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Estimating National Water Use Associated with Unconventional Oil and Gas Development

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Water Availability and Use Science Program of the U.S. Geological Survey

The U.S. Geological Survey's (USGS) Water Availability and Use Science Program (WAUSP) goals are to provide a more accurate assessment of the status of the water resources of the United States and assist in the determination of the quantity and quality of water that is available for beneficial uses. These assessments would identify long-term trends or changes in water availability since the 1950s in the United States and help to develop the basis for an improved ability to forecast water availability for future economic, energy-production, and environmental uses. The National Water Census (http://water.usgs.gov/watercensus/), a research program of the WAUSP, supports studies to develop new water accounting tools and assess water availability at the regional and national scales. Studies supported by this program target focus areas with identified water availability concerns and topical science themes related to the use of water within a specific type of environmental setting. The topical study described in this fact sheet will focus on understanding the relation between production of unconventional oil and gas (UOG) for energy and the water needed to produce and sustain this type of energy development. This relation applies to the life-cycle of renewable and nonrenewable forms of UOG energy and includes extraction, production, refinement, delivery, and disposal of waste byproducts. Water-use data and models derived from this topical study will be applied to other similar oil and gas plays within the United States to help resource managers assess and account for water used or needed in these areas. Additionally, the results from this topical study will be used to further refine the methods used in compiling water-use data for selected categories (for example, mining, domestic self-supplied, public supply, and wastewater) in the USGS's 5-year national water-use estimates reports (http://water.usgs.gov/watuse/).

Water Use and Unconventional Oil and Gas Development

Nonrenewable forms of energy, such as fossil fuels, are currently the primary forms of energy used within the United States (U.S. Energy Information Administration, 2015a). During 2014, crude oil was primarily used for transportation and accounted for 35.4 percent of all U.S. energy consumption, whereas natural gas and coal consumption was primarily used for electric power generation and accounted for 27.9 percent and 18.3 percent, respectively (U.S. Energy Information Administration, 2015a). Crude oil and natural gas deposits are categorized as conventional or unconventional (also referred to as continuous) based primarily on their disposition within the environment (fig. 1). Conventional oil and gas accumulations have discrete deposits with well-defined hydrocarbon-water contacts (where the hydrocarbons are

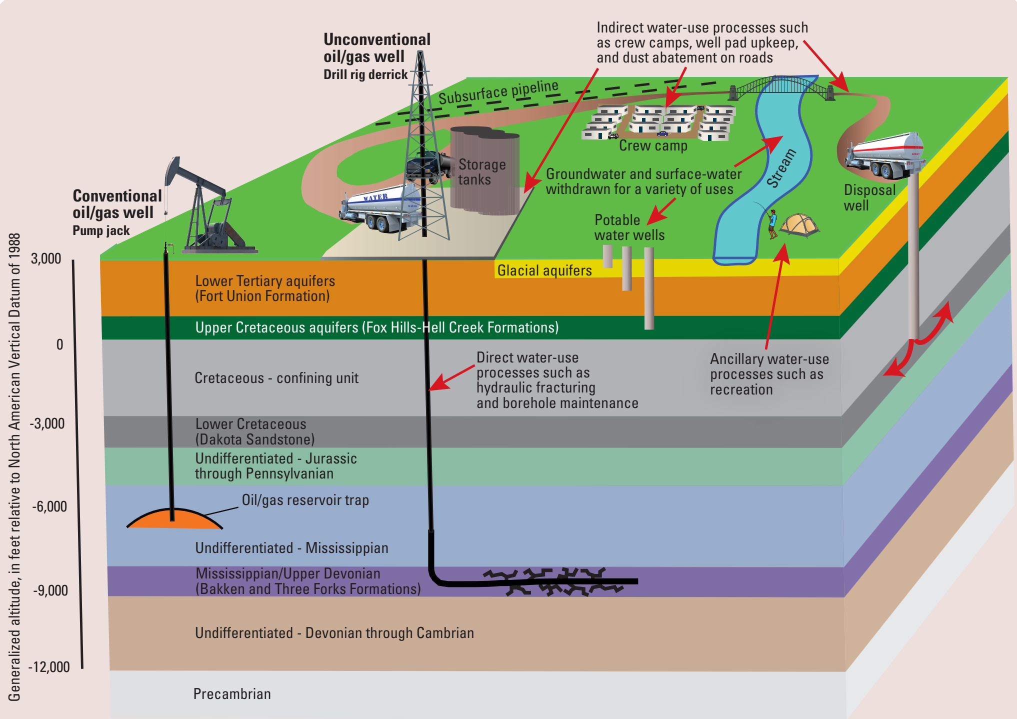

Figure 1. Schematic showing various water-use and energy-development components in an area of conventional and unconventional oil and gas development of the Williston Basin. (Modified from Caldwell and others, 2015, and Seth Haines, U.S. Geological Survey, written commun., 2015.)

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buoyant on a column of water), generally high matrix permeabilities, apparent seals and traps, and relatively high recovery factors (U.S. Geological Survey, 2015). Because of the ease of extraction, conventional oil and gas extraction has historically been the most cost effective to develop through the use of vertical wells. Unconventional oil and gas (UOG) accumulations are described as an oil or gas resource, or both, that is dispersed continuously throughout a geologic formation(s) rather than existing as discrete, localized occurrences (such as those in conventional accumulations) and often require special technical drilling and recovery methods (U.S. Geological Survey, 2015).

Starting in the 2000s, technological advances, scarcity of access to conventional oil and gas accumulations, and the rise of oil and gas prices resulted in development of UOG accumulations. The UOG resources in the United States are being produced using horizontal drilling technologies, which expose a larger amount of reservoir for thin horizontal units to the wellbore compared to vertical wells (fig. 1). Once the well is drilled, fluid (typically water with additives) and proppant (solid material such as silica sand or man-made ceramics) is pumped into the well at high pressure, opening cracks that release oil, gas, or both through a process known as hydraulic fracturing (or fracking), which stimulates movement of hydrocarbons in tight (low permeability and porosity, typically shale) formations (Gaswirth and others, 2013). Rapid UOG development throughout the Nation has led to hundreds of thousands of wells being hydraulically fractured annually (Gallegos and Varela, 2015).

Water availability and the potential for reduction in aquifer storage volumes are important considerations in UOG settings. The process of developing an oil or gas well in a tight shale formation requires large volumes of water for initial fracturing processes: about 2 million gallons per oil well and 4.1 million gallons per gas well (Gallegos and Varela, 2015; Nunez, 2015). Additional water is needed for re-fracturing and borehole maintenance; indirect water uses, such as crew camps and road dust abatement; and ancillary uses, such as supportive energy industries, commercial developments, and recreation. These additional water uses have not been quantified on a regional scale. This fact sheet describes the plans and background for this topical study and emphasizes Phase I.

Background and Selection of Sites

The USGS Energy Resources Program completes scientific investigations to assess the potential for undiscovered oil and gas resources in priority geologic provinces in the United States and around the world. The assessments are based on geologic elements and petroleum processes that allow examination of source rock, hydrocarbon generation, migration, and trapping units and mechanisms (U.S. Geological Survey National Assessment of Oil and Gas Resources Team and Biewick, 2015). Plays are established primarily according to similarities of the rocks and

Synopsis of Plans

The topical study to develop methods to estimate water use for UOG development in the United States is a multiphase study:

- *Phase I.*—Quantify water use associated with UOG development at a pilot site, develop an estimation model, and determine associated uncertainty.
- *Phase II.*—Test the estimation model in other similar plays throughout the Nation to evaluate model capabilities for estimating water use associated with UOG development.
- *Phase III.*—Finalize estimation model and prepare for national assessment.

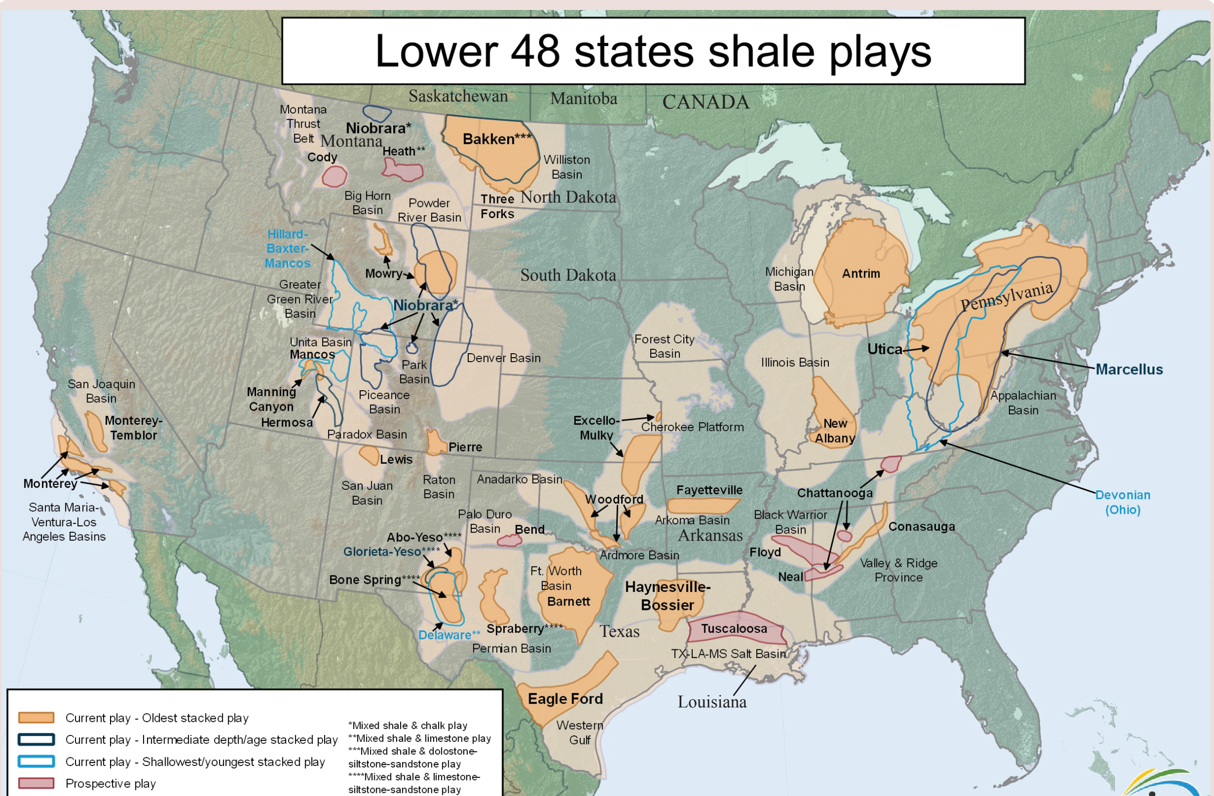

Figure 2. Current (April 2015) and prospective shale plays in the conterminous United States (from U.S. Energy Information Administration, 2015b).

continuity in which oil and gas resources exist. The last USGS comprehensive national assessment was completed in 1995 and used plays as the basic level of assessment (U.S. National Oil and Gas Resource Assessment Team, 1995). The U.S. Energy Information Administration (2015b) has identified current (April 2015) shale plays in the conterminous United States (fig. 2). Since 2000, the USGS National Oil and Gas Assessment has been reassessing basins of the United States that are considered to be priorities for oil and gas resource development, rather than assessing all the basins of the United States, using subdivisions of the total petroleum system as the basic level of assessment. The 32 basins that are being reassessed represent about 97 percent of the discovered and undiscovered oil and gas resources of the United States (U.S. Geological Survey, 2013).

Of the 32 basins reassessed for undiscovered oil and gas resources, 14 were reassessed for unconventional oil (fig. 3). The total mean undiscovered, technically recoverable volume of oil in the United States was estimated to be about 13 billion barrels (U.S. Geological Survey, 2013). Most (56 percent or about 7.4 billion barrels) of mean undiscovered oil is within the Williston Basin (fig. 3; Gaswirth and others, 2013).

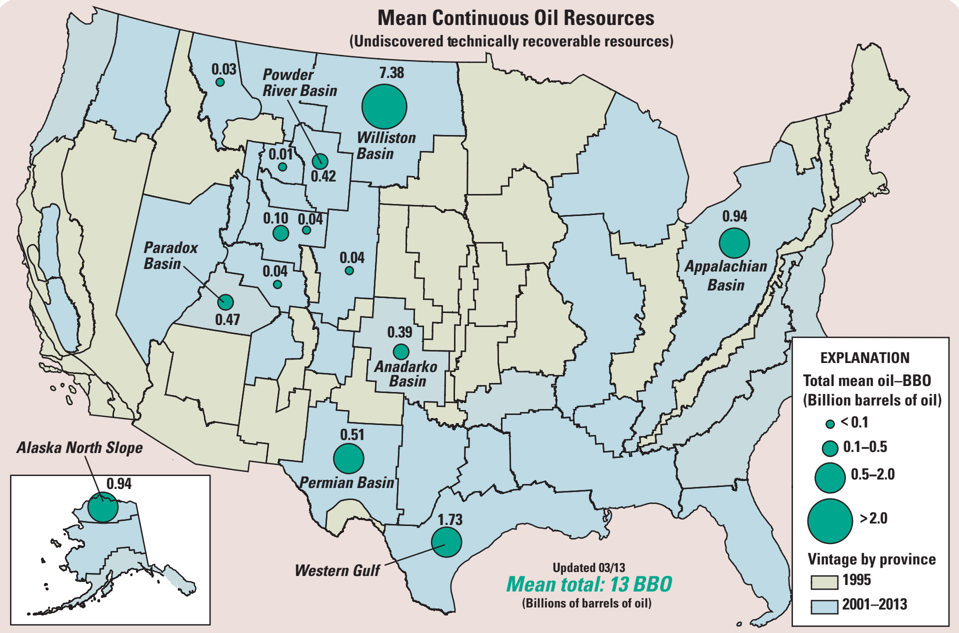

Figure 3. Mean continuous, technically recoverable oil resources in the United States (from U.S. Geological Survey, 2013). Most (56 percent) of the mean undiscovered oil is within the Williston Basin (Gaswirth and others, 2013).

The Williston Basin was selected as the pilot site for Phase I of this topical study. Since 2005, technological advances have rapidly expanded the production from continuous formations in the Northern Great Plains, most notably the Bakken and Three Forks Formations of the Williston Basin in North Dakota and Montana. The Williston Basin provides a unique opportunity to characterize water use associated with UOG development because water use in the Williston Basin was relatively stable from year to year before 2005 (Kenny and others, 2009); therefore, any substantive change in water use since may be attributed to water-use needs to support UOG development. In addition, variability in oil prices affects oil production in the area (North Dakota Department of Mineral Resources, 2016). Recent (2015) reduction in oil prices has resulted in a decrease in new UOG development in the area (Helms, 2015), which may provide the unique ability to better characterize water use associated with rise and decline of UOG development in the Williston Basin and, subsequently, water use in other UOG plays in North America.

Similar patterns in production to that of the Williston Basin can be assumed in other continuous formations around the United States, all of which collectively highlight the need to develop an approach to better characterize water use associated with UOG development. These continuous formations include the Barnett Shale (Ft. Worth Basin, Texas), Eagle Ford (Gulf Coast Basin, Texas), Haynesville-Bossier Shale (Gulf Coast Basin, Louisiana and Texas), Fayetteville Shale (Arkoma Basin, Arkansas), and Marcellus Shale/Utica Shale (Appalachian Basin, Pennsylvania) (fig. 2). Selection of plays for Phase II of this topical study will emphasize areas with the most recent and robust UOG development, and will be used to further develop and calibrate the digital model and provide useful parameters for extrapolation to other UOG plays in the United States.

Williston Basin Pilot Site

The Williston Basin covers more than 100,000 square miles in western North Dakota, northwestern South Dakota, eastern Montana, and the Canadian Provinces of Saskatchewan and Manitoba. Oil and gas was discovered in the Williston Basin in the 1920s and 1930s, but producing well development did not start in North Dakota until the early 1950s when the first well was drilled in 1951 in northwest North Dakota (American Oil and Gas Historical Society, 2015). Conventional (vertical) drilling techniques were profitable within several plays in the Williston Basin but not the Bakken Formation. It was not until the late 1990s when horizontal drilling, hydraulic fracturing technology, and refinements in other support technologies became readily available that the production from the Bakken Formation of low permeability and porosity became economically feasible. Oil production in North Dakota alone has increased from a nominal level (about 35–40 million barrels per year) in 2005 (North Dakota Department of Mineral Resources, 2016) to more than 1 million barrels per day in 2014 (North Dakota State Water Commission, 2015). More than 10,000 unconventional wells were producing from the Bakken and Three Forks Formations in North Dakota in 2015 (Helms, 2015). In 2013, the USGS estimated 7.4 billion barrels of technically recoverable oil for the U.S. part of the Devonian-age Three Forks Formation and the Devonian- and Mississippian-age Bakken Formation of the Williston Basin (fig. 4) (Gaswirth and others, 2013).

Almost 20,000 acre-feet of surface water and groundwater were used for hydraulic fracturing in North Dakota in 2013, amounting to 5 percent of consumptive water use in the State (North Dakota State Water Commission, 2015). In addition, the extremely high salinity of formation water from the Bakken

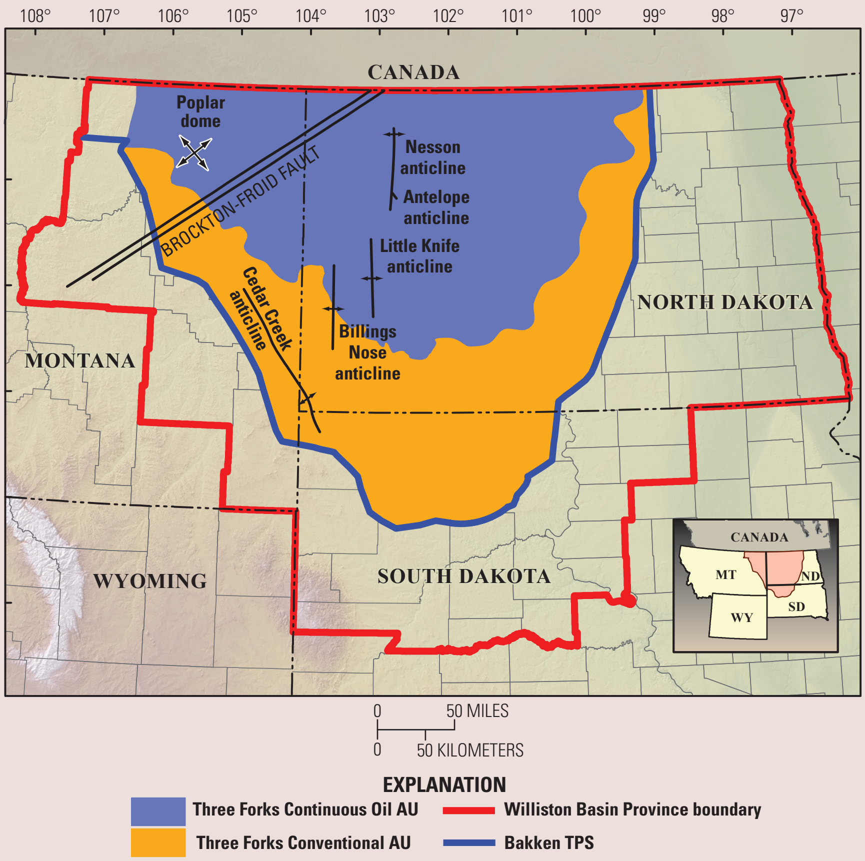

Figure 4. Boundaries of the Williston Basin Province, Bakken total petroleum system (TPS), and Three Forks assessment units (AUs) within the United States (from Gaswirth and others, 2013). The Williston Basin Province is drawn on county and State borders that were completely or partially within the geologically defined Williston Basin. A total petroleum system (TPS) consists of one or more assessment units (AUs), which are mappable pairs of a petroleum system in which discovered and undiscovered fields constitute a single, relatively homogeneous population.

and Three Forks plays can require more than three times more water (6.6 million gallons or more) after the initial fracturing to maintain these wells during the course of their life (30–40 years) (Kiger, 2013; Schuh, 2010). Wastewater produced during drilling, hydraulic fracturing operations, and recovery of oil and gas can be dealt with in several ways including disposal by way ofan underground disposal well (an example of a disposal well is shown in fig. 1), treatment followed by disposal to surface-water bodies, or recycling (with or without treatment) for use in future hydraulic fracturing operations (U.S. Environmental Protection Agency, 2015a). Disposal wells are the primary management practice for wastewater from hydraulic fracturing in most regions of the United States (U.S. Environmental Protection Agency, 2015b).

Energy development is expected to progress in upcoming years within the Williston Basin, with a continued increase in the number of wells drilled and an increase in the associated worker populations (Cwiak and others, 2015). These projections are raising questions by local, State, Tribal, and Federal stakeholders as to the source and availability of water to meet this future demand, effects on downstream users, and effects on the environment. The objectives of this topical water-use study are directly based on the questions generated within the Williston Basin and echoed across the Nation on characterizing water use associated with UOG development.

Phase I of the Water Use Topical Study

The objectives of Phase I of this topical study are to quantify water use associated with UOG development in the Williston Basin, develop estimation methods for water use that can be incorporated into a digital model, and quantify uncertainty associated with water-use estimation methods. This phase began in 2016.

Water-Use Analysis and Data Needs

Water use associated with UOG development in the Williston Basin will be analyzed for Phase I of the topical study. These analyses include water use; sources (such as surface water or groundwater); reuse; and disposal data for direct processes (for example, hydraulic fracturing and borehole maintenance), indirect processes (for example, crew camps, well pad upkeep, and road dust abatement), and ancillary processes (for example, as supportive industries, commercial developments, or recreation) related to UOG development in the Williston Basin from 2005 to 2015 (fig. 1). Available water-use data (direct, indirect, and ancillary) will be compiled and prioritized based on significance to overall water-use processes. Remaining data needs will then be assessed, and a plan will be

More than 10,000 unconventional wells were producing from the Bakken and Three Forks Formations in North Dakota in 2015 (Helms, 2015). Photograph by Joanna Thamke (U.S. Geological Survey).

Temporary crew camps, such as this one near Medora, North Dakota, represent just one of many indirect uses of water that increase in areas of unconventional oil and gas development. Photograph by Joanna Thamke (U.S. Geological Survey).

Water depots, such as this one near Watford, North Dakota, use freshwater from groundwater and surface water to fill water trucks to supply water for unconventional oil and gas development. Photograph by Joanna Thamke (U.S. Geological Survey).

developed for obtaining those data. Water-use data collected for the Williston Basin will be made available through reports and data releases. Concurrent with water-use analysis of the Williston Basin,
characteristics (such as water-use magnitude, UOG processes, and productivity) for a select number of the shale plays in the 14 basins reassessed for unconventional oil (fig. 3; U.S. Geological Survey, 2013) will be evaluated.

Model Development

Methods will be developed to estimate UOG life-cycle processes (that is, water sources, water use, consumptive use, and disposal) for this topical study. Data compiled and collected, and estimation methods, will be used to develop a digital model to estimate water use associated with UOG development. Uncertainty techniques will be evaluated for determining the accuracy of UOG water-use estimates. Additionally, water-use data are not available for all UOG plays and for all lifecycle processes, which also will need to be represented within the uncertainty measurements. The documentation of methods to estimate water use associated with UOG development will be published. The final model and uncertainty estimation tools will be tested in the Williston Basin and the results also will be published before being applied to other similar UOG plays in the United States in Phases II and III.

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