

Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources

Executive Summary

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1 Since the early 2000s, oil and natural gas production in the United States has been transformed
2 through technological innovation. Hydraulic fracturing, combined with advanced directional
3 drilling techniques, made it possible to economically extract oil and gas resources previously
4 inaccessible. The resulting surge in production increased domestic energy supplies and brought
5 economic benefits to many areas of the United States.

6 The growth in domestic oil and gas production also raised concerns about potential impacts to
7 human health and the environment, including potential effects on the quality and quantity of
8 drinking water resources. Some residents living close to oil and gas production wells have reported
9 changes in the quality of drinking water and assert that hydraulic fracturing is responsible for these
10 changes. Other concerns include competition for water between hydraulic fracturing activities and
11 other water users, especially in areas of the country experiencing drought, and the disposal of
12 wastewater generated from hydraulic fracturing.

13 The U.S. Congress urged the U.S. Environmental Protection Agency (EPA) to study the relationship
14 between hydraulic fracturing and drinking water. This report synthesizes available scientific
15 literature and data to assess the potential for hydraulic fracturing for oil and gas to change the
16 quality or quantity of drinking water resources, and identifies factors affecting the frequency or
17 severity of any potential changes. This report can be used by federal, tribal, state, and local officials;
18 industry; and the public to better understand and address any vulnerabilities of drinking water
19 resources to hydraulic fracturing activities.

What is Hydraulic Fracturing?

20 Hydraulic fracturing is a stimulation technique used to increase oil and gas production from
21 underground rock formations. Hydraulic fracturing involves the injection of fluids under pressures
22 great enough to fracture the oil- and gas-producing formations. The fluid generally consists of
23 water, chemicals, and proppant (commonly sand). The proppant holds open the newly created
24 fractures after the injection pressure is released. Oil and gas flow through the fractures and up the
25 production well to the surface.

26 Hydraulic fracturing has been used since the late 1940s and, for the first 50 years, was mostly used
27 in vertical wells in conventional formations.¹ Hydraulic fracturing is still used in these settings, but
28 the process has evolved; technological developments (including horizontal and directional drilling)
29 have led to the use of hydraulic fracturing in unconventional hydrocarbon formations that could not
30 otherwise be profitably produced (see Figure ES-1). These formations include:

¹ Conventional formations often allow oil and natural gas to flow to the wellbore without hydraulic fracturing and typically contain trapped oil and natural gas that migrated from other subsurface locations. Hydraulic fracturing can be used to enhance oil and gas production from these formations. In unconventional formations, hydraulic fracturing is needed to extract economical quantities of oil and gas.

- 1 • **Shales.** Organic-rich, black shales are the source rocks in which oil and gas form on
2 geological timescales. Oil and gas are contained in the pore space of the shale. Some shales
3 contain predominantly gas or oil; many shale formations contain both.
- 4 • **Tight formations.** “Tight” formations are relatively low permeability, non-shale,
5 sedimentary formations that can contain oil and gas. Like in shales, oil and gas are
6 contained in the pore space of the formation. Tight formations can include sandstones,
7 siltstone, and carbonates, among others.
- 8 • **Coalbeds.** In coalbeds, methane (the primary component of natural gas) is generally
9 adsorbed to the coal rather than contained in the pore space or structurally trapped in the
10 formation. Pumping the injected and native water out of the coalbeds after fracturing
11 serves to depressurize the coal, thereby allowing the methane to desorb and flow into the
12 well and to the surface.

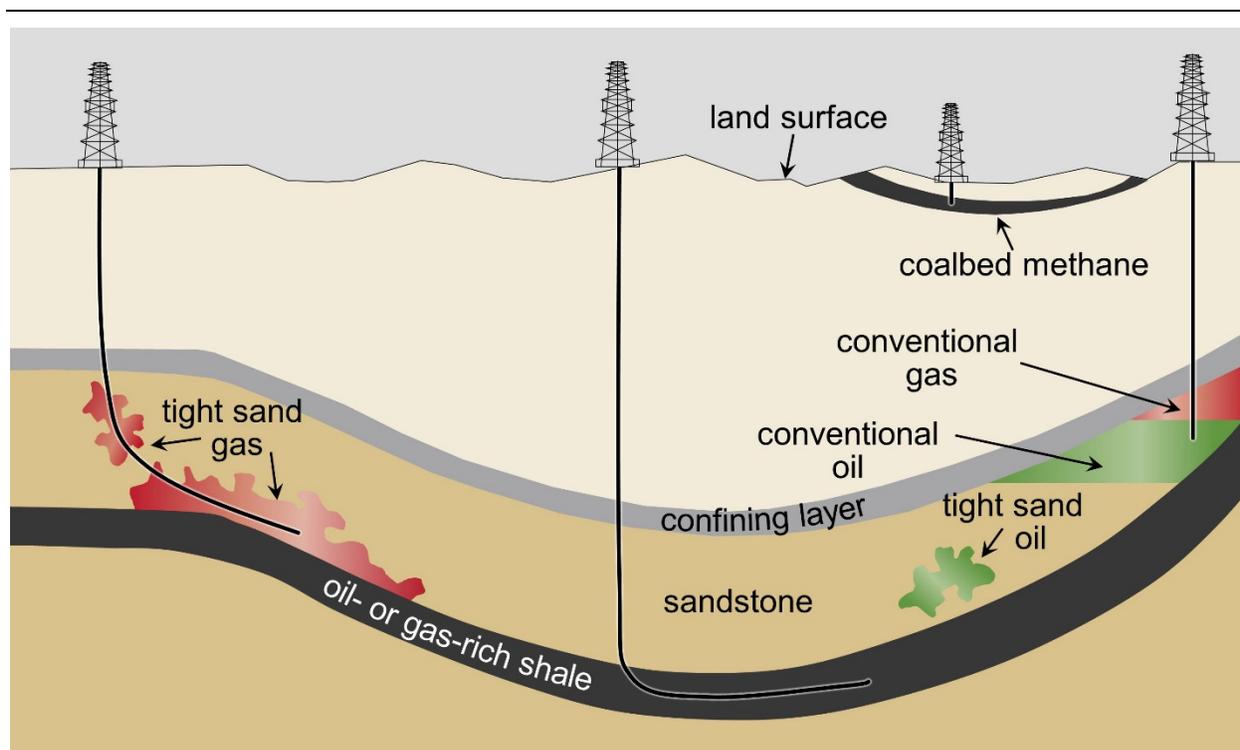


Figure ES-1. Schematic cross-section of general types of oil and gas resources and the orientations of production wells used in hydraulic fracturing.

Shown are conceptual illustrations of types of oil and gas wells. A vertical well is producing from a conventional oil and gas deposit (right). In this case, a gray confining layer serves to “trap” oil (green) or gas (red). Also shown are wells producing from unconventional formations: a vertical coalbed methane well (second from right); a horizontal well producing from a shale formation (center); and a well producing from a tight sand formation (left). Note: Figure not to scale. Modified from [USGS \(2002\)](#) and [Newell \(2011\)](#).

1 The combined use of hydraulic fracturing with horizontal (or more generically, directional) drilling
2 has led to an increase in oil and gas activities in areas of the country with historical oil and gas
3 production, and an expansion of oil and gas activities to new regions of the country.

Scope of the Assessment

4 We defined the scope of this assessment by the following activities involving water that support
5 hydraulic fracturing (i.e., the hydraulic fracturing water cycle; see Figure ES-2):¹

- 6 • **Water acquisition:** the withdrawal of ground or surface water needed for hydraulic
7 fracturing fluids;
- 8 • **Chemical mixing:** the mixing of water, chemicals, and proppant on the well pad to create
9 the hydraulic fracturing fluid;
- 10 • **Well injection:** the injection of hydraulic fracturing fluids into the well to fracture the
11 geologic formation;
- 12 • **Flowback and produced water:** the return of injected fluid and water produced from the
13 formation (collectively referred to as produced water in this report) to the surface, and
14 subsequent transport for reuse, treatment, or disposal; and
- 15 • **Wastewater treatment and waste disposal:** the reuse, treatment and release, or
16 disposal of wastewater generated at the well pad, including produced water.

17 This assessment reviews, analyzes, and synthesizes information relevant to the potential impacts of
18 hydraulic fracturing on drinking water resources at each stage of the hydraulic fracturing water
19 cycle. Impacts are defined as any change in the quality or quantity of drinking water resources.
20 Where possible, we identify the mechanisms responsible or potentially responsible for any impacts.
21 For example, a spill of hydraulic fracturing fluid is a mechanism by which drinking water resources
22 could be impacted.

23 Drinking water resources are defined within this report as any body of ground water or surface
24 water that now serves, or in the future could serve, as a source of drinking water for public or
25 private use. This is broader than most federal and state regulatory definitions of drinking water and
26 encompasses both fresh and non-fresh bodies of water. Trends indicate that both types of water
27 bodies are currently being used, and will continue to be used in the future, as sources of drinking
28 water.

29 This assessment focuses on the potential impacts from activities in the hydraulic fracturing water
30 cycle on drinking water resources. We do this so federal, tribal, state, and local officials; industry;
31 and the public can better understand and address any vulnerabilities of drinking water resources to
32 hydraulic fracturing activities. We do not address other concerns raised about hydraulic fracturing
33 specifically or about oil and gas exploration and production activities more generally. Activities that

¹ In this assessment, we refer to the “EPA” when referencing other EPA studies. If a conclusion or analysis was done specifically by the authors of this assessment, we refer to it and its findings in the first person.

1 are not considered include: acquisition and transport of constituents of hydraulic fracturing fluids
 2 besides water (e.g., sand mining and chemical production) outside of the stated water cycle; site
 3 selection and well pad development; other infrastructure development (e.g., roads, pipelines,
 4 compressor stations); site reclamation; and well closure. A summary and evaluation of current or
 5 proposed regulations and policies is beyond the scope of this report. Additionally, this report does
 6 not discuss the potential impacts of hydraulic fracturing on other water users (e.g., agriculture or
 7 industry), other aspects of the environment (e.g., seismicity, air quality, or ecosystems), worker
 8 health or safety, or communities. Furthermore, this report is not a human health risk assessment. It
 9 does not identify populations that are exposed to chemicals, estimate the extent of exposure, or
 10 estimate the incidence of human health impacts.

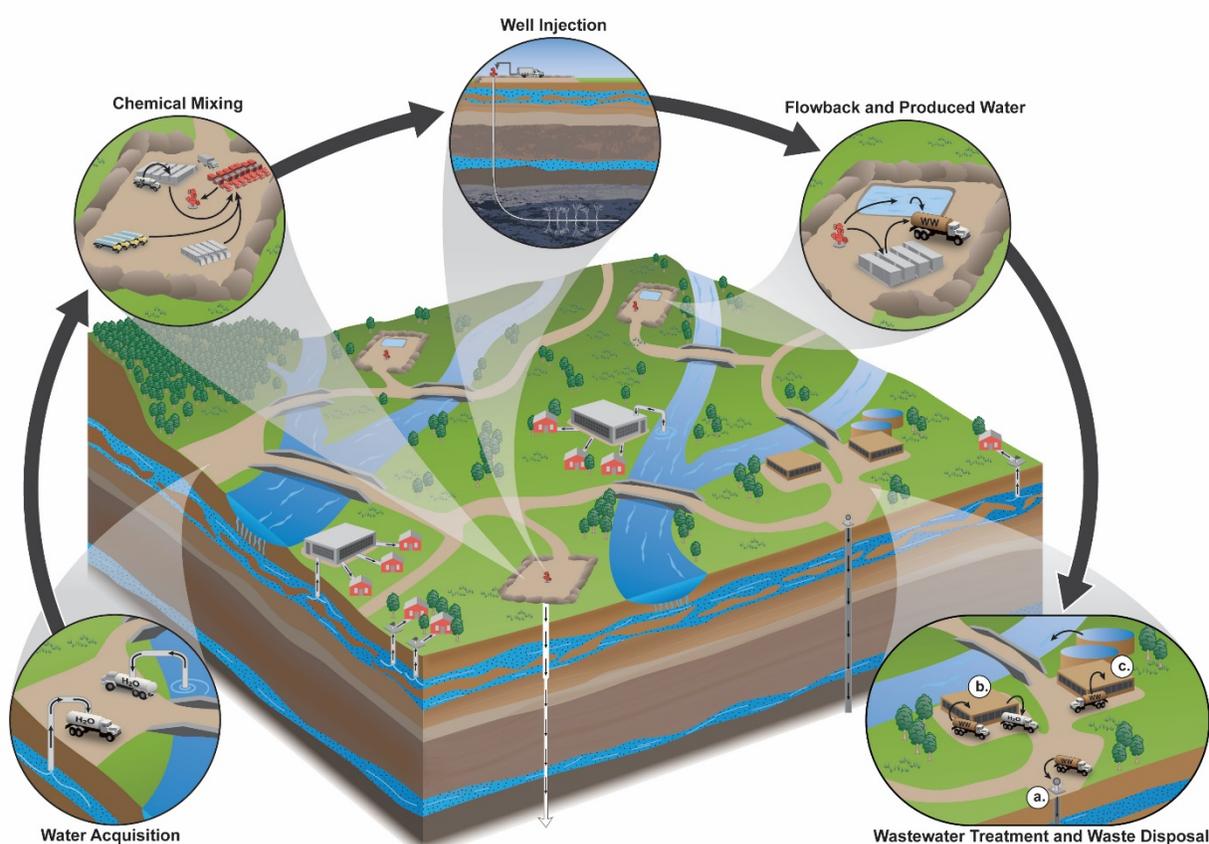


Figure ES-2. The stages of the hydraulic fracturing water cycle.

Shown here is a generalized landscape depicting the activities of the hydraulic fracturing water cycle and their relationship to each other, as well as their relationship to drinking water resources. Arrows depict the movement of water and chemicals. Specific activities in the “Wastewater Treatment and Waste Disposal” inset are (a) underground injection control (UIC) well disposal, (b) wastewater treatment and reuse, and (c) wastewater treatment and discharge at a centralized waste treatment (CWT) facility. Note: Figure not to scale.

Approach

1 This assessment relies on relevant scientific literature and data. Literature evaluated included
2 articles published in science and engineering journals, federal and state government reports, non-
3 governmental organization (NGO) reports, and industry publications. Data sources examined
4 included federal- and state-collected data sets, databases maintained by federal and state
5 government agencies, other publicly-available data and information, and data, including
6 confidential and non-confidential business information, submitted by industry to the EPA.¹ The
7 relevant literature and data complement research conducted by the EPA under its *Plan to Study the*
8 *Potential Impacts of Hydraulic Fracturing on Drinking Water Resources* (hereafter referred to as the
9 “Study Plan”) and published by scientific journals or as peer-reviewed EPA reports; those articles
10 and reports are cited throughout this assessment. The research topic areas and projects described
11 in the Study Plan were designed to meet the data and information needs of this assessment and
12 were developed with substantial expert and public input.

Proximity of Current Activity and Drinking Water Resources

13 Thousands of wells are drilled and fractured every year in the United States, with activities
14 concentrated in specific locations. We estimate 25,000-30,000 new wells were drilled and
15 hydraulically fractured annually in the United States between 2011 and 2014. Additional, pre-
16 existing wells (wells more than one year old that may or may not have been hydraulically fractured
17 in the past) were also likely fractured. Hydraulic fracturing took place in at least 25 states between
18 1990 and 2013. The EPA’s analysis of disclosures made to FracFocus 1.0 (hereafter “FracFocus”)
19 contained wells from 20 of these states.² Almost half of these wells were in Texas. Colorado was a
20 distant second, while Pennsylvania and North Dakota were third and fourth, respectively. Hydraulic
21 fracturing activities were further localized within the 20 states. Of the approximately 1,500
22 counties or county equivalents in these 20 states, slightly over 400 contained all of the wells
23 disclosed to FracFocus during this time period. In Colorado, over 85% of the hydraulically fractured
24 wells disclosed were located in two counties. The price of gas and oil may cause short term
25 volatility in the number of wells drilled and fractured per year, yet hydraulic fracturing is expected
26 to continue to expand and drive an increase in domestic oil and gas production in coming decades.

27 Hydraulically fractured wells can be located near residences and drinking water resources.
28 Between 2000 and 2013, approximately 9.4 million people lived within one mile of a hydraulically

¹ Some information provided to the EPA in response to two separate information requests to service companies and well operators was claimed as confidential business information.

² FracFocus is a publicly accessible website (www.fracfocus.org) managed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission where oil and gas production well operators may disclose information voluntarily or pursuant to state requirements about the ingredients used in hydraulic fracturing fluids at individual wells. The EPA analyzed disclosures from FracFocus 1.0 for over 38,000 oil and gas production wells hydraulically fractured between January 1, 2011 and February 28, 2013. A disclosure refers to data submitted for a specific oil and gas production well for a specific fracture date. Most wells had only one disclosure, but a small number of wells (876 wells) had multiple disclosures. For the purposes of this Executive Summary, we equate disclosures with wells when discussing this study.

1 fractured well. Approximately 6,800 sources of drinking water for public water systems were
2 located within one mile of at least one hydraulically fractured well during the same period. These
3 drinking water sources served more than 8.6 million people year-round in 2013.

4 Although proximity of hydraulic fracturing activities to a drinking water resource is not in of itself
5 sufficient for an impact to occur,, it does increase the potential for impacts. Residents and drinking
6 water resources in areas experiencing hydraulic fracturing activities are most likely to be affected
7 by any potential impacts, should they occur. However, hydraulic fracturing can also affect drinking
8 water resources outside the immediate vicinity of a hydraulically fractured well; a truck carrying
9 wastewater could spill or a release of inadequately treated wastewater could have downstream
10 effects.

Major Findings

11 From our assessment, we conclude there are above and below ground mechanisms by which
12 hydraulic fracturing activities have the potential to impact drinking water resources. These
13 mechanisms include water withdrawals in times of, or in areas with, low water availability; spills of
14 hydraulic fracturing fluids and produced water; fracturing directly into underground drinking
15 water resources; below ground migration of liquids and gases; and inadequate treatment and
16 discharge of wastewater.

17 We did not find evidence that these mechanisms have led to widespread, systemic impacts on
18 drinking water resources in the United States. Of the potential mechanisms identified in this report,
19 we found specific instances where one or more mechanisms led to impacts on drinking water
20 resources, including contamination of drinking water wells. The number of identified cases,
21 however, was small compared to the number of hydraulically fractured wells.

22 This finding could reflect a rarity of effects on drinking water resources, but may also be due to
23 other limiting factors. These factors include: insufficient pre- and post-fracturing data on the quality
24 of drinking water resources; the paucity of long-term systematic studies; the presence of other
25 sources of contamination precluding a definitive link between hydraulic fracturing activities and an
26 impact; and the inaccessibility of some information on hydraulic fracturing activities and potential
27 impacts.

28 Below, we provide a synopsis of the assessment's key findings, organized by each stage of the
29 hydraulic fracturing water cycle. We provide answers to the research questions presented in the
30 Study Plan and Chapter 1. While come citations are provided here, individual chapters should be
31 consulted for additional detail and citations.

Water Acquisition

32 Water is a major component of nearly all hydraulic fracturing operations. It typically makes up
33 almost 90% or more of the fluid volume injected into a well, and each hydraulically fractured well
34 requires thousands to millions of gallons of water. Cumulatively, hydraulic fracturing activities in
35 the United States used on average 44 billion gal of water a year in 2011 and 2012, according to the

1 EPA’s analysis of FracFocus disclosures. Although this represents less than 1% of total annual water
2 use and consumption at this scale, water withdrawals could potentially impact the quantity and
3 quality of drinking water resources at more local scales.¹

Research Questions: Water Acquisition

- **What are the types of water used for hydraulic fracturing?**

4 Water for hydraulic fracturing typically comes from surface water, ground water, or reused
5 hydraulic fracturing wastewater. Hydraulic fracturing operations in the eastern United States
6 generally rely on surface water, while operations in the more semi-arid to arid western states
7 generally use mixed supplies of surface and ground water. In the Marcellus Shale in Pennsylvania,
8 for example, most water used for hydraulic fracturing originates from surface water, whereas
9 surface and ground water are used in approximately equal proportions in the Barnett Shale in
10 Texas (see Figure ES-3a,b). In areas that lack available surface water (e.g., western Texas), ground
11 water supplies most of the water needed for hydraulic fracturing.

12 Across the United States, the vast majority of water used in hydraulic fracturing is fresh, although
13 operators also make use of lower-quality water, including reused hydraulic fracturing wastewater.²
14 Based on available data, the median reuse of wastewater as a percentage of injected volumes is 5%
15 nationally, with the percentage varying by location.³ Available data on reuse trends indicate
16 increased reuse of wastewater over time in both Pennsylvania and West Virginia. Reuse as a
17 percentage of injected volumes is lower in other areas, including regions with more water stress,
18 likely because of the availability of disposal wells. For example, reused wastewater is
19 approximately 18% of injected volumes in the Marcellus Shale in Pennsylvania’s Susquehanna
20 River Basin, whereas it is approximately 5% in the Barnett Shale in Texas (see Figure ES-3a,b).

¹ Water use is water withdrawn from ground- or surface water for a specific purpose, part or all of which may be returned to the local hydrologic cycle. If no water is returned, water use equals water consumption. Water consumption is water that is removed from the local hydrologic cycle following its use (e.g., via evaporation, transpiration, incorporation into products or crops, consumption by humans or livestock) and is therefore unavailable to other water users (Maupin et al., 2014). In the case of hydraulic fracturing, water can be consumed by the loss of injected water to subsurface zones or via underground disposal of wastewaters, among other means.

² In this assessment, hydraulic fracturing “wastewater” refers to both produced water and any other water generated as a hydraulic fracturing site. As used in this assessment, the term “wastewater” is not intended to constitute a term of art for legal or regulatory purposes.

³ Reused wastewater as a percentage of injected water differs from the percentage of wastewater that is managed through reuse, as opposed to other wastewater management options. For example, in the Marcellus in Pennsylvania, approximately 18% of injected water is reused produced water, while approximately 70% of wastewater or more is managed through reuse (Figure ES-3a).

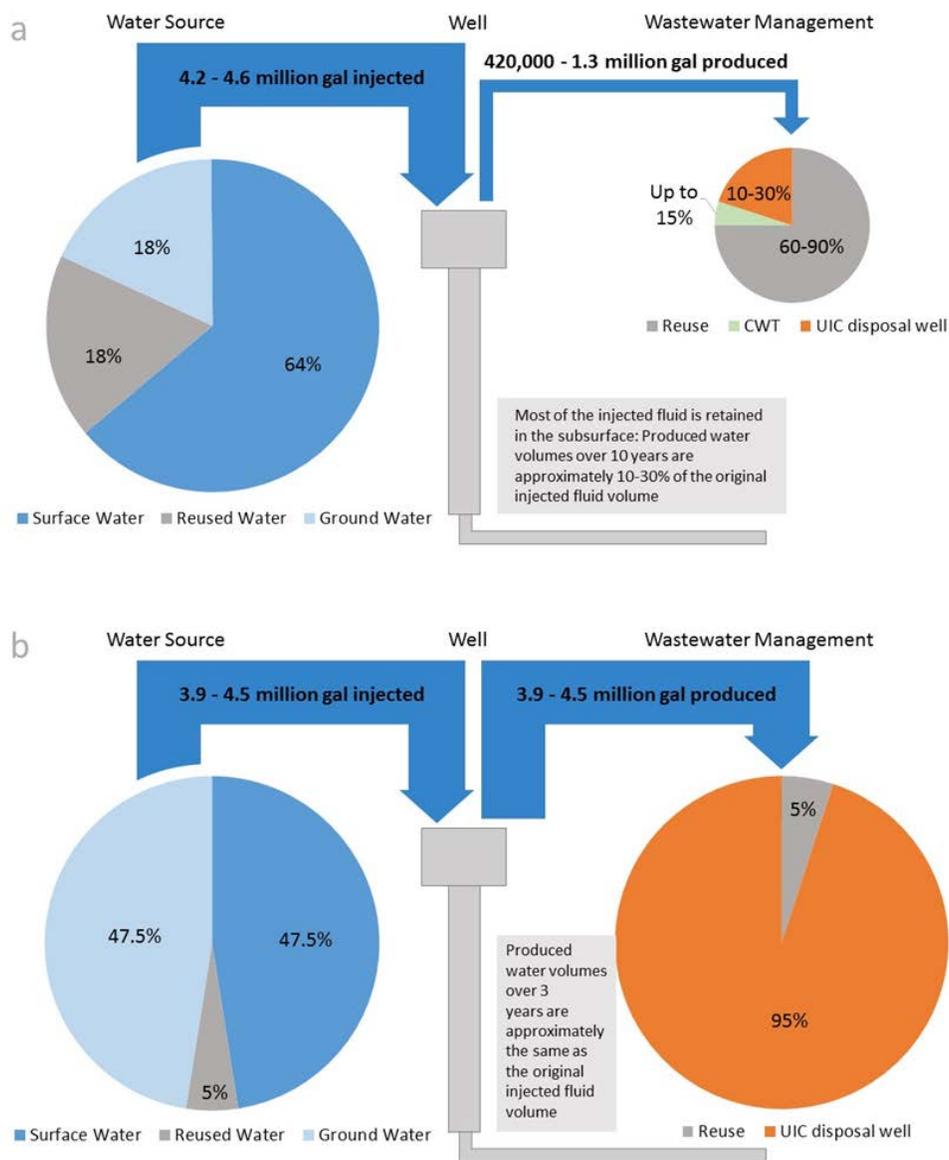


Figure ES-3. Water budgets representative of practices in the Marcellus Shale in the Susquehanna River Basin in Pennsylvania (a) and the Barnett Shale in Texas (b).

Pie size and arrow thickness represent the relative volume of water as it flows through the hydraulic fracturing water cycle. Wastewater going to a centralized waste treatment (CWT) facility may be either discharged to surface water or reused. Wastewater going to an underground injection control (UIC) well is disposed of below ground. These examples represent typical water management practices as depicted for the most recent time period reviewed by this assessment. They do not represent any specific well. Note: Values for Marcellus Shale are specific to the Susquehanna River Basin, except for the produced water volumes. The longest-term measurement available was from the West Virginia portion of the the Marcellus Shale.

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- **How much water is used per well?**

1 The national median volume of water used per hydraulically fractured well is approximately 1.5
2 million gal (5.7 million L), according to the EPA's analysis of FracFocus disclosures. This estimate
3 likely represents a wide variety of fractured well types, including vertical wells that generally use
4 much less water per well than horizontal wells. Thus, published estimates for horizontal shale gas
5 wells are typically higher (e.g., approximately 4 million gallons ([Vengosh et al., 2014](#))). There is also
6 wide variation within and among states and basins in the median water volumes used per well,
7 from more than 5 million gal (19 million L) in Arkansas, Louisiana and West Virginia to less than 1
8 million gal (3.8 million L) in California, New Mexico, and Utah, among others. This variation results
9 from several factors, including well length, formation geology, and fracturing fluid formulation.

- **How might cumulative water withdrawals for hydraulic fracturing affect drinking water quantity?**

10 Cumulatively, hydraulic fracturing uses billions of gallons of water each year at the national and
11 state scales, and even in some counties. As noted above, hydraulic fracturing water use and
12 consumption are generally less than 1% of total annual water use and consumption at these scales.
13 However, there are a few counties in the United States where these percentages are higher. For
14 2011 and 2012, annual hydraulic fracturing water use was 10% or more compared to 2010 total
15 annual water use in 6.5% of counties with FracFocus disclosures analyzed by the EPA, 30% or more
16 in 2.2% of counties, and 50% or more in 1.0% of counties. Consumption estimates followed the
17 same general pattern. In these counties, hydraulic fracturing is a relatively large user and consumer
18 of water.

19 High fracturing water use or consumption alone does not necessarily result in impacts to drinking
20 water resources. Rather, impacts result from the combination of water use or consumption and
21 water availability at local scales. In our survey of published literature, we did not find a case where
22 hydraulic fracturing water use or consumption alone caused a drinking water well or stream to run
23 dry. This could indicate an absence of effects or a lack of documentation in the literature we
24 reviewed. Additionally, water availability is rarely impacted by just one use or factor alone. In
25 Louisiana, for example, the state requested hydraulic fracturing operations switch from ground to
26 surface water, due to concerns that ground water withdrawals for fracturing could, in combination
27 with other uses, adversely affect drinking water supplies.

28 The potential for impacts to drinking water resources from hydraulic fracturing water withdrawals
29 is highest in areas with relatively high fracturing water use and low water availability. Southern
30 and western Texas are two locations where hydraulic fracturing water use, low water availability,
31 drought, and reliance on declining ground water has the potential to affect the quantity of drinking
32 water resources. Any impacts are likely to be realized locally within these areas. In a detailed case
33 study of southern Texas, [Scanlon et al. \(2014\)](#) observed generally adequate water supplies for
34 hydraulic fracturing, except in specific locations. They found excessive drawdown of local ground
35 water in a small proportion (approximately 6% of the area) of the Eagle Ford Shale. They suggested
36 water management, particularly a shift towards brackish water use, could minimize potential future
37 impacts to fresh water resources.

1 The potential for impacts to drinking water quantity due to hydraulic fracturing water use appears
2 to be lower—but not eliminated—in other areas of the United States. Future problems could arise if
3 hydraulic fracturing increases substantially in areas with low water availability, or in times of water
4 shortages. In detailed case studies in western Colorado and northeastern Pennsylvania, the EPA did
5 not find current impacts, but did conclude that streams could be vulnerable to water withdrawals
6 from hydraulic fracturing. In northeast Pennsylvania, water management, such as minimum stream
7 flow requirements, limits the potential for impacts, especially in small streams. In western North
8 Dakota, ground water is limited, but the industry may have sufficient supplies of surface water from
9 the Missouri River system. These location-specific examples emphasize the need to focus on
10 regional and local dynamics when considering potential impacts of hydraulic fracturing water
11 acquisition on drinking water resources.

- ***What are the possible impacts of water withdrawals for hydraulic fracturing on water quality?***

12 Water withdrawals for hydraulic fracturing, similar to all water withdrawals, have the potential to
13 alter the quality of drinking water resources. Ground water withdrawals exceeding natural
14 recharge rates decrease water storage in aquifers, potentially mobilizing contaminants or allowing
15 the infiltration of lower quality water from the land surface or adjacent formations. Withdrawals
16 could also decrease ground water discharge to streams, potentially affecting surface water quality.
17 Areas with large amounts of sustained ground water pumping are most likely to experience
18 impacts, particularly drought-prone regions with limited ground water recharge.

19 Surface water withdrawals also have the potential to affect water quality. Withdrawals may lower
20 water levels and alter stream flow, potentially decreasing a stream's capacity to dilute
21 contaminants. Case studies by the EPA show that streams can be vulnerable to changes in water
22 quality due to water withdrawals, particularly smaller streams and during periods of low flow.
23 Management of the rate and timing of surface water withdrawals has been shown to help mitigate
24 potential impacts of hydraulic fracturing withdrawals on water quality.

Chemical Mixing

25 Hydraulic fracturing fluids are developed to perform specific functions, including: create and
26 extend fractures, transport proppant, and place proppant in the fractures. The fluid generally
27 consists of three parts: (1) the base fluid, which is the largest constituent by volume and is typically
28 water; (2) the additives, which can be a single chemical or a mixture of chemicals; and (3) the
29 proppant. Additives are chosen to serve a specific purpose (e.g., adjust pH, increase viscosity, limit
30 bacterial growth). Chemicals generally comprise a small percentage (typically 2% or less) of the
31 overall injected fluid volume. Because over one million gallons of fluids are typically injected per
32 well, thousands of gallons of chemicals can be potentially stored on-site and used during hydraulic
33 fracturing activities.

34 On-site storage, mixing, and pumping of chemicals and hydraulic fracturing fluids have the potential
35 to result in accidental releases, such as spills or leaks. Potential impacts to drinking water resources
36 from spills of hydraulic fracturing fluids and chemicals depend on the characteristics of the spills,
37 and the fate, transport, and the toxicity of chemicals spilled.

Research Questions: Chemical Mixing

- ***What is currently known about the frequency, severity, and causes of spills of hydraulic fracturing fluids and additives?***

1 The frequency of on-site spills from hydraulic fracturing could be estimated for two states, but not
2 for operations nationally or for other areas. Frequency estimates from data and literature ranged
3 from one spill for every 100 wells in Colorado to between approximately 0.4 and 12.2 spills for
4 every 100 wells in Pennsylvania.¹ These estimates include spills of hydraulic fracturing fluids and
5 chemicals, and produced water reported in state databases. Available data generally precluded
6 estimates of hydraulic fracturing fluid and/or chemical spill rates separately from estimates of an
7 overall spill frequency. It is unknown whether these spill estimates are representative of national
8 occurrences. If the estimates are representative, the number of spills nationally could range from
9 approximately 100 to 3,700 spills annually, assuming 25,000 to 30,000 new wells are fractured per
10 year.

11 The EPA characterized volumes and causes of hydraulic fracturing-related spills identified from
12 selected state and industry data sources. The spills occurred between January 2006 and April 2012
13 in 11 states and included 151 cases in which fracturing fluids or chemicals spilled on or near a well
14 pad. Due to the methods used for the EPA's characterization of spills, these cases were likely a
15 subset of all fracturing fluid and chemical spills during the study's time period. The reported
16 volume of fracturing fluids or chemicals spilled ranged from 5 gal to more than 19,000 gal (19 to
17 72,000 L), with a median volume of 420 gal (1,600 L) per spill. Spill causes included equipment
18 failure, human error, failure of container integrity, and other causes (e.g., weather and vandalism).
19 The most common cause was equipment failure, specifically blowout preventer failure, corrosion,
20 and failed valves. More than 30% of the 151 fracturing fluid or chemical spills were from fluid
21 storage units (e.g., tanks, totes, and trailers).

- ***What are the identities and volumes of chemicals used in hydraulic fracturing fluids, and how might this composition vary at a given site and across the country?***

22 In this assessment, we identified a list of 1,076 chemicals used in hydraulic fracturing fluids. This is
23 a cumulative list over multiple wells and years. These chemicals include acids, alcohols, aromatic
24 hydrocarbons, bases, hydrocarbon mixtures, polysaccharides, and surfactants. According to the
25 EPA's analysis of disclosures to FracFocus, the number of unique chemicals per well ranged from 4
26 to 28, with a median of 14 unique chemicals per well.

27 Our analysis indicates that chemical use varies and that no single chemical is used at all well sites
28 across the country, although several chemicals are widely used. Methanol, hydrotreated light
29 petroleum distillates, and hydrochloric acid were reported as used in 65% or more of wells,
30 according to FracFocus disclosures analyzed by the EPA. Only 32 chemicals, excluding water,
31 quartz, and sodium chloride, were used in more than 10% of wells according to the EPA's analysis

¹ Spill frequency estimates are for a given number of wells over a given period of time. These are not annual estimates nor are they for the lifetime of a well.

1 of FracFocus disclosures. The composition of hydraulic fracturing fluids varies by state, by well, and
2 within the same service company and geologic formation. This variability likely results from several
3 factors, including the geology of the formation, the availability and cost of different chemicals, and
4 operator preference.

5 Estimates from the EPA's database developed from FracFocus suggest median volumes of
6 individual chemicals injected per well ranged from a few gallons to thousands of gallons, with an
7 overall median of 650 gal (2,500 L) per chemical per well. Based on this overall median and
8 assuming 14 unique chemicals are used per well, an estimated 9,100 gal (34,000 L) of chemicals
9 may be injected per well. Given that the number of chemicals per well ranges from 4 to 28, the
10 estimated volume of chemicals injected per well may range from approximately 2,600 to 18,000 gal
11 (9,800 to 69,000 L).

- ***What are the chemical, physical, and toxicological properties of hydraulic fracturing chemical additives?***

12 Measured or estimated physicochemical properties were obtained for 453 chemicals of the total
13 1,076 chemicals reported in hydraulic fracturing fluids. We could not estimate physicochemical
14 properties for the inorganic chemicals or mixtures. The 453 chemicals have a wide range of
15 physicochemical properties.

16 Properties affecting the likelihood of a spilled chemical reaching and impacting a drinking water
17 resource include mobility, solubility, and volatility. Of the 453 chemicals for which physicochemical
18 properties were available, 18 of the top 20 most mobile ones were reported in the EPA's FracFocus
19 database for 2% or less of wells. Choline chloride and tetrakis (hydroxymethyl) phosphonium were
20 exceptions and were reported in 14% and 11% of wells, respectively. These two chemicals appear
21 to be relatively more common, and, if spilled, would move quickly through the environment with
22 the flow of water. The majority of the 453 chemicals associate strongly with soils and organic
23 materials, suggesting the potential for these chemicals to persist in the environment as long-term
24 contaminants. Many of the 453 chemicals fully dissolve in water, but their aqueous solubility varies
25 greatly. Few of the chemicals volatilize, and thus a large proportion of most hydraulic fracturing
26 chemicals tend to remain in water.

27 Oral reference values and oral slope factors meeting the criteria used in this assessment were not
28 available for the majority of chemicals used in hydraulic fracturing fluids, representing a significant
29 data gap for hazard identification.^{1,2} Reference values and oral slope factors are important for
30 understanding the potential human health effects resulting from exposure to a chemical. Chronic
31 oral reference values and/or oral slope factors from selected federal, state, and international
32 sources were available for 90 (8%) of the 1,076 chemicals used in hydraulic fracturing fluids. From

¹ A reference value is an estimate of an exposure to the human population (including susceptible subgroups) for a given duration that is likely to be without an appreciable risk of adverse health effects over a lifetime. Reference value is a generic term not specific to a given route of exposure.

² An oral slope factor is an upper-bound, approximating 95% confidence limit, on the increased cancer risk from a lifetime oral exposure to an agent.

1 U.S. federal sources alone, chronic oral reference values were available for 73 chemicals (7%) of the
2 1,076 chemicals, and oral slope factors were available for 15 chemicals (1%). Of the 32 chemicals
3 reported as used in at least 10% of wells in the EPA's FracFocus database (excluding water, quartz,
4 and sodium chloride), seven (21%) have a federal chronic oral reference value. Oral reference
5 values and oral slope factors are a key component of the risk assessment process, although
6 comprehensive risk assessments that characterize the health risk associated with exposure to these
7 chemicals are not available.

8 Of the chemicals that had values available, the health endpoints associated with those values
9 include the potential for carcinogenesis, immune system effects, changes in body weight, changes in
10 blood chemistry, cardiotoxicity, neurotoxicity, liver and kidney toxicity, and reproductive and
11 developmental toxicity. However, it is important to note that evaluating any potential risk to human
12 populations would require knowledge of the specific chemicals that are present at a particular site,
13 whether or not humans are exposed to those chemicals and, if so, at what levels and for what
14 duration, and the toxicity of the chemicals. Since most chemicals are used infrequently on a
15 nationwide basis, potential exposure is likely to be a local or regional issue, rather than a national
16 issue. Accordingly, consideration of hazards and risks associated with these chemical additives
17 would be most useful on a site-specific basis and is beyond the scope of this assessment.

- ***If spills occur, how might hydraulic fracturing chemical additives contaminate drinking water resources?***

18 There are several mechanisms by which a spill can potentially contaminate drinking water
19 resources. These include overland flow to nearby surface water, soil contamination and eventual
20 transport to surface water, and infiltration and contamination of underlying ground water. Of the
21 151 spills characterized by the EPA, fluids reached surface water in 13 (9% of 151) cases and soil in
22 97 (64%) cases. None of the spills of hydraulic fracturing fluid were reported to have reached
23 ground water. This could be due to an absence of impact; however, it can take several years for
24 spilled fluids to infiltrate soil and leach into ground water. Thus, it may not be immediately
25 apparent whether a spill has reached ground water or not.

26 Based on the relative importance of each of these mechanisms, impacts have the potential to occur
27 quickly, be delayed short or long periods, or have a continual effect over time. In Kentucky, for
28 example, a spill impacted a surface water body relatively quickly when hydraulic fracturing fluid
29 entered a creek, significantly reducing the water's pH and increasing its conductivity ([Papoulias
30 and Velasco, 2013](#)).

Well Injection

31 Hydraulic fracturing fluids are injected into oil or gas wells under high pressures. The fluids flow
32 through the well (commonly thousands of feet below the surface) into the production zone (i.e., the
33 geologic formation being fractured) where the fluid injection pressures are sufficient to create
34 fractures in the rock.

35 There are two major subsurface mechanisms by which the injection of fluid and the creation and
36 propagation of fractures can lead to contamination of drinking water resources: (1) the unintended

1 movement of liquids or gases out of the production well or along the outside of the production well
2 into a drinking water resource via deficiencies in the well's casing or cement, and (2) the
3 unintended movement of liquids or gases from the production zone through subsurface geologic
4 formations into a drinking water resource. Combinations of these two mechanisms are also
5 possible.

Research Questions: Well Injection

- **How effective are current well construction practices at containing fluids—both liquids and gases—before, during, and after fracturing?**

6 Production wells are constructed to access and convey hydrocarbons from the formations in which
7 they are found to the surface, and to isolate fluid-bearing zones (containing oil, gas, or water) from
8 each other. Typically, multiple casings are emplaced and cemented along the wellbore to protect
9 and isolate the oil and/or natural gas from the formations it must travel through to reach the
10 surface.

11 Below ground drinking water resources are often separated from the production well using casing
12 and cement. Cemented surface casing, in particular, is an important well construction feature for
13 isolating drinking water resources from liquids and gases that may move through the subsurface. A
14 limited risk modeling study of selected injection wells in the Williston Basin in North Dakota
15 suggests that the risk of aquifer contamination from leaks inside the well to the drinking water
16 resource decreases by a factor of approximately one thousand when surface casing extends below
17 the bottom of the drinking water resource ([Michie and Koch, 1991](#)). Most wells used in hydraulic
18 fracturing operations have casing and a layer of cement to protect drinking water resources, but
19 there are exceptions: a survey conducted by the EPA of oil and gas production wells hydraulically
20 fractured by nine oil and gas service companies in 2009 and 2010 estimated that at least 3% of the
21 wells (600 out of 23,000 wells) did not have cement across a portion of the casing installed through
22 the protected ground water resource identified by well operators. The absence of cement does not
23 in and of itself lead to an impact. However, it does reduce the overall number of casing and cement
24 barriers fluids must travel through to reach ground water resources.

25 Impacts to drinking water resources from subsurface liquid and gas movement may occur if casing
26 or cement are inadequately designed or constructed, or fail. There are several examples of these
27 occurrences in hydraulically fractured wells that have or may have resulted in impacts to drinking
28 water resources. In one example, an inner string of casing burst during hydraulic fracturing, which
29 resulted in a release of fluids on the land surface and possibly into the aquifer near Killdeer, North
30 Dakota. The EPA found that, based on the data analysis performed for the study, the only potential
31 source consistent with conditions observed in two impacted monitoring wells was the blowout that
32 occurred during hydraulic fracturing ([U.S. EPA, 2015j](#)). In other examples, inadequately cemented
33 casing has contributed to impacts to drinking water resources. In Bainbridge, Ohio, inadequately
34 cemented casing in a hydraulically fractured well contributed to the buildup of natural gas and high
35 pressures along the outside of a production well. This ultimately resulted in movement of natural
36 gas into local drinking water aquifers ([Bair et al., 2010](#); [ODNR, 2008](#)). In the Mamm Creek gas field

1 in Colorado, inadequate cement placement in a production well allowed methane and benzene to
2 migrate along the production well and through natural faults and fractures to drinking water
3 resources ([Science Based Solutions LLC, 2014](#); [Crescent, 2011](#); [COGCC, 2004](#)). These cases illustrate
4 how construction issues, sustained casing pressure, and the presence of natural faults and fractures
5 can work together to create pathways for fluids to migrate toward drinking water resources.

6 Fracturing older wells may also increase the potential for impacts to drinking water resources via
7 movement of gases and liquids from the inside of the production well or along the outside of the
8 production well to ground water resources. The EPA estimated that 6% of 23,000 oil and gas
9 production wells were drilled more than 10 years before being hydraulically fractured in 2009 or
10 2010. Although new wells can be designed to withstand the stresses associated with hydraulic
11 fracturing operations, older wells may not have been built or tested to the same specifications and
12 their reuse for this purpose could be of concern. Moreover, aging and use of the well can contribute
13 to casing degradation, which can be accelerated by exposure to corrosive chemicals, such as
14 hydrogen sulfide, carbonic acid, and brines.

- ***Can subsurface migration of fluids—both liquids and gases—to drinking water resources occur, and what local geologic or artificial features might allow this?***

15 Physical separation between the production zone and drinking water resources can help protect
16 drinking water. Many hydraulic fracturing operations target deep formations such as the Marcellus
17 Shale or the Haynesville Shale (Louisiana/Texas), where the vertical distance between the base of
18 drinking water resources and the top of the shale formation may be a mile or greater. Numerical
19 modeling and microseismic studies based on a Marcellus Shale-like environment suggest that
20 fractures created during hydraulic fracturing are unlikely to extend upward from these deep
21 formations into shallow drinking water aquifers.

22 Not all hydraulic fracturing is performed in zones that are deep below drinking water resources.
23 For example, operations in the Antrim Shale (Michigan) and the New Albany Shale
24 (Illinois/Indiana/Kentucky) take place at shallower depths (100 to 1,900 ft or 30 to 579 m), with
25 less vertical separation between the formation and drinking water resources. The EPA's survey of
26 oil and gas production wells hydraulically fractured by nine service companies in 2009 and 2010
27 estimated that 20% of 23,000 wells had less than 2,000 ft (610 m) of measured distance between
28 the point of shallowest hydraulic fracturing and the base of the protected ground water resources
29 reported by well operators.

30 There are also places in the subsurface where oil and gas resources and drinking water resources
31 co-exist in the same formation. Evidence indicates that hydraulic fracturing occurs within these
32 formations. This results in the introduction of fracturing fluids into formations that may currently
33 serve, or in the future could serve, as a source of drinking water for public or private use. According
34 to the data examined, the overall frequency of occurrence of this practice appears to be low, with
35 the activity generally concentrated in some areas in the western United States. The practice of
36 injecting fracturing fluids into a formation that also contains a drinking water resource directly
37 affects the quality of that water, since some of the fluid likely remains in the formation following
38 hydraulic fracturing. Hydraulic fracturing in a drinking water resource is a concern in the short-

1 term (should there be people currently using these zones as a drinking water supply) and the long-
2 term (if drought or other conditions necessitate the future use of these zones for drinking water).

3 Liquid and gas movement from the production zone to underground drinking water resources may
4 also occur via other production wells or injection wells near hydraulic fracturing operations.
5 Fractures created during hydraulic fracturing can intersect nearby wells or their fracture networks,
6 resulting in the flow of fluids into those wells. These well communications, or “frac hits,” are more
7 likely to occur if wells are close to each other or on the same well pad. In the Woodford Shale in
8 Oklahoma, the likelihood of well communication was less than 10% between wells more than 4,000
9 ft (1,219 m) apart, but rose to nearly 50% between wells less than 1,000 ft (305 m) apart ([Ajani and
10 Kelkar, 2012](#)). If an offset well is not able to withstand the stresses applied during the hydraulic
11 fracturing of a neighboring well, well components may fail, which could result in a release of fluids
12 at the surface from the offset well. The EPA identified incidents in which surface spills of hydraulic
13 fracturing-related fluids were attributed to well communication events.

14 Older or inactive wells—including oil and gas wells, injection wells, or drinking water wells—near a
15 hydraulic fracturing operation may pose an even greater potential for impacts. A study in Oklahoma
16 found that older wells were more likely to be negatively affected by the stresses applied by
17 hydraulic fracturing in neighboring wells ([Ajani and Kelkar, 2012](#)). In some cases, inactive wells in
18 the vicinity of hydraulic fracturing activities may not have been plugged properly—many wells
19 plugged before the 1950s were done so with little or no cement. The Interstate Oil and Gas Compact
20 Commission estimates that over one million wells may have been drilled in the United States prior
21 to a formal regulatory system being in place, and the status and location of many of these wells are
22 unknown ([IOGCC, 2008](#)). State programs exist to plug identified inactive wells, and work is on-
23 going to identify and address such wells.

Flowback and Produced Water

24 Water, of variable quality, is a byproduct of oil and gas production. After hydraulic fracturing, the
25 injection pressure is released and water flows back from the well. Initially this water is similar to
26 the hydraulic fracturing fluid, but as time goes on the composition is affected by the characteristics
27 of the formation and possible reactions between the formation and the fracturing fluid. Water
28 initially produced from the well after hydraulic fracturing is sometimes called flowback in the
29 literature, and the term appears in this assessment. However, hydraulic fracturing fluids and any
30 formation water returning to the surface are often referred to collectively as produced water. This
31 definition of produced water is used in this assessment.

32 The amount of produced water varies, but typically averages 10% to 25% of injected volumes,
33 depending upon the amount of time since fracturing and the particular well (see Figure ES-3a).
34 However, there are exceptions to this, such as in the Barnett Shale in Texas where the total volume
35 of produced water can equal or exceed the injected volume of hydraulic fracturing fluid (see Figure
36 ES-3b). Flow rates are generally high initially, and then decrease over time throughout oil or gas
37 production.

1 Impacts on drinking water resources have the potential to occur if produced water is spilled and
2 enters surface water or ground water. Environmental transport of chemical constituents in
3 produced water depends on the characteristics of the spill (e.g., volume and duration), the
4 composition of spilled fluids, and the characteristics of the surrounding environment.

Research Questions: Flowback and Produced Water

- **What is currently known about the frequency, severity, and causes of spills of flowback and produced water?**

5 Surface spills of produced water from hydraulically fractured wells have occurred. As noted in the
6 Chemical Mixing section above, the frequency of on-site spills from hydraulic fracturing activities
7 could be estimated for two states, but not nationally. Estimates of spill frequencies at hydraulic
8 fracturing sites in Colorado and Pennsylvania, including spills of produced water, ranged from
9 approximately 0.4 to 12.2 spills per 100 wells. Available data generally precluded estimates of
10 produced water spill rates separately from estimates of overall spill frequency. Away from the well,
11 produced water spills from pipelines and truck transport also have the potential to impact drinking
12 water resources.

13 The EPA characterized spill volumes and causes for 225 cases in which produced water spilled on
14 or near a well pad. These spills occurred between January 2006 and April 2012 in 11 states. The
15 median reported volume per produced water spill was 990 gallons (3,750 L), more than double that
16 for spills of hydraulic fracturing fluids and chemicals. The causes of produced water spills were
17 reported as human error, equipment failure, container integrity failure, miscellaneous causes (e.g.,
18 well communication), and unknown causes. Most of the total volume spilled (74%) for all 225 cases
19 combined was caused by a failure of container integrity.

- **What is the composition of hydraulic fracturing flowback and produced water, and what factors might influence this composition?**

20 A combination of factors influence the composition of produced water, including: the composition
21 of injected hydraulic fracturing fluids, the type of formation fractured, subsurface processes, and
22 residence time. The initial chemical composition of produced water primarily reflects the chemistry
23 of the injected fluids. At later times, the chemical composition of produced water reflects the
24 geochemistry of the fractured formation.

25 Produced water varies in quality from fresh to highly saline, and can contain high levels of major
26 anions and cations, metals, organics, and naturally occurring radionuclides. Produced water from
27 shale and tight gas formations typically contains high levels of total dissolved solids (TDS) and ionic
28 constituents (e.g., bromide, calcium, chloride, iron, potassium, manganese, magnesium, and
29 sodium). Produced water also may contain metals (e.g., barium, cadmium, chromium, lead, and
30 mercury), and organic compounds such as benzene. Produced water from coalbed methane
31 typically has much lower TDS levels compared to other produced water types, particularly if the
32 coalbed was deposited under fresh water conditions..

1 We identified 134 chemicals that have been detected in hydraulic fracturing produced water. These
2 include chemicals added during the chemical mixing stage, as well as naturally occurring organic
3 chemicals and radionuclides, metals, and other constituents of subsurface rock formations
4 mobilized by the hydraulic fracturing process. Data on measured chemical concentrations in
5 produced water were available for 75 of these 134 chemicals.

6 Most of the available data on produced water content are for shale and coalbed methane
7 formations, while less data are available for tight formations, such as sandstones. The composition
8 of produced water must be determined through sampling and analysis, both of which have
9 limitations—the former due to challenges in accessing production equipment, and the latter due to
10 difficulties identifying target analytes before analysis and the lack of appropriate analytical
11 methods. Most current data are for inorganic chemicals, while less data exist for organic chemicals.
12 Many more organic chemicals were reported as used in hydraulic fracturing fluid than have been
13 identified in produced water. The difference may be due to analytical limitations, limited study
14 scopes, and undocumented subsurface reactions.

- ***What are the chemical, physical, and toxicological properties of hydraulic fracturing flowback and produced water constituents?***

15 The identified constituents of produced water include inorganic chemicals (cations and anions, i.e.,
16 metals, metalloids, non-metals, and radioactive materials), organic chemicals and compounds, and
17 unidentified materials measured as total organic carbon and dissolved organic carbon. Some
18 constituents are readily transported with water (i.e., chloride and bromide), while others depend
19 strongly on the geochemical conditions in the receiving water body (i.e., radium and barium), and
20 assessment of their transport is based on site-specific factors. We were able to obtain actual or
21 estimated physicochemical properties for 86 (64%) of the 134 chemicals identified in produced
22 water.

23 As in the case of chemicals in hydraulic fracturing fluid, chemical properties that affect the
24 likelihood of an organic chemical in produced water reaching and impacting drinking water
25 resources include: mobility, solubility, and volatility. In general, physicochemical properties suggest
26 that organic chemicals in produced water tend to be less mobile in the environment. Consequently,
27 if spilled, these chemicals may remain in soils or sediments near spill sites. Low mobility may result
28 in smaller dissolved contaminant plumes in ground water, although these chemicals can be
29 transported with sediments in surface water or small particles in ground water. Organic chemical
30 properties vary with salinity, and effects depend on the nature of the chemical.

31 Oral reference values and/or oral slope factors from selected federal, state, and international
32 sources were available for 83 (62%) of the 134 chemicals detected in produced water. From U.S.
33 federal sources alone, chronic oral reference values were available for 70 (52%) of the 134
34 chemicals, and oral slope factors were available for 20 chemicals (15%). Of the chemicals that had
35 values available, noted health effects include the potential for carcinogenesis, immune system
36 effects, changes in body weight, changes in blood chemistry, pulmonary toxicity, neurotoxicity, liver
37 and kidney toxicity, and reproductive and developmental toxicity. As noted above, evaluating any
38 potential risk to human populations would require knowledge of the specific chemicals that are

1 present at a particular site, whether or not humans are exposed to those chemicals and, if so, at
2 what levels and for what duration, and the toxicity of the chemicals. The chemicals present in
3 produced water can vary based on the formation and specific well, due to differences in fracturing
4 fluid formulation and formation geology. Accordingly, consideration of hazards and risks associated
5 with these chemicals would be most useful on a site-specific basis and is beyond the scope of this
6 assessment.

- ***If spills occur, how might hydraulic fracturing flowback and produced water contaminate drinking water resources?***

7 Impacts to drinking water resources from spills or releases of produced water depend on the
8 volume, timing, and composition of the produced water. Impacts are more likely the greater the
9 volume of the spill, the longer the duration of the release, and the higher the concentration of
10 produced water constituents (i.e., salts, naturally occurring radioactive material, and metals).

11 The EPA characterization of hydraulic fracturing-related spills found that 8% of the 225 produced
12 water spills included in the study reached surface water or ground water. These spills tended to be
13 of greater volume than spills that did not reach a water body. A well blowout in Bradford County,
14 Pennsylvania spilled an estimated 10,000 gal (38,000 L) of produced water into a tributary of
15 Towanda Creek, a state-designated trout fishery. The largest volume spill identified in this
16 assessment occurred in North Dakota, where approximately 2.9 million gal (11 million L) of
17 produced water spilled from a broken pipeline and impacted surface and ground water.

18 Chronic releases can and do occur from produced water disposed in unlined pits or impoundments,
19 and can have long-term impacts. Ground water impacts may persist longer than surface water
20 impacts because of lower flow rates and decreased mixing. Plumes from unlined pits used for
21 produced water have been shown to persist for long periods and extend to nearby surface water
22 bodies.

Wastewater Management and Waste Disposal

23 Hydraulic fracturing generates large volumes of produced water that require management. In this
24 section we refer to produced water and any other waters generated onsite by the single term
25 “wastewater.” [Clark and Veil \(2009\)](#) estimated that, in 2007, approximately one million active oil
26 and gas wells in the United States generated 2.4 billion gal per day (9.1 billion L per day) of
27 wastewater. There is currently no reliable way to estimate what fraction of this total volume can be
28 attributed to hydraulically fractured wells. Wastewater volumes in a region can increase sharply as
29 hydraulic fracturing activity increases.

30 Wastewater management and disposal could affect drinking water resources through multiple
31 mechanisms, including: inadequate treatment of wastewater prior to discharge to a receiving
32 water, accidental releases during transport or leakage from wastewater storage pits, unpermitted
33 discharges, migration of constituents in wastewaters following land application, inappropriate
34 management of residual materials from treatment, or accumulation of wastewater constituents in
35 sediments near outfalls of centralized waste treatment facilities (CWTs) or publicly owned
36 treatment works (POTWs) that have treated hydraulic fracturing wastewater. The scope of this

1 assessment excludes potential impacts to drinking water from the disposal of hydraulic fracturing
2 wastewater in underground injection control (UIC) wells.

Research Questions: Wastewater Management and Waste Disposal

- **What are the common treatment and disposal methods for hydraulic fracturing wastewater, and where are these methods practiced?**

3 Hydraulic fracturing wastewater is managed using several options, including: disposal in UIC wells
4 (also called disposal wells); through evaporation ponds; treatment at CWTs, followed by reuse or
5 by discharge to either surface waters or POTWs; reuse with minimal or no treatment; and land
6 application or road spreading. Treatment of hydraulic fracturing wastewater by POTWs was used in
7 the past in Pennsylvania. This decreased sharply following new state-level requirements and a
8 request by the Pennsylvania Department of Environmental Protection (PA DEP) for well operators
9 to stop sending Marcellus Shale wastewater to POTWs (and 15 CWTs) discharging to surface
10 waters.

11 Wastewater management decisions are generally based on the availability and associated costs
12 (including transportation) of disposal or treatment facilities. A survey of state agencies found that,
13 in 2007, more than 98% of produced water from the oil and gas industry was managed via
14 underground injection ([Clark and Veil, 2009](#)). Available information suggests that disposal wells are
15 also the primary management practice for hydraulic fracturing wastewater in most regions in the
16 United States (e.g., the Barnett Shale; see Figure ES-3b). The Marcellus Shale region is a notable
17 exception, where most wastewater is reused because of the small number of disposal wells in
18 Pennsylvania (see Figure ES-3a). Although this assessment does not address potential effects on
19 drinking water resources from the use of disposal wells, any changes in cost of disposal or
20 availability of disposal wells would likely influence wastewater management decisions.

21 Wastewater from some hydraulic fracturing operations is sent to CWTs, which may discharge
22 treated wastewater to surface waters, POTWs, or back to well operators for reuse in other
23 hydraulic fracturing operations. Available data indicate that the use of CWTs for treating hydraulic
24 fracturing wastewater is greater in the Marcellus Shale region than other parts of the country. Most
25 of the CWTs accepting hydraulic fracturing wastewater in Pennsylvania cannot significantly reduce
26 TDS, and many of these facilities provide treated wastewater to well operators for reuse and do not
27 currently discharge treated wastewater to surface water.

28 Reuse of wastewater for subsequent hydraulic fracturing operations may require no treatment,
29 minimal treatment, or more extensive treatment. Operators reuse a substantial amount (ca. 70-
30 90%) of Marcellus Shale wastewater in Pennsylvania (see Figure ES-3a). Lesser amounts of reuse
31 occur in other areas (e.g., the Barnett Shale; see Figure ES-3b). In certain formations, such as the
32 Bakken Shale in North Dakota, there is currently no indication of appreciable reuse.

33 In some cases, wastewater is used for land applications such as irrigation or road spreading for
34 deicing or dust suppression. Land application has the potential to introduce wastewater
35 constituents into surface water and ground water due to runoff and migration of brines. Studies of

1 road spreading of conventional oil and gas brines have found elevated levels of metals in soils and
2 chloride in ground water.

- ***How effective are conventional POTWs and commercial treatment systems in removing organic and inorganic contaminants of concern in hydraulic fracturing wastewater?***

3 Publicly owned treatment works using basic treatment processes are not designed to effectively
4 reduce TDS concentrations in highly saline hydraulic fracturing wastewater—although specific
5 constituents or constituents groups can be removed (e.g., metals, oil, and grease by chemical
6 precipitation or other processes). In some cases, wastewater treated at CWTs may be sent to a
7 POTW for additional treatment and discharge. It is blended with POTW influent to prevent
8 detrimental effects on biological processes in the POTW that aid in the treatment of wastewater.

9 Centralized waste treatment facilities with advanced wastewater treatment options such as reverse
10 osmosis, thermal distillation, or mechanical vapor recompression, reduce TDS concentrations and
11 can treat contaminants currently known to be in hydraulic fracturing wastewater. However, there
12 are limited data on the composition of hydraulic fracturing wastewater, particularly for organic
13 constituents. It is unknown whether advanced treatment systems are effective at removing
14 constituents that are generally not tested for.

- ***What are the potential impacts from surface water disposal of treated hydraulic fracturing wastewater on drinking water treatment facilities?***

15 Potential impacts to drinking water resources may occur if hydraulic fracturing wastewater is
16 inadequately treated and discharged to surface water. Inadequately treated hydraulic fracturing
17 wastewater may increase concentrations of TDS, bromide, chloride, and iodide in receiving waters.
18 In particular, bromide and iodide are precursors of disinfection byproducts (DBPs) that can form in
19 the presence of organic carbon in drinking water treatment plants or wastewater treatment plants.
20 Drinking water treatment plants are required to monitor for certain types of DBPs, because some
21 are toxic and can cause cancer.

22 Radionuclides can also be found in inadequately treated hydraulic fracturing wastewater from
23 certain shales, such as the Marcellus. A recent study by the [PA DEP \(2015b\)](#) found elevated radium
24 concentrations in the tens to thousands of picocuries per liter and gross alpha and gross beta in the
25 hundreds to thousands of picocuries per liter in effluent samples from some CWTs receiving oil and
26 gas wastewater. Radium, gross alpha, and gross beta were also detected in effluents from POTWs
27 receiving oil and gas wastewater (mainly as effluent from CWTs), though at lower concentrations
28 than from the CWTs. Research in Pennsylvania also indicates the accumulation of radium in
29 sediments and soils affected by the outfalls of some treatment plants that have handled oil and gas
30 wastewater, including Marcellus Shale wastewater, and other wastewaters ([PA DEP, 2015b](#);
31 [Warner et al., 2013a](#)). Mobilization of radium from sediments and potential impacts on downstream
32 water quality depend upon how strongly the radium has sorbed to sediments. Impacts may also
33 occur if sediment is resuspended (e.g., following storm events). There is no evidence of radionuclide
34 contamination in drinking water intakes due to inadequately treated hydraulic fracturing
35 wastewater.

1 Hydraulic fracturing wastewaters contain other constituents such as barium, boron, and heavy
2 metals. Barium in particular has been documented in some shale gas produced waters. Little data
3 exist on metal and organic compound concentrations in untreated and treated wastewaters in
4 order to evaluate whether treatment is effective, and whether there are potential downstream
5 effects on drinking water resources when wastewater is treated and discharged.

Key Data Limitations and Uncertainties

6 This assessment used available data and literature to examine the potential impacts of hydraulic
7 fracturing from oil and gas on drinking water resources nationally. As part of this effort, we
8 identified data limitations and uncertainties associated with current information on hydraulic
9 fracturing and its potential to affect drinking water resources. In particular, data limitations
10 preclude a determination of the frequency of impacts with any certainty. These limitations and
11 uncertainties are discussed in brief below.

Limitations in Monitoring Data and Chemical Information

12 While many activities conducted as part of the hydraulic fracturing water cycle take place above
13 ground, hydraulic fracturing itself occurs below ground and is not directly observable. Additionally,
14 potential mechanisms identified in this assessment may result in impacts to drinking water
15 resources that are below ground (e.g., spilled fluids leaching into ground water). Data that could be
16 used to characterize the presence, migration, or transformation of chemicals in the subsurface
17 before, during, and after hydraulic fracturing were found to be scarce relative to the number of
18 hydraulically fractured oil and gas production wells. Specifically, local water quality data needed to
19 compare pre- and post-hydraulic fracturing conditions are not consistently collected or readily
20 available. The limited amount of data collected before and during hydraulic fracturing activities
21 reduces the ability to determine whether hydraulic fracturing affected drinking water resources in
22 cases of alleged contamination.

23 Information (identity, frequency of use, physicochemical and toxicological properties, etc.) on the
24 chemicals associated with the hydraulic fracturing water cycle is not complete and limits
25 understanding of potential impacts on drinking water resources. Well operators claimed at least
26 one chemical as confidential at more than 70% of wells reported to FracFocus and analyzed by the
27 EPA. The identity of these chemicals, and other chemicals in produced water, are needed to
28 understand their properties and would also help inform what chemicals to test for to establish
29 baseline conditions and to test for in the event of a suspected drinking water impact. Of the 1,173
30 total chemicals identified by the EPA in hydraulic fracturing fluid and flowback and produced
31 water, 147 have chronic oral reference values and/or oral slope factors from the sources that met
32 the selection criteria for inclusion in this assessment. Because the majority of chemicals identified
33 in this report do not have chronic oral reference values and/or oral slope factors, risk assessors at
34 the local and regional level may need to use alternative sources of toxicity information that could
35 introduce greater uncertainties.

Other Contributing Limitations

1 We found other limitations that hamper the ability to fully assess the potential impacts of hydraulic
2 fracturing on drinking water resources nationally. These include the number and location of
3 hydraulically fractured wells, the location of drinking water resources, and information on changes
4 in industry practices. The lack of a definitive well count particularly contributes to uncertainties
5 regarding total water use or total wastewater volume estimates, and would limit any kind of
6 cumulative impact assessment. Lack of specific information about private drinking water well
7 locations and the depths of drinking water resources in relation to hydraulically fractured rock
8 formations and well construction features (e.g., casing and cement) limits the ability to assess
9 whether subsurface drinking water resources are isolated from hydraulically fractured oil and gas
10 production wells. Finally, this assessment is a snapshot in time, and the industry is rapidly changing
11 (e.g., the number of wells fractured, the location of activities, and the chemicals used). It is unclear
12 how changes in industry practices could affect potential drinking water impacts in the future.
13 Consideration of future development scenarios was not a part of this assessment, but such an
14 evaluation could help establish potential short- and long-term impacts to drinking water resources
15 and how to assess them.

Conclusions

16 Through this national-level assessment, we have identified potential mechanisms by which
17 hydraulic fracturing could affect drinking water resources. Above ground mechanisms can affect
18 surface and ground water resources and include water withdrawals at times or in locations of low
19 water availability, spills of hydraulic fracturing fluid and chemicals or produced water, and
20 inadequate treatment and discharge of hydraulic fracturing wastewater. Below ground mechanisms
21 include movement of liquids and gases via the production well into underground drinking water
22 resources and movement of liquids and gases from the fracture zone to these resources via
23 pathways in subsurface rock formations.

24 We did not find evidence that these mechanisms have led to widespread, systemic impacts on
25 drinking water resources in the United States. Of the potential mechanisms identified in this report,
26 we found specific instances where one or more of these mechanisms led to impacts on drinking
27 water resources, including contamination of drinking water wells. The cases occurred during both
28 routine activities and accidents and have resulted in impacts to surface or ground water. Spills of
29 hydraulic fracturing fluid and produced water in certain cases have reached drinking water
30 resources, both surface and ground water. Discharge of treated hydraulic fracturing wastewater has
31 increased contaminant concentrations in receiving surface waters. Below ground movement of
32 fluids, including gas, most likely via the production well, have contaminated drinking water
33 resources. In some cases, hydraulic fracturing fluids have also been directly injected into drinking
34 water resources, as defined in this assessment, to produce oil or gas that co-exists in those
35 formations.

36 The number of identified cases where drinking water resources were impacted are small relative to
37 the number of hydraulically fractured wells. This could reflect a rarity of effects on drinking water

1 resources, or may be an underestimate as a result of several factors. There is insufficient pre- and
2 post-hydraulic fracturing data on the quality of drinking water resources. This inhibits a
3 determination of the frequency of impacts. Other limiting factors include the presence of other
4 causes of contamination, the short duration of existing studies, and inaccessible information related
5 to hydraulic fracturing activities.

6 This state-of-the-science assessment contributes to the understanding of the potential impacts of
7 hydraulic fracturing on drinking water resources and the factors that may influence those impacts.
8 The findings in this assessment can be used by federal, state, tribal, and local officials; industry; and
9 the public to better understand and address any vulnerabilities of drinking water resources to
10 hydraulic fracturing activities. This assessment can also be used to help facilitate and inform
11 dialogue among interested stakeholders, and support future efforts, including: providing context to
12 site-specific exposure or risk assessments, local and regional public health assessments, and
13 assessments of cumulative impacts of hydraulic fracturing on drinking water resources over time
14 or over defined geographic areas of interest. Finally, and most importantly, this assessment
15 advances the scientific basis for decisions by federal, state, tribal, and local officials, industry, and
16 the public, on how best to protect drinking water resources now and in the future.

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