median of 2.8 million gal (10.6 million L) (although only usage for the Wattenberg Field was reported). Indeed, the 10th–90th percentiles (2.4–3.8 million gal) (9.1 to 14.4 million L) from Goodwin et al. (2014) are almost completely above those from the EPA FracFocus project database for the Denver Basin (see Appendix Table B-5).[1] It is difficult to draw clear conclusions because of differences in scale (i.e., field in Goodwin versus basin in the project database) and operators (i.e., Noble Energy in Goodwin versus all in the project database). However, it seems plausible that the EPA FracFocus project database may be incomplete for estimating the amount of water used per well in the Denver Basin.

Trends in water use per well are generally lacking for Colorado, with the exception of those reported by Goodwin et al. (2014). They found that water use per well is increasing with well length in the Denver Basin; however, they also observed that water intensity (gallons of water per unit energy extracted) did not change, since energy recovery increased along with water use.

Cumulative water use/consumption: Hydraulic fracturing operations in Colorado cumulatively use billions of gallons of water, but this amount is a small percentage compared to total water used or consumed at the county scale. Operators in both Garfield and Weld Counties, located in the Uinta-Piceance and Denver Basins, respectively, use more than 1 billion gal (3.8 billion L) annually. Fracturing water use and consumption in these counties exceed those in all other Colorado counties combined (see Appendix Table B-2), but the water used for hydraulic fracturing in Garfield and Weld counties is less than 2% and 3% compared to 2010 total water use and consumption, respectively. In comparison, irrigated agriculture accounts for over 90% of the water used in both counties (Maupin et al., 2014; Kenny et al., 2009). Overall, hydraulic fracturing accounts for less than 2% compared to 2010 total water use in all Colorado counties represented in the EPA FracFocus project database (see Appendix Table B-2). Water use estimates based on the EPA FracFocus project database may be low relative to literature and state estimates (Text Box 4-1), but even if estimates from the project database were doubled, hydraulic fracturing water use and consumption would still be less than 4% and 5.5% compared to 2010 total water use and consumption, respectively, in each Colorado county.

In Wyoming, reported water use for hydraulic fracturing is small compared to Colorado (see Appendix Table B-1). Fracturing water use and consumption did not exceed 1% of 2010 total water use and consumption, respectively, in any county (see Appendix Table B-2). Unlike Colorado, Wyoming did not require disclosure to FracFocus during the time period analyzed by the EPA (U.S. EPA, 2015a) (see Appendix Table B-5).

The Colorado Division of Water Resources et al. (2014) project that annual water use for hydraulic fracturing in the state will increase by approximately 16% between 2012 and 2015, but demand in

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[1] Different spatial extents might explain these differences, since Goodwin et al. (2014) focus on 200 wells in the Wattenberg Field of the Denver Basin; however, Weld County is the center of activity in the Wattenberg Field, and the EPA FracFocus project database contains 3,011 disclosures reported in Weld County, with a median water use per of 407,442 gal (1,542,340 L), similar to that for the basin as a whole.

later years is unclear. Even with an increase of 16% or more, hydraulic fracturing would still remain a relatively small user of water at the county scale in Colorado.

Potential for impacts: The potential for water quantity and quality impacts appears to be low at the county scale in Colorado and Wyoming, because fracturing accounts for a low percentage of total water use and consumption (see Figure 4-2a,b). This conclusion is also supported by the comparison of hydraulic fracturing water use to water availability at the county scale (see Text Box 4-2 and Figure 4-5a,b). However, counties in Colorado and Wyoming may be too large to detect the potential for impacts, and local scale studies help provide details at a finer resolution. In a multi-scale case study in western Colorado, the EPA (2015c) also did not observe any impacts in the Upper Colorado River Basin. Due to the high reuse rate of wastewater, they did not identify any locations where fracturing currently contributed to locally high water use intensity. They did conclude, however, that future water use effects were possible (see Text Box 4-4).

Text Box 4-4. Case Study: Impact of Water Acquisition for Hydraulic Fracturing on Local Water Availability in the Upper Colorado River Basin.

The EPA (2015c) conducted a case study to explore the impact of hydraulic fracturing water demand on water availability at the river basin, county, and local scales in the semi-arid Upper Colorado River Basin (UCRB) of western Colorado. The study area overlies the Piceance geologic basin with natural gas in tight sands. Water withdrawal impacts were quantified using a water use intensity index (i.e., the ratio between the volume of water withdrawn at a site for hydraulic fracturing and the volume of available water). Researchers obtained detailed site-specific data on hydraulic fracturing water usage from state and regional authorities, and estimated available water supplies using observations at USGS gage stations and empirical and hydrologic modeling.

They found that water supplies accessed for oil and gas demand were concentrated in Garfield County, and most fresh water withdrawals were concentrated within the Parachute Creek watershed (198 mi^2). However, fresh water makes up a small proportion of the total water used for fracturing due to large quantities of high-quality wastewater produced from the Piceance tight sands. Fresh water is used only for drilling, and the water used for fracturing is reported to be 100% reused wastewater (see Table 4-1). Due to the high reuse rate, The EPA (2015c) did not identify any locations in the Piceance play where fracturing contributed to locally high water use intensity.

Scenario analyses demonstrated a pattern of increasing potential impact with decreasing watershed size in the UCRB. The EPA (2015c) examined hydraulic fracturing water use intensity under the current rates of both directional (S-shaped) and horizontal drilling. They showed that for the more water-intensive horizontal drilling, watersheds had to be larger to meet the same index of water use intensity (0.4) as that for directional drilling (100 mi^2 for horizontal drilling, as compared to 30 mi^2 for directional drilling). To date, most wells have been drilled directionally into the Piceance tight sands, although a trend toward horizontal drilling is expected to increase annual water use per well by about 4 times. Despite this increase, total hydraulic fracturing water use is expected to remain small relative to other users. Currently, irrigated agriculture is the largest water user in the UCRB.

Greater water demand could occur in the future if the water-intensive oil shale extraction industry becomes economically viable in the region. Projections for oil shale water demand indicate that the industry could increase water use for energy extraction in Garfield and Rio Blanco counties.

East of the Rocky Mountains in the Denver Basin, sub-county effects may be possible given the combination of high hydraulic fracturing activity and low water availability, but lack of available data and literature at this scale limits our ability to assess the potential for impacts in this location. Ceres (2014) concludes that all fractured wells in the Denver Basin are in high or extremely high water-stressed areas. Furthermore, the development of the Niobrara Shale in southeast Wyoming occurs in areas already impacted by high agricultural water use from the Ogallala aquifer, including the state's only three ground water control areas, which were established as management districts in the southeast portion of the state in response to declining ground water levels (AMEC, 2014; Wyoming State Engineer's Office, 2014; Tyrrell, 2012; Bartos and Hallberg, 2011). Ground water withdrawals for hydraulic fracturing may have the potential to contribute to water quality degradation particularly in these areas.

Overall, the potential for impacts appears low at the county scale in Colorado and Wyoming, but sub-county effects may be possible particularly east of the Rocky Mountains in the Denver Basin. Lack of available data and literature at the local scale limits our ability to assess the potential for impacts in this location.

4.5.3. Pennsylvania, West Virginia, and Ohio

Pennsylvania had the third most disclosures in the EPA FracFocus project database (6.5% of disclosures) (see Appendix Table B-5 and Figure 4-3). We combine West Virginia and Ohio with Pennsylvania because they share similar geology overlying the Appalachian Basin (including the Marcellus, Devonian, and Utica stacked plays) (see Figure 4-8); however, much less activity is reported in these two states (see Appendix Table B-5).

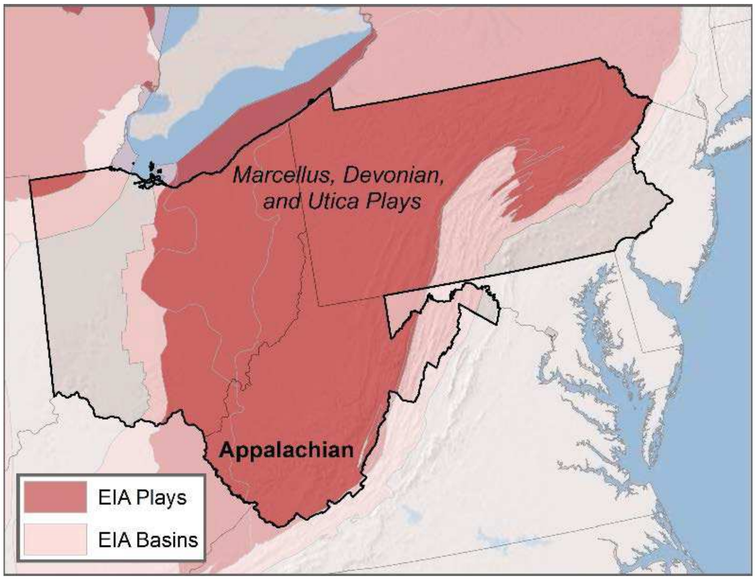

Figure 4-8. Major U.S. EIA shale plays and basins for Pennsylvania, West Virginia, and Ohio (EIA, 2015).

Source: (EIA, 2015b).

Types of water used: Surface water is the primary water source for hydraulic fracturing in Pennsylvania, West Virginia, and Ohio (Mitchell et al., 2013a; SRBC, 2013; West Virginia DEP, 2013; Ohio EPA, 2012b). Available data for Pennsylvania are specific to the Susquehanna River Basin (SRB), where hydraulic fracturing water is sourced mostly from surface water (SRBC, 2013) (see Table 4-3). The industry also uses mostly surface water in West Virginia (West Virginia DEP, 2014, 2013) (see Table 4-3). Although specific data are not available, state reports indicate that most water for hydraulic fracturing in Ohio's Marcellus or Utica Shale formations is sourced from nearby surface water bodies (Ohio EPA, 2012b; STRONGER, 2011b).

Given that surface water is the primary water source, the water used for hydraulic fracturing is most often fresh water in all three states. In both Pennsylvania's SRB and throughout West Virginia, most water for hydraulic fracturing is self-supplied via direct withdrawals from surface water and ground water (U.S. EPA, 2015a; West Virginia DEP, 2013). Operators also purchase water from public water systems, which may include a variety of commercial water brokers (West Virginia DEP, 2014; SRBC, 2013; West Virginia DEP, 2013). Municipal supplies may be used as well, particularly in urban areas of Ohio (STRONGER, 2011b).

Reused hydraulic fracturing wastewater accounted for an estimated 18% and 15% of total water used for fracturing in 2012 in Pennsylvania's SRB and West Virginia, respectively (West Virginia DEP, 2014; Hansen et al., 2013; SRBC, 2013) (see Table 4-1). Available data indicate increased reuse of wastewater over time in this region likely due to the lack of nearby disposal options; from 2010-2012 reused wastewater as a percentage of injected water volume ranged from 10% to 18% and 6% to 15% in Pennsylvania's SRB and West Virginia, respectively (West Virginia DEP, 2014; Hansen et al., 2013). In Ohio's Marcellus and Utica Shales, reuse of wastewater is reportedly uncommon (STRONGER, 2011b), potentially due to the prevalence of disposal wells in Ohio (see Chapter 8).

Aside from reused hydraulic fracturing wastewater, other types of wastewaters reused for hydraulic fracturing may include wastewater treatment plant effluent, treated acid mine drainage, and rainwater collected at various well pads (West Virginia DEP, 2014; SRBC, 2013; West Virginia DEP, 2013; Ziemkiewicz et al., 2013; Ohio EPA, 2012b). No data are available on the frequency of use of these other wastewaters.

Water Use per Well: Operators in these three states reported the third, fourth, and fifth highest median water use nationally in the EPA FracFocus project database, with 5.0, 4.2, and 3.9 million gal (18.9, 15.9, and 14.8 million L) per well in West Virginia, Pennsylvania, and Ohio, respectively (U.S. EPA, 2015b) (see Appendix Table B-5). Hansen et al. (2013) report similar water use estimates for Pennsylvania and West Virginia (see Appendix Table B-5). This correspondence is not surprising, as these estimates are also based on FracFocus data (via Skytruth). For 2011, the year overlapping with the time frame of the EPA FracFocus report (U.S. EPA, 2015a), Mitchell et al. (2013a) report an average of 2.3 million gal (8.7 million L) for vertical wells (62 wells) and 4.6 million gal (17.4 million L) for horizontal wells (612 wells) in the Pennsylvania portion of the Ohio River Basin, based on records from PA DEP. The weighted average water use per well was 4.4 million gal (16.7 million L), similar to results based on the EPA FracFocus project database listed above.

Cumulative water use/consumption: In this tri-state region, highest cumulative water use for hydraulic fracturing is in northeastern Pennsylvania counties. On average, operators in Bradford County reported over 1 billion gal (3.8 billion L) used annually in 2011 and 2012 for fracturing; operators in three other counties (Susquehanna, Lycoming, and Tioga Counties) cumulatively reported 500 million gal (1.9 billion L) or more used annually (see Table 4-2). On average, hydraulic fracturing water use is 3.2% compared to 2010 total county water use for counties with disclosures in the EPA FracFocus project database in these three states (see Table 4-2 and Appendix Table B-2). Susquehanna County in Pennsylvania has the highest percentages relative to 2010 total water use (47%) and consumption (123%).

Potential for impacts: Water availability is higher in Pennsylvania, West Virginia, and Ohio than in many western states, reducing the likelihood of impacts to drinking water quantity and quality. At the county scale, water supplies appear adequate to accommodate this use (Tidwell et al., 2013) (see Text Box 4-2 and Figure 4-5a,b).

However, impacts could still occur at specific withdrawal points. In a second, multi-scale case study, EPA researchers concluded that individual streams in this region can be vulnerable to typical hydraulic fracturing water withdrawals depending on stream size, as defined by contributing basin area (U.S. EPA, 2015c) (see Text Box 4-5). They observed infrequent (in less than 1% of withdrawals) high ratios of hydraulic fracturing water consumption to stream flow (high consumption-to-stream flow events). Passby flows can reduce the frequency of high consumption-to-stream flow events, particularly in the smallest streams (U.S. EPA, 2015c).[1]

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[1] A passby flow is a prescribed, low stream flow threshold below which withdrawals are not allowed. The SRBC uses passby flows to protect streams in the Susquehanna River Basin, an area including much of eastern Pennsylvania (U.S. EPA, 2015c).

Text Box 4-5. Case Study: Impact of Water Acquisition for Hydraulic Fracturing on Local Water Availability in the Susquehanna River Basin.

The EPA (2015c) conducted a second case study analogous to that in the UCRB (see Text Box 4-4), to explore the impact of hydraulic fracturing water demand on water availability at the river basin, county, and local scales in the SRB in northeastern Pennsylvania. The study area overlies the Marcellus Shale gas reservoir. Water withdrawal impacts were quantified using a water use intensity index (see Text Box 4-4). Researchers obtained detailed site-specific data on hydraulic fracturing water usage from state and regional authorities, and estimated available water supplies using observations at USGS gage stations and empirical and hydrologic modeling.

Most water for fracturing in the SRB is self-supplied from rivers and streams with withdrawal points distributed throughout a wide geographic area. Public water systems provide a relatively small proportion of the water needed. Reuse of wastewater makes up approximately 13% to 18% of injected fluid volume on average, as reported by the EPA (2015c) for 2008 to 2011 and Hansen et al. (2013) for 2012, respectively (see Table 4-1). The Susquehanna River Basin Commission (SRBC) regulates water acquisition for hydraulic fracturing and issues permits that set limits on the volume, rate, and timing of withdrawals at individual withdrawal points; passby flow thresholds halt water withdrawals during low flows.

The EPA (2015c) demonstrated that streams can be vulnerable from typical hydraulic fracturing water withdrawals depending on their size, as defined by contributing basin area. Small streams have the potential for impacts (i.e., high water use intensity) for all or most of the year. The EPA (2015c) showed an increased likelihood of impacts in small watersheds (less than 10 mi^2). Furthermore, they showed that in the absence of passby flows, even larger watersheds (up to 600 mi^2) could be vulnerable during maximum withdrawal volumes and infrequent droughts. However, high water use intensity calculated from observed hydraulic fracturing withdrawals occurred at only a few withdrawal locations in small streams; local high water use intensity was not found at the majority of withdrawal points.

Without management of the rate and timing of withdrawals, surface water withdrawals for hydraulic fracturing have the potential to affect both water quantity and quality (Mitchell et al., 2013a). Potential effects are generally applicable, but are especially relevant in this region because surface water is the primary water source for hydraulic fracturing in Pennsylvania, West Virginia, and Ohio. Of greatest concern are small, unregulated streams, particularly under drought conditions or during seasonal low flows (U.S. EPA, 2015c; Vengosh et al., 2014; Mitchell et al., 2013a; Vidic et al., 2013; Rahm and Riha, 2012; Rolls et al., 2012; Kargbo et al., 2010; McKay and King, 2006). Surface water quality impacts may be of concern if a pollution discharge point (e.g., sewage treatment plant, agricultural runoff, or chemical spill) is immediately downstream of a hydraulic fracturing withdrawal (U.S. EPA, 2015c; NYSDEC, 2011).[1] Water quality impacts

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[1] Aside from direct surface water withdrawals, unmanaged withdrawals from public water systems can cause cross-contamination if there is a loss of pressure, allowing the backflow of pollutants from tank trucks into the distribution system. The state of Ohio has issued a fact sheet relevant to this potential concern, intended specifically for public water systems providing water to oil and gas companies (Ohio EPA, 2012a). To prevent potential cross-contamination, Ohio requires a backflow prevention device at cross-connections. For example, bulk loading stations that provide public supply water directly to tank trucks are required to have an air-gap device at the cross-connection to prevent the backflow of contaminants into the public water system (Ohio EPA, 2012a).

associated with reduced water levels may also include possible interference with the efficiency of drinking water treatment plant operations, as increased contaminant concentrations in drinking water sources may necessitate additional treatment and ultimately impact drinking water quality (Water Research Foundation, 2014; Benotti et al., 2010).[1]

Overall, there appears to be adequate surface water for hydraulic fracturing, but there is the potential for impacts to both drinking water quantity and quality, particularly in small streams, if withdrawals are not managed (U.S. EPA, 2015c).

4.5.4. North Dakota and Montana

North Dakota was fourth in the number of disclosures in the EPA FracFocus project database (5.9% of disclosures) (see Appendix Table B-5 and Figure 4-3). We combine Montana with North Dakota because both overlie the Williston Basin (which contains the Bakken play, shown in Figure 4-9), although many fewer wells are reported for Montana (see Appendix Table B-5). The Williston Basin is the only basin with significant activity reported for either state, though other basins are also present in Montana (e.g., the Powder River Basin).

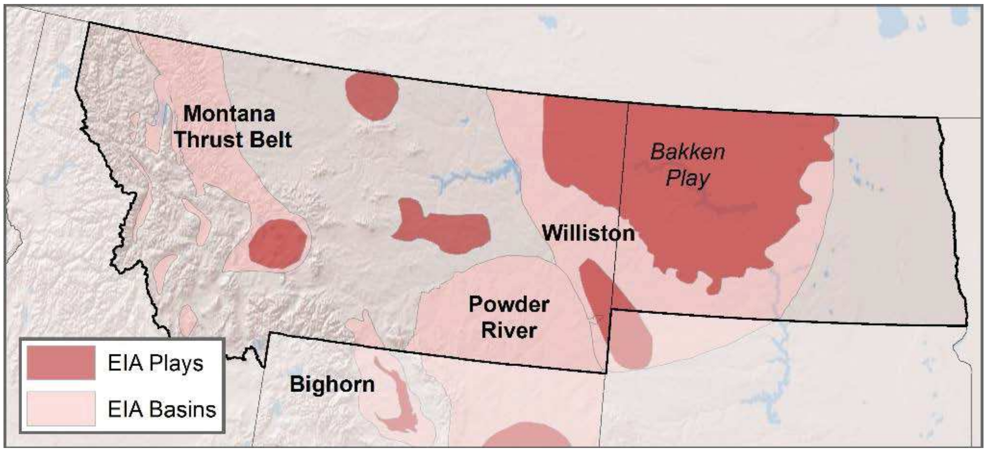

Figure 4-9. Major U.S. EIA shale plays and basins for North Dakota and Montana (EIA, 2015b).

Source: (EIA, 2015b).

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[1] For instance, an increased proportion of organic matter entering a treatment plant may increase the formation of trihalomethanes, byproducts of the disinfection process formed as chlorine react with organic matter in the water being treated (Water Research Foundation, 2014).

Types of water used: Hydraulic fracturing of the Bakken play underlying much of western North Dakota and northeastern Montana depends on both ground and surface water resources. Surface water from the Missouri River system provides the largest source of fresh water in the center of Bakken oil development (North Dakota State Water Commission, 2014; EERC, 2011, 2010; North Dakota State Water Commission, 2010). Apart from the Missouri River system, regional surface waters (i.e., small streams) do not provide a consistent supply of water for the oil industry due to seasonal stream flow variations. Sufficient stream flows generally occur only in the spring after snowmelt (EERC, 2011). Ground water from glacial and bedrock aquifer systems has traditionally supplied much of the water needed for Bakken development, but concerns over limited ground water supplies have led to limits on the number of new ground water withdrawal permits issued (Ceres, 2014; Plummer et al., 2013; EERC, 2011, 2010; North Dakota State Water Commission, 2010).

The water used for Bakken development is described as mostly fresh. The EPA FracFocus report shows that "fresh" was the only source of water listed in almost all disclosures reporting a source of water in North Dakota (U.S. EPA, 2015a).[1] Reuse of Bakken wastewater is limited due to its quality of high TDS, which presents challenges for treatment and reuse. However, the industry is researching treatment technologies for reuse of this wastewater (Ceres, 2014; EERC, 2013, 2011).

Water for hydraulic fracturing is commonly purchased from municipalities or other public water systems in the region. The water is often delivered to trucks at water depots or transported directly to well pads via pipelines (EERC, 2011).

Water Use per Well: Water use per well is intermediate compared with other areas, with a median of 2.0 and 1.6 million gal (7.6 and 6.1 million L) per well in the Williston Basin in North Dakota and Montana, respectively according to the EPA's FracFocus project database (see Appendix Table B-5). The North Dakota State Water Commission reports similar volumes (2.2 million gal (8.3 million L) per well on average for North Dakota) in a summary fact sheet (North Dakota State Water Commission, 2014).[2]

A presentation by the North Dakota Department of Mineral Resources (NDDMR) suggests that Bakken wells require an average of 600 gal (2,300 L) per day of "maintenance water" in addition to the initial water for hydraulic fracturing (North Dakota Department of Mineral Resources, 2013).[3] This extra water is reportedly needed because of the relatively high salt content of Bakken brine, potentially leading to salt buildup, pumping problems, and restriction of oil flow. According to the NDDMR, maintenance water can contribute to large additional volumes over a typical well life span (6.6−8.8 million gal (25-33 million L) over 30−40 years). It is unclear whether this phenomenon is restricted to the Bakken play.

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[1] However, 25% of North Dakota disclosures included information related to water sources (U.S. EPA, 2015a).

[2] The fact sheet is a stand-alone piece, and it is not accompanied by an underlying report.

[3] The NDDMR's presentation that mentions the issue of maintenance water was later picked up and reported on by *National Geographic* (http://news.nationalgeographic.com/news/energy/2013/11/131111-north-dakota-wells-maintenance-water/) and by Ceres (2014). Peer-reviewed studies on the Bakken also report on maintenance water (e.g., Scanlon et al., 2014), but they refer to the same original sources.

Cumulative water use/consumption: Cumulative water use for fracturing in this region is greatest in the northwestern corner of North Dakota. In counties with 2011 and 2012 disclosures to FracFocus, fracturing water use averaged approximately 123 million gal (466 million L) per county annually in the two-state area, with use in McKenzie and Williams Counties in North Dakota exceeding 500 million gal (1.9 billion L) per year (see Appendix Table B-2). There are four counties where 2011 and 2012 average hydraulic fracturing water use was 10% or more of 2010 total water use. Mountrail and Dunn Counties showed the highest percentages. Outside of North Dakota's northwest corner, the rest of the state and Montana showed little cumulative water use from hydraulic fracturing (see Table 4-2 and Appendix Table B-2).

Potential for impacts: In this region, there are concerns about over-pumping ground water resources, but the potential for impacts appears to be low provided the Missouri River is determined to be a sustainable and usable source. This finding of a low potential for impacts is also supported by the comparison of hydraulic fracturing water use to water availability at the county scale (see Text Box 4-2 and Figure 4-5a,b.) This area is primarily rural, interspersed with small towns. Residents use a mixture of surface water and ground water for domestic use depending on the county, with most water supplied by local municipalities (see Appendix Table B-6).

The state of North Dakota and the U.S. Army Corps of Engineers concluded that ground water resources in western North Dakota are not sufficient to meet the needs of the oil and gas industry (U.S. Army Corps of Engineers, 2011; North Dakota State Water Commission, 2010). All users combined currently withdraw approximately 6.2 billion gal (23.5 billion L) of water annually in an 11-county region in western North Dakota, already stressing ground water supplies (U.S. Army Corps of Engineers, 2011). By contrast, the total needs of the oil and gas industry are projected to range from approximately 2.2 and 8.8 billion gal (8.3 and 33.3 billion L) annually by the year 2020 (U.S. Army Corps of Engineers, 2011).

Due to concerns for already stressed ground water supplies, the state of North Dakota limits industrial ground water withdrawals, particularly from the Fox Hills-Hell Creek aquifer (Ceres, 2014; Plummer et al., 2013; EERC, 2011, 2010; North Dakota State Water Commission, 2010). Currently, the oil industry is the largest industrial user of water from the Fox Hills-Hell Creek aquifer in western North Dakota (North Dakota State Water Commission, 2010). Many farms, ranches, and some communities in western North Dakota rely on flowing wells from this artesian aquifer, particularly in remote areas that lack electricity for pumping; however, low recharge rates and prolonged withdrawals throughout the last century have resulted in steady declines in the formation's hydraulic pressure (North Dakota State Water Commission, 2010). Declines in hydraulic pressure do not appear to be associated with impacts to ground water quality; rather, the state is concerned with maintaining flows for users through conservation (North Dakota State Water Commission, 2010).

To reduce pressure on ground water, the state is encouraging the industry to seek surface water withdrawals from the Missouri River system, which if used, may be an adequate resource. The North Dakota State Water Commission concluded the Missouri River and its dammed reservoir, Lake Sakakawea, are the only plentiful and dependable water supplies for the oil industry in western North Dakota (North Dakota State Water Commission, 2010). In 2011, North Dakota authorized the Western Area Supply Project, by which Missouri River water (via the water treatment plant in Williston, North Dakota) will be supplied to help meet water demands, including for oil and gas development, of the state's northwest counties (WAWSA, 2011). Industrial surface water withdrawals are presently allowed in Lake Sakakawea on a temporary and controlled basis while the U.S. Army Corps of Engineers conducts a multi-year study to determine whether surplus water is available to meet the demands of regional municipal and industrial users (U.S. Army Corps of Engineers, 2011).

4.5.5. Oklahoma and Kansas

Oklahoma had the fifth most disclosures in the EPA FracFocus project database (5.0% of disclosures) (see Appendix Table B-5, and Figure 4-3). Three major basins— the Anadarko, which includes the Woodford play; the Arkoma, which includes the Fayetteville play; and the Ardmore, which includes the Woodford play—contain 67% of the disclosures in Oklahoma (see Figure 4-9 and Appendix Table B-5). Few wells were reported for Kansas (Kansas disclosures comprise 0.4% of the EPA FracFocus project database), but because of the shared geology of the Cherokee Platform across the two states, we group Kansas with Oklahoma. Oklahoma and Kansas were two of the three states where a large fraction of wells were not associated with a basin defined by the U.S. EIA (U.S. EPA, 2015b) (see Appendix Table B-5).[1]

Types of water used: Water for hydraulic fracturing in Oklahoma and Kansas comes from both surface and ground water (Kansas Water Office, 2014; Taylor, 2012). Data on temporary water use permits in Oklahoma (which make up the majority of water use permits for Oklahoma oil and gas mining) show that, in 2011, approximately 63% and 37% of water for hydraulic fracturing came from surface and ground water, respectively (Taylor, 2012) (see Table 4-3). General water use in Oklahoma follows an east-west divide, with the eastern half dependent on surface sources and the western half relying heavily on ground water (OWRB, 2014). Water obtained for fracturing is assumed to fit this pattern as well. No data are available on the proportion of hydraulic fracturing water that is sourced from surface versus ground water resources in Kansas.

For both Oklahoma and Kansas, no data are available to describe the extent to which reused wastewater is used as a percentage of total injected volume. However, the quality of Oklahoma's Woodford Shale wastewater has been described as low in TDS, and thus reuse could reduce the demand for fresh water (Kuthnert et al., 2012).

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[1] Alaska was the other state in the EPA FracFocus project database where the U.S. EIA shale basins did not adequately describe well locations, with all 37 wells in Alaska not associated with a U.S. EIA basin. For all other states, U.S. EIA shale basins captured 86%–100% of the wells in the EPA FracFocus project database (U.S. EPA, 2015b).

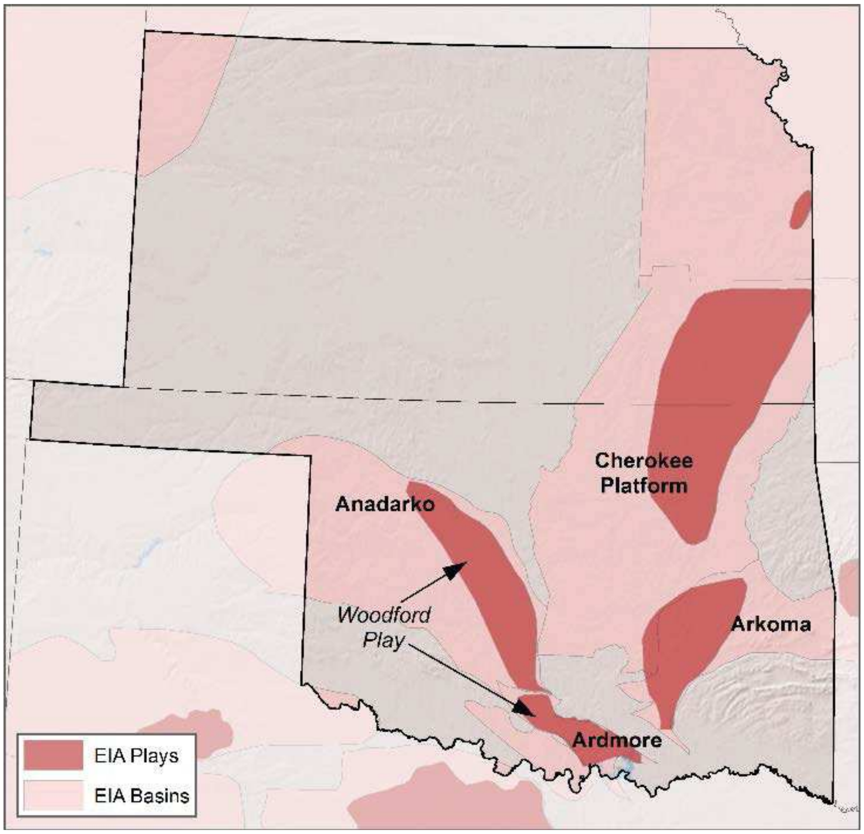

Figure 4-10. Major U.S. EIA shale plays and basins for Oklahoma and Kansas (EIA, 2015).

Source: (EIA, 2015b)

Water Use per Well: State-level estimates of median water use per well in Oklahoma include 2.6 million gal (9.8 million L) and 3 million gal (11 million L) [U.S. EPA (2015b) and, Murray (2013), respectively]. Water use for hydraulic fracturing increased from 2000 to 2011, driven by volumes required for fracturing horizontal wells across the state (Murray, 2013). Within the state there are wide ranges in water use for different formations. According to the EPA FracFocus project database, the Ardmore and Arkoma Basins of Oklahoma, had the highest median water use in the country, with medians of 8.0 and 6.7 million gal (30.3 and 25.4 million L) per well, respectively; whereas the Anadarko Basin had lower median water use per well and higher disclosure counts (3.3 million gal (12.5 million L), 935 disclosures) (see Appendix Table B-5). Wells not associated with a U.S. EIA basin had a median of 1.9 million gal (7.2 million L) per well (592 disclosures) (see Appendix Table B-5). It is not clear why lower water volumes were reportedly used in unassociated wells, but Oklahoma has several CBM deposits in the eastern part of the state where very low water use has been reported (Murray, 2013). Median water use per well in Kansas was 1.5 million gal (5.7 million L), focused mostly in a five-county area in the south-central and southwest portions of the state (see Appendix Table B-5).

Cumulative water use/consumption: Cumulatively, operators reported using an average of 71.9 million gal (272.2 million L) of water annually in Oklahoma counties with disclosures; in

Kansas, this value is only 3.5 million gal (13.2 million L) (see Appendix Table B-2). Average hydraulic fracturing water use in 2011 and 2012 did not exceed 10% of 2010 total water use in any county in Oklahoma or Kansas (see Appendix Table B-2). However, there were six counties in Oklahoma (Alfalfa, Canadian, Coal, Pittsburg, Rogers Mills, and Woods) where fracturing water consumption exceeded 10% of 2010 total county water consumption.

Potential for impacts: The potential for effects on drinking water resources appears to be low in Oklahoma and Kansas, since hydraulic fracturing water use and consumption are generally low as a percentage of total water use and consumption. This finding is generally supported by the comparison of cumulative fracturing water use to water availability at the county scale (see Text Box 4-2 and Figure 4-5a,b). If impacts to water quantity or quality do occur, however, they are more likely to happen in western Oklahoma than in the eastern half of the state or Kansas. Of the six Oklahoma counties where fracturing consumption exceeded 10% of 2010 water consumption, three (Alfalfa, Canadian, and Roger Mills) are in the western half of the state where surface water availability is lowest (Figure 4-6a). Surface water is fully allocated in the Panhandle and West Central regions, encompassing much of the state's northwestern quadrant (OWRB, 2014). As a result, residents generally rely on ground water in western Oklahoma (see Appendix Table B-6), and it is likely that fracturing does as well.

Projecting out to 2060, Oklahoma's Water Plan concludes that aquifer storage depletions are likely in the Panhandle and West Central regions due to over-pumping, particularly for irrigation (OWRB, 2014). Ground water depletions are anticipated to be small relative to storage, but will be the largest in summer months and may lead to higher pumping costs, the need for deeper wells, lower water yields, and detrimental effects on water quality (OWRB, 2014). Drought conditions are likely to exacerbate this problem, and Oklahoma's Water Plan specifically mentions the potential for climate change to affect future water supplies in the state (OWRB, 2014). In the adjacent Texas Panhandle, future irrigation needs may go unmet (TWDB, 2012), and this may be the case in western Oklahoma as well.

Aquifer depletions in western Oklahoma may be associated with ground water quality degradation, particularly under drought conditions. The central portion of the Ogallala aquifer underlying the Oklahoma Panhandle and western Oklahoma contains elevated levels of some constituents (e.g., nitrate) due to over-pumping, although generally it is of better quality than the southern portion of the aquifer (USGS, 2009). Additional ground water withdrawals for hydraulic fracturing in western Oklahoma may add to these water quality issues, particularly in combination with other substantial water uses (e.g., irrigation) (USGS, 2009).

4.5.6. Arkansas and Louisiana

Arkansas and Louisiana were ranked seventh and tenth in the number of disclosures in the EPA FracFocus project database, respectively (see Appendix Table B-5). Hydraulic fracturing activity in Louisiana occurs primarily in the TX-LA-MS Salt Basin, which contains the Haynesville play; activity in Arkansas is dominated by the Arkoma Basin, which contains the Fayetteville play (Figure 4-11).

Types of water used: Surface water is reported as the primary source of water for hydraulic fracturing operations in both Arkansas and Louisiana (ANRC, 2014; LA Ground Water Resources Commission, 2012; STRONGER, 2012). Quantitative information is lacking for Arkansas on the proportion of water sourced from surface versus ground water. However, data are available for Louisiana, where an estimated 87% of water for hydraulic fracturing in the Haynesville Shale is sourced from surface water (LA Ground Water Resources Commission, 2012) (see Table 4-3). In 2008, during the early stages of development, hydraulic fracturing in Louisiana relied heavily on ground water from the Carrizo-Wilcox aquifer, although concerns for the sustainability of ground water resources have more recently prompted the state to encourage surface water withdrawals (LA Ground Water Resources Commission, 2012).

The EPA FracFocus report suggests that significant reuse of wastewater may occur in Arkansas to offset total fresh water used for hydraulic fracturing; 70% of all disclosures reporting a water source indicated a blend of “recycled/surface,” whereas only 3% of disclosures reporting a water source noted “fresh” as the exclusive water source (U.S. EPA, 2015a).[1] According to Veil (2011), Arkansas’ Fayetteville Shale wastewater is of relatively good quality (i.e., low TDS), potentially facilitating reuse. Data are generally lacking on the extent to which hydraulic fracturing wastewater is reused to offset total fresh water use in Louisiana.

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[1] 93% of Arkansas disclosures included information related to water sources (U.S. EPA, 2015a).

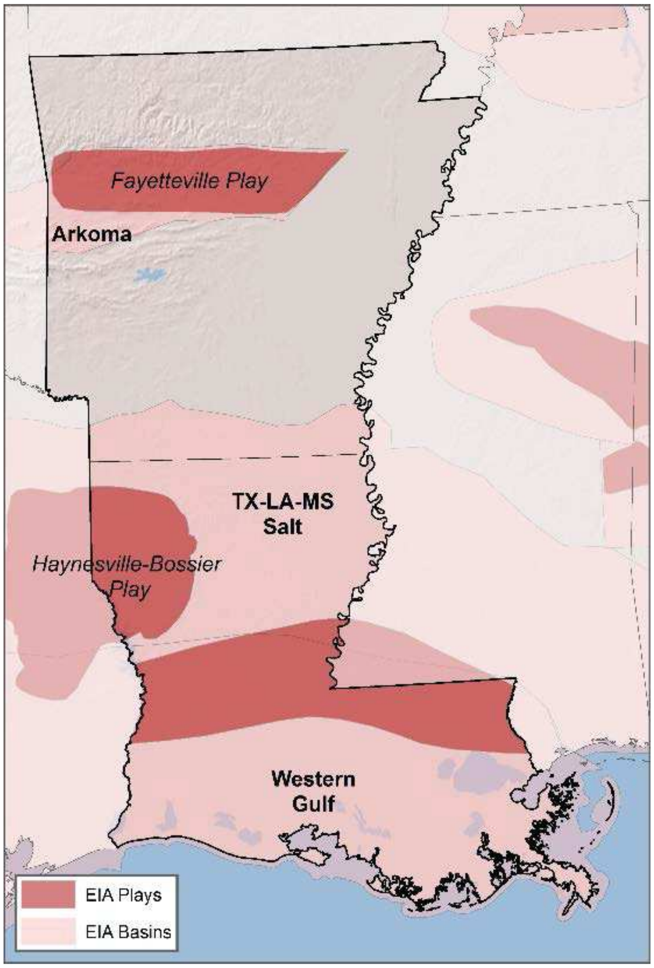

Figure 4-11. Major U.S. EIA shale plays and basins for Arkansas and Louisiana (EIA, 2015b).

Source: (EIA, 2015b).

Water Use per Well: Arkansas and Louisiana have the highest median water use per well in the nation, at 5.3 million and 5.1 million gal (20.1 million and 19.3 million L), respectively based on the EPA FracFocus project database (see Appendix Table B-5).[1]

Cumulative water use/consumption: On average, hydraulic fracturing operations cumulatively use 408 million gal (1.54 billion L) of water each year in Arkansas counties reporting activity, or 9.3% of 2010 total county water use (26.9% of total county consumption) (see Appendix Table B-2). In 2011 and 2012, five counties dominated fracturing water use in Arkansas: Cleburne, Conway, Faulkner, Van Buren, and White Counties (see Appendix Table B-2). Van Buren, which is sparsely populated and thus has relatively low total water use and consumption, is by far the county highest

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[1] According to STRONGER (2012) and STRONGER (2011a), both states require disclosure of information on water use per well, but this has not been synthesized into state level reports.

in hydraulic fracturing water use and consumption relative to 2010 total water use and consumption (56% and 168%, respectively) (see Table 4-2).

In Louisiana, fracturing water use is concentrated in six parishes in the far northwestern corner of the state, associated with the Haynesville play.[1] On average in 2011 and 2012, hydraulic fracturing used 117 million gal (443 million L) of water annually per parish, representing approximately 3.6% and 10.8% of 2010 total water use and consumption, respectively (see Appendix Table B-2). Operators in De Soto Parish used the most water (over 1 billion gal (3.8 billion L) annually). Fracturing water use and consumption was highest relative to 2010 total water use and consumption (35.5% and 83.2%, respectively) in Red River Parish (see Table 4-2). These numbers may be low estimates since Louisiana required disclosures to the state or FracFocus and Arkansas required disclosures to the state, but not FracFocus, during the time period analyzed (U.S. EPA, 2015a) (see Appendix Table B-5).

Potential for impacts: Water availability is generally higher in Arkansas and Louisiana than in states farther west, reducing the potential for impacts to drinking water quantity and quality (Figure 4-6a, Text Box 4-2, and Figure 4-5). There are, however, concerns about over-pumping of ground water resources in northwestern Louisiana. Prior to 2008, most operators in the Louisiana portion of the Haynesville Shale used ground water, withdrawing from the Carrizo-Wilcox, Upland Terrace, and Red River Alluvial aquifer systems (LA Ground Water Resources Commission, 2012). To mitigate stress on ground water, the state issued a water use advisory to the oil and gas industry that recommended Haynesville Shale operators seek alternative water sources to the Carrizo-Wilcox aquifer, which is predominantly used for public supply (LDEQ, 2008). Operators then transitioned to mostly surface water, with a smaller ground water component (approximately 12% of all fracturing water used) (LA Ground Water Resources Commission, 2012). Of this ground water component, the majority (approximately 74%) still came from the Carrizo-Wilcox aquifer (LA Ground Water Resources Commission, 2012).

Although the potential for hydraulic fracturing withdrawals to affect water supplies and water quality in the aquifer appears greatly reduced, it is not entirely eliminated. Despite Louisiana's water use advisory, a combination of drought conditions and higher than normal withdrawals (for all uses, not solely hydraulic fracturing) from the Carrizo-Wilcox and Upland Terrace aquifers caused several water wells to go dry in July 2011. In August 2011, a ground water emergency was declared for southern Caddo Parrish (LA Ground Water Resources Commission, 2012). There are hydraulic fracturing wells in southern Caddo Parrish (U.S. EPA, 2015b), and so it is possible that fracturing withdrawals contributed to the problem of declines in ground water in this instance.

4.5.7. Utah, New Mexico, and California

Together, Utah, New Mexico, and California accounted for approximately 9% of disclosures in the EPA FracFocus project database (3.8%, 3.1% and 1.9% of disclosures, respectively) (see Appendix Table B-5 and Figure 4-3). Almost all reported hydraulic fracturing in Utah and California were in

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[1] Louisiana is divided into parishes, which are similar to counties in other states.

the Uinta-Piceance Basin (99%) and San Joaquin Basin (95%), respectively. Activity in New Mexico mostly occurs in the Permian and San Juan Basins, which together comprised 96% of reported disclosures in that state (see Figure 4-12).

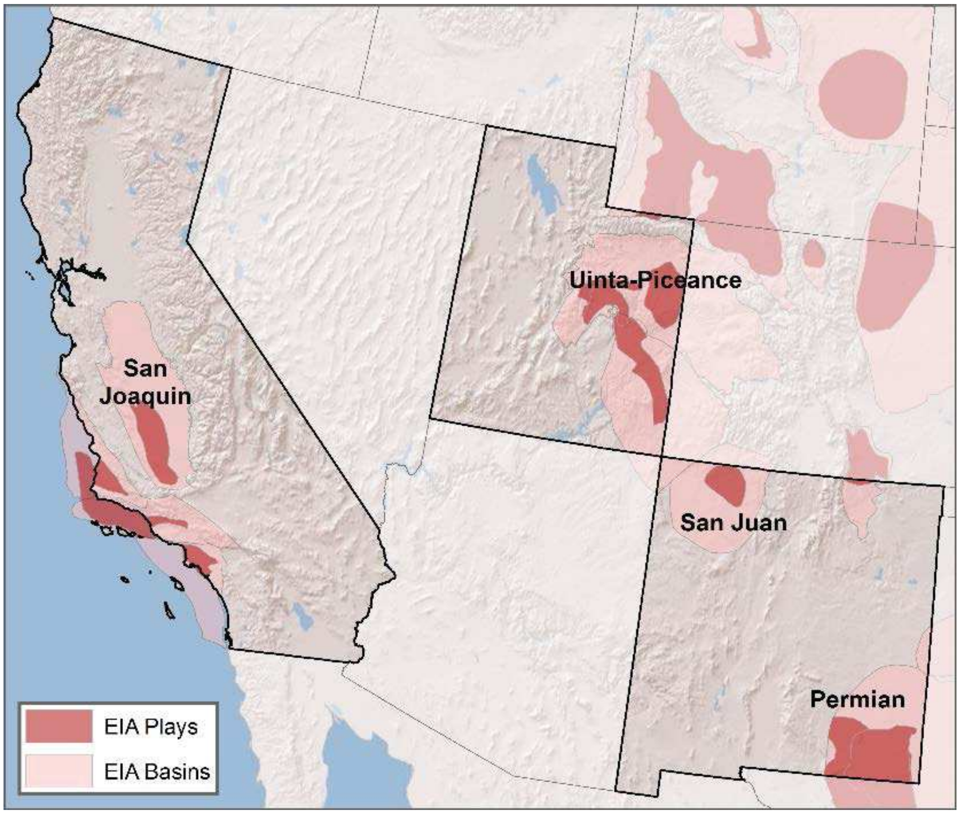

Figure 4-12. Major U.S. EIA shale plays and basins for Utah, New Mexico, and California (EIA, 2015).

Source: (EIA, 2015b).

Types of water used: Of these three states, California has the most information available on the sources of water used for hydraulic fracturing. Most current and proposed fracturing activity is focused in Kern County in the San Joaquin Basin, where well stimulation notices indicate that operators depend mainly on surface water purchased from nearby irrigation districts (CCST, 2014). California irrigation districts receive water allocated by the State Water Project, and deliveries may be restricted or eliminated during drought years (CCST, 2014).[1] In addition to publicly-supplied surface water, operators also may self-supply a smaller proportion of water from on-site ground water wells (CCST, 2014). Operators use primarily fresh water for hydraulic fracturing (96% of well

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[1] The California State Water Project is water storage and distribution system maintained by the California Department of Water Resources, which provides water for urban and agricultural water suppliers in Northern California, the San Francisco Bay Area, the San Joaquin Valley, the Central Coast, and Southern California (California Department of Water Resources, 2015).

stimulation notices reported); reused wastewater (sometimes blended with fresh water) is used in small amounts relative to total water use (4% of well stimulation notices reported) (CCST, 2014) (see Table 4-1).

The source, quality, and provisioning of water used for hydraulic fracturing in Utah and New Mexico are not well characterized. The 2010 New Mexico water use report summarizes withdrawals for a variety of water use categories. In 2010, mining water use (which includes water used for oil and gas production) consisted of 26% and 74% of surface and ground water withdrawals, respectively (NM OSE, 2013). Assuming that hydraulic fracturing follows the same pattern as other mining water uses (e.g., for metals, coal, geothermal), water for hydraulic fracturing in New Mexico would be supplied primarily by ground water withdrawals. To our knowledge, no data are available to characterize the source of water for hydraulic fracturing operations in Utah. In addition, no data are available to describe the extent to which reused wastewater is used as a proportion of total water injected for either Utah or New Mexico.

Water use per well: Median water use per well in Utah, New Mexico, and California is lower than in other states in the EPA FracFocus project database: Utah ranks 13th (approximately 302,000 gal (1.14 million L)), New Mexico ranks 14th (approximately 175,000 gal (662,000 L)), and California ranks 15th (approximately 77,000 gal (291,000 L)) out of the 15 states (see Appendix Table B-5). A likely explanation for the low water use per well in Utah and New Mexico is the prevalence of CBM in the Uinta (Utah) and San Juan (New Mexico) Basins. Low water use per well in California is attributed to the prevalence of vertical wells and the use of crosslinked gels. Vertical wells dominate because the complex geology precludes long horizontal drilling and fracturing (CCST, 2014).

For California, the California Council on Science and Technology (CCST) reports average water use per well of 130,000 gal (490,000 L), which agrees with the state average of approximately 131,700 gal (498,500 L) according to the EPA FracFocus project database (CCST, 2014) (see Appendix Table B-5); this is expected because estimates from CCST are also based on data submitted to FracFocus.

Cumulative water use/consumption: Operators in Utah, New Mexico, and California report using low cumulative amounts of water compared to most other states (see Appendix Table B-1). Only four counties (Duchesne and Uintah Counties in Utah, and Eddy and Lea Counties in New Mexico) required more than 50 million gal (189 million L) annually (see Appendix Table B-2). Fracturing water use and consumption did not exceed 1% of 2010 total water use and consumption in any county.

Potential for impacts: The potential for water quantity and quality impacts from hydraulic fracturing water withdrawals in Utah, New Mexico, and California appears to be low at present (see Text Box 4-2 and Figure 4-5a,b). Hydraulic fracturing does not use or consume much water compared to other users or consumers in these states. As in other states, this does not preclude sub-county effects, and this finding of low potential for impacts could change if fracturing activities increase beyond present levels. This is particularly the case because these states generally have low surface water availability (see Figure 4-6a) and high ground water dependence (see Figure 4-6b),

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and have experienced frequent periods of drought over the last decade (National Drought Mitigation Center, 2015).

4.6. Chapter Synthesis

In this chapter we examine the potential for water acquisition for hydraulic fracturing to affect drinking water quantity and quality. The potential for impacts largely depends on water use, consumption, and availability. Water management—in terms of the type of water used, the timing or location of water withdrawals, or other factors—also can play a role. Because all of these factors vary considerably from place-to-place, any impacts that occur will be location-specific and occur at the spatial scale of the specific drinking water resource (i.e., the particular stream, watershed, or local ground water aquifer). Therefore, it is important to consider the potential for hydraulic fracturing impacts by location.

We examine the potential for impacts by considering (1) the types of water used for hydraulic fracturing; (2) the amounts of water used per well; (3) cumulative estimates of water used and consumed for hydraulic fracturing; and (4) a state-by-state assessment of the potential for impacts based on water use, consumption, and availability. We often could not assess the potential for impacts at a finer resolution than the county scale due to lack of available local-scale data for most areas. Thus, our assessment suggests areas that are more likely than others to experience impacts, but does not necessarily indicate that these impacts will occur. Three case studies (southern Texas, western Colorado, and eastern Pennsylvania), provide an in-depth examination at finer scales, and we rely on those where possible (see Text Boxes 4-3, 4-4, and 4-5).

4.6.1. Major Findings

Water for hydraulic fracturing typically comes from surface water, ground water, or reused wastewater. Because trucking can be a major expense, operators often use water sources as close to well pads as possible. Operators usually self-supply surface or ground water directly, but also may obtain water secondarily through public water systems or other suppliers. Hydraulic fracturing operations in the eastern United States generally rely on surface water, whereas operations in more semi-arid to arid western states use mixed surface and ground water supplies. In areas that lack available surface water (e.g., western Texas), ground water supplies most of the water needed for fracturing unless alternative sources, such as reused wastewater, are available and utilized.

The vast majority of water used for hydraulic fracturing nationally comes from fresh water sources, although some operators also use lower-quality water (e.g., hydraulic fracturing wastewater, brackish ground water, or small proportions of acid mine drainage and wastewater treatment plant effluent). The use of non-fresh sources can reduce competition for current drinking water resources. Nationally, the proportion of reused wastewater is generally low as a percentage of injected volume; based on available data, the median reuse of wastewater as a percentage of injected volume is 5% nationally, but this percentage varies by location (see Table 4-1).[1] Available

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[1] Note that reused water as a percentage of total water injected differs from the percentage of wastewater that is reused (see Section 4.2 and Chapter 8).

data on reuse trends indicate increasing reuse of wastewater over time in both Pennsylvania and West Virginia, likely due to the lack of nearby disposal options. Reuse as a percentage of water injected appears to be low in other areas, likely in part because of the relatively high availability of disposal wells (see Chapter 8).

The median amount of water used per hydraulically fractured well, based on national disclosures to FracFocus, is approximately 1.5 million gal (5.7 million L) of water (U.S. EPA, 2015a, b). This estimate represents a variety of fractured well types, including types that use much less water per well than horizontal shale gas wells. Thus, published estimates for horizontal shale gas wells are typically higher (e.g., approximately 4 million gal (15 million L) per well (Vengosh et al., 2014)). There is also wide variation within and among states and basins in the median water volumes reported per disclosure, from more than 5 million gal (19 million L) in Arkansas and Louisiana to less than 1 million gal (3.8 million L) in Colorado, Wyoming, Utah, New Mexico, and California (U.S. EPA, 2015b). This variation results from several factors, including well length, formation geology, and fracturing fluid formulation (see Section 4.3.3).

Cumulatively, hydraulic fracturing uses billions of gallons of water every year at the national and state scales, and even in some counties. When expressed as a percentage compared to total water use or consumption at these scales, however, hydraulic fracturing water use and consumption is most often a small percentage, generally less than 1%. This percentage may be higher in specific areas. Annual hydraulic fracturing water use was 10% or more compared to 2010 total water use in 6.5% of counties with FracFocus disclosures in 2011 and 2012, 30% or more in 2.2% of counties, and 50% or more in 1.0% of counties (U.S. EPA, 2015a). Consumption estimates follow the same general pattern, but with slightly higher percentages in each category. In these counties, hydraulic fracturing represents a relatively large user and consumer of water.

High hydraulic fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources. Rather, the potential for impacts depends on both water use or consumption and water availability at a given withdrawal point. Our state-by-state assessment examines the intersection between water use or consumption and availability at the county scale. This approach suggests where the potential for impacts exists, but does not indicate where impacts will occur at the local scale. Where possible, we use local-scale case studies in Texas, Pennsylvania, and Colorado to provide details at finer spatial scales.

In our survey of the published literature, we did not find a case where hydraulic fracturing water use by itself caused a drinking water well or stream to run dry. This could indicate an absence of hydraulic fracturing effects on water availability; alternatively, it could reflect that these events are not typically documented in the types of literature we reviewed. Water availability is rarely impacted by just one use or factor alone. For example, drinking water wells in an area overlapping with the Haynesville Shale in northwest Louisiana ran out of water in 2011, due to higher than normal withdrawals and drought (LA Ground Water Resources Commission, 2012). Hydraulic fracturing water use in the area may have contributed to these conditions, along with other water uses and the lack of precipitation. Other impacts to drinking water quantity or quality (e.g., declining aquifer levels, decreased stream flow, increased pollutant concentrations) also may occur before wells and streams actually go dry.

The potential for impacts due to hydraulic fracturing water withdrawals is highest in areas with relatively high fracturing water use and low water availability. Southern and western Texas are two locations where hydraulic fracturing water use combined with low water availability, drought, and reliance on declining ground water sources has the potential to affect the quantity and quality of drinking water resources. Fracturing withdrawals combined with other intensive uses, particularly irrigation, could contribute to ground water quality degradation. Any impacts are likely to be realized locally within these areas. In a detailed case study of southern Texas, Scanlon et al. (2014) observed generally adequate water supplies for hydraulic fracturing, except in specific locations. They found excessive drawdown of local ground water in a small proportion (~6% of the area) of the Eagle Ford play. They suggested water management, particularly a shift towards brackish water use, could minimize potential future impacts to fresh water resources (see Text Box 4-3). County-level data confirm that high brackish water availability in Texas may help offset hydraulic fracturing water demand (see Text Box 4-2).

Comparatively, the potential for hydraulic fracturing water acquisition impacts to drinking water quantity and quality appears to be lower—but not entirely eliminated—in other areas of the United States. Detailed case studies in western Colorado and northeastern Pennsylvania did not show impacts, despite indicating that streams could be vulnerable to water withdrawals from hydraulic fracturing (U.S. EPA, 2015c). High wastewater reuse rates in western Colorado eliminated the need for more fresh water withdrawals. In northeast Pennsylvania, water withdrawals for hydraulic fracturing could result in high water consumption-to-stream flow events, but water management (e.g., passby flows) limited the potential for impacts, especially on small streams (U.S. EPA, 2015c). In western North Dakota, ground water is limited, but the industry may have sufficient supplies of surface water from the Missouri River system. These location-specific examples emphasize the need to focus on regional and local dynamics when considering the potential impacts of hydraulic fracturing water acquisition on drinking water resources.

4.6.2. Factors Affecting Frequency or Severity of Impacts

The potential for hydraulic fracturing water use to affect drinking water resource quantity or quality depends primarily on the amount of water used or consumed versus water availability at a given withdrawal point. Potential impacts to drinking water resources reflect all uses, including hydraulic fracturing demands, compared to available water. Areas with high water use, low water availability, slowly replenishing sources, and/or episodic water shortages (e.g., seasonal or longer-term droughts) are more vulnerable to potential impacts. Areas with high water availability relative to existing uses, high rainfall distributed throughout the year, or high storage capacity, are less likely to be affected.

Water management can alter this dynamic between water use and availability. The type of water used (e.g., fresh, brackish, reused hydraulic fracturing wastewater, other wastewaters) is a major factor that can either increase or decrease the potential for impacts. Replacing a fresh water source with another type of water can reduce the demand for fresh water and decrease potential competition for drinking water. Brackish ground water use may reduce the demand for fresh water and decrease competition for drinking water currently, but this may change if desalinization for drinking water becomes more prevalent in the future (see Chapter 3).

The timing and location of water withdrawals can also affect the potential for impacts, particularly for surface water withdrawals. Withdrawing water from small streams is more likely to result in a high-consumption-to-stream flow event than removing water from larger streams (U.S. EPA, 2015c). Withdrawals during periods of low stream flow are also more likely to result in impacts than withdrawals during high flow periods. Hydraulic fracturing operations may have the ability to withdraw water during periods of high stream flow, and store it for future use during drier periods.

4.6.3. Uncertainties

There are several uncertainties inherent in our assessment of hydraulic fracturing water use and potential effects on drinking water quantity and quality. The largest uncertainties stem from the lack of literature and data on this subject at local scales, and the question of whether any impacts would be documented in the types of literature we reviewed.

We used a state-by-state approach to identify areas where potential impacts are likely, based on relatively high fracturing water use and low water availability. Typically, only data at the county-scale were available. Because impacts occur at smaller spatial scales (i.e., at water withdrawal sites), our assessment suggests the potential for impacts, but does not indicate whether impacts will occur. In only a few places could we use local case studies to determine if potential impacts were realized; these case studies show that local factors can greatly affect whether drinking water resources are impacted.

In our survey of the published literature, we did not find a case where hydraulic fracturing water use alone caused a drinking water well or stream to run dry. This could indicate an absence of hydraulic fracturing effects on water availability, or it could reflect that these events are not typically documented in the types of literature we reviewed. Water availability is rarely impacted by just one use or factor alone. These issues may have limited our findings.

Other uncertainties arise from data limitations regarding the volume and types of water used or consumed for hydraulic fracturing, future water use projections, and water availability estimates. There are no nationally consistent data sources, and therefore water use estimates must be based on multiple, individual pieces of information. For example, in their National Water Census, the USGS includes hydraulic fracturing in the broader category of “mining” water use, but hydraulic fracturing water use is not reported separately (Maupin et al., 2014). There are locations where annual average hydraulic fracturing water use in 2011 and 2012 exceeded total mining water use in 2010, and one county where it exceeded all water use (U.S. EPA, 2015b; Maupin et al., 2014). This could be due to a rapid increase in hydraulic fracturing water use, differences in methodology between the two databases (i.e., the USGS 2010 National Water Census and the EPA FracFocus project database), or both.

The EPA FracFocus project database represents the most extensive database currently available to estimate hydraulic fracturing water use. However, estimates based on the project database form an incomplete picture of hydraulic fracturing water use because most states with data in the project database did not require disclosure to FracFocus during the time period analyzed (U.S. EPA, 2015a) (see Text Box 4-1). We conclude that this likely does not change the overall hydraulic fracturing water use patterns observed across the United States, but could affect our assessment of the potential impacts in specific locations.

Hydraulic fracturing water use data are often provided in terms of water use per well. While this is valuable information, the potential impacts of water acquisition for hydraulic fracturing could be better assessed if data were also available at the withdrawal point. If the total volume, date, and location of each water withdrawal were documented, the quality of the water used and potential effects on availability could be better estimated. For example, surface withdrawal points could be aggregated by watershed to estimate effects on downstream flow. Alternatively, if the location and depth of ground water pumping were documented, these could be aggregated to assess effects on a given aquifer. Some of this information is available in disparate forms, but the lack of nationally consistent data on water withdrawal locations, timing, and amounts—data that are publicly available, easy to access, and easy to analyze—limits our assessment of hydraulic fracturing water use.

Future hydraulic fracturing water use is also a source of uncertainty. Because water withdrawals and potential impacts are concentrated in certain localized areas, water use projections need to match this scale. Projections are available for Texas at the county scale, but more information at the county or sub-county scale is needed in other states with high hydraulic fracturing activity and water availability concerns (e.g., northwest North Dakota, eastern Colorado). Due to a lack of data, we generally could not assess future cumulative water use and the potential for impacts in most areas of the country, nor could we examine these in combination with other relevant factors (e.g., climate change, population growth).

4.6.4. Conclusions

Water acquisition for hydraulic fracturing has the potential to impact drinking water resources by affecting drinking water quantity and quality (see Text Box 4-6). In our survey of the published literature, we did not find a case where hydraulic fracturing water use by itself caused a drinking water well or stream to run dry. However, the potential for impacts to drinking water quantity and quality exists and is highest in areas with relatively high fracturing water use and low water availability. Southern and western Texas are two locations where the potential appears highest due to the combined effects of high hydraulic fracturing activity, low water availability, drought, and reliance on declining ground water sources. Even in locations where water is generally plentiful, localized impacts can still occur in certain instances. Excessive ground water pumping can cause localized drawdowns; surface water withdrawals can affect stream flow, particularly in smaller streams or during low flow periods. These findings emphasize the need to focus on regional and local dynamics when examining potential impacts of hydraulic fracturing water acquisition on drinking water quantity and quality.

Text Box 4-6. Research Questions Revisited.

What are the types of water used for hydraulic fracturing?

- Water for hydraulic fracturing typically comes from surface, ground water, or reused wastewater. Operators often use water sources as close to well pads as possible as trucking is a major expense. Operators usually self-supply surface or ground water directly, but also may obtain water secondarily through public water systems or other suppliers. Hydraulic fracturing operations in the eastern United States generally rely on surface water, whereas operations in more semi-arid to arid western states use mixed surface and ground water supplies. In areas that lack available surface water (e.g., western Texas), ground water supplies most of the water needed for fracturing unless alternative sources, such as reused wastewater, are available and utilized.
- The vast majority of water used nationally comes from fresh water sources, although some operators also use lower-quality water (e.g., hydraulic fracturing wastewater, brackish ground water, or small proportions of acid mine drainage and wastewater treatment plant effluent). The use of non-fresh sources can reduce competition for current drinking water resources. Nationally, the proportion of reused wastewater is generally low as a percentage of injected volume; based on available data, median reuse of wastewater across all basins and plays is 5% of injected volume (see Table 4-1). Available data on reuse trends indicate increasing reuse of wastewater over time in both Pennsylvania and West Virginia, likely due to the lack of nearby disposal options. Reuse as a percentage of water injected appears to be low in other areas, likely in part because of the relatively high availability of disposal wells (see Chapter 8).

How much water is used per well?

- The median amount of water used per hydraulically fractured well, based on national disclosures to FracFocus, is approximately 1.5 million gal (5.7 million L) of water (U.S. EPA, 2015a, b). This estimate represents a variety of fractured well types. There is also wide variation within and among states and basins in the median water volumes reported per disclosure, from more than 5 million gal (19 million L) in Arkansas and Louisiana to less than 1 million gal (3.8 million L) in Colorado, Wyoming, Utah, New Mexico, and California (U.S. EPA, 2015b). This variation results from several factors, including well length, formation geology, and fracturing fluid formulation (see Section 4.3.3).
- Trends indicate that water use per well is increasing in certain locations as horizontal well lengths increase. This may not, however, increase water use per unit energy extracted.

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

- Cumulatively, hydraulic fracturing uses billions of gallons of water every year at the national and state scales, and even in some counties. When expressed as a percentage compared to total water use or consumption at these scales, however, hydraulic fracturing water use and consumption is most often a small percentage, generally less than 1%. This percentage may be higher in specific areas. Annual hydraulic fracturing water use was 10% or more compared to 2010 total water use in 6.5% of counties with FracFocus disclosures in 2011 and 2012, 30% or more in 2.2% of counties, and 50% or more in 1.0% of counties (U.S. EPA, 2015a). Consumption estimates follow the same general pattern, but with slightly higher percentages in each category. In these counties, hydraulic fracturing represents a relatively large user and consumer of water.
- High hydraulic fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources. Rather, the potential for impacts depends on both water use or consumption and water availability at a given withdrawal point. Our state-by-state assessment examines the intersection between water use or consumption and availability at the county scale. This approach suggests where the potential for impacts exists, but does not indicate where impacts will occur at the local scale. Local-scale case studies help provide details at finer spatial scales.
- In our survey of the published literature, we did not find a case where hydraulic fracturing water use by itself caused a drinking water well or stream to run dry. This could indicate an absence of hydraulic fracturing effects on water availability, or it could reflect that these events are not typically documented in the types of literature we reviewed. Water availability is rarely impacted by just one use or factor alone. For example, drinking water wells in an area overlapping with the Haynesville Shale in northwest Louisiana ran out of water in 2011, due to higher than normal withdrawals and drought (LA Ground Water Resources Commission, 2012). Hydraulic fracturing water use in the area may have contributed to these conditions, along with other water uses and the lack of precipitation. Other impacts to drinking water quantity or quality (e.g., declining aquifer levels, decreased stream flow, increased pollutant concentrations) also may occur before wells and streams actually go dry.
- The potential for impacts due to hydraulic fracturing water withdrawals is highest in areas with relatively high fracturing water use and low water availability. Southern and western Texas are two locations where hydraulic fracturing water use combined with low water availability, drought, and reliance on declining ground water sources has the potential to affect the quantity of drinking water resources. Any impacts are likely to be realized locally within these areas. In a detailed case study of southern Texas, Scanlon et al. (2014) observed generally adequate water supplies for hydraulic fracturing, except in specific locations. They found excessive drawdown of local ground water in a small proportion (~6% of the area) of the Eagle Ford play. They suggested water management, particularly a shift towards brackish water use, could minimize potential future impacts to fresh water resources (see Text Box 4-3). County-level data confirm that high brackish water availability in Texas may help offset hydraulic fracturing water demand (see Text Box 4-2).
- The potential for hydraulic fracturing water acquisition impacts to drinking water quantity and quality appears to be lower—but not entirely eliminated—in other areas of the United States. Detailed case studies in western Colorado and northeastern Pennsylvania did not show impacts, despite indicating that streams could be vulnerable to water withdrawals from hydraulic fracturing (U.S. EPA, 2015c). High wastewater reuse rates in western Colorado eliminated the need for more fresh water withdrawals. In northeast Pennsylvania, water withdrawals for hydraulic fracturing could result in high water consumption-to-stream flow events, but water management (e.g., passby flows) limited the potential for impacts, especially on small streams (U.S. EPA, 2015c). In western North Dakota, ground water is limited, but the industry may have sufficient supplies of surface water from the Missouri River system. These

location-specific examples emphasize the need to focus on regional and local dynamics when considering the potential impacts of hydraulic fracturing water acquisition on drinking water resources.

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

- Water withdrawals for hydraulic fracturing, similar to all water withdrawals, have the potential to alter the quality of drinking water resources. Ground water withdrawals exceeding natural recharge rates decrease water storage in aquifers, potentially mobilizing contaminants or allowing the infiltration of lower-quality water from the land surface or adjacent formations. Withdrawals could also decrease ground water discharge to streams, potentially affecting surface water quality. Areas with numerous high-capacity wells and large amounts of sustained ground water pumping are most likely to experience impacts, particularly in drought-prone regions with limited ground water recharge.
- Surface water withdrawals also have the potential to affect water quality. Withdrawals may lower water levels and alter stream flow, potentially decreasing a stream's capacity to dilute contaminants. Case studies by the EPA show that streams can be vulnerable to changes in water quality due to water withdrawals, particularly smaller streams and during periods of low flow (U.S. EPA, 2015c). Management of the rate and timing of surface water withdrawals can help mitigate potential impacts of fracturing withdrawals on water quality.
- Like water quantity effects, any effects of water withdrawals on water quality will likely occur nearest the withdrawal point, again emphasizing the need for location specific assessments.

4.7. References for Chapter 4

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