# Chapter 3

## Drinking Water Resources in the United States

# 3. Drinking Water Resources in the United States

Consideration of how and where hydraulic fracturing activities potentially impact drinking water resources requires an understanding of both the activities and the potentially impacted resources. In Chapter 2, we provided background on hydraulic fracturing and in this chapter, we provide an overview of drinking water resources in the United States. We describe the use of these resources, including patterns in current use and trends for future use (Section 3.1). We then characterize the spatial distribution of hydraulically fractured wells and current surface and ground water supplies throughout the United States (Section 3.2) to evaluate where potential impacts of hydraulic fracturing on drinking water resources may occur.

## 3.1. Current and Future Drinking Water Resources

In this assessment, drinking water resources are defined broadly as any body of ground water or surface water that now serves, or in the future could serve, as a source of drinking water for public or private use. Drinking water resources provide not only water that individuals actually drink but also water used for many additional purposes such as cooking and bathing. Our definition of drinking water resources includes both fresh and non-fresh bodies of water.

The average American uses about 90 gal (341 L) of drinking water per day for indoor and outdoor purposes (e.g., drinking, food preparation, washing clothes and dishes, flushing toilets, and watering lawns or gardens (Maupin et al., 2014; AWWA, 1999). Drinking water is supplied to households by either public water systems (PWSs) or private water systems (private ground water wells and surface water intakes).[1] In 2011, approximately 270 million people (86% of the population) in the United States relied on water supplied to their homes by one of the more than 51,000 community water systems (Maupin et al., 2014; U.S. EPA, 2013b).[2] These systems provided households with nearly 24 billion gal (91 billion L) of water per day (Maupin et al., 2014).[3] In areas without service by PWSs, approximately 43 million people (14% of the population) relied on private sources for drinking water, and private water systems account for about 3.6 billion gal (14 billion L) of daily water withdrawals (Maupin et al., 2014).

Drinking water resources can be surface waters such as rivers, streams, lakes, or reservoirs, as well as ground water aquifers. In 2011, approximately 70% of the population receiving drinking water from PWSs relied on surface water, and 30% relied on ground water (U.S. EPA, 2013b). However,

[1] Public water systems (PWSs) provide water for human consumption from surface or ground water through pipes or other infrastructure to at least 15 service connections or serve an average of at least 25 people for at least 60 days a year (U.S. EPA, 2012e). Private (non-public) water systems serve fewer than 15 connections and fewer than 25 individuals (U.S. EPA, 1991).

[2] The EPA categorizes public water systems as either community water systems, which supply water to the same population year-round, or non-community water systems, which supply water to at least 25 of the same people at least six months per year, but not year-round. Approximately 101,000 non-community water systems provide water to non-residential facilities (e.g., schools, small businesses, churches, and campgrounds (U.S. EPA, 2013b).

[3] The U.S. Geological Survey (USGS) compiles data in cooperation with local, state, and federal environmental agencies to produce water-use information aggregated at the county, state, and national levels. Every five years, data at the county level are compiled into a national water use census and state-level data are published. The most recent USGS water use report was released in 2014, and contains water use estimates from 2010 (Maupin et al., 2014; USGS, 2014b).

the relative importance of surface and ground water sources for supplying drinking water varies geographically (see Figure 3-1). Most larger PWSs rely on surface water and are located in urban areas (U.S. EPA, 2011b), whereas most smaller PWSs rely on ground water and are located in rural areas (U.S. EPA, 2014j, 2013b). In fact, more than 95% of households in rural areas obtain their drinking water from ground water aquifers (U.S. EPA, 2011b).

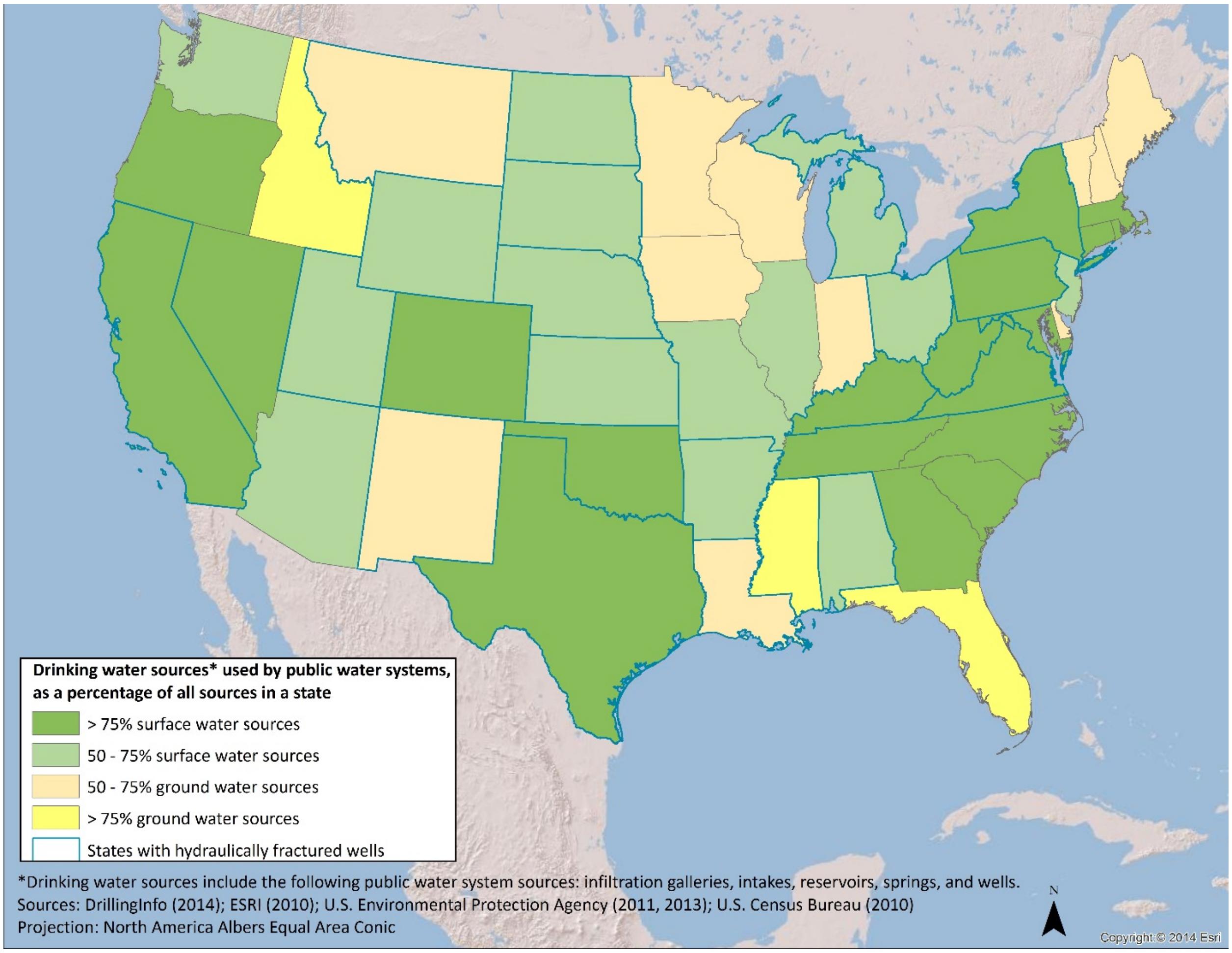


**Figure 3-1. Geographic variability in drinking water sources for public water systems.**

The relative importance of surface and ground water as drinking water sources varies by state. The public water system sources used in this analysis include infiltration galleries, intakes, reservoirs, springs, and wells. States with hydraulically fractured wells were identified from DrillingInfo data.

The future availability of drinking water resources that are considered fresh in the United States will be affected by changes in climate and water use (Georgakakos et al., 2014; U.S. Global Change

Research Program, 2009).[1] Since 2000, about 30% of the total area of the contiguous United States has experienced moderate drought conditions and about 20% has experienced severe drought conditions (National Drought Mitigation Center, 2015; U.S. EPA, 2015r). Declines in surface water resources have already led to increased withdrawals and cumulative net depletions of ground water in some areas (Castle et al., 2014; Georgakakos et al., 2014; Konikow, 2013a; Famiglietti et al., 2011). Other sources of water that might not be considered fresh, such as wastewater from sewage treatment plants, brackish (containing 3,000–10,000 mg/L TDS) and saline (containing more than 10,000 mg/L TDS) surface and ground water, as well as seawater (containing about 35,000 mg/L TDS) are also increasingly being used to meet water demand. Through treatment or desalination, these water sources can reduce the use of high-quality, potable fresh water for industrial processes, irrigation, recreation, and toilet flushing (i.e., non-potable uses). In addition, in 2010, approximately 355 million gal per day (1.3 billion L per day) of treated wastewater was reclaimed through potable reuse projects (NRC, 2012). Such projects use reclaimed wastewater to augment surface drinking water resources or to recharge aquifers that supply drinking water to PWSs (NRC, 2012; Sheng, 2005).

An increasing number of states are developing new water supplies to augment existing water through reuse of reclaimed water, recycling of storm water, and desalination (U.S. GAO, 2014). Most desalination programs currently use brackish water, although plans are underway to expand the use of seawater for desalination in some states. States with the highest installed capacity for desalination include Florida, California, Arizona, and Texas (Cooley et al., 2006). It is likely that various water treatment technologies will continue to expand drinking water resources beyond those currently being considered for use as drinking water. Therefore, these potential future sources are also considered drinking water resources in this assessment.

## 3.2. The Proximity of Drinking Water Resources to Hydraulic Fracturing Activity

The colocation of hydraulic fracturing activities with surface and ground water increases the potential for impacts to current and future drinking water resources (Vengosh et al., 2014; Entrekin et al., 2011). In this section, we analyze the aboveground proximity of hydraulically fractured well sites, drinking water resources (including the location of surface water bodies and ground water wells that supply public water systems), and populated areas.[2]

To determine the spatial relationship between hydraulically fractured wells and populated areas, we analyzed the locations of the approximately 273,000 oil and gas wells that were hydraulically fractured in 25 states between 2000 and 2013 (see Chapter 2) with respect to where people live (i.e., census blocks).[3] Nationwide, approximately 9.4 million people lived within one mile of a

[1] Fresh water qualitatively refers to water with relatively low TDS that is most readily available for drinking water currently.
[2] The vertical proximity of ground water resources to geologic formations and hydraulic fracturing operations is addressed in Chapter 6.
[3] In the analyses in this chapter, we only include the oil and gas production wells that we identified were hydraulically fractured using criteria outlined in Chapter 2 and that began producing between 2000 and 2013. The well data found in DrillingInfo may not represent the full year for 2013 since the frequency with which DrillingInfo updates the database varies by state. The final update performed by DrillingInfo for 2013 ranges by state from June 2013 to December 2013.

hydraulically fractured well for some period of time between 2000 and 2013 (DrillingInfo, 2014a; U.S. Census Bureau, 2010); more than 5.7 million people lived within half a mile of a hydraulically fractured well.

We then analyzed trends in the proximity of hydraulically fractured wells to highly populated areas. For this analysis, we considered metropolitan areas (areas with more than 50,000 people) and micropolitan areas (areas with 10,000 to 49,999 people) (U.S. Census Bureau, 2013c).[1] Approximately 81,300 (30%) of new wells hydraulically fractured between 2000 and 2013 were located within a metropolitan or micropolitan area (see Figure 3-2) (DrillingInfo, 2014a; U.S. Census Bureau, 2013c; U.S. EPA, 2013b; ESRI, 2010). From 2000 to 2008, the number of new wells hydraulically fractured per year within metropolitan and micropolitan areas increased 300%; the proportion of wells hydraulically fractured per year in metropolitan and micropolitan areas almost doubled over the same eight-year period (see Figure 3-3).[2] From 2008 to 2012, however, the number of wells hydraulically fractured per year in metropolitan and micropolitan areas decreased by about half in comparison to the peak of approximately 10,000 wells in 2008 (see Figure 3-3), whereas hydraulic fracturing in areas outside of metropolitan and micropolitan areas increased or remained relatively constant (DrillingInfo, 2014a; U.S. Census Bureau, 2013b).

[1] Metropolitan and micropolitan combined statistical areas are geographic entities delineated by the Office of Management and Budget. Specifically, a metropolitan combined statistical area is a core urban area of 50,000 or more people while a micropolitan combined statistical area is an urban core of at least 10,000, but less than 50,000, people (U.S. Census Bureau, 2013c). These terms are referred to as metropolitan and micropolitan areas in this assessment.
[2] For comparison, the DrillingInfo data indicate an increase in the number of wells estimated to be hydraulically fractured each year, regardless of location, from approximately 12,800 in 2000 to slightly more than 21,600 in 2005 to nearly 23,000 in 2012, the last year for which complete data are available.

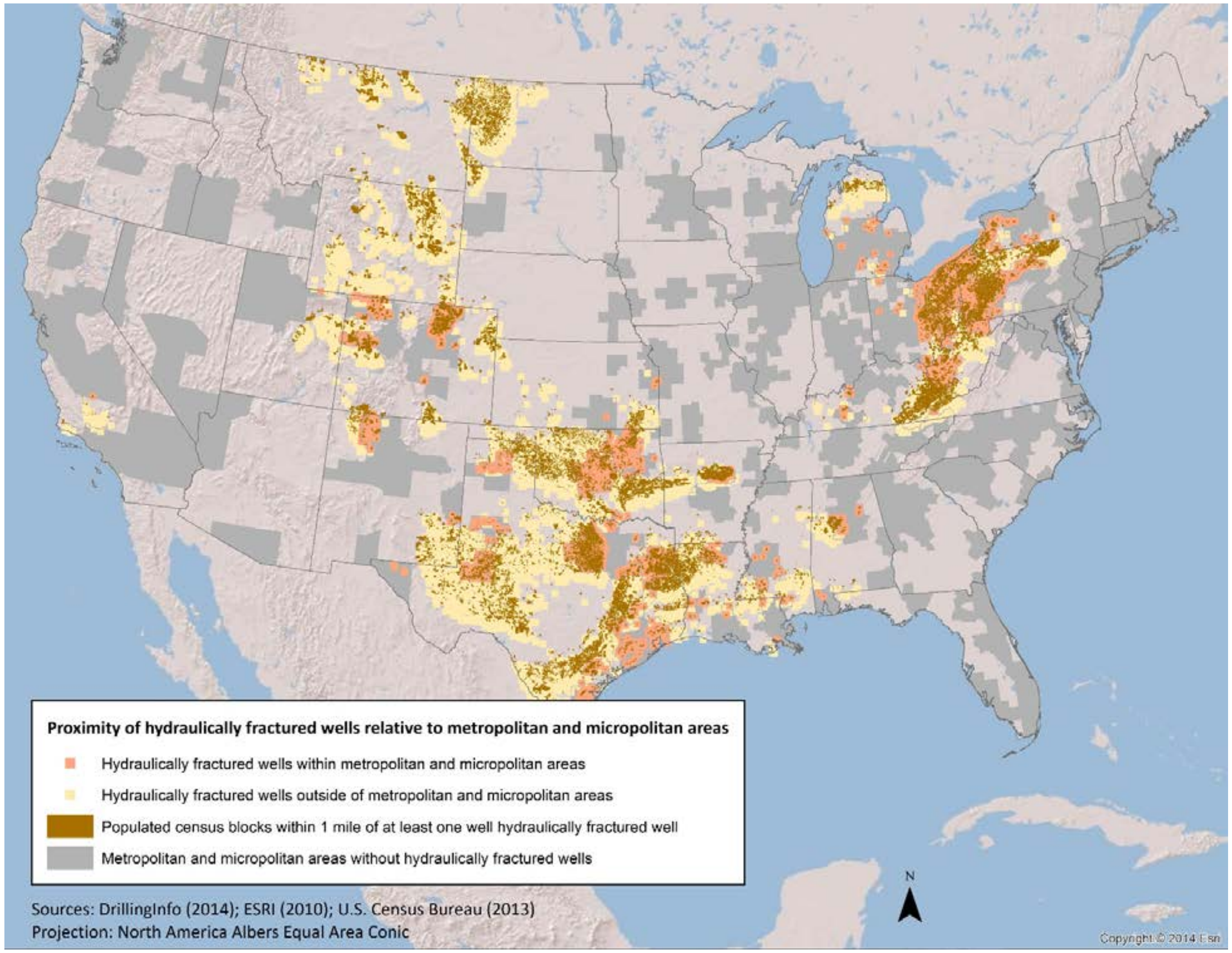


**Figure 3-2. Proximity of hydraulically fractured wells relative to populated areas.**

The estimates of hydraulically fractured wells from 2000 to 2013 developed from the DrillingInfo data were based on several assumptions described in Chapter 2.

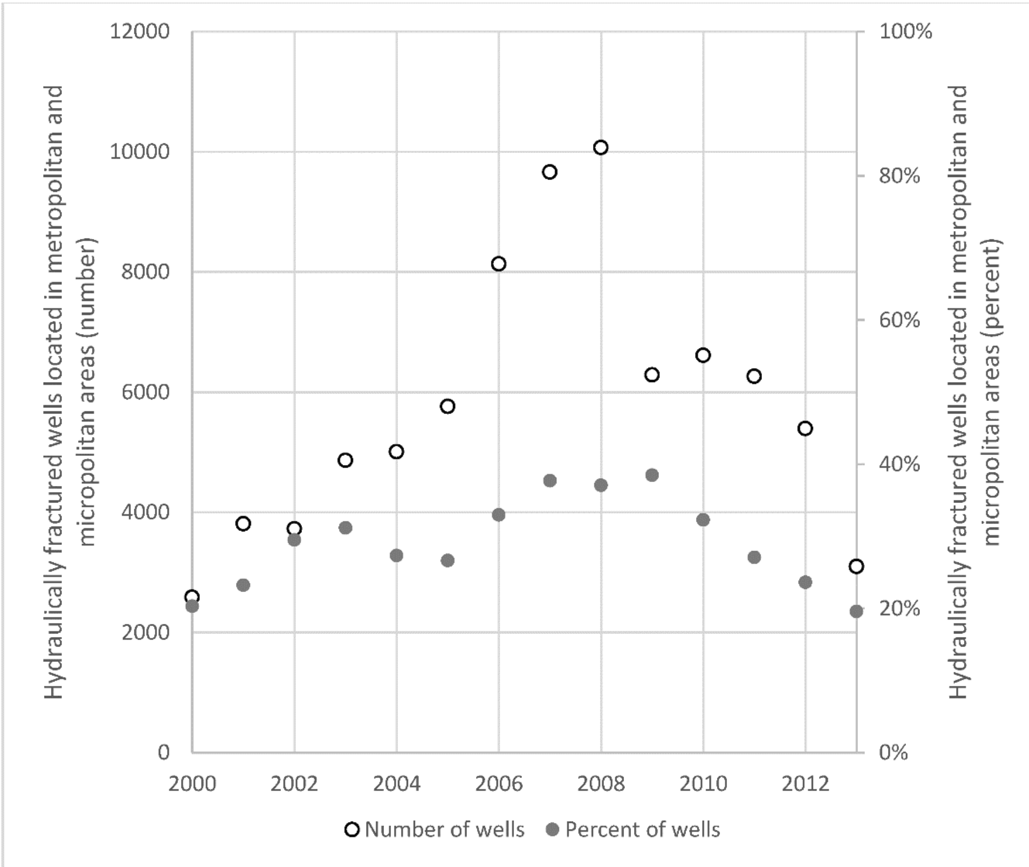


**Figure 3-3. Temporal trends (2000–2013) in the number and percent of hydraulically fractured wells located within populated areas.**

The estimates of hydraulically fractured wells from 2000 to 2013 developed from the DrillingInfo data were based on several assumptions described in Chapter 2. The graph shows the number of hydraulically fractured wells by the year they started producing. Well data may not be complete for 2013 since final updates to the database for 2013 ranged from June 2013 to December 2013, depending on the state. Original data from DrillingInfo (2014a) and U.S. Census Bureau (2013c).

We next considered the proximity of hydraulically fractured wells to water sources for PWSs. We present proximity from both the vantage point of hydraulically fractured wells (e.g., on average, how far away is the nearest PWS source?) and from the vantage point of PWSs (e.g., if there is at least one fractured well within 1 mile of a PWS, are there usually more?).

Based on the 2000–2013 DrillingInfo data, the distance from hydraulically fractured wells to the nearest source supplying a PWS ranged from 0.01 to 41 miles, with an average distance of 6.2 miles (9.9 km) and a median distance of 4.8 miles (7.6 km) (DrillingInfo, 2014a; U.S. EPA, 2014j). These PWS sources included both surface water sources (e.g., infiltration galleries, intakes, reservoirs, and springs) and ground water wells. An estimated 21,900 of hydraulically fractured oil and gas wells (8%) were within 1 mile of at least one PWS source (see Figure 3-4). The maximum number was 40 PWS sources within 1 mile of a single hydraulically fractured well.

Between 2000 and 2013, approximately 6,800 PWS sources had a hydraulically fractured well within a 1 mile radius. Most of these PWS sources were located in Colorado, Louisiana, Michigan, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, and Wyoming (see Figure 3-5). These PWS sources had an average of seven fractured wells and a maximum of 144 fractured wells within that one mile proximity. They also supplied water to 3,924 PWSs—1,609 of which are community water systems—that served more than 8.6 million people year-round in 2013 (U.S. EPA, 2014j; U.S. Census Bureau, 2013a; U.S. EPA, 2013b).[1]

We also analyzed the location of hydraulically fractured wells relative to populations where a high proportion (≥30%, or twice the national average) obtain drinking water from private systems (private ground water wells and surface water intakes).[2] Between 2000 and 2013, approximately 3.6 million people obtained drinking water from private systems in counties with at least one hydraulically fractured well (DrillingInfo, 2014a; USGS, 2014b), and approximately 740,000 people obtained drinking water from private supplies in counties with more than 400 fractured wells (DrillingInfo, 2014a; USGS, 2014b) (see Figure 3-6).[3] These counties were located in Colorado, Kentucky, Michigan, Montana, New Mexico, New York, Oklahoma, Pennsylvania, Texas, and Wyoming (see Figure 3-6).

[1] All PWS types were included in the locational analyses performed. However, only community water systems were used to calculate the number of customers obtaining water from a PWS with at least one source within 1 mile of a hydraulically fractured well. If non-community water systems are included, the estimated number of customers increases by 533,000 people (U.S. EPA, 2012e).
[2] There is no national data set of private water systems. The USGS estimates the proportion of the population reliant on private water systems, referred to as the "self-supplied population," by county, based on estimates of the population without connections to a public water system (Maupin et al., 2014). We used the USGS estimates for this analysis.
[3] Approximately 14% of the U.S. population is supplied by private water systems (Maupin et al., 2014). In this analysis, we only considered counties in which more than double the national average—that is, at least 30% of the county's population—was supplied by private water systems.

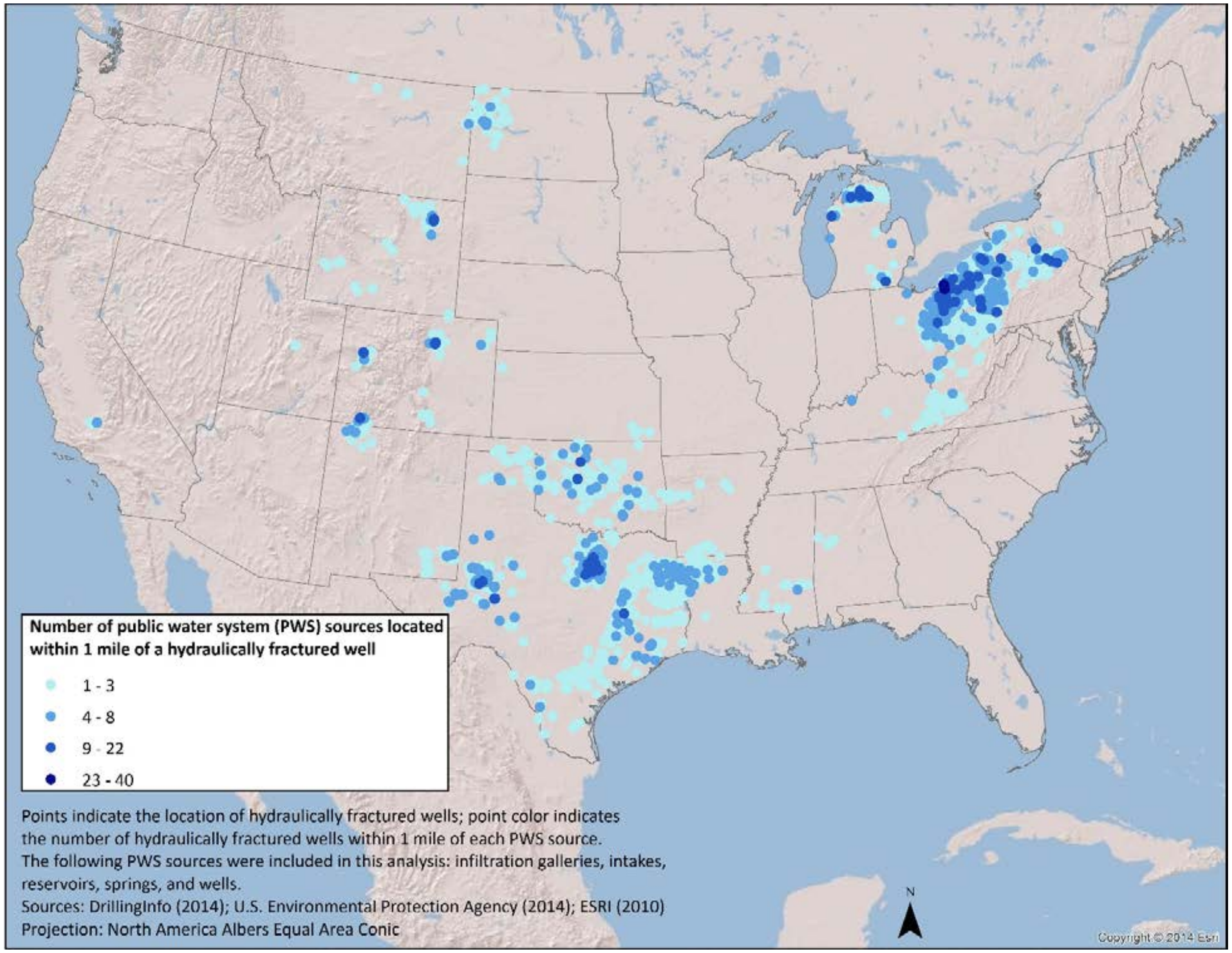


**Figure 3-4. Location and number of public water system (PWS) sources located within 1 mile of a hydraulically fractured well.**

Points indicate the location of hydraulically fractured wells; point color indicates the number of hydraulically fractured wells within 1 mile of each PWS source. The following PWS sources were included in this analysis: infiltration galleries, intakes, reservoirs, springs, and wells. The estimates of wells hydraulically fractured from 2000 to 2013 developed from the DrillingInfo data were based on several assumptions described in Chapter 2.

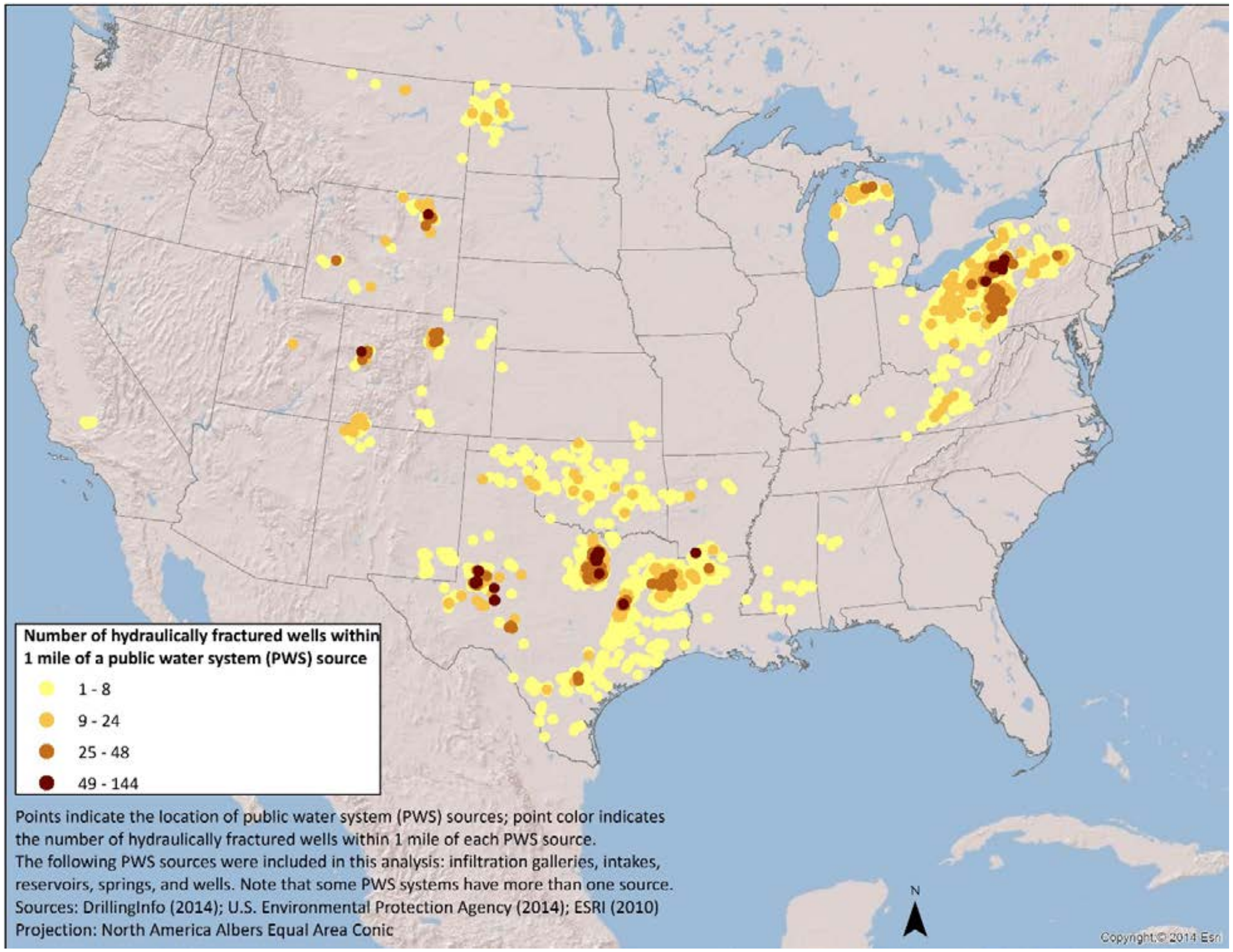


**Figure 3-5. The location of public water system sources within 1 mile of hydraulically fractured wells.**

Points indicate the location of public water system (PWS) sources; point color indicates the number of hydraulically fractured wells within 1 mile of each PWS source. The estimates of wells hydraulically fractured from 2000 to 2013 developed from the DrillingInfo data were based on several assumptions described in Chapter 2.

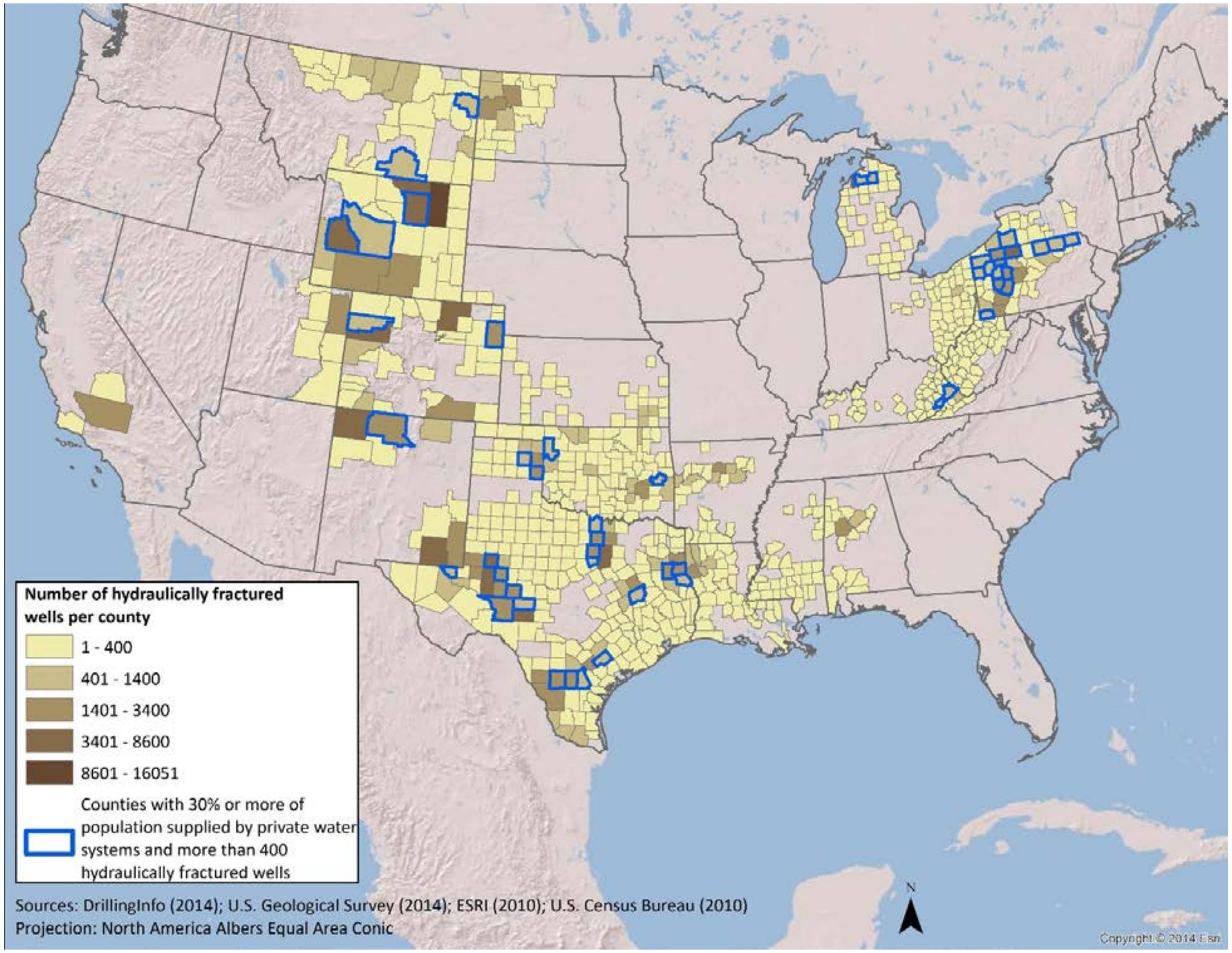


**Figure 3-6. Co-occurrence of hydraulic fracturing activity and populations supplied by private water systems.**

Color indicates the number of hydraulically fractured wells per county. The estimates of wells hydraulically fractured from 2000 to 2013 developed from the DrillingInfo data were based on several assumptions described in Chapter 2. Counties with more than 400 hydraulically fractured wells and in which at least 30% of the population is supplied by private water systems are outlined in blue.

## 3.3. Conclusion

The evaluation of potential hydraulic fracturing impacts on drinking water resources in the United States depends on an understanding of how the country's current and future drinking water needs are and will be met. The U.S. population requires sufficient drinking water resources—that is, bodies of fresh or non-fresh surface or ground water that now serve, or in the future could serve, as a source of water for drinking water for public or private use—to meet everyday needs. Currently, most people in the United States rely on water supplied to their homes via public water systems, and most of this water comes from fresh surface water bodies. Shortages in fresh water availability in the United States, especially in the western United States, have already led some states to augment their water supplies with other water sources (e.g., brackish and saline surface and ground water, seawater, and reclaimed wastewater), suggesting that additional water bodies may provide drinking water as the quantity and quality of existing sources change.

The colocation of hydraulic fracturing activities with drinking water resources increases the potential for these activities to affect the quality and quantity of current and future drinking water resources. While close proximity of hydraulically fractured wells to drinking water resources does not necessarily indicate that an impact has or will occur, information about the relative location of wells and water supplies is an initial step in understanding where potential impacts might occur.

Millions of people live in areas where their drinking water resources are located near hydraulically fractured wells. While most hydraulic fracturing activity from 2000 to 2013 did not occur in close proximity to public water supplies, a sizeable number of hydraulically fractured wells (21,900) were located within 1 mile of at least one PWS source (e.g., infiltration galleries, intakes, reservoirs, springs and ground water wells). Approximately 6,800 sources of drinking water for public water systems, serving more than 8.6 million people year-round, were located within 1 mile of at least one hydraulically fractured well. An additional 3.6 million people obtain drinking water from private systems in counties with at least one hydraulically fractured well and in which at least 30% of the population is reliant on private water systems.

**Text Box 3-1. Major Findings**

***Current and future drinking water resources***

- Most of the U.S. population (270 million in 2011, or 86%) relies on water supplied to their homes through a public water system, 70% of which comes from surface water and 30% of which comes from ground water.
- An estimated 14% of the U.S. population relies on private water systems for drinking water.
- An increasing number of states are developing new drinking water supplies via reuse of reclaimed water, recycling of storm water, and desalination. These new supplies can augment existing water sources.
- Most of the U.S. population (270 million in 2011, or 86%) relies on water supplied to their homes through a public water system, 70% of which comes from surface water and 30% of which comes from ground water.
- An estimated 14% of the U.S. population relies on private water systems for drinking water.
- An increasing number of states are developing new drinking water supplies via reuse of reclaimed water, recycling of storm water, and desalination. These new supplies can augment existing water sources.

***Proximity of drinking water resources to hydraulic fracturing activity***

- Nationwide, while most hydraulic fracturing activity from 2000 to 2013 did not occur in close proximity to public water supplies, a sizeable number of hydraulically fractured wells (21,900) were located within 1 mile of at least one PWS source.
- The distance between wells that were hydraulically fractured between 2000 and 2013 and the nearest source supplying a PWS ranged from 0.01 to 41 miles, with an average distance of 6.2 miles (9.9 km).
- An estimated 6,800 public water system sources were located within 1 mile of a hydraulically fractured oil and gas well between 2000 and 2013. These PWS sources supplied water to 3,924 public water systems and served more than 8.6 million people year-round in 2013.
- Approximately 9.4 million people lived within 1 mile of at least one hydraulically fractured oil and gas well between 2000 and 2013.
- Approximately 3.6 million people obtain drinking water from private systems in counties with at least one hydraulically fractured well and in which at least 30% of the population (i.e., double the national average) is reliant on private water systems.

## 3.4. References for Chapter 3

AWWA (American Water Works Association). (1999). Residential end uses of water. In PW Mayer; WB DeOreo (Eds.). Denver, CO: AWWA Research Foundation and American Water Works Association. http://www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf

Castle, SL; Thomas, BF; Reager, JT; Rodell, M; Swenson, SC; Famiglietti, JS. (2014). Groundwater depletion during drought threatens future water security of the Colorado River Basin. Geophys Res Lett 41: 5904-5911. http://dx.doi.org/10.1002/2014GL061055

Cooley, H; Gleick, PH; Wolff, G. (2006). Desalination, with a grain of salt: A California perspective. Oakland, CA: Pacific Institute for Studies in Development, Environment, and Security. http://www.pacinst.org/wp-content/uploads/2013/02/desalination_report3.pdf

DrillingInfo, Inc., . (2014a). DI Desktop June 2014 download [Database]. Austin, TX: DrillingInfo. Retrieved from http://info.drillinginfo.com/

Entrekin, S; Evans-White, M; Johnson, B; Hagenbuch, E. (2011). Rapid expansion of natural gas development poses a threat to surface waters. Front Ecol Environ 9: 503-511. http://dx.doi.org/10.1890/110053

ESRI (Environmental Systems Research Institute Inc.). (2010). US states shapefile. Redlands, California. Retrieved from http://www.arcgis.com/home/item.html?id=1a6cae723af14f9cae228b133aebc620

Famiglietti, JS; Lo, M; Ho, SL; Bethune, J; Anderson, KJ; Syed, TH; Swenson, SC; de Linage, CR; Rodell, M. (2011). Satellites measure recent rates of groundwater depletion in California's Central Valley. Geophys Res Lett 38: L03403. http://dx.doi.org/10.1029/2010GL046442

Georgakakos, A; Fleming, P; Dettinger, M; Peters-Lidard, C; Richmond, TC; Reckhow, K; White, K; Yates, D. (2014). Water resources. In JM Melillo; TC Richmond; GW Yohe (Eds.), Climate change impacts in the United States (pp. 69-112). Washington, D.C.: U.S. Global Change Research Program. http://www.globalchange.gov/ncadac

Konikow, LF. (2013a). Groundwater depletion in the United States (1900-2008): U.S. Geological Survey Scientific Investigations Report 2013-5079. Reston, VA: U.S. Geological Survey. http://pubs.usgs.gov/sir/2013/5079

Maupin, MA; Kenny, JF; Hutson, SS; Lovelace, JK; Barber, NL; Linsey, KS. (2014). Estimated use of water in the United States in 2010. (USGS Circular 1405). Reston, VA: U.S. Geological Survey. http://dx.doi.org/10.3133/cir1405

National Drought Mitigation Center. (2015). U.S. drought monitor. Available online at http://droughtmonitor.unl.edu/Home.aspx (accessed February 27, 2015).

NRC (National Research Council). (2012). Water reuse: Potential for expanding the nations water supply through reuse of municipal wastewater. Committee on the Assessment of Water Reuse as an Approach for Meeting Future Water Supply Need. Washington, DC: The National Academies Press. http://www.nap.edu/openbook.php?record_id=13303

Sheng, Z. (2005). An aquifer storage and recovery system with reclaimed wastewater to preserve native groundwater resources in El Paso, Texas. J Environ Manage 75: 367-377. http://dx.doi.org/10.1016/j.jenvman.2004.10.007

U.S. Census Bureau. (2010). Special release - census blocks with population and housing unit counts, 2010 TIGER/Line shapefiles [Computer Program]. Suitland, MD: U.S. Census Bureau, Geography Division. Retrieved from https://www.census.gov/geo/maps-data/data/tiger-line.html

U.S. Census Bureau. (2013a). Annual estimates of the resident population: April 1, 2010 to July 1, 2013. Suitland, MD: U.S. Census Bureau, Population Division. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

U.S. Census Bureau. (2013b). Cartographic boundary shapefiles metropolitan and micropolitan statistical areas and related statistical areas (Combined statistical areas, 500k). Suitland, MD. Retrieved from https://www.census.gov/geo/maps-data/data/cbf/cbf_msa.html

U.S. Census Bureau. (2013c). Metropolitan and micropolitan statistical areas main. Available online at http://www.census.gov/population/metro/ (accessed January 12, 2015).

U.S. EPA (U.S. Environmental Protection Agency). (1991). Manual of individual and non-public water supply systems [EPA Report]. (EPA 570/9-91-004). Washington, D.C.

U.S. EPA (U.S. Environmental Protection Agency). (2011b). Ground water cleanup at Superfund Sites [EPA Report]. (EPA 540-K-96 008). Washington, DC: U. S. Environmental Protection Agency, Office Water. http://www.epa.gov/superfund/health/conmedia/gwdocs/brochure.htm

U.S. EPA (U.S. Environmental Protection Agency). (2012e). Public drinking water systems: facts and figures. Washington, DC: U.S. Environmental Protection Agency, Office of Water. http://water.epa.gov/infrastructure/drinkingwater/pws/factoids.cfm

U.S. EPA (U.S. Environmental Protection Agency). (2013b). Drinking water and ground water statistics, fiscal year 2011. Washington, DC: U.S. Environmental Protection Agency, Office of Water. http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf

U.S. EPA (U.S. Environmental Protection Agency). (2014j). Safe drinking water information system (SDWIS). Data obtained from the Office of Water [Database]. Washington, D.C.: Office of Water. Retrieved from http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/index.cfm

U.S. EPA (U.S. Environmental Protection Agency). (2015r). WaterSense: water supply in the U.S. Available online at http://www.epa.gov/WaterSense/pubs/supply.html (accessed January 12, 2015).

U.S. GAO (U.S. Government Accountability Office). (2014). Freshwater: Supply concerns continue, and uncertainties complicate planning. Report to Congressional requesters. (GAO-14-430). Washington, DC: U.S. Government Accountability Office (GAO). http://www.gao.gov/assets/670/663343.pdf

U.S. Global Change Research Program. (2009). Global climate change impacts in the United States. New York, NY: Cambridge University Press. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

USGS (U.S. Geological Survey). (2014b). Estimated use of water in the United States, county-level data for 2010. Reston, VA. http://water.usgs.gov/watuse/data/2010/

Vengosh, A; Jackson, RB; Warner, N; Darrah, TH; Kondash, A. (2014). A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. Environ Sci Technol 48: 36-52. http://dx.doi.org/10.1021/es405118y