shale region in southern Texas found sporadic detections of multiple volatile organic compounds and dissolved gas, providing evidence that "groundwater quality is potentially being affected by neighboring [drilling and fracking] activity, or other

[35] Grant, C. J., Lutz, A. K., Kulig, A. D., & Stanton, M. R. (2016). Fracked ecology: Response of aquatic trophic structure and mercury biomagnification dynamics in the Marcellus Shale Formation. *Ecotoxicology, 25,* 1739–1750. doi: 10.1007/s10646-016-1717-8

[36] Wrenn, D. H., Klaiber, H. A., & Jaenicke, E. C. (2016). Unconventional shale gas development, risk perceptions, and averting behavior: evidence from bottled water purchases. *Journal of the Association of Environmental and Resource Economists, 3*(4), 770-817. doi: 10.1086/688487

[37] Yost, E. E., Stanek, J., & Burgoon, L. D. (2016). A decision analysis framework for estimating the potential hazards for drinking water resources of chemicals used in hydraulic fracturing fluids. *Science of the Total Environment, 574,* 1544–1558. doi: 10.1016/j.scitotenv.2016.08.167

anthropogenic activities, in an episodic fashion." The authors called for a more extensive investigation of possible groundwater contamination in the Eagle Ford basin.[38, 39]

- July 11, 2016 – An interdisciplinary team led by University of Colorado researchers found methane in 42 water wells in the intensely drilled Denver-Julesburg Basin where high volume, horizontal fracking operations began in 2010. By examining isotopes and gas molecular ratios, the researchers determined that the gas contaminating these wells was thermogenic in origin, rather than microbial, and therefore had migrated up into the groundwater from underlying oil- and gas-containing shale. The steady rate of well contamination over time—two cases per year from 2001 to 2014—suggests that well failures, rather than the process of hydraulic fracturing itself, was the mechanism that created migration pathways for the stray gas to reach drinking water sources. Of the 42 affected wells, 11 had already been identified by state regulators as suffering from "barrier failures."[40] Duke University geochemist Avner Vengosh, who was not an author of the paper, commented on the study in an accompanying article in *Inside Climate News*: "The bottom line here is that industry has denied any stray gas contamination: that whenever we have methane in a well, it is always preexisting. The merit of this is that it's a different oil and gas basin, a different approach, and it's saying that stray gas could happen." In this same article, *Inside Climate News* reported that national standards for well construction do not exist nor are there laws governing the type of cement that is used to seal the wellbore and prevent leaks.[41]

- May 24, 2016 – The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) conducted a public health evaluation using groundwater data gathered in 2012 by the U.S. Environmental Protection Agency (EPA) from 64 private drinking water wells in Dimock, Pennsylvania where natural gas drilling and fracking activities began in 2008 and where residents began reporting problems with their water shortly thereafter. The agency found that water samples collected from 27 Dimock wells contained contaminants "at levels high enough to affect human health." These included methane, salts, organic chemicals, and arsenic. In 17 wells, levels of methane were high enough to create risk of fire or explosion.[42] Methane levels were not assessed in wells prior to the start of fracking

[38] Hildenbrand, Z. L., Carlton Jr., D. D., Meik, J. M., Taylor, J. T., Fontenot, B. E., Walton, J. L., … Schug, K. A. (2016). A reconnaissance analysis of groundwater quality in the Eagle Ford shale region reveals two distinct bromide/chloride populations. *Science of the Total Environment, 575,* 672–680. doi: 10.1016/j.scitotenv.2016.09.070

[39] Hildenbrand, Z. L., Carlton Jr., D. D., Meik, J. M., Taylor, J. T., Fontenot, B. E., Walton, J. L., … Schug, K. A. (2017). Corrigendum to "A reconnaissance analysis of groundwater quality in the Eagle Ford shale region reveals two distinct bromide/chloride populations." *Science of the Total Environment, 603–604,* 834-835. doi: 10.1016/j.scitotenv.2017.05.200

[40] Sherwood, O. A., Rogers, J. D., Lackey, G., Burke, T. L., Osborn, S. G., & Ryan, J. N. (2016). Groundwater methane in relation to oil and gas development and shallow coal seams in the Denver-Julesburg Basin of Colorado. *Proceedings of the National Academy of Sciences, 113*(30). doi: 10.1073/pnas.1523267113

[41] Banerjee, N. (2016, July 11). Colorado fracking study blames faulty wells for contamination. *Inside Climate News.* Retrieved from https://insideclimatenews.org/news/11072016/water-contamination-near-colorado-fracking-tied-well-failures

[42] U.S. Agency for Toxic Substances and Disease Registry (2016, May 24). *Health Consultation: Dimock Groundwater Site*. Retrieved from http://www.atsdr.cdc.gov/hac/pha/DimockGroundwaterSite/Dimock_Groundwater_Site_HC_05-24-2016_508.pdf

activities in the area. Hence, the study is limited by lack of pre-drilling baseline data, and investigators did not attempt to determine the source of the contaminants. However, in its focus on identifying health impacts, ATSDR's evaluation is a more comprehensive study than that conducted four years earlier by the EPA and calls into question its earlier, more reassuring conclusions.[43, 44]

- May 9, 2016 – Sampling downstream of a fracking wastewater disposal facility in West Virginia, a U.S. Geological Survey (USGS) team documented changes in microbial communities and found evidence indicating the presence of fracking waste in water and sediment samples collected from Wolf Creek in West Virginia. Specifically, the researchers documented increased concentrations of barium, bromide, calcium, sodium, lithium, strontium, iron, and radium downstream of the disposal well.[45] In a *Washington Post* story about this study, lead author Denise Akob said that the key take-away message "is really that we're demonstrating that facilities like this can have an environmental impact."[46] (This study was done in collaboration with Susan Nagel's team, which studied endocrine-disrupting activity in this same stream. See entry below for April 6, 2016.)

- April 30, 2016 – As part of an investigation based on aerial photographs taken by emergency responders during spring 2016 flooding, the *El Paso Times* documented plumes and sheens of chemicals from tipped-over storage tanks and inundated oil wells and fracking sites entering rivers and streams. "Many of the photos shot during Texas' recent floods show swamped wastewater ponds at fracking sites, presumably allowing wastewater to escape into the environment—and potentially into drinking-water supplies."[47]

- April 27, 2016 – Using geochemical and isotopic tracers to identify the unique chemical fingerprint of Bakken region brines, a Duke University study found that accidental spills of fracking wastewater have contaminated surface water and soils throughout North Dakota where more than 9,700 wells have been drilled in the past decade. Contaminants included salts as well as lead, selenium, and vanadium. In the polluted streams, levels of contaminants often exceeded federal drinking water guidelines. Soils at spill sites showed

[43] Lustgarten, A. (2016, June 9). Federal report appears to undercut EPA assurances on water safety in Pennsylvania. *ProPublica.* Retrieved from https://www.propublica.org/article/federal-report-appears-to-undercut-epa-assurances-water-safety-pennsylvania

[44] U.S. Environmental Protection Agency. (2012, July 25). EPA completes drinking water sampling in Dimock, Pa. [news release]. Retrieved from https://yosemite.epa.gov/opa/admpress.nsf/0/1A6E49D193E1007585257A46005B61AD

[45] Akob, D. M., Mumford, A. C., Orem, W. H., Engle, M. A., Klinges, J. G., Kent, D. B., & Cozzarelli, I. M. (2016). Wastewater disposal from unconventional oil and gas development degrades stream quality at a West Virginia injection facility. *Environmental Science and Technology, 50*(11). doi: 10.1021/acs.est.6b00428

[46] Fears, D. (2016, May 11). This mystery was solved: scientists say chemicals from fracking wastewater can taint fresh water nearby. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2016/05/11/this-mystery-was-solved-scientists-say-chemicals-from-fracking-wastewater-can-taint-fresh-water-nearby/?utm_term=.c27045b60338

[47] Schladen, M. (2016, April 30). Flooding sweeps oil, chemicals into rivers. *El Paso Times.* Retrieved from http://www.elpasotimes.com/story/news/2016/04/30/flooding-sweeps-oil-chemicals-into-rivers/83671348/

elevated levels of radium.[48] The study concluded that "inorganic contamination associated with brine spills in North Dakota is remarkably persistent, with elevated levels of contaminants observed in spill sites up to 4 years following the spill events." In a comment about this study, lead author and Duke University geochemist Avner Vengosh said, "Until now, research in many regions of the nation has shown that contamination from fracking has been fairly sporadic and inconsistent. In North Dakota, however, we find it is widespread and persistent, with clear evidence of direct water contamination from fracking."[49]

- April 6, 2016 – A research team led by Susan Nagel at the University of Missouri traced a spike in endocrine-disrupting activity in a West Virginia stream, Wolf Creek, to an upstream facility that stores fracking wastewater. Levels detected downstream of the waste facility were above levels known to create adverse health effects and alter the development of fish, amphibians, and other aquatic organisms. Endocrine-disrupting compounds were not elevated in upstream sections of the creek.[50, 51] (See also entry for May 9, 2016 above.)

- March 29, 2016 – A study by Stanford University scientists determined that fracking and related oil and gas operations have indeed contaminated drinking water in the town of Pavillion, Wyoming where residents have long complained about foul-tasting water. The researchers found substances in the water that match those used in local fracking operations or found in nearby pits used for the disposal of drilling waste. Chemical contaminants included benzene, a known carcinogen, and toluene, a neurotoxicant. Possible mechanisms for contamination include defective cement well casings; spills and leaks from disposal pits; and underground migration of chemicals into aquifers from the fracked zone, which, in this area, is quite shallow. Also, in the Pavillion area, operators sometimes fracked directly into underground sources of water.[52] One of the authors of this study, Dominic DiGuilio, was also a lead scientist on the EPA's earlier aborted investigation of Pavillion's drinking water. (See entry for December 6, 2015 below.) In an interview about his new research, DiGiulio said that his findings raise concerns about similar water pollution in other heavily fracked regions. "Pavillion isn't geologically unique in the West, and I'm concerned about the Rocky Mountain region of the U.S. The impact on [underground drinking water sources] could be fairly extensive. Pavillion is

[48] Lauer, N. E., Harkness, J. S., & Vengosh A. (2016). Brine spills associated with unconventional oil development in North Dakota. *Environmental Science & Technology, 50*(10). doi: 10.1021/acs.est.5b06349

[49] Nicholas School of the Environment, Duke University. (2016, April 27). Contamination in North Dakota linked to fracking spills [press release]. Retrieved from https://nicholas.duke.edu/about/news/ContaminationinNDLinkedtoFrackingSpills

[50] Kassotis, C. D., Iwanowicz, L. R., Akob, D. M., Cozzarelli, I. M., Mumford, A. C., Orem, W. H., & Nagel, S. C. (2016). Endocrine disrupting activities of surface water associated with West Virginia oil and gas industry wastewater disposal site. *Science of the Total Environment 557-558.* doi: 10.1016/j.sci.tenv.2016.03.113

[51] Bienkowski, B. (2016, April 6). In W. Virginia, frack wastewater may be messing with hormones. *Environmental Health News*. Retrieved from http://www.environmentalhealthnews.org/ehs/news/2016/april/in-w.-virginia-frack-wastewater-may-be-messing-with-hormones

[52] DiGiulio, D. C., & Jackson, R. B. (2016). Impact to underground sources of drinking water and domestic wells from production well stimulation and completion practices in the Pavillion, Wyoming, Field. *Environmental Science & Technology, 50*(8). doi: 10.1021/acs.est.5b04970

like a canary in a coal mine and we need to look at other fields."[53] Co-author Rob Jackson noted, "There are no rules that would stop a company from doing this anywhere else."[54]

- February 22, 2016 – Relying on voluntary disclosures reported to the FracFocus registry and a list compiled by the U.S. Congress, a German team surveyed the physiochemical properties of chemicals used in hydraulic fracturing fluid to evaluate their environmental fate and potential toxicity. Common ingredients included those known to contaminant groundwater, such as solvents, as well as those known to react strongly with other chemicals, such as biocides and strong oxidants, indicating that almost certainly, new chemical products are formed during the process of fracking and its aftermath. Hence, non-toxic additives could potentially react with other substances to create harmful byproducts. The authors conclude that a comprehensive assessment of risks would require an unabridged list of the chemical additives used for fracking, and they call for full disclosure.[55, 56]

- February 9, 2016 – An investigation of water contamination in the Barnett Shale by ABC-affiliate station WFAA in Dallas found numerous violations by operators who ignored regulations that require sealing vertical well pipes with a cement sheath to protect groundwater from stray gas and other vapors that might escape and migrate upwards into overlying aquifers. The WFAA report said that the Texas Railroad Commission, which oversees drilling and fracking operations in Texas, has failed to respond to alleged violations of a rule that requires cement seals around steel well casings in geological zones where drilling has penetrated layers of rock containing oil and gas deposits.[57]

- February 8, 2016 – An investigation by the *Columbus Dispatch* revealed that the amount of water that operators use for hydraulic fracturing in Ohio gas wells increased steadily from 2011 to 2015. The total amount of water increased, as did the volume of water used per well—from an average of 5.6 million gallons per well in 2011 to 7.6 million in 2014. The reason is that the horizontally drilled holes beneath each well have become longer, and these require more water during the fracking process.[58]

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[53] Banerjee, N. (2016, March 29). Fracking study finds toxins in Wyoming town's groundwater and raises broader concerns. *Inside Climate News*. Retrieved from https://insideclimatenews.org/news/29032016/fracking-study-pavillion-wyoming-drinking-water-contamination-epa

[54] Jordan, R. (2016, March 29). Stanford researchers show fracking's impact to drinking water sources. Stanford News. Retrieved from http://news.stanford.edu/2016/03/29/pavillion-fracking-water-032916/

[55] Elsner, M., & Hoelzer, K. (2016). Quantitative survey and structural classification of hydraulic fracturing chemicals reported in unconventional gas production. *Environmental Science & Technology, 50*(7). doi: 10.1021/acs.est.5b02818

[56] Phys.Org. (9 March 2016). How to get a handle on potential risks posed by fracking fluids. Retrieved from http://phys.org/news/2016-03-potential-posed-fracking-fluids.html

[57] Shipp, B. (2016, February 9). Drilling records suggest lax state enforcement. WFAA, Dallas. Retrieved from http://www.wfaa.com/mb/news/local/investigates/rules-ignored-water-fouled-in-barnett-shale/38337835

[58] Arenschield, L. (2016, February 8). Drillers using more water to frack Ohio shale. *The Columbus Dispatch*. Retrieved from http://www.dispatch.com/content/stories/local/2016/02/07/drillers-using-more-water-to-frack-ohio-shale.html

- February 2016 – In a lengthy account to Congress on the status of the underground waste injection well program that is overseen by the EPA, the U.S. Government Accountability Office (GAO) reported that the agency "has not consistently conducted oversight activities necessary to assess whether state and EPA-managed programs are protecting underground sources of drinking water" from contamination by fracking waste. Specifically, the GAO took the EPA to task for failure to require well-specific inspections, collect data on enforcement actions, review permitting requirements by state regulatory agencies, or analyze the resources the agency would need to do all the above to adequately oversee the Underground Injection Control program. The GAO noted that it had once before, in 2014, previously found the EPA negligent in its responsibilities to monitor drinking water sources for possible contamination with fracking waste.[59] (See entry below for September 23, 2014.)

- January 6, 2016 – Yale School of Public Health researchers analyzed more than 1,021 chemicals either used in fracking fluid or created during the process of hydraulic fracturing. They found that 781 of these chemicals lacked basic toxicity data. Of the 240 that remained, 157 were reproductive or developmental toxicants. These included arsenic, benzene, cadmium, formaldehyde, lead, and mercury.[60] Commenting on this study, lead author Nicole Deziel said, "This evaluation is a first step to prioritize the vast array of potential environmental contaminants from hydraulic fracturing for future exposure and health studies. Quantification of the potential exposure to these chemicals, such as by monitoring drinking water in people's homes, is vital for understanding the public health impact of hydraulic fracturing."[61]

- December 15, 2015 – A research team led by geologist Mukul Sharma from Dartmouth College discovered that chemical reactions between fracking fluid and rock can contribute to the toxicity of fracking wastewater. Specifically, the researchers found that fracking fluid can chemically react with the fractured shale in ways that cause barium, a toxic metal, to leach from clay minerals in the Marcellus Shale.[62, 63]

- December 6, 2015 – The *Caspar Star Tribune* investigated the EPA's decision to transfer its study of possible fracking-related drinking water contamination in Pavillion, Wyoming to a state agency in 2013. Preliminary data from the EPA suggested that drilling and fracking operations had contaminated drinking water supplies. To date, the state study has found no definitive link between drilling and water contamination.

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[59] U.S. Government Accountability Office. (2016, February). *Drinking Water: EPA Needs to Collect Information and Consistently Conduct Activities to Protect Underground Sources of Drinking Water.* GAO-16-281. Retrieved from http://gao.gov/assets/680/675439.pdf

[60] Elliot, E. G., Ettinger, A. S., Leaderer, B. P., Bracken, M. B., & Deziel, N. (2016). A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. Advance online publication. *Journal of Exposure Science & Environmental Epidemiology.* doi: 10.1038/jes.2015.81

[61] Greenwood, M. (2016, January 6). Toxins found in fracturing fluid and wastewater, study shows. *Yale News*. Retrieved from http://news.yale.edu/2016/01/06/toxins-found-fracking-fluids-and-wastewater-study-shows

[62] Renock, D., Landis, J. D., & Sharma, M. (2016). Reductive weathering of black shale and release of barium during hydraulic fracturing. *Applied Geochemistry, 65.* doi: 10.1016/j.apgeochem.2015.11.001

[63] Dartmouth College. (15 December 2015). Fracking plays active role in generating toxic metal wastewater, study finds. *Science Daily*. Retrieved from https://www.sciencedaily.com/releases/2015/12/151215134653.htm

Interviews with officials and documents obtained under the Freedom of Information Act revealed that the EPA had bowed to political pressure from state officials and industry representatives and that Wyoming regulators narrowed the scope of the study considerably and conducted little fieldwork.[64] (See also entry above for March 29, 2016.)

- November 19, 2015 – The Science Advisory Board (SAB) for the U.S. Environmental Protection Agency reviewed the EPA's June 2015 draft assessment of fracking's impacts on drinking water, and challenged some of the summary statements that accompanied it, saying that they were over-generalized and not always aligned with the data in the report itself. Specifically, the SAB said, in a draft review, that the data cited by the report were too limited to support the headlined claim in the executive summary that drinking water impacts were neither "widespread" nor "systemic." The SAB also critiqued the study for downplaying local impacts in its conclusions, noting that these impacts can sometimes be severe.[65]

- October 19, 2015 – A six-month investigation by *Penn Live* found long-standing "systemic failures" on the part of the Pennsylvania Department of Environmental Protection to enforce regulations governing drilling and fracking operations. Lack of oversight and reliance on industry self-policing have been the hallmarks of Marcellus Shale development for the past ten years, in violation of Pennsylvanians' constitutional right to clean air and water. Among the findings of this investigation: chronically leaking wastewater impoundments for which no fines or notices were issued to the operator; laboratory coding systems designed to obscure possible detections of certain chemical contaminants in residents' drinking water; and lack of inspections at well sites.[66]

- October 13, 2015 – An international team of researchers found detectable levels of multiple organic chemical contaminants in private drinking water wells in northeastern Pennsylvania where fracking is practiced. One of the compounds was a known additive of fracking fluid. Chemical fingerprinting and noble gas isotopes were used to determine if the contaminants most likely originated from surface spills at the well site or via upward transport from the shale itself. The organic pollutants found in the water did not contain chemical markers—certain elements and salts—that would indicate migration from deep geological strata. The authors concluded that "the data support a transport mechanism…to groundwater via accidental release of fracturing fluid chemicals derived

[64] Storrow, B. (2015, December 6). Pavillion today an EPA in retreat, a narrow state inquiry and no answers. *Caspar Star Tribune*. Retrieved from http://trib.com/business/energy/pavillion-today-an-epa-in-retreat-a-narrow-state-inquiry/article_403f84de-830c-5558-9f3f-ea48fd48d7ca.html?utm_medium=social&utm_source=facebook&utm_campaign=user-share

[65] Banerjee, N. (2015, November 19). EPA finding on fracking's water pollution disputed by its own scientists. *Inside Climate News*. Retrieved from https://insideclimatenews.org/news/19112015/fracking-water-pollution-epa-study-natural-gas-drilling

[66] Woodwell, C. (2016, October 19). Pa. regulators fail to protect environment during Marcellus Shale boom. *Penn Live*. Retrieved from http://www.pennlive.com/midstate/index.ssf/2015/10/state_regulators_fail_to_prote.html

from the surface rather than subsurface flow of these fluids from the underlying shale formation."[67, 68]

- September 23, 2015 – A team of researchers, examining how natural gas drilling and fracking operations across the nation affect creeks, streams and rivers, developed a predictive model and vulnerability index for surface water. They found that "all shale plays, regardless of location, had a suite of catchments that spanned highly degraded to those that are less altered and naturally sensitive to alteration." Surface water in Pennsylvania's Marcellus Shale region is classified by this model as vulnerable to fracking-related impacts because of steep slopes and loose, erodible soils within the watersheds.[69]

- July 30, 2015 – As reported by the *Los Angeles Times*, unlined waste pits and hillside spraying of oil-field wastewater have contaminated groundwater in Kern County, California. Five of six monitoring wells in the 94-acre waste site showed high levels of salt, boron, and chloride, but it is not known how far and fast the contaminated plume has traveled.[70]

- July 21, 2015 – By surveying records for 44,000 wells fracked between 2010 and 2013, researchers from Stanford University, Duke University, and Ohio State University attempted a first-ever assessment of the range of depths at which fracking occurs across the United States. They found that many wells are shallower than widely presumed.[71] As the authors noted, vertical fractures are able to propagate 2,000 feet upward, and hence, "shallow hydraulic fracturing often has greater potential risks of contamination than deeper hydraulic fracturing does." This study showed that drinking water sources may be more vulnerable from upward migration of fracking contaminants than previously presumed. Surprisingly, the researchers found no strong relationship between depth and the volume of water and chemicals used for fracking. Many wells were both shallow and water-intensive, with significant variation in water use from state to state.[72]

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[67] Drollette, B. D., Hoelzer, K., Warner, N. R., Darrah, T. H., Karatum, O., O'Connor, M. P., … Plata, D. L. (2015). Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. *Proceedings of the National Academy of Sciences, 112*(43). doi: 10.1073/pnas.1511474112

[68] Drollette B. D. & Plata, D. A. (2015, October 13). Hydraulic fracturing components in Marcellus groundwater likely from surface operations, not wells. *Phys.Org*. Retrieved from http://phys.org/news/2015-10-hydraulic-fracturing-components-marcellus-groundwater.html

[69] Entrekin, S. A., Maloney, K. O., Kapo, K. E., Walters, A. W., Evan-White, M. A., & Klemow, K. M. (2015). Stream vulnerability to widespread and emergent stressors: a focus on unconventional oil and gas. *PLoS One, 10*(9). doi:10.1371/journal.pone.0137416

[70] Cart, J. (2015, July 30). Central valley wastewater disposal to continue despite contamination. *Los Angeles Times*. Retrieved from http://www.latimes.com/local/california/la-me-oil-waste-pits-20150731-story.html

[71] Jordon, R. (2015, July 21). Shallow fracking raises questions for water, new Stanford research shows. *Stanford University* [press release]. Retrieved from http://news.stanford.edu/news/2015/july/fracking_water-jackson-072115.html

[72] Jackson, R. B., Lowry, E. R., Pickle, A., Kang, M., DiGiullo, D., & Zhao, K. (2015). The depths of hydraulic fracturing and accompanying water use across the United States. *Environmental Science & Technology*, *49*(15). 8969–8976. doi: 10.1021/acs.est.5b01228

- July 9, 2015 – A multi-volume report from the California Council of Science and Technology (CCST) found threats to groundwater in California from several parts of the fracking lifecycle, most notably from toxic wastewater. First, wastewater from California fracking operations is sometimes used for crop irrigation, in which case contaminants may seep from the surface of agricultural areas into groundwater. Second, nearly 60 percent of fracking wastewater in California is disposed of in unlined, open-air pits, a practice that is banned in almost all other states. There are 900 such waste disposal pits in the state, most of which are located in Kern County. Third, for many years, fracking wastewater in California has been mistakenly sent, via injection wells, directly into protected aquifers containing clean freshwater.[73] California's Division of Oil, Gas and Geothermal Resources allowed fracking wastes to be injected into aquifers that it believed were exempt from the U.S. Safe Drinking Water Act. Conceding this mistake, the agency has shut down 23 injection wells for fracking waste disposal and established a two-year timetable for phasing out other wells injecting waste into aquifers that should have been protected.[74] Fracking also threatens California's groundwater resources through water consumption, according to the CCST study. While this volume of water represents a small percentage of overall annual water consumption in California, fracking-related water use is, the study noted, disproportionately concentrated in areas of the state already suffering from water shortages. Further drawdowns of these aquifers may interfere with agricultural and municipal water needs.[75] In addition, because the oil-containing rock layers in California are located closer to the surface than in other states, the state's groundwater is potentially vulnerable to chemical contamination through vertical faults and fissures and via old and abandoned wells. The absence of evidence for direct contamination of groundwater by fracking, the study concluded, reflects absence of investigation rather than evidence of safety.[76]

- June 30, 2015 – The U.S. Geological Survey (USGS) released the first nationwide map of water usage for hydraulic fracturing. It shows wide geographic and temporal variation in the amount of water used to frack a single well. In general, gas wells consume more water per well (5.1 million gallons on average) than oil wells (4 million gallons). Median annual water volumes needed to frack a single horizontal oil or gas well increased dramatically—by a factor of 25 or more—between 2000 and 2014. A typical gas or oil well that is horizontally fracked now requires between six and eight Olympic-sized swimming pools of water. In 2014, the majority (58 percent) of new hydraulically

[73] Shonkoff, S. B. C., Jordan, P., Hays, J., Stringfellow, W. T., Wettstein, Z. S., Harrison, R., Sandelin, W., & McKone, T. E. (2015, July 9). Volume II, Chapter 6: Potential impacts of well stimulation on human health in California. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-6.pdf

[74] Baker, D. R. (2015, July 16). U.S. likely to bar oil-waste dumping into 10 California aquifers. *San Francisco Chronicle.* Retrieved from http://www.sfchronicle.com/business/article/U-S-likely-to-bar-oil-waste-dumping-into-10-6389677.php

[75] Stringfellow, W. T., Cooley H., Varadharajan, C., Heberger, M., Reagan, M. T., Domen, J.K., . . . Houseworth, J. E. (2015, July 9). Volume II, Chapter 2: Impacts of well stimulation on water resources. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-2.pdf

[76] Long, J. C. S, Birkholzer, J. T., & Feinstein, L. C. (2015, July 9). Summary report. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from: http://ccst.us/publications/2015/2015SB4summary.pdf

fracked oil and gas wells were horizontally drilled. The watersheds where the most water was consumed for hydraulic fracturing are mostly located in southern or southwestern states and correspond to the following shale formations: the Eagle Ford and Barnett Shales in Texas; the Haynesville-Bossier Shale in Texas and Louisiana; the Fayetteville Shale in Arkansas; the Tuscaloosa Shale in Louisiana and Mississippi; and the Woodford Shale in Oklahoma. The Marcellus and Utica Shales—which underlie watersheds in parts of Ohio, Pennsylvania, West Virginia, and New York—were also in the top seven water-consuming shale plays in the United States.[77]

- June 26, 2015 – A decade-long USGS study of 11,000 public drinking water wells in California—nearly all the groundwater used for public supply—found high levels of potentially toxic contaminants in about 20 percent of the wells, affecting about 18 percent of the state's population.[78] Although the study did not specifically investigate contaminants from oil and gas extraction, it does provide evidence for farm irrigation draining into groundwater, raising questions about the possible contamination of drinking water aquifers from the reuse of fracking wastewater for crop irrigation.[79]

- June 16, 2015 – A University of Texas research team documented widespread drinking water contamination throughout the heavily drilled Barnett Shale region in northern Texas. The study, which analyzed 550 water samples from public and private water wells, found elevated levels of 19 different hydrocarbon compounds associated with fracking (including the carcinogen benzene and the reproductive toxicant, toluene), detections of methanol and ethanol, and strikingly high levels of 10 different metals.[80] "In the abstract, we can't state that unconventional oil and gas techniques are responsible," the lead author, Zachariah Hildenbrand, said in a media interview. "But when you get into areas where drilling is happening, you find more instances of contamination. It's not coincidental. There are causes for concern."[81]

- June 5, 2015 – The U.S. Environmental Protection Agency's (EPA) long-awaited 600-page draft report on the potential impacts of fracking for drinking water resources confirmed specific instances of drinking water contamination linked to drilling and fracking activities. The report also identified potential mechanisms, both above and below ground, by which drinking water resources can be contaminated by fracking. In

[77] Gallegos, T. J., Varela, B. A., Haines, S. S., & Engle, M. A. (2015). Hydraulic fracturing water use variability in the United States and potential environmental implications. *Water Resources Research*. Accepted author manuscript. doi: 10.1002/2015WR017278

[78] Belitz, K., Fram, M. S., & Johnson, T. D. (2015). Metrics for assessing the quality of groundwater used for public supply, CA, USA: equivalent-population and area. *Environmental Science & Technology*, *9*(14), 8330–8338. doi: 10.1021/acs.est.5b00265

[79] Knickmeyer E., & Smith, S. (2015, July 15). Study finds contaminants in California public-water supplies. *Associated Press.* Retrieved from http://abcnews.go.com/Health/wireStory/study-finds-contaminants-california-public-water-supplies-32476456

[80] Hildenbrand, Z. L., Carlton, D. D., Fontenot, B. E., Meik, J. M., Walton, J.L., Taylor, J. T., . . .Schug, K.A. (2015) A comprehensive analysis of groundwater quality in the Barnett Shale region. *Environmental Science & Technology, 49*(13), 8254-8262. doi: 10.1021/acs.est.5b01526

[81] McPhate, C. (2015, June 18). New study reveals potential contamination. *Denton Record-Chronicle*. Retrieved from http://www.dentonrc.com/local-news/local-news-headlines/20150618-new-study-reveals-potential-contamination.ece

some cases, drinking water was contaminated by spills of fracking fluid and wastewater. In other cases, "[b]elow ground movement of fluids, including gas ... have contaminated drinking water resources." The EPA investigators documented 457 fracking-related spills over six years but acknowledged that they do not know how many more may have occurred. Of the total known spills, 300 reached an environmental receptor such as surface water or groundwater. The EPA also conceded that insufficient baseline drinking water data and a lack of long-term systematic studies limited the power of its findings. The EPA investigation confirmed a number of specific instances where these potential mechanisms did indeed lead to drinking water contamination. An assertion in the EPA's accompanying press release that it had not found "widespread, systemic impacts to drinking water resources" was quoted out of context by many media sources as proof that fracking poses little threat to drinking water. To the contrary, this report confirmed that drilling and fracking activities have contaminated drinking water in some cases and acknowledged that it cannot ascertain how widespread the problem was due to insufficient data.[82] EPA Science Advisor Thomas A. Burke later clarified that the report does not show that fracking is safe. Burke said, "That is not the message of this report. The message of this report is that we have identified vulnerabilities in the water system that are really important to know about and address to keep risks as low as possible."[83]

- May 19, 2015 – A Pennsylvania State University research team documented the presence of a fracking-related solvent, 2-n-Butoxyethanol, in the drinking water from three homes in Bradford County, Pennsylvania, as part of an investigation of private drinking water wells near drilling and fracking operations that contained methane and foam. This finding represents the first fully documented case of a commonly used fracking chemical entering a drinking water source. "The most likely explanation of the incident is that stray natural gas and drilling or [hydrofracking] compounds were driven ~1-3 km along shallow to intermediate depth fractures to the aquifer used as a potable water source."[84] In an accompanying *New York Times* story, lead author Susan Brantley described the geology in northern Pennsylvania "as being similar to a layer cake with numerous layers that extend down thousands of feet to the Marcellus Shale. The vertical fractures are like knife cuts through the layers. They can extend deep underground, and can act like superhighways for escaped gas and liquids from drill wells to travel along, for distances greater than a mile away."[85]

- May 15, 2015 – A research team from the University of Colorado Boulder and California State Polytechnic Institute developed a model for identifying which fracking fluid

[82] U.S. EPA. (2015). *Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources* (External review draft). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/047, 2015. Retrieved from http://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651

[83] Ward Jr., K. (2015, June 7). EPA says new study doesn't show fracking is safe. *Charleston Gazette*. Retrieved from http://www.wvgazettemail.com/article/20150607/GZ01/150609432

[84] Llewellyn G. T., Dorman, F, Westland, J. L., Yoxtheimer, D., Grieve, P. Sowers, T., . . . Brantley, S. L. (2015). Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *Proceedings of the National Academies of Science, 112,* 6325-30. doi: 10.1073/pnas.1420279112/-/DCSupplemental

[85] St. Fleur, N. (2015, May 4). Fracking chemicals detected in Pennsylvania drinking water. *The New York Times*. Retrieved from http://www.nytimes.com/2015/05/05/science/earth/fracking-chemicals-detected-in-pennsylvania-drinking-water.html?_r=0#addendums

chemicals are most likely to contaminate drinking water. Of 996 fracking fluid compounds known to be in use, researchers screened 659 of them for their ability to persist, migrate, and reach groundwater aquifers over a short time scale. Of the fifteen compounds so identified, two were commonly used in fracking operations: naphthalene and 2-butoxyethanol. Both are ingredients in surfactants and corrosion inhibitors. The authors noted that 2-butoxyethanol has been detected in drinking water in a heavily fracked area of Pennsylvania. Exposure to 2-butoxyethanol has been linked to birth defects in animals. Naphthalene is a possible human carcinogen that is toxic to red blood cells and contributes to kidney and liver damage. Researchers did not consider the impact of mixtures, interactions between contaminants, or chemical transformations during the fracking or flowback process and noted, "the need for data on the degradation of many compounds used in fracturing fluids under conditions relevant for groundwater transport."[86]

- May 7, 2015 – A survey of streams in Arkansas, led by the University of Central Arkansas, found alterations in macroinvertebrate communities to be related to drilling and fracking operations in the Fayetteville Shale. Fracking activity near streams was associated with greater sediment and more chlorophyll. "This study suggests that land disturbance from gas development affected stream communities."[87]

- April 20, 2015 – A USGS team analyzed water brought to the surface during natural gas extraction at 13 fracked wells in northern Pennsylvania. They found large variability in the volatile organic compounds and microorganisms in the water samples from different wells. Organic chemical contaminants included benzene, toluene, and perchloroethylene, chloroform, and methylene chloride. The presence of microbes was associated with concentrations of benzene and acetate. Despite the addition of biocides during the fracking process, hydrogen sulfide-producing bacteria were present at culturable levels, along with methogenic and fermenting bacteria. The source of these microorganisms was not determined. "Therefore, we cannot exclude the possibility that these microorganisms are native to the shale formation and reactivated by [hydrofracking] activities, as their physiology does not indicate a terrestrial surficial source."[88]

- April 8, 2015 – A University of Colorado Boulder research team's analysis of the organic chemicals found in liquid waste that flowed out of gas wells in Colorado after they had been fracked revealed the presence of many fracking fluid additives, including biocides, which are potentially harmful if they leak into groundwater. According to the authors, treatment of fracking wastewater must include aeration, precipitation, disinfection, a biological treatment to remove dissolved organic matter, and reverse osmosis

[86] Rogers, J. D., Burke, T. L., Osborn, S. G., & Ryan, J. N. (2015). A framework for identifying organic compounds of concern in hydraulic fracturing fluids based on their mobility and persistence in groundwater. *Environmental Science & Technology Letters, 2,* 158-64.
[87] Johnson, E., Austin, B. J., Inlander, E., Gallipeau, C., Evans-White, M. A., & Entrekin, S. (2015). Stream macroinvertebrate communities across a gradient of natural gas development in the Fayetteville Shale. *Science of the Total Environment*, *530-531,* 323-32. doi: 10.1016/j.scitotenv.2015.05.027
[88] Akob, D. M., Cozzarelli, I. M., Dunlap, D. S., Rowan, E. L., & Lorah, M. M. (2015). Organic and inorganic composition and microbiology of produced waters from Pennsylvania shale gas wells. *Applied Geochemistry,* in press, corrected proofs online April 20. doi: 10.1016/j.apgeochem.2015.04.011

desalination in order for it to be appropriate for non-fracking uses, such as crop irrigation.[89]

- March 18, 2015 – Using a new stream-based monitoring method, a team of scientists with USGS, Pennsylvania State University, and University of Utah found elevated levels of methane in groundwater discharging into a stream near drilling and fracking operations in Pennsylvania. In this same area, several private water wells contained high levels of methane as a result of gas migration near a gas well with a defective casing. The monitoring technique used by the scientists allowed them to demonstrate that the source of the methane was shale gas from the Middle Devonian period, which is the kind of gas found in the Marcellus Shale.[90] Researcher Susan Brantley said, "I found it compelling that using this new method for a reconnaissance of just 15 streams in Pennsylvania, we discovered one instance of natural gas entering the stream, perhaps from a nearby leaking shale gas well."[91]

- March 12, 2015 – A team led by geologist Donald Siegel of Syracuse University found no relationship between methane levels in drinking water wells and proximity to oil or gas wells in a heavily fracked area of northeastern Pennsylvania.[92] However, Siegel failed to reveal in his paper — as is required by the journal — that he had received industry funding from the Chesapeake Energy Corporation. Subsequently, the journal published a lengthy correction that revealed that Chesapeake had not only privately funded the lead author but had provided the baseline groundwater data set. A second author was revealed to be a former employee of Chesapeake, and another had worked as a consultant in the energy sector.[93]

- March 3, 2015 – A Duquesne University study of private drinking water wells in an intensely drilled southwestern Pennsylvania community compared pre-drill and post-drill data on water quality and found changes in water chemistry that coincided with the advent of drilling and fracking activities. Levels of chloride, iron, barium, strontium, and manganese were elevated. In some cases, concentrations exceeded health-based maximum contaminant levels. Methane was detected in most houses tested. Surveys of

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[89] Lester, Y., Ferrer, I., Thurman, E. M., Sitterley, K. A., Korak, J. A., Aiken, G., & Linden, K. G. (2015). Characterization of hydraulic fracturing flowback water in Colorado: Implications for water treatment. *Science of the Total Environment, 512-513,* 637-644. doi: 10.1016/j.scitotenv.2015.01.043

[90] Heilweil, V. M., Grieve, P. L., Hynek, S. A., Brantley, S. L., Solomon, D. K., & Risser, D. W. (2015). Stream measurements locate thermogenic methane fluxes in groundwater discharge in an area of shale-gas development. *Environmental Science & Technology, 49,* 4057-4065. doi: 10.1021/es503882b

[91] U.S. Geological Survey. (2015, April 1). New stream monitoring method locates elevated groundwater methane in shale-gas development area. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=4176&from=rss&utm_source=dlvr.it&utm_medium=facebookhttp://www.readcube.com/articles/10.1002%2F2014WR016382?r3_referer=wol&tracking_action=preview_click&show_checkout=1&purchase_site_license=LICENSE_DENIED_NO_CUSTOMER#.VaPKNYsqdyA

[92] Siegel, D. I., Azzolina, N. A., Smith, B. J., Perry, A. E., & Bothun, R. L. (2015). Methane concentrations in water wells unrelated to proximity to existing oil and gas wells in northeastern Pennsylvania. *Environmental Science & Technology, 49,* 4106-12. doi: 10.1021/es505775c

[93] Siegel, D. I., Azzolina, N. A., Smith, B. J., Perry, A. E., & Bothun, R. L. (2015). Correction to Methane concentrations in water wells unrelated to proximity to existing oil and gas wells in northeastern Pennsylvania. *Environmental Science & Technology, 49,* 4106-12. doi: 10.1021/es505775c

residents revealed widespread complaints about changes in water quality that began after drilling and fracking operations commenced. Violation records from the Pennsylvania Department of Environmental Conservation uncovered possible pathways for water contamination. The researchers concluded that alterations of local hydrology caused by the injection of large volumes of hydraulic fracturing fluids may have mobilized contaminants left over from legacy oil, gas, and mining operations as well as opened pathways for the migration of fracking fluids themselves.[94]

- March 3, 2015 – A research team from Duquesne University reviewed the evidence for environmental impacts to air and water from activities related to shale gas extraction in Pennsylvania and explored potential mechanisms for contamination of air and water related to the drilling and fracking process itself. Among them: deformations of the shale bedrock caused by the injection of large volumes of fluid result in "pressure bulbs" that are translated through rock layers and can impact faults and fissures, so affecting groundwater.[95]

- February 23, 2015 – The arrival of drilling and fracking activities coincided with an increase in salinity in a creek that drains public land in a semi-arid region of Wyoming, determined a USGS study. The dissolved minerals associated with the rise in salinity matched those found in native soil salts, suggesting that disturbance of naturally salt-rich soils by ongoing oil and gas activities, including pipeline, road, and wellpad construction, was the culprit. "As [shale gas and oil] development continues to expand in semiarid lands worldwide, the potential for soil disturbance to increase stream salinity should be considered, particularly where soils host substantial quantities of native salts."[96]

- February 14, 2015 – A review by a *Dickinson Press* news reporter of disposal well files and more than 2,090 mechanical integrity tests revealed that North Dakota frack waste injection wells were often leaky and that state regulators continued to allow fluid injection into wells with documented structural problems even though the wells did not meet EPA guidelines for well bore integrity. Officials with the North Dakota Division of Oil and Gas said they had primary enforcement responsibilities and that EPA guidance did not apply to these wells. The investigation noted, "… a review of state and federal documents, as well as interviews with geologists, engineers, environmental policy experts and lawyers who have litigated under the Safe Drinking Water Act, suggests the agency is loosely interpreting guidance and protocols that are meant to maintain the multiple layers of protection that separate aquifers from the toxic saltwater." *The Dickinson Press*

[94] Alawattegama, S. K., Kondratyuk, T., Krynock, R., Bricker, M., Rutter, J. K., Bain, D. J., & Stolz, J. F. (2015). Well water contamination in a rural community in southwestern Pennsylvania near unconventional shale gas extraction. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 50,* 516-528. doi: 10.1080/10934529.2015.992684

[95] Lampe, D. J., & Stolz, J. F. (2015). Current perspectives on unconventional shale gas extraction in the Appalachian Basin. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, *50*(5), 434-446. doi: 10.1080/10934529.2015.992653

[96] Bern, C. R., Clark, M. L., Schmidt, T. S., Nolloway, J. M., & McDougal, R. R. (2015). Soil disturbance as a driver of increased stream salinity in a semiarid watershed undergoing energy development. *Journal of Hydrology, 524,* 123-136. doi: doi.org/10.1016/j.jhydrol.2015.02.020

is the daily newspaper for Stark County in southwest North Dakota.[97]

- February 11, 2015 – The *Los Angeles Times* analyzed self-reported testing results on fracking wastewater that California drillers were required to submit to the state. Samples of wastewater collected from 329 fracked oil wells found that virtually all—98 percent—contained benzene at levels that exceeded standards for permissible concentrations in drinking water. This finding likely underrepresents the extent of the problem, according to the newspaper investigation, because many operators failed to comply with reporting requirements. The discovery that fracking wastewater is high in benzene is particularly alarming in light of the admission by the state of California that it had inadvertently allowed frack waste disposal directly into aquifers containing clean water that could potentially be used for drinking. Those wells are now the subject of federal and state review.[98]

- February 1, 2015 – An investigation of the chemical make-up of fracking fluid found that the compositions of these mixtures vary widely according to region and company, making the process of identifying individual compounds difficult. Classes of hydrocarbon-based chemicals include solvents, gels, biocides, scale inhibitors, friction reducers, and surfactants. Chemical analysis identified around 25 percent of the organic compounds that are believed to be present in fracking fluid and that are necessary to test for in identifying groundwater and drinking water contamination.[99] Dr. Imma Ferrer, lead author, explained in a *Science Daily* article about her research that "[b]efore we can assess the environmental impact of the fluid, we have to know what to look for."[100]

- January 30, 2015 – A USGS review of national water quality databases found that insufficient data exist to understand the impact of fracking on drinking water.[101] In a media interview, lead author Zack Bowen said, "There are not enough data available to be able to assess the potential effects of oil and gas development over larger geographic areas."[102]

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[97] Brown, A. (2015, February 14). Lacking integrity? State regulatory officials don't follow EPA guidance on saltwater disposal wells. *The Dickinson Press*. Retrieved from http://www.thedickinsonpress.com/energy/bakken/3679507-lacking-integrity-state-regulatory-officials-dont-follow-epa-guidance

[98] Cart. J. (2015, February 11). High levels of benzene found in fracking waste water. *Los Angeles Times*. Retrieved from http://www.latimes.com/local/california/la-me-fracking-20150211-story.html#page=1

[99] Ferrer, I., & Thurman, E.M. (2015), Chemical constituents and analytical approaches for hydraulic fracturing waters. *Trends in Environmental Analytical Chemistry*, *5,* 18-25, doi: 10.1016/j.teac.2015.01.003

[100] Elsevier. (2015 April 8). Fracking fluids contain potentially harmful compounds if leaked into groundwater. *ScienceDaily*. Retrieved from http://www.sciencedaily.com/releases/2015/04/150408090323.htm?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+sciencedaily%2Fearth_climate%2Frecycling_and_waste+%28Recycling+and+Waste+News+--

[101] Bowen, Z. H., Oeisner, G. P., Cade, B., Gallegos, T. J., Farag, A. M., Mott, D. N., . . . Varela, B. A. (2015). Assessment of surface water chloride and conductivity trends in areas of unconventional oil and gas development—why existing national data sets cannot tell us what we would like to know. *Water Resources Research, 51,* 704-15. doi: 10.1002/2014WR016382

[102] Phillips, S. (2015, March 3). USGS: fracking water quality data "scarce." *StateImpact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2015/03/03/usgs-fracking-water-quality-data-scarce/

- January 21, 2015 – A team of researchers from the USGS and Virginia Tech University established that petroleum-based hydocarbons can break down underground in ways that promote the leaching of naturally occurring arsenic into groundwater. Arsenic is a known human carcinogen that causes bladder, lung, and skin cancer. Elevated levels of arsenic in drinking water represent a public health threat.[103] Researchers found that arsenic concentrations in a hydrocarbon plume can reach 23 times the current drinking water standard of 10 micrograms per liter. The authors of the study said that the metabolism of carbon-rich petroleum products by subterranean microbes is involved in a complex geochemical process that leads to mobilization of arsenic into aquifers.[104]

- January 14, 2015 – Researchers from Duke University, Dartmouth College, and Stanford University found high levels of iodide, bromide, and ammonium in samples of wastewater from fracking operations in both the Marcellus and Fayetteville Shales. These same chemicals were present when fracking wastewater was discharged into rivers and streams at three treatment sites in Pennsylvania and during an accidental spill in West Virginia. Iodide and bromide are known to create toxic disinfection byproducts when downstream water is subsequently chlorinated for drinking water. In water, ammonium can convert to ammonia, which is toxic to aquatic life. The authors noted that this is the first study to identify ammonium and iodide as widespread in fracking waste discharges.[105] In an interview with the *Pittsburgh Post-Gazette*, lead author Avner Vengosh said that the findings raise new concerns about the environmental and health impacts of wastewater from drilling and fracking operations.[106]

- November 27, 2014 – An interdisciplinary team of researchers found methane contamination in drinking water wells located in eight areas above the Marcellus Shale in Pennsylvania and the Barnett Shale in Texas, with evidence of declining water quality in the Barnett Shale area. By analyzing noble gases and their isotopes (helium, neon, argon), the investigators were able to isolate the origin of the fugitive methane in drinking water. The results implicate leaks through cement well casings as well as via naturally occurring cracks and fissures in the surrounding rock.[107] In a related editorial, one of the study's authors, Robert Jackson, called on the EPA to reopen its aborted investigation into

[103] U.S. Geological Survey (2015, January. 26). Natural breakdown of petroleum underground can lace arsenic into groundwater. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=4110&from=rss&utm_source=dlvr.it&utm_medium=facebook#.VavGXIsqdyA

[104] Cozzarelli, I. M. Schreiber, M. D., Erickson, M. L., & Ziegler, B. A. (2015). Arsenic cycling in hydrocarbon plumes: secondary effects of natural attenuation. *Groundwater*. doi: 10.1111/gwat.12316

[105] Harkness, J. S., Dwyer, G. S., Warner, N. R., Parker, K. M., Mitch, W. A, & Vengosh, A. (2015). Iodide, bromide, and ammonium in hydraulic fracturing and oil and gas wastewaters: environmental implications. *Environmental Science & Technology*, *49,* 1955-63. doi: 10.1021/es504654n

[106] Hopey, D. (2015, January 15). Study: high levels of pollutants from drilling waste found in Pa. rivers. *Pittsburgh Post-Gazette*. Retrieved from http://powersource.post-gazette.com/powersource/latest-oil-and-gas/2015/01/14/Study-High-levels-of-pollutants-from-drilling-waste-found-in-Pennsylvania-rivers-shale/stories/201501140143

[107] Darrah, T. H., Vengosh, A., Jackson, R. B., Warner, N. R., & Poreda, R. J. (2014). Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. *Proceedings of the National Academy of Sciences, 111* (39), 14076-14081. doi: 10.1073/pnas.1322107111

drinking water contamination in heavily fracked areas of Texas. Jackson also emphasized that methane migration through unseen cracks in the rock surrounding the wellbore "raises the interesting possibility that a drilling company could follow procedures — cementing and casing below the local aquifer — and still create a potential pathway for gas to migrate into drinking water."[108]

- November 26, 2014 – A critical review of biocides in fracking fluid by a Colorado State team found that the fate of these chemicals underground is not known and their toxicity not well understood. While many biocides are short-lived, some may transform into more toxic or persistent compounds. Among the most common chemical components of fracking fluid, biocides are used to inhibit the growth of deep-life microorganisms, including sulfate-reducing bacteria that contribute to corrosion of well casings and can form biofilms that prevent the upward flow of natural gas. Oxidizing biocides that are chlorine- or bromine-based can react with other fracking chemicals and may produce toxic halogenated byproducts. The authors noted biocides pose a unique risk for drinking water when fracking liquid waste is treated for discharge to surface water via sewage treatment plants. Sub-lethal concentrations may contribute to adaptation of surviving microorganisms and, hence, antibiotic resistance of pathogens. They cited particular concern over surface spills and well integrity issues associated with casing or cement failure.[109]

- November 3, 2014 – The West Virginia Department of Environmental Protection confirmed that three private drinking water wells were contaminated when Antero Resources mistakenly drilled into one of its own gas wells. Benzene, a human carcinogen, and toluene, a reproductive toxicant, were detected in the drinking water at concentrations four times the legal maximum limit. Additionally, a nearby abandoned gas well, a drinking water well, and an actively producing gas well were all pressurized as a result of the mishap and began exhibiting "artesian flow."[110]

- October 22, 2014 – A follow-up to the August 2014 Environmental Integrity Project report describes an even greater potential public health threat from a loophole in the Safe Drinking Water Act, wherein companies are allowed to inject other petroleum products (beyond diesel) without a permit, and many of these non-diesel drilling fluids contain even higher concentrations of the same toxins found in diesel. The authors recommend that "EPA should revisit its guidance and broaden the categories of diesel products that

[108] Jackson, R. (2014, December 1). Reopen Barnett Shale water probe. *The Texas Tribune*. Retrieved from http://tribtalk.org/2014/12/01/reopen-barnett-shale-water-probe/

[109] Kahrilas, G. A. Blotevogel, J., Stewart, P. S., & Borch T. (2015). Biocides in hydraulic fracturing fluids: a critical review of their usage, mobility, degradation, and toxicity. *Environmental Science & Technology, 49,*16-32. doi: 10.1021/es503724k

[110] Board, G. (2014, November 3). September drilling accident contaminated water in Doddridge County. *West Virginia Public Broadcasting*. Retrieved from http://wvpublic.org/post/dep-september-drilling-accident-contaminated-water-doddridge-county

require Safe Drinking Water Act permits before they can be injected into oil and gas wells."[111]

- October 20, 2014 – While developing a technique to fingerprint and trace accidental releases of hydraulic fracturing fluids, researchers showed that liquid waste from shale gas fracking operations is chemically different than waste flowing out of conventional wells. The researchers hypothesized that the hydraulic fracturing process itself liberates elements from clay minerals in the shale formations, including boron and lithium, which then enter the liquid waste.[112]

- October 15, 2014 – Four thousand gallons of liquid fracking waste dumped into Waynesburg sewer system was discovered by sewage treatment plant workers in Greene County, Pennsylvania. The Department of Environmental Protection surmised that "someone removed a manhole cover in a remote location and dumped the fluid." The treatment plant discharges into a creek that feeds the Monongahela River, which provides drinking water to more than 800,000 people.[113]

- October 6, 2014 – A state investigation that found no fracking-related water contamination in a drinking water well in Pennsylvania's Washington County was invalidated by testimony presented to the state Environmental Hearing Board. Not all contaminants that were present in the water were reported, and the investigation relied on obsolete testing methods. More sophisticated testing revealed the presence of several chemical contaminants in the well water. The well is located 2,800 feet down gradient from a drilling site and fracking waste pit where multiple spills and leaks more than four years earlier had contaminated two springs.[114]

- September 23, 2014 – In a two-part audit of records, the U.S. Government Accountability Office (GAO) found that the EPA is failing to protect U.S. drinking water sources from fracking-related activities such as waste disposal via injection wells. Nationwide, 172,000 injection wells accept fracking waste; some are known to have contaminated drinking water. And yet, both short-term and long-term monitoring is lax, and record-keeping varies widely from state to state. The EPA neither mandates nor recommends a fixed list of chemicals for monitoring on the grounds that "injection fluids can vary widely in composition and contain different naturally occurring chemicals and fluids used in oil and

[111] Schaeffer, E. & Bernhardt, C. (2014, October 22). Fracking's toxic loophole. The Environmental Integrity Project. Retrieved from http://environmentalintegrity.org/wp-content/uploads/FRACKINGS-TOXIC-LOOPHOLE.pdf

[112] Warner, N. R., Darrah, T. H., Jackson, R. B., Millot, R., Kloppmann, W., & Vengosh, A. (2014). New tracers identify hydraulic fracturing fluids and accidental releases from oil and gas operations. *Environmental Science & Technology, 48*(21), 12552–12560. doi: 10.1021/es5032135

[113] Hopey, D. (2014, October 15). Waynesburg officials investigate dumping of fracking wastewater. *Pittsburgh Post-Gazette*. Retrieved from http://powersource.post-gazette.com/news/environment/2014/10/15/Waynesburg-investigates-dumping-of-fracking-wastewater/stories/201410150056

[114] Hopey, D. (2014, October 6). Testimony: obsolete tests tainted shale analysis. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/companies-powersource/2014/10/06/Testimony-Obsolete-tests-tainted-shale-analysis/stories/201410060075

gas production depending on the source of the injection fluid."[115] Disposal of oil and gas waste via injection wells is, in fact, subject to regulation under the Safe Drinking Water Act, but, in practice, no one knows exactly what the waste contains, and regulations are deficient. In the United States, at least two billion gallons of fluids are injected into the ground *each day* to enable oil and gas extraction via fracking or to dispose of liquid waste from fracking operations.[116, 117]

- September 18, 2014 – Range Resources was fined a record $4.5 million by the Pennsylvania Department of Environmental Protection for contaminating groundwater. The culprits were six leaking pits in Washington County that each held millions of gallons of fracking wastewater.[118]

- September 12, 2014 – A Pennsylvania State ecosystems scientist, together with USGS scientists, reviewed the current knowledge of the effects of fracking and its associated operations on terrestrial and aquatic ecosystems in 20 shale plays in the U.S. Findings of species and habitats at highest risk include (in addition to land-based examples) vernal pond inhabitants and stream biota. The research builds on previous reviews identifying "three main potential stressors to surface waters: changes in water quantity (hydrology), sedimentation, and water quality." Researchers determined that there are no published data specifically on the effects of fracking on forest-dwelling amphibians, but "many species breed in vernal ponds which are negatively affected by changes in water quantity and quality and direct disturbance. Many amphibians are also highly sensitive to road salts." Given that the U.S. EPA recently found 55% of all rivers and streams to be in poor condition, these researchers warned, "Large-scale development of shale resources might increase these percentages." They expressed concern for the native range of brook trout by the cumulative effects of shale development, especially in Pennsylvania.[119]

- September 9, 2014 – A research team from Stanford and Duke Universities discovered that fracking wastewater processed by sewage treatment plants contributes to the formation of carcinogenic chemical byproducts. These raise public health risks when downstream surface water is used for drinking. Even when fracking wastewater was diluted by a factor of 10,000, the bromides and iodides in the waste reacted with organic matter to create highly toxic halogenated compounds—at troublingly high concentrations. These toxic compounds are not filterable by municipal wastewater treatment plants.

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[115] U.S. Government Accountability Office. (2014, September 23). Drinking water: characterization of injected fluids associated with oil and gas production. GAO-14-657R. Retrieved from http://www.gao.gov/products/GAO-14-857R.

[116] Sadasivam N. (2014, July 29). Report criticizes EPA oversight of injection wells, *ProPublica.* Retrieved from http://www.propublica.org/article/report-criticizes-epa-oversight-of-injection-wells

[117] U.S. Government Accountability Office. (June 27, 2014). EPA program to protect underground sources from injection of fluids associated with oil and gas production needs improvement. GAO-14-555. Retrieved from http://www.gao.gov/products/GAO-14-555

[118] Hopey, D. (2014, September 18). Range resources to pay $4.15M penalty. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/local/2014/09/18/DEP-orders-Range-Resources-to-pay-4-million-fine/stories/201409180293

[119] Brittingham, M. C., Maloney, K. O., Farag, A. M., Harper, D. D., & Bowen, Z. H. (2014). Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. *Environmental Science & Technology*, *48*(19), 11034–11047. doi: dx.doi.org/10.1021/es5020482

Halogenated disinfection byproducts in drinking water are linked to both colon and bladder cancers.[120]

- August 29, 2014 – A review of Pennsylvania Department of Environmental Protection files on fracking-related damage to drinking water—which are kept on paper and stored in regional offices—revealed that 243 private water supplies in 22 counties had been contaminated or had lost flow and dried up as a result of nearby drilling and fracking operations in the past seven years. Pollutants included methane, metals, and salts as well as carbon-based compounds (ethylene glycol and 2-butoxyethanol) that are known to be constituents of fracking fluid. As reported by the *Pittsburgh Post-Gazette*, this tally—which came as a response to multiple lawsuits and open-records requests by media sources—was the first time the agency "explicitly linked a drilling operation to the presence of industrial chemicals in drinking water."[121, 122]

- August 13, 2014 – Over the last decade, drilling companies have repeatedly claimed they are no longer using diesel fuel in fracking, although a 2011 investigation by U.S. House Democrats concluded otherwise. The Environmental Integrity Project examined disclosure data submitted to FracFocus and identified at least 351 wells in 12 states that have been fracked over the last four years with one or more of the five prohibited products identified as diesel. EIP researchers also discovered numerous fracking fluids with high diesel content for sale online, including over a dozen products sold by Halliburton and advertised as additives, friction reducers, emulsifiers, etc.[123]

- August 13, 2014 – An international team of researchers found high levels of carbon-based compounds in liquid fracking waste. These impurities can react with chlorine and bromine to create toxic byproducts. This study suggests that chemical treatment of liquid fracking waste will magnify its toxic potency, as will reusing and recycling it.[124] The European Commission subsequently published a summary of these findings.[125]

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[120] Parker, K. M., Zeng, T., Harkness, J., Vengosh, A., & Mitch, W. A. 2014. Enhanced formation of disinfection byproducts in shale gas wastewater-impacted drinking water supplies. *Environmental Science & Technology*, *48*(19), 11161–11169. doi: 10.1021/es5028184

[121] Pennsylvania Department of Environmental Protection. (2014 August 29). Water supply determination letters. Retrieved from http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination_Letters/Regional_Determination_Letters.pdf

[122] Legere, L. (2014, September 9). DEP releases updated details on water contamination near drilling sites: some 240 private supplies damaged by drilling in the past 7 years. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/policy-powersource/2014/09/09/DEP-releases-details-on-water-contamination/stories/201409090010

[123] Greene, M. (2014, August 13). Fracking beyond the law: Despite industry denials, investigation reveals continued use of diesel in hydraulic fracturing. The Environmental Integrity Project. Retrieved from http://environmentalintegrity.org/wp-content/uploads/Fracking-Beyond-the-Law.pdf

[124] Maguire-Boyle, S. J., & Barron, A. R. (2014). Organic compounds in produced waters from shale gas wells. *Environ. Sci.: Processes Impacts*, *16,* 2237-2248. doi: 10.1039/C4EM00376D

[125] European Commission. (2015, February 19). Chemical composition of fracking wastewater. *Science for Environment Policy, 404.* Retrieved from http://ec.europa.eu/environment/integration/research/newsalert/pdf/chemical_composition_of_fracking_wastewater_404na4_en.pdf

- August 13, 2014 – A team from Lawrence Berkeley National Laboratory reported that scientific efforts to understand the hazards of fracking continue to be hampered by industry secrecy. A comprehensive examination of the chemical formulations of fracking fluid—whose precise ingredients are protected as proprietary business information—revealed that no publicly available toxicity or physical chemical information was available for one-third of all the fracking chemicals surveyed. Another ten percent of chemicals, including biocides and corrosion inhibitors, were known to be toxic to mammals.[126, 127]

- August 12, 2014 – A Stanford University research team working in the Pavillion gas basin in Wyoming documented that fracking in shallow layers of bedrock, including those that serve as drinking water aquifers, is not uncommon. This finding overturns the industry claim that oil and gas deposits targeted by fracking operations are located at much greater depths than underground drinking water sources and are isolated from them by hundreds of feet of impermeable rock. Because it is exempt from provisions of the Safe Drinking Water Act, fracking in drinking water aquifers is not prohibited by law.[128]

- August 3, 2014 – An investigation by the *Pittsburgh Post-Gazette* found that half of all fracking-related spills that resulted in violations and fines were not discovered by the gas companies themselves, even though Pennsylvania state law requires them to pro-actively seek and report such incidents. The newspaper's analysis of hundreds of thousands of state and company documents showed that self-regulation in the gas fields is a failure. One-third of all spills were discovered by state inspectors, while one-sixth were found by residents. Likely, much contamination is entirely undetected and unreported.[129]

- July 21, 2014 – An investigation by the *Columbus Dispatch* showed that Halliburton delayed disclosure to federal and state EPA agencies of the full list of chemicals that spilled into a creek following a fire on one of its well pad in Monroe County, Ohio. Although the creek is an important supply of drinking water for downstream communities and the spill precipitated a mass die-off of fish and other aquatic wildlife, five full days passed before EPA officials were provided a full inventory of chemicals used at Halliburton's operation. As a result, the public was denied knowledge of potential chemical exposures.[130]

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[126] Stringfellow, W. T., Domen, J. K., Carmarillo, M. K., Sandelin, W. L., Tinnacher, R., Jordan, P., . . . Birkholzer, J. (August 13, 2014). Characterizing compounds used in hydraulic fracturing: a necessary step for understanding environmental impacts. Presentation before the American Chemical Society conference, San Francisco. Abstract retrieved from http://abstracts.acs.org/chem/248nm/program/view.php?obj_id=262051&terms=

[127] Robinson, P. (2014, August 19). Fracking fluid survey shows missing information. *Scientific American*. Retrieved from http://www.scientificamerican.com/article/fracking-fluid-survey-shows-missing-information/

[128] Banerjee, N. (2014, August 12). Oil companies fracking into drinking water sources, new research finds. *Los Angeles Times*. Retrieved from http://www.latimes.com/nation/la-na-fracking-groundwater-pavillion-20140811-story.html#page=1

[129] Hamill, S. D. (2014, August 3). Drillers did not report half of spills that led to fines. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/news/state/2014/08/03/Drillers-did-not-report-half-of-spills-that-led-to-fines/stories/201408020142

[130] Arenschield, L. (2014, July 21). Halliburton delayed releasing details on fracking chemicals after Monroe County spill. *The Columbus Dispatch*. Retrieved from http://www.dispatch.com/content/stories/local/2014/07/21/details-on-chemicals-trickle-in-after-spill.html

- July 17, 2014 – A team of environmental scientists, biologists, and engineers, from institutions including the University of Michigan and McGill University, assessed the current state of understanding of the impact fracking and its associated activities have on the ecological health of surface waters. Though various approaches such as geographic information systems and site monitoring provide insights into potential risks to aquatic ecosystems, the authors concluded that inadequate data currently exist. They identified possible outcomes such as, "erosion and sedimentation, increased risk to aquatic ecosystems from chemical spills or runoff, habitat fragmentation, loss of stream riparian zones, altered biogeochemical cycling, and reduction of available surface and hyporheic water volumes because of withdrawal-induced lowering of local groundwater levels."[131]

- July 7, 2014 – California Department of Gas, Oil, and Geothermal Resources ordered seven energy companies to stop injecting liquid fracking waste into aquifers. The ongoing drought that has compelled farmers to supplement irrigation with water drawn from groundwater sources prompted state officials to look at the status of aquifers previously considered too deep for use or too poor in quality. They discovered that at least seven injection wells were very likely pumping liquid fracking waste into protected groundwater supplies rather than aquifers that had been sacrificed for the purpose of waste disposal. Across the United States, more than 1000 aquifers are exempt from any type of pollution protection at all, and many of these are in California, according to a related *ProPublica* investigation.[132]

- June 25, 2014 – A study by Cornell University researchers found that fracking fluid and fracking wastewater mobilized previously deposited chemical contaminants in soil particles in ways that could potentially exacerbate the impacts of fracking fluid spills or leaks. The research team concluded that, by interfering with the ability of soil to bond to and sequester pollutants such as heavy metals, fracking fluids may release from soils an additional repository of contaminants that could migrate into groundwater.[133]

- June 23, 2014 – Building on earlier findings that water samples collected from sites with confirmed fracking spills in Garfield County, Colorado exhibited moderate to high levels of estrogen and androgen-disrupting activity, a University of Missouri team extended their investigation to other types of hormonal effects. As reported at a joint meeting of the International Society of Endocrinology and the Endocrine Society, their research documented that commonly used fracking chemicals can also block the receptors for thyroid hormone, progesterone, and glucocorticoids (a family of hormones involved in both fertility and immune functioning). Of 24 fracking chemicals tested, all 24 interfered

[131] Burton Jr., G. A., Basu, N., Ellis, B. R., Kapo, K. E., Entrekin, S. & Nadelhoffer, K. (2014). Hydraulic "fracking": are surface water impacts an ecological concern? *Environmental Toxicology and Chemistry*, *33*(8), 1679-1689.

[132] Lustgarten, A. (2014, July 18). California halts injects of fracking waste, warning it may be contaminating aquifers. *ProPublica.* Retrieved from http://www.propublica.org/article/ca-halts-injection-fracking-waste-warning-may-be-contaminating-aquifers

[133] Sang, W., Stoof, C., Zhang, W., Morales, V., Gao, B., Kay, R., . . . Steenhuis, T. (2014). Effect of hydrofracking fluid on colloid transport in the unsaturated zone. *Environmental Science & Technology*, *48*(14), 8266–8274. Retrieved from http://pubs.acs.org/doi/abs/10.1021/es501441e

with the activity of one or more important hormone receptors. There is no known safe level of exposure to hormone-disrupting chemicals.[134]

- May 11, 2014 – According to the U.S. Government Accountability Office, the federal government is failing to inspect thousands of oil and gas wells located on public land, including those that pose special risks of water contamination or other environmental damage. An investigation by the Associated Press found that the Bureau of Land Management "had failed to conduct inspections on more than 2,100 of the 3,702 wells that it had specified as 'high priority' and drilled from 2009 through 2012. The agency considers a well 'high priority' based on a greater need to protect against possible water contamination and other environmental safety issues."[135]

- March 25, 2014 – An industry-funded study of oil and gas well integrity found that more than six percent of wells in a major shale exploration region in Pennsylvania showed evidence of leaking and conceded that this number is likely an underestimate. Researchers concluded that the percentage of wells with some form of well barrier or integrity failure is highly variable and could be as high as 75 percent. A separate analysis in the same study found 85 examples of cement or casing failures in Pennsylvania wells monitored between 2008 and 2011.[136]

- March 7, 2014 – In a comprehensive evaluation, Duke University scientists and colleagues reviewed the state of knowledge on possible effects of shale gas and hydraulic fracturing on water resources in the United States and concluded, "Analysis of published data (through January 2014) reveals evidence for stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes in some disposal and spill sites."[137]

- February 19, 2014 – A Pennsylvania court found a gas corporation guilty of contaminating a woman's drinking water well in Bradford County. Methane levels after fracking were 1,300 to 2,000 times higher than baseline, according to the court brief. Iron levels and turbidity had also increased. The brief stated, "In short, Jacqueline Place lived for ten months deprived totally of the use of her well, and even after its 'restoration,' has been burdened with a water supply with chronic contamination, requiring constant

[134] The Endocrine Society (2014, June 23). Hormone-disrupting activity of fracking chemicals worse than initially found. *Science Daily.* Retrieved from http://www.sciencedaily.com/releases/2014/06/140623103939.htm?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+sciencedaily%2Ftop_news%2Ftop_health+%28ScienceDaily%3A+Top+Health+News%29

[135] Yen, H. (2014, May 11). Fed govt failed to inspect higher risk oil wells. *Associated Press*. Retrieved from http://bigstory.ap.org/article/fed-govt-failed-inspect-higher-risk-oil-wells

[136] Davies, R. J., Almond, S., Ward, R. S., Jackson, R. B., Adams, C., Worrall, F., . . . Whitehead, M. A. (2014). Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. *Marine and Petroleum Geology, 56*, 239-254. doi: 10.1016/j.marpetgeo.2014.03.001

[137] Vengosh, A., Jackson, R. B., Warner, N., Darrah, T. H., & Kondash, A. (2014). A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States [Abstract]. *Environmental Science & Technology*. doi: 10.1021/es405118y

vigilance and ongoing monitoring."[138]

- January 16, 2014 – Data from the Colorado Oil and Gas Conservation Commission showed that fracking-related chemical spills in Colorado exceed an average rate of one spill per day. Of the 495 chemical spills that occurred in that state over a one-year period of time, nearly a quarter impacted ground or surface water. Sixty-three of the spills spread within 1,500 feet of pigs, sheep, and cows; 225 spread within 1,500 feet of buildings.[139]

- January 10, 2014 – Duke University water tests revealed ongoing water contamination in Parker County, Texas, providing evidence that the EPA had prematurely ended its prior investigation into the water contamination.[140] A letter sent to the EPA from more than 200 environmental organizations called on the agency to re-open its investigation.[141]

- January 5, 2014 – An Associated Press investigation into drinking water contamination from fracking in four states—Pennsylvania, Ohio, West Virginia, and Texas—found many cases of confirmed water contamination and hundreds more complaints. The Associated Press noted that their analysis "casts doubt on industry view that it rarely happens."[142]

- December 24, 2013 – A report from the EPA Inspector General concluded that evidence of fracking-related water contamination in Parker County, Texas was sound and faulted the EPA for prematurely ending its investigation there, relying on faulty water testing data from the gas industry in doing so, and failure to intervene when affected residents' drinking water remained unsafe.[143] As reported by *Business Insider*, "The EPA Screwed Up When It Dropped This Fracking Investigation."[144]

- December 16, 2013 – Lead by Susan Nagel of the University of Missouri School of Medicine, researchers documented endocrine-disrupting properties in chemicals commonly used as ingredients of fracking fluid and found similar endocrine-disrupting

[138] Gibbons, B. (2014, February 19). Woman wins case against Chesapeake Jaqueline Place of Terry Township to receive compensation for well contamination. *Thedailyreview.com*. Retrieved from http://thedailyreview.com/news/woman-wins-case-against-chesapeake-jaqueline-place-of-terry-township-to-receive-compensation-for-well-contamination-1.1636832

[139] Tomasic, J. (2014, January 16). Colorado drilling data: More than a spill a day. *The Colorado Independent*. Retrieved from http://www.coloradoindependent.com/145629/colorado-drilling-data-more-than-a-spill-a-day

[140] Drajem, M. (2014, January 9). Duke fracking tests reveal dangers driller's data missed. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2014-01-10/epa-s-reliance-on-driller-data-for-water-irks-homeowners.html

[141] Drajem, M. (2014, January 27). EPA needs fracking review: 'Gasland' maker, environmentalists. *Bloomberg*. Retrieved from http://go.bloomberg.com/political-capital/2014-01-27/epa-needs-fracking-review-gasland-producer-environmentalists-say/.

[142] Begos, K. (2014, January 05). 4 states confirm water pollution from drilling. *USA Today*. Retrieved from http://www.usatoday.com/story/money/business/2014/01/05/some-states-confirm-water-pollution-from-drilling/4328859/

[143] Banjeree, N. (2013, December 24). EPA report on fracking in Texas raises new concerns. *Los Angeles Times*. Retrieved from http://www.latimes.com/nation/la-na-epa-fracking-20131225,0,6042944.story#ixzz2oVB9FXVY

[144] Miedema, D. (2013, December 25). The EPA screwed up when it dropped this fracking investigation. *Business Insider*. Retrieved from http://www.businessinsider.com/epa-criticized-for-dropping-fracking-investigation-2013-12

activity in groundwater and surface water samples collected near drilling and fracking sites in Garfield County, Colorado. Endocrine disruptors are chemicals that interfere with the activity of hormones in the body and, at very low concentrations, can raise the risk of reproductive, metabolic, and neurological disorders, especially when exposures occur in early life. [145, 146, 147]

- December 7, 2013 – Reporting on the second gas leak at a single gas well in one month, the Fort Worth *Star-Telegram* uncovered another inherent risk of fracking for groundwater contamination: Silica sand, which is used as an ingredient in fracking fluid for its ability to prop open the shale fractures, can damage steel pipes as it flows back up the well along with the gas. According to Dan Hill, head of the petroleum engineering department at Texas A&M University, new wells are the most susceptible to sand erosion because "the amount of sand and gas rushing through valves and flow lines is at its greatest when a well first goes into production."[148]

- November 28, 2013 – An Associated Press investigation uncovered nearly 300 oil pipeline spills in North Dakota in the previous ten months, all with no public notification. These were among some 750 "oil field incidents" that had occurred in the state over the same time period, also without public notification. Until the AP inquiry, industry and state officials had kept quiet about one particular "massive spill" that had been accidentally discovered by a wheat farmer. Even small spills can contaminate water sources permanently and take cropland out of production.[149]

- November 26, 2013 – A USGS report found serious impacts of fracking on watersheds and water quality throughout the Appalachian Basin, as well as issues with radiation and seismic events. As noted in the report, the knowledge of how extraction affects water resources has not kept pace with the technology.[150, 151] Meanwhile, clean fresh water is becoming an increasingly scant resource. A report prepared for the U.S. State Department

[145] Kassotis, C. D., Tillitt, D. E., Davis, J. W., Hormann, A. M., & Nagel, S. C. (2013). Estrogen and androgen receptor activities of hydraulic fracturing chemicals and surface and ground water in a drilling-dense region. *Endocrinology*. doi: 10.1210/en.2013-1697

[146] Banerjee, N. (2013, December 16). Hormone-disrupting chemicals found in water at fracking sites. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2013/dec/16/science/la-sci-fracking-health-20131217

[147] Endocrine Society. (2013, December 16). Fracking chemicals disrupt hormone function. *ScienceDaily*. Retrieved from www.sciencedaily.com/releases/2013/12/131216140428.htm

[148] Hirst, C., & Fuquay, J. (2013, December 7). Second leak reported at east Fort Worth gas well site. *Star-Telegram*. Retrieved from http://www.star-telegram.com/2013/12/07/5399740/second-leak-reported-at-east-fort.html?rh=1

[149] MacPherson, J. (2013, October 28). Nearly 300 pipeline spills in North Dakota have gone unreported to the public since January 2012. *Huffington Post*. Retrieved from http://www.huffingtonpost.com/2013/10/28/pipeline-spills-north-dakota_n_4170133.html?ncid=edlinkusaolp00000003

[150] Kappel, W. M., Williams, J. H., & Szabo, Z. (2013). Water resources and shale gas/oil production in the Appalachian Basin - Critical issues and evolving developments. *U.S. Geological Survey*. Retrieved from http://pubs.usgs.gov/of/2013/1137/pdf/ofr2013-1137.pdf

[151] Mall, A. (2013, November 26). New USGS analysis: Threats to water, wildlife, and health from oil and gas development in the Appalachian basin [Web log post]. Retrieved from http://switchboard.nrdc.org/blogs/amall/new_usgs_analysis.html

forecasts a serious freshwater shortage by 2030, with global demand exceeding supply by 40 percent.[152]

- November 22, 2013 – A USGS study of pollution from oil production in North Dakota, where horizontal drilling and hydraulic fracturing are heavily used, identified two potential plumes of groundwater contamination covering 12 square miles. The cause was traced to a casing failure in a wastewater disposal well. Drilling companies had incorrectly assumed that, once injected underground, the wastewater would remain contained. According to *EnergyWire*, the development of the Bakken oil formation is "leaving behind an imprint on the land as distinct as the ones left by the receding ice sheets of the ice age."[153]

- September 10, 2013 – Pennsylvania Attorney General Kathleen Kane filed criminal charges against Exxon Mobil Corporation's subsidiary, XTO Energy Corporation, for a spill of 50,000 gallons of toxic drilling wastewater in 2010 that contaminated a spring and a tributary of the Susquehanna River. In July, XTO settled civil charges for the incident without admitting liability by agreeing to pay a $100,000 fine and improve its wastewater management.[154]

- September 10, 2013 – Out of concern for risks posed to drinking water in the nation's capital, George Hawkins, General Manager of DC Water, Washington, DC's local water provider, called for a prohibition on horizontal drilling and hydraulic fracturing in the George Washington National Forest until the process can be proven safe.[155] The Potomac River is the source of the District's water supply and has its headwaters in the George Washington National Forest, which sits atop the Marcellus Shale. The general managers of Fairfax Water, provider of drinking water for Fairfax County, Virginia, and the U.S. Army Corps of Engineers have called for a similar prohibition.[156]

- September 3, 2013 – The North Dakota Department of Mineral Resources voiced concern about an increasing number of fracking well blowouts (23 incidents in the past year) that result in spills and public safety threats.[157]

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[152] National Intelligence Council. (2012, February 2). *Global Water Security: Intelligence Community Assessment,* (ICA 2012-08). Retrieved from http://www.dni.gov/files/documents/Special%20Report_ICA%20Global%20Water%20Security.pdf

[153] Vaidyanathan, G. (2013, November 22). Bakken shale: As oil production sets in, pollution starts to migrate -- scientists. *E&E Publishing, LLC*. Retrieved from http://www.eenews.net/stories/1059990892

[154] Maykuth, A. (2013, September 13). Shale criminal charges stun drilling industry. *Philly.com*. Retrieved from http://articles.philly.com/2013-09-13/news/42012429_1_xto-energy-inc-criminal-charges-attorney-general

[155] Letter from George Hawkins, General Manager, DC Water, to U.S. Secretary of Agriculture, Thomas Vilsack, (Sept. 10, 2013), http://www.washingtoncitypaper.com/blogs/housingcomplex/2013/09/20/dc-water-chief-urges-agriculture-secretary-not-to-allow-fracking-near-d-c/

[156] Wiener, A. (2013, September 20). DC Water Chief urges Agriculture Secretary not to allow fracking near D.C. *Washington City Paper*. Retrieved from http://www.washingtoncitypaper.com/blogs/housingcomplex/2013/09/20/dc-water-chief-urges-agriculture-secretary-not-to-allow-fracking-near-d-c/

[157] Sun Staff. (2013, September 3). More blowouts a concern for N.D. *The Jamestown Sun*. Retrieved from http://www.jamestownsun.com/content/more-blowouts-concern-nd

- August 28, 2013 – A joint USGS and U.S. Fish and Wildlife Service study documented a causal link between a fracking wastewater spill and the widespread death of fish in the Acorn Fork, a creek in Kentucky.[158]

- July 25, 2013 – A University of Texas at Arlington study of drinking water found elevated levels of arsenic and other heavy metals in some samples from private drinking water wells located within five kilometers of active natural gas wells in the Barnett Shale.[159]

- July 3, 2013 – *ProPublica* reported that the EPA was wrong to have halted its investigation of water contamination in Wyoming, Texas and Pennsylvania—where high levels of benzene, methane, arsenic, oil, methane, copper, vanadium, and other chemicals associated with fracking operations have been documented.[160] Although numerous organizations and health professionals around the country have since called on the agency to resume its investigation, no action has been taken.

- June 6, 2013 – Reviewing hundrends of regulatory and legal filings, *Bloomberg News* reported that drillers have offered out-of-court cash settlements and property buyouts to homeowners who claim that fracking ruined their water. These agreements typically come with gag orders and sealed records. This strategy, the investigation noted, allows the industry to continue claiming that no cases of water contamination due to fracking have ever been confirmed, impedes public health research, and shields data from regulators, policy makers, and the new media.[161] The EPA also long ago noted how non-disclosure agreements between oil and gas operators and landowners challenge scientific progress and keep examples of drilling harm secret from the public. In a 1987 report, the EPA wrote, "In some cases, even the records of well-publicized damage incidents are almost entirely unavailable for review. In addition to concealing the nature and size of any settlement entered into between the parties, impoundment curtails access to scientific and administrative documentation of the incident."[162]

- June 3, 2013 – A study by Duke University researchers linked fracking with elevated levels of methane, ethane, and propane in nearby groundwater.[163] Published in

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[158] Papoulias, D., & MacKenzie, T. (2013, August 28). Hydraulic fracturing fluids likely harmed threatened Kentucky fish species. *USGS Newsroom*. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=3677

[159] Fontenot, B. E., Hunt, L. R., Hildenbrand, Z. L., Carlton Jr., D. D., Oka, H., Walton, J. L., . . . Schug, K. A. (2013). An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale formation. *Environmental Science & Technology, 47*(17), 10032-10040. doi: 10.1021/es4011724

[160] Lustgarten, A. (2013, July 3). EPA's abandoned Wyoming fracking study one retreat of many. *ProPublica*. Retrieved from http://www.propublica.org/article/epas-abandoned-wyoming-fracking-study-one-retreat-of-many

[161] Efstathiou, J., Jr., & Drajem, M. (2013, June 5). Drillers silence fracking claims with sealed settlements. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2013-06-06/drillers-silence-fracking-claims-with-sealed-settlements.html

[162] Environmental Protection Agency. (1987). *Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy* (Rep.). 137-138. Washington, D.C.: U.S. Environmental Protection Agency.

[163] Jackson, R. B., Vengosh, A., Darrah, T. H., Warner, N. R., Down, A., Poreda, R. J., . . . Karr, J. D. (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences*, 110(28), 11250-11255. doi: 10.1073/pnas.1221635110

Proceedings of the National Academy of Sciences, the study included results from 141 northeastern Pennsylvania water wells. Methane levels were, on average, six times higher in drinking water wells closer to drilling sites when compared with those farther away, while ethane was 23 times higher.[164]

- May 19, 2013 – In Pennsylvania, the *Scranton Times-Tribune* released details of an investigation that revealed at least 161 cases of water contamination from fracking between 2008 and the fall of 2012, according to state Department of Environmental Protection records.[165]

- April 2013 – Researchers analyzing publicly available Colorado data found 77 surface spills impacting groundwater in Weld County alone. Samples of these spills often exceeded drinking water maximum contaminant levels (MCLs) for benzene, toluene, ethylbenzene and xylene; for benzene, a known carcinogen, 90% of the samples exceeded the legal limit.[166]

- March 4, 2013 – Researchers at the University of Pittsburgh Graduate School of Public Health analyzed samples of gas drilling wastewater discharged to surface water through wastewater treatment plants. Barium, strontium, bromides, chlorides, and benzene all exceeded levels known to cause human health impacts.[167]

- December 9, 2012 – State data in Colorado showed more than 350 instances of groundwater contamination resulting from more than 2,000 spills from oil and gas operations over the past five years. Further, as the *Denver Post* reported, "Contamination of groundwater—along with air emissions, truck traffic and changed landscapes—has spurred public concerns about drilling along Colorado's Front Range."[168]

- May 4, 2012 – A report for the Canadian Government, released under the Access to Information Act, reviewed the process, the regulatory framework globally, and the potential health hazards related to shale gas extraction. Additionally, the report evaluated mechanisms for potential impacts and summarized the data knowledge and data gaps. Regarding water contamination, the report determined, "Although quantitative data are lacking, the qualitative data available indicate that potential contamination of water

[164] CBS/AP. (2013, June 25). Methane found in Pa. drinking water near fracked wells. *CBS News*. Retrieved from http://www.cbsnews.com/news/methane-found-in-pa-drinking-water-near-fracked-wells/

[165] Legere, L. (2013, May 19). Sunday Times review of DEP drilling records reveals water damage, murky testing methods. *The Times-Tribune*. Retrieved from http://thetimes-tribune.com/news/sunday-times-review-of-dep-drilling-records-reveals-water-damage-murky-testing-methods-1.1491547

[166] Gross, S. A., Avens, H. J., Banducci, A. M., Sahmel, J., Panko, J. M., & Tvermoes, B. E. (2013). Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. *Journal of the Air & Waste Management Association, 63*(4), 424-432. doi: 10.1080/10962247.2012.759166

[167] Ferrar, K. J., Michanowicz, D. R., Christen, C. L., Mulcahy, N., Malone, S. L., & Sharma, R. K. (2013). Assessment of effluent contaminants from three facilities discharging Marcellus shale wastewater to surface waters in Pennsylvania. *Environmental Science & Technology, 47*(7), 3472-3481. doi: 10.1021/es301411q

[168] Finley, B. (2012, December 9). Drilling spills reaching Colorado groundwater; state mulls test rules. *The Denver Post*. Retrieved from http://www.denverpost.com/environment/ci_22154751/drilling-spills-reaching-colorado-groundwater-state-mulls-test#ixzz2EihHU2fg

related to the shale gas industry may present hazard to the public health, especially for local population." Regarding air contamination: "air emissions related to the shale gas industry present health hazards since the air pollutants originating from the vehicles and engines fuelled by diesel are toxic to the respiratory and cardiovascular systems and can cause premature mortality, volatile organic compounds have been associated to neurotoxicity and some of these compounds (e.g. benzene) as well as NORMs are known or possible human carcinogens." The report concluded, "Any step of shale gas exploration/exploitation may represent a potential source of drinking water and air contamination; Hydraulic fracturing and wastewater disposal were identified as the main potential sources of risk."[169]

- January 11, 2012 – The USGS reported that the Marcellus Shale is already highly fractured and that numerous fissures naturally occurring within the formation could potentially provide pathways for contaminants to migrate vertically into water supplies.[170]

- October 25, 2011 – After receiving new information from two companies, members of Congress updated their findings to show that "between 2005 and 2009, oil and gas service companies injected 32.7 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 20 states."[171]

- October 17, 2011 – Thomas P. Jacobus, General Manager of the U.S. Army Corps of Engineers' Washington Aqueduct, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest because of concern that fracking poses risks to drinking water. The Washington Aqueduct—which provides drinking water to Washington, DC, Arlington County, Virginia, and Falls Church, Virginia—is supplied by the Potomac River, which has its headwaters in the George Washington National Forest that sits atop the Marcellus Shale. Jacobus said, "Enough study on the technique [hydraulic fracturing] has been published to give us great cause for concern about the potential for degradation of the quality of our raw water supply…."[172]

- October 11, 2011 – Charles M. Murray, General Manager of Fairfax Water, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest. "Natural gas development activities have the potential to impact the quantity and quality

[169] Louis, S. (2012, May 4). Potential health hazards from shale gas exploration and exploitation–Drinking water and ambient air. Presented to Health Canada by SANEXEN Environmental Services; 0/Ref.: RA11-410. Document released under the (Canadian) Access to Information Act.
[170] U.S. Geological Survey, New York Water Science Center. (2012, January 11). *Comments on the revised draft supplemental generic environmental impact statement*. (Rep.). Retrieved from http://www.ewg.org/sites/default/files/report/ReviseddraftSGEIS_USGScomments_Version3_0.pdf
[171] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, October 25). *Committee on Energy & Commerce* (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/index.php?q=news/reps-waxman-markey-and-degette-report-updated-hydraulic-fracturing-statistics-to-epa
[172] Jacobus, T. P. (2012, April 25). Draft environmental impact statement for the George Washington National Forest [Letter written October 17, 2011 to K. Landgraf]. Retrieved, from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5366331.pdf

of Fairfax Water's source water," Murray wrote. "Downstream water users and consumers will bear the economic burden if drinking water sources are contaminated or the quality of our source water supply is degraded."[173] Fairfax Water provides drinking water for Fairfax County in Virginia.

- September 7, 2011 – In its draft Supplemental Generic Environmental Impact Statement (SGEIS), the New York State Department of Environmental Conservation (NYS DEC) acknowledged that "there is questionable available capacity"[174] for New York's public sewage treatment plants to accept drilling wastewater, yet the agency said that it would allow those facilities to accept such waste if the plants meet permitting conditions.[175] The NYS DEC proposed underground injection as one alternative to sewage treatment procession of fracking waste. Although it is a common method of disposal for fracking wastewater,[176] the last significant government study of pollution risks from oil and gas wastewater injection wells occurred in 1989 and found multiple cases of costly groundwater contamination.[177] In subsequent years, studies have continued to link underground injection of drilling wastewater to pollution as well as earthquakes.[178]

- September 2011 – A team led by Theo Colburn of The Endocrine Disruptor Exchange found that 25 percent of chemicals known to be used in fracking fluids are implicated in cancer, 37 percent could disrupt the endocrine system, and 40 to 50 percent could cause nervous, immune and cardiovascular system problems. The research team also found that more than 75 percent could affect the skin, eyes, and respiratory system, resulting in various problems such as skin and eye irritation or flu-like symptoms.[179]

- August 4, 2011 – As reported by the *New York Times,* the EPA had alerted Congress in 1987 about a case of water contamination caused by fracking. Its report documented that

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[173] Murray, C. M. (n.d.). Draft environmental impact statement for the George Washington National Forest [Letter written October 11, 2013 to K. Landgraf]. Retrieved from http://www.svnva.org/wp-content/uploads/fairfax-wash-aquaduct-gwnf-comments.pdf

[174] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-62, Rep.).

[175] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-57 through 6-63, Rep.).

[176] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-64, Rep.).

[177] United States Government Accountability Office. (1989, July 5). Drinking water: Safeguards are not preventing contamination from injected oil and gas wastes. Retrieved from http://www.gao.gov/products/RCED-89-97

[178] Fountain, H. (2012, January 1). Disposal halted at well after new quake in Ohio. *The New York Times*. Retrieved from http://www.nytimes.com/2012/01/02/science/earth/youngstown-injection-well-stays-shut-after-earthquake.html

[179] Colborn, T., Kwiatkowski, C., Schultz, K., & Bachran, M. (2011). Natural gas operations from a public health perspective. *Human and Ecological Risk Assessment: An International Journal, 17*(5), 1039-1056. doi: 10.1080/10807039.2011.605662

a shale gas well hydraulically fractured at a depth of more than 4,200 feet contaminated a water supply only 400 feet from the surface.[180, 181, 182]

- May 17, 2011 – The state of Pennsylvania fined Chesapeake Energy Corporation $900,000 for an incident in which improper cementing and casing in one of the company's gas wells allowed methane to migrate underground and contaminate 16 private drinking water wells in Bradford County.[183]

- May 17, 2011 – A Duke University study documented "systematic evidence for methane contamination of drinking water associated with shale gas extraction."[184] The study showed that methane levels were 17 times higher in water wells near drilling sites than in water wells in areas without active drilling.[185]

- April 22, 2011 – Describing one of many blowouts, the Associated Press reported on a shale gas well in Canton, Pennsylvania that spewed thousands of gallons of chemical-laced water on farmland and into a stream for two consecutive days before being brought under control.[186]

- April 18, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) released the second of two reports issued in 2011. Their analysis of hydraulic fracturing fluids used by the 14 leading oil and natural gas service companies between 2005 and 2009 found, among other things, that the companies used more than 650 different products that contained chemicals that are known or possible human carcinogens, regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants under the Clean Air Act. The report also showed that "between 2005 and 2009, the companies used 94 million gallons of 279 products that contained at least one chemical or component that the manufacturers deemed proprietary or a trade secret … in most cases the companies stated that they did not have access to proprietary information about products they purchased 'off the shelf' from chemical suppliers. In these cases, the companies are injecting fluids containing

[180] Urbina, I. (2011, August 4). A tainted water well, and concern there may be more. Retrieved from http://www.nytimes.com/2011/08/04/us/04natgas.html
[181] U.S. Environmental Protection Agency. (1987). *Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy* (Rep.). 4-22, 4-23. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012D4P.PDF
[182] Horwitt, D. (2011, August 3). Cracks in the facade. *Environmental Working Group*. Retrieved from http://www.ewg.org/research/cracks-façade
[183] Levy, M. (2011, May 18). DEP fines Chesapeake $1 million. *Pressconnects.com*. Retrieved from http://www.pressconnects.com/viewart/20110517/NEWS01/105170345/DEP-fines-Chesapeake-1-million
[184] Osborn, S. G., Vengosh, A., Warner, N. R. & Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences*, *108,* 8172-8176. doi: 10.1073/pnas.1100682108
[185] Duke University. (2011). Methane levels 17 times higher in water wells near hydrofracking sites, study finds. *ScienceDaily*. Retrieved from http://www.sciencedaily.com/releases/2011/05/110509151234.htm
[186] The Associated Press. (2011, April 22). Crews stop flow of drilling fluid from Pennsylvania well. *Syracuse.com*. Retrieved from http://www.syracuse.com/news/index.ssf/2011/04/crews_stop_flow_of_drilling_fl.html

chemicals that they themselves cannot identify."[187] These findings were reported in the *New York Times*.[188]

- January 2011 – A team of scientists led by a University of Central Arkansas researcher called attention to the threat posed to surface waters by rapidly expanding shale gas development, noting a lack of data collection accompanying the rush to drill. "Gas wells are often close to surface waters that could be impacted by elevated sediment runoff from pipelines and roads, alteration of stream flow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater."[189]

- January 31, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) reported that "between 2005 and 2009, oil and gas service companies injected 32.2 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 19 states." Furthermore, revealing apparent widespread violation of the Safe Drinking Water Act, the investigation found that no oil and gas service companies had sought—and no state or federal regulators had issued—permits for the use of diesel fuel in hydraulic fracturing.[190]

- April 29, 2010 – In 2010, the Colorado Oil and Gas Conservation Commission fined Occidental Petroleum Corporation (OXY) USA a record $390,000 for an incident of pollution, discovered in 2008, when its drilling wastes leaked through an unlined pit, contaminated two springs with benzene, and polluted other nearby water sources. In addition, the regulators separately fined OXY USA $257,400 for a nearby case of pollution, also discovered in 2008, in which a torn liner in a pit caused drilling waste fluids to leak out and contaminate two springs with benzene.[191]

[187] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, April 18). Committee on Energy & Commerce (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf

[188] Urbina, I. (2011, April 17). Chemicals Were Injected Into Wells, Report Says. *The New York Times*. Retrieved from http://www.nytimes.com/2011/04/17/science/earth/17gas.html

[189] Entrekin, S., Evans-White, M., Johnson, B., & Hagenbuch, E. (2011). Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and the Environment, 9*(9), 503-511. doi: 10.1890/110053

[190] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, January 31). *Committee on Energy & Commerce* (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/index.php?q=news/waxman-markey-and-degette-investigation-finds-continued-use-of-diesel-in-hydraulic-fracturing-f

[191] Webb, D. (2010, April 29). Record fine, second one against Oxy approved. *Grand Junction Sentinel*. Retrieved from http://www.gjsentinel.com/news/articles/record-fine-second-one-against-oxy-approved

- June 5, 2009 – A leaking pipe carrying fracking waste in Washington County, Pennsylvania, polluted a tributary of Cross Creek Lake, killing fish, salamanders, crayfish, and aquatic insect life in approximately three-quarters of a mile of the stream.[192]

- April 26, 2009 – Officials in three states linked water contamination and methane leaks to gas drilling. Incidents included a case in Ohio where a house exploded after gas seeped into its water well and multiple cases of exploding drinking water wells in Dimock, Pennsylvania.[193]

- November 13, 2008 – *ProPublica* reported more than 1,000 cases of drilling-related contamination documented by courts and state and local governments in Colorado, New Mexico, Alabama, Ohio, and Pennsylvania.[194]

- December 15, 2007 – In Bainbridge, Ohio, a gas well that was improperly cemented and subsequently fractured by Ohio Valley Energy Systems Corporation allowed natural gas to migrate outside of the well, causing a home to explode. In addition, 23 nearby water wells were contaminated, two of which were located more than 2,300 feet from the drilling site.[195, 196, 197]

[192] Pittsburgh Post-Gazette. (2009, June 5). Waste from Marcellus shale drilling in Cross Creek Park kills fish. *Pittsburgh Post-Gazette*. Retrieved, from http://www.post-gazette.com/washington/2009/06/05/Waste-from-Marcellus-shale-drilling-in-Cross-Creek-Park-kills-fish/stories/200906050136

[193] Lustgarten, A. (2009, April 26). Officials in three states pin water woes on gas drilling. *ProPublica*. Retrieved from http://www.propublica.org/article/officials-in-three-states-pin-water-woes-on-gas-drilling-426

[194] Lustgarten, A. (2008, November 13). Buried secrets: Is natural gas drilling endangering U.S. water supplies? *ProPublica*. Retrieved from http://www.propublica.org/article/buried-secrets-is-natural-gas-drilling-endangering-us-water-supplies-1113

[195] Ohio Department of Natural Resources Division of Mineral Resources Management. (2008, September 1). *Report on the investigation of the natural gas invasion of aquifers in Bainbridge Township of Geauga County, Ohio*. (Rep.). Retrieved from http://www.ohiodnr.com/mineral/bainbridge/tabid/20484/default.aspx

[196] Bair, E. S., Freeman, D. C., & Senko, J. M. (2010, June). *Expert panel technical report, subsurface gas invasion Bainbridge Township, Geauga County, Ohio* (Rep.). Retrieved from http://oilandgas.ohiodnr.gov/portals/oilgas/pdf/bainbridge/DMRM%200%20Title%20Page,%20Preface,%20Acknowledgements.pdf

[197] Ohio Department of Natural Resources, Order Number 2009-17 (Apr. 14, 2009) (see attachments A, B).