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# Water Use and Management in the Bakken Shale Oil Play

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# ACRONYM LIST

| | |
|---|---|
| API | American Petroleum Institute |
| EUR | estimated ultimate recovery |
| GIS | Graphical Information System |
| HUC | Hydrologic Unit Code |
| NDDMR | North Dakota Department of Mineral Resources |
| NORM | naturally occurring radioactive materials |
| TDS | total dissolved solids |
| USGS | U.S. Geological Survey |

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## ABSTRACT

Development in the Bakken shale oil play of North Dakota has seen significant growth since 2008. Extraction of oil from the Bakken play requires the employment of hydraulic fracturing techniques, which can use, on average, between 1.7 and 2.4 million gallons of water per well. This study provides an overview of water quantity impacts of development in the North Dakota portion of the Bakken play by estimating water demand for hydraulic fracturing, estimating domestic water demand by the large oil services population that has temporarily moved to the area, quantifying existing water resources, and discussing the means for meeting future demand. Water use for hydraulic fracturing in the North Dakota portion of the Bakken play is estimated utilizing data from FracFocus.org and the North Dakota Department of Mineral Resources, and is found to have grown from 680 million gallons in 2008 to almost 4.3 billion gallons in 2012. Most of this use is concentrated in 2 out of 14 watershed subbasins covering the area of study. It is estimated that the growth in oil service workers temporarily residing in Williams County, at the center of the development activity, has resulted in an increase in domestic water demand equal to the increase in demand from hydraulic fracturing activities across the North Dakota Bakken play. Existing groundwater sources are not equal to the growing demand for water due to oil development, but surface water sources in the area—primarily the Missouri River system—appear to be more than able to accommodate anticipated growth, provided that access is acquired. To better and more fully characterize the situation, more data is needed on actual water used for hydraulic fracturing activities, the specific sources of water for those activities, the amount of maintenance water needed over the lifetime of a well, and the economic viability of flowback water recycling for hydraulic fracturing.

# 1 INTRODUCTION

Oil extraction from the Bakken shale oil deposit, or *play*, of western North Dakota and surrounding areas has increased rapidly since development began around 2008. This rapid development has greatly impacted local economies, communities, and environments. The City of Williston, at the center of the Bakken development, experienced less than 2.5 percent annual growth prior to 2009 (U.S. Census Bureau, 2012). In 2013, it was the fastest growing micropolitan area in the country with 10.7 percent growth over the previous year (U.S. Census Bureau, 2014b). North Dakota had the highest growth in personal income in the nation in 2013—for the sixth time in the past seven years—which was primarily attributed to oil development (U.S. Bureau of Economic Analysis, 2014; Port, 2014). According to locals, along with this rapid growth has come a lack of housing and services, greatly increased traffic, more stress on local sewer systems, more crime, more garbage, an increasing number of incidents of spills and pollution, and many other impacts (Suarez, 2012). Among these impacts is the increased demand for water, which is used by shale oil wells and by transient oil workers who now reside in the area.

The oil in the Bakken play is contained within unconnected pores in shale. To release the oil for production, a mixture of water and other ingredients is pumped at high pressure into wells that are drilled horizontally through the shale play. The high pressure causes the rock to fracture, opening connecting pathways between pores, and enabling oil to flow back to the well. Hydraulic fracturing of a single shale well can use 2 to 8 million gallons of water or more, depending on the play (Clark et al., 2013). While typical water volumes for hydraulic fracturing in the Bakken play are on the lower end of this range, with hundreds to thousands of wells being installed in the Bakken play every year, the water use could be significant. After a well is hydraulically fractured, much of the injected water returns to the surface, along with naturally occurring water released from the rock formation. This produced water normally contains high levels of total dissolved solids (TDS) as well as varying levels of naturally occurring radioactive materials (NORM) and must be treated, disposed of, and/or recycled.

This paper utilizes publicly available well installation and water injection data from FracFocus.org and the North Dakota Department of Mineral Resources (NDDMR) to estimate water use in the North Dakota portion of the Bakken play since 2008. It compares this volume with annual stream flow data for the watershed subbasins (U.S. Geological Survey [USGS] HUC-8 subbasins) where the wells have been installed, estimates changes in domestic water consumption due to growth of the oil services population in the area, and discusses water sources and management of water produced from hydraulically fractured wells. Overall, this paper serves as an introduction to water use and management for oil development in the Bakken play.

# 2 METHODS

The primary analysis in this report concerns quantifying the water used for all hydraulic fracturing that occurred in the North Dakota region of the Bakken play from 2008 to 2012. This was accomplished by acquiring oil well data from two sources: FracFocus.org (FracFocus, 2013) and the North Dakota Department of Mineral Resources' well database (NDDMR, 2013). FracFocus.org is a privately hosted online registry where oil and gas developers may disclose information regarding hydraulic fracturing activities to the public. Included in the disclosed information are the latitude and longitude location data and volume of water used for hydraulic fracturing for each well. In addition, the American Petroleum Institute (API) number is included; this is a unique identifier for any well drilled in the United States. The NDDMR has a much more comprehensive database of wells, which reports location data and API number (along with other data such as vertical depth) for every well that is legally drilled in the state, but does not report hydraulic fracturing water volumes.

Using an automated program, the pertinent well data for the North Dakota portion of the Bakken play was downloaded from FracFocus.org. This data was compared to well data acquired from NDDMR. To estimate the water used for hydraulic fracturing for all wells in the North Dakota portion of the Bakken play, the two data sets were merged in a Geographical Information System (GIS) program based on the API well identification numbers. Duplicate entries and outliers in well depth and water volumes were deleted. Of the 4,624 wells that were identified as having been installed in the North Dakota portion of the Bakken play from 2008 to 2012, approximately 1,640 were reported in the FracFocus.org data. The average hydraulic fracturing water volume for these 1,640 wells was assigned to the remaining 2,984 wells that were missing this information because they were only reported by NDDMR, not FracFocus.org. The resulting water volume data were used to estimate annual hydraulic fracturing water demand for the entire North Dakota portion of the Bakken play.

The data were also used to report the number of wells installed and amount of water used within each USGS Hydrologic Unit Code 8 (HUC-8) watershed subbasin overlying the Bakken play. The HUC-8 subbasins were used to organize the data so that surface-water flow volumes could be compared to water used for hydraulic fracturing in the same geographic area. This comparison is for illustration purposes only, because there is no easy way to link hydraulic fracturing activities to their specific water sources. As discussed in the *Water Sources* section, much of the water used for hydraulic fracturing in North Dakota comes from public or private water depots. Records indicating which water depots were used for each hydraulic fracturing occurrence could not be found. While the locations of the water depots are known (Shaver, 2012), it cannot be assumed that the closest water depot was utilized because, as a brief review of North Dakota State Water Commission permit applications show, the amount of water available and its intended use varies widely among sources (NDSWC, 2014). Therefore, it should not be assumed that all of the water used for hydraulic fracturing within a HUC-8 subbasin was sourced from the same subbasin.

# 3 WATER DEMAND

## 3.1 HYDRAULIC FRACTURING

Water is used in many aspects of well installation and operation, including as a primary constituent of drilling mud and the cement used to case and seal the well from non-target rock formations. However, the volume of water used for the hydraulic fracturing phase dwarfs that of all other phases of well installation and development (Clark et al., 2013). Using the method described in the previous section, the yearly water demand for hydraulic fracturing in the Bakken play was estimated for 2008–2012. The results are provided in Table 1. Figure 1 illustrates the annual consumption by HUC-8 watershed subbasin. Annual well installations overlaid on total water consumption per HUC-8 subbasin for 2008 and 2012 are provided in Figures 2 and 3, respectively. Well installation maps are provided for all five years from 2008 to 2012 in the appendix.

As shown in Table 1, the amount of water consumed for hydraulic fracturing activities in the Bakken play has more than quadrupled over the five years from 2008 to 2012. This is also true for the annual rate of well installation. However, the increase in water consumption is not wholly due to an increasing rate of development; the amount of water used for hydraulic fracturing per well in the Bakken play has increased by 40 percent since 2008. Figures 2 and 3 show that the more centrally located HUC-8 subbasins have the most water consumed by hydraulic fracturing. These also tend to be the largest subbasins in the North Dakota portion of the Bakken play (many of the subbasins on the periphery extend into other states or Canada, but only the development on, and the areas of, the North Dakota portions of them were considered for this report). The largest subbasins could be expected to have the most water consumption simply because they have more land area for development. Figure 4 normalizes for differences in land area by displaying the density of water consumption by square mile for each subbasin (represented by the red diamonds, which correspond to the right-hand y-axis). The two subbasins with the largest consumption of water for hydraulic fracturing (Lake Sakakawea and Lower Little Missouri), which represent over 70 percent of the consumed water, also have the highest density of consumption. However, there is no discernable overall relationship between

**TABLE 1 Annual Total Water Consumption for Hydraulic Fracturing in the North Dakota Bakken Play**

| Year | Total Water Consumed (millions of gallons) | Number of Wells | Average Volume per Well (millions of gallons) |
|---|---|---|---|
| 2008 | 680 | 401 | 1.70 |
| 2009 | 851 | 465 | 1.83 |
| 2010 | 1365 | 758 | 1.80 |
| 2011 | 2589 | 1199 | 2.16 |
| 2012 | 4290 | 1801 | 2.38 |

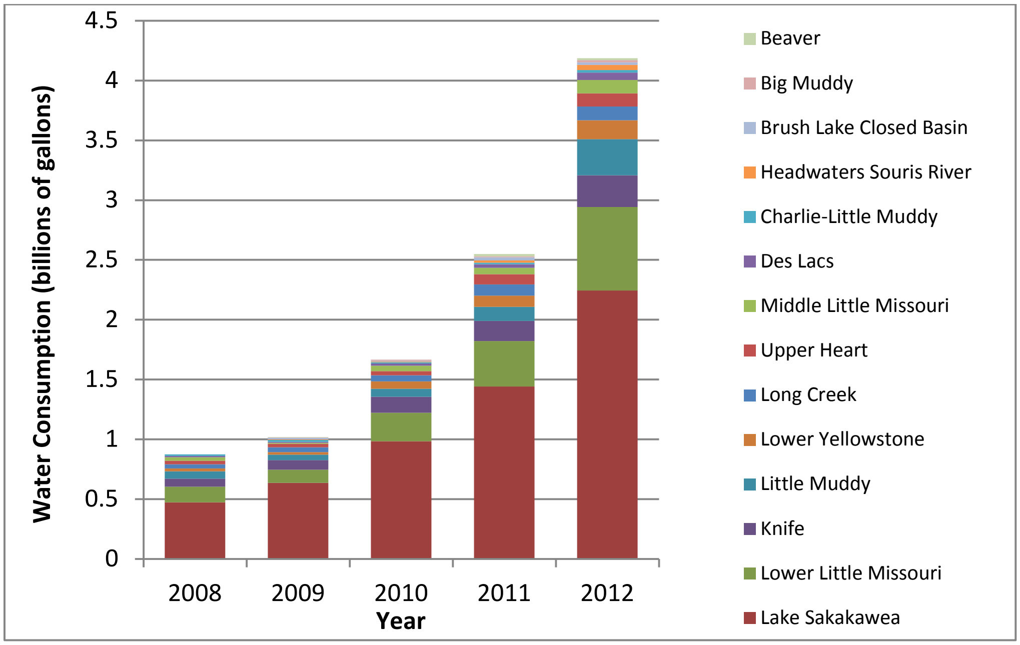


**FIGURE 1 Annual Total Water Consumption for Hydraulic Fracturing in the North Dakota Bakken Play by HUC-8 Subbasin**

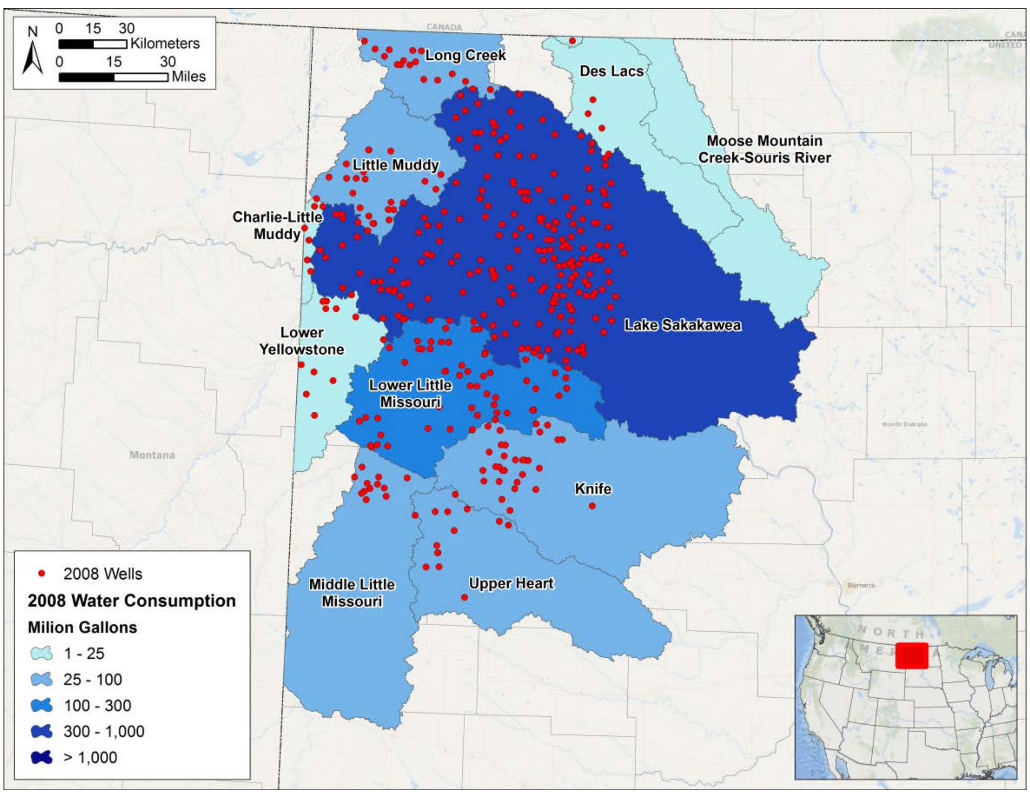


**FIGURE 2 2008 Hydraulic Fracturing Locations and Water Use by HUC-8 Subbasin in the North Dakota Bakken Shale Play**

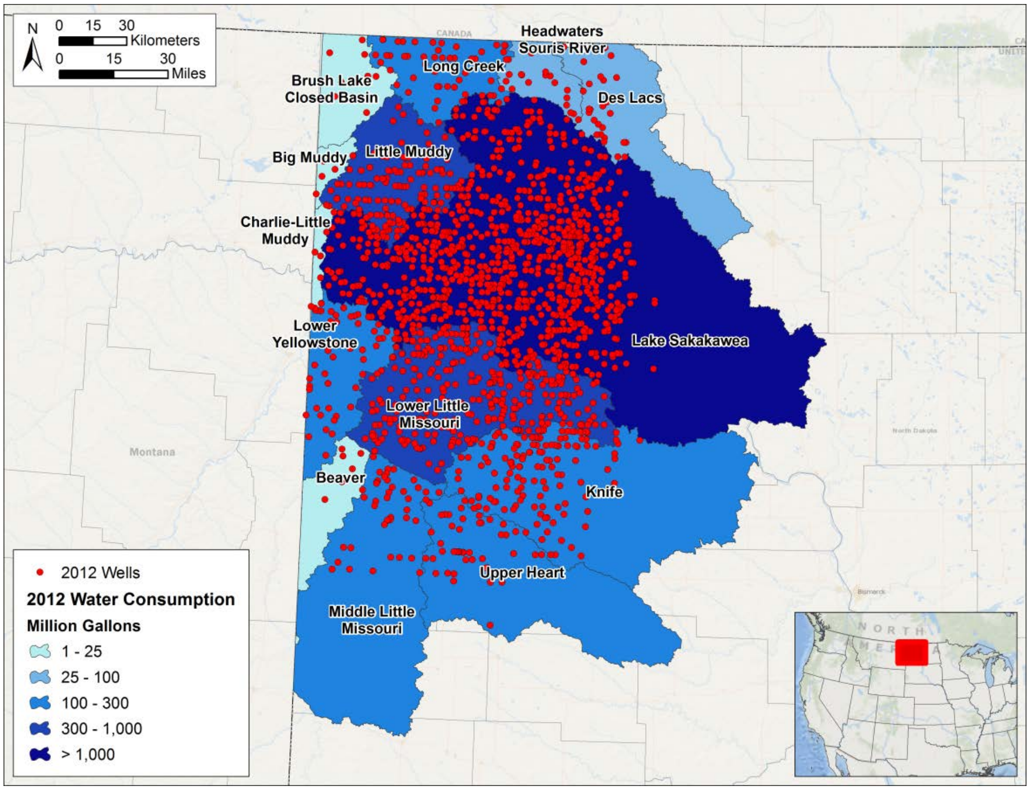


**FIGURE 3 2012 Hydraulic Fracturing Locations and Water Use by HUC-8 Subbasin in the North Dakota Bakken Shale Play**

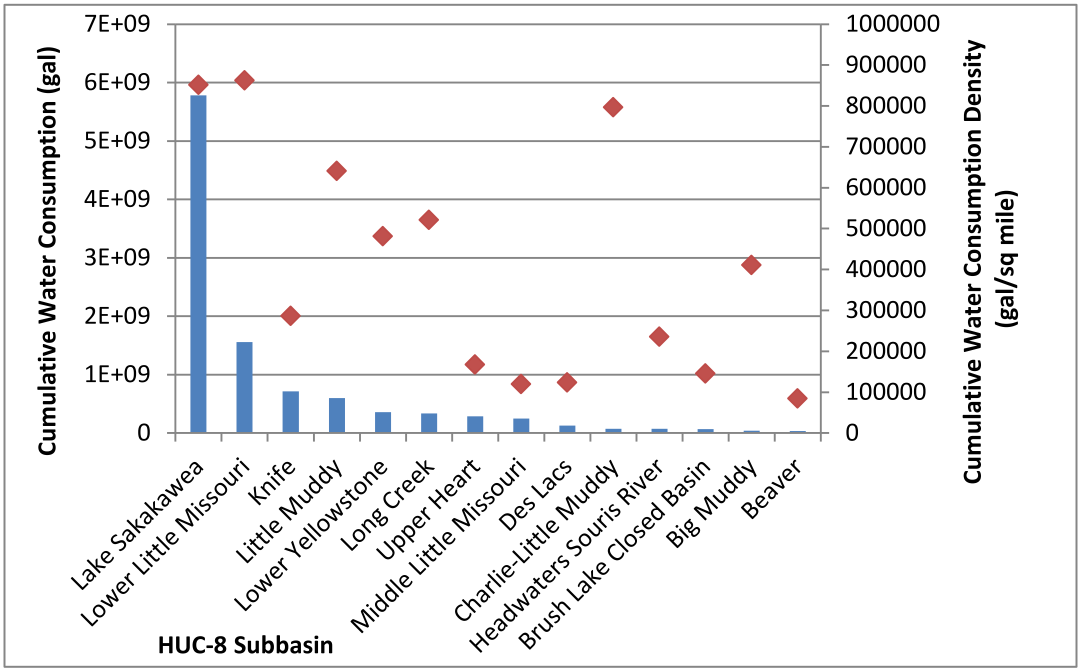


**FIGURE 4 Cumulative (2008–2012) Water Consumption Compared with Water Consumption Density for North Dakota Bakken HUC-8 Subbasins**

water consumption and density of water consumption for all of the subbasins. As can be seen in Figures 2 and 3, even if development is dense in some portions of a subbasin, large swaths of it may be untouched by Bakken development.

### 3.2 MAINTENANCE WATER

A recent article in *National Geographic* highlighted a new source of water consumption for wells that appears to be unique to the Bakken wells, or at least much more significant for the Bakken than for other shale plays (Kiger, 2013). The high salinity of the formation water within the basin (see *Produced Water Management* section) necessitates periodic flushing of wells to eliminate salt buildup within the well bore, which can negatively impact production rates. While little has been published about this process, Kiger (2013) referenced NDDMR estimates that seem to show that the water volumes required can be fairly significant over the lifetime of the well—on the order of 400–600 gallons/day (Helms, 2013). At this point in time, it is not well understood how this estimate was generated and what it implies in terms of frequency and volume of fluid required for flushing individual wells. When more data is obtained, it may be appropriate and significant to incorporate maintenance water volumes into further lifecycle water analyses of the Bakken play. After reaching out to industry contacts, one major producer in the Bakken (that has asked not to be named) stated that although they do require water for maintenance activities, their wells currently require significantly less water than estimated in Kiger (2013). The producer also stated that the water used for such activities is often brackish and thus is less likely to strain fresh water resources. Furthermore, a clear and consistent definition of "maintenance water" is needed.

### 3.3 PRODUCTION NORMALIZED LIFETIME WATER CONSUMPTION

Table 2 displays water consumption for Bakken oil wells normalized by the lifetime total barrels of oil equivalent produced by a typical well in the play. A number of scenarios were generated to explore uncertainty in a few key parameters: a well's lifetime production, or estimated ultimate recovery (EUR), the volume of maintenance water required, and typical well lifetime. The hydraulic fracturing volume for all scenarios was assumed to be the 2012 average volume from Table 1. The results range from 0.1 gallons of water per gallon of crude oil produced for a scenario with no maintenance water and high EUR to 0.79 gallons of water per gallon of crude oil produced for a scenario assuming high maintenance water requirements, long well lifetime, and low EUR. The addition of maintenance water, illustrated in Figure 5, does have a significant impact on the normalized lifetime water consumption and thus needs to be better understood (see *Maintenance Water* section). When a lower estimate of maintenance water for existing wells based upon industry input is used, the range of water consumption values falls in a narrower range of 0.17 to 0.40 gallons of water per gallon of crude oil. These results assume that a well is only hydraulically fractured once. It is possible that in the future some wells will be refractured, which will increase the water consumption, lifetime, and EUR of the well. The high uncertainty in the average EUR also has a large impact on the results. These values should not be considered true lifecycle water requirements because important stages such as well drilling, transportation, and processing were not included. However, as noted previously, the water requirements for other stages of well development and production tend to be small relative to those for hydraulic fracturing (Clark et al., 2013).

**TABLE 2 Bakken Well Water Consumption Normalized by Output**

| Scenario # | HF Water (gal/well) | Maintenance Water (gal/day) | EUR (bbl) | Well Lifetime (yr) | Normalized Lifetime Water Requirement (gal water/gal oil) |
|---|---|---|---|---|---|
| 1 | 2,400,000 | 0 | 550,000[b] | 30 | 0.10 |
| 2 | 2,400,000 | 0 | 270,000[c] | 30 | 0.21 |
| 3 | 2,400,000 | 200[d] | 550,000[b] | 30 | 0.20 |
| 4 | 2,400,000 | 400[a] | 550,000[b] | 30 | 0.29 |
| 5 | 2,400,000 | 600[a] | 550,000[b] | 30 | 0.39 |
| 6 | 2,400,000 | 200[d] | 270,000[c] | 30 | 0.40 |
| 7 | 2,400,000 | 400[a] | 270,000[c] | 30 | 0.60 |
| 8 | 2,400,000 | 600[a] | 270,000[c] | 30 | 0.79 |
| 9 | 2,400,000 | 200[d] | 550,000[b] | 20 | 0.17 |
| 10 | 2,400,000 | 400[a] | 550,000[b] | 20 | 0.23 |
| 11 | 2,400,000 | 600[a] | 550,000[b] | 20 | 0.29 |
| 12 | 2,400,000 | 200[d] | 270,000[c] | 20 | 0.34 |
| 13 | 2,400,000 | 400[a] | 270,000[c] | 20 | 0.47 |
| 14 | 2,400,000 | 600[a] | 270,000[c] | 20 | 0.60 |

Sources: [a] Helms 2013; [b] EIA 2011; [c] Cook 2013; [d] Estimate based upon industry input

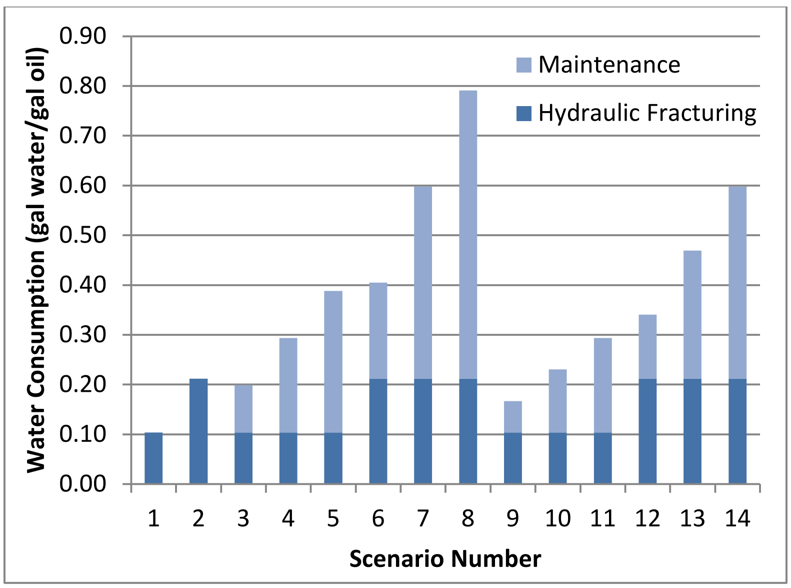


**FIGURE 5 Normalized Lifetime Water Consumption Scenarios**

## 3.4 DOMESTIC WATER DEMAND

The rapid growth in oil development in the Bakken play has led to large increases in the local population, which also has an effect on water consumption. Water demand in the region has increased due to the daily personal needs of the oilfield workers—a population size that is significant in comparison to the previous population of the area. To be complete, it is important that any analysis of the increased regional water demand caused by oil development in the Bakken play include demand for domestic water use by people who would not otherwise be in the region were it not for the oilfield development. Unfortunately, it is very difficult to determine exactly what portion of the population increase in western North Dakota over the past five years has been due to Bakken development. Rosters of oilfield workers are difficult to obtain, come from many sources, and are constantly changing. The most recent U.S. decennial census count failed to capture many oilfield workers because of their transient nature (Hodur and Bangsund, 2013).

The best estimate found for the population of oilfield service workers comes from North Dakota State University (Hodur and Bangsund, 2013). The study estimates, among other things, the oilfield service population for Williams County in 2012 and forecasts it five years later in 2017. Williams County contains the City of Williston, which is the commercial center of activity in the Bakken region and is currently the fastest growing micropolitan area in the country, by percent growth (U.S. Census Bureau, 2014b). Because estimates for the entire Bakken region were not found, and because Williams County is currently the center of population growth in the Bakken region, the estimates for Williams County are used here to characterize the impact of all Bakken development on public water demand.

According to Hodur and Bangsund (2013), the oilfield service populations of Williams County in 2012 and 2017 are estimated to be approximately 49,000–51,000 and 66,700–70,100, respectively. For comparison, the U.S. Census Bureau–estimated permanent resident population of Williams County in 2012 was 26,744 (U.S. Census Bureau, 2014a). Using average domestic water demand and population data from the latest USGS records (USGS, 2005), an average per-capita domestic water demand of 85,560 gallons was calculated for Williams County. This per-capita figure was then multiplied by the estimates for the service worker populations to produce the estimated additional domestic water demand in Williams County due to oil development in the Bakken (see Table 3). This analysis did not attempt to quantify differences that may exist in per capita domestic water use between the oilfield service population and the previous permanent population of the area, and thus may over or under estimate domestic water consumption.

**TABLE 3 Domestic Water Demand from Oilfield Service Population**

| Estimate | 2012 | 2017 |
|---|---|---|
| Oilfield Service Population[a] | 50,000 | 68,400 |
| Service Population Domestic Water Use (millions of gallons) | 4,280 | 5,850 |

[a] Source: Hodur and Bangsund 2013

The 4,280 million gallons of additional domestic water use estimated for Williams County in 2012 is only slightly less than the 4,290 million gallons estimated to have been used for the hydraulic fracturing of all oil wells in the Bakken play in 2012. Assuming that service populations grew throughout the Bakken region in 2012 (not just Williams County), this analysis estimates that the domestic water demand impact of oilfield workers may be at least as large as the industrial water demand impact from the actual oil development activities. However, this relationship may not be true for post-development oilfield operation. As Table 2 illustrates, maintenance water needs may greatly increase industrial water demand during the lifetime of the well. In addition, the population of long-term (beyond 2017) maintenance workers was not included in the North Dakota State University study. Therefore, a specific conclusion cannot yet be drawn concerning the lifetime relationship between domestic and commercial water demand from Bakken oil development. Generally, it appears that domestic water use is a significant part of overall water demand from this development.

# 4 WATER SOURCES

Finding cost-effective sources of fresh water for oil development in the Bakken play is becoming increasingly difficult. Currently, much of the water used for hydraulic fracturing is sourced from public or private water distribution sites, known as water depots, and trucked to the well site (Kurz et al., 2011; Scheyder, 2013). Water depots can source their water from groundwater reserves or from surface water. However, the only reliable source of surface water in the western part of North Dakota is the Missouri River System—including Lake Sakakawea, the third-largest manmade reservoir in the country. Withdrawals from Lake Sakakawea are limited by the U.S. Army Corps of Engineers (Shaver, 2012, Kurz et al., 2011), and development in the Bakken is trending farther away from it (Stepan et al., 2010). Transporting water is expensive and, as a result, many oil developers source their water from the closest water depot—often a private water depot that uses groundwater (Scheyder, 2013).

However, groundwater depots alone cannot meet future demand (Shaver, undated; Stepan et al, 2010). As of August 2012, there were 85 permitted water depots in the Bakken region, 73 of which source from groundwater (Shaver, 2012). Up to 3.7 billion gallons of groundwater are permitted for withdrawal annually; up to 10.3 billion gallons are permitted for withdrawal from surface waters (one permit for withdrawal from Lake Sakakawea accounts for 7.8 billion gallons of this total) (Shaver, 2012). According to these totals, the water supply system in the Bakken region of North Dakota should be able to meet the hydraulic fracturing demand estimated by this report (4.29 billion gallons in 2012) by utilizing surface water sources. The 2012 estimate for hydraulic fracturing demand does not account for future growth in hydraulic fracturing activities, nor does it include growth in water demand for domestic use and other activities associated with oil development.

Owners of water depots do not pay for the water that they sell, and with so much demand for water, great pressure to expand the water depot system is being exerted by landowners who could profit by installing depots on their land, as exhibited by the high number of permit applications in recent years (Kurz et al., 2011; Scheyder, 2013). While many new withdrawal permits are pending, the combination of permit applications being contested by environmental groups and the permitting authority (the North Dakota State Water Commission) being concerned about shrinking groundwater resources means that some of the permit applications will likely be denied (Kurz et al., 2011; Shaver, undated).

The conclusion from this analysis and stated in the existing literature is that North Dakota is dependent on surface water to meet its hydraulic fracturing water demand (Shaver, undated; Kurz et al., 2011). Despite the shortage in groundwater availability, western North Dakota appears to have plenty of water; it is contained in surface water in the Missouri River system (Kurz et al., 2011; Kiger, 2013; Scheyder, 2013). Research for this report using annual stream flow data from USGS broadly confirms the large amount of surface water present (see Table 4), although it should be noted that this report did not investigate how much of this surface water resource is legally available for use. Determining water rights to all surface water in the Bakken region is well beyond the scope of this study. However, the largest surface water body in the area by far, Lake Sakakawea, has at least 32.5 billion gallons of annual surplus water that is being made available by the U.S. Army Corps of Engineers (see below). The North Dakota State Water Commission appears to believe there is plenty available, since it is encouraging the expanded use of Missouri River system water (Stepan et al., 2010).

**TABLE 4 2012 USGS Stream Flow by HUC-8 Subbasin Compared to Water Demand for Hydraulic Fracturing**

| HUC-8 Subbasin | Demand (gal) | Stream Flow (gal)[a] | Demand as a Percentage of Surface Flow |
|---|---|---|---|
| Beaver | 1.49E+07 | 3.16E+09 | 0.47% |
| Big Muddy | 2.03E+07 | 3.22E+10 | 0.06% |
| Brush Lake Closed Basin | 1.99E+07 | 1.96E+10 | 0.10% |
| Charlie-Little Muddy | 2.26E+07 | 3.75E+10 | 0.06% |
| Des Lacs | 5.98E+07 | 6.09E+09 | 0.98% |
| Headwaters Souris River | 4.33E+07 | No Data | – |
| Knife | 2.66E+08 | 1.90E+10 | 1.40% |
| Lake Sakakawea | 2.24E+09 | 8.31E+10 | 2.70% |
| Little Muddy | 3.02E+08 | 4.84E+09 | 6.25% |
| Long Creek | 1.16E+08 | No Data | – |
| Lower Little Missouri | 6.99E+08 | 2.07E+10 | 3.37% |
| Lower Yellowstone | 1.57E+08 | 1.78E+11 | 0.09% |
| Middle Little Missouri | 1.14E+08 | 7.58E+09 | 1.51% |
| Upper Heart | 1.08E+08 | 9.97E+09 | 1.08% |

[a] Source: USGS 2013

As noted above, access to the water and its transportation to well sites can be an issue, but at least one major project has made the use of water from the Missouri River easier. The Western Area Water Supply Project is a network of pipelines being constructed to supply potable water for municipal, rural, and industrial needs in a large area surrounding the hub of Bakken activity in North Dakota: the City of Williston (Western Area Water Supply Project, 2014; Kiger, 2013). Because there is excess capacity in the system, the government-backed cooperative in charge of the project is allowing up to 20 percent of its water to be distributed and sold for hydraulic fracturing activities, which some private water depot owners see as a threat (Scheyder, 2013). In 2009 and 2010, permit applications were made to allow withdrawal of over 7.8 billion gallons annually from Lake Sakakawea. The company applying for these permits planned to distribute the water via underground pipeline to areas where Bakken drilling is occurring (Stepan et al., 2010). In December 2010, the U.S. Army Corps of Engineers, which controls water diversion from Lake Sakakawea, temporarily made available 32.5 billion gallons of surplus water annually until 2015. During this time, a study to examine a permanent reallocation may be conducted (U.S. Army Corps of Engineers, 2010).

Another possible source of water for Bakken development is the use of brackish groundwater or the reuse of saline flowback water from hydraulic fracturing activity. The water would have to be treated for it to be suitable for reuse. More information on this possibility is contained in the following section. While flowback water is not currently being reused on a large scale in the Bakken, independent water providers see water treatment/recycling technology as the main threat to their business in the future (Kiger, 2013). As explained below, it appears to be a viable technology, but the economics of deploying it at scale in the Bakken are not yet known.

# 5 PRODUCED WATER MANAGEMENT

After a shale well is hydraulically fractured, water flows back out of it—typically in large volumes for the first several days after fracturing activities cease. Normally, smaller amounts of water will continue to be produced along with the oil for the lifetime of the well. The water produced from the well is a mixture of the water that was injected into it and naturally occurring water that was previously locked in the shale formation. Produced water is normally saline (due to dissolved solids acquired in the shale formation), sometimes laced with NORM, and must be treated for reuse or properly disposed of.

The salinity of produced water varies among different shale plays. It also differs based on factors such as the specific well location, volume of water produced, and length of time flowback water is exposed to the formation (Stepan et al., 2010; Nolen, 2011; Mantell, 2011). Therefore, the TDS detected in produced water can vary widely within a play. Nevertheless, some plays clearly produce water with higher TDS levels than others—see Table 5. Produced water in the Bakken play tends to be among the most saline of all the major plays in the United States (Shaffer et al., 2013).

**TABLE 5 Produced Water TDS Levels from Major U.S. Shale Plays**

| Shale Play | TDS (mg/L) |
|---|---|
| Barnett | 60,000[a]<br>500 – 200,000[b]<br>50,000 – 140,000[c] |
| Bakken | 35,000 – 400,000[d]<br>150,000 – 219,000[e] |
| Fayetteville | 25,000[a]<br>3,000 – 80,000[b]<br>15,000[c] |
| Haynesville | 120,000[a]<br>500 – 250,000[b] |
| Marcellus | 180,000[a]<br>10,000 – 300,000[b]<br>40,000 – >120,000[c] |
| Woodford | 110,000[a] |

Sources: [a] Nolen 2011; [b] Alleman 2011; [c] Mantell 2011; [d] Shaffer et al. 2013; [e] Stepan et al. 2010

The quantity of water produced also varies between plays. Stepan et al. (2010) found that in the Bakken play, 17 to 47 percent of the injected volume is produced within 10 days of reopening the well after hydraulic fracturing. While this is a wide range, even at the low end this is one of the highest 10-day flowback fractions of any major shale play (Clark et al., 2013), meaning there is a comparatively large amount of produced water that must be dealt with.

Currently, produced water in the Bakken play is extensively disposed of through deep-well injection (Kurz et al., 2011). The produced water is pumped back down into the ground into depleted oil formations or deep saline water reservoirs. With oil wells currently being drilled and hydraulically fractured at a rate of over 1,800 per year, many disposal wells are required to handle the flowback water. Over 400 salt water disposal wells are currently operating in North Dakota, over 100 of which have been installed since the beginning of 2008 (NDDMR, 2014).

An alternative disposal/source option is the reuse of produced water for hydraulically fracturing other wells. Such recycling is practiced to varying degrees in other shale plays. Little or no recycling occurs in the Haynesville shale, while close to 90 percent of produced water is recycled in the Marcellus (Clark et al., 2013). Currently, no produced water is recycled during normal operations in the Bakken play. Stepan et al. (2010) determined that widespread recycling of produced water in the Bakken play is not likely to become economically viable, primarily due to very high salinity (as high as 220,000 mg/L). The high salinity is difficult, energy intensive, and expensive to treat.

However, very recently, steps have been taken toward recycling some produced water in the Bakken play. In August 2013, Halliburton unveiled a water recycling process specifically developed for the Bakken play, which it was ready to offer to oil producers in the region (Geiver, 2013). The North Dakota Industrial Commission, in December 2013, approved a proposal by Statoil for the “first significant pilot test of recycling water for hydraulic fracturing in the Bakken,” which will use Haliburton’s technology (Shale Play Water Management, 2014).

# 6 CONCLUSIONS

Much research is needed to fully characterize and adequately analyze water use and management in the Bakken shale oil play. There is an overall lack of publically available information on this topic, particularly in the peer-reviewed literature. However, from the information gleaned for this report, it seems clear that water consumption due to development of the Bakken play is a significant impact for the residents of western North Dakota. It also appears that there are pathways to avert possible shortages in groundwater availability by making use of surface water resources and possibly through recycling. There appears to be abundant water resources in the Missouri River system, including Lake Sakakawea, although access for future demand is not fully settled. Water recycling is a nascent technology in the Bakken play and not yet economically proven, but it could contribute to meeting future water demand. Research is needed to develop more data characterizing produced water volumes and quality so that ranges for volumes can be narrowed and the possibility of recycling can be better understood. Ongoing research with recycling efforts specific to the Bakken is important for a region where local groundwater shortages are possible and water transportation distances can be great. The role of maintenance water, possibly unique to the Bakken play in the United States, needs to be elucidated so that water use over the lifetime of shale oil wells can be accurately determined.

Water use for hydraulic fracturing in the Bakken play grew from 680 million gallons in 2008 to almost 2.3 billion gallons in 2012. Municipal water use from the oil services population in Williams County alone accounted for almost as much demand as hydraulic fracturing. Oil development in the Bakken play is expected to continue to grow through 2020 and beyond (Hodur and Bangsund, 2013), and water use for hydraulic fracturing and the oil services population will grow proportionately unless efficiencies are found or recycling becomes widespread. If surface water is utilized, shortages should be avoided. However, planning is necessary to ensure that groundwater resources are not overly relied upon to support this expected growth in Bakken oil development.

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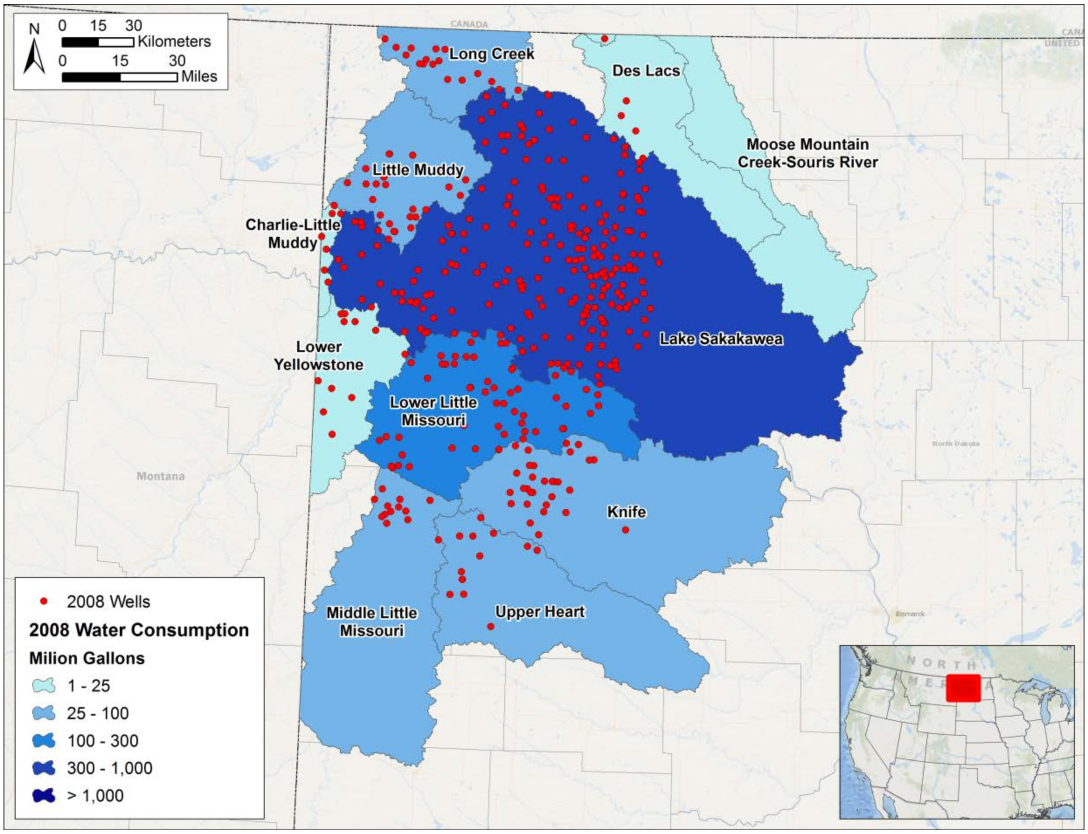
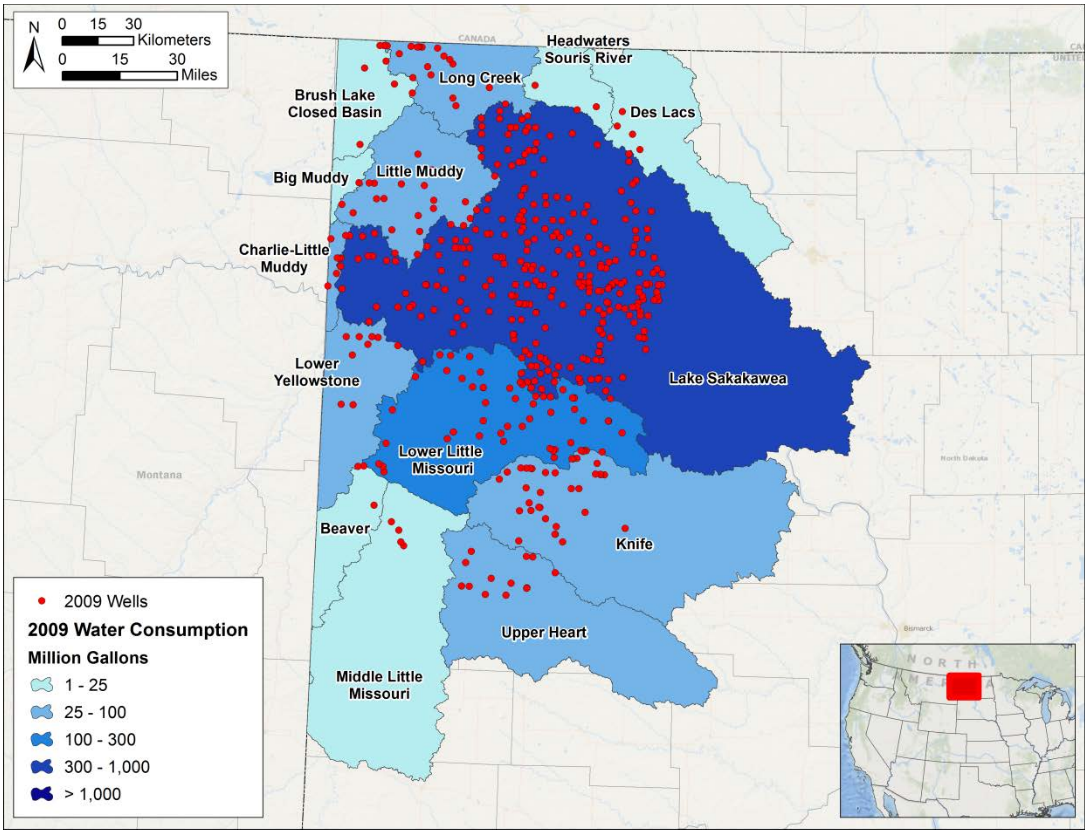
# APPENDIX: HYDRAULIC FRACTURING LOCATIONS AND WATER USE BY HUC-8 SUBBASIN IN THE NORTH DAKOTA BAKKEN SHALE PLAY (2008-2012)

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Lake Sakakawea
Lower Little
Missouri
Montana
North Dakota
Beaver
Knife
2009 Wells
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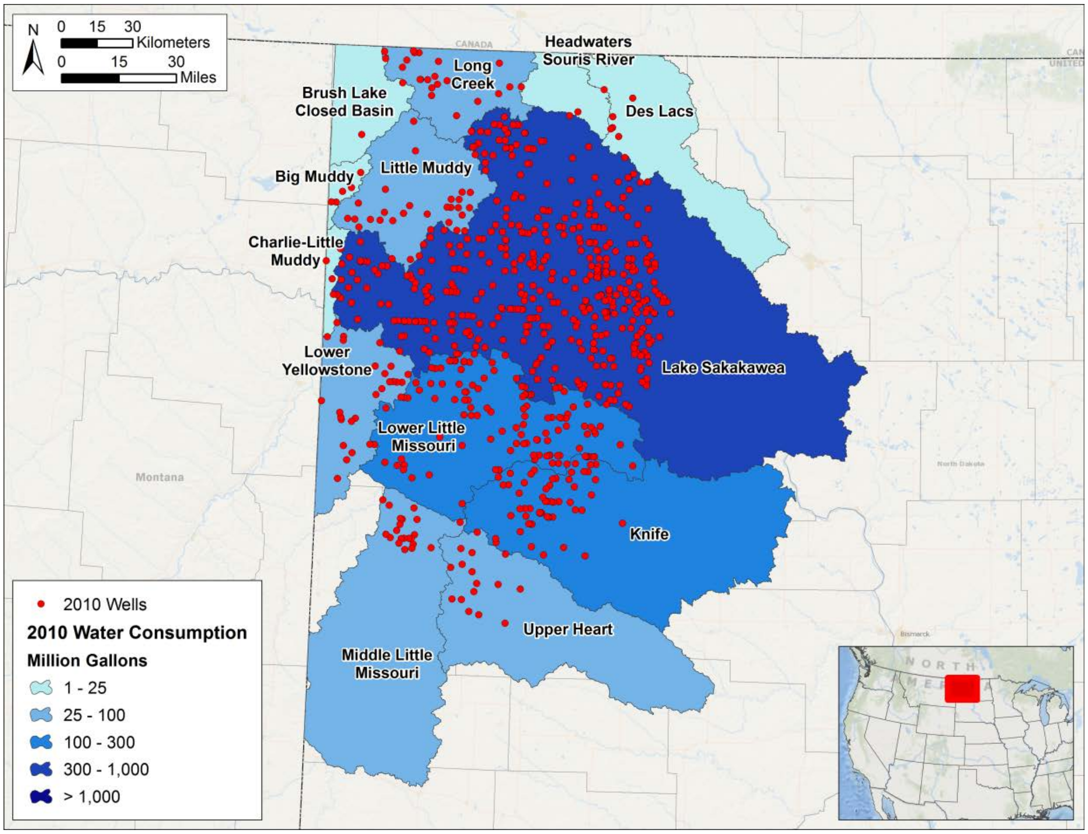
Middle Little
Missouri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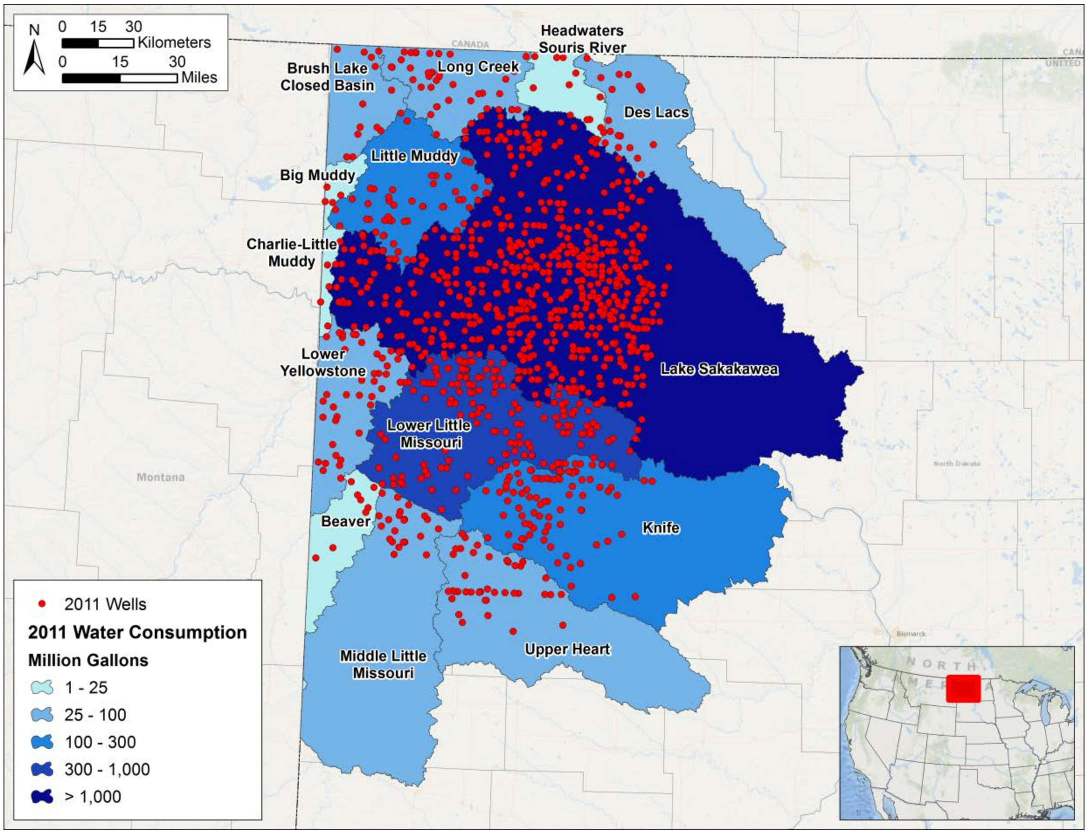
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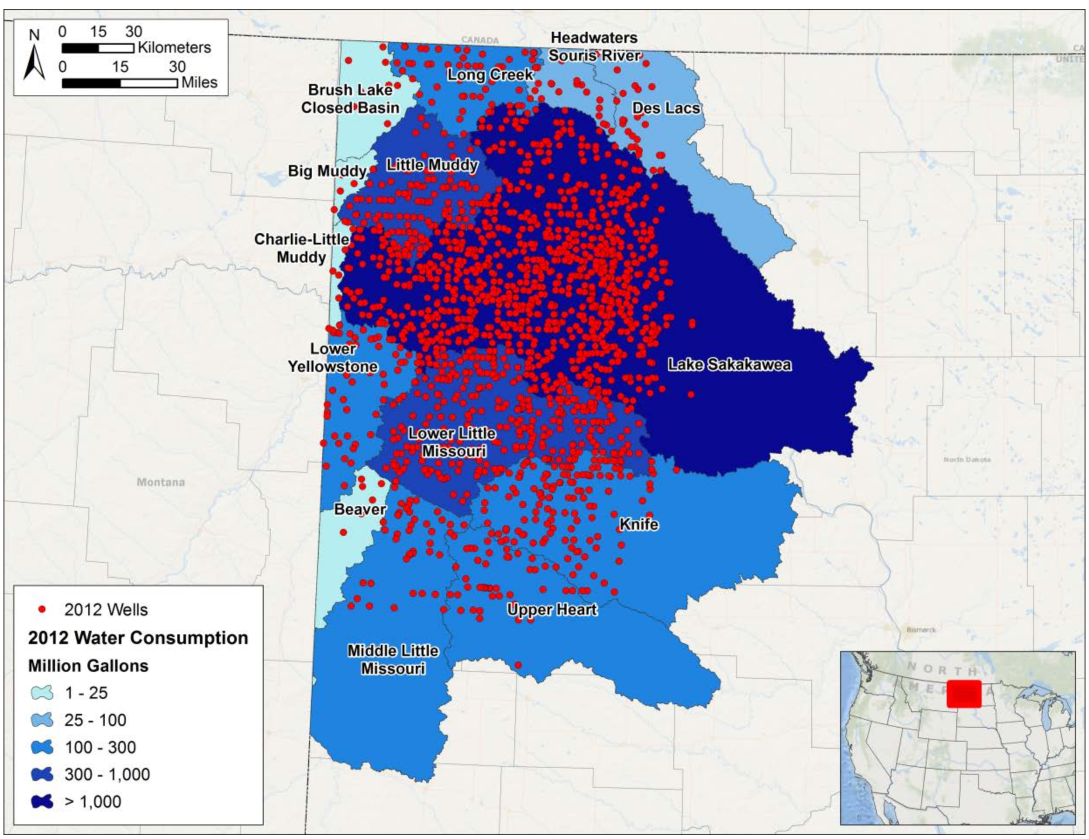
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