Fracking by the Numbers

The Damage to Our Water, Land and Climate from a Decade of Dirty Drilling

Environment America Research & Policy Center

Frontier Group

Fracking by the Numbers

The Damage to Our Water, Land and Climate from a Decade of Dirty Drilling

Written by:

Elizabeth Ridlington and Kim Norman
Frontier Group

Rachel Richardson
Environment America Research & Policy Center

April 2016

Acknowledgments

Environment America Research & Policy Center sincerely thanks Amy Mall, Senior Policy Analyst, Land & Wildlife Program, Natural Resources Defense Council; Courtney Bernhardt, Senior Research Analyst, Environmental Integrity Project; and Professor Anthony Ingraffea of Cornell University for their review of drafts of this document, as well as their insights and suggestions. Frontier Group interns Dana Bradley and Danielle Elefritz provided valuable research assistance. Our appreciation goes to Jeff Inglis for data assistance. Thanks also to Tony Dutzik and Gideon Weissman of Frontier Group for editorial help.

We also are grateful to the many state agency staff who answered our numerous questions and requests for data. Many of them are listed by name in the methodology.

The authors bear responsibility for any factual errors. The recommendations are those of Environment America Research & Policy Center. The views expressed in this report are those of the authors and do not necessarily reflect the views of our funders or those who provided review.

Environment America Research & Policy Center is a 501(c)(3) organization. We are dedicated to protecting our air, water and open spaces. We investigate problems, craft solutions, educate the public and decision-makers, and help the public make their voices heard in local, state and national debates over the quality of our environment and our lives. For more information about Environment America Research & Policy Center or for additional copies of this report, please visit www.environmentamericacenter.org.

Frontier Group provides information and ideas to help citizens build a cleaner, healthier, fairer and more democratic America. We address issues that will define our nation's course in the 21st century—from fracking to solar energy, global warming to transportation, clean water to clean elections. Our experts and writers deliver timely research and analysis that is accessible to the public, applying insights gleaned from a variety of disciplines to arrive at new ideas for solving pressing problems. For more information about Frontier Group, please visit www.frontiergroup.org.

Layout: Harriet Eckstein Graphic Design

Cover: *Fracking-related activity has turned this well pad in western Pennsylvania into an industrial site.* Doug Duncan/USGS

Contents

Executive Summary

The combination of two technologies—hydraulic fracturing and horizontal drilling—has enabled the oil and gas industry to engage in an effort to unlock oil and gas in underground rock formations across the United States. "Fracking," however, has also led to tremendous environmental harm and put the health and safety of communities across the country at risk.

Since 2005, according to industry and state data, **more than 137,000 fracking wells have been drilled or permitted in more than 20 states**, but the scale of fracking's impact on our environment can be difficult to grasp. This report quantifies some of the key environmental and public health-related impacts triggered by fracking during the technology's decade-long spread across the country. To protect the public and our environment, states should take action to ban fracking, or, failing that, to ensure that oil and gas companies are held to the highest level of environmental performance, transparency and accountability.

Toxic Chemicals and Health

Fracking uses vast quantities of chemicals known to harm human health**.** According to industry-reported data in the FracFocus database, oil and gas wells fracked across the U.S. between 2005 and 2015 used at least:

- 5 billion pounds of hydrochloric acid, a caustic acid (p. 22-24);
- 1.2 billion pounds of petroleum distillates, which can irritate the throat, lungs and eyes; cause dizziness and nausea; and can include toxic and cancer-causing agents; and
- 445 million pounds of methanol, which is suspected of causing birth defects.
- The exact identities of many other chemicals are unknown because they are kept secret as proprietary information.

People living or working nearby can be exposed to these chemicals if they enter drinking water after a spill or if they become airborne.

- A recent analysis by researchers at the Yale School of Public Health identified 157 chemicals used in fracking that are toxic; the toxicity of 781 other fracking chemicals examined by the researchers is unknown (p. 10).
- A 2014 study by scientists at Lawrence Berkeley National Laboratory reported that an estimated 10 percent of chemicals used in fracking fluid are known to be toxic to humans or aquatic life (p. 10).

Table ES-1. National Environmental and Public Health-Related Impacts of Fracking

Fracking Wells since 2005	At least 137,000
Water Used since 2005	At least 239 billion gallons
Toxic Wastewater Produced in 2014, selected states	At least 14 billion gallons
Land Directly Damaged since 2005	679,000 acres
Global Warming Pollution from Well Completions in 2014 (methane)	At least 5.3 billion pounds

Wastewater and Drinking Water Supplies

Fracking threatens drinking water supplies**.** Across the country, fracking wastewater has leaked from retention ponds or escaped from faulty disposal wells, putting drinking water at risk. Wastewater from fracked wells includes not only the toxic chemicals injected into the well but also naturally occurring radioactive materials that can be brought to the surface.

- Fracking wells produced at least 14 billion gallons of wastewater in 2014. Wastewater production data is not available in some of the states with the most wells, including Texas and North Dakota, meaning that the total amount of fracking wastewater produced in the United States is higher than is estimated here (p. 21-22).

- Pennsylvania regulators have confirmed at least 260 instances of private well contamination from fracking operations since 2005, a number that is likely a severe underestimate (p. 10).

- Data from fracking wells in Pennsylvania from 2010 to 2012 show a 6 to 7 percent rate of well failure due to compromised structural integrity (p. 11).

Water Consumption

Fracking requires huge volumes of water for each well—water that is often needed for other uses or to maintain healthy aquatic ecosystems.

- At least 239 billion gallons of water have been used in fracking since 2005, an average of 3 million gallons per well (p. 24-25).

- Water used in fracking becomes unsuitable for most uses other than fracking another well.

- Farmers can be particularly impacted by the oil and gas industry's demand for freshwater, especially in drought-stricken regions of the country. In one water auction in Colorado in 2012, oil and gas companies paid up to $3,300 for an acre-foot of water, as much as 100 times what farmers typically pay (p. 13).

Global Warming

Methane from fracking operations adds global warming pollution to the atmosphere.

- Bringing new fracked wells into production in 2014 released at least 5.3 billion pounds of methane. That's equivalent to annual global warming emissions from 22 coal-fired power plants (p. 25).

- Methane, a global warming pollutant 86 times more powerful than carbon dioxide over the course of 20 years, is released at multiple steps during fracking, including during hydraulic fracturing and well completion, and in the processing and transport of gas to end users.

Destruction of Natural Landscapes

Well pads, new access roads, pipelines and other infrastructure built for fracking turn forests and rural landscapes into industrial zones.

- Infrastructure to support fracking has directly damaged at least 679,000 acres of land since 2005, an area slightly smaller than Yosemite National Park (p. 25-26).

- As well pads, roads, pipelines and other gas infrastructure replace forests and farmland, the nation loses wildlife habitat and the remaining wild areas are increasingly fragmented and inhospitable to wildlife. For example, the mule deer population in Wyoming's Pinedale Mesa declined 40 percent from 2001 to 2015, a period of extensive gas development (p. 16).

- Well operators are supposed to restore damaged landscapes after drilling operations are complete, but full restoration is nearly impossible, especially as oil and gas producers struggle financially and may lack the resources to fund land restoration.

Other Impacts

Other public health threats from fracking include air pollution and earthquakes.

- Air pollution from fracking contributes to the formation of ozone "smog," which reduces lung function among healthy people, triggers asthma attacks, and has been linked to increases in school absences, hospital visits and premature death. Other air pollutants from fracking and the fossil fuel-fired machinery used in fracking have been linked to cancer and other serious health effects.

- The injection of fracking wastewater into underground wells has been linked to earthquakes in several states. In 2014, residents in the central and eastern U.S. felt 659 earthquakes, compared to an average of just 21 per year from 1973 to 2008, according to the U.S. Geological Survey (p. 19).

To address the environmental and public health threats from fracking across the nation, states should prohibit fracking. No plausible system of regulation appears likely to address the scale and severity of fracking's impacts.

In places where fracking does continue to take place:

- Fracking should be subject to all relevant environmental laws. Federal policymakers must close the loopholes exempting fracking from key provisions of our nation's environmental laws.

- Our most important natural areas should be kept off limits. Federal officials should ban fracking on our public lands, including national parks, national forests, and sources of drinking water.

Table ES-2. Estimated Impacts of Fracking, Selected States. Data are cumulative impacts since 2005, except where noted.

State	Wells Fracked	Hydrochloric Acid Used (thousand pounds)	Methanol Used (thousand pounds)	Wastewater Produced in 2014 (million gallons)	Water Consumed (million gallons)	Methane Released from Well Completion in 2014 (million pounds)	Land Disturbed (acres)
Arkansas	6,496	142,406	2,025	unavailable	11,290	144	22,858
California	3,405	1,034	489	1,057	237	140	15,940
Colorado	22,615	68,663	10,042	3,139	19,142	395	105,866
Louisiana	2,883	15,136	2,045	unavailable	4,880	50	16,010
New Mexico	4,318	70,798	4,403	8,592	3,132	125	35,273
North Dakota	8,224	82,198	88,168	unavailable	14,891	517	33,718
Ohio	1,594	105,447	1,942	313	7,771	136	9,118
Oklahoma	7,421	455,225	17,147	unavailable	19,582	546	41,210
Pennsylvania	9,233	1,806,032	5,396	1,821	24,732	295	52,813
Texas	54,958	2,148,789	302,501	unavailable	120,215	2,521	257,272
Utah	4,949	35,926	1,414	unavailable	916	186	35,478
West Virginia	2,670	64,134	1,174	unavailable	7,651	88	15,272
Wyoming	7,277	18,074	5,870	70	2,528	116	29,836
TOTAL	**137,743**	**5,038,953**	**444,786**	**14,993**	**239,166**	**5,340**	**679,148**

Defining "Fracking"

In this report, when we refer to the impacts of "fracking," we include impacts resulting from all of the activities needed to bring a gas or oil well into production using high-volume (more than 100,000 gallons of water) hydraulic fracturing, to operate that well, and to deliver the gas or oil produced from that well to market. The oil and gas industry often uses a more restrictive definition of "fracking" that includes only the actual moment in the extraction process when rock is fractured—a definition that obscures the broad changes to environmental, health and community conditions that result from the use of fracking in oil and gas extraction.

- The oil and gas industry—not taxpayers, communities or families—should pay the costs of damage caused by fracking. Policymakers should require robust financial assurance from fracking operators at every well site.
- The public's right to know about fracking's environmental damage must be respected. More complete data on fracking should be collected and made available to the public, enabling us to understand the full extent of the harm that fracking causes to our environment and health.

Introduction

In 2013, Environment America Research & Policy Center and Frontier Group released an analysis of the cumulative impacts of fracking. Fracking is the relatively new process of injecting water, chemicals and sand into horizontal wells under high pressure to crack rock and release oil and gas. Our 2013 report filled a gap in public knowledge by showing how fracking's damage is not limited to just a few drinking water wells that produce flammable water. Our report documented how much water fracking wells had consumed and how much wastewater they had produced, how much air and global warming pollution fracking had released, and how many acres of habitat had been damaged in more than 20 states.

Though our report compiled data that hadn't been presented before, it was an incomplete accounting of fracking's impacts, because data about fracking were incomplete and difficult to obtain. More information has become available since that 2013 report, though it is far from complete and the number of fracked wells has greatly increased.

Now, more than two years later, we present an updated and more complete assessment of the impacts of fracking across the country. In addition to updated data on the number of fracked wells in each state, water consumption, wastewater production, global warming pollution and habitat damage, the new accounting includes information about the toxic chemicals used in each state. That's because industry-reported data on some of the chemicals used in fracking are now available for analysis, offering the opportunity to better understand the environmental and public health risks of fracking.

While this new report is a more comprehensive telling of fracking's consequences, gaps remain in our knowledge. Not all states require disclosure of which wells are fracked, or what chemicals have been used. Reported information is often incomplete or inaccurate, preventing analysis of a large subset of wells.

This report synthesizes the best data currently available about fracking, updating and expanding on our previous report. We hope it inspires members of the public and policymakers to take decisive action to address the destruction caused by fracking.

Fracking Poses Grave Threats to the Environment and Public Health

Over the past decade, the oil and gas industry has used hydraulic fracturing to extract oil and gas from previously inaccessible rock formations deep underground. The use of high-volume hydraulic fracturing—colloquially known as "fracking"—has expanded dramatically from its origins in the Barnett Shale region of Texas a decade ago to tens of thousands of wells nationwide today.

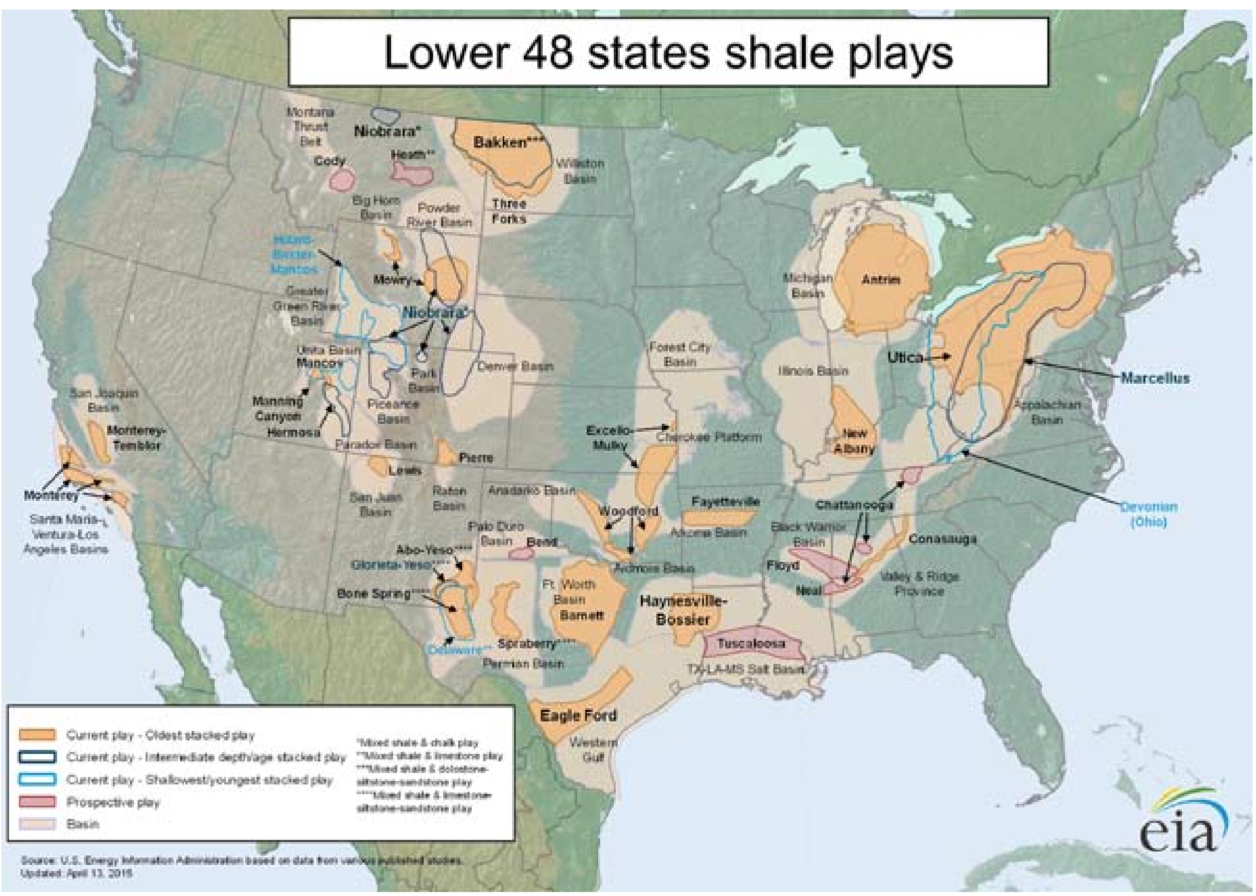
Roughly half of U.S. states, stretching from New York to California, sit atop shale or other rock formations with the potential to produce oil or gas using fracking. (See Figure 1.)

Fracking has unleashed oil and gas drilling in many of these shale formations—posing severe threats to the environment and public health.

Contaminating Drinking Water

Fracking has polluted both groundwater and surface waterways such as rivers, lakes and streams. Fracking pollution can enter our

Figure 1. Shale Gas and Oil Plays[1]



waterways at several points in the process—including surface leaks and spills of fracking fluid, well blowouts, the escape of methane and other contaminants from the well itself into groundwater, and the long-term migration of contaminants underground.

Fracking operations have contaminated water supplies across the country. In January 2015, 3 million gallons of fracking wastewater leaked out of a pipe in western North Dakota, contaminating two creeks that feed into the Missouri River, a source of drinking water for nearby towns.[2] In Ohio, in 2014 about 16,000 gallons of oil-based lubricant leaked into a tributary of the Ohio River, which supplies drinking water to millions of people.[3]

Pennsylvania regulators have confirmed at least 260 instances of private well contamination from fracking operations since 2005, though the real number is likely higher. Independent journalists and documentary filmmakers at *Public Herald* have identified 2,309 complaints of pollution of private water wells from 17 out of the 40 Pennsylvania counties where fracking takes place.[4]

Spills and Leaks of Fracking Fluids

Toxic substances in fracking chemicals and wastewater are associated with a variety of negative health effects. Chemical components of fracking fluids, for example, have been linked to cancer, endocrine disruption and neurological and immune system problems.[5] Researchers at the Yale School of Public Health analyzed more than 1,000 chemicals found in fracking fluid and wastewater. Toxicity data were not available for three-quarters of the chemicals; of the chemicals for which toxicity data were available, 65 percent were toxic.[6] In other words, at least 15 percent of the chemicals used in fracking are toxic. A 2014 study by scientists at Lawrence Berkeley National Laboratory reported that around 10 percent of chemicals used in fracking fluid are known to be toxic to humans or aquatic life.[7]

Spills of toxic fracking chemicals present a threat to public health and the environment. For example, a 2014 study of surface and groundwater samples from heavily-fracked Garfield County, Colorado, revealed elevated levels of endocrine-disrupting chemicals linked to infertility, birth defects and cancer.[8]

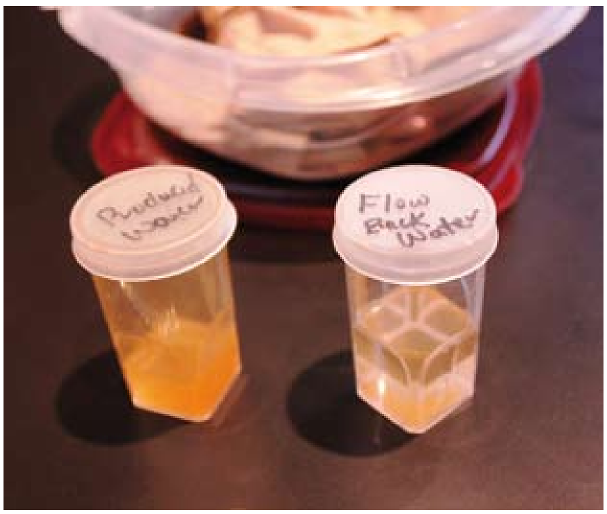
There are many pathways by which fracking fluids can contaminate drinking water supplies. Spills from trucks, leaks from other surface equipment or wastewater impoundments, and well blowouts can release polluted water to groundwater and surface water. Such spills, leaks and other incidents are common:

- In June 2014 in Amwell Township, Pennsylvania, a torn liner for a wastewater impoundment resulted in a leak that contaminated 15,000 tons of soil with chlorine. Further testing revealed groundwater contamination.[9]

Fracking Fluids Spill into Buckeye Creek, Doddridge County, West Virginia, 2009; Photo by Ed Wade Jr. and Wetzel County Action Group

- Researchers with the Environmental Protection Agency have identified 457 spills in 11 states caused by fracking operations from 2006 to 2012, and concluded that this likely undercounts the actual number of fracking-related spills.[10]

- A 2013 EPA report estimated that there are 1.3 spills on or near well pads for every 100 fracked wells in Colorado.[11] In Pennsylvania, spill rate estimates range from 0.4 to 12.2 per 100 fracked wells.[12]



Samples of produced water and flowback water from fracking. Photo: "Dr. Helen Boylan Breaks Down Fracking," WCN 24/7, CC BY-NC 2.0 https://creativecommons.org/licenses/by-nc/2.0/

Leakage of Methane and Other Contaminants from Fracking Wells

Water contamination can also occur underground. A study by researchers at Duke University showed that Pennsylvania residential drinking water wells located close to fracking wells were more likely to be contaminated with methane, with faulty fracking well casings as a likely source.[13] Data from fracking wells in Pennsylvania from 2010 to 2012 show a 6 to 7 percent rate of well failure due to compromised structural integrity.[14] Earlier this year, a jury convicted a company of contaminating drinking water wells in Dimock Township, Pennsylvania, with methane after drilling wells that were faulty.[15]

Other pollutants can travel underground, too. A recent analysis of 550 groundwater samples drawn from aquifers overlying the Barnett Shale formation of Texas found elevated levels of 10 different metals as well as 19 different chemical compounds associated with hydraulic fracturing, including benzene, toluene, ethylbenzene and xylene.[16] Another study found higher concentrations of arsenic, selenium and strontium in drinking water wells in the region, perhaps the result of the disturbance fracking creates underground.[17]

Leakage of Toxic Fracking Waste

The wastewater produced from fracking wells contains pollutants both from fracking fluids and from natural sources underground. Wastewater returns to the surface in huge volumes—both as "flowback" immediately after fracking and "produced water" over a longer period while a well is producing oil or gas. Yet fracking operators have no safe, sustainable way of dealing with this toxic waste. The approaches that drilling companies have devised for dealing with wastewater can pollute waterways:

- Waste pits can fail. A 2015 review of drilling waste management in four states in the Marcellus and Utica Shale regions revealed inadequate oversight by regulators, leading to several incidents of contamination.[18] In 2014, a court fined a Pennsylvania operator $4.15 million after it failed to contain spilled fracking wastewater from six impoundments, which spread to surrounding soil and water.[19] In Ohio, where no specific regulations govern the use of pits and impoundments to dispose of fracking waste, inspectors have attributed at least 63 incidents of water contamination to the improper construction or maintenance of these facilities.[20]

- Drilling companies may deliberately dump wastewater, spread it on roads to control dust or melt ice, or use it for irrigation.[21] Pollutants from the water can then contaminate local waterways. For example, in Pennsylvania in 2010, XTO Energy, an ExxonMobil subsidiary, was charged with dumping more than 5,000 gallons of wastewater onto the ground at a well site in Lycoming County, polluting a nearby stream.[22]

- Drilling companies can mistakenly dump waste into drinking water sources. State officials in California have admitted allowing oil companies to dump nearly three billion gallons of drilling wastewater into clean water aquifers due to a "paperwork" error. Regulators subsequently found elevated levels of nitrate, arsenic and thallium in half of the samples tested.[23]

- Deep disposal wells are a common destination for fracking waste, but these wells can fail over time, allowing the wastewater and its pollutants to mix with groundwater or surface water.[24] For example, fracking wastewater injected into a disposal well contaminated the Cenozoic Pecos Alluvium Aquifer near Midland, Texas.[25]

- Pressure from injection wells may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers. For example, at two injection wells in Ohio, toxic chemicals pumped underground in the 1980s, supposedly secure for at least 10,000 years, migrated into a well within 80 feet of the surface over the course of two decades.[26] Investigators believe that excessive pressure within the injection well caused the rock to fracture, allowing chemicals to escape.

Fracking waste in Kern County, CA. Photo: Sarah Craig/Faces of Fracking, CC BY-NC-ND 2.0, https://creativecommons.org/licenses/by-nc-nd/2.0/

Consuming Scarce Water Resources

Each well that is fracked requires hundreds of thousands or millions of gallons of water, depending on the formation and the depth and length of any horizontal portion of the well. Unlike most industrial uses of water, in which water returns to the water cycle for further use, water used in fracking typically cannot be cleaned up for a broad range of other uses. Water used in fracking either remains in the well, is "recycled" (used in the fracking of new wells), or is disposed of in deep injection wells, where it is unavailable to recharge aquifers. Thus, fracking takes billions of gallons out of the water supply annually.

In some areas, fracking makes up a significant share of overall water demand. Texas' Eagle Ford Shale oil play used nearly 18 billion gallons of water in 2013, roughly 16 percent of the area's total water consumption.[27]

Demand for water by oil and gas companies has harmed farmers and local communities. For example, the municipal water supply went dry in Barnhart, Texas, in 2013, after excessive water withdrawals for fracking compounded the effects of a years-long drought.[28] Across the Permian Basin, companies have drilled wells and purchased well water drawn from the Edwards-Trinity-Plateau Aquifer, drying up water supplies for residential and agricultural use.

Competition for limited water resources from fracking can increase water prices for farmers and communities—especially in arid western states. In 2012, in parts of Colorado, oil and gas companies paid up to $3,300 for an acre-foot of water. Ranchers and farmers, who paid between $30 and $100 for the same amount of water in previous years, were unable to match the rates paid by oil and gas companies, threatening farmers' ability to continue to grow food.[29]

Nationally, nearly half of all fracking wells are located in regions with very limited water supplies. A 2013 study by Ceres, a coalition of business and environmental interests, found that 47 percent of fracked oil and gas wells were located in regions with "high" or "extremely high" water stress and that more than 55 percent of wells fracked from 2011 to 2013 were located in areas experiencing drought.[30] Ninety-six percent of wells in California and 97 percent of wells in Colorado were located in regions of high or extremely high water stress, where 40 to over 80 percent of available surface and groundwater was already allocated for other uses.[31]

Endangering Public Health with Air Pollution

Air pollution from fracking threatens the health of people living and working close to the wellhead, as well as those far away. Children, the elderly and those with respiratory diseases are especially at risk.

Fracking produces air pollution as the well is drilled and fracked and gas is vented or flared. Emissions from trucks carrying water and materials to well sites, as well as from compressor stations and other fossil fuel-fired machinery, contribute to air pollution. Well operations, storage of gas liquids, and other activities related to fracking add to the pollution toll.

Making Local Residents Sick

People who live close to fracking sites are exposed to a variety of air pollutants including volatile organic compounds (VOCs) such as benzene, xylene and toluene. These chemicals can cause a wide range of health problems—from eye irritation and headaches to asthma and cancer.[32]

A 2014 Colorado study linked prenatal exposure to fracking chemicals in the air, specifically toluene, xylenes, and benzene, to higher rates of birth defects. Researchers found that the risk of giving birth to infants with congenital heart or neural tube defects increases with proximity to natural gas extraction sites. In fact, children of mothers living within 10 miles of gas wells were 30 percent more likely to be born with congenital heart disease and twice as likely to have a neural tube defect.[33] A large number of people may be at risk of such effects: As of 2013, more than 15 million people in the U.S. lived within one mile of a natural gas well drilled since 2000, and in some areas, such as Johnson County, Texas, 99.5 percent of residents lived within one mile.[34]

VOCs are not the only air pollutants released during natural gas extraction. A 2015 study measured levels of polycyclic aromatic hydrocarbons (PAHs) such as benzo[a]pyrene, fluoranthene and benzo[b]fluoranthene around Ohio fracking sites and found that concentration of PAHs was higher closer to wells. Researchers estimated that the excess lifetime cancer risk is over 30 percent higher for people living within one tenth of a mile of a natural gas extraction site than for those who resided more than a mile away.[35]

Exposing Workers to Unsafe Pollution

Workers at drilling sites also suffer from health impacts. In 2013, the National Institute for Occupational Safety and Health (NIOSH) found that workers at 15 out of 17 drilling sites in Colorado and Wyoming were exposed to hazardous levels of airborne benzene when they opened the hatches of tanks on top of fracking wells to measure flowback, a routine step in the drilling process. According to the Centers for Disease Control, benzene exposure can cause severe damage to the nervous system, kidneys, liver, blood and the immune system.[36] Between 2010 and 2014, NIOSH attributed nine worker deaths to acute hydrocarbon exposure from oilfield vapors.[37]

Fracking workers also face an increased risk of lung disease as a result of inhaling silica dust from sand injected into wells. Nearly half of 116 tested air samples from fracking sites in Arkansas, Colorado, North Dakota, Pennsylvania and Texas contained levels of silica that exceeded the Occupational Safety and Health Administration's (OSHA) legal limit for workplace exposure. Nine percent of the samples exceeded the legal limit for silica by a factor of 10, exceeding the threshold at which half-face respirators can effectively protect workers.[38]

Regional Air Pollution Threats

Fracking also produces a variety of pollutants that contribute to regional air pollution problems. VOCs and nitrogen oxides (NO_x) emitted from gas formations or equipment used in drilling contribute to the formation of ozone "smog," which reduces lung function among healthy people, triggers asthma attacks, and has been linked to increases in school absences, hospital visits and premature death.[39]

The extent of the air pollution problem from fracking is not fully known. A 2014 investigation by the Center for Public Integrity revealed inadequate emissions monitoring by the state of Texas at the Eagle Ford Shale formation, where there are more than 7,000 completed oil and gas wells. The 20,000 square mile area has only five air monitors, all located on the formation's fringes where emissions are much lower. The investigation also found that punishment is minimal to nonexistent for violations of emissions standards. Of 164 documented violations between 2010 and November 2013, the Texas Commission on Environmental Quality issued fines in only two cases.[40]

Exacerbating Global Warming

Global warming is a profound threat to virtually every aspect of nature and human civilization –disrupting the functioning of ecosystems, increasing the frequency and violence of extreme weather, and ultimately jeopardizing health, food production, and water resources for Americans and people across the planet.

Fracking's primary impact on the climate is through the release of methane, which is a far more potent contributor to global warming than carbon dioxide. Over a 100-year timeframe, a pound of methane has 34 times the heat-trapping effect of a pound of carbon dioxide.[41] Methane is even more potent relative to carbon dioxide at shorter timescales, at least 86 times more over a 20-year period.

Intentional venting of gas and accidental gas leaks release substantial amounts of methane into the atmosphere. Multiple studies have found high methane leakage rates at fracked wells.

- Aircraft-based air sampling over Colorado's Front Range allowed researchers from the University of Colorado Boulder (CU Boulder), the National Oceanic and Atmospheric Administration (NOAA), and the University of California, Davis to estimate that 4.1 percent of natural gas produced in the area escapes into the atmosphere.[42]
- In southwestern Pennsylvania, an area with extensive fracking activity, researchers from Purdue, Cornell, CU Boulder, Penn State and NOAA estimated that 7 percent of natural gas produced in the region escapes to the atmosphere.[43]
- A 2014 analysis of satellite measurements of air composition found that as a proportion of total energy production, methane emissions comprised 10.1 percent over the Bakken formation and 9.1 percent over the Eagle Ford Shale.[44]

Not every study has found high levels of methane leakage from fracking wells, but those that have found lower levels of leakage often suffer from questionable assumptions or methodologies. One widely-cited study conducted by a team from the University of Texas, Austin, that found very low methane leakage rates drew upon a small number of wells that had been selected by oil and gas companies with an incentive to minimize estimates of leakage.[45] That same study drew from Environmental Protection Agency emissions estimates that have been found to greatly underestimate emissions.[46] Other studies have made overly optimistic assumptions about total lifetime production from each gas well, lowering the calculated life-cycle emissions of electricity produced from natural gas.[47]

The conclusion from all these studies is that in some cases, fracking clearly releases large volumes of methane to the atmosphere. Controlling methane emissions from fracking wells may be technically possible, but it has not been the norm at America's oil and gas wells. (The first state to adopt methane control requirements was Colorado, which took action in 2014.[48] The federal government didn't adopt standards until mid-2015, and those are just for new wells.[49])

In addition, other elements of the natural gas transmission, storage and distribution system that is fed by fracking can leak large amounts of methane. A failing storage well in Southern California's Aliso Canyon released more than 100,000 tons of methane, the largest methane leak in U.S. history.[50]

Damaging America's Natural Heritage

Fracking transforms rural and natural areas into industrial zones. This development threatens national parks and national forests, damages the integrity of landscapes and habitats, and contributes to water pollution problems that threaten aquatic ecosystems.

Before drilling can begin, land must be cleared of vegetation and leveled to accommodate drilling equipment, gas collection and processing equipment, and vehicles. Additional land must be cleared for roads to the well site, as well as for any pipelines and compressor stations needed to deliver gas to market. According to a 2015 analysis of the areas of the Marcellus Shale in Pennsylvania most suitable for fracking, the development of natural gas infrastructure results in 17 to 23 acres of land cover disturbance per well pad. This could reduce the amount of interior forest, at least 300 feet from the forest edge, by 5 to 10 percent across the region studied.[51]

As oil and gas companies expand fracking activities, national parks, national forests and other iconic landscapes are increasingly at risk. Places the industry is seeking to open for fracking include:

- **White River National Forest –** This 2.3 million acre area in the Rocky Mountains includes mountain peaks, clear trout streams, aspen groves and wildlife habitat. Not only is it a destination for hikers, campers and other outdoor enthusiasts, but it is also a vital part of the local economy. While federal policymakers have taken important steps towards preventing future drilling in some portions of the White River National Forest, there are currently 65 leases held by oil and gas companies in roadless areas.[52]

- **Desolation Canyon** – This remote canyon on the Green River in eastern Utah is one of the nation's premier river-rafting destinations, framed by red rock sandstone and surrounded by wildlands. The Bureau of Land Management has given initial approval to 1,300 oil and gas wells in the area around Desolation Canyon.[53] If those wells are drilled, pipelines, wellheads and access roads would undermine the wilderness characteristics of the area.[54]

- **Delaware River Basin** – This basin, which spans New Jersey, New York, Pennsylvania and Delaware, is home to three national parks and provides drinking water to 15 million people.[55] If efforts to lift the current moratorium on fracking in the area succeed, one study predicts that 4,000 new wells could be fracked there. This could damage over 100,000 acres of land, cause erosion, reduce the water supply and potentially contaminate nearby drinking water.[56]

The disruption and fragmentation of natural habitat can put wildlife at risk. In Wyoming, for example, extensive gas development in the Pinedale Mesa region has coincided with a significant reduction in the region's population of mule deer, which declined by 40 percent between 2001 and 2015.[57] In northwest Colorado, scientists found that gas drilling operations decreased the number of mule deer living on land deemed essential for the species' wintertime survival by

The Bureau of Land Management has given initial approval for 1,300 fracked oil and gas wells in the area around Desolation Canyon, a development that could lead to destruction of the region's wilderness characteristics. Photo: Ray Bloxham/SUWA

Even after drilling equipment has been removed, the well pad fragments habitat. Photo: Joshua Doubek, CC BY-SA 3.0, http://creativecommons.org/licenses/by-sa/3.0

between 25 and 50 percent. Deer stayed about a half mile away from well pads, likely trying to avoid the loud machines and bright lights.[58]

Birds may also be vulnerable, especially those that depend on grassland habitat. Species such as the northern harrier, snowy owl, rough-legged hawk and American kestrel rely on 30 to 100 acres of undisturbed grassland for breeding or wintering habitat.[59] Roads, pipelines and well pads for fracking may fragment grassland into segments too small to provide adequate habitat.

The clearing of land for well pads, roads and pipelines may threaten aquatic ecosystems by increasing sedimentation of nearby waterways and decreasing shade. A study by the Academy of Natural Sciences of Drexel University found an association between increased density of gas drilling activity and degradation of ecologically important headwater streams.[60]

Water contamination related to fracking can cause fish to die. For example, after fracking equipment failed at an Ohio site in 2014, a fire broke out, causing trucks to explode and thousands of gallons of toxic chemicals to leak into an Ohio River tributary. More than 70,000 fish died as a result.[61]

Imposing Costs on Communities

Fracking operations add traffic congestion and stretch local demand for public services in communities, imposing a wide range of costs on area residents.

Ruining Roads, Straining Services

As a result of its heavy use of publicly available infrastructure and services, fracking imposes both immediate and long-term costs on taxpayers. Throughout the initial period of construction and drilling, fracking operations add between 7,000 and 10,000 single truck journeys per well pad.[62] This puts stress on roadways and bridges not constructed to handle such volumes of heavy traffic. Analysts at the RAND Corporation estimate that Pennsylvania roads sustain $13,000 to $23,000 worth of damage for each fracked well.[63]

Risks to Local Businesses, Homeowners and Taxpayers

Fracking imposes damage on the environment, public health and public infrastructure, with significant economic costs, especially in the long run after the initial rush of drilling activity has ended.

Pollution, stigma and uncertainty about the future implications of fracking can depress the prices of nearby properties. One study found Pennsylvania homes that depend on private groundwater lost an average of $33,214 in value when a shale well was drilled within nine-tenths of a mile.[64]

Fracking also has the potential to affect agriculture, both directly through damage to livestock from exposure to fracking fluids, and indirectly through economic changes that undermine local agricultural economies. A Cornell University study found dozens of cases in six states in which farm animals exposed to fracking fluids suffered illness, death or reproductive issues. One farmer reported that about 70 of his cows died after wastewater from nearby gas drilling was released into the pond from which they drank. Surviving cows subsequently delivered an unusually high number of stillborn or stunted calves.[65]

Governments are sometimes forced to spend tax money to clean up orphaned wells—wells that were never properly closed and whose owners, in many cases, no longer exist as functioning business entities. Though oil and gas companies face a legal responsibility to plug wells and reclaim drilling sites, they have a track record of leaving the public holding the bag.[66] For example, Texas alone has nearly 10,000 orphaned oil and gas wells, in addition to an unknown number of unrecorded old, unidentified wells.[67] The state has spent more than $230 million to plug orphaned wells.

States lack the resources to deal with all the orphaned wells. In 2014, Pennsylvania plugged only 48 wells from a list of 8,371 orphans.[68] Ohio has managed to finance the plugging of 40 to 50 wells per year, though the state likely has thousands of wells that need attention.[69]

Threatening Public Safety

Fracking harms public safety by increasing traffic in rural areas where roads are not designed for such high volumes, by creating an explosion risk from methane, and by increasing earthquake activity.

Increasing traffic—especially heavy truck traffic—has contributed to an increase in traffic crashes and fatalities. In northern Pennsylvania, vehicle crash rates were significantly higher in counties where unconventional gas drilling took place.[70] In Texas, per capita traffic fatalities have risen 18 percent over the last decade in counties with extensive fracking activity.[71] Around the Eagle Ford Shale play in southern Texas, traffic fatalities increased by 48 percent from 2008 to 2013, compared with a statewide decrease of 3 percent.[72]

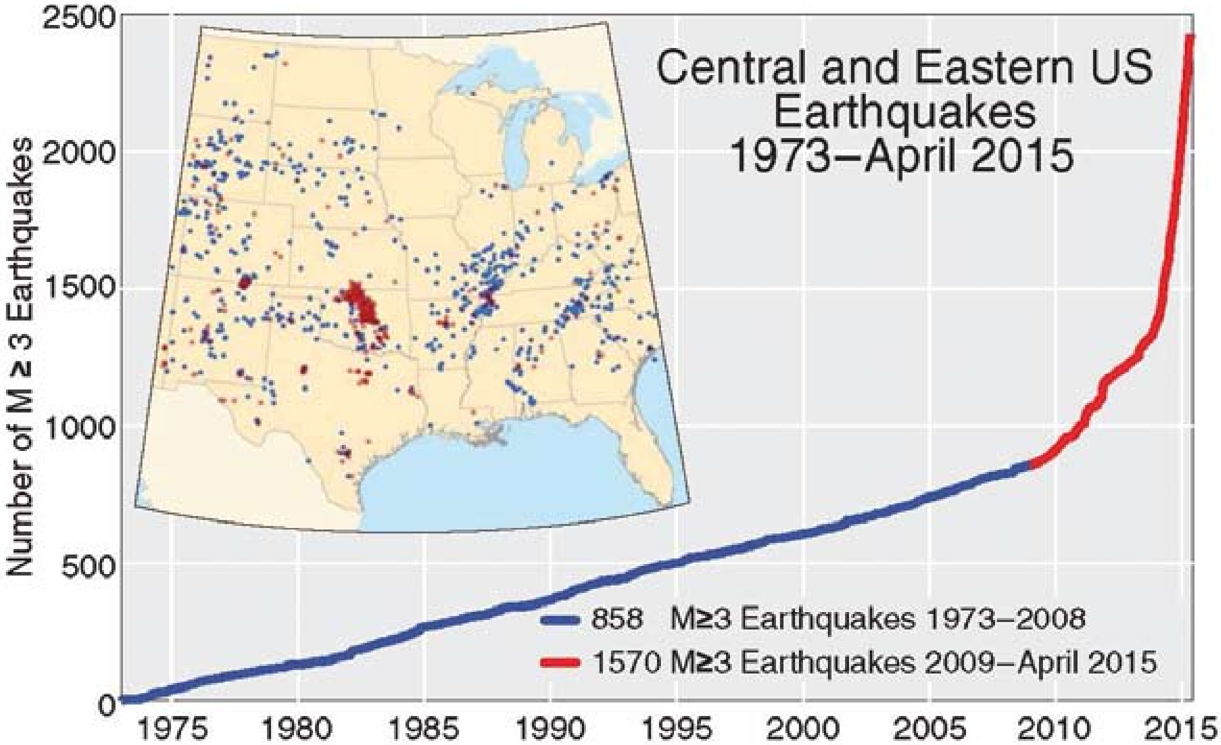
Methane contamination of well water poses a risk of explosion if the gas builds up. In 2014, four members of a family living right outside the Barnett Shale in Texas suffered severe burns when their water wellhead exploded. The family alleges that nearby drilling caused methane to leak into the well which sparked the explosion.[73] In 2014, an accident at an Ohio fracking site released flammable pollutants that emergency management officials feared could cause an explosion. Roughly 400 residents were evacuated from their homes in Jefferson County.[74]

Earthquake damage in Oklahoma in 2011 linked to underground wastewater injection. Photo: Brian Sherrod/United States Geological Survey

Another public safety hazard stems from earthquakes triggered by injection well wastewater disposal, which can increase pressure on faults. Such induced quakes have happened in Arkansas, Colorado, Kansas, Ohio, Oklahoma and Texas.[75]

According to the U.S. Geological Survey, the average number of earthquakes of magnitude 3 and larger in the central and eastern states rose from 21 per year between from 1973 through 2008 to 99 per year between 2009 and 2013.[76] This annual rate continues to rise: in 2014, these regions experienced 659 earthquakes of magnitude 3 or greater.[77] Oklahoma has been particularly hard hit, with seismic activity 40 times greater since 2008 than in previous years.[78]

Figure 1. USGS Chart Shows Earthquakes Are More Common with Increase in Fracking[79]



Tallying the State and National Impacts of Fracking

Fracking imposes numerous costly impacts on our environment and public health. This report updates our previous estimates of several key environmental and economic impacts of hydraulic fracturing.

Quantifying the cumulative impacts of fracking at a state or national scale is made difficult, in part, by differing definitions and data collection practices for unconventional drilling used in the states. These variations in data make it difficult to isolate high-volume fracking from other practices. To address this challenge, we collected data on unconventional drilling targets (shale gas, shale oil, and tight-gas sands) and practices (horizontal and directional drilling) to ensure the comprehensiveness of the data. Where possible, we then narrowed the data to include only those wells using high-volume hydraulic fracturing involving more than 100,000 gallons of water between January 2005 and June 2015.

The data presented in the following sections come from multiple sources, including state databases, estimates from knowledgeable state employees, and information provided by oil and gas companies to a national website. As a result, the quality of the data varies and figures may not be directly comparable from state to state. Nonetheless, the numbers paint a picture of the extensive environmental and public health damage caused by fracking.

Wells Fracked by State

The most basic measure of fracking's scope is a tally of how many fracking wells have been drilled. In addition, having an accurate count of wells by state offers a basis for estimating specific impacts to water, air and land.

Fracking has occurred in more than 20 states (see Table 2), involving more than 137,000 wells. In the eastern U.S., Pennsylvania reports the most fracking wells since 2005, with more than 9,000 wells tapping into the Marcellus and Utica shales. More than 8,000 fracking wells have been drilled in North Dakota to produce oil from the Bakken formation. Other states with the most fracking include Colorado and Texas.

Wastewater Produced

While there are many ways in which fracking can contaminate drinking water, one of the most serious threats comes from the millions of gallons of toxic wastewater produced by fracking, which can leak into water supplies.

Fracked wells produced at least 14 billion gallons of wastewater in 2014. Table 3 shows how much wastewater has been produced from fracking wells in selected states where water production data is available. These estimates are for wastewater only, and do not include other toxic

Table 1. National Environmental and Public Health-Related Impacts of Fracking

Fracking Wells since 2005	At least 137,000
Water Used since 2005	At least 239 billion gallons
Toxic Wastewater Produced in 2014, selected states	At least 14 billion gallons
Land Directly Damaged since 2005	679,000 acres
Global Warming Pollution from Well Completions in 2014 (methane)	At least 5.3 billion pounds

Table 2. Estimate of Fracking Wells by State

State	Wells Fracked Since 2005
Alabama	49
Arkansas	6,496
California	3,405
Colorado	22,615
Kansas	810
Louisiana	2,883
Michigan	49
Mississippi	103
Montana	539
Nebraska	5
Nevada	4
New Mexico	4,318
North Dakota	8,224
Ohio	1,594
Oklahoma	7,421
Pennsylvania	9,233
South Dakota	2
Tennessee	30
Texas	54,958
Utah	4,949
Virginia	108
West Virginia	2,670
Wyoming	7,277
TOTAL	**137,743**

Table 3. Wastewater from Fracking in 2014

State	Million gallons
Alabama	49
California	1,057
Colorado	3,139
New Mexico	8,592
Ohio	313
Pennsylvania	1,821
Wyoming	70

wastes from fracking, such as drilling muds and drill cuttings.

The tremendous volume of wastewater generated is difficult to dispose of. Injection wells for wastewater have caused earthquakes in several states, some of which are repositories for wastewater from neighboring states. For example, in 2014, Ohio injection wells accepted 693 million gallons of oil and gas wastewater, more than 3.5 times the amount of waste injected in 2009.[80] (See map of Ohio disposal wells.) Much of this waste comes from Pennsylvania and West Virginia.[81]

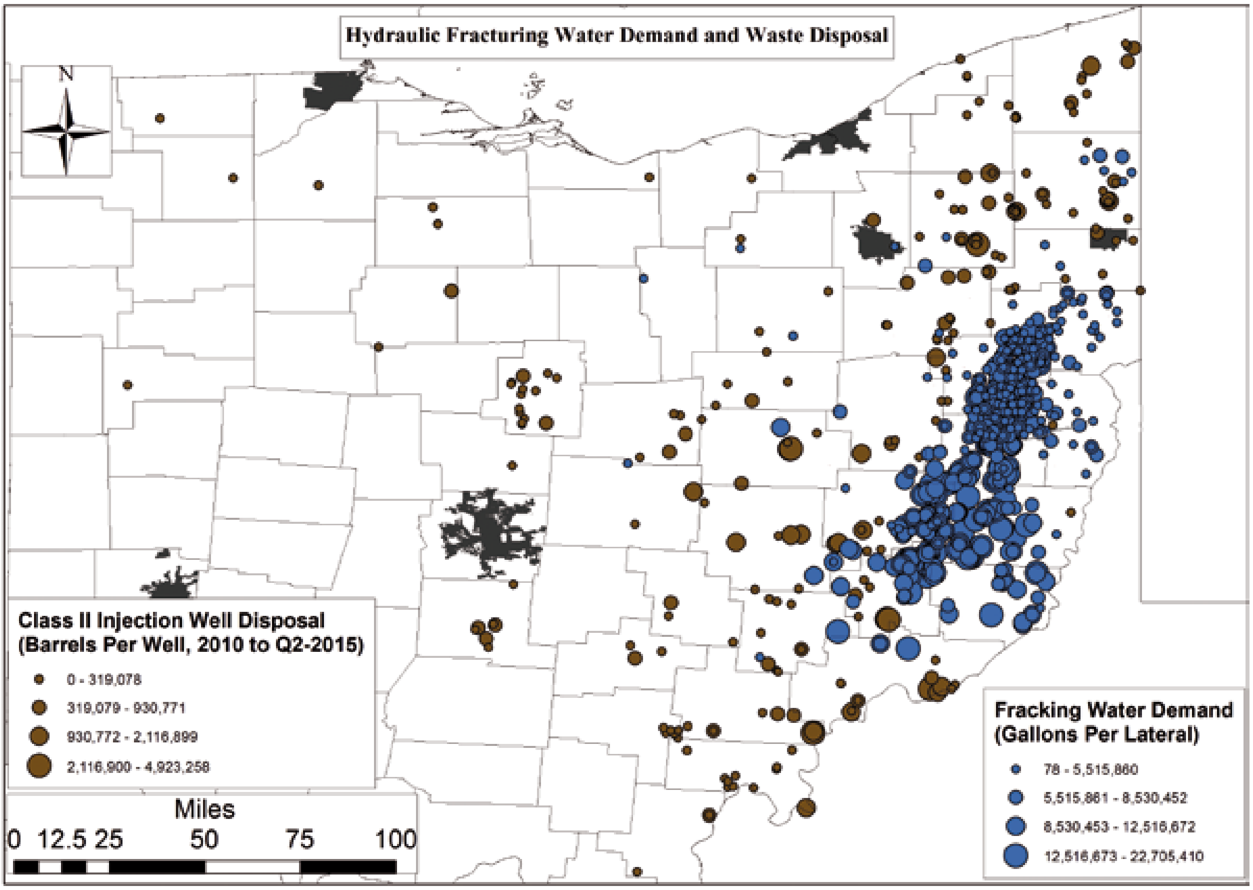
Waste from oil and gas fracking is exempt from the hazardous waste provisions of the federal Resource Conservation Recovery Act (RCRA), exacerbating the toxic threats posed by fracking wastewater. For other industries, the threats posed by toxic waste have been at least reduced due to the adoption of the RCRA, which provides a national framework for regulating hazardous waste. In other industries, illegal dumping is reduced by cradle-to-grave tracking and criminal penalties. Health-threatening practices such as open waste pits, disposal in ordinary landfills, and road spreading are prohibited.

Chemicals Used

Fracking fluid consists of water mixed with chemicals and sand that is pumped underground to frack wells. Though in percentage terms, chemicals are a small component of fracking fluid, the total volume of chemicals used is immense. Should they enter the air or drinking water, they present a threat to human health. According to an analysis of the industry-supported FracFocus database, some of the most common chemicals include:

- Hydrochloric acid, a caustic acid.[82]
- Methanol, which is suspected to cause birth defects.[83]
- Petroleum distillates, which can irritate the throat, lungs and eyes, and cause dizziness

Figure 2. Map of Ohio Fracking Water Use and Wastewater Disposal



Fracking wastewater is disposed into Class II injection wells in Ohio. Greenish-brown circles are wells receiving wastewater, measured in barrels of wastewater; blue circles represent water consumption at fracked wells, measured in gallons. Data mapped by Ted Auch at FracTracker Alliance.

and nausea.[84] This category of chemical can include toxic and cancer-causing agents.[85]

- Benzene, a cancer-causing chemical that evaporates easily, creating an inhalation risk.[86]

- Naphtha, a central nervous system depressant. Long-term exposure to naphtha may cause cancer.[87]

- Formaldehyde, a carcinogen that can cause nose, throat and eye irritation, and increase the risk of asthma.[88]

- Ethylene glycol, a central nervous system depressant that can also cause heart, respiratory and kidney damage.[89] Low-level exposure can cause eye and respiratory irritation.

- Sodium hydroxide, a highly corrosive chemical that is particularly hazardous to workers and anybody exposed to an undiluted spill.[90]

These toxic substances can enter drinking water supplies from the well, well pad or in the wastewater disposal process.

Table 4. Chemicals Reported by Industry in FracFocus, Selected States (thousand pounds)

State	Hydrochloric Acid*	Methanol	Petroleum Distillates	Ethylene Glycol	Benzene	Formaldehyde	Naphtha/ Naphthalene	Total Identified Chemicals
California	1,034	489	4,560	379	0	0	48	77,497
Colorado	68,663	10,042	55,872	4,804	3	443	8,090	1,668,654
New Mexico	70,798	4,403	34,013	2,401	5	19	3,251	833,430
North Dakota	82,198	88,168	87,948	21,556	762	2	12,508	3,891,405
Pennsylvania	1,806,032	5,396	50,194	5,421	0	36	3,013	2,186,034
Texas	2,148,789	302,501	751,153	82,852	161	70	91,704	10,436,835

* Hydrochloric acid is hydrogen chloride in water. The concentration of hydrogen chloride varies from one fracking operation to another.

^ Total identified chemicals excludes water, quartz, sand and products explicitly identified as proppants. It may still include water used as part of a chemical solution and proppants not explicitly identified as such.

Nationally, fracking operators have reported to FracFocus that they have used 5 billion pounds of hydrochloric acid, 1.2 billion pounds of petroleum distillate, and 400 million pounds of methanol. The specific mix of fracking chemicals used varies from region to region. For example, no benzene use was reported in Ohio, Pennsylvania or West Virginia, where most fracking occurs in the Marcellus Shale. Total reported benzene use in Colorado was a fraction of what was reported in North Dakota, even though Colorado has more wells.

Water Used

Fracking has used at least 239 billion gallons of water across the nation, according to industry-reported data in FracFocus. (See Table 5.) Most of that is freshwater from surface or groundwater sources, with only a small share consisting of brackish water or treated and re-used water from other frack jobs.[91]

The greatest total water consumption occurred in Texas, with half the reported national total. Other states with high water use include Pennsylvania, Oklahoma, Colorado and North Dakota. On average, each well fracked in Colorado uses the same amount of water as 20 Denver-area households use in a year.[92]

As with chemical use, there is regional variation in water usage per well. Fracking in Ohio,

Table 5. Water Used, 2005 to mid-2015, Selected States

State	Total Water Use (million gallons)	Average Water Use Per Well (gallons)
California	237	117,879
Colorado	19,142	2,326,439
New Mexico	3,132	1,363,390
North Dakota	14,891	2,941,093
Ohio	7,771	7,324,137
Oklahoma	19,582	3,062,622
Pennsylvania	24,732	5,532,851
Texas	120,215	3,276,787
West Virginia	7,651	7,743,438
National Total	239,166	3,073,209

Pennsylvania and West Virginia uses more water per well than fracking in other regions. California wells report using a very low volume of water. Water use tends to be higher in horizontally drilled wells, especially those with long lateral arms, and gas wells, on average, require more water than do oil wells. Water use per well is lower in shale plays that can be tapped with vertical or directional wells.[93]

Methane Pollution Released

Completion of fracking wells released approximately 5.3 billion pounds of methane into the atmosphere in 2014. That's equivalent to the annual global warming emissions from 22 coal-fired power plants or 17 million passenger vehicles.[94] (See Table 6.) In California in 2014, newly completed wells released an estimated 140 million pounds of methane in the course of normal operations, approximately 70 percent of the amount leaked from the failing gas storage well in Porter Ranch.[95]

Table 6. Methane Emissions from Wells Completed in 2014

State	Methane (pounds)	Equivalent to emissions from this many cars
California	139,782,500	453,836
Colorado	395,476,950	1,284,006
Kansas	38,063,850	123,583
Louisiana	49,891,600	161,984
Mississippi	9,892,300	32,118
Montana	24,945,800	80,992
New Mexico	124,944,050	405,659
North Dakota	517,195,250	1,679,192
Ohio	135,696,550	440,570
Oklahoma	546,011,950	1,772,752
Pennsylvania	295,478,700	959,339
Texas	2,520,816,100	8,184,404
Utah	185,803,200	603,252
Wyoming	115,911,950	376,335
TOTAL	**5,339,906,550**	**17,337,224**

This estimate is very conservative. It only counts emissions that occur as a well is brought into production, not emissions from ongoing operation of wells, or the processing or transportation of gas. It is also based on "bottom-up" estimates of emissions from various stages of fracking, an approach that has been shown to underestimate emissions, perhaps because average emission estimates for each piece of equipment fail to account for the fact that just a few pieces of faulty equipment can release inordinate amounts of methane.[96]

In North Dakota, for example, satellite measurements detected a large increase in methane in 2009 to 2011 compared to 2006 to 2008, which researchers attribute to an increase in fracking.[97] Emissions were 2.2 billion pounds per year higher by the 2009 to 2011 period than in the earlier period. That emissions rate is more than four times higher than our 2014 estimate for North Dakota.

Acres of Land Damaged

Nationally, land directly damaged for fracking totals at least 679,000 acres. This estimate includes the amount of land that has been cleared for roads, well sites, pipelines and related infrastructure in each state. In comparison, Yosemite National Park encompasses 760,000 acres.[98]

However, the total amount of habitat and landscape affected by fracking is much greater. A study of fracking development in Pennsylvania estimated that forest fragmentation affected more than twice as much land as was directly impacted by development.[99] A single well-pad can mar a vista seen from miles around.

The number of wells drilled on a single well pad has risen over time, meaning that newer wells on average have a smaller impact than older wells. As of mid-2013, more than half of new wells were drilled on multi-well pads, up sharply from 2009.[100] Drilling practices also vary from one shale play to another. In Texas' Barnett shale, more than 80 percent of wells were drilled on multi-well pads by mid-2013, versus 10 percent in the Permian Basin that straddles the Texas-New Mexico border.[101]

Fracking activity in Colorado damaged at least 100,000 acres, a conservative estimate given that the Niobrara Shale that is the target of much drilling in Colorado likely has fewer multi-well pads than the national average.[102] That's roughly equal to the area within Denver city limits.[103]

Table 7. Land Damaged for Fracking, Selected States

State	Acres
Colorado	105,866
New Mexico	35,273
North Dakota	33,718
Ohio	9,118
Pennsylvania	52,813
Texas	257,272
West Virginia	15,272

Recommendations

Across the country, fracking is contaminating drinking water, damaging open space, and warming our climate. Yet despite ample evidence of the dangers that fracking poses to the environment and our health, the practice continues in states across the country, and remains largely exempt from parts of the laws designed to protect people from dangerous air and water pollution, including the Safe Drinking Water Act, the Clean Water Act, the Clean Air Act and the Resource Conservation Recovery Act.[104]

Fracking is so dangerous to the environment, public health and the climate that we should phase out the practice altogether. In the meantime, we should not allow fracking to begin in additional regions and should enact baseline protections for communities where it is already occurring.

Ban Fracking Wherever Possible

Scientists agree that in order to avoid the worst impacts of global warming, we must keep the vast majority of fossil fuels in the ground.[105] That means here in the U.S., the extensive oil and gas reserves that the federal government has identified as extractable with fracking should not be tapped.[106] To protect the climate, the federal government should stop issuing new leases for fracking and other forms of fossil fuel development on our public lands.

State governments should ban fracking as Vermont and New York have done. Vermont became the first state to ban fracking in 2012.[107] Maryland passed a 2.5 year-long ban on fracking in 2015.[108] New York banned fracking in 2015.[109] (The Empire State still accepts wastewater from states such as Pennsylvania, which it often then spreads over roads to melt ice, raising public health concerns.[110]) States bordering areas with heavy fracking activity should bar the disposal of fracking waste so they will not become dumping grounds for fracking operations.

Several U.S. cities and counties have passed local laws against fracking.[111] Pittsburgh outlawed fracking within city limits in 2010.[112] In 2012, Boulder County and Fort Collins, Colorado, imposed moratoriums on new fracking permits.[113] New Mexico's Mora County became the first U.S. county to ban fracking in 2013, fearing contamination of drinking water wells; the ban was overturned by a federal judge in 2015.[114] More recently in California, the City of Los Angeles passed a moratorium on fracking and Santa Cruz County and the City of Beverly Hills banned the practice entirely.[115]

In November 2014, voters in several communities banned fracking, including in Denton, Texas, which sits atop the Barnett Shale and is home to more than 275 fracked wells.[116] The voter-approved ban on fracking in Denton succeeded a year after the Dallas City Council passed a set of tough drilling regulations, including a ban on drilling within 1,500 feet of homes.[117] Unfortunately, the state of Texas subsequently enacted legislation that overturns these bans and prohibits local communities from protecting themselves from fracking.[118]

Targeted efforts to protect national parks and other public lands that supply drinking water to millions of residents have kept some important areas off limits to fracking. For example, after Ohio residents wrote letters protesting fracking in Wayne National Forest, the sole drinking water source for 70,000 people, the Bureau of Land Management changed its rules to prevent fracking there.[119] Pennsylvania has banned new fracking on state lands.[120]

Given the scale and severity of fracking's impacts, banning fracking is the prudent and necessary course to protect the environment and public health. At a minimum, state officials should allow cities, towns and counties to protect their own citizens through local bans and restrictions on fracking.

Furthermore, if we are to address the problem of global warming, oil and gas use must decline quickly and dramatically. Even heavily regulated and perfectly executed fracking is a threat to our climate. Fossil fuel reserves must stay in the ground.

Enact Baseline Protections to Protect Communities and Lands on the Frontlines of Fracking

Where fracking is already happening, state and federal officials must take action to hold the oil and gas industry to the highest standards of environmental protection, transparency and accountability.

- Congress should close the loopholes that exempt fracking from key provisions of federal environmental laws. These include the Safe Drinking Water Act, the Clean Water Act and the Clean Air Act.

- Federal and state governments should protect treasured open spaces and vital drinking water supplies from the risks of fracking. Fracking should not be allowed on public lands, including national parks, national forests or watersheds that supply drinking water.

- Policymakers should end the most dangerous drilling practices and insist that drillers minimize their impacts on the environment. Fracking operators should no longer be allowed to use open waste pits for holding wastewater. The use of toxic chemicals should not be allowed in fracking fluids. Operators should be required to meet aggressive water use reduction goals and to recycle wastewater.

- Federal and state policymakers should act to slash methane leaks from all steps in the oil and gas production process. The federal government should implement strong limits on new oil and gas facilities, and adopt new rules to address emissions from existing fossil fuel sources.

- State and federal officials should ensure that the oil and gas industry—rather than taxpayers, communities or families—pays the costs of the damage caused by fracking by requiring robust financial assurance, such as bonds, from operators at every well site.

- The public has a right to know how fracking operations are affecting the environment and public health. The data currently available on fracking are inconsistent, incomplete and difficult to analyze. To remedy this, oil and gas companies should be required to report all fracking wells drilled, all chemicals used, amount of water used, and volume of wastewater produced and toxic substances therein. Reporting should occur into an accessible, national database, with chemical use data provided 90 days before drilling begins.

The rapid spread of fracking across America in the last decade has caused widespread harm to our environment and our health. By limiting fracking and ensuring that all oil and gas production is tightly regulated, the nation can take the first steps toward healing the damage.

Appendix A. Total Impacts of Fracking

Data are cumulative impacts since 2005, except where noted.

State	Wells Fracked	Hydrochloric Acid Used (thousand pounds)	Methanol Used (thousand pounds)	Wastewater Produced in 2014 (million gallons)	Water Consumed (million gallons)	Methane Released from Well Completion in 2014 (million pounds)	Land Disturbed (acres)
Alabama	49	378	4	unavailable	9	5	153
Arkansas	6,496	142,406	2,025	unavailable	11,290	144	22,858
California	3,405	1,034	489	1,057	237	140	15,940
Colorado	22,615	68,663	10,042	3,139	19,142	395	105,866
Florida	1	unavailable	unavailable	unavailable	unavailable	0	5
Kansas	810	13,113	513	unavailable	738	38	4,498
Louisiana	2,883	15,136	2,045	unavailable	4,880	50	16,010
Michigan	49	4,105	17	unavailable	92	0	238
Mississippi	103	872	803	unavailable	473	10	572
Montana	539	5,809	788	unavailable	793	25	2,210
Nebraska	5	66	16	unavailable	6	0	23
Nevada	4	26	0	unavailable	1	1	19
New Mexico	4,318	70,798	4,403	8,592	3,132	125	35,273
North Dakota	8,224	82,198	88,168	unavailable	14,891	517	33,718
Ohio	1,594	105,447	1,942	313	7,771	136	9,118
Oklahoma	7,421	455,225	17,147	unavailable	19,582	546	41,210
Pennsylvania	9,233	1,806,032	5,396	1,821	24,732	295	52,813
South Dakota	2	unavailable	unavailable	unavailable	unavailable	0	9
Tennessee	30	unavailable	unavailable	unavailable	unavailable	0	140
Texas	54,958	2,148,789	302,501	unavailable	120,215	2,521	257,272
Utah	4,949	35,926	1,414	unavailable	916	186	35,478
Virginia	108	575	25	unavailable	10	1	618
West Virginia	2,670	64,134	1,174	unavailable	7,651	88	15,272
Wyoming	7,277	18,074	5,870	70	2,528	116	29,836
TOTAL	**137,743**	**5,038,953**	**444,786**	**14,993**	**239,166**	**5,340**	**679,148**

Unavailable means data were not available from FracFocus or from state sources. See methodology for details.

Appendix B.
FracFocus Water Use, by State

The data below are based on an analysis of information reported in FracFocus. Records for thousands of wells had to be excluded because of incomplete or questionable data. See methodology for full details.

State	Water consumed (million gallons)	Wells included in water analysis	Water per well (gallons)
Alabama	9	128	72,993
Arkansas	11,290	2,613	4,320,520
California	237	2,008	117,879
Colorado	19,142	8,228	2,326,439
Florida	unavailable	unavailable	unavailable
Kansas	738	419	1,760,735
Louisiana	4,880	1,281	3,809,729
Michigan	92	15	6,164,517
Mississippi	473	65	7,272,824
Montana	793	378	2,097,964
Nebraska	6	3	1,991,927
Nevada	1	4	135,820
New Mexico	3,132	2,297	1,363,390
North Dakota	14,891	5,063	2,941,093
Ohio	7,771	1,061	7,324,137
Oklahoma	19,582	6,394	3,062,622
Pennsylvania	24,732	4,470	5,532,851
South Dakota	unavailable	unavailable	unavailable
Tennessee	unavailable	unavailable	unavailable
Texas	120,215	36,687	3,276,787
Utah	916	2,955	309,997
Virginia	10	57	176,742
West Virginia	7,651	988	7,743,438
Wyoming	2,528	2,639	957,857
TOTAL	**239,166**	**77,823**	**3,073,209**

Unavailable means no usable data were reported for the state in FracFocus. See methodology for details.

Appendix C.
FracFocus Chemical Use, by State

The data below are based on an analysis of information reported in FracFocus. Records for thousands of wells had to be excluded because of incomplete or questionable data. See methodology for full details. Data are in thousands of pounds.

State	Hydrochloric Acid*	Methanol	Petroleum Distillates	Ethylene Glycol	Benzene	Formaldehyde	Naphtha/ Naphthalene	Total Identified Chemicals
Alabama	378	4	156	4	0	0	1	1,817
Arkansas	142,406	2,025	8,487	800	0	0	1	199,980
California	1,034	489	4,560	379	0	0	48	77,497
Colorado	68,663	10,042	55,872	4,804	3	443	8,090	1,668,654
Florida	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Kansas	13,113	513	683	190	0	1	345	58,941
Louisiana	15,136	2,045	46,395	1,629	0	0	10,415	696,208
Michigan	4,105	17	300	18	0	0	177	12,106
Mississippi	872	803	2,078	199	19	0	2,568	48,630
Montana	5,809	788	5,207	859	46	11	691	123,687
Nebraska	66	16	2	36	0	0	3	377
Nevada	26	0	0	1	0	0	2	3,025
New Mexico	70,798	4,403	34,013	2,401	5	19	3,251	833,430
North Dakota	82,198	88,168	87,948	21,556	762	2	12,508	3,891,405
Ohio	105,447	1,942	46,039	1,732	0	10	4,276	345,560
Oklahoma	455,225	17,147	68,512	7,262	0	7	11,584	114,4762
Pennsylvania	1,806,032	5,396	50,194	5,421	0	36	3,013	2,186,034
South Dakota	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Tennessee	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Texas	2,148,789	302,501	751,153	82,852	161	70	91,704	10,436,835
Utah	35,926	1,414	5,546	5,736	0	3	2,581	1,426,605
Virginia	575	25	63	1	0	0	0	31,954
West Virginia	64,134	1,174	27,334	1,680	0	25	814	181,239
Wyoming	18,074	5,870	11,265	1,095	0	0	9,164	1,337,141
TOTAL	5,038,953	444,786	1,206,586	138,767	997	626	161,236	23,262,096

Unavailable (UNA) means no usable data were reported for the state in FracFocus. See methodology for details.
* Hydrochloric acid is hydrogen chloride in water. The concentration of hydrogen chloride varies from one fracking operation to another.
^ Total identified chemicals excludes water, quartz, sand and products explicitly identified as proppants. It may still include water used as part of a chemical solution and proppants not explicitly identified as such.

Methodology

This report seeks to estimate the cumulative impacts of fracking for oil and gas in the United States. We attempted to limit the scope of the data included in the report to wells using high-volume hydraulic fracturing with horizontal drilling, because that new technology has the greatest environmental impacts. We focused on wells fracked since January 2005, when the modern fracking methods responsible for the environmental damage we discuss in this report were first widely applied in the U.S. However, the definition of and data collection practices for unconventional drilling vary significantly from state to state, making it difficult—and in some cases impossible—to limit our study only to those wells that have been developed using high-volume fracking.

To ensure that our estimates included the most comprehensive data possible, we began by collecting—largely from state oil and gas regulators, as described below—data on unconventional drilling targets and practices (excluding acidization). Where possible, we then narrowed the data to include only those wells using high-volume hydraulic fracturing involving more than 100,000 gallons of water and/or directional/horizontal drilling so as to focus on drilling techniques that have come into use in the past decade. In many states, the information needed to identify these wells was lacking. In those states, we included all wells using unconventional drilling practices in the data. Below, we explain what types of drilling are included in the data for each state.

Counting the Number of Wells in Each State

To count the number of high-volume fracked wells in each state, we relied on the FracFocus database managed by the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission, and each state's record of drilled wells.

Count from FracFocus: By definition, wells listed in FracFocus are fracked, and the database includes information on water use, enabling us to identify high-volume wells. For our state-by-state count of wells, we removed wells that reported using less than 100,000 gallons of water, and resolved internal inconsistencies in the state names and codes used in the database.

Count from state databases: High-volume fracked wells are not as easy to identify in state databases. Some states identify hydraulically fractured wells, but don't indicate the volume of water used, in which case we counted all wells. Other states don't explicitly identify hydraulically fractured wells but do indicate which wells are horizontally or directionally drilled. We assume these are fracked wells. Information on data and analysis methods used for each state is presented below.

Combined count from FracFocus and state databases: In many cases, state databases include wells not included in FracFocus, and vice versa. State databases may include records for wells fracked in the years before FracFocus was created, and FracFocus may include wells not yet reported to the state. We reconciled these two sources to obtain a more accurate total for each state, removing duplicates and using FracFocus to identify which wells in state records used low volumes of water. Details of this analysis for each state are below.

Alabama

A list of permit numbers for 49 Alabama wells that have been fracked since 2005 was obtained from Elbert Patterson, Petroleum Engineer, State Oil and Gas Board of Alabama, personal communication, 28 August 2015.

Data on produced water are not available for download—they must be looked up well by well—and were not collected for this report.

Arkansas

A list of permitted wells with permit status dates from January 2005 through June 2015 was obtained from Arkansas Oil and Gas Commission, ftp://www.aogc2.state.ar.us/, 15 September 2015. Horizontally drilled wells are designated by an "H" in the state-issued well number.

We used permitted wells as a proxy for the number of wells that have been drilled, because about 99 percent of all permitted wells are drilled, per James Vinson, Webmaster, Arkansas Oil and Gas Commission, personal communication, 8 September 2015.

No reliable data on produced water from horizontally drilled wells in Arkansas were available.

California

We combined two data sources to estimate the number of high-volume fracked wells in California.

Data on the total number of drilled wells were obtained from the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR) website, accessed 15 September 2015 at www.consrv.ca.gov/dog/maps/Pages/GISMapping2.aspx. We used the excel file titled "all wells," which was posted on 23 July 2015 and includes wells drilled through 21 June 2015. Within this file, we counted the number of directional and horizontal hydraulically fractured wells with spud dates between January 2005 and June 2015, of which there were more than 10,000. This includes many low-volume wells.

To narrow this list, we queried FracFocus, to which California does not require well operators to report. FracFocus includes fewer than 1,000 high-volume fracked wells, a count that is likely incomplete because reporting is voluntary.

The true number of high-volume fracked wells in California, therefore, is likely between 1,000 and 10,000. To estimate the true figure, we calculated the percentage of wells in each county reported to FracFocus that are high-volume, and applied that percentage to the number of horizontally and directionally drilled wells by county in the DOGGR database. This resulted in an estimate of slightly more than 3,000 high-volume fracked wells.

Water production information was obtained from California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, *California Production 2014*, accessed 21 January 2016 at ftp://ftp.consrv.ca.gov/pub/oil/new_database_format. We included 2014 production from known high-volume fracked wells.

Colorado

Data on fracked wells in Colorado come from two sources.

Since April 2012, Colorado has required that well operators report fracking activity to FracFocus. From April 2012 to June 2015, 6,206 high-volume fracked wells were reported to FracFocus.

Before April 2012, there is no firm data on the number of fracked wells in Colorado. Based on conversations with staff at the Colorado Oil and Gas Commission (including Diana Burn, Eastern Colorado Engineering Supervisor, Colorado Oil and Gas Commission, personal communication, 4 September 2013), we estimated the number of fracked wells before April 2012 by counting spud dates of wells in Weld, Boulder, Garfield and Mesa counties. A list of all wells in Colorado was obtained from Colorado Oil & Gas Conservation Commission, Colorado Oil and Gas Information System (COGIS), *2015 Production Report*, downloaded 17 October 2015, from cogcc.state.co.us/data.html#/cogis.

Water production data are for 2014 production from high-volume wells identified in FracFocus from April 2012 onward, and in Weld, Boulder, Garfield and Mesa counties in COGIS from January 2005 through March 2012.

Florida

Florida has only one permitted fracking well and it is currently not producing, per Levi Sciara, Engineer, Florida Department of Environmental Protection, personal communication, 7 August 2015.

Illinois

Illinois has not had any permit applications filed for high volume hydraulic fracturing, per Doug Shutt, Oil and Gas Resource Management Supervisor, Illinois Department of Natural Resources, personal communication, 14 August 2015. The FracFocus database lists one fracked well in Wayne County that had used over 100,000 gallons of water. We do not have production information for this well.

Indiana

A list of hydraulically fracked wells was acquired by using the Department of Natural Resources Well Search tool and filtering for "Hydraulically Fracked Wells Only," accessed at www.in.gov/dnr/dnroil, 20 July 2015. The state of Indiana does not include any date information for wells in this dataset.

FracFocus does not contain data on any Indiana wells.

Kansas

We counted the number of high-volume fracked wells in Kansas using a combination of FracFocus data and information from the state.

Kansas has required reporting to FracFocus since December 2013. From then through June 2015, there were 218 high-volume fracked wells in the state.

For 2005 through November 2013, data on "horizontal or slant wells" in Kansas were obtained from the Kansas Geological Survey's List of Oil and Gas wells, accessed at chasm.kgs.ku.edu, 10 September 2015. There were 592 wells with spud dates during our selected time period.

We were unable to obtain data on water production.

Kentucky

Kentucky has only three high-volume fracked wells (using over 80,000 gallons of fluid at any one stage, or over 320,000 gallons of fluid in aggregate), per Brandon Nuttall, Kentucky Geological Survey, personal communication, 7 August 2015. In Kentucky, horizontal wells are not typically fractured with water but with a nitrogen/foam fracturing substance instead.

Louisiana

We counted the number of high-volume fracked wells in Louisiana using a combination of FracFocus data and information from the state.

Louisiana does not require reporting to FracFocus. Nonetheless, there were 1,653 high-volume fracked wells reported from the beginning of 2011 through June 2015.

A list of completed horizontally drilled wells since 2005 was obtained from Sharron Allement, Mineral Production Specialist, Louisiana Department of Natural Resources, Office of Conservation Engineering and Administrative Division, personal communication, 4 August 2015. We counted wells completed between January 2005 and December 2010, and added it to the figure obtained from FracFocus.

Louisiana does not track wastewater production volumes.

Michigan

The Michigan Department of Environmental Quality website states that 49 active permits have been issued for high volume (greater than 100,000 gallons) horizontal wells in Michigan since 2008, accessed at www.michigan.gov/documents/deq, 7 August 2015. Fracking was not closely tracked or regulated before 2008 (Mark Snow, Supervisor, Permits and Bonding Unit, personal communication, 21 July 2015).

Mississippi

Mississippi did not require permits for fracked wells until 2013 and thus data from previous years are incomplete, per David Snodgrass, Inspector and Geologist, Mississippi State Oil and Gas Board, personal communication, 7 August 2015. We obtained a list of wells approved for "frack jobs" and permitted since March 2013.

Montana

Montana does not require reporting to the FracFocus database. However, we opted to use FracFocus data instead of data collected by Montana because state data likely include a number of coalbed methane wells. FracFocus included 540 high-volume fracked wells.

A tally of new horizontal and recompleted horizontal wells in Montana Board of Oil and Gas Conservation, *Horizontal Well Completion Count*, accessed at www.bogc.dnrc.mt.gov, 14 August 2015, turned up 1,359 wells, including some coalbed methane wells.

Water production information was not available.

Nebraska

Nebraska does not track which wells are fracked. FracFocus shows five high-volume fracked wells have been drilled in Nebraska. Nebraska has only two horizontal wells, per Bill Sydow, Director of the Nebraska Oil and Gas Conservation Commission, personal communication, 27 July 2015.

Water production numbers for horizontal wells were not available.

Nevada

Nevada has only four fracked wells, three of which are exploratory, per Richard Perry, Programs Manager, Nevada Commission on Mineral Resources, Division of Minerals, Oil, Gas, and Geothermal, personal communication, 10 August 2015. Data from FracFocus indicate they are high volume wells. The three exploratory wells are not producing and there are no available production data for the fourth.

New Mexico

New Mexico does not track which wells are fracked, nor does it require reporting to FracFocus. We calculated the number of fracked wells by combining two sources: the state's list of horizontally drilled wells, and wells voluntarily reported to FracFocus.

Data on the number of horizontally drilled wells were used as a proxy for fracked wells. Data were obtained from the New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division, *OCD Data and Statistics*, accessed at www.emnrd.state.nm.us/OCD/statistics.html, 11 September 2015. Horizontally-drilled wells are designated by an "H" at the end of the well name. One well with status "never drilled" was excluded from our count.

From FracFocus, we identified fracked wells in New Mexico. We combined the state list of wells with the FracFocus list of wells and excluded any known low-volume wells.

Water production data for 2014 were obtained from the GO-TECH Petroleum website, accessed 21 January 2016 at gotech.nmt.edu/gotech/Petroleum_Data/allwells.aspx.

North Dakota

Data on all horizontal wells were obtained from the North Dakota Industrial Commission, Department of Mineral Resources, Oil and Gas Division website, *Bakken Horizontal Wells by Producing Zone*, accessed at www.dmr.nd.gov/oilgas/bakkenwells.asp, 14 September 2015. We assumed that all horizontal wells are fracked and that all fracking in the state happens in the Bakken Shale. Because spud dates were not listed, we instead used completion dates between January 2005 and June 2015 in each of six producing zones (Middle Bakken, Three Forks, Middle Bakken/Three Forks, Lodgepole, Upper Bakken Shale and Lodgepole/Middle Bakken formations).

North Dakota does not track annual water production.

Ohio

For Ohio, we included data for wells drilled in both the Marcellus and Utica/Point Pleasant shales from Ohio Department of Natural Resources, Division of Oil & Gas Resources, *Cumulative Permitting Activity*, accessed at oilandgas.ohiodnr.gov/shale#SHALE, 10 September 2015. There were 1,565 Utica/Point Pleasant wells with a status of "drilled," "drilling," or "producing" and 29 Marcellus shale wells.

Production data for 2014 were obtained from Ohio Department of Natural Resources, Division of Oil & Gas Resources, *Oil & Gas Well Production*, accessed at oilandgas.ohiodnr.gov/production, 21 January 2016.

Oklahoma

Oklahoma requires drillers to report to FracFocus and does not maintain a separate list of fracked wells. We used FracFocus data. Water production data were not available.

Pennsylvania

Data for all unconventional wells with spud dates between January 2005 and June 2015 were obtained from Pennsylvania Department of Environmental Protection, *Oil and Gas Reports: SPUD Data Report*, www.portal.state.pa.us, 9 January 2016.

Data on water production in 2014 from Pennsylvania's unconventional wells came from the Pennsylvania Department of Environmental Protection, *PA DEP Oil & Gas Reporting Website—Statewide Data Downloads by Reporting Period*, accessed at www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx, 9 January 2016. Our wastewater tally included "Drilling Fluid Waste," "Fracing Fluid Waste" and "Produced Fluid."

South Dakota

Only two wells have been hydraulically fractured in South Dakota in the past ten years (one in 2009 and one in 2011), per Lucy Dahl of the South Dakota Department of Environment and Natural Resources, Minerals and Mining Program, personal communication, 11 August 2015. Water production information is not available for either of these wells.

Tennessee

Data on fracked wells in Tennessee came from Ron Clendening, Geologist, Oil & Gas Contacts, Division of Geology, Tennessee Department of the Environment and Conservation, personal communication, 8 July 2013 and 11 August 2015.

We were unable to obtain an estimate of wastewater production.

Texas

Texas began keeping track of fracking wells in February 2012. Separately, data are available on fracked wells from 2005 to 2009. To estimate the number of fracked wells in the intervening years, we relied on multiple data sources.

- 2005-2009: We assume that from 2005 through 2009, the bulk of fracking activity in Texas occurred in the Barnett Shale and was barely beginning elsewhere. A total of 8,746 new horizontal wells were drilled in the Barnett Shale from 2005 through 2009, per *Powell Barnett Shale Newsletter*, 18 April 2010, as cited in Zhongmin Wang and Alan Krupnick, *A Retrospective Review of Shale Gas Development in the United States*, Resources for the Future, 2013. The Eagle Ford Shale was first drilled in 2008 and by 2009 there were 107 producing oil and gas wells, per Texas Railroad Commission, *Eagle Ford Information*, accessed at www.rrc.state.tx.us/eagleford, 3 September 2013.

- 2010: Nearly 40 percent of wells drilled in 2010 were fracked using more than 100,000 gallons of water, per Table 7 of Jean-Philippe Nicot et al., Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, for the Texas Water Development Board, *Current and Projected Water Use in the Texas Mining and Oil and Gas Industry*, June 2011. We multiplied 39.7 percent times the 8,133 "new drill dry/completions" in 2010, per Railroad Commission of Texas, *Summary of*

Drilling, Completion and Plugging Reports, accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 19 July 2013.

- January 2011 through January 2012: We calculated the number of fracking wells in this period by multiplying the number of wells drilled by an estimate of the percentage of those wells that were fracked. The number of "new drill dry/completions" came from Railroad Commission of Texas, *Summary of Drilling, Completion and Plugging Reports,* accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 3 September 2013. We interpolated between 2010 and February 2012 using the percentage of wells that were fracked using the 2010 estimate of 39.7 percent, described above, and the percent fracked from February 2012 to April 2013. Beginning in February 2012, drilling companies in Texas have been required to report their drilling activities to FracFocus. 14,762 wells were fracked in Texas in that period that used more than 100,000 gallons of water. This number of wells equals 75 percent of all "new drill dry/completions" in the same period in Railroad Commission of Texas, *Summary of Drilling, Completion and Plugging Reports,* accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 3 September 2013.

- From February 2012 through June 2015, FracFocus lists 37,788 high-volume frack jobs.

Texas does not track water production.

Utah

We counted the number of high-volume fracked wells in Utah using a combination of FracFocus data and information from the state.

Utah has required reporting to FracFocus since November 2012. We counted the number of high-volume fracked wells from November 2012 through June 2015.

For earlier data, we counted horizontally or directionally drilled wells with completion dates from January 2005 through October 2012 in Department of Natural Resources, Utah Division of Oil, Gas & Mining, *Wells Completed*, oilgas.ogm.utah.gov/Data_Center, 21 September 2015. It is likely that all horizontally or directionally drilled wells have been fracked, per Brad Hill, Permitting Manager, Utah Division of Oil, Gas & Mining, Department of Natural Resources, personal communication, 21 September 2015. We excluded coalbed methane wells.

We were unable to obtain single-year data on produced water.

Virginia

We counted all wells of type "horizontal gas" or "horizontal gas w/ PL" with completion dates between January 2005 and June 2015, listed by the Virginia Department of Mines, Minerals, and Energy Division of Gas and Oil Information System, Drilling Report, accessed at www.dmme.virginia.gov, 14 September 2015.

We were unable to obtain data on produced water in Virginia.

West Virginia

We combined data from three sources to estimate the number of high-volume fracked wells in West Virginia.

We counted 1,231 completed permit records from January 2005 to December 2011 for drilling targeting the Marcellus Shale, data downloaded from West Virginia Department of Environmental protection, *Oil and Gas Well Search*, apps.dep.wv.gov/oog/wellsearch_new.cfm, accessed 22 September 2015. Per Melanie Hinkins, Permitting Technician, Department of Environmental Protection, Office of Oil and Gas, we can assume that all wells drilled in the Marcellus Shale have been fracked and that all pre-2012 fracking has primarily occurred in the Marcellus Shale, personal communication, 22 September 2015. We excluded wells marked with status "never drilled." This count may include low-volume wells. In 2012, West Virginia mandated the reporting of all horizontally drilled wells—defined as "any well site, other than a coalbed methane well, drilled using a horizontal drilling method, and which disturbs three acres or more of surface, excluding pipelines, gathering lines and roads, or utilizes more than two hundred ten thousand gallons of water in any thirty day period." Data on these "H6A" issued permits came from West Virginia Department of Environmental Protection, Office of Oil and Gas, *22-6A Permit Issuance Monthly Report*, accessed at www.dep.wv.gov/oil-and-gas/Horizontal-Permits, 11 September 2015. Because this definition is narrower than parameters applied to other state counts, it likely results in an undercount of high-volume fracked wells.

In July 2013, West Virginia began requiring reporting to FracFocus. We counted 692 fracked wells that used more than 100,000 gallons of water from July 2013 through June 2015.

Wyoming

Our count of fracked wells in Wyoming relies on completed well data from the Wyoming Oil and Gas Conservation Commission website database, accessed 21 September 2015 at wogcc.state.wy.us/online_stats_bk/main_menu.cfm. We included all horizontal oil wells in Wyoming and gas wells (any drilling configuration) in Sublette and Sweetwater counties with completion dates between January 2005 and June 2015. Horizontally-drilled oil wells likely have been hydraulically fractured, but directional and vertical oil wells likely have not, per Frank Ingham, Engineer with the Wyoming Oil and Gas Conservation Commission, personal communication, 21 September 2015. Gas wells in Sublette and Sweetwater counties have been hydraulically fractured, but the fracking status of gas wells in other counties is not known.

We were able to obtain wastewater production data by county, and reported production for Sublette and Sweetwater counties only, because the vast majority of wells in those counties are fracked.

Methane Emissions

Methane emissions were calculated based on well completions by state in 2014. The number of wells completed in each state, calculated as described in the previous section, was multiplied by estimated methane emissions from well completion. We assumed 85 percent of gas is vented, not flared, during completion, and that methane emissions are 115,000 kilograms per completion, per James Littlefield et al., "Using Common Boundaries to Assess Methane Emissions," *Journal of Industrial Ecology*, doi: 10.1111/jiec.12394, 14 January 2016.

The EPA data on which this element of the Littlefield et al. calculation is based assumes the same emission rate for well completions and workovers, per U.S. Environmental Protection Agency, *Greenhouse Gas Emissions Reporting from the Petroleum and Natural Gas Industry: Background Technical Support Document*, 2011, 88. EPA estimates the amount of natural gas in flowback water is 9,175 Mcf per well, based on studies suggesting natural gas in flowback water could be as low as 700 or as high as 20,000 Mcf.

Our estimate has two limitations of note. First, it does not include methane emissions from pipelines, compressor stations, and condensate tanks, or carbon dioxide emissions from equipment used to produce gas. Second, it may not accurately reflect emissions from fracked shale wells that produce oil rather than gas. The data we obtained on well completions do not distinguish between wells fracked for oil versus gas and therefore we have chosen to apply this estimate for unconventional gas wells to all wells. In 2013, we spoke with two experts in the field who believed at the time that, given the lack of better data on emissions from oil wells, it was reasonable to assume that fracked oil wells had substantial methane emissions. We made that same assumption in this calculation because better data were not available.

Land Disturbed

Estimated landscape impacts are the result of calculating the number of single-well pads versus multi-well pads, estimating the acres affected by each type of pad, and adding in an assumption about acres affected for support infrastructure.

Information on the number of wells that have been drilled on single-well pads versus multi-well pads came from Kevin Thuot, DrillingInfo, *On the Launch Pad: The Rise of Pad Drilling*, 4 February 2014, archived at web.archive.org/web/20160210231226/http://info.drillinginfo.com/launch-pad-rise-pad-drilling/. That source provides quarterly data for nine different shale plays. We used the highest quarterly estimate of the percent of wells drilled on multi-well pads from 2013 from each play, a conservative decision for two reasons. First, some plays experienced large quarterly variations in the number of wells drilled on multi-well pads, and second, a smaller percentage of wells drilled before 2013 were on multi-well pads. For states that tap multiple plays or for states that tap a play not listed by our source, we made a conservative estimate.

We assumed multi-well pads hold two wells each in Ohio, Pennsylvania, Virginia and West Virginia, per New York State Department of Environmental Conservation, *Final Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Regulatory Program for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, April 2015, 6-78. Wells in other states are assumed to hold an average of four wells per multi-well pad, per Richard Mason, DrillingInfo, *The Next Evolutionary Step in Pad Drilling*, 5 February 2015, archived at web.archive.org/web/20160212001520/http://info.drillinginfo.com/pad-drilling-2-point-0/.

We assume single-well pads are four acres in most states, based on estimates from multiple sources that well pads cover three to five acres. See, for example, Chesapeake Energy, *Shale Operators Overview* (powerpoint), no date, archived at web.archive.org/web/20160215212754/https://jfs.ohio.gov/owd/Initiatives/Docs/Chesapeake-Ohio-Basic-Drilling.pdf; and WPX Energy, *WPX Working on a 36-Well Pad in the Piceance* (press release), no date, archived at web.archive.org/web/20160215213035/http://www.wpxenergy.com/news-and-media/press-releases/2014/wpx-working-on-a-36-well-pad-in-the-piceance.aspx. For Ohio, Pennsylvania, Virginia and West Virginia, we assume wells pads are 3.1 acres, per New York State Department of Environmental Conservation, *Final Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Regulatory Program for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, April 2015, 6-77.

Multi-well pads are assumed to cover seven acres, per Brian Hicks, Energy & Capital, *Multi-Well Pad Will Sink OPEC*, 13 December 2012, archived at web.archive.org/save/http://www.energyandcapital.com/articles/multi-well-pad/2892. This is lower than the estimate in Erik Bauss, "Modern Well Development Technology Produces Big Time Environmental Benefit for Michigan," *EnergyInDepth*, 24 October 2012, archived at web.archive.org/web/20160212002525/http://energyindepth.org/national/modern-well-development-technology-produces-big-time-environmental-benefits-for-michigan/.

Other infrastructure, such as roads and pipelines, are assumed to affect an additional 5.7 acres per pad in states tapping into the Marcellus Shale, per New York State Department of Environmental Conservation, *Final Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Regulatory Program for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, April 2015, 6-77. In all other states, other infrastructure was assumed to disturb 4.75 acres, per U.S. Department of the Interior, Bureau of Land Management, Colorado State Office, Northwest Colorado Office, White River Field Office, *Draft Resource Management Plan Amendment and Environmental Impact Statement for Oil and Gas Development*, August 2012.

Water and Chemical Use

Assembling the Data

FracFocus.org offers the most comprehensive database of water and chemicals that have been used in frack jobs. The website is run by the Groundwater Protection Council, a non-profit association of state regulators of oil and gas drilling, and the Interstate Oil and Gas Compact Commission, a multi-state association.[121] The site itself is funded by the oil and gas industry.[122]

FracFocus.org has significant drawbacks:

- Companies enter the data themselves directly, and are not subject to verification or validation of their entries.[123]
- Companies are allowed to withhold information on chemicals used in fracking by classifying them as trade secrets.[124]
- Reporting to the database is not mandatory in all states, and in states where it currently is mandatory, reporting didn't begin until years after fracking started.

Nevertheless, it is the best and most complete data available. In early 2015, for the first time, FracFocus made some of its data available for bulk download.[125]

To assemble the data for this report, several vintages of FracFocus data had to be accessed and brought together in a single database When FracFocus launched in January 2011, disclosure forms were submitted on paper or via electronic PDF, and were neither submitted nor later entered into the system in a machine-readable format. This format was called "FracFocus 1.0."[126]

Starting in November 2012, a new format, called "FracFocus 2.0," was made available for data entry. That included chemical data in machine-readable format, but was not the mandatory submission format until May 31, 2013.[127] Only after May 31, 2013, was "FracFocus 2.0" the sole format for submitting disclosure data.[128]

As a result, the bulk-downloadable data available from FracFocus included only summary information (without chemical disclosure) for records submitted in the "FracFocus 1.0." For data submitted in "FracFocus 2.0" format, the chemical disclosure data were available in the bulk download.[129]

To include in our analysis the data submitted in the "FracFocus 1.0" format required the incorporation of data released by the U.S. Environmental Protection Agency, which in March 2015 published an analysis of all the "FracFocus 1.0" data, as provided to the agency directly by FracFocus.[130]

The EPA conducted quality-assurance processes, but not real-world-comparison data validation, before releasing the data used in its analysis to the public.[131]

FracFocus.org Data

We downloaded a bulk data package from FracFocus.org in September 2015. The three data files were processed through Microsoft SQL Server software according to the instructions provided on the FracFocus website and archived at web.archive.org/web/20150520202149/http://data.fracfocus.org/DigitalDownload/FracFocus-SQLtoAccess.pdf.

The three data files were joined according to the instructions provided on the FracFocus website and archived at web.archive.org/web/20150520202248/http://fracfocus.org/data-download, though at one point we used a "left join" instead of an "inner join" to avoid losing data.

U.S. Environmental Protection Agency Data

The EPA-processed data from the "FracFocus 1.0" format were downloaded from www2.epa.gov/hfstudy/epa-project-database-developed-fracfocus-1-disclosures on 6 May 2015.

The "QAWell" table and "QAIngredient" table in the EPA data were queried to assemble all records of all wells and the ingredient information associated with those wells.

Determining Chemical Use at Fracked Wells

The FracFocus and EPA data have multiple records for each frack job, detailing each chemical used in that job. In total, the data for 142,000 frack jobs at 100,000 wells were located in 3.5 million records.

We selected frack jobs begun between January 1, 2005 and June 30, 2015, and then took several measures to ensure reliable data.

In Step 1, we excluded records that listed a chemical on a frack job's reporting form but no ingredient concentration in the final composition of the fracking fluid.

For Step 2, we wanted only reliable records regarding base fluid water usage, the primary component of fracking fluid that carries sand and chemicals. We excluded records with either too much or too little base fluid water concentration. Specifically, we excluded records from frack jobs where:

- the base fluid water maximum concentration was indicated in the data as exceeding 101 percent of the job's fracking fluid, or
- the base fluid water maximum concentration was indicated in the data as being less than 50 percent of the job's fracking fluid.

In Step 3, we looked for reliable records regarding ingredient usage. FracFocus requires reporting of each ingredient's *maximum* percentage concentration in fracking fluid. If a fracking fluid's composition was significantly modified during the course of a fracking job, all the ingredients' maximum concentrations, when added together, could, therefore, exceed 100 percent. Using these numbers would likely result in overestimates of chemical amounts.

If a report was incomplete, the sum of the disclosed ingredients' maximum concentrations could be far below 100 percent. With no way to know the concentrations of the missing ingredients, we assumed they, if reported, could potentially bring the total above 100 percent. Using these numbers, therefore, could result in overestimates of the amounts of those chemicals that were reported.

To ensure we were basing our analysis on fracking fluids whose composition was completely reported and substantially uniform throughout the entire frack job, we excluded records from frack jobs where:

- the total component maximum concentration was indicated in the data as exceeding 101 percent of the job's fracking fluid,[132] or

Table M-1. Quantifying Data Validation Exclusions

Source	Starting Point: All records for frack jobs at all wells	Step 1: Records with nonzero ingredient concentration in HF fluid	Percent kept	Step 2: Records within reasonable water base fluid concentration limits	Percent kept from previous step	Step 3: Records within reasonable ingredient concentration limits	Percent kept from previous step	Percent kept overall
EPA – FracFocus 1.0	1,169,023	927,525	80%	828,103	89%	776,487	94%	66%
FracFocus bulk download (FracFocus 2.0)	2,338,564	2,249,300	98%	2,116,919	94%	1,873,857	89%	80%
Total	**3,507,587**	**3,176,825**	**92%**	**2,945,022**	**93%**	**2,650,344**	**90%**	**76%**

- the total component maximum concentration was indicated in the data as being less than 95 percent of the job's fracking fluid.[133]

These steps left for analysis 2.65 million records from 81,000 frack jobs at 78,000 wells. Our analysis, therefore, was conducted on 76 percent of available records, describing 57 percent of frack jobs at 78 percent of wells, suggesting that the estimates of chemical use in this report likely significantly understate total chemical use in fracking.

As Table M-1 shows, 80 percent of the records from the FracFocus bulk download had valid data usable in this analysis. And following EPA's data quality efforts, 66 percent of the data downloaded from the EPA were usable.[134] This may be because the EPA's analysis depended first on converting PDF files into a machine-readable database format, a process that can easily introduce errors, such as by placing data values in incorrect fields.

Calculating Chemical Amounts

To calculate the amount of each chemical used, we first calculated each frack job's total mass. The source data included both gallons of water used and the percentage by mass of water in the fracking fluid as a whole. As the mass of a gallon of water is a known value, this allows determination of the total mass of the fracking fluid.

Records detailing water use were those where the Chemical Abstracts Service Registry number was 7732-18-5, or where the trade name, purpose or ingredient name included the words "water," "base," "carrier," "H2O" and the like. The exact list of criteria is available upon request. Many fracking jobs had multiple such records, because water is an ingredient in many fracking additives. For example, in 15 percent hydrochloric acid, the remaining 85 percent is water.

Many fracking jobs, however, also had multiple records indicating substances used in the "base fluid" or "carrier fluid." Using only the larger of these to calculate the total mass would result in an erroneously high mass result, which would in turn lead to erroneously high chemical amounts. To ensure a conservative result for the total mass calculation, we used the sum of all percentage by mass for water records.

For data on chemicals, rather than water, we made the following assumptions:

- We assumed that the listed name of the chemical correctly identifies the chemical. We did not check the CAS number against the listed name of the chemical in the FracFocus database.

- Some chemicals, such as hydrochloric acid, are solutions that include water. Because of how the data are reported in FracFocus, the water component could not be systematically determined and thus data reported in this paper for those chemicals may incorporate water used for dilution.

- Fracking operations may use ceramics and other synthetic materials in addition to or in place of sand, but do not consistently identify them as solid proppants as opposed to liquid substances. Our tally of chemicals includes some of these solid proppants.

For each fracking job, each ingredient's percentage by mass was multiplied by the job's total mass, to arrive at a mass of that ingredient in that job. Chemical masses were then added across fracking jobs, by state, to arrive at a total of each chemical used in fracking.

This method is the same as that used by media organizations in Texas and Ohio to determine amounts of chemicals used in fracking wells in those states.[135]

This method makes four key assumptions:

- It assumes that the quantity listed in the base fluid amount is, in fact, for water. In FracFocus 1.0 data submissions this field had varying labels, referring to "base," "fluid" or "water," with operators asked to identify whether the base fluid was water or something else.

In 93 percent of records in FracFocus 1.0, the base fluid was water.[136] The assumption that this field referred to water was used by the U.S. Environmental Protection Agency when calculating cumulative water volumes.[137] In FracFocus 2.0 data, this distinction is clearer: One field is labeled “TotalBaseWaterVolume” and another is labeled “TotalBaseNonWaterVolume.” Our analysis used the “TotalBaseWaterVolume” field for calculating the total job mass.

- It assumes the value given for the concentration of the chemical ingredient in the total hydraulic fracturing fluid in percentage by mass remained constant throughout the frack job. Companies may vary their chemical compositions over the course of a frack job. However, FracFocus only asks them to report the maximum concentration, meaning there is no way to identify periods of time when the concentration might have been below that maximum level.

- It uses only the field indicating the percentage of the chemical ingredient in the overall fracking fluid. Another field provides the percentage of the chemical ingredient in an additive—if an acid is in solution, for example, it would say the solution was 50 percent acid. The labeling on the FracFocus forms and in its documentation is clear that these two fields are unrelated and do not need to be factored together.

- It assumes the water used in fracking jobs is fresh, weighing 8.33 pounds per gallon.[138] Fresh water was selected because it is the most conservative assumption: If this model had assumed brackish water was used, the amounts of chemicals would have been higher, by 0.03 percent.[139]

The chemical totals we use in this report are the sums of the data reported in FracFocus and EPA databases; the results are not extrapolated to represent any additional wells.

Notes

1 U.S. Department of Energy, Energy Information Administration, *Lower 48 States Shale Gas Plays,* updated 13 April 2015, archived at web.archive.org/web/20160328164939/https://www.eia.gov/oil_gas/rpd/shale_gas.pdf.

2 Ernest Scheyder, "Millions of Gallons of Saltwater Leak into North Dakota Creek," *Reuters*, 22 January 2015, archived at web.archive.org/web/20160328165031/http://www.reuters.com/article/us-usa-north-dakota-spill-idUSKBN0KV1ZR20150123.

3 Mark Gillispie, "Cleanup Continues for Drilling Leak near Marietta," *Associated Press*, 8 May 2014, archived at web.archive.org/web/20160328165134/http://www.ohio.com/news/break-news/cleanup-continues-for-drilling-leak-near-marietta-1.486500.

4 "30-Month Report Finds PADEP Fracking Complaint Investigations Are 'Cooked' and Shredded," *Public Herald*, 21 September 2015, archived at web.archive.org/web/20160328165134/http://www.ohio.com/news/break-news/cleanup-continues-for-drilling-leak-near-marietta-1.486500.

5 Theo Colborn et al., "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, 2011.

6 Elise G. Elliott et al., "A Systematic Evaluation of Chemicals in Hydraulic-Fracturing Fluids and Wastewater for Reproductive and Developmental Toxicity," *Journal of Exposure Science and & Environmental Epidemiology*, doi: 10.1038/jes.2015.81, 6 January 2016.

7 Philip Robinson, "Audit of Fracking Fluids Highlights Data Deficiencies," C*hemistry World,* 15 August 2014, archived at web.archive.org/web/20160328165437/http://www.rsc.org/chemistryworld/2014/08/audit-fracking-fluids-highlights-data-deficiencies.

8 Christopher Kassotis et al., "Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region," *Endocrinology*, 155(3): 897-907, doi: 10.1210/en.2013-1697, March 2014.

9 Mike Jones and Scott Beveridge, "DEP: Jon Day Impoundment Contaminated Groundwater," *Observer Reporter*, 10 June 2014.

10 Burden et al., U.S. Environmental Protection Agency, *Review of State and Industry Spill Data: Characterization of Hydraulic Fracturing-Related Spills*, Office of Research and Development, Washington, DC., doi: EPA/601/R-14/001, May 2015.

11 U.S. Environmental Protection Agency, data received from oil and gas exploration and production companies, including hydraulic fracturing service companies 2011 to 2013. Non-confidential business information source documents are located in Federal Docket ID: EPA-HQ-ORD2010-0674.2013.

12 0.04: Brantley et al., "Water Resource Impacts During Unconventional Shale Gas Development: The Pennsylvania Experience," *International Journal of Coal Geology*, 126: 140-156, doi: 10.1016/j.coal.2013.12.017, 1 June 2014; 12.2: Rahm et al., "Shale Gas Operator Violations in the Marcellus and What They Tell Us about Water Resource Risks," *Energy Policy*, 82: 1-11, doi: 10.1016/j.enpol.2015.02.033, July 2015.

13 Jeff Tollefson, "Gas Drilling Taints Groundwater," *Nature News*, 25 June 2013, archived at web.archive.org/web/20160328165958/http://www.nature.com/news/gas-drilling-taints-groundwater-1.13259.

14 Anthony Ingraffea, Physicians, Scientists and Engineers for Healthy Energy, *Fluid Migration Mechanisms Due to Faulty Well Design and/or Construction: An Overview and Recent Experiences in the Pennsylvania Marcellus Play*, January 2013.

15 Laura Legere, "Jury Awards Last Dimock Plaintiffs $4.2 Million over Water Well Contamination," *Pittsburgh Post-Gazette*, 10 March 2016, archived

at web.archive.org/web/20160314192330/http://powersource.post-gazette.com/powersource/companies/2016/03/10/Jury-awards-last-Dimock-plaintiffs-4-2-million-over-water-well-contamination-Cabot-Marcellus-Shale/stories/201603100161.

16 Zacariah Hildenbrand et al., "A Comprehensive Analysis of Groundwater Quality in the Barnett Shale Region," *Environmental Science & Technology*, 49 (13), 8254–8262, doi: 10.1021/acs.est.5b01526, 2015.

17 Brian Fontenot et al., "An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation," *Environmental Science & Technology*, doi: 10.1021/es4011724, 2013.

18 Nadia Steinzor and Bruce Baize, "Wasting Away: Four States' Failure to Manage Gas and Oil Field Waste from the Marcellus and Utica Shale," *Earthworks*, April 2015, archived at web.archive.org/web/20160328170559/https://www.earthworksaction.org/library/detail/wasting_away_full_report.

19 Don Hopey, "Range Resources to Pay $4.15 Million Penalty," *Pittsburg Post-Gazette*, 18 September 2014, archived at web.archive.org/web/20160402004702/http://www.post-gazette.com/local/2014/09/18/DEP-orders-Range-Resources-to-pay-4-million-fine/stories/201409180293.

20 See note 18.

21 Public Employees for Environmental Responsibility, *Don't Drink the Fracking Fluids! Toxic Well Flowback Pumped for Consumption by Wildlife and Livestock* (press release), 9 July 2013, archived at web.archive.org/save/http://yubanet.com/usa/Don-39-t-Drink-the-Fracking-Fluids.php#.VvllanqVGuh.

22 Will Kennedy, "Exxon Charged with Illegally Dumping Waste in Pennsylvania," *Bloomberg*, 11 September 2013.

23 Stephen Stock et al., "Waste Water from Oil Fracking Injected into Clean Aquifers," *NBC Bay Area,* 14 November 2014.

24 Abrahm Lustgarten, "Injection Wells: The Poison Beneath Us," *ProPublica*, 21 June 2012.

25 Kate Galbraith and Terrence Henry, "As Fracking Proliferates in Texas, So Do Disposal Wells," *TexasTribune*, 29 March 2013.

26 Abrahm Lustgarten, "Whiff of Phenol Spells Trouble," *ProPublica*, 21 June 2012.

27 Bridget R. Scanlon, Robert C. Reedy and Jean-Philippe Nicot, "Comparison of Water Use for Hydraulic Fracturing for Shale Oil and Gas Production versus Conventional Oil," *Environmental Science and Technology*, doi: 10.1021/es502506v, 18 September 2014; and Bridget R. Scanlon, Robert C. Reedy and Jean-Philippe Nicot, "Will Water Scarcity in Semiarid Regions Limit Hydraulic Fracturing of Shale Plays?" *Environmental Research Letters*, 9(12), doi: 10.1088/1748-9326/9/12/124011, 8 December 2014.

28 Suzanne Goldenberg, "A Texan Tragedy: Ample Oil, No Water," *The Guardian*, 11 August 2013.

29 Jack Healy, "For Farms in West, Oil Wells Are Thirsty Rivals," *New York Times*, 5 September 2012.

30 Monika Freyman and Ryan Salmon, Ceres, *Hydraulic Fracturing & Water Stress: Growing Competitive Pressures for Water*, May 2013.

31 Monika Freyman, Ceres, *Hydraulic Fracturing and Water Stress: Water Demand by the Numbers*, February 2014.

32 Lisa McKenzie et al., "Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources," *Science of the Total Environment*, 424: 79-87, doi: 10.1016/j.scitotenv.2012.02.018, 1 May 2012.

33 Lisa McKenzie et al., "Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado," *Environmental Health Perspectives*, 122: 412-417, doi: 10.1289/ehp.1306722, April 2014.

34 Russell Gold and Tom McGinty, "Energy Boom Puts Wells in America's Backyards," *The Wall Street Journal*, 25 October 2013.

35 L. Blair Paulik et al., "Impact of Natural Gas Extraction on PAH Levels in Ambient Air," *Environmental Science & Technology*, 49(8), 5203-5210, doi: 10.1021/es506095e, 2015.

36 Eric J. Esswein et al., "Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results," *Journal of Occupational and Environmental Hygiene*, 11(10), doi: 10.1080/15459624.2014.933960, 1 August 2014.

37 National Institute for Occupational Safety and Health, *UPDATE: Reports of Worker Fatalities during Manual Tank Gauging and Sampling in the Oil and Gas Extraction Industry* (blog), 10 April 2015.

38 U.S. Occupational Safety and Health Administration, *Hazard Alert: Worker Exposure to Silica During Hydraulic Fracturing*, accessed at www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html, 3 July 2012.

39 U.S. Environmental Protection Agency, *Ozone and Your Patients' Health: Training for Health Care Providers*, 11 August 2012, archived at web.archive.org/web/20160401053029/https://www3.epa.gov/apti/ozonehealth/keypoints.html.

40 Lisa Song, Jim Morris, and David Hasemyer, "Fracking Boom Spews Toxic Air Emissions on Texas Residents," *Inside Climate News*, 18 February 2014.

41 Gunnar Myhre et al., "Anthropogenic and Natural Radiative Forcing," in T.F. Stocker et al. (eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2013), 714.

42 Gabrielle Pétron et al., "Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study," *Journal of Geophysical Research*, 117(D4): D04304, doi: 10.1029/2011JD016360, 27 February 2012.

43 Dana Caulton et al., "Toward a Better Understanding and Quantification of Methane Emissions from Shale Gas Development," *Proceedings of the National Academy of Sciences* 111(17): 6237-6242, doi: 10.1073/pnas.1316546111, 14 April 2014.

44 Oliver Schneising et al., "Remote Sensing of Fugitive Methane Emissions from Oil and Gas Production in North American Tight Geologic Formations," *Earth's Future*, 2 (10): 548–558, doi: 10.1002/2014EF000265, 6 October 2014.

45 David Allen et al., "Measurements of Methane Emissions at Natural Gas Production Sites in the United States," *Proceedings of the National Academy of Sciences*, 110(44): 17768-17773, doi: 10.1073/pnas.1304880110, September 2013.

46 Adam Brandt et al., "Methane Leaks from North American Natural Gas Systems," *Science*, 343: 733-735, doi: 10.1126/science.1247045, 14 February 2014.

47 Assumptions in studies from Garvin Heath et al., "Harmonization of Initial Estimates of Shale Gas Life Cycle Greenhouse Gas Emissions for Electric Power Generation," *Proceedings of the National Academy of Sciences*, 111(31): E3167-E3176, doi: 10.1073/pnas.1309334111, 21 April 2014, compared to EIA and USGS data as presented in J. David Hughes, *Drill, Baby, Drill: Can Unconventional Fuels Usher in a New Era of Energy Abundance* (Santa Rosa, CA: Post Carbon Institute, February 2013), 76.

48 Lesley McClurg, "State Approves Tighter Regulations on Oil and Gas Emissions," *Colorado Public Radio*, 25 February 2014, archived at web.archive.org/save/http://www.cpr.org/news/story/state-approves-tighter-regulations-oil-and-gas-emissions.

49 Megan Verlee, "Colorado Well Positioned for EPA Methane Rules, But Problem Worse Than Thought," *Colorado Public Radio*, 18 August 2015, archived at web.archive.org/web/20160327220506/http://www.cpr.org/news/story/colorado-well-positioned-epa-methane-rules-problem-worse-thought.

50 Amina Khan, "Porter Ranch Leak Declared Largest Methane Leak in U.S. History," *Los Angeles Times*, 25 February 2016, archived at web.archive.org/web/20160314191840/http://www.latimes.com/science/sciencenow/la-sci-sn-porter-ranch-methane-20160225-story.html.

51 Steven Habicht, Lars Hanson and Paul Faeth, "The Potential Environmental Impact from Fracking in the Delaware River Basin," *CNA*, August 2015, archived at web.archive.org/web/20160401053215/http://www.delawareriverkeeper.org/resources/Reports/CNA%20Impacts%20in%20DRB.8.15.pdf.

52 The Wilderness Society, *Too Wild to Drill*, July 2015, archived at web.archive.org/web/20160401053256/http://wilderness.org/sites/default/files/TooWildtoDrill.pdf.

53 David Garbett, Staff Attorney, Southern Utah Wilderness Alliance, personal communication, 31 March 2016.

54 See note 52.

55 Sandy Bauers, "Delaware River Basin Commission Head Steps Down," *The Inquirer* (Philadelphia, Pa.), 14 September 2013.

56 Alan Neuhauser, "Forest Service OKs Fracking in Forest Near Nation's Capital," *US News & World Report*, 19 November 2014.

57 Hall Sawyer and Ryan Nielson, Western Ecosystems Technology, Inc., *Mule Deer Monitoring in the Pinedale Anticline Project Area: 2015 Annual Report*, prepared for the Pinedale Anticline Project Office, 17 December 2015, archived at web.archive.org/web/20160219233245/http://www.wy.blm.gov/jio-papo/papo/wildlife/reports/dec2015/2015MuleDeer-dar.pdf.

58 Joseph M. Northrup, Charles R. Anderson Jr. and George Wittemyer, "Quantifying Spatial Habitat Loss from Hydrocarbon Development through Assessing Habitat Selection Patterns of Mule Deer," *Global Change Biology*, doi: 10.1111/gcb.13037, 12 August 2015.

59 New York State Department of Environmental Conservation, *Revised Draft 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*, 7 September 2011, 6-74.

60 Academy of Natural History of Drexel University, *A Preliminary Study on the Impact of Marcellus Shale Drilling on Headwaters Streams*, accessed at www.ansp.org/research/environmental-research/projects/marcellus-shale-preliminary-study, 18 June 2012.

61 Mariah Blake, "Halliburton Fracking Spill Mystery: What Chemicals Polluted an Ohio Waterway?" *Mother Jones*, 24 July 2014.

62 Mike Stephenson, "Fracking: What Does it Mean for Local People?" *Earth and Environmental Science*, 15 September 2015.

63 Shmuel Abramzon et al., "Estimating the Consumptive Use Costs of Shale Natural Gas Extraction on Pennsylvania Roadways," *Journal of Infrastructure Systems*, 20(3), doi: 06014001, September 2014.

64 Lucija Muehlenbachs, Elisheba Spiller, and Christopher Timmins, *The Housing Market Impact of Shale Gas Development, NBER Working Paper 19796*, January 2014, archived at web.archive.org/web/20160220000228/https://econ.ucalgary.ca/sites/econ.ucalgary.ca/files/MuehlenbachShaleDrillingW14.pdf.

65 Michelle Bamberger and Robert E. Oswald, "Impacts of Gas Drilling on Human and Animal Health," *New Solutions: A Journal of Environmental and Occupational Health Policy*, 22(1): 51-77, doi: 10.2190/NS.22.1.e, 2012.

66 Tony Dutzik, Benjamin Davis and Tom Van Heeke, Frontier Group, and John Rumpler, Environment America Research & Policy Center, *Who Pays the Costs of Fracking? Weak Bonding Rules for Oil and Gas Drilling Leave the Public at Risk*, July 2013.

67 Railroad Commission of Texas, Oil Field Cleanup Program, *Annual Report – Fiscal Year 2015*, 17 November 2015.

68 Dan Frosch and Russell Gold, "How 'Orphan' Wells Leave States Holding the Cleanup Bag," *The Wall Street Journal*, 25 February 2015.

69 Ibid.

70 Jove Graham et al., "Increased Traffic Accident Rates Associated with Shale Gas Drilling in Pennsylvania," *Accident Analysis & Prevention*, 74: 203-209, doi: 10.1016/j.aap.2014.11.003, January 2015.

71 "Fracking Boom Producing Deadly Side Effects," *Associated Press*, 5 May 2014.

72 Dianne Rahm, Billy Fields and Jayce L. Farmer, "Transportation Impacts of Fracking in the Eagle Ford Shale Development in Rural South Texas: Perceptions of Local Government Officials," *Journal of Rural & Community Development*, 10(2): 78-99, 2015.

73 Jim Malewitz, "Well Explosion Could Put Pressure on Texas Regulators," *The Texas Tribune*, 2 September 2015.

74 Laura Arenschield, "Most Allowed Back Home after Fracking-well Blowout in Eastern Ohio," *The Columbus Dispatch*, 30 October 2014.

75 Ryan Schuessler, "Southern Kansas Sees Sudden Spike in Earthquakes," *Washington Post*, 27 October 2015; Max Brantley, "Arkansas Sets Example in Responding to Earthquake Threats from Fracking," *Arkansas Times*, 25 April 2015, archived at web.archive.org/web/20160330191515/http://www.arktimes.com/ArkansasBlog/archives/2015/04/25/arkansas-sets-example-in-responding-to-earthquake-threats-from-tracking; Katie M. Keranen et al., "Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by

Massive Wastewater Injection" *Science*, 345 (6195): 448-451, doi: 10.1126/science.1255802, 25 July 2014; Mark Peterson et al., U.S. Geological Survey, *One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes*, doi: 10.3133/ofr20161035, 2016.

76 U.S. Geological Survey, "Induced Earthquakes," accessed 26 October 2015 at earthquake.usgs.gov/research/induced.

77 Ibid.

78 Katie M. Keranen et al., "Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by Massive Wastewater Injection" *Science*, 345 (6195): 448-451, doi: 10.1126/science.1255802, 25 July 2014.

79 See note 76.

80 Adam Kron, Environmental Integrity Project, and Jared Knicley, Natural Resources Defense Council, letter to Gina McCarthy, U.S. Environmental Protection Agency, *Notice of Intent to Sue for Violation of Nondiscretionary Duties under the Resource Conservation and Recovery Act with Respect to Wastes Associated with the Exploration, Development, or Production of Oil and Gas*, 26 August 2015, archived at web.archive.org/web/20160202010157/http://environmentalintegrity.org/wp-content/uploads/2015-08-26-OG-Wastes-RCRA-Notice-Letter-FINAL.pdf.

81 Center for Health, Environment and Justice, *Ohio*, 1 February 2016, archived at web.archive.org/web/20160202011406/http://chej.org/campaigns/nofracking/resources/ohio/.

82 Occupational Health and Safety Administration, U.S. Department of Labor, "Hydrogen Chloride," *OSHA Occupational Chemical Database*, n.d.

83 National Institute of Occupational Safety and Health, U.S. Centers for Disease Control and Prevention, "Methanol: Systemic Agent," *Emergency Response Safety and Health Database*, 20 November 2014, archived at web. archive.org/web/20150522204219/http://www.cdc.gov/niosh/ershdb/emergencyresponsecard_29750029.html.

84 Centers for Disease Control and Prevention, *Occupational Health Guidelines for Petroleum Distillates (Naphtha)*, September 1978, archived at web.archive.org/web/20160401051953/http://www.cdc.gov/niosh/docs/81-123/pdfs/0492.pdf.

85 Environmental Working Group, *California's Fracking Fluids: The Chemical Recipe*, 12 August 2015, available at www.ewg.org/research/california-s-toxic-fracking-fluid-chemical-recipe/health-hazards-fracking-chemicals.

86 National Library of Medicine, Toxicology Data Network, *Benzene*, accessed at toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+35, 31 March 2016.

87 Fischer Scientific, *Material Safety Data Sheet: Benzine (Petroleum Naphtha),* 9 February 2010, as posted at University of Akron, Health and Safety Department.

88 Centers for Disease Control and Prevention, Agency for Toxics Substances and Disease Registry, *Public Health Statement: Formaldehyde*, September 2008, available at www.atsdr.cdc.gov/toxprofiles/formaldehyde_fig_1_1.jpg.

89 National Institutes of Health, PubChem*, Compound Summary for CID 174: Ethylene Glycol*, accessed pubchem.ncbi.nlm.nih.gov/compound/ethylene_glycol#section=Top, 29 January 2016.

90 New Jersey Department of Health, *Hazardous Substance Fact Sheet: Sodium Hydroxide*, revised April 2010, archived at web.archive.org/web/20160401051620/http://nj.gov/health/eoh/rtkweb/documents/fs/1706.pdf.

91 Based on data for Texas' Barnett Shale presented in Jean-Phillipe Nicot et al., "Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective," *Environmental Science & Technology*, doi: 10.1021/es404050r, 27 January 2014. Approximately five percent of water used in frack jobs was reused or recycled water from previous frack jobs, and three percent was brackish water from aquifers.

92 Denver Water residential customers use an average of 115,000 gallons per year. Denver Water, *2015 Water Rates*, archived at web.archive.org/web/20160206000805/http://www.denverwater.org/BillingRates/RatesCharges/2015-rates/.

93 Tanya Gallegos et al., "Hydraulic Fracking Water Use Variability in the United States and Potential Environmental Implications" *Water Resources Research*, doi: 10.1002/2015WR017278, 24 July 2015.

94 Methane emissions calculated as described

in methodology. Coal-fired power plants calculated with U.S. Environmental Protection Agency, *Methane Emissions Reductions Calculator*, accessed at www3.epa.gov/gasstar/tools/calculator.html#results, 1 February 2016. Results updated assuming methane has a global warming potential of 34: see note 41.

95 See note 50.

96 David Lyon et al, "Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region," *Environmental Science & Technology,* doi: 10.1021/es506359c, 7 July 2015.

97 See note 44.

98 National Park Service, *Big Bend National Park: How Big Is It?*, archived at web.archive.org/web/20160223001136/http://www.nps.gov/bibe/learn/management/park_sizes.htm, 22 February 2016.

99 Nels Johnson et al., The Nature Conservancy, *Pennsylvania Energy Impacts Assessment, Report 1: Marcellus Shale Natural Gas and Wind*, 15 November 2010, archived at web.archive.org/web/20160401051425/http://www.nature.org/media/pa/tnc_energy_analysis.pdf.

100 Kevin Thuot, DrillingInfo, *On the Launch Pad: The Rise of Pad Drilling*, 4 February 2014, archived at web.archive.org/web/20160210231226/http://info.drillinginfo.com/launch-pad-rise-pad-drilling/.

101 Ibid.

102 Ibid.

103 U.S. Census Bureau, *QuickFacts: Denver City, Colorado*, 11 February 2016.

104 Natural Resources Defense Council, *NRDC Policy Basics: Fracking* (fact sheet), February 2013, archived at web.archive.org/web/20160401050803/https://www.nrdc.org/sites/default/files/policy-basics-fracking-FS.pdf.

105 Christopher McGlade and Paul Ekins, "The Geographic Distribution of Fossil Fuels Unused When Limiting Global Warming to 2° C," *Nature*, 517: 1870190, doi: 10.1038/nature14016, 8 January 2015.

106 The U.S. Energy Information Administration estimates that there are 78 billion barrels of unproved technically recoverable oil and 949 trillion cubic feet of gas in shale formations. For comparison, the U.S. produced 1.7 billion barrels of oil from unconventional sources in 2015 and 13.4 trillion cubic feet of gas from shale in 2014. Reserves: U.S. Energy Information Administration, *Assumptions to the AEO, Oil and Gas Supply Module, Table 9.3*, September 2015, archived at web.archive.org/web/20160402001213/https://www.eia.gov/forecasts/aeo/assumptions/pdf/oilgas.pdf. Unconventional gas production: U.S. Energy Information Administration, *Petroleum & Other Liquids: Drilling Productivity Report*, 7 March 2016, archived at web.archive.org/web/20160402001649/https://www.eia.gov/petroleum/drilling/; Shale oil production: U.S. Energy Information Administration, *Natural Gas: Shale Gas Production,* 19 November 2015, archived at web.archive.org/web/20160402001352/https://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm.

107 State of Vermont, *Act 152: An Act Relating to Hydraulic Fracturing Wells for Natural Gas and Oil Production*, available at legislature.vermont.gov/bill/acts/2012.

108 Timothy Cama, "Maryland Bans Fracking," *The Hill*, 1 June 2015, archived at web.archive.org/web/20160401050913/http://thehill.com/policy/energy-environment/243625-maryland-bans-fracking.

109 Freeman Klopott, "N.Y. Officially Bans Fracking With Release of Seven-Year Study," *Bloomberg Business*, 29 June 2015.

110 Matthew Dondiego, "Senate Dems Push Laws to Outlaw the Treatment and Use of Fracking Waste," *The Legislative Gazette*, 19 May 2014.

111 Food and Water Watch, "List of Bans Worldwide," accessed 31 March 2016, available at keeptapwatersafe.org/global-bans-on-fracking.

112 "Pennsylvania: Pittsburgh Forbids Gas Drilling," *The Associated Press*, 17 November 2010.

113 Jackie Fortier, "Boulder County Drilling Moratorium Extended," *KUNC*, 13 November 2014; and Bente Birkeland, "Longmont, Fort Collins Fracking Cases Get Their Say in State Supreme Court," *KVNF*, 11 December 2016, archived at web.archive.org/web/20160315160917/http://kvnf.org/post/longmont-fort-collins-fracking-cases-get-their-say-state-supreme-court.

114 Julie Cart, "New Mexico County First in Nation to Ban Fracking to Safeguard Water," *LA Times,* 28 May 2013, and "Judge Overturns Mora County's Drilling

Ordinance," *Associated Press*, 20 January 2015.

115 Karen Hansen, "Los Angeles Joins Dallas, NY, VT, Colorado Cities Trend to Halt Fracking," *Examiner*, 28 February 2014, archived at web.archive.org/web/20160401045827/http://www.examiner.com/article/los-angeles-joins-dallas-ny-vt-colorado-cities-trend-to-halt-fracking; Rory Carroll, "Santa Cruz Becomes First California County to Ban Fracking," *Reuters*, 20 May 2014, archived at web.archive.org/web/20160401045714/http://www.reuters.com/article/california-fracking-idUSL1N0O700J20140521.

116 Anastasia Pantsios, "Fracking Bans Pass in Denton, Texas, Two California Counties and One Ohio Town," *EcoWatch*, 5 November 2014, archived at web.archive.org/web/20160401045933/http://ecowatch.com/2014/11/05/fracking-ban-passes/.

117 Randy Lee Loftis, "Dallas OKs Gas Drilling Rules that Are among Nation's Tightest," *Dallas Morning News*, 12 December 2013, archived at web.archive.org/web/20160327213620/http://www.dallasnews.com/news/metro/20131211-dallas-oks-gas-drilling-rules-that-are-among-nations-tightest.ece.

118 Aleem Maqbool, "The Texas Town that Banned Fracking (and Lost)," *BBC News*, 16 June 2015, archived at web.archive.org/save/http://www.bbc.com/news/world-us-canada-33140732.

119 Amy Mall, Natural Resources Defense Council, *Drinking Water for Millions – including D.C. – at Risk without Stronger BLM Fracking Rules* (blog), 28 November 2012, archived at web.archive.org/web/20160401050535/https://www.nrdc.org/experts/amy-mall/drinking-water-millions-including-dc-risk-without-stronger-blm-fracking-rules; Katie Woods, "No Fracking in Wayne National Forest, Changes to BLM Rules," *Shale Gas Reporter*, 22 August 2014, archived at web.archive.org/web/20160401050620/http://shalegasreporter.com/news/fracking-wayne-national-forest-changes-blm-rules/16908.html.

120 Susan Phillips, "Gov. Wolf Bans New Fracking in State Parks and Forests," *StateImpact*, 29 January 2015, archived at web.archive.org/web/20160314183219/https://stateimpact.npr.org/pennsylvania/2015/01/29/gov-wolf-bans-new-drilling-in-state-parks-and-forests/.

121 Katie Colaneri, "Transparency About Fracking Chemicals Remains Elusive," *WHYY Newsworks*, 7 August 2014, archived at web.archive.org/web/20150520202729/http://www.newsworks.org/index.php/thepulse/item/71184-transparency-about-fracking-chemicals-remains-elusive.

122 Ibid.

123 Ibid.

124 Ibid.

125 FracFocus.org, *FracFocus Data Download*, archived at web.archive.org/web/20150526150919/http://fracfocus.org/data-download.

126 Ibid.

127 Ibid.

128 Ibid.

129 Ibid.

130 U.S. Environmental Protection Agency, *Analysis of Hydraulic Fracturing Fluid Data from the FracFocus Chemical Disclosure Registry 1.0* (EPA/601/R-14/003), March 2015.

131 Ibid.

132 Total component concentration was calculated by adding the concentration values for each component in a frack job.

133 Ibid.

134 EPA's efforts: see note 130.

135 See note 118; Bob Downing, "Fracturing Natural Gas Wells Requires Hundreds of Tons of Chemical Liquids," *Akron Beacon Journal*, 11 February 2012, archived at web.archive.org/web/20150521141913/http://www.ohio.com/news/local/fracturing-natural-gas-wells-requires-hundreds-of-tons-of-chemical-liquids-1.264478.

136 U.S. Environmental Protection Agency, "Overview of the EPA's Study of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources" (fact sheet), *Analysis of Hydraulic Fracturing Fluid Data from the FracFocus Chemical Disclosure Registry 1.0*, March 2013, archived at web.archive.org/web/20150521154533/http://www2.epa.gov/sites/production/files/2015-03/documents/fact_sheet_analysis_of_hydraulic_fracturing_fluid_data_from_the_fracfocu.pdf.

137 See note 130.

138 U.S. Geological Survey, “Water Properties: Facts and Figures About Water,” *USGS Water Science School*, 1 May 2015, archived at web.archive.org/web/20150521201911/https://water.usgs.gov/edu/water-facts.html.

139 Assuming brackish water had 3,000 milligrams of total dissolved solids (TDS) per liter, or 0.025 pounds per gallon. That level is the lowest level of TDS for “brackish” groundwater as defined by the Texas Commission on Environmental Quality, per Remediation Division, Texas Commission on Environmental Quality, *Groundwater Classification* (RG-366/TRRP-8), March 2010.