Chapter 4

Water Acquisition

4. Water Acquisition

4.1. Introduction

Water is a crucial component of nearly all hydraulic fracturing operations, making up approximately 90% or more of fluid injected into a well (U.S. EPA, 2015a; GWPC and ALL Consulting, 2009). Given that at least 25,000 to 30,000 wells may be fractured each year (Chapter 2), and that each well requires thousands to millions of gallons of water (Section 4.3), the potential exists for effects on the quantity of drinking water resources. Large volume water withdrawals also could alter the quality of drinking water resources by decreasing dilution of pollutants by surface waters, or in the case of ground water, allowing the infiltration of lower-quality water from the land surface or adjacent formations.

In this chapter, we consider potential effects of water acquisition for hydraulic fracturing on both drinking water resource quantity and quality, and where possible, identify factors that affect the frequency or severity of impacts. We define drinking water resources broadly, to include not just currently designated drinking waters, but waters that could in the future be used as drinking water sources (see Chapter 1). Although most available data and literature pertain to water use, we discuss water consumption where possible.[1]

We provide an overview of the types of hydraulic fracturing water used (Section 4.2); the amount of water used per well (Section 4.3); and cumulative water use and consumption estimates (Section 4.4).[2] We then discuss these three factors for 15 states where hydraulic fracturing presently occurs and consider the potential for hydraulic fracturing water withdrawals to affect water quantity and quality in localities within those states (Section 4.5). We primarily discuss results at the state and county level because data are most available at these scales. Moreover, states and localities often differ in industry activity, formation type, and water availability, all of which affect potential impacts.[3] Lastly, we provide a synthesis that summarizes major findings, factors affecting the frequency or severity of impacts, uncertainties, and conclusions (Section 4.6).

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[1] Water use is water withdrawn for a specific purpose, part or all of which may be returned to the local hydrologic cycle. 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). Hydraulic fracturing water consumption can occur through evaporation from storage ponds, the retention of water in the subsurface through imbibition, or disposal in Underground Injection Control (UIC) Class II injection wells.

[2] In this chapter, cumulative annual water use or water consumption refers to the amount of water used or consumed by all hydraulic fracturing wells in a given area per year.

[3] There is no standard definition for water availability, and it has not been assessed recently at the national scale (U.S. GAO, 2014). Instead, a number of water availability indicators have been suggested (e.g., Roy et al., 2005). Here, availability is most often used to qualitatively refer to the amount of a location's water that could, currently or in the future, serve as a source of drinking water (U.S. GAO, 2014), which is a function of water inputs to a hydrologic system (e.g., rain, snowmelt, groundwater recharge) and water outputs from that system occurring either naturally or through competing demands of users. Where specific numbers are presented, we note the specific water availability indicator used.

4.2. Types of Water Used

Water used for hydraulic fracturing generally comes from surface water (i.e., rivers, streams, lakes, and reservoirs), ground water aquifers, or reused hydraulic fracturing wastewater.[1,2,3] These sources can vary in their initial water quality and in how they are provisioned to hydraulic fracturing operations. In this section, we provide an overview of the sources (Section 4.2.1), water quality (Section 4.2.2), and provisioning of water (Section 4.2.3) required for hydraulic fracturing. Detailed information on the types of water used by state and locality is presented in Section 4.5.

4.2.1. Source

Whether water used in hydraulic fracturing originates from surface or ground water resources is largely determined by the amount of water needed and the type of locally available water sources. Water transportation costs can be high, so the industry tends to acquire water from nearby sources if available (Nicot et al., 2014; Mitchell et al., 2013a; Kargbo et al., 2010). Surface water is typically available to supply most of the water needed in the eastern United States, whereas mixed supplies of surface and ground water are used in the more semi-arid to arid western states. In western states that lack available surface water resources, ground water supplies the majority of water needed for fracturing unless alternative sources, such as reused wastewater, are available and utilized. Local policies also may direct the industry to seek withdrawals from designated sources (U.S. EPA, 2013a): for instance, some states have encouraged the industry to seek water withdrawals from surface water rather than ground water due to concerns over aquifer depletion (Section 4.5).

The reuse of wastewater from past hydraulic fracturing operations can reduce the need for fresh surface or ground water and offset total new water withdrawals for hydraulic fracturing.[4,5] Based on available data, the median reuse of wastewater as a percentage of injected volume is 5% nationally, but this percentage varies by location (Table 4-1).[6,1]

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[1] Throughout this chapter we sometimes refer to “reused hydraulic fracturing wastewater” as simply “reused wastewater” because this is the dominant type of wastewater reused by the industry. When referring to other types of reused wastewater not associated with hydraulic fracturing (e.g., acid mine drainage, wastewater treatment plant effluent) we specify the source of the wastewater.

[2] We use the term “reuse” regardless of the extent to which the wastewater is treated (Nicot et al., 2014); we do not distinguish between reuse and recycling except when specifically reported in the literature.

[3] We use “wastewater” as a general term to include both flowback and produced water that may be reused in hydraulic fracturing; we do not distinguish between flowback and produced water except when specifically reported in the literature.

[4] Hydraulic fracturing wastewater may be stored on-site in open pits, which may also collect rainwater and runoff water. We do not distinguish between the different types of water that are collected on-site during oil and gas operations, and assume that most of the water collected on-site at well pads is hydraulic fracturing wastewater.

[5] We use the term “fresh water” to qualitatively refer to water with relatively low TDS that is most readily and currently available for drinking water. We do not use the term to imply an exact TDS limit.

[6] Throughout this chapter, we preferentially report medians where possible because medians are less sensitive to outlier values than averages. Where medians are not available, averages are reported.

The reuse of wastewater for hydraulic fracturing is limited by the amount of water that returns to the surface during production (Nicot et al., 2012). In the first 10 days of well production, 5% to almost 50% of injected fluid volume may be collected, with values varying across geologic formations (see Chapter 7, Table 7-1). Longer duration measurements are rare, but between 10% and 30% of injected fluid volume has been collected in the Marcellus Shale in Pennsylvania over 9 years of production, while over 100% has been collected in the Barnett Shale in north-central Texas over six years of production (see Chapter 7, Table 7-2). Assuming that 10% of injected fluid volume is collected in the first 30 days and the reuse rate is 100%, it would take 10 wells to produce enough water to hydraulically fracture a new well. As more wells are hydraulically fractured in a given area, the potential for wastewater reuse increases.

Besides hydraulic fracturing wastewater, other wastewaters may be reclaimed for use in hydraulic fracturing. These may include acid mine drainage, wastewater treatment plant effluent, and other sources of industrial and municipal wastewater (Nicot et al., 2014; Ziemkiewicz et al., 2013). Limited information is available on the extent to which these other wastewaters are used.

Table 4-1. Percentage of injected water volume that comes from reused hydraulic fracturing wastewater in various states, basins, and plays.

States listed by order of appearance in the chapter. See Section 4.5 for additional discussion of reuse practices by state and locality and variation over time where data are available.

State, basin, or play	Available estimate	Year of estimate (NA = not available)

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[1] This chapter examines reused wastewater as a percentage of injected volume because reused wastewater may offset total fresh water acquired for hydraulic fracturing. In contrast, Chapter 8 of this assessment discusses the total percentage of the generated wastewater that is reused rather than managed by different means (e.g., disposal in Class II injection wells). This distinction is sometimes overlooked, which sometimes leads to a misrepresentation of the extent to which wastewater is reused to offset total fresh water used for hydraulic fracturing.

State, basin, or play	Available estimate	Year of estimate (NA = not available)
Texas—Barnett Shale	5%[a]	2011
Texas—Eagle Ford Shale	0%[a]	2011
Texas—TX-LA-MS Salt Basin[b]	5%[a]	2011
Texas—Permian Basin (far west portion)	0%[a]	2011
Texas—Permian Basin (Midland portion)	2%[a]	2011
Texas—Anadarko Basin	20%[a]	2011
Colorado—Garfield County, Uinta-Piceance Basin	100%[c]	NA
Colorado—Wattenberg Field, Denver-Julesburg Basin	0%[d]	NA
Pennsylvania—Marcellus Shale, Susquehanna River Basin	18%[e]	2012
West Virginia—Marcellus Shale, Statewide	15%[f]	2012
California—Monterey Shale, Statewide	4%[g]	2014
Overall Mean[h]	15%	
Overall Median[i]	5%	

[a] Estimated percentage of recycling/reused water in 2011 (Nicot et al., 2012).

[b] Nicot et al. (2012) refer to this region of Texas as the East Texas Basin.

[c] Based on industry practices reported in U.S. EPA (2015c).

[d] Reflects an assumption of reuse practices by Noble Energy in the Wattenberg Field of Colorado’s Denver-Julesburg Basin, as reported by Goodwin et al. (2014).

[e] Volume of flowback injected as a percentage of total water injected, 2012 (Hansen et al., 2013). This is the most recent estimate available. For 2008 to 2011, reuse as a percentage of injected volume averaged 13%, with a median of 8%, according to U.S. EPA (2015c).

[f] Reused fracturing water as a percentage of total water used for hydraulic fracturing, 2012, calculated from data provided by the West Virginia DEP (2014).

[g] Reported data on planned hydraulic fracturing operations as described in 249 well stimulation notices submitted during the first half of January 2014 to CCST (2014). Of these notices, 4% indicated planned use of produced water (sometimes blended with fresh water) for fracturing, while 96% indicated planned use of only fresh water.

[h] The overall mean is not weighted by the number of wells in a given state, basin, or play.

[i] The overall median is not weighted by the number of wells in a given state, basin, or play.

4.2.2. Quality

Water quality is an important consideration when sourcing water for hydraulic fracturing. Fresh water is often preferred to maximize hydraulic fracturing fluid performance and to ensure compatibility with the geologic formation being fractured. This finding is supported by the EPA’s analysis of disclosures to FracFocus 1.0 (hereafter the EPA FracFocus report) (U.S. EPA, 2015a), as well as by regional analyses from Texas (Nicot et al., 2012) and the Marcellus (Mitchell et al., 2013a).[1,2] Fresh water was the most commonly cited water source by companies included in an analysis of nine hydraulic fracturing service companies on their operations from 2005 to 2010 (U.S. EPA, 2013a). Three service companies noted that the majority of their water was fresh because it required minimal testing and treatment (U.S. EPA, 2013a).[3] The majority of the nine service companies recommended testing for certain water quality parameters (pH and maximum concentrations of specific cations and anions) in order to ensure compatibility among the water, other fracturing fluid constituents, and the geologic formation (U.S. EPA, 2013a).

The reuse of hydraulic fracturing wastewater may be limited by water quality. As a hydraulically fractured well ages, the wastewater quality begins to resemble the water quality of the geologic formation and may be characterized by high TDS (Goodwin et al., 2014). High concentrations of TDS and other individual dissolved constituents in wastewater, including specific cations (calcium, magnesium, iron, barium, strontium), anions (chloride, bicarbonate, phosphate, and sulfate), and microbial agents, can interfere with hydraulic fracturing fluid performance by producing scale in the wellbore or by interfering with certain chemical additives in the hydraulic fracturing fluid (e.g., high TDS may inhibit the effectiveness of friction reducers) (Gregory et al., 2011; North Dakota State Water Commission, 2010). Due to these limitations, wastewater may require treatment to meet the level of water quality desired in the hydraulic fracturing fluid formulation. Minimal treatment or blending of wastewater and fresh water is sometimes done to dilute high TDS or other constituents. Fresh water typically makes up the largest proportion of the base fluid when blended with water sources of lesser quality (U.S. EPA, 2015a).[4] However, direct reuse of wastewater with minimal or no treatment is sometimes possible with higher-quality wastewater (U.S. EPA, 2015c) (Section 4.5.2). No data are currently available to characterize the relative frequency of reuse done with treatment, minimal treatment, or no treatment.

4.2.3. Provisioning

Water for hydraulic fracturing is typically either self-supplied by the industry or purchased from public water systems.[5] Self-supplied water for fracturing generally refers to permitted direct

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[1] FracFocus is a national hydraulic fracturing registry for oil and gas well operators to disclose information about hydraulic fracturing well locations, and water and chemical use during hydraulic fracturing operations developed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission (U.S. EPA, 2015a). The registry was originally established in 2011 for voluntary reporting. However, six of the 20 states discussed in this assessment required disclosure to FracFocus at various points between January 1, 2011 and February 28, 2013, the time period analyzed by the EPA; another three of the 20 states offered the choice of reporting to FracFocus or the state during this same time period (see Appendix Table B-5 for states and disclosure start dates) (U.S. EPA, 2015a).

[2] Of all disclosures to FracFocus that indicated a source of water for the hydraulic fracturing base fluid, 68% listed "fresh" as the only source of water used. Note, 29% of all disclosures considered in the EPA's FracFocus report included information on the source of water used for the base fluid (U.S. EPA, 2015a).

[3] Service companies did not provide data on the percentage of fresh water versus non-fresh water used for hydraulic fracturing (U.S. EPA, 2015a).

[4] In FracFocus disclosures indicating that fresh water was used in any combination with "recycled," "produced," or "brine," the median concentration of fresh water across all states ranged from 69% to 93% (U.S. EPA, 2015a).

[5] According to Section 1401(4) of the Safe Drinking Water Act, a public water system is defined as system that provides water for human consumption from surface or ground water through pipes or other infrastructure to at least 15 service connections, or an average of at least 25 people, for at least 60 days per year. Public water systems may either be publicly or privately owned.

withdrawals from surface or ground water or the reuse of wastewater. Nationally, self-supplied water is more common, although there is much regional variation (U.S. EPA, 2015a; CCST, 2014; Mitchell et al., 2013a; Nicot et al., 2012). Public water systems encompass a variety of water suppliers (U.S. EPA, 2015c). Water purchased from municipal public water systems can be provided either before or after treatment (Nicot et al., 2014). Water for hydraulic fracturing is also sometimes purchased from smaller private entities, such as local land owners (Nicot et al., 2014).

4.3. Water Use Per Well

In this section, we provide an overview of the amount of water used per well during hydraulic fracturing. We discuss water use in the life cycle of oil and gas operations (Section 4.3.1), national patterns and associated variability (Section 4.3.2), as well as the factors affecting water use per well including well length, geology, and fracturing fluid formulation (Section 4.3.3). More detailed state- and locality-specific information on water use per well is provided in Section 4.5.

4.3.1. Hydraulic Fracturing Water Use in the Life Cycle of Oil and Gas

Water is needed throughout the life cycle of oil and gas production and use, including both at the well for processes such as well pad preparation, drilling, and fracturing (i.e., the upstream portion), and later for end uses such as electricity generation, home heating, or transportation (i.e., the downstream portion) (Jiang et al., 2014; Laurenzi and Jersey, 2013). Most of the water used and consumed in the upstream portion of the life cycle occurs during hydraulic fracturing (Jiang et al., 2014; Clark et al., 2013; Laurenzi and Jersey, 2013).[1] Water use per well estimates in this chapter focus on hydraulic fracturing in the upstream portion of the oil and gas life cycle.[2]

4.3.2. National Patterns of Water Use Per Well for Fracturing

Hydraulic fracturing for oil and gas requires a large volume of water to create sufficient pressures. According to the EPA's project database of disclosures to FracFocus 1.0 (hereafter the EPA FracFocus project database), the median volume of water used per well, based on

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[1] Laurenzi and Jersey (2013) reported that hydraulic fracturing accounted for 91% of upstream water consumption, based on industry data for 29 wells in the Marcellus Shale. (91% was calculated from their paper by dividing hydraulic fracturing fresh water consumption (13.7 gal (51.9 L)/Megawatt-hour (MWh)) by total upstream fresh water consumption (15.0 gal (56.8 L)/MWh) and multiplying by 100). Similarly, Jiang et al. (2014) reported that 86% of water consumption occurred at the fracturing stage for the Marcellus, based on Pennsylvania Department of Environmental Protection (PA DEP) data on 500 wells. The remaining water was used in several upstream processes (e.g., well pad preparation, well drilling, road transportation to and from the wellhead, and well closure once production ended). Clark et al. (2013) estimated lower percentages (30%–80%) of water use at the fracturing stage for multiple formations. Although their estimates for the fraction of water used at the fracturing stage may be low due to their higher estimates for transportation and processing, the estimates by Clark et al. (2013) similarly illustrate the importance of the hydraulic fracturing stage in water use, particularly in terms of the upstream portion of the life cycle.

[2] When the full life cycle of oil and gas production and use is considered (i.e., both upstream and downstream water use), most water is used and consumed downstream. For example, in a life cycle analysis of hydraulically fractured gas used for electricity generation, Laurenzi and Jersey (2013) reported that only 6.7% of water consumption occurred upstream (15.0 gal (56.8 L)/MWh), while 93.3% of fresh water consumption occurred downstream for power plant cooling via evaporation (209.0 gal (791.2 L)/MWh).

37,796 disclosures nationally, was 1.5 million gal (5.7 million L) (U.S. EPA, 2015b).[1] There was substantial variability around this median, however, with 10th and 90th percentiles of 74,000 and 6 million gal (280,000 and 23 million L) per well, respectively.[2] Even in specific basins and plays, water use per well varied widely. Water injected also can vary within a single field; Laurenzi and Jersey (2013) reported volumes for the Wattenberg Field of the Niobrara play ranging from 1 to 6 million gal (3.8 to 23 million L) per well (10th to 90th percentile).

4.3.3 Factors Affecting Water Use Per Well

Water use varies depending on many factors, including well length, geology, and the composition of the fracturing fluid.

Well length: Well length is a principal driver of the amount of water used per well. Increases in well length affect total water volumes injected primarily by allowing a larger fracture volume to be stimulated (Economides et al., 2013). Fracture volume is the volume of the fractures in the geologic formation that fill with hydraulic fracturing fluid. The total volume of injected fluid equals fracture volume plus the volume of the wellbore itself, plus any fluid lost due to “leakoff” or other unintended losses.[3] Thus, as wells get longer, fracture, well, and total volumes all increase. This is particularly evident in longer horizontal wells versus vertical wells. For example, median water use in horizontal gas wells was over 35 times higher than in vertical gas wells (2.9 million gal vs. 82,000 gal (11 million L vs. 310,000 L), respectively) between the years 2000 and 2010 (USGS, 2015).

Geology: Geologic characteristics also influence the amount of water used per well. There are three major formation types: shales, tight sands, and coalbeds (see Chapter 2). Reported differences in water use for shales versus tight sands are rare. However, Nicot et al. (2012) reported that total water use in tight sand formations is less than half of that of shale in Texas, although results were not reported per well.

In contrast to hydrocarbons from shales and tight sands, coalbed methane (CBM) comes from coal seams that often have a high initial water content and tend to occur at much shallower depths (U.S. EPA, 2015l). Thus, dewatering is often necessary to stimulate production of CBM. In addition, geologic pressures are lower (leading to higher permeability) and well lengths are shorter, all of which result in lower water use per well. Water use per well in CBM operations can be lower by an order of magnitude or more compared to operations in shales or tight sands. For example, Murray (2013) reported water use across formations in Oklahoma, and found that water use in the CBM-dominated Hartshorn Formation was much lower than in the shale gas-dominated Woodford Formation.

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[1] Water use data from the EPA’s FracFocus project database were obtained from disclosures made to FracFocus 1.0. Although disclosures were made on a per well basis, a small proportion of the wells were associated with more than one disclosure (i.e., 876 out of 37,114, based on unique API numbers) (U.S. EPA, 2015b). For the purposes of this chapter, we discuss water use per disclosure in terms of water use per well.

[2] Although the EPA FracFocus report shows 5th and 95th percentiles, we report 10th and 90th percentiles throughout this chapter to further reduce the influence of outliers.

[3] Leakoff is the fraction of the injected fluid that infiltrates into the formation (e.g., through an existing natural fissure) and is not recovered during production. See Chapter 6 for more information about leakoff.

Fracturing Fluid Type: The majority of wells use fracturing fluids that consist mostly of water (U.S. EPA, 2015a; Yang et al., 2013; GWPC and ALL Consulting, 2009). The EPA inferred that more than 93% of reported disclosures to FracFocus used water as a base fluid (U.S. EPA, 2015a). The median reported concentration of water in the hydraulic fracturing fluid was 88% by mass, with 10th and 90th percentiles of 77% and 95%, respectively. Only roughly 2% of disclosures (761 wells) reported the use of non-aqueous substances as base fluids, typically either liquid-gas mixtures of nitrogen (643 disclosures, 84% of non-aqueous formulations) or carbon dioxide (83 disclosures, 11% of non-aqueous formulations). Both of these formulations still contained substantial amounts of water, as water made up roughly 60% (median value) of fluid in them (U.S. EPA, 2015a). Other formulations were rarely reported. Non-aqueous formulations are discussed further in Chapter 5.

4.4. Cumulative Water Use and Consumption

In this section we provide an overview of cumulative water use and consumption for hydraulic fracturing at the national, state, and county scales. We then compare these values to total water use and consumption. We discuss both use and consumption because hydraulic fracturing is both a user and consumer of water. Water use refers to water withdrawn for a specific purpose, part or all of which may be returned to the local hydrologic cycle. Water consumption refers to water that is removed from the local hydrologic cycle following its use, and is therefore unavailable to other users (Maupin et al., 2014). Hydraulic fracturing water consumption can occur through such means as evaporation from storage ponds, the retention of water in the subsurface through imbibition, or disposal in UIC Class II injection wells. In the latter two cases, the water consumed is generally completely removed from the hydrologic cycle. In this section, water consumption estimates are derived from USGS water use data, and therefore both use and consumption are presented with the published water use numbers being first.

4.4.1. National and State Scale

Cumulatively, hydraulic fracturing uses and consumes billions of gallons of water each year in the United States, but at the national or state scale, it is a relatively small user (and consumer) of water compared to total water use and consumption. According to the EPA's FracFocus project database, hydraulic fracturing used 36 billion gal (136 billion L) of water in 2011, and 52 billion gal (197 billion L) in 2012; therefore, hydraulic fracturing used an annual average of 44 billion gal (167 billion L) of water in 2011 and 2012 across all 20 states in the project database (U.S. EPA, 2015a, b). Cumulative national water use for hydraulic fracturing can also be estimated by multiplying the water use per well by the number of wells hydraulically fractured. If the median water use per well (1.5 million gal) (5.7 million L) from the EPA's FracFocus project database is multiplied by 25,000 to 30,000 wells fractured annually (see Chapter 2), cumulative national water use for hydraulic fracturing is estimated to range from 37.5 to 45.0 billion gal (142 to 170 billion L) annually. Other calculated estimates have ranged higher than this, including estimates of approximately 80 billion gal (300 billion L) (Vengosh et al., 2014) and 50-72 billion gal (190-273 billion L) (U.S. EPA, 2015c). These estimates are higher due to differences in the estimated water use per well and the number of wells used as multipliers. For example, (Vengosh et al., 2014) derived the estimate of approximately 80 billion gal (300 billion L) by multiplying an average of 4.0 million gal (15 million

L) per well (estimated for shale gas wells) by 20,000 wells (the approximate total number of fractured wells in 2012).[1]

All of these estimates of cumulative water use for hydraulic fracturing are small relative to total water use and consumption at the national scale. For example, in the combined 20 states where operators reported water use to FracFocus in 2011 and 2012 (U.S. EPA, 2015b), annual hydraulic fracturing water use and consumption averaged over those two years was less than 1% of total annual water use and consumption in 2010 (see Appendix Table B-1).[2,3]

At the state scale, hydraulic fracturing also generally uses billions of gallons of water cumulatively, but accounts for a low percentage of total water use or consumption. Of all states, operators in Texas used the most water cumulatively (47% of cumulative water use reported in the EPA FracFocus project database) (U.S. EPA, 2015b) (see Appendix Table B-1). This was due to the large number of wells in that state. Over 94% of reported cumulative water use occurred in just seven of the 20 states in the EPA FracFocus project database: Texas, Pennsylvania, Arkansas, Colorado, Oklahoma, Louisiana, and North Dakota (U.S. EPA, 2015b). Hydraulic fracturing is a small percentage when compared to total water use (<1%) and consumption (<3%) in each individual state (see Appendix Table B-1). Other studies have shown similar results, with hydraulic fracturing water use and consumption ranging from less than 1% of total use in West Virginia (West Virginia DEP, 2013), Colorado (Colorado Division of Water Resources; Colorado Water Conservation Board; Colorado Oil and Gas Conservation Commission, 2014), and Texas (Nicot et al., 2014; Nicot and Scanlon, 2012), to approximately 4% in North Dakota (North Dakota State Water Commission, 2014).

4.4.2. County Scale

Cumulative water use and consumption for hydraulic fracturing is also relatively small in most, but not all, counties in the United States (see Table 4-2, Figure 4-1, and Figure 4-2a,b). Reported

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[1] This could result in an overestimation because the estimate of 20,000 wells was derived in part from FracFocus, and these wells are not necessarily specific to shale gas; they may include other types of wells that use less water (e.g., CBM). The estimate of 1.5 million gal (5.7 million L) per well based on the EPA FracFocus project database likely leads to a more robust estimate when used to calculate national cumulative water use for hydraulic fracturing because it includes wells from multiple formation types (i.e., shale, tight sand, and CBM), some of which use less water than shale gas wells on average (U.S. EPA, 2015b).

[2] The USGS compiles water use estimates approximately every five years in the National Water Census including the 1995 Census in Solley et al. (1998); 2005 Census in Kenny et al. (2009); and 2010 Census in Maupin et al. (2014). The 2010 version is the most updated version available. The Census includes uses such as public supply, irrigation, livestock, aquaculture, thermoelectric power, industrial, and mining at the national, state, and county scale. The 2010 Census included hydraulic fracturing water use in the mining category; there was no designated category for hydraulic fracturing alone.

[3] Percentages were calculated by averaging annual water use for hydraulic fracturing in 2011 and 2012 for a given state or county (U.S. EPA, 2015b), and then dividing by 2010 USGS total water use (Maupin et al., 2014) and multiplying by 100. Note, the annual hydraulic fracturing water use reported in FracFocus was not added to the 2010 total USGS water use value in the denominator, and is simply expressed as a percentage compared to 2010 total water use or consumption. This was done because of the difference in years between the two datasets, and because the USGS 2010 Census (Maupin et al., 2014) included hydraulic fracturing water use estimates in their mining category. This approach is consistent with that of other literature on this topic; see Nicot and Scanlon (2012). See footnotes for Appendix Table B-1 and Table 4-2 for description of the consumption estimate calculations.

fracturing water use in FracFocus in 2011 and 2012 was less than 1% compared to 2010 USGS total water use in 299 of the 401 reporting counties (U.S. EPA, 2015b) (see Figure 4-2a and Appendix Table B-2). However, hydraulic fracturing water use was 10% or more compared to total water use in 26 counties, 30% or more in nine counties, and 50% or more in four counties (see Table 4-2 and Figure 4-2a). McMullen County in Texas had the highest percentage at over 100% compared to 2010 total water use.[1] Total consumption estimates followed the same pattern, but with more counties in the higher percentage categories (hydraulic fracturing water consumption was 10% or more compared to total water consumption in 53 counties; 30% or more in 25 counties; 50% or more in 16 counties; and over 100% in four counties) (see Table 4-2 and Figure 4-2b). Note, estimates based on the EPA's FracFocus project database may form an incomplete picture of hydraulic fracturing water use in a given state or county because the majority of states with data in the project database did not require disclosure to FracFocus during the time period analyzed (U.S. EPA, 2015a). We conclude that this likely does not substantially alter the overall patterns observed in Figure 4-2a,b (see Text Box 4-1 for further details).

These percentages depend both upon the absolute water use and consumption for hydraulic fracturing and the relative magnitude of other water uses and consumption in that state or county. For instance, a rural county, with a small population, might have relatively low total water use prior to hydraulic fracturing.[2] Also, just because water is used in certain county does not necessarily mean it originated in that county. While the cost of trucking water can be substantial (Slutz et al., 2012), and the industry tends to acquire water from nearby sources when possible (see Section 4.2.1), water can also be piped in from more distant, regional supplies. Despite these caveats, it is clear that hydraulic fracturing is generally a relatively small user (or consumer) of water at the county level, with the exception of a small number of counties where water use and consumption for fracturing can be high relative to other uses and consumption.

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[1] Estimates of use or consumption exceeded 100% when hydraulic fracturing water use averaged for 2011 and 2012 exceeded total water use or consumption in that county in 2010.

[2] For example, McMullen County, Texas mentioned above contains a small number of residents (707 people in 2010, according to the U.S. Census Bureau (2014)).

Table 4-2. Annual average hydraulic fracturing water use and consumption in 2011 and 2012 compared to total annual water use and consumption in 2010, by county.

Only counties where hydraulic fracturing water was 10% or greater compared to 2010 total water use are shown (for full table see Appendix Table B-2). Annual average hydraulic fracturing water use data in 2011 and 2012 from the EPA's FracFocus project database (U.S. EPA, 2015b). Total annual water use data in 2010 from the USGS (Maupin et al., 2014). States listed by order of appearance in the chapter.

State	County	Total annual water use in 2010 (millions of gal)[a]	Annual average hydraulic fracturing water use in 2011 and 2012 (millions of gal)[b]	Hydraulic fracturing water use compared to total water use (%)[c]	Hydraulic fracturing water consumption compared to total water consumption (%)[c,d]
Texas	McMullen	657.0	745.9	113.5	350.4
	Karnes	1861.5	1055.2	56.7	120.1
	La Salle	2474.7	1288.7	52.1	93.7
	Dimmit	4073.4	1794.2	44.0	81.3
	Irion	1335.9	411.4	30.8	74.5
	Montague	3989.5	925.3	23.2	77.8
	De Witt	2394.4	546.6	22.8	48.6
	Loving	781.1	138.4	17.7	94.1
	San Augustine	1131.5	182.1	16.1	50.8
	Live Oak	1916.3	294.0	15.3	40.1
	Wheeler	6522.6	858.0	13.2	21.5
	Cooke	4533.3	454.3	10.0	29.9
Pennsylvania	Susquehanna	1617.0	751.3	46.5	123.4
	Sullivan	222.7	66.5	29.9	79.8
	Bradford	4354.5	1059.4	24.3	78.2
	Tioga	2909.1	566.3	19.5	47.3
	Lycoming	5854.6	704.6	12.0	33.8
West Virginia	Doddridge	405.2	78.5	19.4	69.4
Ohio	Carroll	1127.9	152.7	13.5	37.3

State	**County**	**Total annual water use in 2010 (millions of gal)**[a]	**Annual average hydraulic fracturing water use in 2011 and 2012 (millions of gal)**[b]	**Hydraulic fracturing water use compared to total water use (%)**[c]	**Hydraulic fracturing water consumption compared to total water consumption (%)**[c,d]
North Dakota	Mountrail	1248.3	449.4	36.0	98.3
	Dunn	1076.8	309.5	28.7	43.1
	Burke	394.2	63.6	16.1	40.8
	Divide	806.7	102.2	12.7	18.6
Arkansas	Van Buren	1587.8	899.6	56.7	168.8
Louisiana	Red River	1606.0	569.6	35.5	83.2
	Sabine	1522.1	395.2	26.0	76.6

[a] County-level data accessed from the USGS website (http://water.usgs.gov/watuse/data/2010/) on November 11, 2014. Total water withdrawals per day were multiplied by 365 days to estimate total water use for the year (Maupin et al., 2014).

[b] Average of water used for hydraulic fracturing in 2011 and 2012 as reported to FracFocus (U.S. EPA, 2015b).

[c] Percentages were calculated by averaging annual water use for hydraulic fracturing reported in FracFocus in 2011 and 2012 for a given state or county (U.S. EPA, 2015b), and then dividing by 2010 USGS total water use (Maupin et al., 2014) and multiplying by 100.

[d] Consumption values were calculated with use-specific consumption rates predominantly from the USGS, including 19.2% for public supply, 19.2% for domestic use, 60.7% for irrigation, 60.7% for livestock, 14.8% for industrial uses, 14.8% for mining (Solley et al., 1998), and 2.7% for thermoelectric power (USGS, 2014h). We used rates of 71.6% for aquaculture (from Verdegem and Bosma, 2009) (evaporation per kg fish + infiltration per kg)/total water use per kg); and 82.5% for hydraulic fracturing (consumption value calculated by taking the median value for all reported produced water/injected water percentages in Tables 7-1 and 7-2 of this assessment and then subtracting from 100%). If a range of values was given, the midpoint was used. Note, this aspect of consumption is likely a low estimate since much of this produced water (injected water returning to the surface) is not subsequently treated and reused, but rather disposed of in UIC Class II injection wells—see Chapter 8).

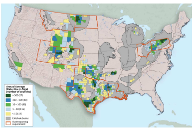

Figure 4-1. Annual average hydraulic fracturing water use in 2011 and 2012 by county (U.S. EPA, 2015b).

Source: (U.S. EPA, 2015b). Water use in millions of gallons (Mgal). Counties shown with respect to major U.S. Energy Information Administration (EIA) shale basins (EIA, 2015b). Orange borders identify states that required some degree of reporting to FracFocus 1.0 in 2011 and 2012.

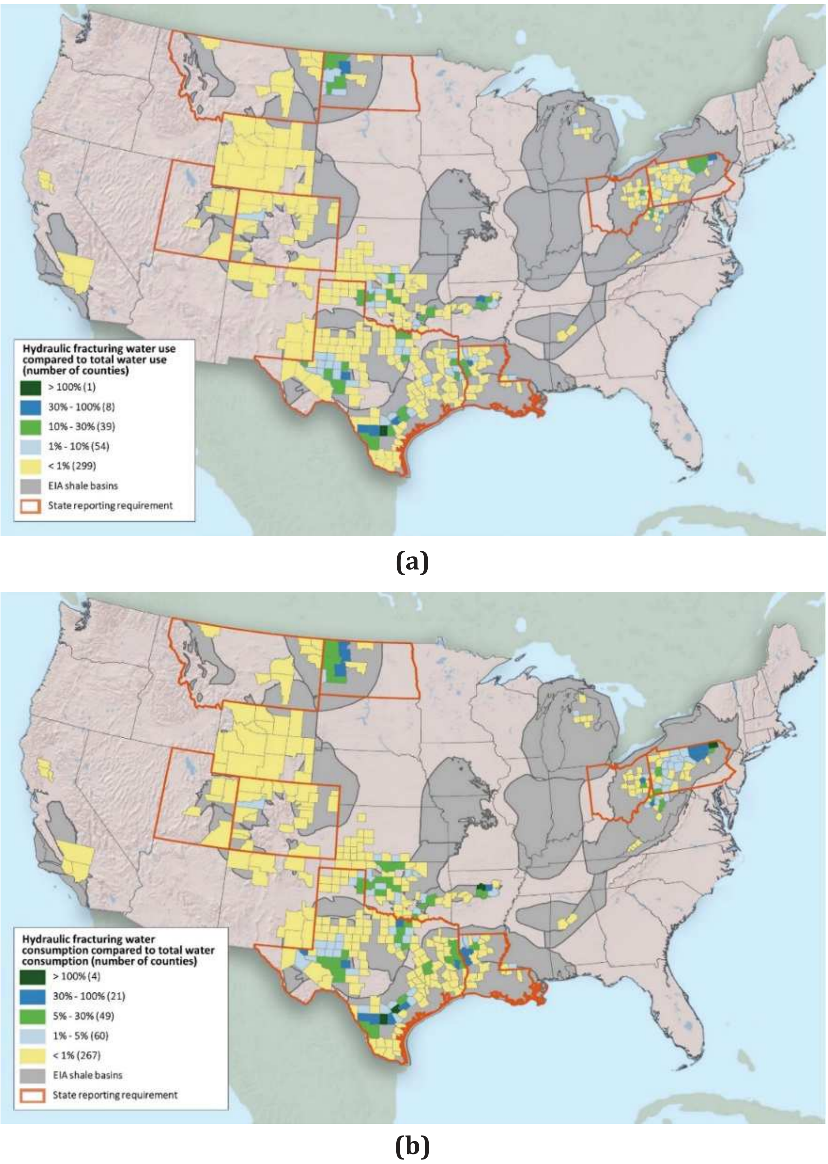

Figure 4-2. (a) Annual average hydraulic fracturing water use in 2011 and 2012 compared to total annual water use in 2010, by county, expressed as a percentage; (b) Annual average hydraulic fracturing water consumption in 2011 and 2012 compared to total annual water consumption in 2010, by county, expressed as a percentage.

Annual average hydraulic fracturing water use data in 2011 and 2012 from the EPA's FracFocus project database (U.S. EPA, 2015b). Total annual water use data in 2010 from the USGS (Maupin et al., 2014). See Table 4-2 for descriptions of calculations for estimating consumption. Counties shown with respect to major U.S. EIA shale basins (EIA, 2015b). Orange borders identify states that required some degree of reporting to FracFocus 1.0 in 2011 and 2012. Note: Values over 100% denote counties where the annual average hydraulic fracturing water use or consumption in 2011 and 2012 exceeded the total annual water use or consumption in that county in 2010.

Text Box 4-1. Using the EPA's FracFocus Project Database to Estimate Water Use for Hydraulic Fracturing.

FracFocus is a national hydraulic fracturing registry managed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission (GWPC, 2015). The registry was established in 2011 for voluntary reporting. However, six of the 20 states discussed in this assessment required disclosure to FracFocus at various points between January 1, 2011 and February 28, 2013, the time period analyzed by the EPA; another three of the 20 states offered the choice of reporting to FracFocus or the state during this same time period (U.S. EPA, 2015a). Estimates based on the EPA's FracFocus project database likely form an incomplete picture of hydraulic fracturing water use because most states with data in the project database (14 out of 20) did not require disclosure to FracFocus during the time period analyzed (U.S. EPA, 2015a).

Cumulative water use for fracturing is a function of the water use per well and the total number of wells fractured. For water use per well, we found seven literature values for comparison with values from the EPA's FracFocus project database. On average, water use estimates per well in the project database were 77% of literature values (the median was 86%); Colorado's Denver Basin was the only location where the project database estimate as a percentage of the literature estimate was low (14%) (see Appendix Table B-3). In general, water use per well estimates from the EPA's FracFocus project database appear to provide a reasonable approximation for most areas for which we have data, with the exception of the Denver Basin of Colorado.

For number of wells, we compared data in the EPA's FracFocus project database to numbers available in state databases from North Dakota, Pennsylvania, and West Virginia (see Appendix Table B-4). These were the state databases from which we could distinguish hydraulically fractured wells from total oil and gas wells. On average, we found that the EPA FracFocus project database included 67% of the wells listed in state databases for 2011 and 2012 (see Appendix Table B-4). Unlike North Dakota and Pennsylvania, West Virginia did not require operators to report fractured wells to FracFocus during this time period, possibly explaining its lower reporting rate. Multiplying the average EPA FracFocus project database values of 77% for water use per well and 67% for well counts yields 52%. Thus, the EPA FracFocus project database estimates for water use could be slightly over half of the estimates from these three state databases during this time period. These values are based on a small sample sizes (7 literature values and 3 state databases) and should be interpreted with caution. Nevertheless, these numbers at the very least suggest that estimates based on the EPA's FracFocus project database may form an incomplete picture of hydraulic fracturing water use during this time period.

To assess how this might affect hydraulic fracturing water use estimates in this chapter, we doubled the water use value in the EPA's FracFocus project database for each county, an adjustment much higher than any likely underestimation. Even with this adjustment, fracturing water use was still less than 1% of 2010 total water use in the majority of U.S. counties (299 counties without adjustment versus 280 counties with adjustment). The number of counties where hydraulic fracturing water use was 30% or more of 2010 total county water use increased from nine to 21 with the adjustment.

These results indicate that most counties have relatively low hydraulic fracturing water use, relative to total water use, even when accounting for likely underestimates. Since consumption estimates are derived from use, these will also follow the same pattern. Thus, potential underestimates based on the EPA's FracFocus project database likely do not substantially alter the overall pattern shown in Figure 4-2. Rather, underestimates of hydraulic fracturing water use would mostly affect the percentages in the small number of counties where fracturing already constitutes a higher percentage of total water use and consumption.

4.5. Potential for Water Use Impacts by State

High fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources. Rather, impacts most often result from the combination of water use and water availability at a given withdrawal point. Where water availability is high compared to water withdrawn for hydraulic fracturing, this water use can be accomodated. However, where water availability is low compared to use, hydraulic fracturing withdrawals are more likely to impact drinking water resources. Water management, such as the type of water used or the timing or location of withdrawals, can modify this relationship. All of these factors can vary considerably by location.

Besides potential water quantity effects, water withdrawals for hydraulic fracturing have the potential to alter the quality of drinking water resources. This possibility is not unique to the oil and gas industry, as any large-volume water withdrawal has the potential to affect water quality. Although there is little research that specifically connects water withdrawals for hydraulic fracturing to potential water quality impacts, multiple studies have described the impact of drought or industrial withdrawals on water quality (Georgakakos et al., 2014; Whitehead et al., 2009; Murdoch et al., 2000; Schindler, 1997). For instance, in the absence of controls, surface water withdrawals can lower water levels and alter stream flows, potentially decreasing a stream's capacity to dilute contaminants (Mitchell et al., 2013a; Entrekin et al., 2011; NYSDEC, 2011; van Vliet and Zwolsman, 2008; IPCC, 2007; Environment Canada, 2004; Murdoch et al., 2000). Furthermore, ground water withdrawals exceeding natural recharge rates may lower the water level in aquifers, potentially mobilizing contaminants or allowing the infiltration of lower-quality water from the land surface or adjacent formations (USGS, 2003; Jackson et al., 2001).

In the following section, we assess the potential for water quantity and quality impacts by location, organized by state. We focus our discussion on the 15 states that account for almost all disclosures reported in the EPA FracFocus project database (U.S. EPA, 2015b): Texas (Section 4.5.1); Colorado and Wyoming (Section 4.5.2); Pennsylvania, West Virginia, and Ohio (Section 4.5.3); North Dakota and Montana (Section 4.5.4); Oklahoma and Kansas (Section 4.5.5); Arkansas and Louisiana (Section 4.5.6); and Utah, New Mexico, and California (Section 4.5.7).[1] Each section describes the extent of hydraulic fracturing activity in that state or group of states; the type of water used in terms of source, quality, and provisioning; and the water use per well. We then discuss cumulative estimates and the potential for impacts to drinking water resources in the context of water availability.

We have ordered the states by the number of hydraulically fractured wells reported, and combined states with similar geographies or activity. Most of the available data did not allow us to assess the potential for impacts at a finer resolution than the county scale. Any potential adverse impacts are most likely to be observed locally at a particular withdrawal point. Therefore, our analysis most often suggests where the potential for impacts exists, but does not indicate where impacts will occur at the local scale. Where possible, we utilize local-scale case studies in southern Texas, western Colorado, and eastern Pennsylvania to provide details at a much finer resolution, and offer insight into whether any impacts from water acquisition for hydraulic fracturing were realized in these areas.

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[1] We do not highlight the remaining five states included in the EPA FracFocus project database because of low reported activity: Virginia (90 disclosures), Alabama (55), Alaska (37), Michigan (15), and Mississippi (4).

4.5.1. Texas

Hydraulic fracturing in Texas accounts for the bulk of the activity reported nationwide, comprising 48% of the disclosures in the EPA FracFocus project database (U.S. EPA, 2015b) (see Figure 4-3 and Appendix Table B-5). There are five major basins in Texas: the Permian, Western Gulf (includes the Eagle Ford play), Fort Worth (includes the Barnett play), TX-LA-MS Salt (includes the Haynesville play), and the Anadarko (see Figure 4-4); together, these five basins contain 99% of Texas' reported wells (see Appendix Table B-5).

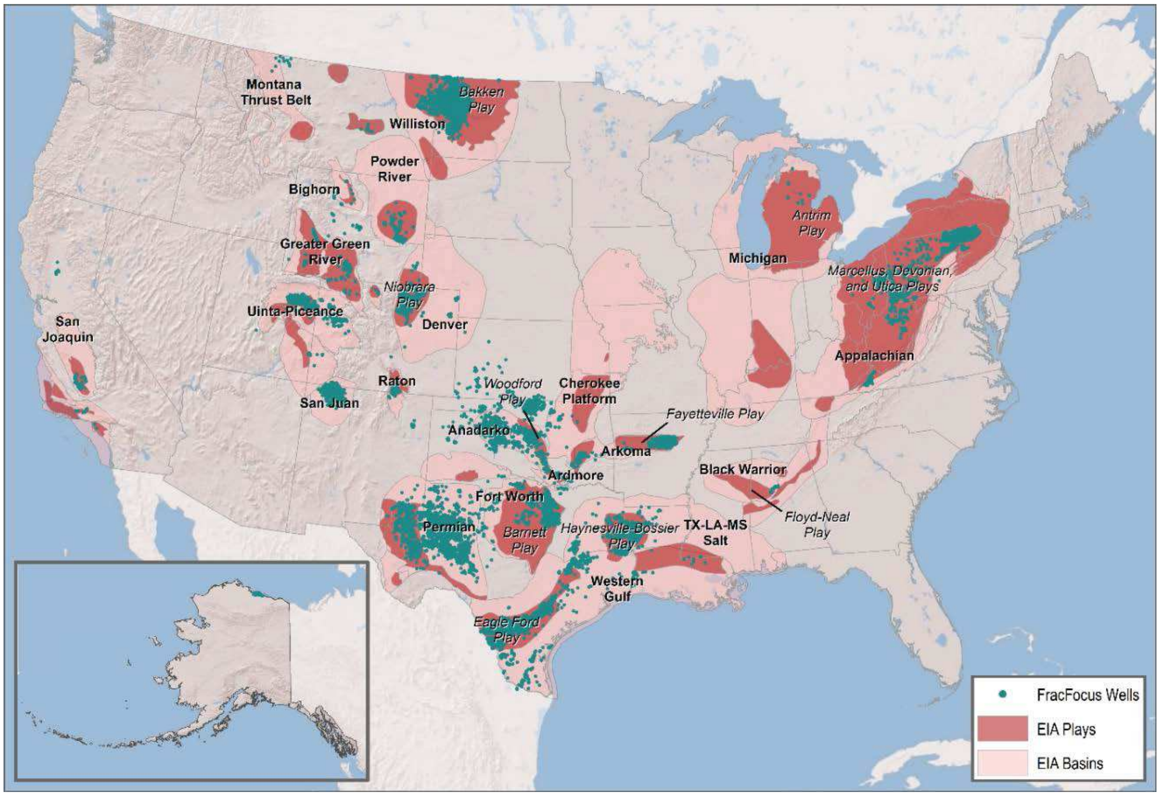

Figure 4-3. Locations of wells in the EPA FracFocus project database, with respect to U.S. EIA shale plays and basins (EIA, 2015; US. EPA, 2015b).

Note: Hydraulic fracturing is conducted in geologic settings other than shale; therefore, some wells on this map are not associated with any EIA shale play or basin. (EIA, 2015b; U.S. EPA, 2015b).

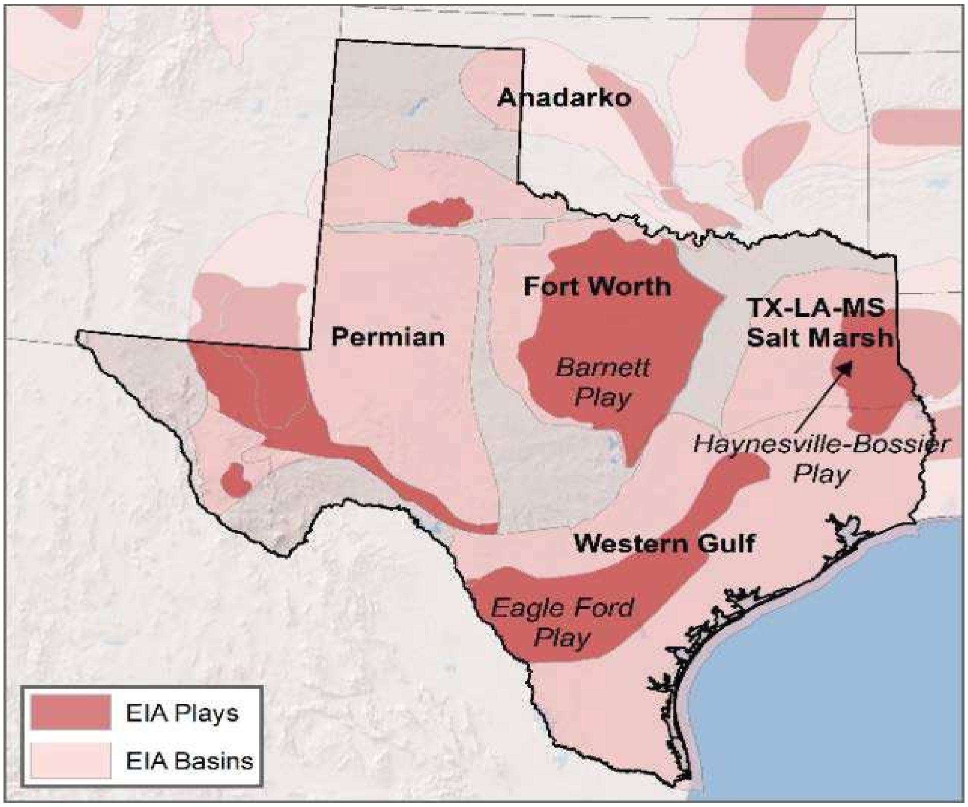

Figure 4-4. Major U.S. EIA shale plays and basins for Texas (EIA, 2015).

Source: (EIA, 2015b)

Types of water used: What is known about water sources in Texas largely comes from direct surveys and interviews with industry operators and water suppliers (Nicot et al., 2014; Nicot et al., 2012). Overall, ground water is the dominant source throughout most of the state (Nicot et al., 2014; Nicot et al., 2012) (see Table 4-3). The exception is the Barnett Shale, where both surface and ground water are used in approximately equal proportions.

Hydraulic fracturing in Texas uses mostly fresh water (Nicot et al., 2012).[1] The exception is the far western portion of the Permian Basin, where brackish water makes up an estimated 80% of total hydraulic fracturing water use. Brackish water is used to a lesser extent in the Anadarko Basin and the Midland portion of the Permian Basin (see Table 4-4). Reuse of wastewater as a percentage of total water injected is generally very low (5% or less) in all major basins and plays in Texas, except for the Anadarko Basin in the Texas Panhandle, where it is 20% (Nicot et al., 2012) (see Table 4-1).

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[1] The EPA FracFocus report shows that “fresh” was the only source of water listed in 91% of all disclosures reporting a source of water in Texas (U.S. EPA, 2015a). However, 19% of Texas disclosures included information related to water sources (U.S. EPA, 2015a).

Table 4-3. Estimated proportions of hydraulic fracturing source water from surface and ground water.

States listed by order of appearance in the chapter.

Location	Surface water	Ground water
Texas—Barnett Shale	50%[a]	50%[a]
Texas—Eagle Ford Shale	10%[b]	90%[b]
Texas—TX-LA-MS Salt Basin[c]	30%[b]	70%[b]
Texas—Permian Basin	0%[b]	100%[b]
Texas—Anadarko Basin	20%[b]	80%[b]
Pennsylvania—Marcellus Shale, Susquehanna River Basin	78%[d]	22%[d]
West Virginia—Statewide, Marcellus Shale	91%[e]	9%[e]
Oklahoma—Statewide	63%[f]	37%[f]
Louisiana—Haynesville Shale	87%[g]	13%[g]

[a] Nicot et al. (2014).

[b] Nicot et al. (2012).

[c] Nicot et al. (2012) refer to this region of Texas as the East Texas Basin.

[d] Estimated proportions are for 2011 (U.S. EPA, 2015c).

[e] Estimated proportions are for 2012, the most recent estimate for a full calendar year available from West Virginia DEP (2014). Data from the West Virginia DEP show the proportion of water purchased from commercial brokers as a separate category and do not specify whether purchased water originated from surface or ground water. Therefore, we excluded purchased water in calculating the relative proportions of surface and ground water shown in Table 4-3 (West Virginia DEP, 2014).

[f] Proportion of surface and ground water permitted in 2011 by Oklahoma's 90-day provisional temporary permits for oil and gas mining. Temporary permits make up the majority of water use permits for Oklahoma oil and gas mining (Taylor, 2012).

[g] Data from October 1, 2009, to February 23, 2012, for 1,959 Haynesville Shale natural gas wells (LA Ground Water Resources Commission, 2012).

Table 4-4. Brackish water use as a percentage of total hydraulic fracturing water use in Texas' main hydraulic fracturing areas, 2011.

Adapted from Nicot et al. (2012).[a]

Play	Percent
Barnett Shale	3%
Eagle Ford Shale	20%
Texas portion of the TX-LA-MS Salt Basin[b]	0%
Permian Basin – Far West	80%
Permian Basin – Midland	30%
Anadarko Basin	30%

[a] Nicot et al. (2012) present the estimated percentages of brackish, recycled/reused, and fresh water relative to total hydraulic fracturing water use so that the percentages of the three categories sum to 100%.

[b] Nicot et al. (2012) refer to this region of Texas as the East Texas Basin.

The majority of water used in Texas for hydraulic fracturing is self-supplied via direct ground or surface water withdrawals (Nicot et al., 2014). Less often, water is purchased from local landowners, municipalities, larger water districts, or river authorities (Nicot et al., 2014).

Water use per well: Water use per well varies across Texas' basins, with reported medians of 3.9 million gal (14.8 million L) in the Fort Worth Basin, 3.8 million gal (14.4 million L) in the Western Gulf, 3.3 million gal (12.5 million L) in the Anadarko, 3.1 million gal (11.7 million L) in the TX-LA-MS Salt, and 840,000 gal (3.2 million L) in the Permian (see Appendix Table B-5). Relatively low water use in the Permian Basin, which contains roughly half the reported wells in the state, is due to the abundance of vertical wells, mostly for oil extraction (Nicot et al., 2012).

Water use per well is increasing in most locations in Texas. In the Barnett Shale, water use per horizontal well increased from a median of 1.25 million gal (4.73 million L) in 2001 to 4.7 million gal (17.8 million L) in 2012, as the number of wells and horizontal lengths increased (Nicot et al., 2014). Similar increases in lateral length and water use per well were reported for the Texas-Haynesville, East Texas, Anadarko, and most of the Permian Basin (Nicot et al., 2012; Nicot and Scanlon, 2012).[1]

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[1] It should be noted that energy production also increases with lateral lengths, and therefore, water use per unit energy produced—typically referred to as water intensity—may remain the same or decline despite increases in per-well water use (Nicot et al., 2014; Laurenzi and Jersey, 2013).

Cumulative water use/consumption: Cumulative water use and consumption for hydraulic fracturing can be significant in some Texas counties. Texas contains five of nine counties nationwide where operators used more than 1 billion gal (3.8 billion L) of water annually for hydraulic fracturing, and five of nine counties nationwide where fracturing water use in 2011 and 2012 was 30% or more compared to total water use in those counties in 2010 (see Table 4-2, Figure 4-2a, and Appendix Table B-2).[1,2]

According to detailed county-level projections, water use for hydraulic fracturing is expected to increase with oil and gas production in the coming decades, peaking around the year 2030 (Nicot et al., 2012). The majority of counties are expected to have relatively low cumulative water use for fracturing in the future, but cumulative hydraulic fracturing water use could equal or exceed 10%, 30%, and 50% compared to 2010 total county water use in 30, nine, and three counties, respectively, by 2030 (see Appendix Table B-7). Thus, potential hydraulic fracturing water acquisition impacts in Texas may be most likely to occur over the next 15–25 years as water demand for fracturing is highest.

Potential for impacts: Of all locations surveyed in this chapter, the potential for water quantity and quality impacts due to hydraulic fracturing water use appears to be highest in western and southern Texas. This area includes the Anadarko, the Western Gulf (Eagle Ford play), and the Permian Basins. According to Ceres (2014), 28% and 87% of the wells fractured in the Eagle Ford play and Permian Basin, respectively, are in areas of high to extremely high water stress.[3] A comparison of hydraulic fracturing water use to water availability at the county scale also suggests the potential for impacts (see Text Box 4-2 and Figure 4-5). The Texas Water Development Board estimates that overall demand for water (including water for hydraulic fracturing) out to the year 2060 will outstrip supply in southern and western Texas (TWDB, 2012). Moreover, the state has experienced moderate to extreme drought conditions for much of the last decade (National Drought Mitigation Center, 2015). The 2012 Texas State Water Plan emphasizes that “in serious drought conditions, Texas does not and will not have enough water to meet the needs of its people, its businesses, and its agricultural enterprises” (TWDB, 2012).

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[1] Texas also contains 10 of the 25 counties nationwide where hydraulic fracturing water consumption was greater than or equal to 30% of 2010 total water consumption (see Table 4-2).

[2] Nicot and Scanlon (2012) found similar variation among counties when they compared hydraulic fracturing water consumption to total county water consumption for the Barnett play. Their cumulative consumption estimates ranged from 581 million gal (2.20 billion L) in Parker County to 2.7 billion gal (10.2 billion L) in Johnson County, representing 19.3% and 29.7% compared to total water consumption in those counties, respectively. Fracturing in Tarrant County, part of the Dallas-Fort Worth area, consumed 1.6 billion gal (6.1 billion L) of water, 1.4% compared to total county water consumption (Nicot and Scanlon, 2012).

[3] Ceres (2014) compared well locations to areas categorized by a water stress index, characterized as follows: extremely high (defined as annual withdrawals accounting for greater than 80% of surface flows); high (40–80% of surface flows); or medium-to-high (20–40% of surface flows).

Text Box 4-2. Hydraulic Fracturing Water Use as a Percentage of Water Availability Estimates.

Researchers at Sandia National Laboratories assessed county-level water availability across the continental United States (Tidwell et al., 2013). Assessments of water availability in the United States are generally lacking at the county scale, and this analysis—although undertaken for siting new thermoelectric power plants—can be used to assess potential impacts of hydraulic fracturing.

The authors generated annual availability estimates for five categories of water: unappropriated surface water, unappropriated ground water, appropriated water potentially available for purchase, brackish groundwater, and wastewater from municipal treatment plants (Tidwell et al., 2013). In the western United States, water is generally allocated by the principle of prior appropriation—that is, first in time of use is first in right. New development must use unappropriated water or purchase appropriated water from vested users. In their analysis, the authors assumed 5% of appropriated irrigated water could be purchased; they also excluded wastewater required to be returned to streams and the wastewater fraction already reused. Given regulatory restrictions, they considered no fresh water to be available in California for new thermoelectric plants.

Combining their estimates of unappropriated surface and ground water and appropriated water potentially available for purchase, we derived a fresh water availability estimate for each county (except for those in California) and then compared this value to reported water use for hydraulic fracturing (U.S. EPA, 2015b). We also added the estimates of brackish and wastewater to fresh water estimates to derive estimates of total water availability and did a similar comparison. Since the water availability estimates already take into account current water use for oil and gas operations, these results should be used only as indicator of areas where shortages might arise in the future.

Overall, hydraulic fracturing water use represented less than 1% of fresh water availability in over 300 of the 395 counties analyzed (see Figure 4-5a). This result suggests that there is ample water available at the county scale to accommodate hydraulic fracturing in most locations. However, there was a small number of counties where hydraulic fracturing water use was a relatively high percentage of fresh water availability. In 17 counties, fracturing water use actually exceeded the index of fresh water available; all of these counties were located in the state of Texas and were associated with the Anadarko, Barnett, Eagle Ford, and Permian basins/plays (see Figure 4-4). In Texas counties with relatively high brackish water availability, hydraulic fracturing water use represented a much smaller percentage of total water availability (fresh + brackish + wastewater) (see Figure 4-5b). This finding illustrates that potential impacts can be avoided or reduced in these counties through the use of brackish water or wastewater for hydraulic fracturing; a case study in the Eagle Ford play in southwestern Texas confirms this (see Text Box 4-3).

Text Box 4.2 (continued): Hydraulic Fracturing Water Use as a Percentage of Water Availability Estimates.

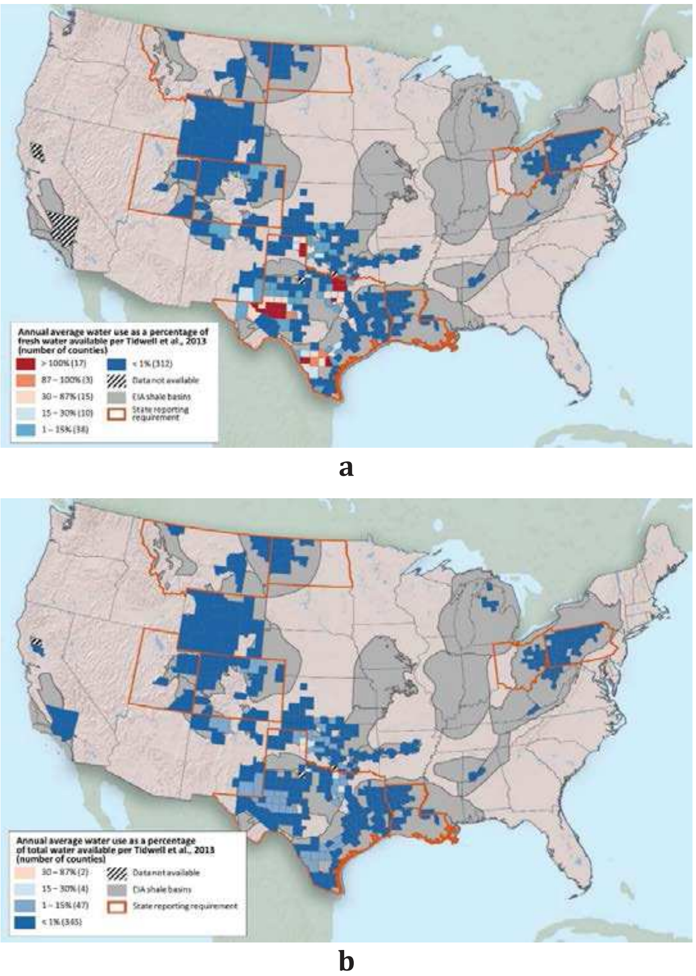

Figure 4-5. Annual average hydraulic fracturing water use in 2011 and 2012 compared to (a) fresh water available and (b) total water (fresh, brackish, and wastewater) available, by county, expressed as a percentage.

Counties shown with respect to major U.S. EIA shale basins (EIA, 2015b). Orange borders identify states that required some degree of reporting to FracFocus 1.0 in 2011 and 2012. Data from U.S. EPA (2015b) and Tidwell et al. (2013); data from Tidwell et al. (2013) supplied from the U.S. Department of Energy (DOE) National Renewable Energy Laboratory on January 28, 2014 and available upon request from the U.S. DOE Sandia National Laboratories. The analysis by Tidwell et al. (2013) was done originally for thermoelectric power generation. As such, it was assumed that no fresh water could be used in California for this purpose due to regulatory restrictions, and therefore no fresh water availability data were given for California (a). The total water available for California is the sum of brackish water plus wastewater only (b).

Surface water availability is generally low in western and southern Texas (Figure 4-6a), and both fracturing operations and residents rely heavily on ground water (Figure 4-6b). Similar to trends nationally, ground water aquifers in Texas have experienced substantial declines caused by withdrawals (Konikow, 2013b; TWDB, 2012; George et al., 2011). Ground water in the Pecos Valley, Gulf Coast, and Ogallala aquifers in southern and western Texas is estimated to have declined by roughly 5, 11, and 43 cubic miles (21, 45.5, and 182 cubic kilometers), respectively, between 1900 and 2008 (Konikow, 2013b).[1] The Texas Water Development Board expects ground water supply in the major aquifers to decline by 30% between 2010 and 2060, mostly due to declines in the Ogallala aquifer (TWDB, 2012).[2] Irrigated agriculture is by far the dominant user of water from the Ogallala aquifer (USGS, 2009), but fracturing operations, along with other uses, now contribute to the aquifer's depletion.

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[1] The estimate of total net volumetric groundwater depletion for the Gulf Coast aquifer is the sum of the individual depletion estimates for the north (Houston area), central, and southern (Winter Garden area) parts of the Texas Gulf Coast aquifer. Ground water depletion from the Carrizo-Wilcox aquifer is included in the estimate for the southern portion of the Gulf Coast aquifer (Konikow, 2013b).

[2] TWDB (2012) defines ground water supply as the amount of ground water that can be produced given current permits and existing infrastructure. By contrast, TWDB (2012) defines ground water availability as the amount of ground water that is available regardless of legal or physical availability. Total ground water availability in Texas is expected to decline by approximately 24% between 2010 and 2060 (TWDB, 2012).

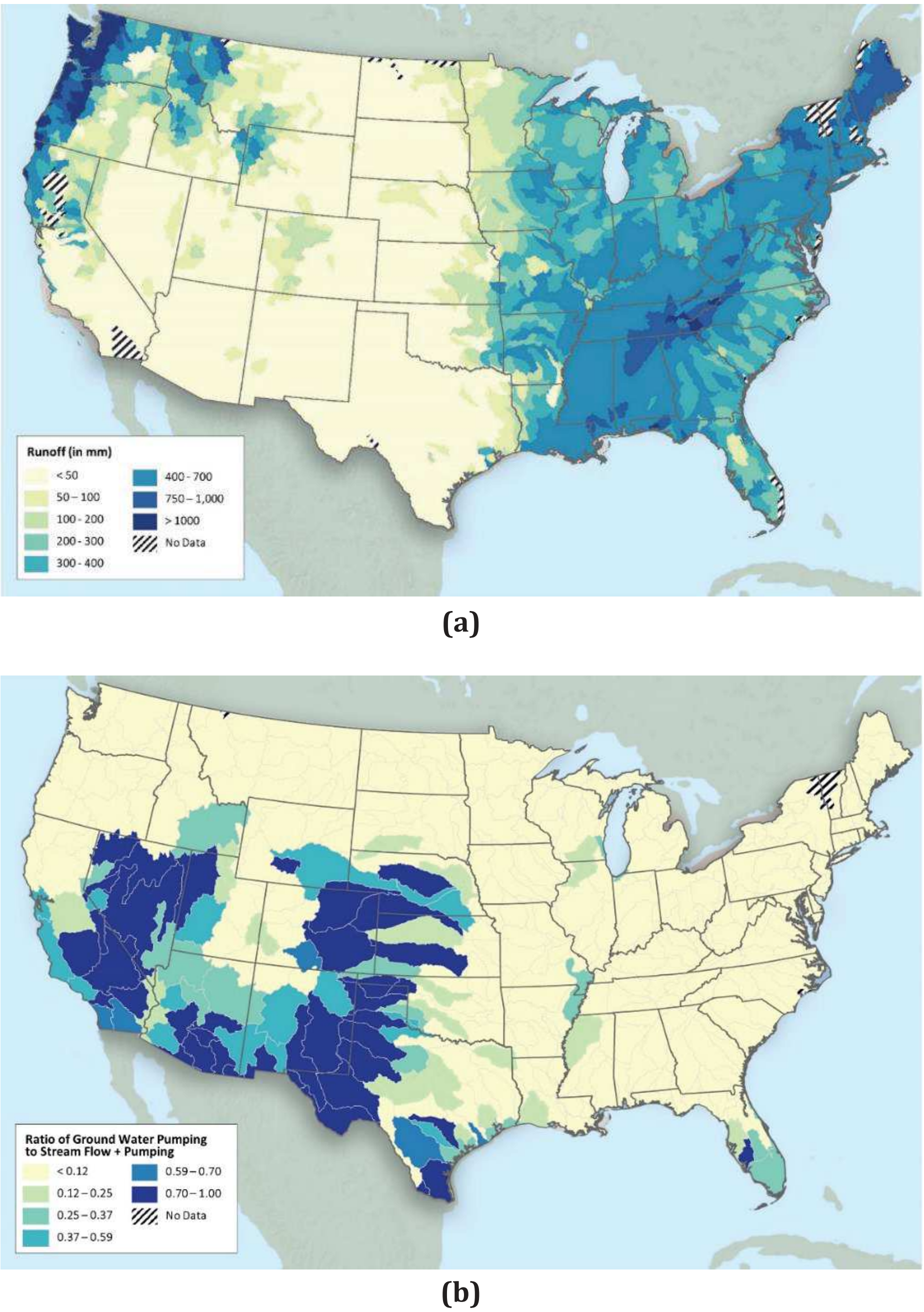

Figure 4-6. (a) Estimated annual surface water runoff from the USGS; (b) Reliance on ground water as indicated by the ratio of ground water pumping to stream flow and pumping.

Estimates for Figure 4-6a were calculated at the 8-digit hydrological unit code (HUC) scale by dividing annual average daily stream flow (from October 1, 2012 to September 30, 2013) by HUC area. Data accessed from the USGS (USGS, 2014g). Higher ratios (darker blues) in Figure 4-6b indicate greater reliance on ground water. Figure redrawn from Tidwell et al. (2012), using data provided by the U.S. Department of Energy's Sandia National Laboratories on December 12, 2014.

Extensive ground water pumping can induce vertical mixing of high-quality ground water with recharge water from the land surface that has been contaminated by nitrate or pesticides, or with lower-quality ground water from underlying geologic formations (USGS, 2009; Konikow and Kendy, 2005). Ground water quality degradation associated with aquifer pumping is well documented in the southern portion of the Ogallala aquifer in the Texas panhandle. The quality of ground water used by many private, public supply, and irrigation wells is poorest in the aquifer's southern portion, with elevated concentrations of TDS, chloride, nitrate, fluoride, manganese, arsenic, and uranium (Chaudhuri and Ale, 2014a; USGS, 2009, 2007). Elevated levels of these constituents result from both natural processes and human activities such as ground water pumping (Chaudhuri and Ale, 2014a; USGS, 2009). Similar patterns of ground water quality degradation (i.e., salinization and contamination) have also been observed in other Texas aquifers.[1]

Ground water withdrawals for hydraulic fracturing, along with irrigation and other uses, may contribute to water quality degradation associated with intensive aquifer pumping in western and southern Texas. Areas with numerous high-capacity wells and large amounts of sustained ground water pumping are most likely to experience ground water quality degradation associated with withdrawals (USGS, 2009, 2007). Given that Texas is prone to drought conditions, ground water recharge is limited, making the already declining aquifers in southern and western Texas especially vulnerable to further ground water depletion and resulting potential impacts to ground water quality (USGS, 2009; Jackson et al., 2001).

This survey of the available literature and data points to the potential for impacts in southern and western Texas, but generally does not indicate whether impacts will occur at the local scale around specific withdrawal points. An exception is a case study in the Eagle Ford play of southwestern Texas that compared water demand for hydraulic fracturing with water supplies at the scale of the play, county, and one square mile (Scanlon et al., 2014). The authors observed generally adequate water supplies for hydraulic fracturing, except in specific locations, where they found excessive drawdown of local ground water in a small proportion (~6% of the area) of the Eagle Ford play (see Text Box 4-3).

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[1] Persistent salinity has also been observed in west Texas, specifically in the southern Ogallala, northwest Edwards-Trinity (plateau), and Pecos Valley aquifers, largely due to prolonged irrigational ground water pumping and ensuing alteration of hydraulic gradients leading to ground water mixing (Chaudhuri and Ale, 2014b). High levels of ground water salinization associated with prolonged aquifer depletion have also been documented in the Carrizo-Wilcox and southern Gulf Coast aquifers, underlying the Eagle Ford Shale in south Texas (Chaudhuri and Ale, 2014b; Konikow, 2013b; Boghici, 2009). Further, elevated levels of constituents, including nitrate, lead, fluoride, chloride, sulfate, iron, manganese, and TDS, have been reported in the Carrizo-Wilcox aquifer (Boghici, 2009).

Text Box 4-3. Case Study: Water Profile of the Eagle Ford Play, Texas.

Researchers from the University of Texas published a detailed case study of water supply and demand for hydraulic fracturing in the Eagle Ford play in southwestern Texas (Scanlon et al., 2014). This effort assembled detailed information from state and local water authorities, and proprietary industry data on hydraulic fracturing, to develop a portrait of water resources in this 16-county area.

Scanlon et al. (2014) compared water demand for hydraulic fracturing currently and over the projected play life (20 years) relative to water supply from ground water recharge, ground water storage (brackish and fresh), and stream flow. Using detailed ground water availability models developed by the Texas Water Development Board, they reported that water demand for hydraulic fracturing in 2013 was 30% of annual ground water recharge in the play area, and over the 20-year play lifespan it was projected to be 26% of groundwater recharge, 5-8% of fresh groundwater storage, and 1% of brackish ground water storage. The dominant water user in the play is irrigation (62 to 65% of water use, 53 to 55% of consumption), as compared with hydraulic fracturing (13% of water use and 16% of consumption). At the county level, projected water demand for hydraulic fracturing over the 20-year period was low relative to freshwater supply (ranging from 0.6-27% by county, with an average of 7.3%). Similarly, projected total water demand from all uses was low relative to supply, excluding two counties with high irrigation demands (Frio, Zavala), and one county with no known ground water supplies (Maverick).

Although supply was found to be sufficient even in this semi-arid region, there were important caveats especially at sub-county scales. The researchers found no water level declines over much of the play area assessed (69% of the play area), yet in some areas they estimated ground water drawdowns of up to 50 feet (12% of the play area), and in others of 100 feet or more (6% of the play area). This was corroborated with well monitoring data that showed a sharp decline in water levels in several ground water monitoring wells after hydraulic fracturing activity increased in 2009. The researchers concluded that any impacts in these locations could be minimized if brackish ground water were used. Projected hydraulic fracturing water use represents less than 1% of total brackish ground water storage in the play area. By contrast, they concluded there is limited potential for reuse of wastewater in this play because of small volumes available (less than or equal to 5% of hydraulic fracturing water requirements).

The potential for water quantity and quality effects appears to be lower in north-central and eastern Texas, in areas including the Barnett and Haynesville plays. Residents obtain water for domestic use—which includes use of water for drinking—from a mixture of ground water and surface water sources (see Appendix Table B-6). Counties encompassing Dallas and Fort Worth rely mostly on publically-supplied surface water (TWDB, 2012) (see Appendix Table B-6).

Although the Trinity, the major aquifer in northeast Texas, is projected to decline only slightly between 2010 and 2060 (TWDB, 2012), Bene et al. (2007) estimate that hydraulic fracturing ground water withdrawals will increase from 3% of total ground water use in 2005 to 7%–13% in 2025, suggesting the potential for localized aquifer drawdown and potential impacts to water quality. Additionally, ground water quality degradation associated with aquifer drawdown has been documented in the Trinity and Woodbine aquifers underlying much of the Barnett play, with both aquifers showing high levels of salinization (Chaudhuri and Ale, 2013).

Overall, the potential for impacts appears higher in western and southern Texas, compared to the northeast part of the state. Impacts are likely to be localized drawdowns of ground water, as shown by a detailed case study of the Eagle Ford play (see Text Box 4-3). Scanlon et al. (2014) suggested that a shift towards brackish water use could minimize potential future impacts to fresh water resources. This finding is consistent with our county-level data (see Text Box 4-2).

4.5.2. Colorado and Wyoming

Colorado had the second highest number of disclosures in the EPA FracFocus project database, (13% of disclosures) (see Figure 4-3 and Appendix Table B-5). We combine Colorado and Wyoming because of their shared geology of the Denver Basin (including the Niobrara play) and the Greater Green River Basin (see Figure 4-7). There are three major basins reported for Colorado: the Denver Basin; the Uinta-Piceance Basin; and the Raton Basin. Together these basins contain 99% of reported wells in the state, although the bulk of the activity in Colorado is in the Denver Basin (see Appendix Table B-5). Fewer wells (roughly 4% of disclosures) are present in Wyoming. There are two major basins reported for Wyoming (Greater Green River and Powder River) that together contain 86% of activity in the state (see Appendix Table B-5).

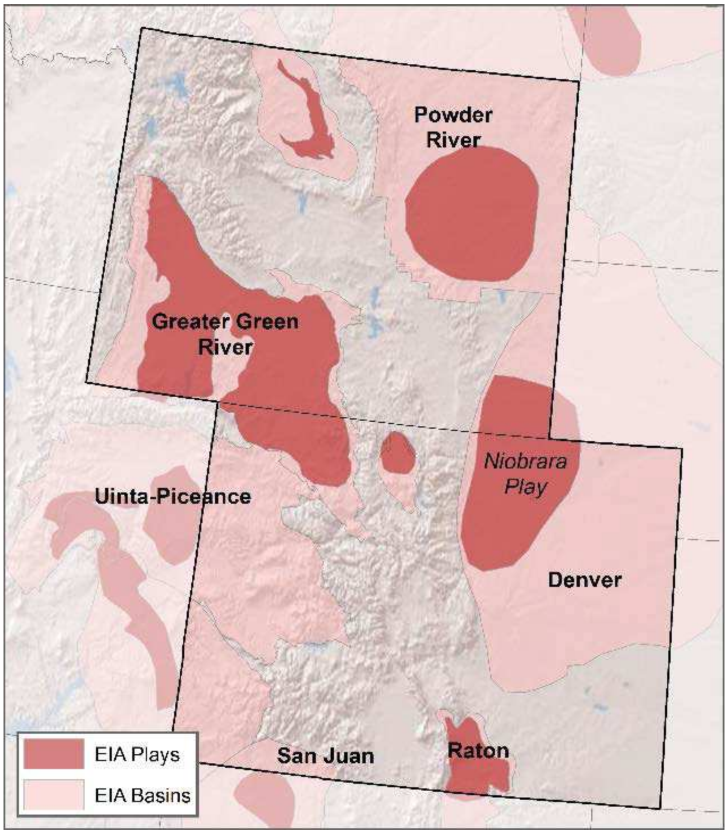

Figure 4-7. Major U.S. EIA shale plays and basins for Colorado and Wyoming (EIA, 2015).

Source: (EIA, 2015b)

Types of water used: Water for hydraulic fracturing in Colorado and Wyoming comes from both ground water and surface water, as well as reused wastewater (Colorado Division of Water Resources; Colorado Water Conservation Board; Colorado Oil and Gas Conservation Commission, 2014; BLM, 2013b). The only publicly available information on water sources for each state is a list of potential sources; it does not appear that either state provides more specific information on water sources for hydraulic fracturing. In the Uinta-Piceance Basin of northwestern Colorado, the EPA (2015c) reports that most of the fresh water used for fracturing comes from surface water, although fresh water sources make up a small proportion of the total water used. In the Denver Basin (Niobrara play) of southeastern Wyoming, qualitative information suggests that ground water supplies much of the water used for fracturing, although no data were available to characterize the ratio of ground water to surface water withdrawals (AMEC, 2014; BLM, 2013b; Tyrrell, 2012).

Non-fresh water sources (e.g., industrial and municipal wastewater, brackish ground water, and reused hydraulic fracturing wastewater) are sometimes listed as potential alternatives to fresh water for fracturing in both Colorado and Wyoming (Colorado Division of Water Resources; Colorado Water Conservation Board; Colorado Oil and Gas Conservation Commission, 2014; BLM, 2013b); no data are available to show the extent to which these non-fresh water sources are used at the state or basin level. In northwest Colorado's Garfield County (Uinta-Piceance Basin), the EPA (2015c) reports that fresh water is used solely for drilling and that reused wastewater supplies nearly all the water for hydraulic fracturing (see Table 4-1). This estimate of reused wastewater as a percentage of injected volume is markedly higher than in other locations and results from the geologic characteristics of the Piceance tight sand formation, which has naturally high water content and produces large volumes of relatively high-quality wastewater (U.S. EPA, 2015c).

In contrast, a study by Goodwin et al. (2014) assumed no reuse of wastewater for hydraulic fracturing operations by Noble Energy in the Denver-Julesburg Basin of northeastern Colorado (see Table 4-1). It is unclear whether this assumption is indicative of reuse practices of other companies in the Denver-Julesburg Basin. The difference in reused wastewater rates reported by the EPA (2015c) and Goodwin et al. (2014) may indicate an east-west divide in Colorado (i.e., low reuse in the east versus high reuse in the west), due at least in part to differences in wastewater volumes available for reuse. However, further information is needed to adequately characterize reuse patterns in Colorado.

Water Use per Well: Water use per well varies across Colorado, with median values of 1.8 million, 400,000, and 96,000 gal (6.8 million, 1.5 million, and 363,000 L) in the Uinta-Piceance, Denver, and Raton Basins, respectively according to the EPA FracFocus project database (see Appendix Table B-5). Low water volumes per well are reported in Wyoming (see Appendix Table B-5). Low volumes reported for the Raton Basin of Colorado and the Powder River Basin of Wyoming are due to the prevalence of CBM extraction in these locations (U.S. EPA, 2015l; USGS, 2014d).

More difficult to explain are the low volumes reported for the Denver Basin in the EPA FracFocus project database. These values are lower than any other non-CBM basin reported in Appendix Table B-5. Goodwin et al. (2014) report much higher water use per well in the Denver Basin, with a