Williston Basin Groundwater Availability, United States and Canada

The Williston Basin contains important oil and gas resources for the Nation. Freshwater supplies are limited in this semiarid area, and oil and gas development can require large volumes of freshwater. Groundwater is the primary source of water for many water users in the Williston Basin, so to better understand these resources, the U.S. Geological Survey (USGS) assessed the groundwater availability in this area. The final phase of this assessment included a computer model that simulates how groundwater flows in the aquifer systems and simulates how changes in water use and natural conditions may affect the water resources. These results provide a tool for land and water-resource managers to determine how water can be used for multiple purposes in the Williston Basin. For additional information about this assessment and more in-depth descriptions and results, see Long and others (2018).

Assessing Groundwater Availability on a National Scale

The USGS's Water Availability and Use Science Program (formerly the Groundwater Resources Program) is assessing groundwater availability throughout the United States to gain a better understanding of the status of the Nation's groundwater resources and how changes in land use, water use, and climate may affect those resources. The goal of this national assessment is to improve our ability to forecast water availability to meet human and ecological needs. Assessments will be completed for the Nation's principal aquifer systems (large regional systems of multiple geologic units that can provide substantial quantities of water) to help characterize how much water is currently available, how water availability is changing, and how much water we can expect to have in the future (Reilly and others, 2008).

The primary objective of the Williston Basin groundwater availability study is to identify spatial and temporal changes in the overall water budget by more fully determining the processes that control how water enters, moves through, and leaves the groundwater system. Development of tools such as computer models can help hydrologists to better understand this groundwater system, to analyze forecasts about this system from natural and human stresses, and to analyze water quality and ecosystem health throughout the region.

The Importance of Groundwater and Energy Reserves in the Williston Basin

The Williston Basin (fig. 1) is a shallow and wide basin that underlies a land area of about 135,000 square miles beneath Montana,

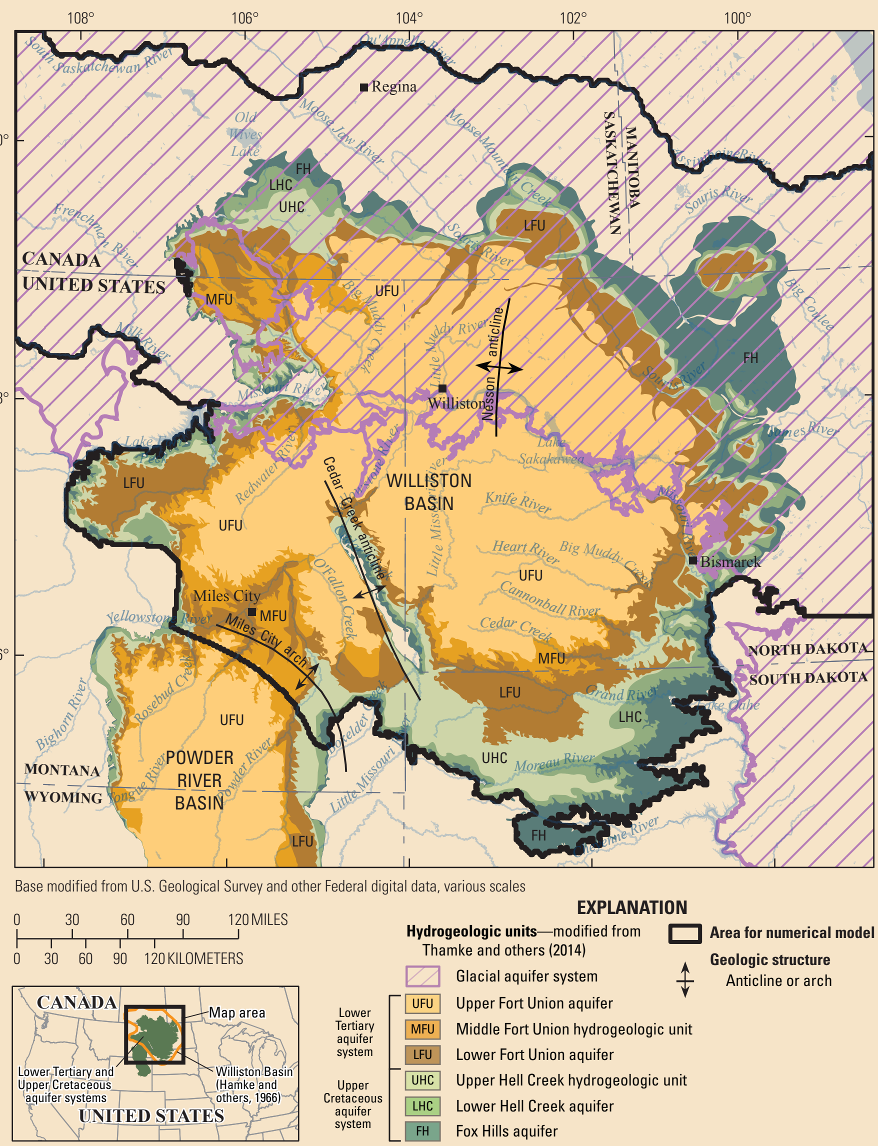

Figure 1. The three uppermost aquifer systems in the Williston Basin comprise seven hydrogeologic units. These three aquifer systems are the most accessible and primary sources of groundwater because they overlie as much as 3,000 feet of shale. Map modified from Long and others, 2018.

North Dakota, and South Dakota in the United States and Manitoba and Saskatchewan in Canada. In this basin, the three uppermost aquifer systems—the glacial, lower Tertiary, and Upper Cretaceous aquifer systems—are as much as 3,000 feet (ft) thick and overlie shale that serves as a barrier to underlying saline aquifers. Within the study area, the climate is semiarid, is driest in the southwest (6 inches per year [in/yr] of precipitation), and is wettest in the east (greater than 30 in/yr of precipitation). The recharge to groundwater is about 10 percent of the precipitation. Water from streams and rivers (surface water) is heavily appropriated in most of the study area (Schuh, 2010) and is not always a dependable water supply in stream reaches that may flow intermittently. Groundwater levels have declined markedly in parts of the study area, resulting in a need for users to obtain water from other sources (North Dakota State Water Commission, 2015) and resulting in development of recommendations for conservation measures (Montana Department of Natural Resources and Conservation, 2014).

The Williston Basin has been an important domestic oil and natural gas producing region since the 1950s. Previously inaccessible formations, such as the Bakken and Three Forks Formations, have been developed substantially since the mid-2000s because of improved precision horizontal drilling and hydraulic fracturing methods. These development methods require considerable volumes of freshwater, mostly from shallow aquifers or surface waters. Water use per oil well for hydraulic fracturing increased by about six times from 2005 to 2014 and averaged about 2.4 million gallons per well in 2014 (Scanlon and others, 2016). There were 3.7 million hydraulic fracturing treatments (sometimes called “frac jobs”) reported during 2000–15 in and near the Williston Basin (Barnhart and others, 2018). As the demand for energy increases in the United States, so does the demand for water used to produce many forms of that energy. Fortunately, one of the wettest periods of precipitation was during 2007–14 (Long and others, 2018), which was concurrent with substantial energy development in the area.

Understanding Groundwater Availability in the Williston Basin

The concept of groundwater availability is more than just how much water can be pumped from any given aquifer. Groundwater availability is a complex topic that is dependent on many factors, including the quantity and quality of water, climate variability, human use, aquifer characteristics, changes in groundwater storage, and changes in the ease of extracting groundwater. Initial steps to understand and assess the groundwater availability of the three uppermost principal aquifer systems in the Williston Basin included development of a three-dimensional framework of the geology and hydrology that defined characteristics such as aquifer thickness and depth to water (Thamke and others, 2014), and development of a conceptual model that defined groundwater-flow directions and amounts of surface water and groundwater (Long and others, 2014). Using this information, a computer model of groundwater flow was developed to help assess changes in groundwater storage and groundwater levels that potentially would result from human activity and climate variability (Davis and Long, 2018a; Davis and Long, 2018b; Davis and Long, 2018c). This model is a mathematical representation of groundwater flow through the three aquifer systems using information about aquifer properties and groundwater recharge, discharge, and levels, and physical processes governing groundwater flow. Models are useful tools for investigating how the complex groundwater system is affected by the interconnected variations in water supply, water demand, management strategies, exchange of groundwater and surface-water, and climatic variation on the groundwater system.

A few key findings from this study include the following:

- The groundwater table in aquifers near the land surface closely resembles the undulating land topography, and flow directions are from upland areas toward streams (fig. 2).
- In the deeper aquifers, groundwater-flow directions follow a regional pattern from southwest to northeast, and minimal influence is from the land surface (fig. 2).
- The main components of recharge to groundwater are precipitation and infiltration from streams and reservoirs. Irrigation recharge and groundwater inflow from outside the Williston Basin were determined to be only a small part of total groundwater recharge.
- The deepest aquifer system has the smallest water budget—less than one-third as large as each of the other two shallower systems—yet accounts for about 70 percent of the total well withdrawals in the basin.

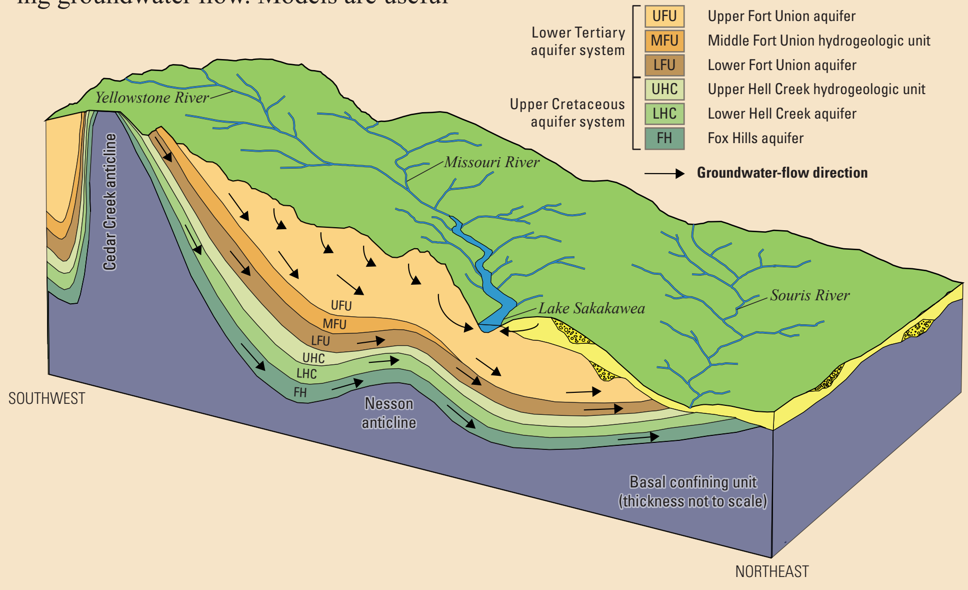

Figure 2. Groundwater in the shallower aquifer systems generally flows towards rivers and streams, whereas groundwater in the deeper aquifer systems flows towards the northeastern part of the Williston Basin. Diagram modified from Long and others, 2018.

- Most groundwater discharge is to streams and reservoirs. Groundwater pumping is a small part (less than 5 percent) of the total water budget; however, groundwater withdrawals from wells have increased from 1960 to 2005 and have caused groundwater levels to drop locally.

In addition to the general understanding of the aquifer systems, specific scenarios were evaluated using the computer model. Key notable findings resulted from scenarios that include evaluating the following:

- *Scenario 1.*—Effects of flowing wells (wells that discharge water without a pump because the water in the well reaches the ground surface under the natural pressure of the aquifer) in the Fox Hills and Hell Creek aquifers. Model simulations of continuous flow from these wells during 1960–2035 indicate the following:
    - Groundwater levels would decline the most during 1960–2005; however, the area of drawdown would continue to enlarge after 2005.
    - Areas with the largest groundwater-level declines (more than 100 ft) are near the Yellowstone, Missouri, and Little Missouri Rivers, where most flowing wells are located. However, groundwater-level declines would flatten after 2010 because modeled flow rates would decrease slightly in wells because of decreasing hydraulic pressures, and nearly one-quarter of the simulated wells would cease to flow by 2035 (fig. 3).
    - Modeled flow rates for flowing wells are much larger than actual flow rates, possibly because of inadequate sealing or corrosion of wells that could result in water leaking into the overlying aquifers and not discharging at the land surface.
- *Scenario 2.*— Effects of a 10-year study-area-wide drought. Groundwater declines are greatest (as much as 230 ft) in the climatically wet eastern part of the Williston Basin during drought conditions. Groundwater in the dry western areas of the Williston Basin was less susceptible to drought conditions.
- *Scenario 3.*—Effects of a 10-year drought with increased pumping for energy development during 2006–15.
    - The reduced amount of groundwater recharge during drought conditions had a greater effect on the water budget than increased groundwater withdrawals because of energy development.
    - The total effect to groundwater levels by adding pumping wells to support energy development is small regionally, but locally, the effects to groundwater levels can be substantial.

Groundwater is often the only water resource available in this drought-prone region. Photograph near Bainville, Montana, during a drought period; used with permission from Whitten Photography.

Large quantities of freshwater are needed year round for oil and gas development. Overall, groundwater use for oil and gas development has minimal effect on the basin; however, locally the effect can be substantial. The water stored in these tanks during the winter near Watford City, North Dakota, will be used as part of the hydraulic fracturing process. Photograph used with permission from Whitten Photography.

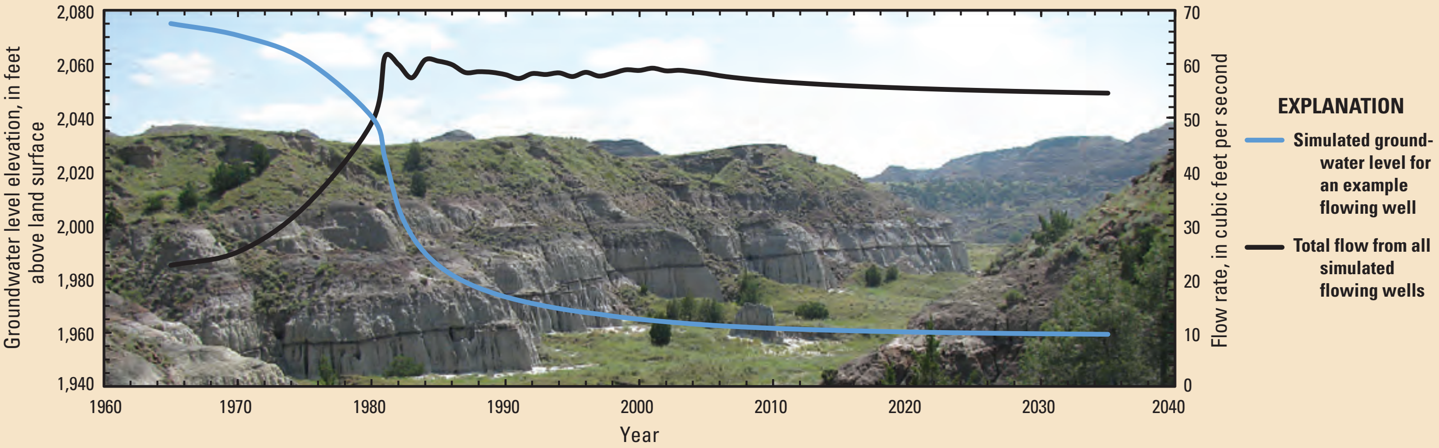

Figure 3. The computer model simulation demonstrates that as total flow from all simulated flowing wells (black line) in the Fox Hills and Hell Creek aquifers increased, the groundwater level (blue line) declined in response. Background photograph of Hell Creek Formation by Kevin Dennehy, U.S. Geological Survey.

Where to Find More Information

For more information about this study, including downloadable data and publications, go to https://www.usgs.gov/centers/wy-mt-water/science/williston-and-powder-river-basins-groundwater-availability-study.

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By Joanna N. Thamke, Andrew J. Long, and Kyle W. Davis

Photograph of lower Tertiary aquifer system, 8 miles south of Medora, North Dakota. Photograph by Whitten Photography, July 2012, used with permission.

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