Prepared in cooperation with the Bureau of Land Management

Potential Effects of Energy Development on Environmental Resources of the Williston Basin in Montana, North Dakota, and South Dakota—Water Resources

Chapter C of
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Scientific Investigations Report 2017–5070–C
Version 1.1, October 2022

U.S. Department of the Interior
U.S. Geological Survey

Front cover. An oil well pump jack in a grassland in Stark County, North Dakota. Photograph by Larry D. Igl, U.S. Geological Survey.

Back cover. An oil well pump jack in a grassland in Fallon County, Montana. Photograph by Larry D. Igl, U.S. Geological Survey.

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By Timothy T. Bartos, Steven K. Sando, Todd M. Preston, Gregory C. Delzer, Robert F. Lundgren, Rochelle A. Nustad, Rodney R. Caldwell, Zell E. Peterman, Bruce D. Smith, Kathleen M. Macek-Rowland, David A. Bender, Jill D. Frankforter, and Joel M. Galloway

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
barrel (bbl; petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
billion gallons (Bgal)	3,785,412	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
million acre-feet (MAF)	1.2335×10^9	cubic meter (m^3)

Multiply	By	To obtain
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Energy	
kilowatthour (kWh)	3,600,000	joule (J)
megawatthour (MWh)	3.6×10^9	joule (J)
gigawatthour (GWh)	3.6×10^{12}	joule (J)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).

A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2015 was from October 1, 2014, to September 30, 2015.

Stable isotope ratios of oxygen ($^{18}O/^{16}O$) and hydrogen (^{2}H [deuterium]/^{1}H) are shown in delta (δ) notation as $\delta^{18}O$ and $\delta^{2}H$, in per mil (parts per thousand).

Abbreviations

AL	action level
BFEG	Bakken Federal Executive Group
CGCSRL	Geophysics and Geochemistry Science Center Laboratory
CO_2	carbon dioxide
$\delta^{2}H$	a measure of the ratio of stable isotopes hydrogen-2 and hydrogen-1
$\delta^{18}O$	a measure of the ratio of stable isotopes oxygen-18 and oxygen-16
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
GIS	geographic information system
HUC	Hydrologic Unit Code
MBMG	Montana Bureau of Mines and Geology
MCL	maximum contaminant level
MDEQ	Montana Department of Environmental Quality
NAWQA	National Water-Quality Assessment
NDDH	North Dakota Department of Health
NDSWC	North Dakota State Water Commission
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus Version 2
NPWGD	National Produced Waters Geochemical Database

NWI	National Wetlands Inventory
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
NWQMC	National Water-Quality Monitoring Council
PRISM	Parameter-elevation Regression on Independent Slopes Model
PV	photovoltaics
Reclamation	Bureau of Reclamation
RM	river mile
SDDENR	South Dakota Department of Environment and Natural Resources
SMCL	secondary maximum contaminant level
SNG	synthetic natural gas
STEWARDS	Sustaining the Earth's Watersheds–Agricultural Research Database System
STORET	Storage and Retrieval data warehouse
SWSTAT	U.S. Geological Survey Surface-Water Statistics program
TDS	total dissolved solids
USACE	U.S. Army Corp of Engineers
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WQP	Water-Quality Portal

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Abstract

The Williston Basin has been a leading oil and gas producing area for more than 50 years. While oil production initially peaked within the Williston Basin in the mid-1980s, production rapidly increased in the mid-2000s, largely because of improved horizontal (directional) drilling and hydraulic fracturing methods. In 2012, energy development associated with the Bakken Formation was identified as a priority requiring collaboration toward improved timeliness of issuing permits for new wells combined with reasonable measures to maintain environmental quality. Shortly thereafter, the Bakken Federal Executive Group was created to address common challenges associated with energy development. The Bakken Federal Executive Group partner agencies identified a gap in current understanding of the cumulative environmental challenges attributed to energy development throughout the area, resulting in an effort to aggregate scientific data and identify additional research and information needs related to natural resources within areas of energy development in the Williston Basin. As part of this effort, water resources in the area (including groundwater; streams and rivers; and lakes, reservoirs, and wetlands) were characterized and described in terms of physical occurrence, flow characteristics, recharge, water quality, and water use. Similarly, waters produced during energy-development activities also were characterized even though these waters are not considered usable resources within the area. Groundwater resources were characterized by the major hydrogeologic units, or aquifers, identifying the units that supply most groundwater used for domestic, stock, agricultural, and industrial purposes. The groundwater characterization included other deeper hydrogeologic units in the Williston Basin that may be a useable source of water with treatment, have utility as a reservoir for reinjection of produced waters, or be a source of minerals and energy resources. A generalized groundwater budget and flow system identifying the sources of recharge (stream infiltration, precipitation, and movement [leakage] from other aquifers) and the general groundwater flow direction is included for each of the major hydrogeologic units. Rivers and streams within the Williston Basin with 10 or more years of continuous streamflow data were identified. For a subset of these sites, streamflow characteristics, including the monthly and annual mean flow, were generated to identify seasonal and interannual changes in streamflow and thus provide information on the drivers and reliability of streamflow at the seasonal or multiyear scale. Daily streamflow and annual extreme flows (peak and low flow) also were estimated for the subset of sites. The daily streamflow and annual extreme flow values provide information on short-term or extreme events that are relevant to infrastructure design and evaluating spills, leaks, or accidental discharges of water or petroleum products. Surface-water features (lakes, ponds, and wetlands) were classified using the Cowardin system and identified on the National Wetlands Inventory maps generated by the U.S. Fish and Wildlife Service. The spatial distribution of the surface-water features was analyzed by State, county, and specifically in comparison to the Prairie Pothole Region. The proximity of the surface-water features to energy development infrastructure (specifically oil or gas well pads) was evaluated. It was determined that, although oil or gas wells are often near a surface-water feature, most surface-water features do not have wells nearby, with the exception of wells in the Prairie Pothole Region. Water-quality data were aggregated from two data sources: (1) the Water-Quality Portal, sponsored by the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), and National Water Quality Monitoring Council; and (2) a data compilation completed as part of the USGS National Water-Quality Assessment project. The Water-Quality Portal integrates publicly available water-quality data from databases maintained by the USGS, EPA, and U.S. Department of Agriculture, including water-quality data from Tribal, State, and local databases. Water-quality data for 15 commonly measured water-quality constituents were aggregated for groundwater, rivers and streams, and lakes and reservoirs. For each aggregated dataset (groundwater, rivers and streams, and lakes and reservoirs), analyses of the water-quality data included summary statistics, maps of spatial distribution of constituent values, boxplots of constituent values by timeframe or hydrogeologic unit, spatial comparisons of site locations and constituent values to petroleum well density, and comparisons

of the constituent values measured to EPA drinking-water standards/guidelines. Produced water includes all fluids brought to the surface along with the targeted hydrocarbons as part of the oil and gas exploration and extraction processes. These fluids may include formation water (waters that co-exist with rock/oil/gas), hydraulic fracturing fluids, and other combinations of water and chemicals used during oil and gas well drilling, development, treatments, recompletions, and workovers. Produced water datasets were aggregated from two sources: the USGS National Produced Waters Geochemical database (ver. 2.1) and a series of projects focused specifically on sampling produced water in the Williston Basin from 2010 to 2014. The National Produced Waters Geochemical database was useful for a general understanding of produced-water chemistry. Produced waters are characterized by extreme salinity and contain elevated concentrations of other constituents (including arsenic, barium, cadmium, lead, zinc, radium-226/radium-228, and ammonium) that could negatively affect water and aquatic resources if released. Produced waters also have a generally unique chemical (isotopic) signature that may be useful in tracking water from different geologic units; for example, the oxygen/deuterium and strontium ratio values measured in brine waters from the Bakken Formation are distinct from brines collected from other geologic units in the Williston Basin.

Water-use information related to energy production in the area also was aggregated and summarized. The summary of water use is not limited to oil and gas production but includes water used to produce all types of energy resources in the Williston Basin, including coal/lignite, thermoelectric power, oil and gas, hydropower, biomass and biofuels, wind, geothermal, and solar. Each State has its own methods for regulating and reporting water usage within its jurisdiction. These methods can introduce problems when examining water use from sources, such as the Missouri River or Fox Hills aquifer, that are shared across political boundaries. Without the one-to-one match for usage types and amounts used from a water source, it is difficult to develop a comprehensive water budget for the water source being evaluated. A large amount of freshwater is required to prepare a well for oil and gas well production; in some cases, 3 to 7 million gallons of water are needed per well. The EPA estimates that hydraulic fracturing in the Williston Basin uses between 70 to 140 billion gallons per year. Water also is used for myriad other purposes related to ancillary oil and gas extraction. In addition to water used for immediate energy development, the expanded human workforce migrating into the area and other support staff who have moved into the area during the development also use water.

Research and information needs were identified that could be relevant in the evaluation of the effects of energy development on water resources. Information needs related to the evaluation of groundwater resources include the following: improved potentiometric-surface maps for glacial units; availability of a uniform stream network digital geographic coverage that spans the international boundary with Canada; enhanced surface-water use information with regards to the gain and loss of streamflow to shallow groundwater, which would increase understanding groundwater and surface-water interactions; and expanded geophysical assessments. Gaps in the availability of streamflow data include the lack of information on ice-jam flooding despite potential for effects to infrastructure (pipelines, roads, and facilities) and an understanding of the cumulative effects of largely undocumented stock and diversion dams. Although this study resulted in the aggregation of a large quantity of water-quality data, the availability of consistently collected, systematically processed and reported data over large parts of the Williston Basin is sparse. Few samples have been analyzed for constituents that may indicate the effect of energy development on water resources. Constituents that could be considered include boron, chloride, bromide, iodine, fluoride, manganese, lithium, radium, strontium isotopes, volatile organic compounds, and isotopes of inorganic ions (such as hydrogen and carbon). Collaboration between Tribal, Federal, State, and local entities to identify a common study design, common monitoring constituents, and consistent sampling locations would generate datasets with broad utility and would likely result in overall cost savings for monitoring over time. Similarly, there is a need for standardized sample collection, processing, laboratory analytical methods, and the collection of ancillary data for produced waters sampling. Additional characterization of the range of chemical, microbial, and isotopic compositions and quantities of “end-member” produced waters, and the collection of time-series datasets to document the changes in produced waters during and after well development also were needs identified during this study. Water-use estimates would be improved through the implementation of comprehensive studies of water use from groundwater and surface-water sources using consistent methodologies across the Williston Basin. The submission of chemical and water data related to hydraulic fracturing collected by the oil and gas industry would add to the quantity of available data. Consistent implementation of regulations and monitoring controls across political boundaries (State, county, and international) would further improve the consistency of data available for the estimates of water use.

Introduction

The Williston Basin energy development area (hereinafter referred to as the “Williston Basin”), includes parts of Montana, North Dakota, and South Dakota in the United States and the provinces of Manitoba and Saskatchewan in Canada (fig. 1), and has been a leading energy production area since the 1950s (Anna and others, 2011; Gleason and Tangen, 2014; Thamke and others, 2014). Because demands for energy continued to increase, energy development in the Williston Basin increased substantially beginning in the mid-2000s, primarily because of improved horizontal drilling and hydraulic fracturing methods used in previously inaccessible formations, such as the Bakken and Three Forks Formations (fig. 2) (Gaswirth and others, 2013).

Figure 1. Geographic extent of the glacial and Northern Great Plains aquifer systems in the United States in relation to the Williston Basin.

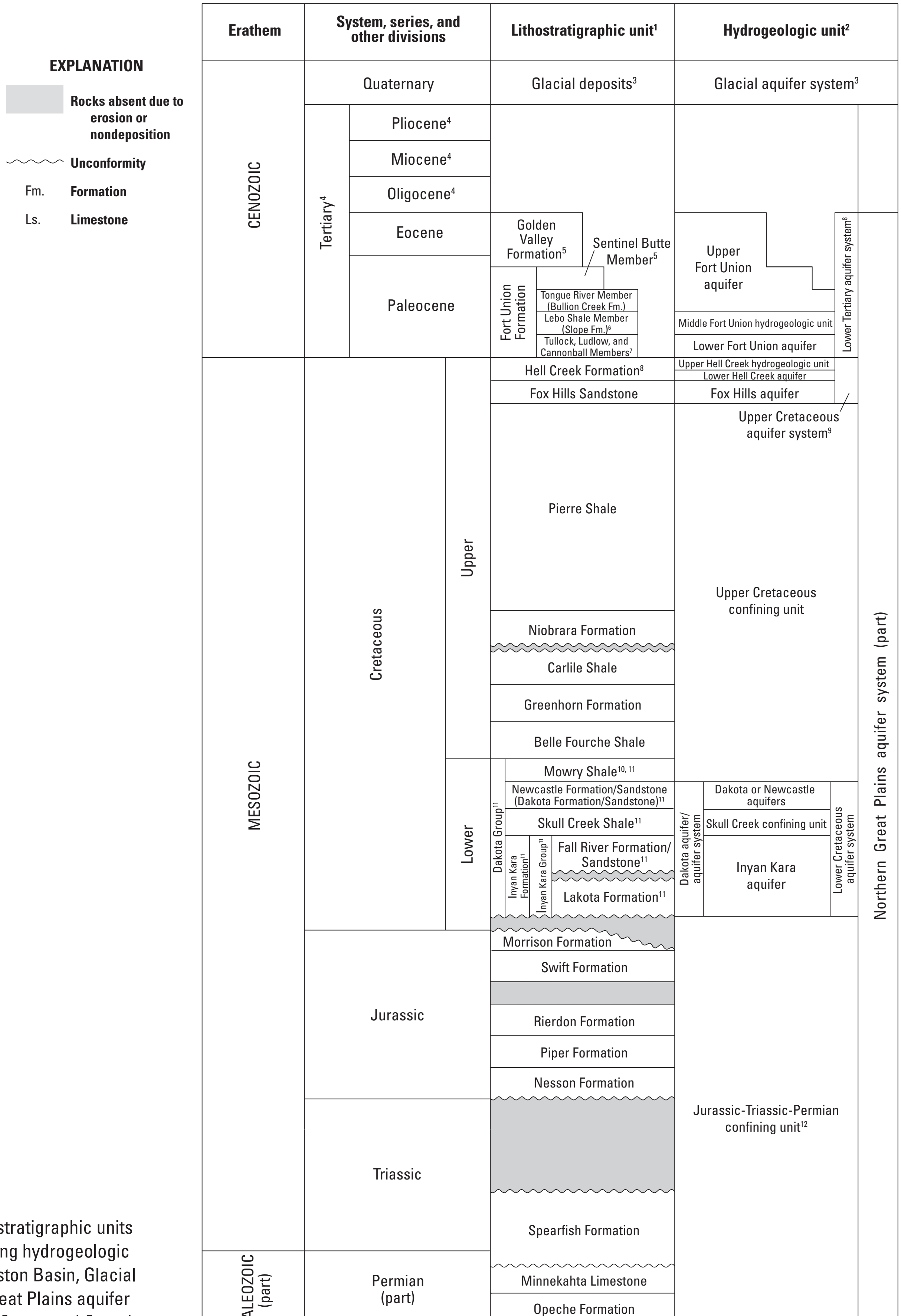


Figure 2. Lithostratigraphic units and corresponding hydrogeologic units in the Williston Basin, Glacial and Northern Great Plains aquifer systems, United States and Canada.

Erathem	System, series, and other divisions	Lithostratigraphic unit[1]	Hydrogeologic unit[2]			
PALEOZOIC (part)	Permian (part)	Minnelusa Group or Formation and equivalents[13]	Pennsylvanian aquifer system		Upper Paleozoic aquifers	Northern Great Plains aquifer system (part)
	Pennsylvanian					
	Mississippian	Big Snowy Group	Confining unit			
		Madison Group — Charles Formation	Madison aquifer[14]			
		Madison Group — Mission Canyon Limestone				
		Madison Group — Lodgepole Limestone				
		Bakken Formation	Bakken-Three Forks confining unit			
	Devonian					
		Three Forks Formation				
		Birdbear (Nisku) Formation	Confining unit Birdbear aquifer		Lower Paleozoic aquifers and confining units	
		Duperow Formation	Duperow aquifer			
		Souris River Formation	Confining unit Souris River-Dawson Bay aquifer[15]			
		Dawson Bay Formation				
		Prairie Formation	Confining unit			
		Winnipegosis Formation	Winnipegosis aquifer			
		Ashern Formation	Confining unit			
	Silurian					
		Interlake Formation	Interlake-Stonewall aquifer[16]			
	Ordovician	Stonewall Formation				
		Stony Mountain Formation	Confining unit	Cambrian-Ordovician aquifer system		
		Red River (Yeoman) Formation	Red River aquifer			
		Winnipeg Formation	Confining unit			
			Cambrian-Ordovician aquifer[17]			
	Cambrian	Deadwood Formation				
PRECAMBRIAN		Lower boundary of the Northern Great Plains aquifer system				

Figure 2. Lithostratigraphic units and corresponding hydrogeologic units in the Williston Basin, Glacial and Northern Great Plains aquifer systems, United States and Canada.—Continued

[1]Compiled from Bluemle (1983, 1988); Bluemle and others (1986); Vuke and others (2007); and Murphy and others (2009).

[2]Compiled or modified from Downey (1982, 1984a, b, 1986); Bredehoeft and others (1983); Butler, 1984; Case, 1984; Downey and Dinwiddie (1988); Busby and others (1991); Bachu and Hitchon (1996); Whitehead (1996); Benn and Rostron (1998); Alkalali (2002); Margitai (2002); Whittaker and others (2004); Palombi (2008); and Thamke and others (2014).

[3]Generally located north of the Missouri River.

[4]Upper Tertiary units (Pliocene, Miocene, and Oligocene) exist only in a small part of the study area and are not included herein.

[5]Golden Valley Formation present in local areas. Sentinel Butte Member present in central part of the Williston Basin and a small contiguous area in Montana.

[6]Pinches out north of the Missouri River. Mapped as the Tongue River Formation in South Dakota by Martin and others (2004).

[7]Cannonball Member present in the southern and eastern parts of the Williston Basin. Slope Formation is above the Cannonball Member in southern North Dakota. Ludlow Member is present in the southern part of North Dakota.

[8]Includes all but the lower part of the Ravenscrag Formation in Saskatchewan and the Turtle Mountain Formation in Manitoba (Thamke and others, 2014).

[9]Includes the lower Ravenscrag Formation (Paleocene), the Frenchman and Eastend Formations (Cretaceous) in Saskatchewan, and the Boissevain and Pierre Formations (Cretaceous) in Manitoba (Thamke and others, 2014).

[10]Mowry Shale is Lower Cretaceous but is included in the Upper Cretaceous confining unit.

[11]Inyan Kara identified as a formation in North Dakota (Murphy and others, 2009) and as a group consisting of the Fall River Sandstone and Lakota Formation in South Dakota (Fahrenbach, 2010). In North Dakota, the Inyan Kara Formation is grouped with the overlying Skull Creek Shale, Newcastle Formation, and Mowry Shale into the Dakota Group (Murphy and others, 2009). In the Montana portion of the Williston Basin, Inyan Kara generally is not currently (2020) used to identify equivalent strata; however, the Fall River Formation is currently used/recognized and strata equivalent to the Lakota Formation/Sandstone are identified as the Kootenai Formation (Vuke and others, 2007; Condon, 2000).

[12]Parts of the various lithostratigraphic units composing the Jurassic-Triassic-Permian confining unit are sufficiently permeable in some areas to contain local aquifers.

[13]Includes the Broom Creek, Tyler, and Amsden Formations where present (Bluemle and others, 1986).

[14]Also known as the Mississippian aquifer system (Downey and Dinwiddie, 1988; Bachu and Hitchon, 1996).

[15]Also known as the Manitoba aquifer (Whittaker and others, 2004).

[16]Also known as the Silurian-Upper Ordovician aquifer (Benn and Rostron, 1998) or the Ordo-Silurian aquifer (Whittaker and others, 2004).

[17]Also known as the Cambro-Winnipeg aquifer (Benn and Rostron, 1998) or the Cambro-Ordovician aquifer (Whittaker and others, 2004).

Executive Order 13604 (March 22, 2012) directs Federal agencies to improve the timeliness of issuing permits for new energy development with the Bakken Formation combined with reasonable measures to maintain environmental quality. Shortly thereafter, the BFEG (see chapter B of this report, table 1) was created to address common challenges associated with energy development, with a focus on understanding the cumulative environmental challenges attributed to energy development throughout the area. To improve understanding of the natural resources in the area, the U.S. Geological Survey (USGS), in cooperation with the Bureau of Land Management, began work to synthesize existing information on environmental resources in the area to support management decisions related to energy development.

Energy Development in the Williston Basin

Oil exploration began in the Williston Basin (fig. 1) a century ago in 1917, and large-scale production began in the 1950s with nearly continuous exploration since then (Ling and others, 2014). The early stages of production in the Williston Basin began with conventional oil and gas development using vertical wells that extracted hydrocarbons from structural or stratigraphic settings in which the hydrocarbons were trapped within a well-defined water-hydrocarbon interface (Schenk and Pollastro, 2002).

Oil production using conventional extraction methods peaked within the Williston Basin in the mid-1980s. Domestic production of both natural gas and oil has increased steadily since 2005 due to increased productivity from unconventional sources (Healy and others, 2015). Unconventional oil and gas resources, such as the Bakken Formation in the Williston Basin, include low-permeability sandstones and shales, often referred to as “tight-oil” formations, and consist of oil and gas dispersed through one or more geologic layers with no obvious water-hydrocarbon contact (Healy and others, 2015).

The two most important of technological advances that have enabled development of unconventional oil and gas resources within the Williston Basin and elsewhere are (1) horizontal (directional) drilling and (2) hydraulic fracturing (Healy and others, 2015). Horizontal (directional) drilling allows wells to extend several thousand feet horizontally within an oil or gas reservoir. Hydraulic fracturing enhances the permeability of the reservoir rock by applying high pressure using fluid mixtures to isolated sections of the well bore to create fractures in the rock. These hydraulic fracturing fluids open or enlarge fractures that can extend several hundred feet away from the well.

The Williston Basin experienced a large energy boom because of large-scale development of the underlying Bakken Formation. Estimated mean undiscovered volumes of 7.4 billion barrels (bbl) of oil, 6.7 trillion cubic feet (ft^3) of natural gas, and 0.53 bbl of natural gas liquids in the Bakken and Three Forks Formations (fig. 2) in the Williston Basin indicate energy development will continue in this area (Gaswirth and others, 2013).

Purpose and Scope

The purpose of this report is to describe the water resources in the Williston Basin in Montana, North Dakota, and South Dakota (fig. 1). Water resources are characterized in terms of the groundwater; streams and rivers; and lakes, reservoirs, and wetlands of the area. The resources also are described in terms of physical occurrence, flow characteristics, recharge, water quality, and water use. Waters produced during energy development activities also are discussed even though these waters are not considered usable resources in the area. The resources also are described in terms of research and information needs. This report provides information and data that can be used to develop effective techniques to assess issues related to energy development activities.

Table 1. Interpolated volumes, thicknesses, and horizontal hydraulic conductivity values of the glacial, lower Tertiary, and Upper Cretaceous aquifer systems in the Williston Basin (modified from Thamke and others, 2014).

[K_h, horizontal hydraulic conductivity; --, not available]

Hydrogeologic unit or aquifer system	Volume, in trillion cubic feet	Thickness, in feet	K_h, in feet per day
Glacial aquifer system	150	0–756	0.01–24
Lower Tertiary aquifer system	1,002	0–2,246	--
Upper Fort Union aquifer	549	0–1,917	0.14–9.8
Middle Fort Union hydrologic unit	145	0–520	0.01–7.8
Lower Fort Union aquifer	307	0–668	0.14–5.5
Upper Cretaceous aquifer system	1,005	0–1,047	--
Upper Hell Creek hydrologic unit	337	0–738	0.10–5.5
Lower Hell Creek aquifer	296	0–548	0.10–1.7
Fox Hills aquifer	372	0–422	0.06–1.0

Groundwater Resources

Groundwater in the Williston Basin (fig. 1) is present in aquifers composed of water-saturated and permeable unconsolidated glacial and alluvial deposits of Quaternary age, and water-saturated and permeable consolidated sedimentary bedrock ranging from Tertiary to Cambrian in age (fig. 2). Aquifers in the Tertiary- to Cambrian-age sedimentary bedrock and all intervening impermeable or low-permeability layers (confining units) in the Williston Basin are part of a thick, areally extensive regional transboundary aquifer system in the United States and Canada identified as the Northern Great Plains aquifer system (figs. 1 and 2) (Downey, 1984a, 1984b, 1986, 1987; Dinwiddie and Downey, 1986; Downey and others, 1987; Downey and Dinwiddie, 1988; Whitehead, 1996). In the United States, this aquifer system covers not only the Williston Basin in North and South Dakota and Montana, but also parts of Wyoming and a small area in northwestern Nebraska (fig. 1).

As shown in cross section *A–A′*, numerous permeable and intervening low-permeability lithostratigraphic units or parts of units compose the hydrogeologic units (aquifers/aquifer systems and confining units) of the regional Northern Great Plains aquifer system (figs. 1–3). Sedimentary bedrock aquifers consist primarily of Tertiary- and Cretaceous-age sandstones and Paleozoic-age carbonate rocks and less commonly of sandstones (Downey, 1984a, 1984b, 1986, 1987; Bredehoeft and others, 1983; Butler, 1984; Downey and others, 1987; Hannon, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996; Whitehead, 1996; Benn and Rostron, 1998; LeFever, 1998; Thamke and others, 2014). Precambrian-age igneous rocks that underlie the Northern Great Plains aquifer system (fig. 3) in the Williston Basin are deeply buried, yield little water, and are considered to be the lower boundary of the aquifer system (Downey, 1986; Downey and Dinwiddie, 1988; Bachu and Hitchon, 1996; Benn and Rostron, 1998).

Widely distributed unconsolidated glacial and locally present alluvial deposits overlie parts of the Northern Great Plains aquifer system throughout much of the Williston Basin. Water-saturated and permeable parts of these deposits are extensively developed (for example, Paulson, 1983; Winter and others, 1984) and are the sources of water to thousands of wells in the Williston Basin. Because shallow groundwater flow in these deposits is primarily local and substantially different from the predominantly deep confined regional flow in the underlying bedrock aquifers, glacial and alluvial aquifers generally are not included as part of the Northern Great Plains aquifer system (Downey, 1986; Downey and Dinwiddie, 1988; Whitehead, 1996).

Three uppermost principal aquifer systems supply most groundwater used in the Williston Basin. From shallowest (stratigraphically youngest) to deepest (stratigraphically oldest), these are the glacial, lower Tertiary, and Upper Cretaceous aquifer systems (fig. 2). The lower Tertiary and Upper Cretaceous aquifer systems are the uppermost units of the Northern Great Plains aquifer system (figs. 1, 2). These aquifer systems supply most freshwater used for domestic, stock, agricultural, and industrial purposes in the Williston Basin. Because most groundwater used in the study area is withdrawn from these three aquifer systems, they are described in greater detail herein than underlying aquifers/aquifer systems. The deeper Lower Cretaceous (sandstones), upper Paleozoic (sandstones and carbonate rocks), and lower Paleozoic (sandstones and carbonate rocks) aquifers/aquifer systems (fig. 2) are used rarely and undeveloped in most of the Williston Basin because of either uneconomical drilling depths, poor groundwater quality unsuitable for most uses without treatment, or both. Immediately outside of the Williston Basin, the Lower Cretaceous aquifer system and upper and lower Paleozoic aquifers are used where present at economical drilling depths, and where the quality of the groundwater is acceptable for use.

Most-Used Hydrogeologic Units

Thamke and others (2014) constructed a hydrogeologic framework that defined and described the three uppermost principal aquifer systems in the Williston Basin for the United States and Canada, placing emphasis on the lower Tertiary and Upper Cretaceous aquifer systems (fig. 4). This framework included a detailed description of the lithostratigraphic and hydrogeologic units composing three aquifer systems as shown in figures 4–8 and described in table 1. A three-dimensional representation of these aquifer systems in the Williston Basin is shown in figure 5.

The glacial, lower Tertiary, and Upper Cretaceous aquifer systems are hydraulically separated from all underlying Northern Great Plains aquifer system aquifers/aquifer systems by a confining unit composed primarily of 800 to more than 3,000 feet (ft) of low-permeability Upper Cretaceous marine shale (identified herein as the “Upper Cretaceous confining unit,” composed of strata in the Pierre Shale through Mowry Shale; fig. 2). The bowl-shaped structure of the Williston Basin causes the bedrock aquifer units to become exposed (crop out) in a pattern where the older rocks of the Upper Cretaceous aquifer system crop out around the outer margins of the basin and the younger rocks of the lower Tertiary aquifer system crop out in the center of the basin.

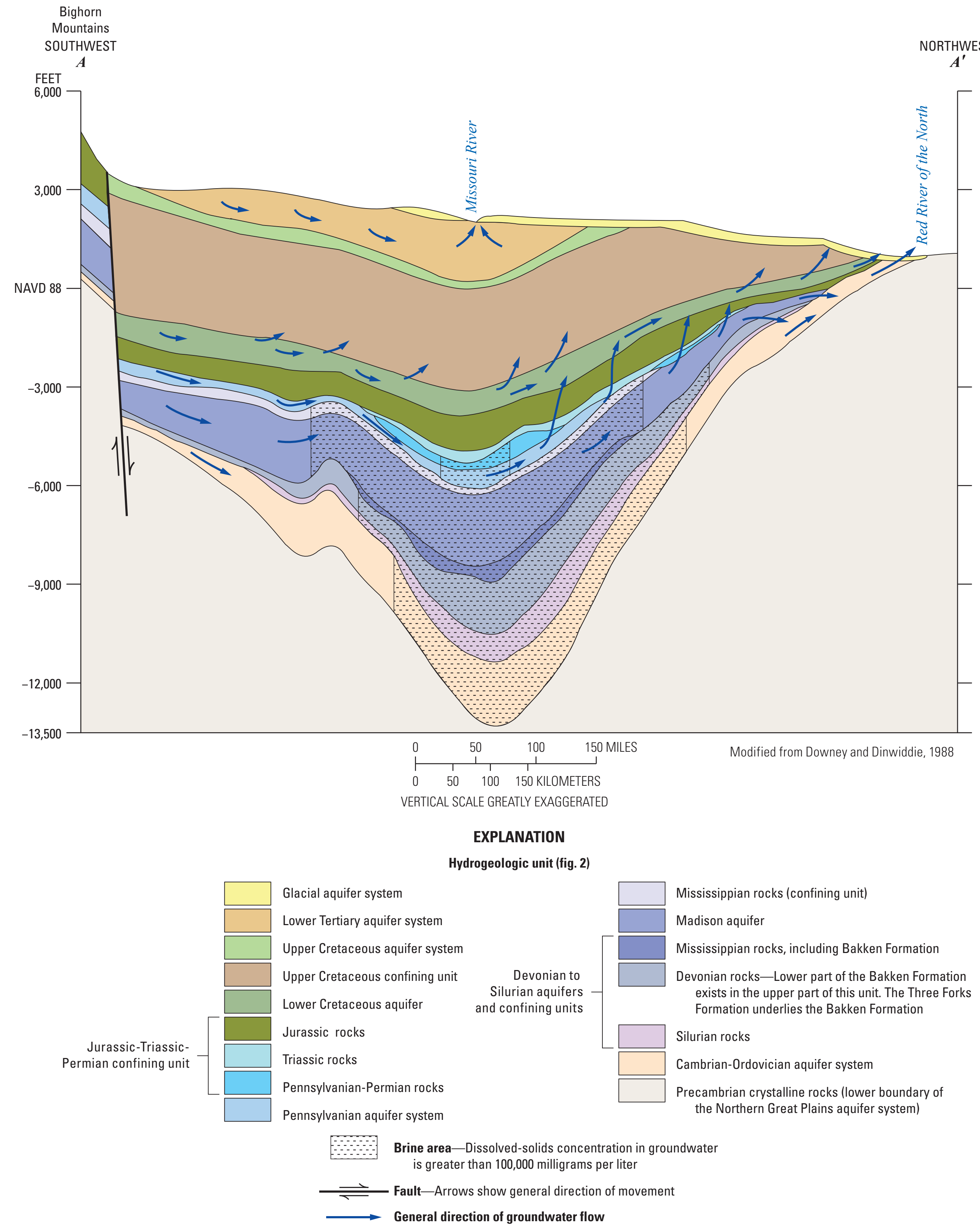
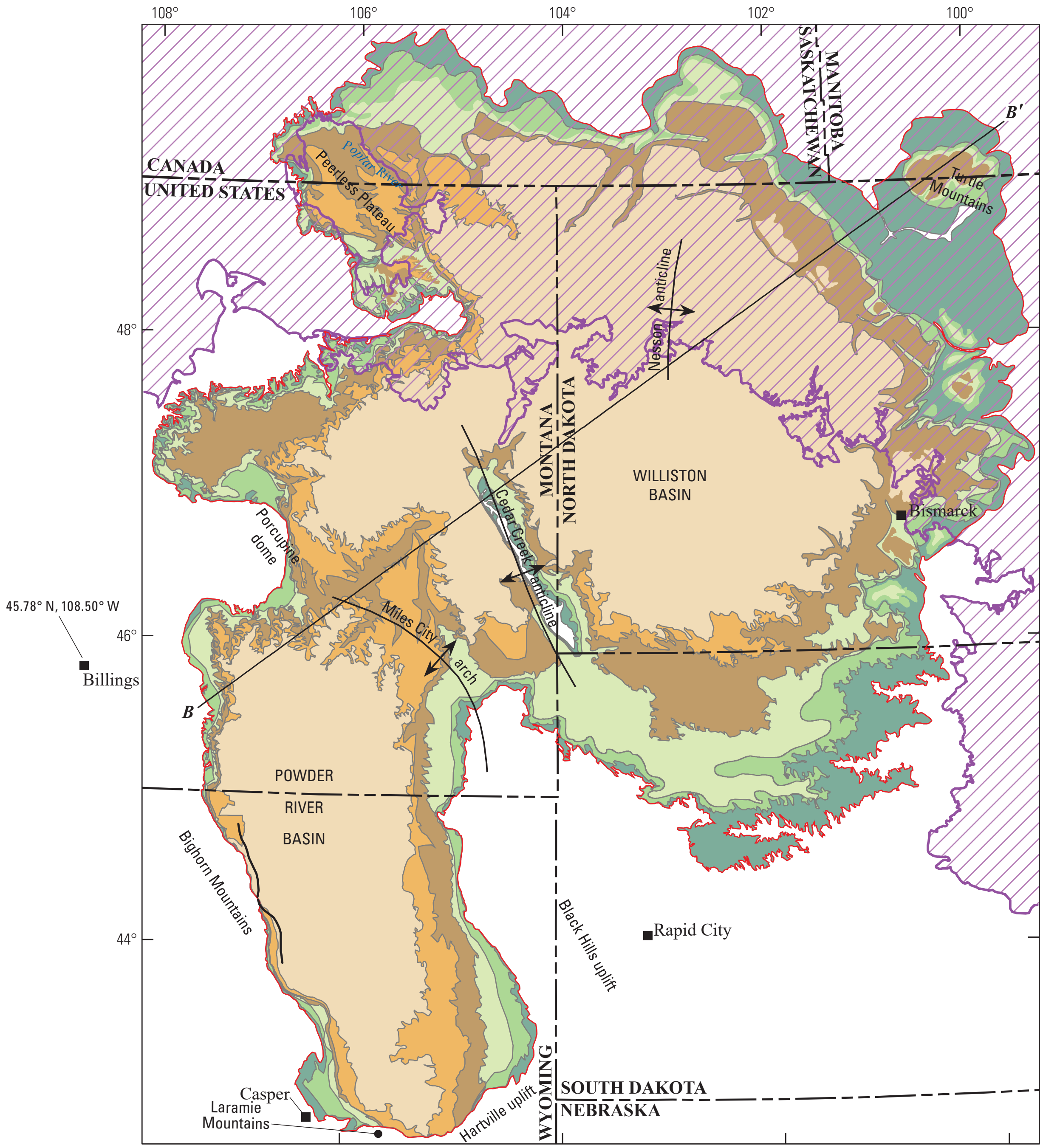


Figure 3. Diagrammatic hydrogeologic cross-section *A–A′* through part of the Northern Great Plains aquifer system (modified from Downey and Dinwiddie, 1988). Line of section shown in figure 1.



Base modified from U.S. Geological Survey and other Federal digital data, various scales
North American Lambert Conformal Conic projection
North American Datum of 1983

EXPLANATION

Hydrogeologic units from Thamke and others (2014)

Glacial aquifer system

Lower Tertiary aquifer system
- Upper Fort Union aquifer
- Middle Fort Union hydrogeologic unit
- Lower Fort Union aquifer

Upper Cretaceous aquifer system
- Upper Hell Creek hydrogeologic unit
- Lower Hell Creek aquifer
- Fox Hills aquifer

Extent of total estimated Williston Basin control volume for water balance (table 2)

Cross section *B*–*B′* (fig. 6)

Geologic structures modified from Peterson (1984) and Love and Christiansen (1985)

Anticline or arch

Fault

Figure 4. Geographic extent of the glacial, lower Tertiary, and Upper Cretaceous aquifer systems and corresponding hydrogeologic units within and around the Williston Basin, and the cross-section *B*–*B′*, United States and Canada.

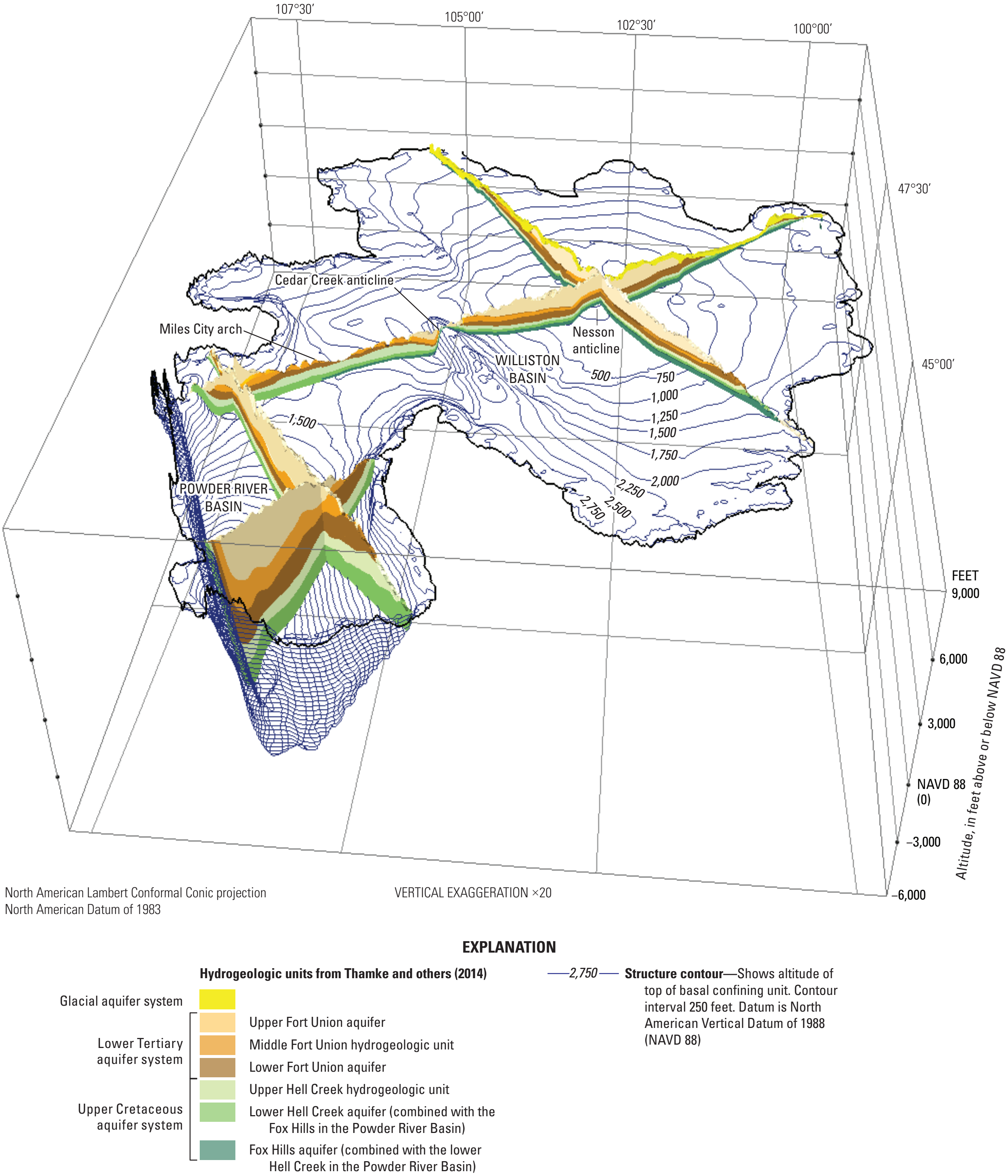


Figure 5. Generalized cross section showing three-dimensional framework of the glacial, lower Tertiary, and Upper Cretaceous aquifer systems in the Williston Basin (modified from Thamke and others, 2014).

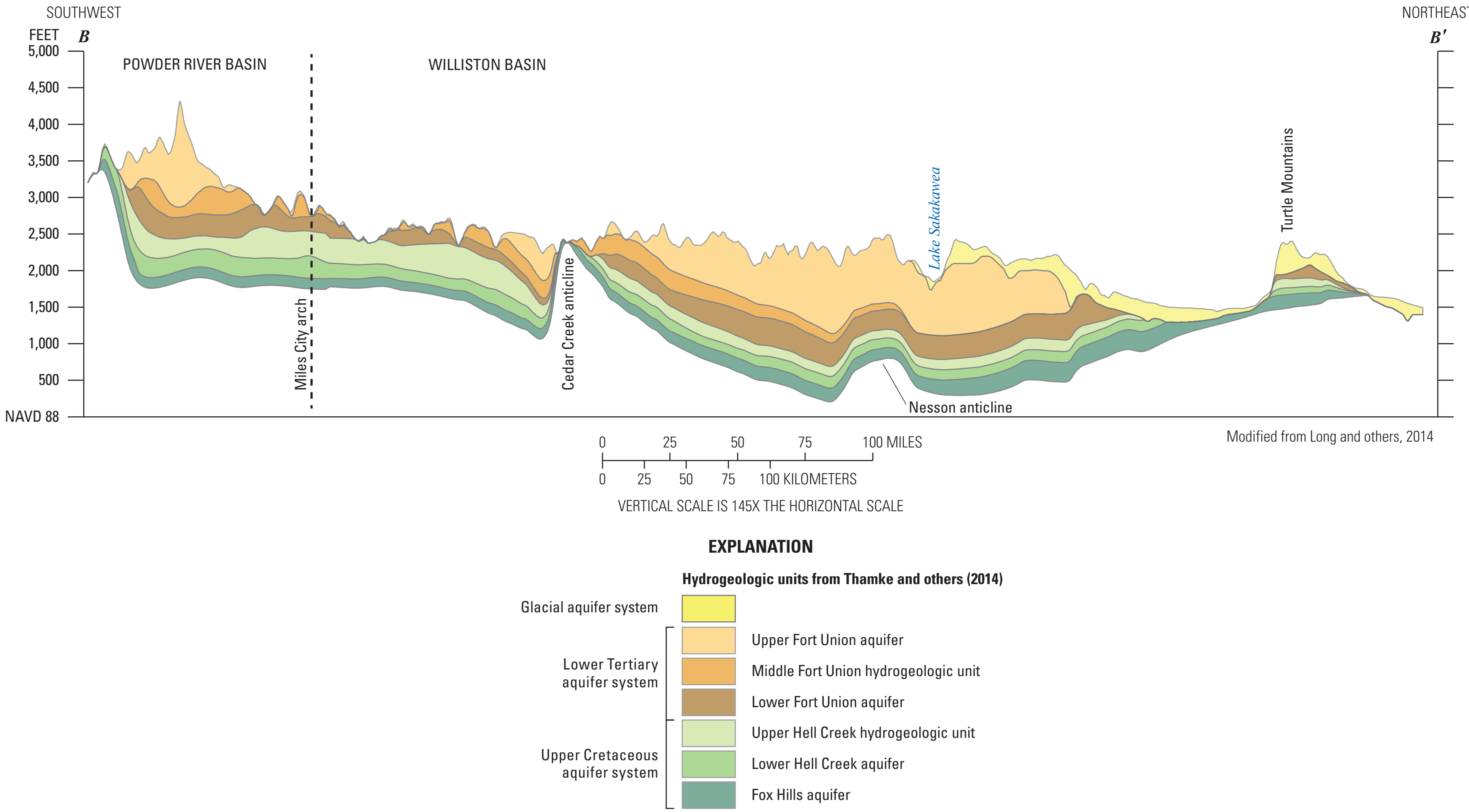
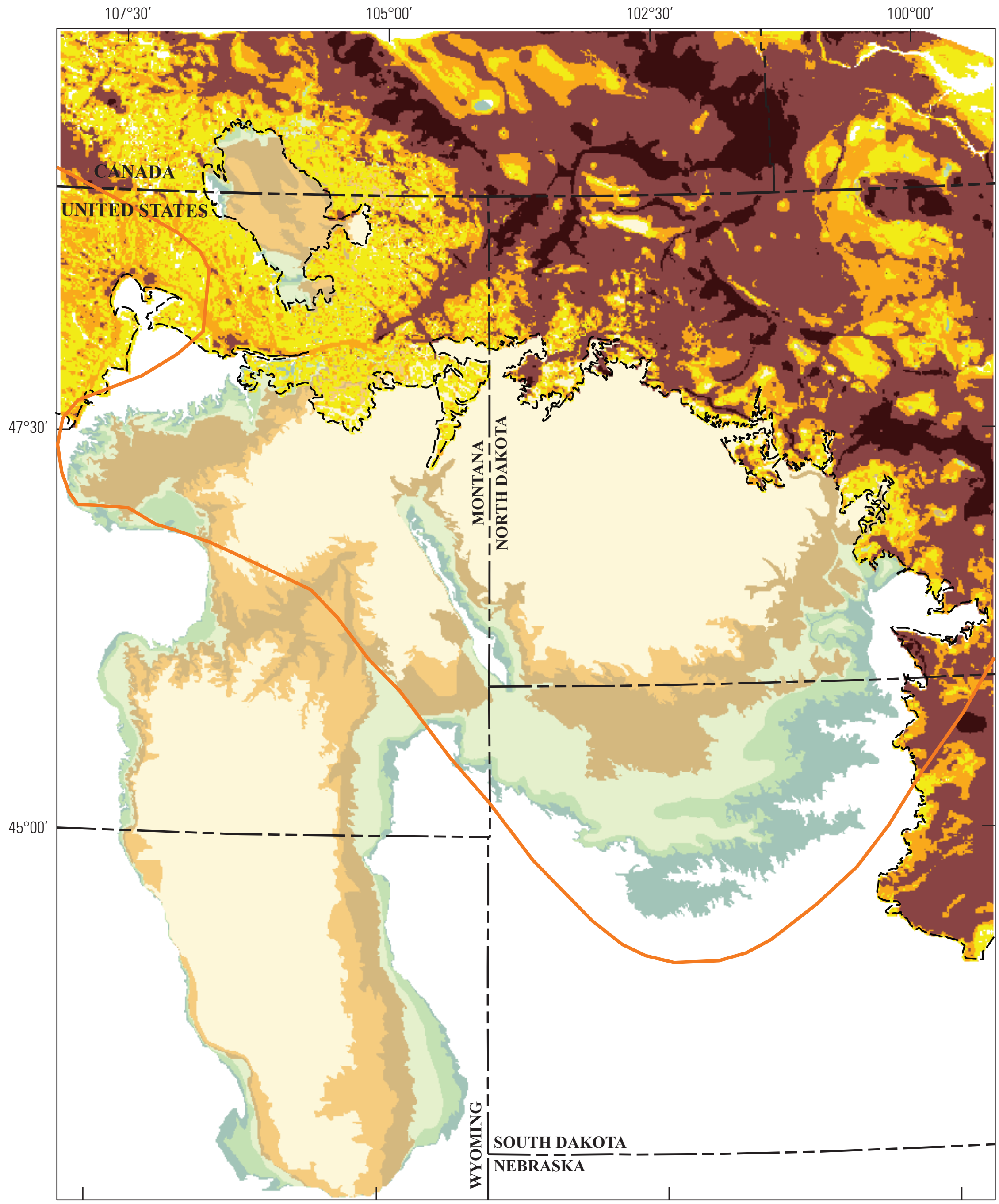


Figure 6. Hydrogeologic cross-section *B–B′* showing the glacial, lower Tertiary, and Upper Cretaceous aquifer systems in the Williston Basin (modified from Long and others, 2014). Line of section shown in figure 4.



Base from U.S. Geological Survey digital data, 2013, 1:1,000,000
North American Lambert Conformal Conic projection
North American Datum of 1983

0 25 50 75 100 MILES
0 25 50 75 100 KILOMETERS

EXPLANATION

Glacial aquifer system thickness, in feet

- Less than or equal to 50
- Greater than 50 to 100
- Greater than 100 to 300
- Greater than 300 to 756

Hydrogeologic units from Thamke and others (2014)

Lower Tertiary aquifer system
- Upper Fort Union aquifer
- Middle Fort Union hydrogeologic unit
- Lower Fort Union aquifer

Upper Cretaceous aquifer system
- Upper Hell Creek hydrogeologic unit
- Lower Hell Creek aquifer
- Fox Hills aquifer

Williston Basin boundary

Approximate geographic extent of the glacial aquifer system

Figure 7. Thickness of the glacial aquifer system in and near the Williston Basin (modified from Thamke and others, 2014).

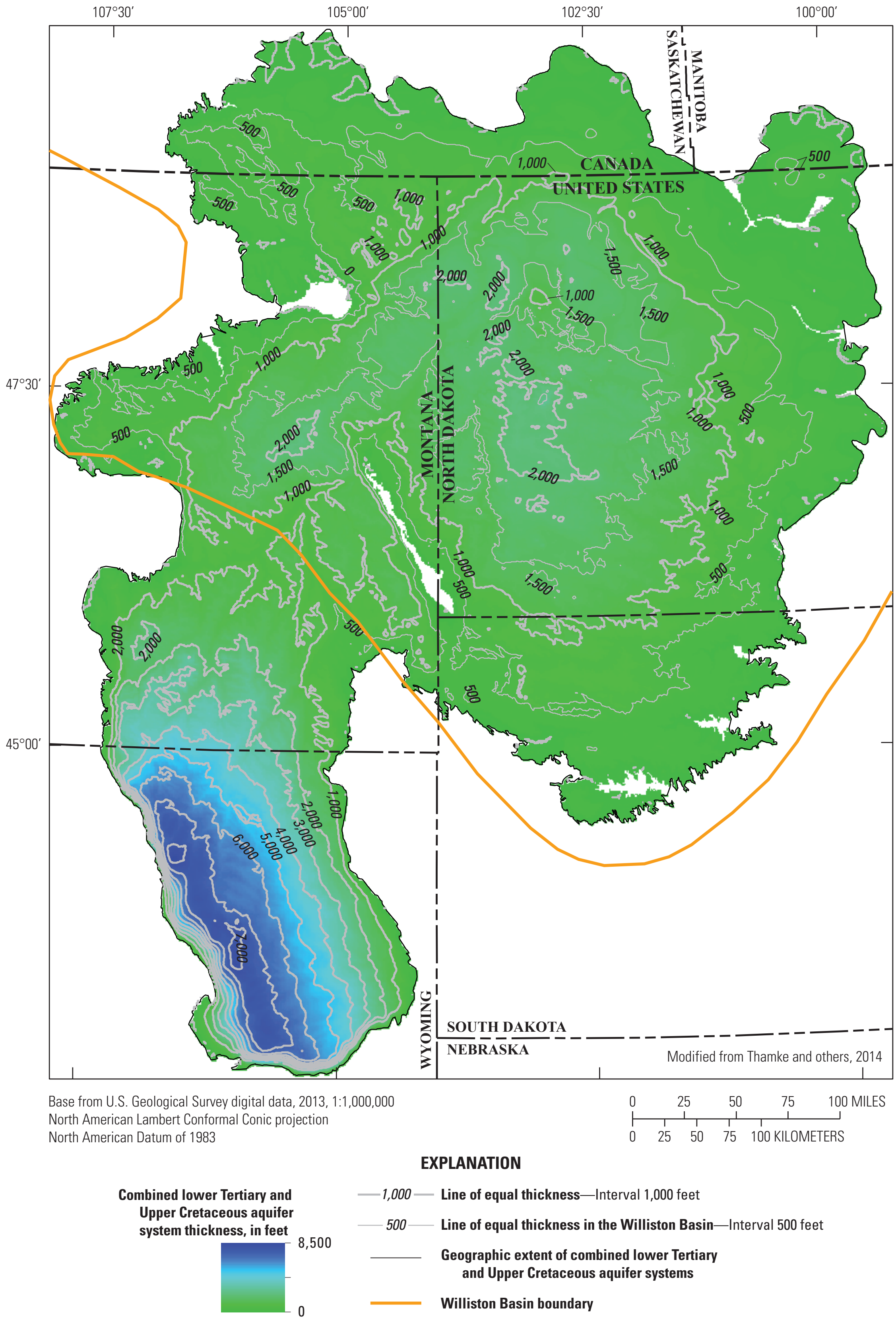


Figure 8. Thickness of the combined lower Tertiary and Upper Cretaceous aquifer systems in the Williston Basin (modified from Thamke and others, 2014).

Glacial Aquifer System

The glacial aquifer system overlies parts of the lower Tertiary and Upper Cretaceous aquifer systems in the northeastern part of the Williston Basin (figs. 3–6; Thamke and others, 2014). The glacial aquifer system consists of Quaternary-age (fig. 2) unconsolidated till, silt, clay, outwash sand and gravel, and occasional cobbles and boulders deposited by continental glaciers. Estimated glacial aquifer system volume in the Williston Basin (United States and Canada) is 150 trillion ft^3 (table 1). Widely differing lithologic characteristics result in an aquifer/aquifer system that is characterized by multiple disconnected and locally productive sand and gravel aquifers buried beneath till and other glacial or surficial deposits, and that typically is in preglacial valleys that exist in the buried bedrock surface (Paulson, 1983; Winter and others, 1984; Kehew and Boettger, 1986; Cummings and others, 2012; Pugin and others, 2014). These productive buried sand and gravel aquifers are sources of water for thousands of shallow wells in the Williston Basin. Thickness of glacial aquifer system deposits in the Williston Basin varies locally; maximum thickness is estimated to be 756 ft, and the deposits are thickest in northern and north central North Dakota (fig. 7). Hydraulic characteristics of the glacial aquifer system differ widely because of highly variable lithology, but the deposits can be highly productive in places (table 1).

Lower Tertiary Aquifer System

The lower Tertiary aquifer system in the Williston Basin consists of the upper and lower Fort Union aquifers separated by the middle Fort Union hydrogeologic unit (figs. 2, 4–6; Thamke and others, 2014). The aquifer system is estimated to be as thick as 2,246 ft and has a volume of about 1,002 trillion ft^3 (table 1). Rocks composing the lower Tertiary aquifer system represent many depositional environments, most commonly continental and nearshore (fluvial, deltaic, tidal, and barrier-shoreface) depositional environments; and less commonly, marine depositional environments (Flores and Bader, 1999; Flores and others, 1999). Because of spatially variable lithology reflective of these many depositional environments, the middle Fort Union and upper Hell Creek hydrogeologic units may act as confining units in some areas and aquifers in other areas.

The upper Fort Union aquifer (figs. 2, 4–7) is composed of as much as 1,917 ft (table 1) of massive, crossbedded, light-yellow to light-yellow-gray sandstone, sandy mudstone, gray shale, carbonaceous shale, and thick coal beds and associated clinker deposits (permeable rocks created by the natural burning of coal beds). Rocks composing the upper Fort Union aquifer generally are light-colored compared to the underlying middle Fort Union hydrogeologic unit. In the Williston Basin, the upper Fort Union aquifer is present in Montana and North Dakota but not in South Dakota (fig. 4; Thamke and others, 2014). The specific formations or formation members that compose the aquifer are shown in figure 2, and their properties are described in table 1. Thickness of the upper Fort Union aquifer is greatest in the central part of the Williston Basin, near the Montana/North Dakota border, and thins at the edges where erosion has removed most of the unit (fig. 6). Because of geographic occurrence at or near land surface (fig. 4) and greater permeability throughout much of the Williston Basin, the upper Fort Union aquifer is the most used aquifer of the lower Tertiary aquifer system.

The middle Fort Union hydrogeologic unit (figs. 2, 4–7; Thamke and others, 2014) is present throughout the central part of the Williston Basin but thins toward the northeast and pinches out along the northeastern one-third of the basin (figs. 5, 6). The specific formations or formation members that compose the aquifer are shown in figure 2, and their properties are described in table 1. Composed of as much as 520 ft of alternating beds of sandstone, siltstone, mudstone, claystone, and lignite, rocks in the middle Fort Union hydrogeologic unit generally are finer-grained and darker-colored than rocks in the overlying upper Fort Union Formation and underlying lower Fort Union Formation. Because of spatially variable lithology, the middle Fort Union hydrogeologic unit may act as a confining unit in some areas and as an aquifer in other areas.

Present throughout most of Williston Basin, the lower Fort Union aquifer (figs. 2, 4–7) is composed of as much as 668 ft (table 1) of yellow-weathering sandstones and light-gray-weathering sandy mudstones interfingering with alternating brown and gray beds of sandstone, siltstone, claystone, mudstone, and lignite. The specific formations or formation members that compose the aquifer are shown in figure 2, and selected physical properties are described in table 1.

Upper Cretaceous Aquifer System

The Upper Cretaceous aquifer system is the deepest and most areally extensive of the three most-used aquifer systems underlying the Williston Basin (figs. 2, 3–7). From top to bottom, the Upper Cretaceous aquifer system consists of the upper Hell Creek hydrogeologic unit, lower Hell Creek aquifer, and Fox Hills aquifer (figs. 2, 4–7; Thamke and others, 2014). All three Upper Cretaceous hydrogeologic units are present throughout most of the Williston Basin (figs. 4–6). Estimated volume of the Upper Cretaceous aquifer system is 1,005 trillion ft^3 in the Williston Basin (table 1).

The upper Hell Creek hydrogeologic unit (figs. 2, 4–7) is composed of as much as 738 ft (table 1) of alternating layers of gray and brown mudstone, siltstone, sandstone, and sparse lignite beds in the upper part of the Hell Creek Formation deposited by meandering channels with point bars and channel plugs. Lithology in the underlying lower part of the Hell Creek Formation is similar, so the upper Hell Creek hydrogeologic unit is defined where the percentage of sandstone is generally smaller. Like the middle Fort Union hydrogeologic unit, the upper Hell Creek hydrogeologic unit may act as a confining unit in some areas and as an aquifer in other areas because of spatially variable lithology.

The lower Hell Creek aquifer (figs. 2, 4–7) consists of rocks in the lower part of the Hell Creek Formation that were deposited as the basal part of a Late Cretaceous continental clastic wedge that extended from the Rocky Mountains to the central plains and was deposited in the swamps and flood plains on or near a deltaic front adjacent to the Late Cretaceous inland sea (Murphy, 2001). Channel deposits and erosional surfaces are common in the lower Hell Creek Formation comprising the aquifer (Flores, 1992). Maximum thickness of the lower Hell Creek aquifer is as much as 548 ft in the Williston Basin (fig. 6; table 1).

Present throughout the Williston Basin (fig. 4), the Fox Hills aquifer consists of the Fox Hills Sandstone and is the deepest hydrogeologic unit of the Upper Cretaceous aquifer system (figs. 2, 5–7). As much as 422 ft (table 1) of interbedded mudstone, siltstone, and sandstone compose the Fox Hills aquifer; these rocks were deposited in shore, nearshore, and delta plain environments during the final stage of the Late Cretaceous inland sea (Cvancara, 1976; Murphy, 2001).

Groundwater Budget and Flow System

Groundwater recharge to the glacial, lower Tertiary, and Upper Cretaceous aquifer systems (figs. 1, 3–7) is from direct infiltration of rainfall and snowmelt on outcrop areas (precipitation recharge), streamflow losses to underlying units (stream infiltration), infiltration of irrigation waters (irrigation recharge), and groundwater inflow from the Powder River Basin (table 2; Whitehead, 1996; Aurand, 2013; Bednar, 2013; Long and others, 2014). Total estimated recharge to these aquifer systems in the Williston Basin is 4,560 cubic feet per second (ft^3/s) (table 2; Long and others, 2014). Stream infiltration and precipitation recharge composed most of the recharge, accounting for 71 and 26 percent of total recharge, respectively; irrigation recharge and groundwater inflow accounted for only 2 and less than 1 percent of total recharge, respectively (table 2; Long and others, 2014). Estimated mean precipitation recharge for the Williston Basin for 1981 through 2005 was 0.18 inch per year (in/yr) (1,190 ft^3/s; table 2) or about 1.1 percent of precipitation (Long and others, 2014).

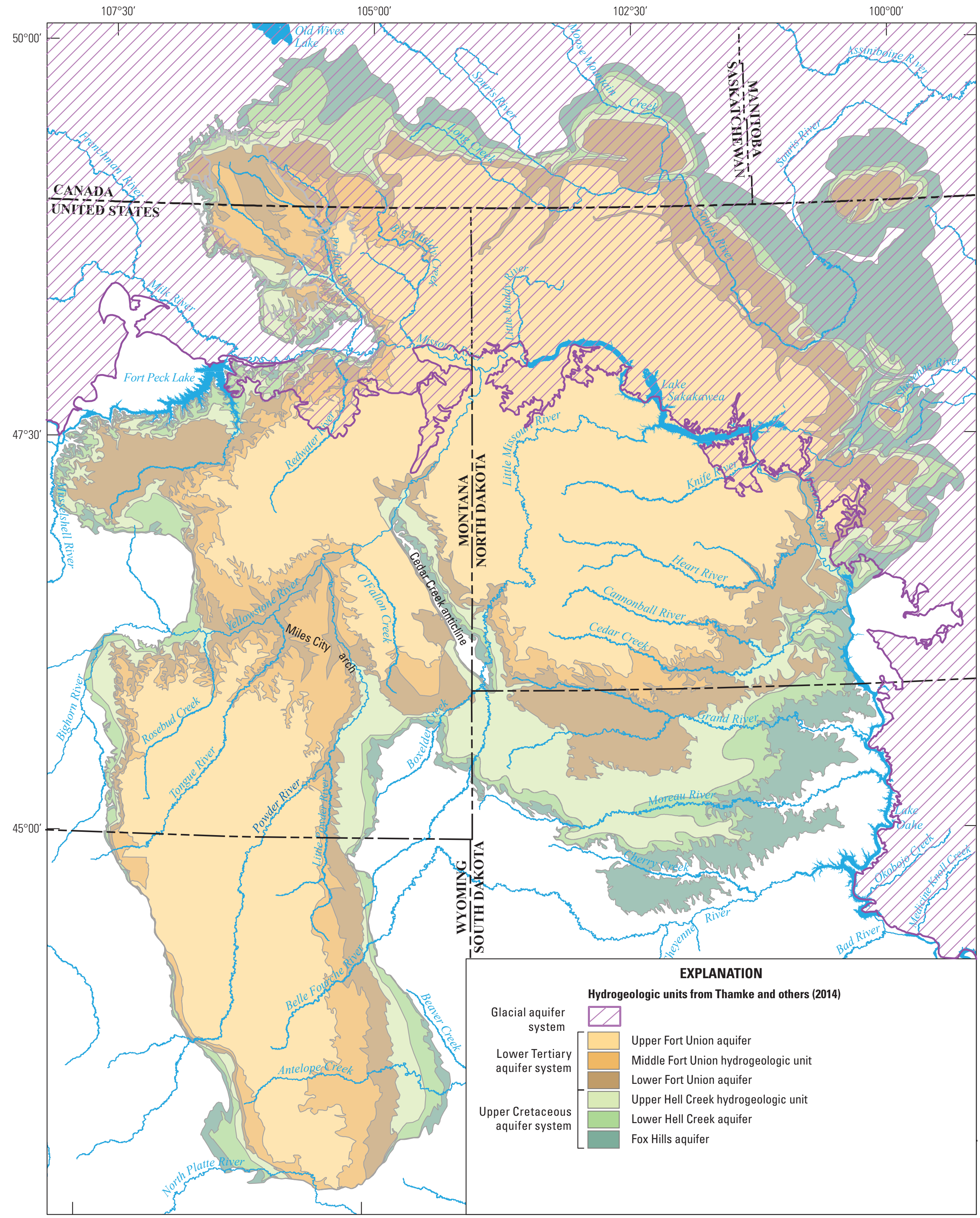
Water in the lower Tertiary and Upper Cretaceous aquifer systems primarily is under confined conditions except along basin margins and in aquifers in the upper part of the hydrogeologic units, which are characterized by topographically controlled local flow systems (Whitehead, 1996; Long and others, 2014; Thamke and others, 2014). Depth to the water table in unconfined parts of the lower Tertiary and Upper Cretaceous aquifer systems ranges from 0 to 823 ft (mean=97 ft) (Long and others, 2014). The water table is shallowest near streams and deepest in upland areas. Horizontal hydraulic gradients are largest in the upper Fort Union aquifer as indicated by the closeness of the contours, and smallest in the Upper Cretaceous aquifer system (fig. 9). Where aquifers in the lower Tertiary and Upper Cretaceous aquifer systems are covered by the glacial aquifer system or unconsolidated alluvial deposits, water can percolate downward through these deposits to the bedrock aquifers. South of the glacial aquifer system where the upper Fort Union aquifer is unconfined, the potentiometric surface is topographically controlled and generally follows the orientation of land-surface slopes, resulting in localized groundwater flow from topographically high areas toward stream valleys (fig. 9; Thamke and others, 2014; Long and others, 2014). Potentiometric surfaces in the other lower Tertiary and Upper Cretaceous hydrogeologic units indicates

Table 2. Estimated average groundwater recharge and discharge components for 1981 through 2005 for the combined glacial, lower Tertiary, and Upper Cretaceous aquifer systems within the Williston Basin control volume area (modified from Long and others, 2014).

[<, less than; NA, not applicable]

Recharge or discharge component	Estimated Williston Basin control volume (fig. 4)		Period of record
	Cubic foot per second	Percentage of total	
Groundwater recharge			
Precipitation recharge	1,190	26	1981–2005
Stream infiltration	3,260	71	1900–2005
Irrigation recharge	98	2	1981–2005
Groundwater inflow from the Powder River Basin	8	<1	NA
Total recharge	4,560	100	NA
Groundwater discharge			
Discharge to streams	4,420	97	1900–2005[a]
Groundwater withdrawal	126	3	1981–2005
Discharge to reservoirs	10	<1	NA
Total discharge	4,560	100	NA

[a]Data through 2011 were used for about 4 percent of the streamgages.



Base modified from U.S. Geological Survey and other Federal digital data, various scales
North American Lambert Conformal Conic projection
North American Datum 1983

0 25 50 75 100 MILES
0 25 50 75 100 KILOMETERS

Figure 9. Potentiometric surfaces of the upper Fort Union aquifer, lower Fort Union aquifer, and Upper Cretaceous aquifer system in the Williston Basin (modified from Thamke and others, 2014). An interactive version of this map is available for download at https://doi.org/10.3133/sir20175070C.

groundwater flow generally is from the west and southwest toward the east, where the groundwater regionally discharges to streams (fig. 9). Potentiometric surfaces for the upper and lower Fort Union aquifers are similar in the northern and western parts of the Williston Basin, except for less relief for the lower Fort Union aquifer, indicating probable hydraulic connection between the two aquifers (fig. 9).

The glacial, lower Tertiary, and Upper Cretaceous aquifer systems discharge in the form of groundwater discharge to streams and reservoirs; and withdrawals from wells for domestic, irrigation, public-supply, and self-supplied industrial uses (groundwater withdrawal) (Whitehead, 1996; Aurand, 2013; Bednar, 2013; Long and others, 2014). Most of this groundwater discharge is to streams, representing an estimated 97 percent or 4,420 ft^3/s of the total discharge for the units in the Williston Basin (table 2; Long and others, 2014).

Several studies have documented local groundwater-level declines because of flowing artesian wells; these wells flow continuously because of hydrostatic pressure. Declines from flowing artesian wells open to the Fox Hills and lower Hell Creek aquifers have been noted near the Yellowstone, Little Missouri, and Knife Rivers in Montana and North Dakota (not shown; Smith and others, 2000; Honeyman, 2007a, b, c; Fischer, 2013). Locally, flowing artesian wells that discharge water from the Upper Cretaceous aquifer system may allow leakage into the overlying lower Tertiary aquifer system because of inadequate sealing or corrosion of these wells (Fischer, 2013; Long and others, 2014).

Other Hydrogeologic Units

Other hydrogeologic units are described in this section. These include the Upper Cretaceous confining unit, Lower Cretaceous aquifer system, Jurassic-Triassic-Permian confining unit, and Paleozoic aquifers/aquifer systems.

Upper Cretaceous Confining Unit

A substantial confining unit underlies the Upper Cretaceous aquifer system and overlies the Lower Cretaceous aquifer system throughout the Williston Basin (figs. 2, 3). The specific lithostratigraphic units that compose the unit are shown in figure 2 (Downey, 1986; Downey and Dinwiddie, 1988; Thamke and others, 2014). Dark, clayey, low-permeability marine shale composes most of the confining unit. Thickness of the confining unit ranges from 800 to more than 3,000 ft (Anna, 1986; Downey, 1986; Downey and Dinwiddie, 1988; fig. 3). Although shale composes most of the unit, interbedded sandstone beds within the shales (Tourtelot, 1962; Carlson, 1979; Murphy, 2001) can contain local aquifers (Downey, 1986; Downey and Dinwiddie, 1988; Busby and others, 1995). In addition, the Pierre Shale in northern North Dakota can act locally as an aquifer where near-surface fracture zones have developed (Downey, 1973).

Lower Cretaceous Aquifer System

Present throughout the Williston Basin, the Lower Cretaceous aquifer system (fig. 3) consists primarily of water-saturated and permeable sandstone beds containing aquifers interbedded with finer-grained rocks such as siltstone and shale. The specific lithostratigraphic units that compose the individual Lower Cretaceous aquifers and confining units of the aquifer system are shown in figure 2 (Dyer and Goehring, 1965; Butler, 1984; Case, 1984; Downey, 1984a, 1984b, 1986; Peter, 1982; Schoon, 1984; Downey and Dinwiddie, 1988; Busby and others, 1995; Whitehead, 1996). Combined thickness of all Lower Cretaceous rocks in the Williston Basin generally ranges from about 100 to 500 ft (fig. 6; Downey, 1986).

Many investigators divide the Lower Cretaceous aquifer system into the Newcastle or Dakota aquifers (composed of the Newcastle Formation/Sandstone or the Dakota Formation/Sandstone [older alternative name for rocks in parts of North Dakota and South Dakota equivalent to the Newcastle Formation], respectively) and the Inyan Kara aquifer (composed of sandstone beds in the Inyan Kara Formation in North Dakota, Fall River and Lakota Formations of the Inyan Kara Group in South Dakota, and Fall River and Kootenai Formations in eastern Montana; fig. 2). The Lower Cretaceous aquifer system is also commonly identified as the Dakota aquifer or aquifer system, or Dakota-Newcastle aquifer system (fig. 2; Bredehoeft and others, 1983; Butler, 1984; Case, 1984; Peter, 1982; Wartman, 1984). Where present, the Skull Creek Shale is classified as a confining unit that separates the two aquifers (fig. 2). Where the Skull Creek Shale pinches out in central and eastern North Dakota and South Dakota, the two aquifers merge into a single aquifer. The Lower Cretaceous (Dakota) aquifer system has been studied extensively because of the large quantities of water that can be developed from the aquifer system in some areas (primarily outside of the Williston Basin), and because it is considered to be a classic example of an artesian aquifer system (for example, Bredehoeft and others, 1983; Leonard and others, 1984).

Lower Cretaceous aquifers are unused as sources of water in much of the Williston Basin because of the depth of these resources (as much as 10,000 ft in the central part of the basin), saline waters, and availability of shallower groundwater; however, water is withdrawn for domestic, municipal, and agricultural uses where the aquifers are present at shallower depths, and waters are fresher adjacent to and immediately outside the western and southwestern margin of the Williston Basin (for example, Bredehoeft and others, 1983; Butler, 1984; Case, 1984; Wartman, 1984). In these areas, wells are completed in the aquifers because drilling depths are economical, and waters are fresh or slightly saline because of proximity to aquifer recharge areas. Many wells constructed in these areas flow in response to artesian pressure.

In parts of the Williston Basin where petroleum is extracted from deeper formations with saline and briny waters, Lower Cretaceous formations historically have been, and continue to be, used as reservoirs for injection of liquid wastes generated as part of the production process (Wartman, 1984; Kurz and others, 2016; Scanlon and others, 2016). Most (93 percent or more by volume) of the produced waters associated with the Bakken oil play disposed of through injection are injected into the Inyan Kara Formation within the Lower Cretaceous (Dakota) aquifer system in western North Dakota where total dissolved solids (TDS) ranges from 10,000 to 30,000 milligrams per liter (mg/L) (Kurz and others, 2016; Bader, 2017; Ge and others, 2018). The Dakota aquifer system is a favorable target of disposal because of suitable injection characteristics and because aquifer depth is about 1,500 to 2,000 ft shallower than other saline aquifers suitable for produced water disposal (Kurz and others, 2016).

Infiltration on outcrops along the flanks of structural uplifts adjacent to the basin recharges the Lower Cretaceous aquifer system. Additional potential recharge to the Lower Cretaceous aquifer system originates from either upward movement of water from the underlying Paleozoic aquifers in areas where confining units are either thin or absent (fig. 10; Kolm and Peter, 1984; Butler, 1984; Case, 1984; Downey and Dinwiddie, 1988), or downward movement of water to the aquifer from or through the overlying Upper Cretaceous confining unit (Pierre Shale) through fractures (Neuzil and others, 1982; Peter, 1982). Regional groundwater movement in the Lower Cretaceous aquifer system is towards the east and northeast from recharge areas along the flanks of structural uplifts in the western and southwestern Williston Basin (for example, Black Hills uplift) (fig. 10; Butler, 1984; Case, 1984; Lobmeyer, 1985; Downey and Dinwiddie, 1988; Bachu and Hitchon, 1996). The Lower Cretaceous aquifer system discharges primarily through (1) lateral leakage to adjacent hydrogeologic units (figs. 3, 10), (2) upward leakage to overlying hydrogeologic units in areas in eastern South Dakota and North Dakota (figs. 3, 10), (3) withdrawals from wells, (4) artesian flow from unused wells, and (5) leakage from improperly abandoned and sealed wells (Butler, 1984; Case, 1984; Lobmeyer, 1985; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996).

Freshwater in the Lower Cretaceous aquifer system is present in the Williston Basin only in a small area north and east of the Black Hills uplift (fig. 11). Upward leakage of highly mineralized water from underlying hydrogeologic units may contribute substantially to the salinity (Butler, 1984; Wartman, 1984; Busby and others, 1995). Lower Cretaceous aquifers contain slightly saline water (dissolved-solids concentration ranging from greater than 1,000 to 3,000 mg/L) throughout most of South Dakota and a large area in southeastern North Dakota (fig. 11). The aquifers contain saline waters (dissolved-solids concentration ranging from greater than 3,000 to 10,000 mg/L) in most of the rest of the Williston Basin area, except in the deep parts in northeastern Montana and northern and northwestern North Dakota (fig. 11; Busby and others, 1995) where the aquifers contain very saline and briny waters (dissolved-solids concentration ranging from more than 10,000 to more than 35,000 mg/L. The spatial extent of dissolved solids concentrations ranging from 10,000 to more than 35,000 mg/L were not mapped at the time of this publication (Kurz and others, 2016), and were depicted as only greater than 10,000 mg/L in figure 11.

Jurassic-Triassic-Permian Confining Unit

Jurassic- to Permian-age lithostratigraphic units compose a regional confining unit in the Williston Basin, and specific formations that compose the unit are identified in figure 2 (Downey, 1986; Downey and Dinwiddie, 1988; Bachu and Hitchon, 1996). Lithology of the confining unit represents many depositional environments, including sandstone, siltstone, shale, limestone, and evaporates. Because of predominantly fine-grained lithology and, in particular, the widely present interbedded evaporates/salts, this confining unit prevents vertical water movement between all overlying Lower Cretaceous and other younger units (fig. 2) and all underlying Paleozoic units (fig. 2) in most of the Williston Basin (Downey, 1986; Downey and Dinwiddie, 1988; Busby and others, 1995). Locally, parts of the Swift, Rierdon, and Piper Formations (fig. 2) may be sufficiently permeable to yield water to wells and be classified as aquifers (Whitehead, 1996).

Paleozoic Aquifers/Aquifer Systems

Studies of the Williston Basin in the United States and Canada have identified regional bedrock aquifers/aquifer systems in the upper and lower Paleozoic lithostratigraphic units below the Jurassic-Triassic-Permian confining unit (figs. 2, 3; Downey, 1984a, b, 1986, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996; Whitehead, 1996; Benn and Rostron, 1998). Upper and lower Paleozoic lithostratigraphic units are of variable composition throughout the Williston Basin, and many of the units or parts of the units function as aquifers, petroleum reservoirs, or both; however, few water wells are completed in Paleozoic aquifers in the Williston Basin primarily because of deep burial throughout most geographic extent and availability of groundwater from shallower aquifers/aquifer systems with sufficient quantity and quality of water for most uses. Where deeply buried, Paleozoic aquifers typically contain very saline waters, and commonly contain a spatially variable mixture of fluids including water, brine, oil, and natural gas.

Upper Paleozoic Units

Upper Paleozoic aquifers and confining units are composed of generally deeply buried Permian- to Mississippian-age lithostratigraphic units (figs. 2, 3). Water-saturated and permeable marine sandstone in the Permian- and Pennsylvanian-age Minnelusa Group or Formation and stratigraphic equivalents compose the Pennsylvanian aquifer system in the Williston Basin (fig. 2; Downey, 1984a, 1986; Downey and Dinwiddie, 1988; Busby and others, 1995). The aquifer system is confined from above by the Jurassic-Triassic-Permian

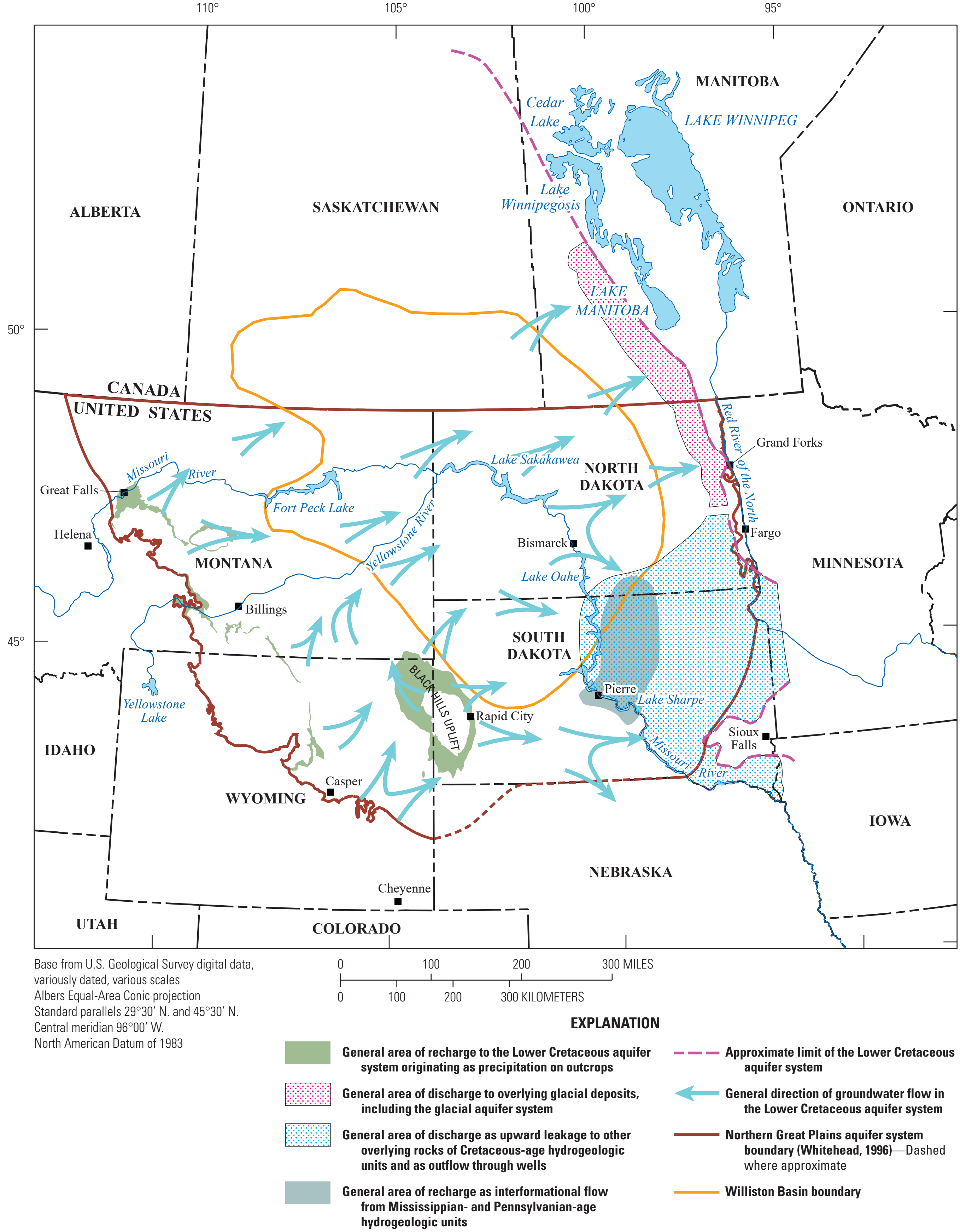


Figure 10. General areas of recharge to, discharge from, and groundwater flow in the Lower Cretaceous aquifer system in the Williston Basin and adjacent areas, United States and Canada (modified from Downey and Dinwiddie, 1988).

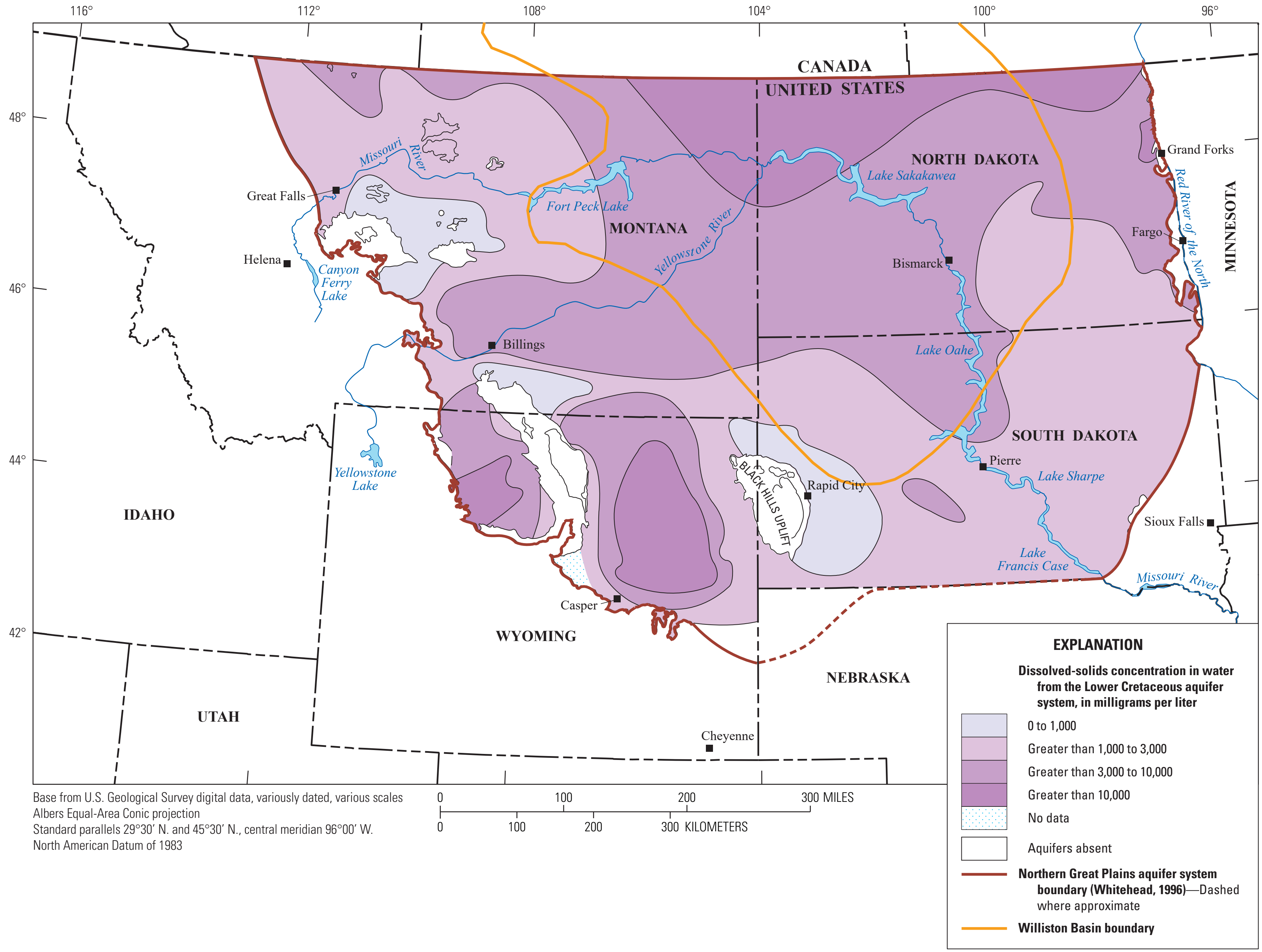


Figure 11. Dissolved-solids concentrations in water from the Lower Cretaceous aquifer system in the Williston Basin (modified from Whitehead, 1996).

confining unit and below by a confining unit composed of the Mississippian-age Big Snowy Group and the Charles Formation of the Madison Group (fig. 2). The Pennsylvanian aquifer system is mainly undeveloped as a source of water supply in the Williston Basin. Some produced water associated with the Bakken oil play is disposed of by injection into the Minnelusa Group or Formation (Kurz and others, 2016).

Below the Charles Formation, water-saturated and permeable carbonate rocks (limestone and dolomite) in parts of the Mission Canyon and Lodgepole Limestones of the Madison Group compose the Madison aquifer in the Williston Basin (fig. 2; Downey, 1984a, 1986; Downey and Dinwiddie, 1988; Busby and others, 1995). Some studies also have indicated that the Madison Group likely can be divided into a series of fluid-bearing aquifers/reservoirs, in contrast to being mapped as a single aquifer (for example, Jensen and Rostron, 2006; Palombi, 2008). The Madison Group ranges in thickness from less than 200 ft along the eastern margin of the Williston Basin to as much as 2,800 ft in the deepest part in northwestern North Dakota and northeastern Montana (Busby and others, 1995). Porosity and permeability in the carbonate rocks that compose much of the Madison Group (and other Paleozoic units) varies substantially because of differing geological and hydrological processes (MacCary and others, 1983; Thayer, 1983; Downey, 1984a, 1986). The Madison aquifer is used as a source of water for many different uses outside of and near the Williston Basin, most notably in the Black Hills uplift area where the Madison aquifer is developed as a source of water for many different uses and has been extensively studied (for example, Carter and others, 2002). In much of the Williston Basin, the Madison Group is an important petroleum reservoir, and the geologic and hydrogeologic characteristics of the unit have been studied to understand fluid flow in relation to petroleum generation and accumulation (Downey and others, 1987; Peterson and MacCary, 1987; Gaber, 1992; Berg and others, 1994; DeMis, 1995; Toop and Tóth, 1995; Burrus and others, 1996; LeFever, 1998; Jensen and Rostron, 2006). Some produced water associated with the Bakken oil play is disposed of by injection into the Madison Group (Kurz and others, 2016).

Lower Paleozoic Units

Lower Paleozoic aquifers and confining units are composed of generally deeply buried pre-Madison Group Mississippian- to Cambrian-age lithostratigraphic units overlying the Precambrian basement (figs. 2, 3). Permeable zones in these units comprise aquifers, petroleum reservoirs, or both. Aquifers are composed primarily of permeable carbonate rocks (limestone and dolomite) and sandstone, whereas confining units are composed primarily of shale, shaley carbonate rocks, evaporates/salts, and filled breccias (Downey, 1984a, 1986, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996; Benn and Rostron, 1998; Alkalali, 2002; Khan and Rostron, 2004; Palombi, 2008). Because of spatially variable lithology, lower Paleozoic lithostratigraphic/hydrogeologic units may act as confining units in some areas and aquifers in other areas. Although these units have little water-supply development potential in most of the Williston Basin because of deep burial and predominantly saline and briny waters, considerable effort has been made to understand fluid flow and hydrochemistry in the lower (and upper) Paleozoic aquifers and confining units, or both because they contain extensive mineral and energy resources. Description of these numerous studies is beyond the scope of this summary, but the reader is referred to numerous studies examining these characteristics in Paleozoic aquifers in the Williston Basin (Hanshaw and others, 1978; Downey, 1984a, b, 1986, 1987; Leonard and others, 1984; Downey and others, 1987; Hannon, 1987; Downey and Dinwiddie, 1988; Busby and others, 1991, 1995; Berg and others, 1994; DeMis, 1995; Toop and Tóth, 1995; Bachu and Hitchon, 1996; Burrus and others, 1996; Benn and Rostron, 1998; LeFever, 1998; Iampen and Rostron, 2000; Alkalali, 2002; Margitai, 2002; Rostron and Holmden, 2003; Jensen and Rostron, 2006; Khan and Rostron, 2004; Palombi and Rostron, 2006; Palombi, 2008; Anna, 2013). In addition, lower Paleozoic hydrogeologic units continue to be studied because of potential use of the deep saline and briny aquifers as reservoirs and the associated confining units as geologic reservoir traps/seals for disposal of nuclear waste (Sandberg, 1962; Brunskill, 2006) and anthropogenic carbon dioxide (CO_2; Whittaker and others, 2002, 2004; Whittaker and Gilboy, 2003; Khan and Rostron, 2004; Fisher and others, 2005; Sorensen and others, 2009; Houseworth and others, 2011; Liu and others, 2014).

A confining unit composed of the Mississippian- and Devonian-age Bakken and Devonian-age Three Forks Formations underlies the Madison aquifer and separates the overlying upper Paleozoic aquifers from the underlying lower Paleozoic aquifers and confining units where present (fig. 2). The Bakken Formation is a petroleum source and reservoir that produces large volumes of petroleum, commonly in combination with the underlying Three Forks Formation (Pollastro and others, 2013). Most of the oil production from the Bakken Formation is from the middle member, an oil-bearing aquifer/reservoir confined by the impermeable upper and lower members (Whittaker and others, 2004; Kreis and others, 2006; Jensen and Rostron, 2006; Palombi, 2008). Bakken Formation thickness is estimated to be as much as 160 ft in the U.S. part of the Williston Basin (LeFever, 2008). The Three Forks Formation underlies the Bakken Formation where present and consists of as much 270 ft of marine and nonmarine generally low-permeability mudstone, dolomite, and anhydrite (Bottjer and others, 2011). Some earlier investigators combined the Bakken and Three Forks Formations with additional stratigraphically older and deeper Devonian and Silurian lithostratigraphic units into a much larger confining unit in the U.S. part of the Williston Basin (Downey, 1984a, b; Downey and others, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995). More recent studies grouped the Bakken and Three Forks Formations without the additional Devonian and Silurian lithostratigraphic units into a single confining unit (Bachu and Hitchon, 1996; Benn and Rostron, 1998; Grasby and Betcher, 2002; Palombi, 2008) identified informally herein as the “Bakken-Three Forks confining unit" (fig. 2). Where present, the Bakken-Three Forks confining unit is a substantial regional confining unit that restricts fluid flow in overlying stratigraphically younger hydrogeologic units such as the upper Paleozoic aquifers/aquifer systems from underlying lower Paleozoic aquifers/aquifer systems in much of the Williston Basin (Bachu and Hitchon, 1996; Benn and Rostron, 1998).

Below the Bakken-Three Forks confining unit, all or parts of six Devonian- to Ordovician-age lithostratigraphic units of variable composition compose a series of alternating aquifers and confining units (fig. 2; Benn and Rostron, 1998; Alkalali, 2002; Grasby and Betcher, 2002; Palombi and Rostron, 2006; Palombi, 2008). Bachu and Hitchon (1996) grouped all aquifers and confining units between the Bakken-Three Forks and Prairie Formation confining units into an aquifer system identified as the Devonian aquifer system. Many of these units are oil bearing in parts of the Williston Basin (Anna, 2013). Earlier hydrogeologic and hydrochemical studies completed primarily to evaluate water-supply potential (Downey, 1984a, 1984b; Downey and Dinwiddie, 1988; Busby and others, 1995) and fluid flow in relation to petroleum systems (Downey and others, 1987; DeMis, 1995) grouped these units with the overlying Bakken and Three Forks Formations into a single thick regional confining unit (Bakken Formation to Stonewall Formation; fig. 2). Rocks composing aquifers in this stratigraphic sequence consist mainly of permeable carbonate rocks and less commonly permeable breccias, anhydrite, siltstone, and shale. Evaporites in parts of this stratigraphic sequence contribute substantially to the confining nature of parts of the lithostratigraphic units (Downey, 1986; Downey and Dinwiddie, 1988; Palombi, 2008). The combined thickness of all Silurian and Devonian rocks in the Williston Basin ranges from less than 500 to more than 3,000 ft (Busby and others, 1995).

Similar to the overlying stratigraphic sequence, Cambrian- and Ordovician-age rocks below the Ordovician Stony Mountain Formation contain a series of alternating aquifers and confining units (fig. 2). Deposited as shoreward facies of a transgressive sea, rocks of Cambrian and Ordovician age consist primarily of marine shale, limestone, and sandstone. Combined thickness of Cambrian and Ordovician rocks ranges from less than 500 ft along the Williston Basin margins to as much as 2,000 ft in the deepest part of the basin (Downey and Dinwiddie, 1988). Earlier studies grouped the Cambrian and Ordovician rocks in the Stony Mountain to Deadwood Formation stratigraphic sequence into a single thick regional aquifer/aquifer system identified as the Cambrian-Ordovician aquifer or aquifer system (fig. 2; Downey, 1984a, 1986; Downey and others, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995); the basal aquifer system (Bachu and Hitchon, 1996); or, more broadly, the lower Paleozoic aquifers (Whitehead, 1996). Subsequent studies have subdivided the Cambrian-Ordovician aquifer into two aquifers (Red River and Cambrian-Ordovician aquifers) and two confining units (Stony Mountain and Winnipeg confining units) (fig. 2; Bachu and Hitchon, 1996; Benn and Rostron, 1998; Grasby and Betcher, 2002; Margitai, 2002; Rostron and Holmden, 2003; Palombi, 2008). The Red River aquifer, also known as the Yeoman aquifer, consists of permeable parts of the Ordovician Red River (Yeoman) Formation (MacCary and others, 1983; Benn and Rostron, 1998; Grasby and Betcher, 2002; Margitai, 2002; Whittaker and others, 2002, 2004; Whittaker and Gilboy, 2003; Palombi and Rostron, 2006; Palombi, 2008). The Red River Formation consists of a thick sequence of carbonate rocks (limestone and dolomite), and the unit is a major petroleum reservoir in the Williston Basin (Anna, 2013).

Overlain by the Winnipeg Group or Formation confining unit and underlain by rocks of the Precambrian basement, the Cambrian-Ordovician aquifer is the basal aquifer of the Northern Great Plains aquifer system (fig. 2). Deeply buried in most of the Williston Basin, the Cambrian-Ordovician aquifer consists of siliciclastic rocks (sandstones) in the lower part of the Ordovician Winnipeg Group or Formation and the underlying Cambrian Deadwood Formation (fig. 2; Benn and Rostron, 1998; Grasby and Betcher, 2002; Margitai, 2002; Palombi, 2008). The sandstone composition of the Cambrian-Ordovician aquifer contrasts with all overlying lower Paleozoic aquifers composed primarily of carbonate rocks. Permeability of the sandstones composing the aquifer is reduced because of compaction from deep burial (Downey and Dinwiddie, 1988); nevertheless, the deeply buried Cambrian-Ordovician aquifer is considered to have sufficient permeability to possibly serve as a reservoir for disposal of anthropogenic CO_2 in parts of the basin (Whittaker and others, 2004; Khan and Rostron, 2004; Fisher and others, 2005; Houseworth and others, 2011; Liu and others, 2014).

Groundwater-Flow System

Recharge to the upper and lower Paleozoic aquifers generally happens outside of the Williston Basin on the high elevation flanks of structural uplifts to the west and southwest, and immediately adjacent to the southwestern basin margin (figs. 12–14; Downey, 1984a, 1984b; Hannon, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996; Benn and Rostron, 1998; LeFever, 1998; Rostron and Holmden, 2003). Along the flanks of these structural uplifts, rocks composing the aquifers were warped upward and exposed (crop out) because of erosion. Infiltration of freshwater on the outcrops in these highland areas from precipitation (snow and rain) and ephemeral and perennial streamflow losses enters (recharges) the aquifers. Much of this recharge enters local groundwater flow systems, is discharged locally to springs, and seeps along the mountain flanks (Swenson, 1968). Groundwater not discharged from the local flow system eventually enters the regional groundwater-flow systems and generally flows slowly from the west and southwest toward the east and northeast, ultimately discharging to areas along the eastern and northeastern basin margin in North and South Dakota and parts of Manitoba (figs. 3, 12–14; Swenson, 1968; Downey, 1973; Downey, 1984a, b; Hannon, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; DeMis, 1995; Bachu and Hitchon, 1996; LeFever, 1998; Margitai, 2002).

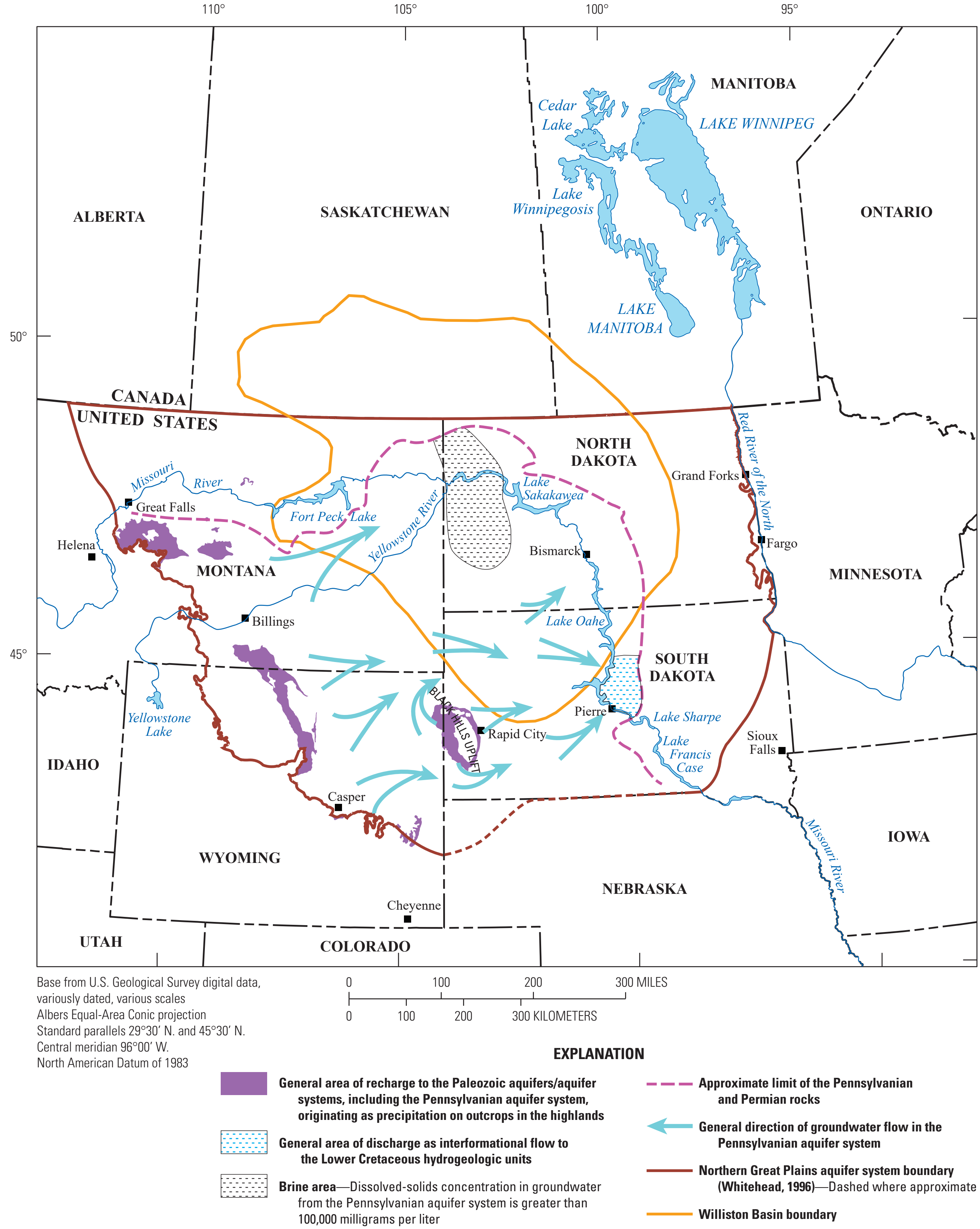


Figure 12. General areas of recharge to the Paleozoic aquifers/aquifer systems, and general direction of groundwater flow in, and discharge from, the Pennsylvanian aquifer system in the Williston Basin and adjacent areas, United States and Canada (modified from Downey and Dinwiddie, 1988).

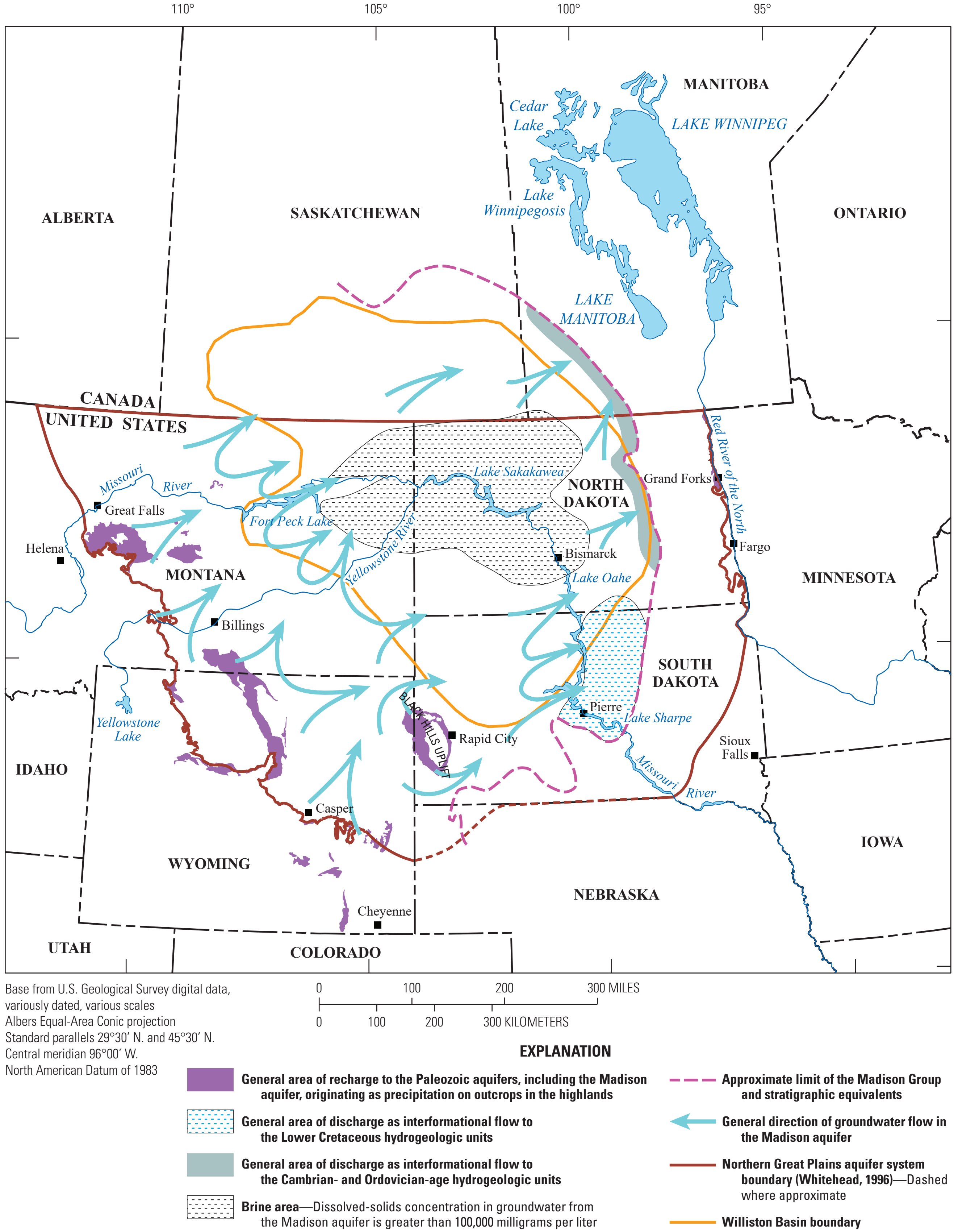


Figure 13. General areas of recharge to the Paleozoic aquifers/aquifer systems, and general direction of groundwater flow in, and discharge from, the Madison aquifer in the Williston Basin and adjacent areas, United States and Canada (modified from Downey and Dinwiddie, 1988).

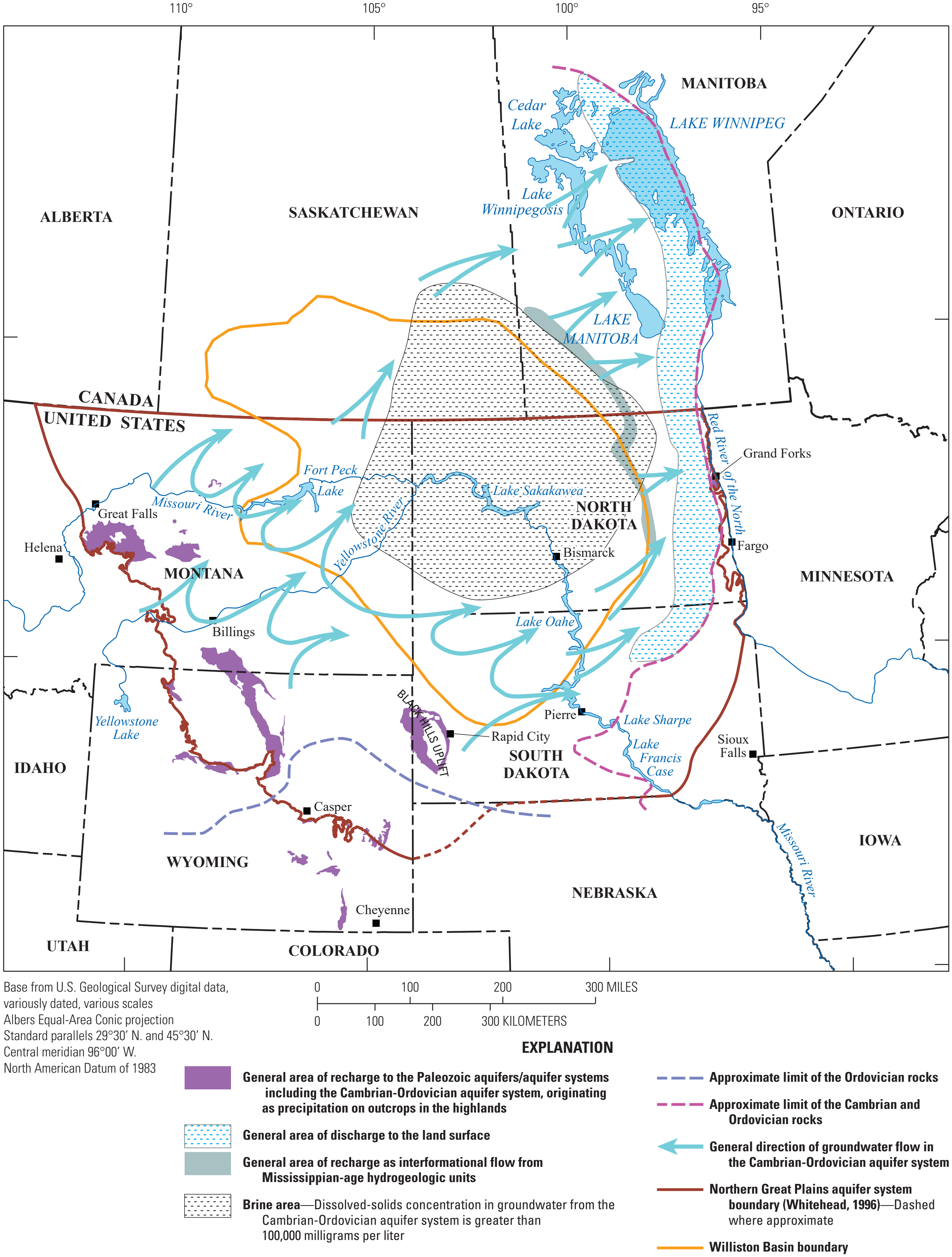


Figure 14. General areas of recharge to the Paleozoic aquifers/aquifer systems, and general direction of groundwater flow in, and discharge from, the Cambrian-Ordovician aquifer system in the Williston Basin and adjacent areas, United States and Canada (modified from Downey and Dinwiddie, 1988).

Estimated rates of regional flow in the Paleozoic aquifers indicate groundwater movement is slow, generally ranging from less than 2 to 10 feet per year (ft/yr) for the Madison aquifer and less than 2 to as much as 75 ft/yr for the Cambrian-Ordovician aquifer (Downey and Dinwiddie, 1988). Discharge from the Pennsylvanian aquifer system and Madison aquifer flows to adjacent and overlying aquifer systems along eastern subcrops, and much of this discharge is as recharge to the overlying Lower Cretaceous aquifers in eastern North and South Dakota (figs. 3, 12, 13; Swenson, 1968; Downey, 1973, 1984a, b; Downey and Dinwiddie, 1988). Discharge from the Cambrian-Ordovician aquifer system flows to overlying shallow aquifers/aquifer systems or through springs and seeps in North Dakota east of the Williston Basin margin and to overlying glacial till in northeastern North Dakota and Manitoba (fig. 14; Swenson, 1968; Downey, 1973; Downey and Dinwiddie, 1988; Bachu and Hitchon, 1996).

In the Williston Basin, upper Paleozoic aquifers and lower Paleozoic aquifers and confining units contain freshwater only in the southernmost part of the basin east of the Black Hills uplift in South Dakota (figs. 15, 16) where infiltrating meteoric waters recharge the exposed aquifer outcrops. Upper and lower Paleozoic aquifers/confining units contain saline and briny waters throughout the rest of their geographic extent, including the dense brine with dissolved-solids concentrations greater than 100,000 mg/L present in much of eastern Montana and central North Dakota (figs. 3, 15, 16). Dissolved-solids concentrations increase toward the basin center and with increasing depth, except for local anomalies (Bachu and Hitchon, 1996; Benn and Rostron, 1998). Fresher and less-dense groundwater is hypothesized to flow laterally around and above the margins of the dense brine (dissolved-solids concentrations greater than 100,000 mg/L) present in parts of the upper and lower Paleozoic aquifers/confining units buried in the deepest part of the basin (figs. 3, 15, 16; Downey and others, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Bachu and Hitchon, 1996; Benn and Rostron, 1998; LeFever, 1998). Most groundwater flowing laterally around the dense brine discharges to shallower aquifers in eastern North Dakota, whereas groundwater flowing above the dense brine moves upward to the Quaternary unconsolidated glacial- and alluvial-deposit aquifers overlying the Northern Great Plains aquifer system and ultimately discharges to springs, streams, and lakes in eastern North Dakota (figs. 12–14). Some of this water reaches the land surface as saline springs or seeps. A small component of the regional groundwater-flow system not diverted around the dense basinal brine is hypothesized to flow east and northeast through the brine at rates much less than the rest of the regional groundwater-flow system (Downey and others, 1987; Downey and Dinwiddie, 1988; Busby and others, 1995; Toop and Tóth, 1995; Bachu and Hitchon, 1996; LeFever, 1998; Jensen and Rostron, 2006).

River and Stream Resources

The Williston Basin (fig. 1) is within two major river systems—the Missouri River system and the Hudson Bay system. The closed Devils Lake Basin (not shown in fig. 1) in the northeastern Williston Basin in North Dakota does not typically contribute streamflow to a major river system. About 86 percent of the Williston Basin is in the Missouri River system, about 12 percent of the Williston Basin is in the Hudson Bay system, and about 2 percent is in the closed Devils Lake Basin.

This section will describe (1) information on existing streamflow data that are available for streams in the Williston Basin, (2) streamflow characteristics for streamgages in the Williston Basin with generally more than 50 years of record, and (3) research and data-collection needs to address information and data gaps. The information on streamflow characteristics is presented in sections for major rivers (including the Missouri and Yellowstone Rivers) and large streams.

Available Streamflow Data

Within the Williston Basin, 360 USGS streamgages have 10 or more years of data collection through water year 2014; a water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. The locations and summary information for these streamgages are presented in Appendix figure 1–1 and table 1–1 and summary information also is included in the associated data release (Boughton and others, 2022, table 1–1). For 194 of the 360 streamgages, year-round or seasonal continuous streamflow data have been collected in all, or part of, their data-collection periods to produce daily streamflow records and annual peak-flow records that represent the maximum instantaneous discharge for each year of a streamgage's operation. Total drainage areas for the 194 streamgages with available continuous-record data range from 1.34 to 208,700 square miles (mi^2; median=723 mi^2). The length of data collection for the 194 streamgages ranges from 10 to 112 years (median=about 25 years).

For 166 of the 360 streamgages, data collection has been restricted to crest-stage operations that involve recording the maximum stream stage for each year, making periodic instantaneous discharge measurements, and analyzing the stream-stage and discharge data to produce annual peak-flow records. Total drainage areas for the 166 crest-stage streamgages range from 0.06 to 240 mi^2 (median=3.0 mi^2). The length of data collection for the 166 crest-stage streamgages ranges from 10 to 56 years (median=19 years).

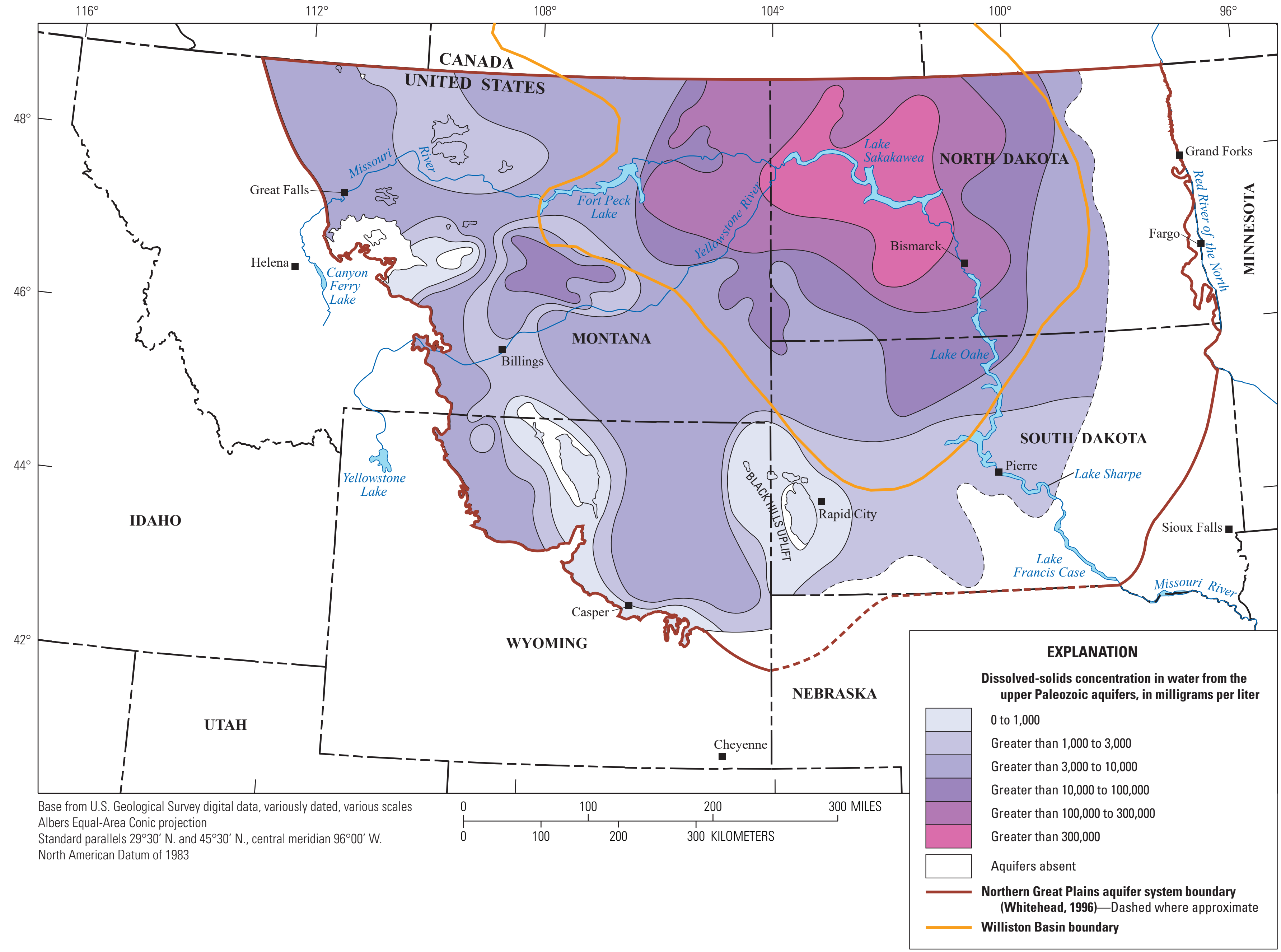


Figure 15. Dissolved-solids concentrations in water from upper Paleozoic aquifers in the Williston Basin and adjacent areas (modified from Whitehead, 1996).

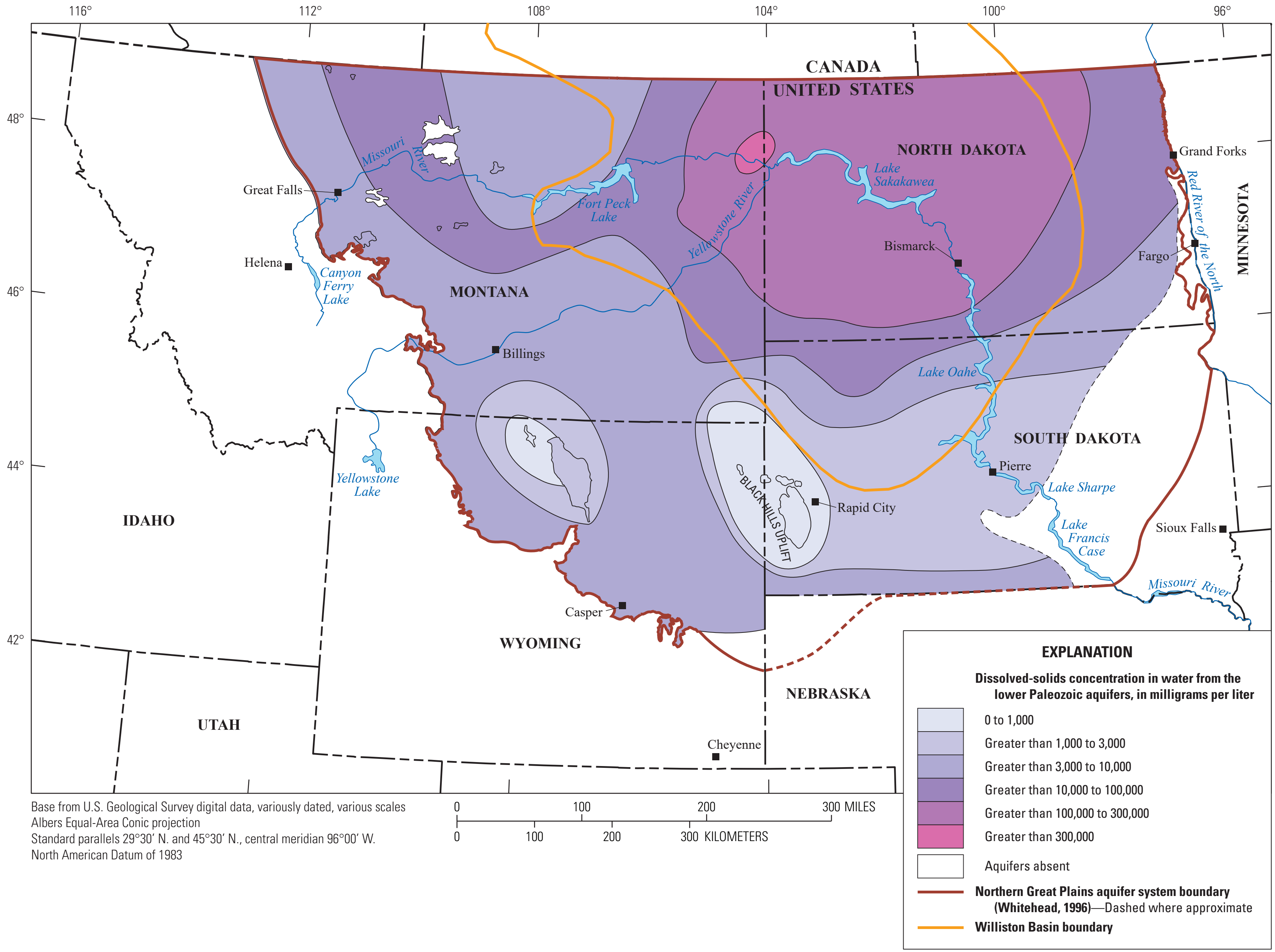


Figure 16. Dissolved-solids concentrations in water from the lower Paleozoic aquifers and confining units in the Williston Basin and adjacent areas (modified from Whitehead, 1996).

Streamflow Characteristics

To describe streamflow characteristics within the Williston Basin, 17 streamgages (table 3) were selected primarily because of record length and representation of large areas (fig. 17). The selected streamgages generally had greater than 50 years of data collection each within a 61-year base period of water years 1954 through 2014 or represented a large area of the Williston Basin. The start of the base period was defined primarily by the closure of Garrison Dam (fig. 17) on the Missouri River (forming Lake Sakakawea), and the subsequent large-scale coordination of reservoir operations on the Missouri River (U.S. Army Corps of Engineers [USACE], 2006). Within the 1954 through 2014 base period, all the selected streamgages have consistent hydrologic regimes with respect to regulation; that is, for streamgages affected by major reservoirs, the major reservoirs were in place before 1954.

The selected streamgages were classified as representing either major rivers or large streams (table 3). Major rivers (that is, the Missouri and Yellowstone Rivers with total drainage areas greater than 50,000 mi^2) flow into and through the Williston Basin but have substantial parts of their drainage basins upstream from the Williston Basin. In contrast, the large streams have total drainage areas that range from about 551 to 22,452 mi^2, and generally all or most of their drainage basins are within the Williston Basin (contributing drainage basin area). The large streams were further classified by ecoregion (U.S. Environmental Protection Agency [EPA], 2013b): (1) the Northwestern Glaciated Plains ecoregion, (2) the Northern Glaciated Plains ecoregion, or (3) the Northwestern Great Plains ecoregion.

The streamflow characteristics presented represent data analysis completed on different temporal scales. Monthly and annual streamflow characteristics facilitate discussion of seasonal and interannual variability in streamflow and provide general information on primary drivers of streamflow, and reliability of streamflow on seasonal and multiple-year scales. Daily streamflow and annual extreme flow characteristics provide information on critical short-term (weekly, daily, or instantaneous) and extreme streamflow conditions, such as floods or zero-streamflow conditions. Daily streamflow and annual extreme flow characteristics provide hydrologic information that might be relevant to infrastructure design and evaluating potential causes and environmental effects of accidental spills of product, leakages of water extracted from oil and coal-bed methane wells, or the intentional illegal discharges of the extracted waters.

Streamflow Data Compilation and Analysis

Daily mean streamflow and annual peak-flow data for the selected streamgages were retrieved from the USGS National Water Information System (NWIS; USGS, 2015c) database. Data retrievals were restricted to complete water years within the 1954 through 2014 base period. Monthly and annual mean streamflows were computed from the daily mean streamflows using the USGS Automated Data and Processing System (USGS, 2003) and summary statistics of the monthly and annual mean streamflows are presented in a data release (Boughton and others, 2022, table 1–2). Some streamgages did not have complete streamflow records for all of the 61 years in the 1954–2014 base period; for those streamgages, the summary statistics of the monthly and annual mean streamflows were computed for the periods of record indicated in table 1–2 (Boughton and others, 2022).

Duration hydrograph data were computed using the USGS Surface-Water Statistics program (SWSTAT; USGS, 2015b). Duration hydrograph data are presented for the nonexceedance 10th-, 25th-, 50th- (median), 75th-, and 90th percentiles for each day of the water year (figs. 18–20). The 10th-percentile duration streamflow value for a given day indicates a low-streamflow condition such that streamflows are less than or equal to the value for the given day only 10 percent of the time. Conversely, the 90th-percentile duration streamflow value for a given day indicates a high-streamflow condition such that streamflows are less than or equal to the value for the given day 90 percent of the time.

Annual 7-day low-flow data were computed using the USGS SWSTAT (USGS, 2015b). The annual 7-day low flow is the lowest mean streamflow for any 7 consecutive days in a given year. The annual 7-day low flow was computed according to the standard climatic year of April 1 through March 31.

The magnitude of the variability in streamflow characteristics among the selected streamgages introduces challenges in presenting the information. In figures 18–20, log-scale plots are used with the intent of showing the large relative variability in characteristics among the selected streamgages while also maintaining some resolution in the characteristics of individual streamgages. The log-scale presentation does not allow accurate presentation of low values near zero. Thus, in figures 19–20 the y-axis minimum is set to 1 ft^3/s; in those figures, actual streamflow values less than 1 ft^3/s were plotted at 1 ft^3/s, which is considered a reasonable representation of at or near-zero streamflows.

Table 3. Information on selected streamgages on major rivers and large streams in or near the Williston Basin, 1954 through 2014.

[Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends. --, not available, NAVD 88, North American Vertical Datum of 1988]

Streamgage number or geographic area	Streamgage name	Stream classification (and ecoregion, if applicable)	Latitude, in decimal degrees	Longitude, in decimal degrees	Drainage area, in square miles	
					Total	Contributing
05056000	Sheyenne River near Warwick, North Dakota	Large stream (Northern Glaciated Plains)	47.8056	−98.7162	2,070	760
05124000	Souris River near Westhope, North Dakota	Large stream (Northern Glaciated Plains)	48.9964	−100.9585	16,900	6,600
06132000	Missouri River below Fort Peck Dam, Montana	Major river	48.0444	−106.3563	56,490	56,490
06174500	Milk River at Nashua, Montana	Large stream (Northwestern Glaciated Plains)	48.1301	−106.3643	22,452	20,254
06177500	Redwater River at Circle, Montana	Large stream (Northwestern Great Plains)	47.4140	−105.5756	551	551
06181000	Poplar River near Poplar, Montana	Large stream (Northwestern Glaciated Plains)	48.1709	−105.1786	3,140	3,140
06185500	Missouri River near Culbertson, Montana	Major river	48.1235	−104.4733	89,959	89,858
06309000	Yellowstone River at Miles City, Montana	Major river	46.4208	−105.8600	48,288	47,596
06329500	Yellowstone River near Sidney, Montana	Major river	47.6774	−104.1554	69,099	68,407
06330000	Missouri River near Williston, North Dakota	Major river	48.1081	−103.7146	164,500	164,500
06337000	Little Missouri River near Watford City, North Dakota	Large stream (Northwestern Great Plains)	47.5903	−103.2519	8,310	8,310
06340500	Knife River at Hazen, North Dakota	Large stream (Northwestern Great Plains)	47.2853	−101.6221	2,240	2,240
06342500	Missouri River at Bismarck, North Dakota	Major river	46.8142	−100.8214	186,400	186,400
06349000	Heart River near Mandan, North Dakota	Large stream (Northwestern Great Plains)	46.8339	−100.9746	3,310	3,310
06354000	Cannonball River at Breien, North Dakota	Large stream (Northwestern Great Plains)	46.3761	−100.9344	4,100	4,100
06357800	Grand River at Little Eagle, South Dakota	Large stream (Northwestern Great Plains)	45.6578	−100.8182	5,316	5,316
06360500	Moreau River near Whitehorse, South Dakota	Large stream (Northwestern Great Plains)	45.2558	−100.8429	4,889	4,872
Williston Basin area	--	--	--	--	--	--

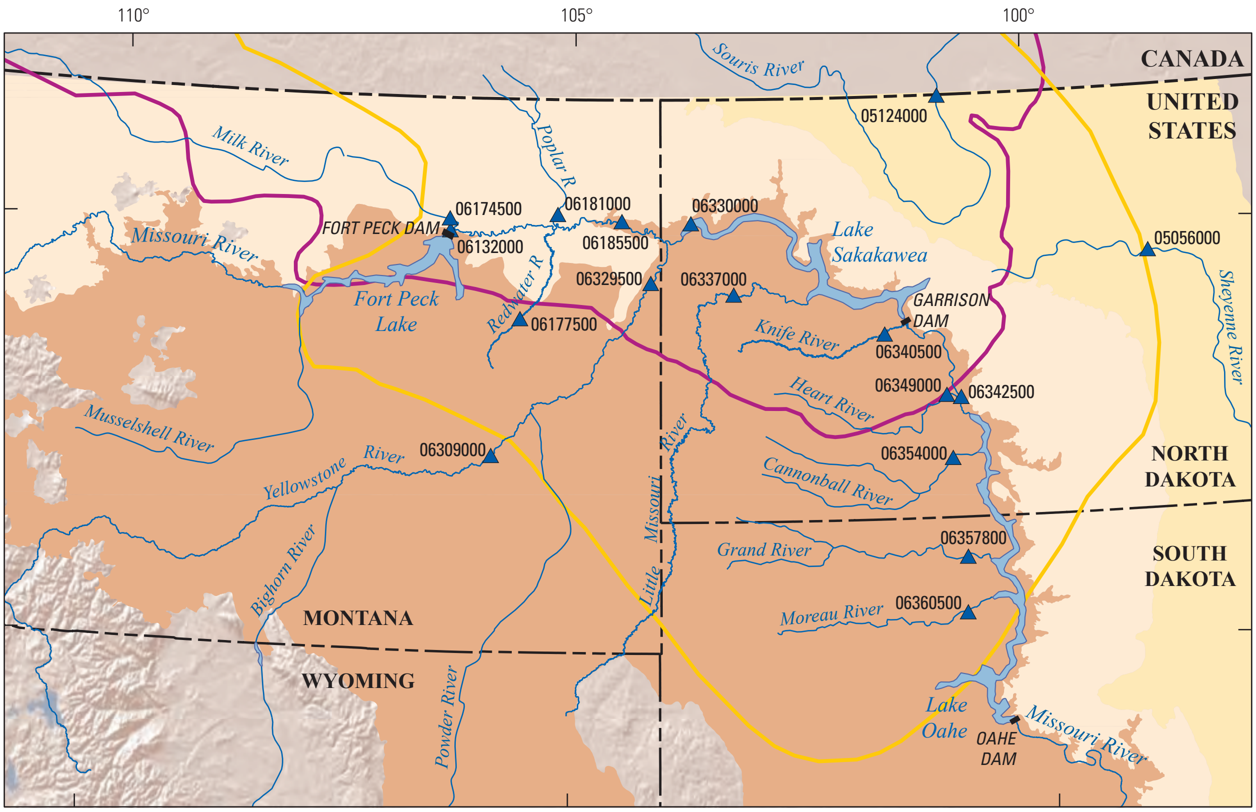
Table 3. Information on selected streamgages on major rivers and large streams in or near the Williston Basin, 1954 through 2014.—Continued

[Water year is the 12-month period from October 1 through September 30, and is designated by the calendar year in which it ends. --, not available, NAVD 88, North American Vertical Datum of 1988]

Streamgage number or geographic area	Streamgage name	Mean elevation, in feet above NAVD 88	Mean annual precipitation, in inches	Mean annual air temperature, in degrees Fahrenheit	Percentage of drainage area or study area covered by lakes and wetlands[1]	Drainage basin/water yield, in percent[2]	Period of analysis, in water years	Number of water years in period of analysis
05056000	Sheyenne River near Warwick, North Dakota	1,628	17.5	39.7	9.6	Sheyenne River/9.8	1954–2014	61
05124000	Souris River near Westhope, North Dakota	1,840	17.1	37.8	8.4	Souris River/5.0	1954–2014	61
06132000	Missouri River below Fort Peck Dam, Montana	4,654	17.6	40.8	--	Missouri River, Fort Peck/12.6	1954–2000, 2002–14	60
06174500	Milk River at Nashua, Montana	3,007	13.5	40.5	2.5	Milk River/3.0	1954–2014	61
06177500	Redwater River at Circle, Montana	2,809	12.8	42.8	0.3	Redwater River/1.7	1954–71, 1975–2004, 2010–13	52
06181000	Poplar River near Poplar, Montana	2,700	13.9	39.0	0.6	Poplar River/3.5	1954–69, 1976–79, 1982–2014	53
06185500	Missouri River near Culbertson, Montana	3,974	16.0	41.6	--	Missouri River, Culbert/9.7	1959–2014	56
06309000	Yellowstone River at Miles City, Montana	5,490	17.8	41.1	0.5	Yellowstone River, Miles City/18.3	1954–2014	61
06329500	Yellowstone River near Sidney, Montana	4,994	16.7	41.9	0.5	Yellowstone River, Sidney/14.0	1954–2014	61
06330000	Missouri River near Williston, North Dakota	--	--	--	--	Missouri River, Williston/--	1954–1964	11
06337000	Little Missouri River near Watford City, North Dakota	3,101	15.3	42.9	0.7	Little Missouri River/5.5	1954–2014	61
06340500	Knife River at Hazen, North Dakota	2,190	16.7	41.0	1.0	Knife River/5.9	1954–2014	61
06342500	Missouri River at Bismarck, North Dakota	2,211	--	--	--	Missouri River, Bismarck/--	1954–2014	61
06349000	Heart River near Mandan, North Dakota	2,340	16.8	41.0	1.0	Heart River/6.5	1954–2014	61
06354000	Cannonball River at Breien, North Dakota	2,420	16.6	42.4	1.4	Cannonball River/5.0	1954–2014	61
06357800	Grand River at Little Eagle, South Dakota	2,582	16.4	42.8	1.2	Grand River/4.0	1954–2014	61
06360500	Moreau River near Whitehorse, South Dakota	2,623	16.5	44.0	1.4	Moreau River/4.7	1954–2014	61
Williston Basin area	--	--	16.0	40.3	4.7	Williston Basin/--	--	--

[1]Percentage of area covered by lakes and wetlands was determined by geographic information system (GIS) analysis of the National Wetlands Inventory dataset (U.S. Fish and Wildlife Service, 2014). For an individual streamgage, the analysis was restricted to the part of the drainage area within the Williston Basin area boundary. Although the analysis does not include the entire drainage areas of the streamgages, reasonable representation of relative differences in depressional storage among streamgages is provided.

[2]The drainage basin water yield is defined as the ratio (expressed in percentage) of the mean annual runoff in inches (from Boughton and others, 2022, table 1–2) relative to the mean annual precipitation in inches (from previous column in this table).



Base map modified from U.S. Geological Survey, Esri, and Commission for Environmental Cooperation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

EXPLANATION

U.S. Environmental Protection Agency level III ecoregion (U.S. Environmental Protection Agency, 2013b)

- Northern Glaciated Plains
- Northwestern Glaciated Plains
- Northwestern Great Plains

Williston Basin boundary

Bakken Formation boundary

06360500 **U.S. Geological Survey streamgage and identifier**

Figure 17. Locations of selected streamgages on major rivers and large streams in or near the Williston Basin.

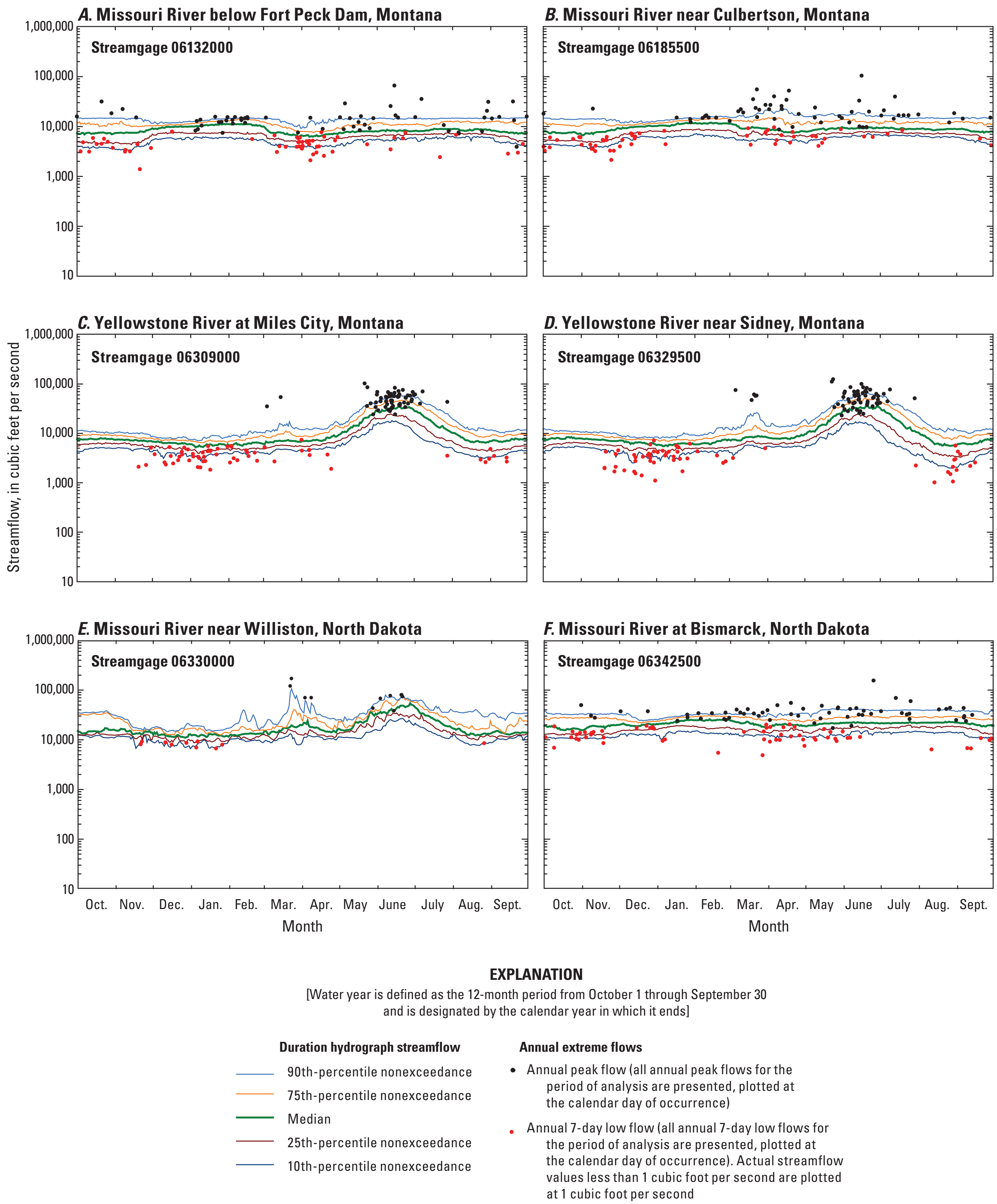
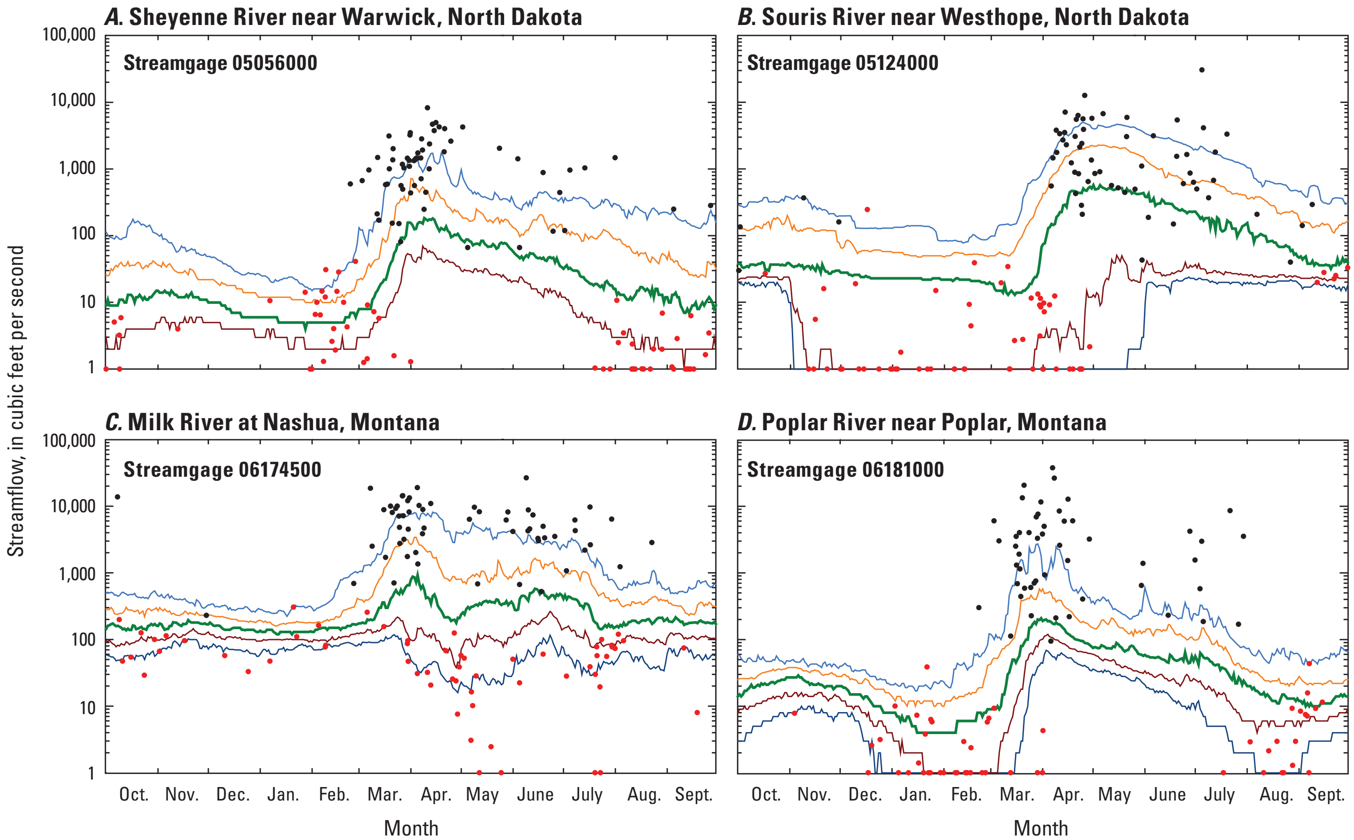


Figure 18. Duration hydrograph streamflow statistics and annual extreme flows for selected streamgages on major rivers in the Williston Basin, Montana, North Dakota, and South Dakota.



EXPLANATION

[Water year is defined as the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends]

Duration hydrograph streamflow

- 90th-percentile nonexceedance
- 75th-percentile nonexceedance
- Median
- 25th-percentile nonexceedance
- 10th-percentile nonexceedance

Annual extreme flows

- Annual peak flow (all annual peak flows for the period of analysis are presented, plotted at the calendar day of occurrence)
- Annual 7-day low flow (all annual 7-day low flows for the period of analysis are presented, plotted at the calendar day of occurrence). Actual streamflow values less than 1 cubic foot per second are plotted at 1 cubic foot per second

Figure 19. Duration hydrograph streamflows and annual extreme flows for selected streamgages on large streams in the Northern and Northwestern Glaciated Plains ecoregions.

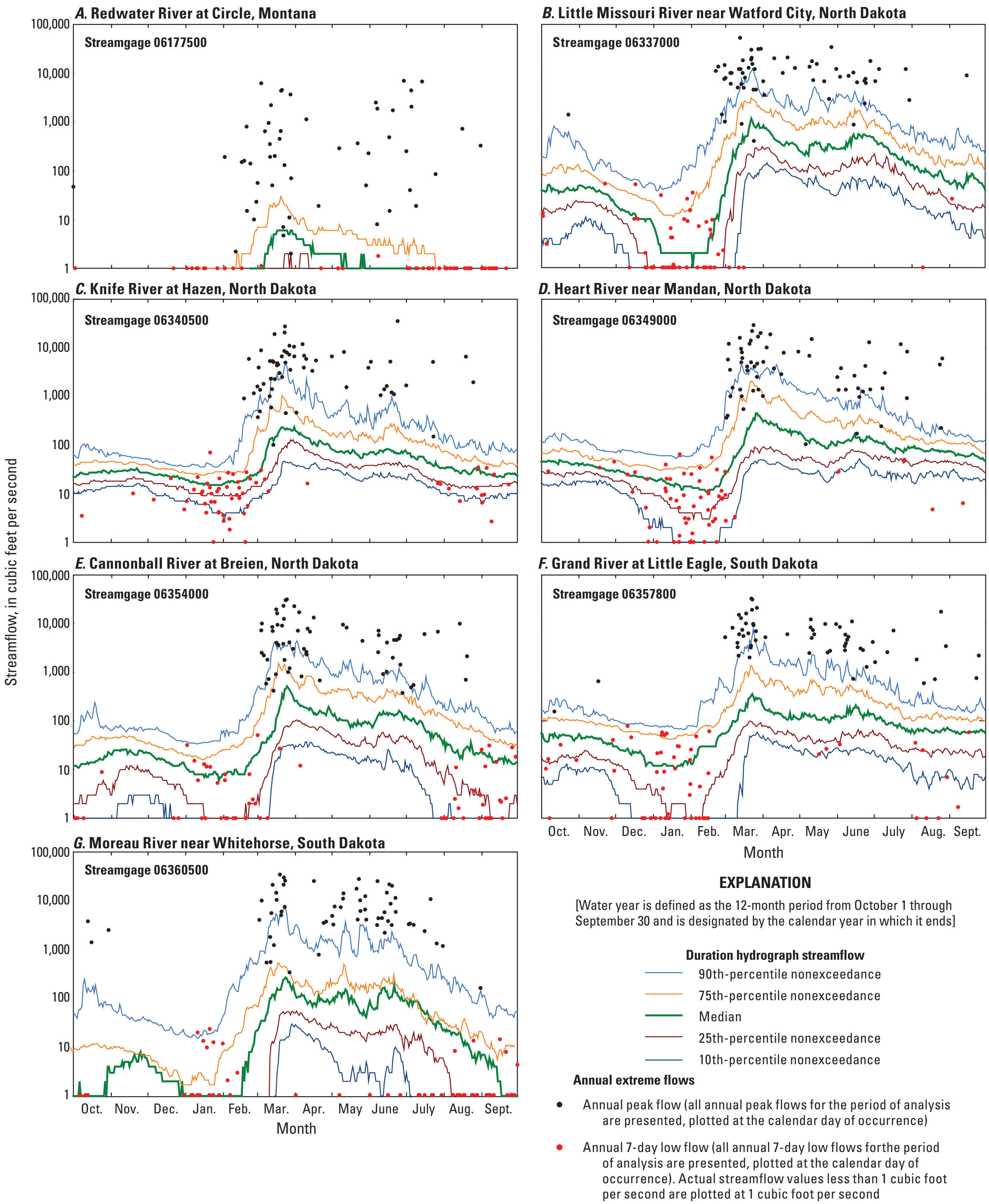


Figure 20. Duration hydrograph streamflows and annual extreme flows for selected streamgages on large streams in the Northwestern Great Plains ecoregion.

In addition to the graphical presentation of streamflow characteristics in figures 18–20, summary statistics were computed for the streamflow characteristics of monthly and annual mean streamflows, and annual extreme flows (that is, the annual peak flow and the annual 7-day low flow) and have been presented in tabular form in a data release (Boughton and others, 2022, tables 1–2 and 1–3). The summary statistics include the minimum, 10th-percentile, 25th-percentile, 50th-percentile (median), mean, 75th-percentile, 90th-percentile, and maximum values. The percentile values represent nonexceedance percentiles and, for each streamflow characteristic, were determined by ranking the data from lowest to highest and dividing the rank by the total number of observations; thus, the percentiles represent the frequency of occurrence within the years of the analysis period, with no adjustment to represent probability of occurrence within longer periods. For the annual extreme flows (that is, the annual peak flow and the annual 7-day low flow), frequency analyses often are done to estimate probabilities within longer periods for purposes, including structure design or regulation of wastewater discharges; however, such frequency analyses are appropriately done on a station-by-station basis using all available data. The use of the common base period of 1954 through 2014 in this study results in truncated datasets for some streamgages that would not be appropriate for frequency analysis.

Hydrographic information presented (including drainage area, stream length, mean elevation, and in some cases percentage of basin greater than 6,000 ft in elevation) was determined by geographic information system (GIS) analysis of medium resolution (1:100,000 scale and 30 meter) digital datasets. The digital datasets include the National Elevation Dataset (Gesch and others, 2002), National Hydrography Dataset (NHD; USGS, 2015a), and National Hydrography Dataset Plus Version 2 (NHDPlus; Horizon Systems Corporation, 2013); however, drainage areas for streamgages that are reported in tables were obtained from the NWIS database (USGS, 2015c) and were determined using various methods. Climatic basin characteristics information (including mean annual precipitation and mean annual air temperature) was determined by GIS analysis of the Parameter-elevation Regression on Independent Slopes Model (PRISM; PRISM Climate Group, 2004) and the Long Term mean Climate Grids for Canada (Natural Resources Canada, 2015). Information on density of depressional storage, or percentage of drainage area covered by lakes and wetlands, was determined by GIS analysis of the National Wetlands Inventory (NWI) dataset (U.S. Fish and Wildlife Service [USFWS], 2014).

Several drainage basin characteristics of the 17 selected streamgages are presented in table 3. Also included in table 3 is the drainage basin water yield, which provides an index of the efficiency in translating the deposited atmospheric precipitation into streamflow past a streamgage. The drainage basin yield is defined as the ratio (expressed in percentage) of the mean annual runoff in inches (Boughton and others, 2022, table 1–2) relative to the mean annual precipitation in inches (table 3).

Major Rivers

The Missouri and Yellowstone Rivers are considered major rivers that flow into and through the Williston Basin (fig. 17). These major rivers have substantial parts of their drainage basins that are outside the Williston Basin, but they also have long segments of their channels within the area.

Description of Major River Hydrography

Missouri River enters the upper reaches of Fort Peck Lake west of the Williston Basin (fig. 17), at which point the drainage area is about 41,000 mi^2. A substantial part of the Missouri River Basin upstream from the Williston Basin (hereinafter referred to as the "upstream Missouri River Basin") is mountainous; about 31 percent of the drainage area is higher than 6,000 ft in elevation. Much of the streamflow generated in the upstream Missouri River Basin results from high-elevation snowmelt that typically happens in May and June (Pederson and others, 2010); however, the upstream Missouri River Basin is somewhat strongly regulated because four major reservoirs have multipurpose operations that include flood control. The four reservoirs individually have total storage capacities that exceed 325,000 acre-feet (acre-ft) and cumulatively have about 4,300,000 acre-ft of total storage capacity (Sando and others, 2016).

Within the Williston Basin, Fort Peck Lake extends about 110 miles (mi) from the western boundary of the Williston Basin to Fort Peck Dam (fig. 17). Fort Peck Lake has a storage capacity of 18,463,000 acre-ft, and maximum depth at full pool of about 220 ft (USACE, 2015a). The largest tributary to Fort Peck Lake is the Musselshell River, which has a drainage area of about 8,000 mi^2. From Fort Peck Dam, the Missouri River flows for about 185 mi to the confluence with the Yellowstone River. The largest tributaries in this reach are the Milk River and the Poplar River (fig. 17). Upstream from the confluence with the Yellowstone River, the Missouri River has a drainage area of about 90,000 mi^2, and about 15 percent of the drainage area is higher than 6,000 ft in elevation.

As it enters the western boundary of the Williston Basin (fig. 17), the Yellowstone River has a drainage area of about 48,000 mi^2, and about 33 percent of the basin is higher than 6,000 ft in elevation. Similar to the upstream Missouri River Basin, much of the streamflow generated in the upstream Yellowstone River Basin results from high-elevation snowmelt that typically happens in May and June (Pederson and others, 2010); however, the upstream Yellowstone River Basin (with a single major reservoir with multipurpose operations that include flood control) has substantially less major regulation than the upstream Missouri River Basin because just one primary reservoir is in operation on the river. Bighorn Lake, formed by Yellowtail Dam (not shown in fig. 1), is on the Bighorn River far upstream from the Williston Basin and has a total storage capacity of about 1,400,000 acre-ft (Bureau of Reclamation, 2015b). Within the Williston Basin, the Yellowstone River flows from the western boundary for about

170 mi to the confluence with the Missouri River (fig. 17). The largest tributary to the Yellowstone is the Powder River with a drainage area of about 13,400 mi^2, most of which is outside of the Williston Basin. The Intake Diversion Dam and canal (not shown in fig. 1), on the Yellowstone River about 70 mi upstream from the confluence with the Missouri River, diverts streamflow from the Yellowstone River to the Lower Yellowstone Project (Bureau of Reclamation, 2015a). The Intake Diversion Dam canal has a capacity of about 1,200 ft^3/s and on a mean annual basis diverts about 327,046 acre-ft, or about 450 ft^3/s of streamflow (Bureau of Reclamation, 2015a). At its confluence with the Missouri River, the Yellowstone River has a drainage area of about 69,000 mi^2, and about 25 percent of the drainage area is higher than 6,000 ft in elevation.

From the confluence with the Yellowstone River, the Missouri River flows about 15 to 35 mi (depending on the storage in Lake Sakakawea) to the upper reaches of Lake Sakakawea formed by Garrison Dam (fig. 17). At full pool, Lake Sakakawea extends for about 175 mi, has a storage capacity of 23,821,000 acre-ft, and has a maximum depth of about 180 ft (USACE, 2015b). The largest tributary to Lake Sakakawea is the Little Missouri River (fig. 17). From Garrison Dam, the Missouri River flows about 80 to 130 mi (depending on the storage in Lake Oahe) to the upper reaches of Lake Oahe, which is formed by Oahe Dam (fig. 17). The largest tributaries in the reach are the Knife River and the Heart River (fig. 17). At full pool, Lake Oahe has a storage capacity of 23,137,000 acre-ft, and a maximum depth of about 205 ft (USACE, 2015c). The distance from the upper reaches of Lake Oahe to Oahe Dam at full pool is about 230 mi; however, the main body of Lake Oahe exits the Williston Basin about 95 mi downstream from the upper reaches. The largest tributaries to Lake Oahe in the Williston Basin are the Cannonball, Grand, Moreau, and Sheyenne Rivers (fig. 17).

Description of Major River Streamflow Characteristics

Duration hydrographs of daily streamflows are presented in conjunction with annual extreme flows (that is, annual peak-flow and annual 7-day low-flow data) for the six streamgages (06132000, 06185500, 06309000, 06329500, 06330000, and 06342500; fig. 18) on the major rivers (fig. 17). The summary statistics of monthly and annual mean streamflows and summary statistics of annual extreme flows for these streamgages described below are presented as a data release (Boughton and others, 2022, tables 1–2 and 1–3, respectively).

Streamflows for the Missouri River below Fort Peck Dam, Montana (streamgage 06132000; contributing drainage area of 56,490 mi^2; table 3; figs. 17, 18*A*), represent the releases from Fort Peck Lake that are controlled by complex reservoir operations described in USACE (2006). The large effects of regulation are evidenced by generally small seasonal and interannual variability in streamflows. Median monthly releases range from 6,710 ft^3/s in April to 11,000 ft^3/s in February, and median annual runoff is 2.14 inches (in.) (Boughton and others, 2022, table 1–2). Annual peak flows range from 3,900 to 65,900 ft^3/s (median=14,400 ft^3/s) (Boughton and others, 2022, table 1–3), and are in many months, but most often are in January and February (fig. 18*A*). Annual 7-day low flows range from 1,390 to 7,860 ft^3/s (median=4,410 ft^3/s) (Boughton and others, 2022, table 1–3) and most often are in October through November and March through April (fig. 18*A*).

Streamflows for Missouri River near Culbertson, Mont. (streamgage 06185500; contributing drainage area of 89,858 mi^2; table 3; figs. 17, 18*B*), also are strongly affected by regulation from Fort Peck Dam (fig. 17). Median monthly streamflows range from 7,470 ft^3/s in October to 11,600 ft^3/s in February, and median annual runoff is 1.45 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 8,620 to 104,000 ft^3/s (median=16,700 ft^3/s) (Boughton and others, 2022, table 1–3), and are in many months, but most often are in March and April (fig. 18*B*). Differences in the timing of annual peak flows between streamgages 06132000 and 06185500 primarily reflect tributary inflows from the Milk and Poplar Rivers in March and April. Annual 7-day low flows range from 2,130 to 9,590 ft^3/s (median=5,580 ft^3/s) (Boughton and others, 2022, table 1–3), and most often are in March through May and during October through December (fig. 18*B*). The streamflow characteristics for streamgage 06185500 represent strong effects of regulation by Fort Peck Dam with generally small effects from tributary inflows. Median annual streamflow of the Missouri River increases by about 6 percent from 8,910 ft^3/s at streamgage 06132000 to 9,450 ft^3/s at streamgage 06185500 (fig. 17) (Boughton and others, 2022, table 1–2), associated with an increase in drainage area of about 59 percent. Most of the Missouri River streamflow is generated upstream from the Williston Basin, and streamflow inputs generally are small in the reach from below Fort Peck Dam to the confluence with the Yellowstone River.

The Yellowstone River at Miles City, Mont. (streamgage 06309000; contributing drainage area of 47,596 mi^2; table 3; figs. 17, 18*C*), is about 15 mi upstream from the western boundary of the Williston Basin and largely is unaffected by regulation structures. Streamflows for streamgage 06309000 reflect a high-elevation-snowmelt dominated hydrologic regime within a large predominantly unregulated drainage basin. The snowmelt-dominated hydrologic regime is evidenced by somewhat large seasonal variability in streamflows but generally small interannual (year-to-year) variability in streamflows. Median monthly streamflows range from 5,760 ft^3/s in January to 29,700 ft^3/s in June, and median annual runoff is 3.37 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 24,100 to 102,000 ft^3/s (median=48,100 ft^3/s) (Boughton and others, 2022, table 1–3). About 95 percent of annual peak flows have been in mid-May through early July (fig. 18*C*), but about 28 percent of annual peak stages have been in late-February or March (USGS, 2015c), presumably associated with the start of low-elevation snow and ice melt, the transition from ice cover to open-channel streamflow, and the formation of ice jams that can impound streamflow and increase the river stage. Annual 7-day low flows range from 1,830 to 7,450 ft^3/s (median=3,460 ft^3/s) (Boughton and others, 2022, table 1–3) and happen most frequently in December through February (fig. 18*C*).

The Yellowstone River near Sidney, Mont. (streamgage 06329500; contributing drainage area of 68,407 mi^2; table 3; figs. 17, 18*D*), is about 155 mi downstream from streamgage 0630900 and about 30 mi upstream from the confluence with the Missouri River. Streamflow for streamgage 06329500 reflects a high-elevation-snowmelt dominated hydrologic regime within a large predominantly unregulated drainage basin. Median monthly streamflow ranges from 6,160 ft^3/s in January to 32,600 ft^3/s in June, and median annual runoff is 2.40 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 23,000 to 124,000 ft^3/s (median=54,300 ft^3/s) (Boughton and others, 2022, table 1–3). About 95 percent of annual peak flows have been in mid-May through early July (fig. 18*D*); however, about 25 percent of annual peak stages have been in late-February or March (USGS, 2015c), presumably associated with the start of low-elevation snow and ice melt, the transition from ice cover to open-channel streamflow, and the formation of ice jams that can impound streamflow and increase the river stage. Annual 7-day low flows range from 1,010 to 7,140 ft^3/s (median=3,180 ft^3/s) Boughton and others, 2022, table 1–3), and most often are in December and January (fig. 18*D*). Median annual streamflow of the Yellowstone River only increases by about 2.5 percent from 11,800 ft^3/s at streamgage 06309000 to 12,100 ft^3/s at streamgage 06329500 (Boughton and others, 2022, table 1–2), associated with an increase in drainage area of about 43 percent. The small increase in median annual streamflow between streamgages 06309000 and 06329500 is partly affected by a diversion canal about 40 mi upstream from streamgage 06329500, which on a mean annual basis diverts about 450 ft^3/s. But clearly most of the Yellowstone River streamflow is generated upstream from the Williston Basin, and streamflow inputs generally are small within the Williston Basin.

The Missouri River near Williston, North Dakota (streamgage 06330000; contributing drainage area of 164,500 mi^2; table 3; figs. 17, 18*E*), is about 30 mi downstream from the confluence of the Missouri and Yellowstone Rivers. The period of analysis for streamgage 06330000 is short (1954–64; 11 years; table 3) within the period of coordinated operations of Fort Peck and Garrison Dams. Data for streamgage 06330000 are presented to provide a general qualitative description of the somewhat short but complex reach where the strongly regulated streamflow inputs of the Missouri River interact with the predominantly unregulated inputs of the Yellowstone River. Median monthly streamflow ranges from 11,700 ft^3/s in January to 41,500 ft^3/s in June, and median annual runoff is 1.63 in (Boughton and others, 2022, table 1–2). For streamgage 06330000, the highest and lowest streamflow months (June and January, respectively) are consistent with the highest and lowest streamflow months for the predominantly unregulated Yellowstone River near streamgage 06329500 (fig. 17). Annual peak flows range from 38,100 to 170,000 ft^3/s (median=73,400 ft^3/s) (Boughton and others, 2022, table 1–3). About 65 percent of annual peak flows have been in May and June (fig. 18*E*), and about 35 percent of annual peak flows have been in March and early April. In about 45 percent of years, annual peak stage has happened in late March and early April (USGS, 2015c), presumably associated with the start of low-elevation snow and ice melt and the transition from ice cover to open-channel streamflow. Annual 7-day low flows range from 6,640 to 9,190 ft^3/s (median=8,260 ft^3/s) (Boughton and others, 2022, table 1–3), and most often are in November through January (fig. 18*E*).

The Missouri River at Bismarck, N. Dak. (streamgage 06342500; contributing drainage area of 186,400 mi^2; table 3; figs. 17, 18*F*), is about 75 mi downstream from Garrison Dam. Streamflows for streamgage 06342500 are strongly regulated by complex reservoir operations of Lake Sakakawea described in USACE (2006). Median monthly streamflow ranges from 16,600 ft^3/s in October to 24,500 ft^3/s in February, and median annual runoff is 1.57 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 17,100 to 155,000 ft^3/s (median=33,600 ft^3/s) (Boughton and others, 2022, table 1–3). Annual peak flows can happen in any month but most frequently have been in January through July (fig. 18*F*). Annual 7-day low flows range from 4,860 to 20,400 ft^3/s (median=11,200 ft^3/s) (Boughton and others, 2022, table 1–3), and most often have been in March through June and October through November (fig. 18*F*).

Large Streams

In general, streamflow characteristics of streams originating in or near the Williston Basin are driven by complex interactions between climatic, geologic, topographic, and land-cover and use characteristics; and interactions of groundwater and surface water. Anthropogenic activities, including reservoir and irrigation operations, also contribute to streamflow variability. Streams in the Williston Basin generally have large seasonal and interannual variability in streamflows. Large-scale spatial differences in streamflow characteristics are substantially affected by spatial variability in precipitation, air temperature, and drainage characteristics (especially the density of depressional storage or percentage of area covered by lakes and wetlands). Variability in snowpack accumulation in relation to the frequency and intensity of spring and summer rainfall contributes to differences in seasonal streamflow characteristics among streams.

Throughout the Williston Basin, mean monthly air temperatures consistently are below freezing in December through February (PRISM Climate Group, 2004), when precipitation most often is accumulating snowfall. Throughout most of the Williston Basin, in March and April, mean monthly air temperatures generally increase to near or above freezing, which causes snowmelt runoff with associated varying amounts of streamflow. Snowmelt runoff and streamflows can be enhanced by frozen-soil conditions (Dunne and Black, 1971; Shanley and Chalmers, 1999) and ice-jam releases (White and Zufelt, 1994). The highest precipitation months are May through July (PRISM Climate Group, 2004; Mock, 1996), and mean precipitation for these months accounts for about 55 percent of mean annual precipitation. In May through July, precipitation most often is rainfall, and streamflow variably responds to the spring and summer rainfall.

Large Streams in the Northern and Northwestern Glaciated Plains Ecoregions

The northern and eastern parts of the Williston Basin are in the Northern Glaciated Plains and Northwestern Glaciated Plains ecoregions (Bryce and others, 1996; Woods and others, 2002). In or near the Williston Basin, four long-term streamgages are on large streams in the Northern and Northwestern Glaciated Plains ecoregions: (1) Sheyenne River near Warwick, N. Dak. (streamgage 05056000); (2) Souris River near Westhope, N. Dak. (streamgage 05124000); (3) Milk River at Nashua, Mont. (streamgage 06174500); and (4) Poplar River near Poplar, Mont. (streamgage 06181000) (fig. 17; table 3). Duration hydrographs of daily streamflows are presented in conjunction with annual extreme flows (that is, annual peak-flow and annual 7-day low flow data) for the four streamgages on large streams in the Northern and Northwestern Glaciated Plains ecoregions (fig. 19).

The Sheyenne River originates within the Williston Basin and flows about 190 mi from its headwaters to the eastern boundary of the Williston Basin (fig. 17). The Sheyenne River is not regulated by major reservoirs within the Williston Basin. The Sheyenne River near Warwick, N. Dak. (streamgage 05056000; fig. 17; contributing drainage area of 760 mi^2; table 3; fig. 19*A*), is about 5 mi downstream from the eastern boundary of the Williston Basin. In relation to the entire Williston Basin and the other large streams, the Sheyenne River drainage basin has high mean annual precipitation (17.5 in.), low mean annual air temperature (39.7 degrees Fahrenheit [°F]), and a high percentage of lakes and wetlands (9.6 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to high drainage basin water yield (9.8 percent; table 3). Median monthly streamflows range from 5.2 ft^3/s in January to 199 ft^3/s in April, and median annual runoff is 1.20 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 66 to 8,200 ft^3/s (median=1,090 ft^3/s) (Boughton and others, 2022, table 1–3). About 75 percent of annual peak flows have been in March and April (fig. 19*A*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 41 ft^3/s (median=2.0 ft^3/s) Boughton and others, 2022, table 1–3), and most often are in February through March and in late July through September (fig. 19*A*). At or near-zero streamflows are more likely in the summer than in the winter.

The Souris River originates in the Williston Basin in Saskatchewan, Canada, flows through part of North Dakota, and then flows into Manitoba, Canada (fig. 17). Several reservoirs in Saskatchewan and North Dakota regulate streamflows of the Souris River. The Souris River near Westhope, N. Dak. (streamgage 05124000; contributing drainage area of 6,600 mi^2; table 3; fig. 19*B*), is near where the Souris River exits the Williston Basin (fig. 17). In relation to the entire Williston Basin and the other large streams, the Souris River drainage basin has high mean annual precipitation (17.1 in.), low mean annual air temperature (37.8 °F), and a high percentage of lakes and wetlands (8.4 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to moderate drainage basin water yield (5.0 percent; table 3). Median monthly streamflows range from 23 ft^3/s in January and February to 474 ft^3/s in May, and median annual runoff is 0.40 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 30 to 30,400 ft^3/s (median=1,100 ft^3/s) (Boughton and others, 2022, table 1–3). About 60 percent of annual peak flows have been in April and May (fig. 19*B*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 245 ft^3/s (median=1.5 ft^3/s) (Boughton and others, 2022, table 1–3). Annual 7-day low flows most often are in November through April (fig. 19*B*). At or near-zero streamflows are somewhat likely in the winter.

The Milk River originates in northwestern Montana, then flows northeast into Alberta, Canada, then eventually re-enters Montana and flows for about 90 mi to where it enters the western boundary of the Williston Basin, and then flows for about 430 mi through the Williston Basin to its confluence with the Missouri River (fig. 17). The Milk River is extensively regulated, primarily for large-scale irrigation operations. The Milk River at Nashua, Mont. (streamgage 06174500; contributing drainage area of 20,254 mi^2; table 3; fig. 19*C*), is about 23 mi upstream from the confluence with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Milk River drainage basin has low mean annual precipitation (13.5 in.), moderate air mean annual temperature (40.5 °F), and moderate percentage of lakes and wetlands (2.5 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to low drainage basin water yield (3.0 percent; table 3). Median monthly streamflows range from 130 ft^3/s in January to 700 ft^3/s in June, and median annual runoff is 0.32 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 229 to 26,500 ft^3/s (median=4,880 ft^3/s) (Boughton and others, 2022, table 1–3). About 50 percent of annual peak flows have been in March and April (fig. 19*C*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 305 ft^3/s (median=54 ft^3/s) (Boughton and others, 2022, table 1–3), and most often are in April through May and July (fig. 19*C*). At or near-zero streamflows are seldom.

The Poplar River originates in Saskatchewan, Canada, and flows southeast for about 125 mi through the Williston Basin to where it enters the Missouri River (figs. 1 and 17). Morrison Dam located on the East Poplar River approximately 5 miles upstream from the U.S.-Canadian border, regulates Poplar River streamflows to a small extent; however, numerous small stock dams and diversion dams are present in the Poplar River Basin. The Poplar River near Poplar, Mont. (streamgage 06181000; contributing drainage area of 3,140 mi^2; table 3; fig. 19*D*), is about 11 mi upstream from the confluence with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Poplar River drainage basin has low mean annual precipitation (13.9 in.), low mean annual air temperature (39.0 °F), and low percentage of lakes and wetlands (0.6 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to low drainage basin water yield (3.5 percent; table 3). Median monthly streamflows range from 5.2 ft^3/s in January to 161 ft^3/s in April, and median annual runoff is 0.31 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 94 to 37,400 ft^3/s (median=2,500 ft^3/s) (Boughton and others, 2022, table 1–3). About 75 percent of annual peak flows have been in March and April (fig. 19*D*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 39 ft^3/s (median=2 ft^3/s) (Boughton and others, 2022, table 1–3), and most often are in January through February and August through September (fig. 19*D*). At or near-zero streamflows are more likely in the winter than in the summer.

Large Streams in Northwestern Great Plains

The southern and western parts of the Williston Basin are in the Northwestern Great Plains ecoregion (Bryce and others, 1996; Woods and others, 2002). Within the Williston Basin, seven long-term streamgages are on large streams in the Northwestern Great Plains ecoregion: (1) Redwater River at Circle, Mont. (streamgage 06177500); (2) Little Missouri River near Watford City, N. Dak. (streamgage 06337000); (3) Knife River at Hazen, N. Dak. (streamgage 06340500); (4) Heart River near Mandan, N. Dak. (streamgage 06349000); (5) Cannonball River at Breien, N. Dak. (streamgage 06354000); (6) Grand River at Little Eagle, South Dakota (streamgage 06357800); and (7) Moreau River near Whitehorse, S. Dak. (streamgage 06360500) (fig. 17; table 3). Duration hydrographs of daily streamflows are presented in conjunction with annual extreme flows (that is, annual peak-flow and annual 7-day low flow data) for the seven streamgages on large streams in the Northwestern Great Plains ecoregion (fig. 20).

The Redwater River originates within the Williston Basin and flows for about 175 mi to its confluence with the Missouri River (fig. 17). At the confluence with the Missouri, the Redwater River has a drainage area of about 2,100 mi^2. The Redwater River is not regulated by major reservoirs, but numerous small stock dams and diversion dams are in the Redwater River drainage basin. The Redwater River at Circle, Mont. (streamgage 06177500; contributing drainage area of 551 mi^2; table 3; fig. 20*A*), is about 60 mi downstream from the Redwater River headwaters and about 115 mi upstream from the confluence with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Redwater River drainage basin has low mean annual precipitation (12.8 in.), high mean annual air temperature (42.8 °F), and low percentage of lakes and wetlands (0.3 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to low drainage basin water yield (1.7 percent; table 3). Streamgage 06177500 was included in this study because it provides representation of streamflow characteristics for a substantial part of the Williston Basin in the Northwestern Great Plains ecoregion between the main-stem Missouri River and the Yellowstone River. Generally, median duration hydrograph streamflows at streamgage 06177500 are at or near zero throughout most of the year except during a short period from early March through the middle of May (fig. 20*A*). Median monthly streamflows range from 0.05 ft^3/s in September to 8.0 ft^3/s in March, and median annual runoff is 0.10 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 2.0 to 6,960 ft^3/s (median=214 ft^3/s) (Boughton and others, 2022, table 1–3). About 55 percent of annual peak flows have been in February and March (fig. 20*A*) associated with the typical snowmelt runoff period. About 45 percent of annual peak flows have been in May through August from spring and summer precipitation. High flows in May through August can have flash-flood characteristics, when streamflows rapidly increase within a few hours from at or near zero to streamflows reaching several thousand cubic feet per second. Annual 7-day low flows range from 0 to 2.0 ft^3/s (median=0 ft^3/s) (Boughton and others, 2022, table 1–3).

The Little Missouri River originates in northeastern Wyoming, flows northeast for about 100 mi to the southwestern boundary of the Williston Basin, and then flows for about 590 mi through the Williston Basin to where it enters Lake Sakakawea (fig. 17). The Little Missouri River is not regulated by major reservoirs, but numerous small stock dams and diversion dams are in the Little Missouri River drainage basin. The Little Missouri River near Watford City, N. Dak. (streamgage 06337000; contributing drainage area of 8,310 mi^2; table 3; fig. 20*B*), is about 50 mi upstream from where the river enters Lake Sakakawea (fig. 17). In relation to the entire Williston Basin and the other large streams, the Little Missouri River drainage basin has moderate mean annual precipitation (15.3 in.), high mean annual air temperature (42.9 °F), and low percentage of lakes and wetlands (0.7 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to moderate drainage basin water yield (5.5 percent; table 3). Median monthly streamflows range from 2.4 ft^3/s in January to 897 ft^3/s in March, and median annual runoff is 0.70 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 400 to 52,800 ft^3/s (median=10,000 ft^3/s) (Boughton and others, 2022, table 1–3). About 50 percent of annual peak flows have been in February and March (fig. 20*B*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 53 ft^3/s (median=0 ft^3/s) (Boughton and others, 2022, table 1–3). Annual 7-day low flows almost exclusively happen from December through mid-March and routinely are at or near zero (fig. 20*B*).

The Knife River originates within the Williston Basin and flows for about 240 mi from its headwaters to its confluence with the Missouri River (fig. 17). The Knife River is not regulated by major reservoirs, but numerous small stock dams and diversion dams are in the Knife River Basin. The Knife River at Hazen, N. Dak. (streamgage 06340500; contributing drainage area of 2,240 mi^2; table 3; fig. 20*C*), is about 25 mi upstream from the confluence of the Knife River with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Knife River drainage basin has high mean annual precipitation (16.7 in.), moderate mean annual air temperature (41.0 °F), and moderate percentage of lakes and wetlands (1.0 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to high drainage basin water yield (5.9 percent; table 3). Median monthly streamflows range from 17 ft^3/s in January to 360 ft^3/s in March, and median annual runoff is 0.75 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 100 to 35,300 ft^3/s (median=3,900 ft^3/s) (Boughton and others, 2022, table 1–3). About 70 percent of annual peak flows have been in February through mid-April (fig. 20*C*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 70 ft^3/s (median=10 ft^3/s) (Boughton and others, 2022, table 1–3) and most often are in January through mid-March (fig. 20*C*). At or near-zero streamflows are seldom.

The Heart River originates within the Williston Basin and flows for about 320 mi from its headwaters to its confluence with the Missouri River (fig. 17). Streamflows of the Heart River are regulated by two major reservoirs, Patterson Lake and Heart Butte Lake (not shown in fig. 1), with multipurpose operations that include flood control. In addition, numerous small stock dams and diversion dams are in the Heart River drainage basin. The Heart River near Mandan, N. Dak. (streamgage 06349000; contributing drainage area of 3,310 mi^2; table 3; fig. 20*D*), is about 12 mi upstream from the confluence of the Heart River with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Heart River drainage basin has high mean annual precipitation (16.8 in.), moderate mean annual air temperature (41.0 °F), and moderate percentage of lakes and wetlands (1.0 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to high drainage basin water yield (6.5 percent; table 3). Median monthly streamflows range from 16 ft^3/s in January to 331 ft^3/s in March, and median annual runoff is 0.70 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 103 to 29,200 ft^3/s (median=3,780 ft^3/s) (Boughton and others, 2022, table 1–3). About 60 percent of annual peak flows have been in March and April (fig. 20*D*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 64 ft^3/s (median=8.0 ft^3/s) (Boughton and others, 2022, table 1–3), almost exclusively happen from December through mid-March (fig. 20*D*), and occasionally are at or near zero.

The Cannonball River originates within the Williston Basin and flows for about 385 mi from its headwaters to its confluence with the Missouri River (fig. 17). The Cannonball River is not regulated by major reservoirs, but numerous small stock dams and diversion dams are in the Cannonball River drainage basin. The Cannonball River at Breien, N. Dak. (streamgage 06354000; contributing drainage area of 4,100 mi^2; table 3; fig. 20*E*), is about 35 mi upstream from the confluence of the Cannonball River with the Missouri River (fig. 17). In relation to the entire Williston Basin and the other large streams, the Cannonball River drainage basin has moderate mean annual precipitation (16.6 in.), moderate mean annual air temperature (42.4 °F), and low percentage of lakes and wetlands (1.4 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to moderate drainage basin water yield (5.0 percent; table 3). Median monthly streamflows range from 9.6 ft^3/s in January to 263 ft^3/s in March, and median annual runoff is 0.57 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 374 to 31,100 ft^3/s (median=4,100 ft^3/s) (Boughton and others, 2022, table 1–3). About 60 percent of annual peak flows have been in March through mid-April (fig. 20*E*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 51 ft^3/s (median=2.0 ft^3/s) (Boughton and others, 2022, table 1–3), most often are in January through February and August through September (fig. 20*E*), and often are at or near zero.

The Grand River originates within the Williston Basin and flows for about 350 mi from its headwaters to its confluence with Lake Oahe (fig. 17). Streamflows of the Grand River are regulated by Shadehill Reservoir (not shown in fig. 1) with multipurpose operations that include flood control. In addition, numerous small stock dams and diversion dams are in the Grand River drainage basin. The Grand River at Little Eagle, S. Dak. (streamgage 06357800; contributing drainage area of 5,316 mi^2; table 3; fig. 17; fig. 20*F*), is about 20 mi upstream from the confluence of the Grand River with Lake Oahe (fig. 17). In relation to the entire Williston Basin and the other large streams, the Grand River drainage basin has moderate mean annual precipitation (16.4 in.), high mean annual air temperature (42.8 °F), and moderate percentage of lakes and wetlands (1.2 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to moderate drainage basin water yield (4.0 percent; table 3). Median monthly streamflows range from 13 ft^3/s in January to 361 ft^3/s in March, and median annual runoff is 0.37 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 155 to 32,400 ft^3/s (median=5,200 ft^3/s) (Boughton and others, 2022, table 1–3). About 40 percent of annual peak flows have been in March and early April (fig. 20*F*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 78 ft^3/s (median=8.5 ft^3/s) (Boughton and others, 2022, table 1–3), most often are in mid-December through mid-February (fig. 20*F*), and somewhat often are at or near zero.

The Moreau River originates within the Williston Basin and flows for about 440 mi from its headwaters to its confluence with Lake Oahe (fig. 17). The Moreau River is not regulated by major reservoirs, but numerous small stock dams and diversion dams are in the Moreau River drainage basin. The Moreau River near Whitehorse, S. Dak. (streamgage 06360500; contributing drainage area of 4,872 mi^2; table 3; fig. 20*G*), is about 40 mi upstream from the confluence of the Moreau River with Lake Oahe (fig. 17). In relation to the entire Williston Basin and the other large streams, the Moreau River drainage basin has moderate mean annual precipitation (16.5 in.), high mean annual air temperature (44.0 °F), and moderate percentage of lakes and wetlands (1.4 percent; table 3); these characteristics interact with other drainage basin characteristics and contribute to moderate drainage basin water yield (4.7 percent; table 3). Median monthly streamflows range from 0.36 ft^3/s in January to 301 ft^3/s in March, and median annual runoff is 0.39 in. (Boughton and others, 2022, table 1–2). Annual peak flows range from 159 to 34,200 ft^3/s (median=5,500 ft^3/s) (Boughton and others, 2022, table 1–3). About 30 percent of annual peak flows have been in March and early April (fig. 20*G*) associated with the typical snowmelt runoff period. Annual 7-day low flows range from 0 to 23 ft^3/s (median=0 ft^3/s) (Boughton and others, 2022, table 1–3), most often are in January through mid-February and July through September (fig. 20*G*), and often are at or near zero.

Lake and Wetland Resources

This section provides information on surface-water features (including saline seeps, wetlands, ponds, and lakes) of the Willison Basin area. Three major reservoirs exist in the Williston Basin and are considered lake resources: Fort Peck Lake, Lake Sakakawea, and Lake Oahe (fig. 17). Metric units are used to present the information described in this section because it is based on earlier work by Preston and Chesley-Preston (2015) who utilized metric units.

Spatial Distribution of Lakes and Wetlands

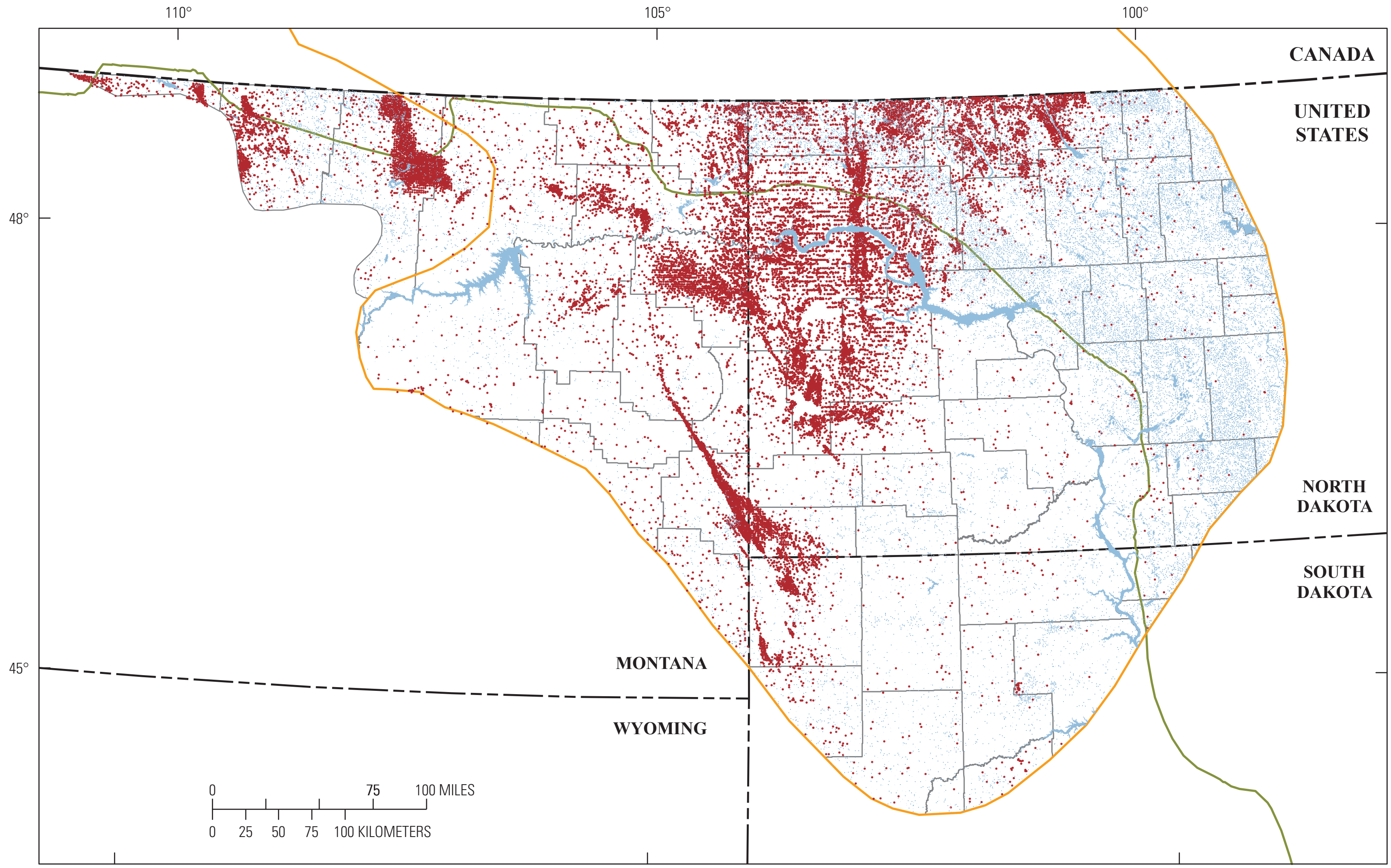
Statewide NWI datasets were acquired for Montana, North Dakota, and South Dakota (USFWS, 2014). Spatial distribution information, specifically number, area, and percentage of coverage of NWI features, were calculated for the Williston Basin, the area inside and outside of the Prairie Pothole Region, and for each State and county (fig. 21).

The NWI datasets use the full Cowardin classification system to delineate wetlands and deepwater habitats (Cowardin and others, 1979) and provide simplified wetland types. A total of 1,428,501 NWI palustrine and lacustrine features were identified using the Cowardin system within the Williston Basin, but these features only encompassed five wetland types (freshwater emergent wetland, freshwater forested/shrub wetland, freshwater pond, lake, and other). The wetland classifications freshwater emergent wetland and freshwater forested/shrub wetland were combined into a single wetland category producing a total of four NWI classifications discussed hereafter. These four classifications (collectively referred to as surface-water features), listed by increasing relative size and permanence, are (1) wetland, (2) pond, (3) lake, and (4) other.

Because the NWI dataset uses the full Cowardin classification, multiple polygons with different classifications can comprise a single surface-water feature, and this commonly results in a single feature appearing as multiple rings or parts. These multiple classifications in one feature were joined to produce a single feature dataset with the objective of keeping the highest NWI classification (wetland<pond<lake<other) for all surface-water features within each drainage basin; for example, a multi-ringed wetland was merged into a single feature classified as wetland. Also, ponds and wetlands along a lake margin were merged with the lake and would be reclassified as lake. This polygon collapse process reduced the total number of surface-water features from 1,428,501 to 1,317,519. It is important to note that for the spatial distribution calculations a feature that crossed a geographic boundary was counted as a surface-water feature for both geographic units, whereas only the area within each geographic unit was included in the area and percentage of coverage calculations.

Within the Williston Basin, the total number, area, and percentage of coverage of surface-water features are greater in the Prairie Pothole Region than the area outside of the region (figs. 1, 21; table 4); for example, the Prairie Pothole Region (78,240 square kilometers [km^2]) covers only 28.9 percent of the Williston Basin (270,589 km^2) (fig. 21) yet contains three times the number of surface-water features as the area outside the region. Despite having nearly three-quarters of all surface-water features within the Williston Basin, the area of surface-water features in the Prairie Pothole Region is only 1.2 times greater than the area of surface-water features outside the region, mainly because several large lakes along the Missouri River exist outside the region. Finally, the percentage of the landscape covered by surface-water features is 2.9 times greater within the Prairie Pothole Region compared to the area outside the region (table 4).

The spatial distribution of surface-water features also varied among Montana, North Dakota, and South Dakota (table 5). Although the area of North Dakota in the Williston Basin is only 1.4 times larger than that of Montana (128,189 and 91,577 km^2, respectively), North Dakota has more than 6.6 times as many surface-water features as Montana (1,087,789 and 164,503 surface-water features, respectively). Similarly, the area of North Dakota in the Williston Basin is only 2.7 times greater than South Dakota (47,266 km^2), yet it has 16.6 times as many surface-water features (1,087,789 and 65,342 surface-water features, respectively). North Dakota also has more than 4.1 and 8.3 times the area of surface-water features (9,088 km^2) compared to Montana (2,188 km^2) and South Dakota (1,095 km^2) (table 5). The percentage of coverage of surface-water features is about 1.9 and 2.9 times greater in North Dakota (7 percent) compared to Montana (2.3 percent) and South Dakota (1.2 percent) (table 5).



Base map modified from U.S. Geological Survey, Esri, Montana Board of Oil and Gas, North Dakota Oil and Gas Division, South Dakota Department of Enviornmental and Natural Resources digital data, variously dated, various scales.
Well data current as of July, 2016. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum 1983

EXPLANATION

Surface-water feature—Data from U.S. Fish and Wildlife Service (2014)

Williston Basin boundary

Prairie Pothole Region boundary

County line

Oil or gas well

Figure 21. Proximity of surface-water features to oil and gas wells in the Williston Basin.

Table 4. The total number, area, and percentage of coverage of surface-water features, not including streams and rivers, for the Williston Basin and the parts of the Williston Basin inside and outside of the Prairie Pothole Region.

[>, greater than]

	Williston Basin			Inside Prairie Pothole Region			Outside Prairie Pothole Region		
	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent
Wetland	1,190,460	4,895	1.8	953,147	3,743	4.8	237,745	1,157	0.6
Pond	117,254	1,967	0.7	32,007	1,120	1.4	85,297	849	0.4
Lake	3,254	5,486	2	2,520	1,907	2.4	749	3,694	1.9
Other	6,551	22	>0.1	381	1	>0.1	6,172	21	>0.1
Total	1,317,519	12,371	4.6	988,055	6,772	8.7	329,963	5,721	3

Table 5. The total number, area, and percentage of coverage of surface-water features, not including streams and rivers, for the parts of Montana, North Dakota, and South Dakota within the Williston Basin.

[>, greater than]

	Montana			North Dakota			South Dakota		
	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent	Total number	Area, in square kilometers	Coverage of surface-water feature, in percent
Wetland	128,033	612	0.7	1,025,931	4,046	3.1	36,568	237	0.3
Pond	35,392	358	0.4	56,680	1,319	1	25,210	290	0.3
Lake	357	1,216	1.3	2,701	3,717	2.9	207	552	0.6
Other	721	3	>0.1	2,477	5	>0.1	3,357	14	>0.1
Total	164,503	2,188	2.3	1,087,789	9,088	7	65,342	1,095	1.2

Finally, the spatial distribution of surface-water features varied among individual counties within the Williston Basin area (figs. 21, 22). A total of 72 counties are located wholly or partially within the Williston Basin area with the total number, area, and percentage of coverage of surface-water features for the top 25 ranked counties in each of these three categories shown in figure 22. Ward County, N. Dak., contains the greatest total number of surface-water features (92,190), whereas Petroleum County, Mont., contains the least (10) (fig. 22; Boughton and others, 2022, table 2–1). In terms of total area of all surface-water features, McLean County, N. Dak., contains the greatest area (922.1 km^2), whereas Rosebud County, Mont., contains the least (1.2 km^2) (Boughton and others, 2022, table 2–2). Ramsey County, N. Dak., has the greatest percentage of coverage of total surface-water features (33.2 percent), whereas Billings County, N. Dak., has the least (0.2 percent) (Boughton and others, 2022, table 2–3). The number, area, and percentage of coverage of surface-water features by county for each State are provided in data release tables 2–1, 2–2, and 2–3, respectively (Boughton and others, 2022).

Proximity of Lakes and Wetlands to Energy Development

The Williston Basin contains a large amount of energy development infrastructure as indicated by the presence of oil and gas wells (fig. 21), which can be near surface-water features. The collapsed surface-water feature NWI dataset (described in the previous section) was analyzed in relation to the oil and gas well databases from the Montana Board of Oil and Gas Conservation, the North Dakota Industrial Commission, and the South Dakota Department of Environment and Natural Resources (SDDENR) to investigate the proximity of

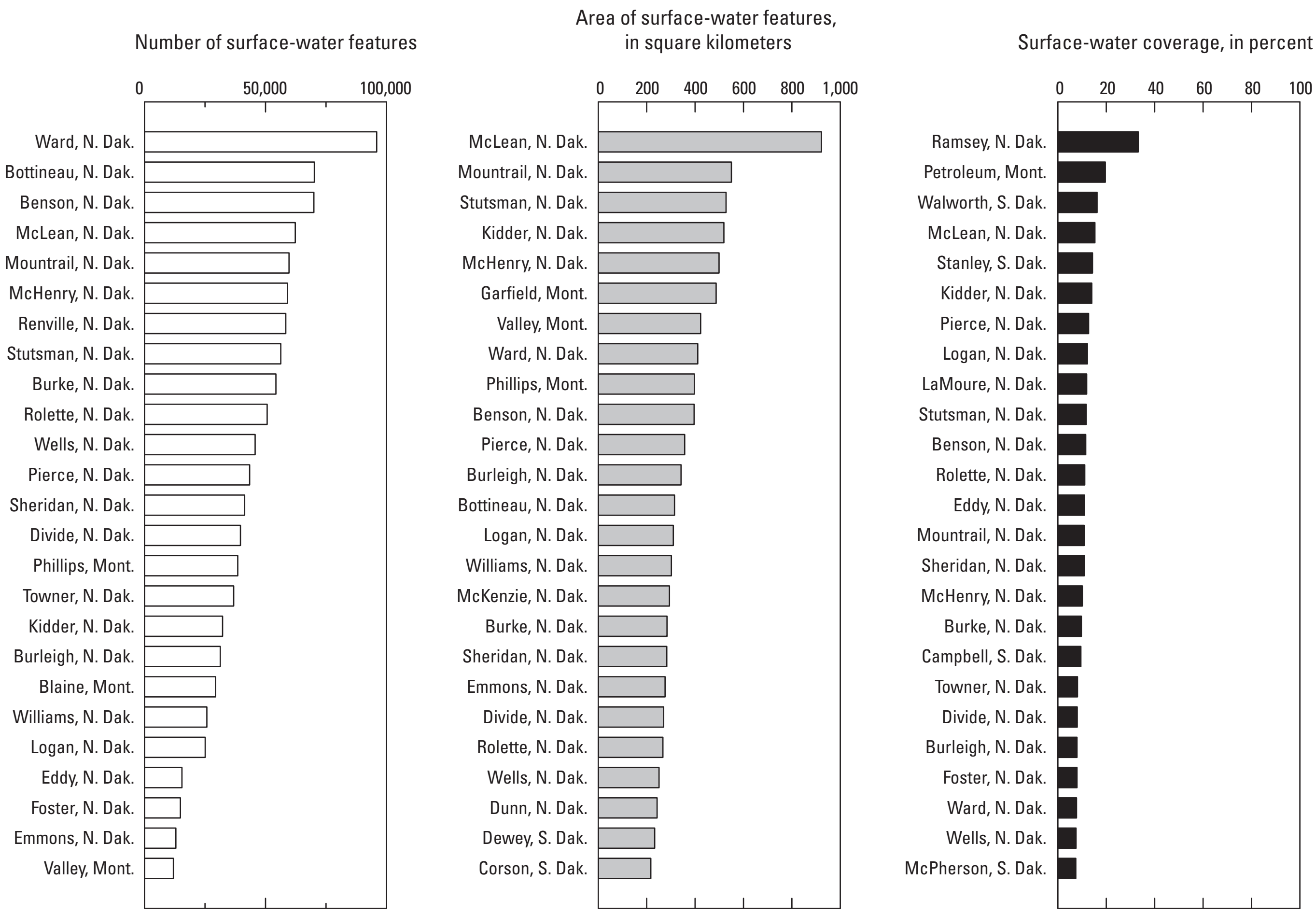


Figure 22. Summary statistics of surface-water features, not including streams and rivers, for the top 25 counties in the Williston Basin, ranked by total number of surface-water features, total area of surface-water features, and the percentage of the County covered by surface-water features.

surface-water features to energy-related wells. All oil or gas well data were acquired on March 11, 2015, and only wells that had drilling completed by this date were selected, resulting in a total of 41,535 wells. Proximity analyses to determine the number, area, and percentage of surface-water features within 0.4, 0.8 and 1.6 kilometers (km) of at least one oil or gas well were completed for the Williston Basin, the area inside and outside of the Prairie Pothole Region (table 6), and each State and County (Boughton and others, 2022, tables 2–4, 2–5, and 2–6).

The number and area of surface-water features near oil or gas wells was calculated by first determining a buffer around each surface-water feature at 0.4, 0.8 and 1.6 km. Next, the surface-water features were clipped to the geographic extents of the proximity analyses of the area inside and outside the Prairie Pothole Region and the area of each State and County. The area of the surface-water features was recalculated before each analysis, and the total number and area of surface-water features were summed for each geographic extent. If a surface-water feature crossed a geographic boundary but was near an oil or gas well anywhere around its perimeter, the feature was included in the total number of surface-water features near wells for both extents; however, only the area in the given extent was calculated. Similarly, if a surface-water feature was within a given extent yet was near an oil or gas well outside that extent, the feature was still included in the total number and area of surface-water features for that extent. The percentage of surface-water features near oil and gas wells was calculated by dividing the total number of surface-water features near wells within each buffer distance by the total number of surface-water features within each geographic extent.

Across the Williston Basin, most oil or gas wells (98.7 percent) are within 1.6 km of surface-water features, whereas most surface-water features (69.6 percent) were not near oil or gas wells; however, this number will likely decrease with expected future development. Although many surface-water features are near only one well, some surface-water features are near numerous oil and gas wells, and some wells are near numerous surface-water features. The proximity of surface-water features to oil and gas wells in the Williston

Table 6. Total number, area, and percentage of surface-water features, not including streams and rivers, near (0.4, 0.8, and 1.6 kilometers) oil and gas wells in the Williston Basin and the parts of the Williston Basin inside and outside of the Prairie Pothole Region.

Type	0.4-kilometer buffer			0.8-kilometer buffer			1.6-kilometer buffer		
	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent
Williston Basin									
Wetland	82,704	353	6.9	191,385	709	16.1	367,491	1,327	30.9
Pond	7,345	199	6.3	15,821	313	13.5	30,708	505	26.2
Lake	325	1,901	10	583	2,042	17.9	1,000	2,262	30.7
Other	396	2	6	896	3	13.7	1,795	6	27.4
Total	90,770	2,455	6.9	208,685	3,066	15.8	400,994	4,100	30.4
Inside Prairie Pothole Region									
Wetland	65,358	261	6.9	151,741	527	15.9	293,087	1,000	30.7
Pond	2,328	82	7.3	5,053	149	15.8	9,870	261	30.8
Lake	234	321	9.3	435	444	17.3	767	641	30.4
Other	36	0.2	9.4	72	0.3	18.9	148	0.5	38.8
Total	67,956	665	6.9	157,301	1,120	15.9	303,872	1,903	30.8
Outside Prairie Pothole Region									
Wetland	17,382	92	7.3	39,726	182	16.7	74,552	327	31.4
Pond	5,020	116	5.9	10,779	163	12.6	20,854	244	24.4
Lake	93	1,580	12.4	150	1,598	20	236	1,621	31.5
Other	360	1	5.8	824	3	13.4	1,647	6	26.7
Total	22,855	1,790	6.9	51,479	1,946	15.6	97,289	2,197	29.5

Basin was different inside and outside the Prairie Pothole Region (fig. 21; table 6). The Prairie Pothole Region covers only 28.9 percent of the Williston Basin (fig. 21) and contains only 29.1 percent (12,087) of the total identified oil and gas wells (41,535); however, the Prairie Pothole Region contains about three times as many surface-water features near oil and gas wells in all three buffer distances (0.4, 0.8, and 1.6 km) as compared to the area outside the region (fig. 21; table 6). Although the area outside the Prairie Pothole Region contains fewer surface-water features near oil and gas wells, the area of these surface-water features was greater in all three buffer distances compared to area inside of the region, mainly because of the presence of several large lakes along the Missouri River outside of the region. Finally, the percentage of surface-water features near oil and gas wells was similar for the areas inside and outside of the Prairie Pothole Region (table 6). This reflects the fact that there are about three times as many surface-water features inside the Prairie Pothole Region compared to the area outside the region. A more thorough analysis on the proximity of surface-water features to oil and gas wells for the Prairie Pothole Region is provided in Tangen and others (2014).

The proximity of surface-water features to oil and gas wells also varied among States (table 7). North Dakota has about 2.1 and 24.7 times as many oil and gas wells as Montana and South Dakota, respectively; however, it also has 6.5 and 16.6 times as many surface-water features, respectively. Additionally, the total number and area of surface-water features near oil and gas wells in North Dakota are much greater than Montana and South Dakota in all three buffer distances. Similarly, Montana has a much greater number of wells and surface-water features compared to South Dakota and, therefore, a greater total number and area of surface-water features near oil and gas wells. Notably, the percentage of surface-water features near oil and gas wells in all three buffer distances was highest in Montana, followed by North Dakota and South Dakota.

The number and proximity of surface-water features to oil and gas wells also varied among individual counties within the Williston Basin (Boughton and others, 2022, tables 2–4, 2–5, 2–6). The total number, area, and percentage of surface-water features near wells for the top 25 ranked counties in each of these three buffer distances are shown on figures 23, 24, and 25. Renville County, N. Dak., had the greatest total number

Table 7. Total number, area, and percentage of surface-water features, not including streams and rivers, near (0.4, 0.8, and 1.6 kilometers) oil and gas wells in the parts of Montana, North Dakota, and South Dakota in the Williston Basin.

Type	0.4-kilometer buffer			0.8-kilometer buffer			1.6-kilometer buffer		
	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent	Total number	Area, in square kilometers	Surface-water features near oil and gas wells, in percent
Montana									
Wetland	11,412	79	8.9	23,092	132	18	44,687	233	34.9
Pond	2,538	98	7.2	4,996	123	14.1	9,735	168	27.5
Lake	98	145	27.5	141	165	39.5	216	208	60.5
Other	96	0.6	13.3	182	0.9	25.2	330	2	45.8
Total	14,144	322	8.6	28,411	422	17.3	54,968	610	33.4
North Dakota									
Wetland	70,960	272	6.9	167,324	571	16.3	320,136	1,079	31.2
Pond	4,481	90	7.9	9,982	172	17.6	18,877	307	33.3
Lake	220	1,750	8.1	430	1,868	15.9	764	2,044	28.3
Other	223	0.5	9	466	0.8	18.8	833	2	33.6
Total	75,884	2,113	7	178,202	2,612	16.4	340,610	3,431	31.3
South Dakota									
Wetland	343	2	0.9	988	6	2.7	2,700	15	7.4
Pond	327	11	1.3	849	17	3.4	2,108	30	8.4
Lake	9	6	4.3	16	9	7.7	25	10	12.1
Other	78	0.5	2.3	250	1	7.4	635	3	18.9
Total	757	20	1.2	2,103	32	3.2	5,468	59	8.4

of surface-water features near oil and gas wells in each of the three buffer distances (14,692 [0.4-km buffer; fig. 23], 32,362 [0.8-km buffer; fig. 24], and 51,195 [1.6-km buffer; fig. 25]; Boughton and others, 2022, table 2–4). McLean County, N. Dak., had the greatest area of surface-water features near oil and gas wells in each of the three buffer distances (455.2 km^2 [0.4-km buffer; fig. 23], 465.5 km^2 [0.8-km buffer; fig. 24], and 487.7 km^2 [1.6-km buffer; fig. 25]; Boughton and others, 2022, table 2–5). McKenzie County, N. Dak., had the greatest percentage of surface-water features near oil and gas wells in the 0.4-km buffer (34.0 percent; fig. 23) and 0.8-km buffer (62.9 percent; fig. 24), whereas Liberty County, Mont. had the greatest percentage in the 1.6-km buffer of a well (92.3 percent; fig. 25) (Boughton and others, 2022, table 2–6). No surface-water features were within the 0.4-km buffer for five counties: Petroleum and Rosebud Counties, Mont.; LaMoure County, N. Dak.; and McPherson and Pennington Counties, S. Dak. Three of these counties (Petroleum, LaMoure, and McPherson Counties) had no surface-water features within 0.8 or 1.6 km of an oil or gas well either.

Quality of Water Resources

Numerous local, State, Tribal, and Federal agencies have been collecting water-quality data within the Williston Basin for decades. Other water-quality monitoring, such as that completed by private industry, may often be proprietary and not available to the public. Water-quality samples have been collected from groundwater, springs, streams, rivers, lakes, reservoirs, storm water, wastewater discharge points, and other surface-water and groundwater features. Samples were collected for several reasons including compliance monitoring, after known pollutant releases (for example, spills), or characterization of water-quality conditions of a particular water resource. The types of data collected, the sample collection protocols, analytical methods, and reporting processes differ greatly. As such, the availability of consistently collected, systematically processed and reported data over large parts of the Williston Basin is sparse; however, a substantial amount of water-quality data is available that provides insight regarding the condition of the water quality within the Williston Basin.

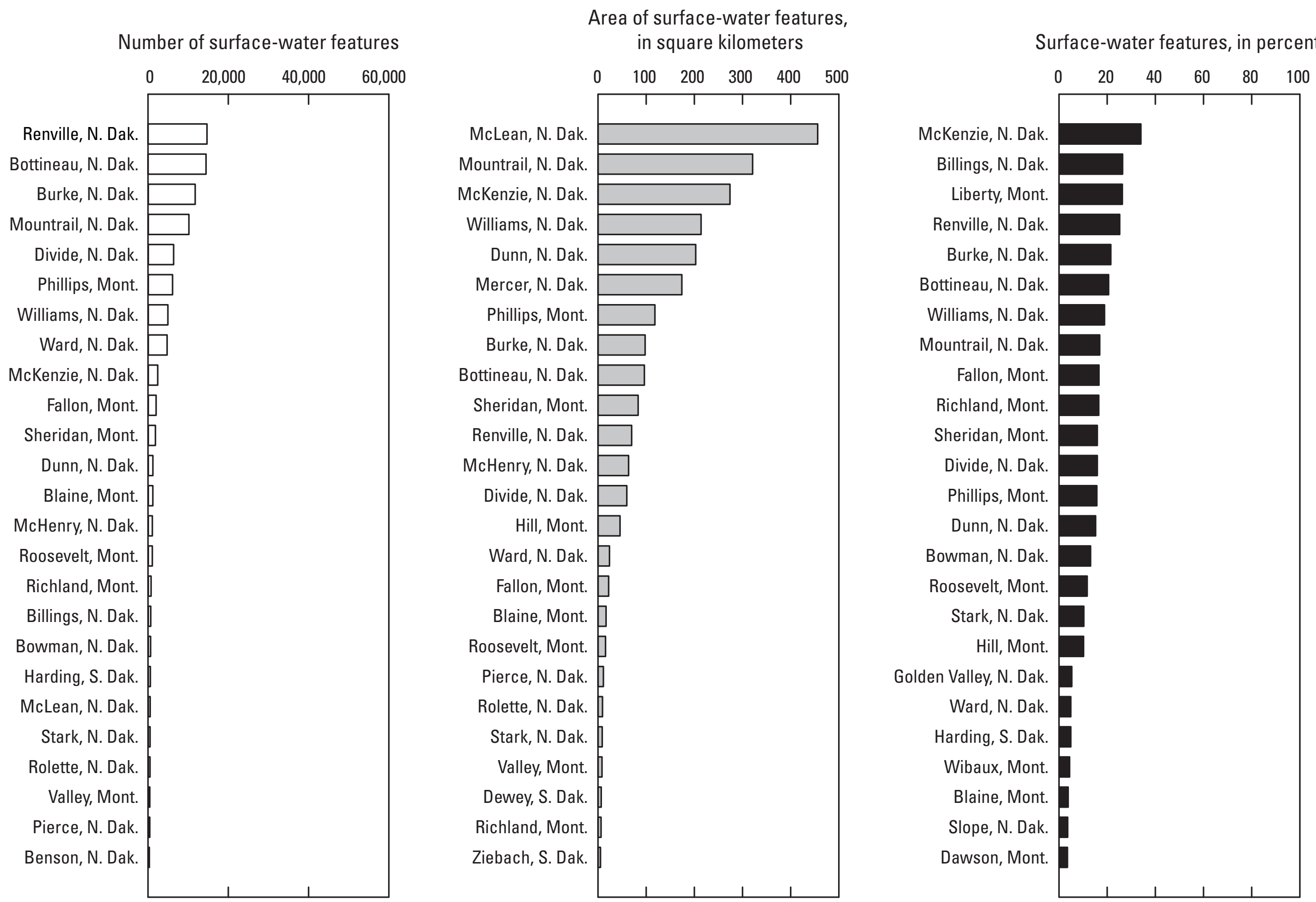


Figure 23. The top 25 counties wholly or partially in the Williston Basin, ranked by total number, area, and percentage of surface-water features within 0.4 kilometer of at least one oil or gas well.

Water-Quality Data Consolidation

Water-quality monitoring associated with energy development is typically coordinated at the State level, and accessibility of these data differs by State (Bowen and others, 2015). Most data used to characterize water-quality within the Williston Basin, data were obtained from the Water-Quality Portal (WQP) (National Water Quality Monitoring Council [NWQMC], 2015). Additional data was acquired as part of the USGS's National Water Quality Assessment (NAWQA) Program's data compilation with processing steps used to identify river and stream sites throughout the Nation with samples suitable for water-quality, pesticide, and ecology trend analysis (Oelsner and others, 2017).

The WQP is a cooperative service sponsored by the USGS, the EPA, and the NWQMC. The WQP integrates publicly available water-quality data through an exchange from the USGS NWIS database (USGS, 2015c), the EPA Storage and Retrieval (STORET) data warehouse (EPA, 2015), and the U.S. Department of Agriculture (USDA) Sustaining The Earth's Watersheds—Agricultural Research Data System (STEWARDS) (Steiner and others, 2008). The WQP retrieves water-quality data from more than 400 Federal, State, Tribal, and local databases. The WQP had 252 million records as of 2015 and contains water-quality data, including physical measurements and chemical and biological metadata (NWQMC, 2015). The data compilation for the NAWQA project was completed during 2012 and 2013 and was an aggregation of water-quality data from Federal, State, and local agencies that was not available in the EPA STORET data warehouse, USGS NWIS database, or other nationally available databases (Oelsner and others, 2017). The water-quality data were compiled from western states and provided results from early 1938 through 2014.

Data from the WQP and the NAWQA project compilation were combined and used, in part, to identify for further evaluation, 5 commonly monitored water-quality field measurements or constituents (hereafter referred to as "primary constituents") along with 10 trace metals common in produced waters (Guerra and others, 2011; EPA, 2012; Galloway and others, 2012). Collectively, this extensive quality-control review will result in an updated, more accurate dataset for future analyses of the selected water-quality constituents. The dataset will serve as a solid foundation for an initial review of selected

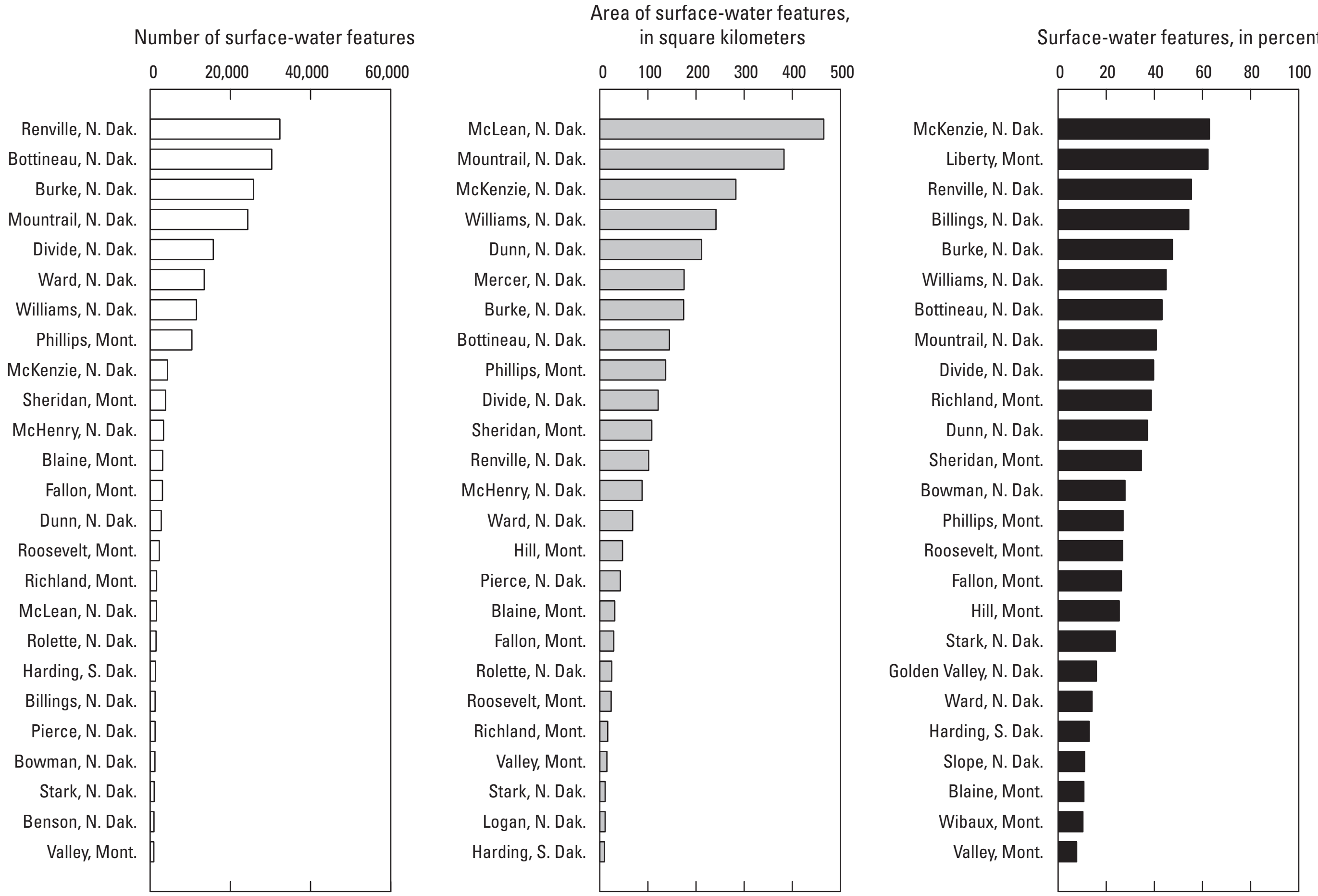


Figure 24. The top 25 counties wholly or partially in the Williston Basin, ranked by total number, area, and percentage of surface-water features within 0.8 kilometer of at least one oil or gas well.

water-quality constituents in the Williston Basin, and provide a tool to compliment current and future water-quality monitoring programs. These data may provide background information useful for evaluating effects of energy development.

Development of Water-Quality Dataset

Water-quality data were retrieved from the WQP for each County within the Williston Basin for samples of groundwater, springs, streams, rivers, lakes, reservoirs, and wetlands. The retrieved data included samples collected from 1900 to 2015. Water-quality data were retrieved from the NAWQA data compilation for sites in Montana, North Dakota, and South Dakota. For each site sampled in either dataset that included locational information (latitude/longitude), those sites within the boundary of the Williston Basin were selected for further analyses. The two datasets were then aggregated to form one primary dataset that could be used to characterize available data for the Williston Basin.

This dataset was initially culled, which included, in part, removing known duplicate sites or samples and known quality-control samples (for example, blank and replicate samples). In addition, numerous constituents had multiple naming conventions (for example, “total dissolved solids,” or “TDS,” or “solids, dissolved”). Once a constituent or measurement was selected for more detailed analyses, a consistent name was selected and used. Additional refinement, further discussed below, was not trivial and involved extensive review and quality-control checks.

Although data were synthesized for groundwater, springs, streams, rivers, lakes, reservoirs, and wetlands, focus was placed on three groundwater and surface-water features: (1) groundwater; (2) streams and rivers (combined); and (3) lakes and reservoirs (combined). Data in WQP and the NAWQA project’s data compilation included samples collected since the early 1900s, but the number of samples collected increased in the early 1970s in groundwater and streams/rivers, presumably because of implementation of the Clean Water Act of 1972 (EPA, 1972). While data for samples collected in 2015 were available, the period from 1970 through 2014 was selected for further analyses. This period includes a timeframe during the peak of conventional oil production (late 1970s), and timeframes before and during

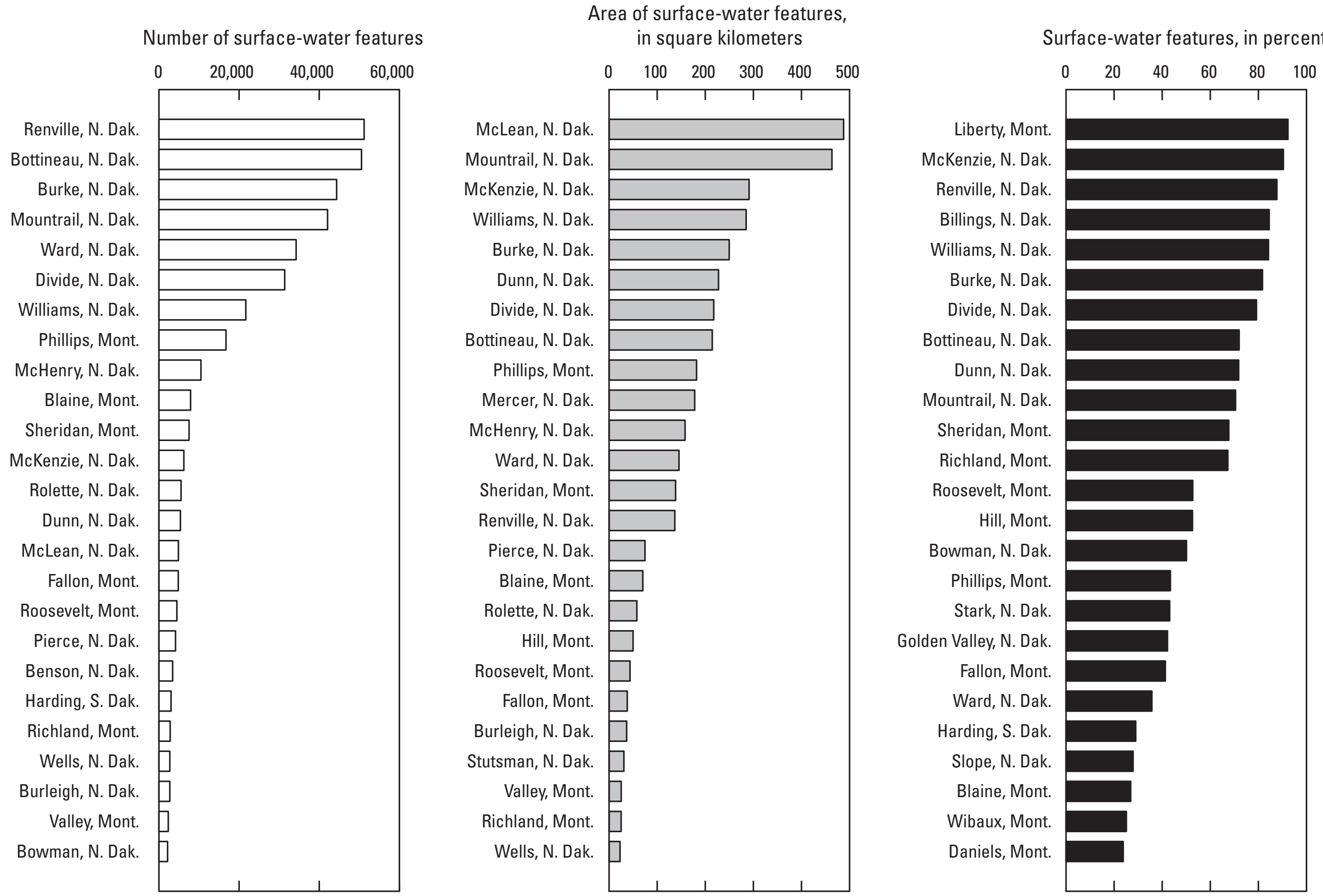


Figure 25. The top 25 counties wholly or partially in the Williston Basin, ranked by total number, area, and percentage of surface-water features within 1.6 kilometers of at least one oil or gas well.

the increased use of hydraulic fracturing for unconventional oil and gas development in the Williston Basin (mid-2000s). The total and cumulative number of stream and river samples collected per year is shown on figure 26 (a similar pattern was observed for groundwater samples). The reduction in samples beginning in about 2012 may, in part, be attributed to an agency delay loading the data to the database.

Selection of Water-Quality Data for Analyses

A total of 289, 498, and 334 individual constituents were analyzed in groundwater, streams and rivers, and lakes and reservoirs, respectively, regardless of the naming convention, constituent fraction type, or reported unit types. Summaries of the constituents analyzed in groundwater, streams and rivers, and lakes and reservoirs are available in a data release (Boughton and others, 2022, tables 3–1, 3–2, 3–3). The data included, in part, field measurements, major ions, trace elements, nutrients, volatile organic compounds, pesticides, and other physical properties. Collectively, this information was used to identify five commonly monitored water-quality constituents: (1) specific conductance, (2) TDS, (3) pH, (4) sulfate, and (5) chloride. These constituents were among the most commonly measured in all three groundwater and surface-water features (groundwater, streams and rivers, and lakes and reservoirs) and also are considered important with respect to the quality of produced water in the Williston Basin.

Selected constituent concentrations in the water-quality data were compared to EPA drinking-water maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and action levels (ALs) (EPA, 2009, 2012). An MCL is an enforceable standard that refers to the highest level or concentration that is allowed in drinking water supplied by public water systems for protection of health. An SMCL is a nonenforceable guideline and addresses either cosmetic or aesthetic effects, such as taste, odor, and color. An AL is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

In total, 10 secondary water-quality constituents, all trace metals, also were selected for evaluation because they are

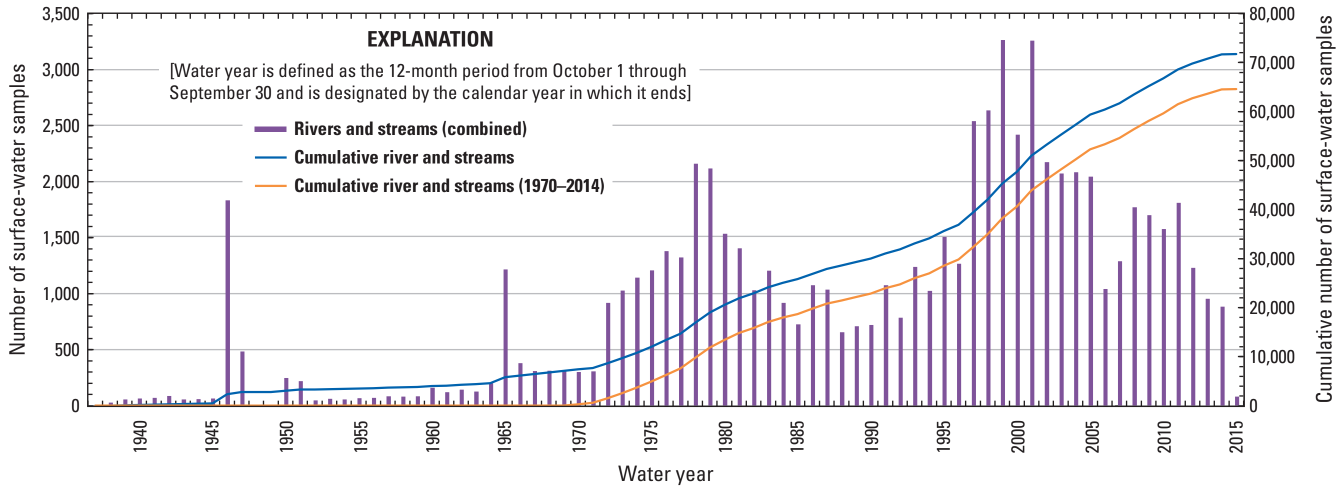


Figure 26. Number of stream and river samples collected in the Williston Basin, 1970 through 2015.

common in produced waters, have comparable EPA drinking-water standards, and were used for evaluation of water-quality characteristics for streams in North Dakota (Guerra and others, 2011; EPA, 2009, 2012; Galloway and others, 2012). The 10 secondary constituents were aluminum, arsenic, barium, chromium, copper, iron, lead, selenium, strontium, and zinc. Although the period of 1970 through 2014 was used for evaluation of the 5 commonly monitored constituents, the period from 1993 through 2014 was used for evaluation of the 10 secondary trace metal constituents because there were substantial changes in sample collection and analytical methods for these constituents beginning in 1993 (USGS, 1992, 1993).

Proper and consistent use of reporting units determined if water-quality data were retained for evaluation; for example, specific conductance values only were retained if the units were identified as microsiemens per centimeter at 25 degrees Celsius (µS/cm). TDS concentrations were retained if reported as either measured or calculated; however, when both types of data were available, precedence was placed on measured concentrations. Values for pH were reported as either “pH” or “pH (lab),” and when values were reported for both, precedence was placed on using values recorded as “pH.” Only the analyses for chloride, sulfate, and the 10 secondary constituents from the dissolved fraction of samples were retained. Concentrations for constituents with multiple reporting units were adjusted to the most common reporting unit. Sulfate only was evaluated if the units were identified as milligrams per liter as sulfate.

Censoring levels, such as “less than,” often are used when constituent concentrations are too low to be accurately quantified. Many of the constituents have a wide range of analytical censoring levels for numerous reasons. Censoring levels can change through time and among laboratories because of changes in sensitivity of laboratory equipment or analytical methods or changes in protocol for determining the censoring level. The censoring level is generally higher than the method detection limit, which is the lowest concentration for which a compound can be detected (but not necessarily accurately quantified) (Childress and others, 1999). Determination of a common assessment level among the reporting levels for each constituent evaluated was beyond the scope of this report.

Sampling locations that had an analytical value for at least one of the five commonly monitored constituents (specific conductance, TDS, pH, sulfate, and chloride) became likely candidates for retention and further analysis. Duplicate analyses were common for some sampling locations. In the case of true duplicate (quality-control) samples, the latter samples were removed from the database. Often, the same sampling location was sampled by multiple agencies on different dates and times, and each agency used their own sampling site name or identifier for the same location. All groundwater, streams and rivers, and lakes and reservoir locations were evaluated to ensure that each sampling location was identified uniquely.

Collectively, this extensive quality-control review and application resulted in an updated, more accurate dataset for future analyses of the constituents (Boughton and others, 2022). It is important to note that the dataset may require further refinement to improve accuracy, but this refinement is beyond the scope of this study. Some values that remain in the dataset are questionable and not likely representative of true environmental conditions; however, they are publicly available from the WQP (National Water Quality Monitoring Council, 2015), the USGS NAWQA data compilation (Oelsner and others, 2017), or the Montana Bureau of Mines and Geology (Montana Bureau of Mines and Geology, 2021). As such, some minimum and maximum values or concentrations may be lower or higher than actual values. Median values or concentrations are likely to be representative of environmental conditions. This is an important consideration for future use of this dataset, especially for constituents not summarized in this report. Regardless, the resultant dataset will serve as a solid basis for an initial review of selected water-quality results in the Williston Basin and provides important information to compliment current and future water-quality monitoring programs.

Groundwater Data

Each groundwater site was examined for locational information, aquifer screening information, and depth component (well completion depth, bottom of screened interval, or sample collection depth) information. If a groundwater site was within 100 meters of another site with the same aquifer name, the well completion depth and screened intervals were compared. If well depths, or screened intervals, for the sites were within 5 meters, the sites were considered the same site, and data from both sites were combined. If a USGS station identifier was present for one of the duplicate sites, the USGS identifier was selected as the preferred station identifier for combining the data from the sites, and duplicate water-quality data were removed. No duplicate groundwater site identifiers were detected even though more than one agency will occasionally monitor the same well. Duplicates were not detected because likely duplicate candidates did not have the required ancillary information to be included: aquifer sampled or depth component.

In total, 25 categories of groundwater samples were documented in the primary database. These included, in part, those coded as plugged, unused, destroyed, or unknown. The importance of data from these types of wells is uncertain; therefore, emphasis was placed solely on those coded as domestic, municipal, observation, industrial, production, stock, and well.

Only samples from wells screened in a known aquifer with locational information (latitude and longitude) and a known depth (well completion depth, bottom of screened interval, or sample collection depth) were retained for analyses. In total, samples were collected from 295 uniquely coded aquifers during 1970 through 2014 (Boughton and others, 2022, table 3–4). Samples were grouped based on four categories of aquifer systems: (1) Quaternary unconsolidated (including the alluvial and glacial aquifers/aquifer system); (2) lower Tertiary; (3) Upper Cretaceous; and (4) unknown/deeper (Boughton and others, 2022, table 3–4). Only samples from the Quaternary unconsolidated aquifers, and lower Tertiary and Upper Cretaceous aquifer systems were evaluated. Samples from 7,502 wells were evaluated for at least 1 of the 5 commonly monitored constituents, including 3,194 in the Quaternary unconsolidated, 2,505 in the lower Tertiary, and 1,803 in the Upper Cretaceous aquifer systems. A list of the groundwater sites by aquifer is available in a data release (Boughton and others, 2022, table 3–5).

River and Streams Data

For river and stream locations, sites were investigated further if they were within 100 meters of each other. The site names were compared to determine if the sites were on the same waterbody. If the site names were not descriptive, a GIS coverage with the NHD stream reaches was used to determine the waterbody. If there was a USGS station identifier for one of the duplicate sites, the USGS site identifier was selected as the preferred station identifier for combining the data from the sites, and duplicate water-quality data were removed.

Eight categories of river and stream samples were documented in the primary database including: (1) canal irrigation; (2) ditch or canal; (3) facility municipal sewage; (4) irrigation and returns; (5) river/stream; (6) stream; (7) stream:canal; or (8) stream:ditch. Similar to groundwater, the importance of data from some of these categories is uncertain; therefore, emphasis was placed on those coded as river/stream and stream.

Rivers and streams have greater temporal variability than groundwater and lakes. As such, it was determined that for a stream and river site to be further evaluated, it needed to be sampled at least 10 times from 1970 through 2014. After aggregating all duplicate sites, those sites with fewer than 10 samples for any of the 5 commonly monitored constituents were removed, resulting in 329 sites available for river and stream water-quality characterization (Boughton and others, 2022, table 3–6).

Lakes and Reservoirs Data

For lakes and reservoirs locations, if a site was within 100 meters of another site, further investigation was warranted. The site names were compared to determine if the sites were on the same waterbody. If the site names were not descriptive, a GIS coverage was used to determine if the sites were on the same waterbody. If there was a USGS station identifier for the one of the duplicate sites, the USGS site identifier was selected as the preferred station identifier for combining the data from the sites, and duplicate water-quality data were removed.

Four categories of lakes and reservoir samples were documented in the primary database including (1) lake; (2) lake/reservoir/impoundment; (3) reservoir; and (4) pond. Again, the importance of some of these types of sites is uncertain; therefore, emphasis was placed on those coded as lakes, reservoirs, and lake/reservoir/impoundments. Hereafter, samples from "lakes and reservoirs" will be referred to as samples from "lakes."

For lakes, samples often are collected at different depths. For the purposes of this report, if samples were collected at different depths from the same site on the same date and time, the values for properties other than pH were averaged. For pH, the mean value of all depths at a location was used. The mean was determined by calculating the mean hydrogen ion activity value for each location and converting back into standard pH units. After aggregating duplicate sites, 839 lake sites were available for data characterization (Boughton and others, 2022, table 3–7).

Characterization of Water Quality in the Williston Basin

Water-quality data are presented in a broad framework. The five commonly monitored constituents (specific conductance, TDS, pH, sulfate, and chloride) were analyzed graphically through use of bubble plots to characterize breakpoints in measurements or concentrations, as determined from a GIS coverage. This analysis also incorporated a characterization of the number of oil or gas wells in the Williston Basin. In the case of streams and rivers, and lakes and reservoirs, the number of oil and gas wells are presented within USGS eight-digit Hydrologic Unit Codes (HUC–8; U.S. Geological Survey, 2015a). A second graphical representation used boxplots, which are graphical representations of statistical values of concentrations (TIBCO Software, Inc., 2014).

Tabular analyses including summary statistics for each of the five commonly monitored constituents have been published in a data release. The data release contains analyses for groundwater resources (Boughton and others, 2022, tables 3–8 to 3–12), streams and rivers (Boughton and others, 2022, tables 3–16 to 3–20), and lakes (Boughton and others, 2022, tables 3–22 to 3–31), along with summary statistics for the 10 trace metals (tables 8, 9, 10; Boughton and others, 2022, tables 3–13 through 3–15, 3–21, 3–32). In all cases, figures and statistical summaries were calculated with no consideration for period of record, sampling dates (other than during 1970 through 2014), sampling times, or censoring levels. Measurements or concentrations that were less than detection levels (non-detections) were not included in the statistical summaries.

Groundwater Quality

From 1970 to 2014, the USGS and two state agencies (Montana Bureau of Mines and Geology [MBMG] and North Dakota State Water Commission [NDSWC]) collected and analyzed groundwater samples from 7,502 groundwater wells in the Williston Basin for at least 1 of the 5 commonly monitored constituents. A total of 3,194, 2,505, and 1,803 wells completed in the Quaternary unconsolidated, lower Tertiary, and Upper Cretaceous aquifer systems, respectively, were sampled for at least 1 of the 5 constituents (Boughton and others, 2022, table 3–5). Most of these wells were sampled only once during this period; however, some were sampled as many as 92 times, but not for all five constituents. A list of the aquifers sampled by aquifer system, and information on the location and depth of each well are provided in the associated data release (Boughton and others, 2022, tables 3–4, 3–5). Summary statistics by well for each of the five commonly monitored constituents are provided in tables 3–8 to 3–12 of the data release (Boughton and others, 2022). The range and statistical distribution of these constituents are shown using boxplots (fig. 27).

The spatial distribution of wells sampled and range in measurements or concentrations (Boughton and others, 2022) for the five commonly monitored constituents are shown in figures 28 to 32. Wells completed in the Quaternary unconsolidated aquifer system are distributed throughout the study area, but well density is greater in the northeastern part of the Williston Basin. This is likely due to more glacial aquifer material being present in this area in comparison to other areas. The fewest wells completed in the Quaternary unconsolidated aquifer system are in the south central and southwestern parts of the Williston Basin, again likely because of less glacial and alluvial material present in these areas (fig. 1). Wells completed in the lower Tertiary aquifer system are reasonably distributed in the Williston Basin, except for the northeastern and southern parts of the area. Wells completed in the Upper Cretaceous aquifer system are not as well distributed in comparison to the other aquifer systems. Within the Williston Basin, there are no wells present in the northern and eastern parts of North Dakota and the eastern part of South Dakota. There may be multiple reasons for wells to be sampled more frequently in specific areas for certain aquifer units. Regardless, this information may be beneficial in designing future water-quality monitoring programs because it helps to identify gaps in spatial coverage by aquifer system and in analytical results for specific constituents. In addition, the data may provide a basis for future comparisons of measurements or concentrations.

Specific conductance measured in groundwater samples from 5,059 wells collected from 1970 to 2014 were summarized for each well. Specific conductance and median specific conductance (for wells with more than one measurement) range from 2.9 to 807,299 µS/cm for the Quaternary unconsolidated aquifer system, 153 to 49,001 µS/cm for the lower Tertiary aquifer system, and 180 to 15,000 µS/cm for the Upper Cretaceous aquifer system (figs. 27*A*, 28; Boughton and others, 2022, table 3–8). Although the data are publicly available, the minimum specific conductance values may not be representative of environmental conditions. Among the three aquifer systems, specific conductance varies the most in waters from the Quaternary unconsolidated aquifer system (Boughton and others, 2022, table 3–8). In general, the range in specific conductance tends to be smaller in waters from the Upper Cretaceous aquifer system. Specific conductance tends to be more variable in waters from the lower Tertiary and Quaternary unconsolidated aquifer systems (fig. 27*A*).

TDS was measured in groundwater samples from 5,831 wells in the Williston Basin (Boughton and others, 2022, table 3–9), but concentrations are only summarized for 5,545 wells in which TDS was measured above detection levels (figs. 27*B*, 29). TDS concentrations and median TDS concentrations (for wells with more than one measurement) range from 103 to 39,200 µS/cm for the Quaternary unconsolidated aquifer system, 79 to 29,198 µS/cm for the lower Tertiary aquifer system, and 142 to 7,720 µS/cm for the Upper Cretaceous aquifer system (figs. 27*B*, 29; Boughton and others, 2022, table 3–9).

Table 8. Summary of trace metals measured in groundwater samples from the Williston Basin, from 1993 to 2014.

[EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; AL, action level; SMCL, secondary maximum contaminant level; --, not available]

Trace metal	Number of wells by analysis fraction type		List of analytical censoring levels for dissolved trace metals, in micrograms per liter	Total number of dissolved analyses	Summary statistics for detected concentration in dissolved fraction, in micrograms per liter				Number of nondetections	EPA (2009, 2012) levels,[1] in micrograms per liter	
	Dissolved	Total			Minimum	Mean	Maximum	Number of dissolved analyses with values reported as detections		MCL or AL	SMCL
Quaternary unconsolidated											
Aluminum	48	--	1.6, 1.7, 3.4, 11, 15, 30, 50	63	1.70	34.1	80.0	21	42	--	50–200
Arsenic	65	--	0.022, 0.03, 0.12, 1, 5	108	0.43	10.2	68.7	90	18	10	--
Barium	48	--	0.07, 0.2	63	12.9	141	947	63	0	2,000	--
Chromium	48	--	0.06, 0.12, 0.35, 1, 2, 5, 10	63	0.06	3.59	10.0	37	26	100	--
Copper	47	--	0.4, 0.5, 0.8, 1, 2, 5, 10	61	0.25	2.60	11.9	32	29	1,300	1,000
Iron	82	2	3, 3.2, 5, 6, 10, 50	139	3.00	1,405	9,600	115	24	--	300
Lead	61	--	0.015, 0.03, 0.08, 0.125, 1, 2, 5, 100	101	0.02	21.3	400	21	80	15	--
Selenium	66	--	0.03, 0.08, 0.15, 1, 5	110	0.08	4.40	30.2	54	56	50	--
Strontium	67	--	0.2	83	100	883	7,200	83	0	--	--
Zinc	48	--	0.6, 1.4, 2, 2.8, 5, 7, 10	62	0.95	24.3	415	34	28	--	5,000
Lower Tertiary											
Aluminum	16	--	30, 50	27	0.95	44.2	244	12	15	--	50–200
Arsenic	23	--	1, 5	44	0.25	2.48	17.1	34	10	10	--
Barium	16	--	1, 5	27	1.00	67.9	715	27	0	2,000	--
Chromium	17	--	1, 5, 10	27	0.20	100	1,430	18	9	100	--
Copper	15	--	3, 50	26	0.10	5.04	24.3	19	7	1,300	1,000
Iron	35	1	2	60	3.00	592	5,270	55	5	--	300
Lead	23	--	1, 2, 5, 10, 100	44	0.04	4.56	20.0	16	28	15	--
Selenium	23	--	1, 5	44	0.45	3.98	29.7	28	16	50	--
Strontium	33	--	4	40	7.53	1,479	9,621	39	1	--	--
Zinc	16	--	2, 5, 10	27	0.20	30.6	258	21	6	--	5,000

Table 8. Summary of selected trace metal data in the Williston Basin at groundwater sites with samples analyzed during 1993 through 2014.—Continued

[EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; AL, action level; SMCL, secondary maximum contaminant level; --, not available]

Trace metal	Number of wells by analysis fraction type		List of analytical censoring levels for dissolved trace metals, in micrograms per liter	Total number of dissolved analyses	Summary statistics for detected concentration in dissolved fraction, in micrograms per liter				Number of nondetections	EPA (2009, 2012) levels,[1] in micrograms per liter	
	Dissolved	Total			Minimum	Mean	Maximum	Number of dissolved analyses with values reported as detections		MCL or AL	SMCL
Upper Cretaceous											
Aluminum	19	--	1.6, 30, 50	30	4.40	235	900	6	24	--	50–200
Arsenic[2]	23	--	0.12, 1, 5	49	0.46	[2]4.6	[2]26.9	24	25	10	--
Barium	19	--	0.2	30	5.90	153	3,300	30	0	2,000	--
Chromium	19	--	1, 2, 5, 6, 10	30	1.00	17.3	95.6	12	18	100	--
Copper	19	--	0.4, 0.8, 2, 5, 10	30	0.57	5.96	19.5	14	16	1,300	1,000
Iron	39	--	3, 5, 6, 10, 50	64	3.00	382	5,600	49	15	--	300
Lead	23	--	0.08, 0.16, 1, 2, 5, 100	49	1.00	1.92	3.84	5	44	15	--
Selenium	23	--	0.08, 0.16, 1, 5	49	1.00	14.4	114	26	23	50	--
Strontium	33	--	--	40	20.0	518	2,900	40	0	--	--
Zinc	19	--	0.6, 2, 5, 10	30	1.00	24.0	230	20	10	--	5,000

[1]A MCL is the maximum permissible level of a contaminant in water delivered to users of a public-water system and is a health-based enforceable regulation. SMCLs are nonenforceable guidelines regarding cosmetic or aesthetic effects of drinking water. An AL is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

[2] One large arsenic detection (973 micrograms per liter) in Boughton and others (2022, table 3–15) was removed for calculation of summary statistics. This value is anomalously large in comparison to all other arsenic concentrations measured in the Upper Cretaceous aquifer system (0.46–26.9 micrograms per liter; this table if this value is not used to calculate summary statistics), and the value is much greater than the one other detection (1 microgram per liter) in the same well. Retention of the larger value would result in a larger calculated mean (44.9 micrograms per liter) and maximum detected concentration (973 micrograms per liter).

Table 9. Summary of selected trace metal data in the Williston Basin at stream and river sites that had 10 or more samples collected during 1993 through 2014.

[EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; AL, action level; SMCL, secondary maximum contaminant level; --, not available]

Trace metal	Number of sites by analysis fraction type		List of analytical censoring levels for dissolved trace metals, in micrograms per liter	Total number of dissolved analyses	Summary statistics for detected concentration in dissolved fraction, in micrograms per liter				Number of nondetections	EPA (2009, 2012) levels,[1] in micrograms per liter	
	Dissolved	Total			Minimum	Mean	Maximum	Number of dissolved analyses with values reported as detections		MCL or AL	SMCL
Aluminum	56	47	0.009, 0.01, 1, 1.6, 1.7, 2, 3, 3.4, 4, 6.6, 8, 10, 11, 17, 20, 50	1,345	1	168	25,982	437	908	--	50–200
Arsenic	57	69	0.022, 0.03, 0.044, 0.06, 0.12, 0.18, 0.2, 0.26, 0.9, 1, 2, 5	2,173	0.4	3.81	35	1,688	485	10	--
Barium	53	64	0.05, 0.07, 0.08, 0.14, 0.2, 0.4, 1, 100	1,418	7.36	63.3	866	1,400	18	2,000	--
Chromium	49	47	0.8, 1, 2, 5, 10	1,130	0.59	3.95	31.6	387	743	100	--
Copper	52	51	0.23, 0.4, 0.5, 1, 1.3, 2.4, 5, 10	1,255	0.74	4.51	94.9	890	365	1,300	1,000
Iron	63	110	0.007, 0.01, 0.05, 3, 3.2, 4, 6, 6.4, 7, 8, 9.6, 10, 16, 18, 19.2, 24, 30, 50	2,527	3.1	155	28,900	1,860	667	--	300
Lead	55	59	0.015, 0.03, 0.045, 0.06, 0.075, 0.08, 0.12, 0.15, 0.16, 0.2, 0.24, 1, 2, 5, 9, 10, 100	2,037	0.017	2.15	98	120	1,917	15	--
Selenium	57	59	0.03, 0.04, 0.06, 0.08, 0.2, 0.3, 0.33, 0.4, 0.5, 0.7, 1, 2, 5	2,234	0.18	2.64	280	947	1,287	50	--
Strontium	45	2	0.08, 0.2, 0.4	1,147	18	583	2,300	1,147	0	--	--
Zinc	49	58	0.2, 0.6, 1, 1.2, 1.4, 1.8, 2, 2.8, 3, 4, 4.2, 5, 5.6, 9, 10, 14, 20	1,192	0.26	6.74	307	745	447	--	5,000

[1]A MCL is the maximum permissible level of a contaminant in water delivered to users of a public-water system and is a health-based enforceable regulation. SMCLs are nonenforceable guidelines regarding cosmetic or aesthetic effects of drinking water. An AL is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

Table 10. Summary of selected trace metal data in the Williston Basin at lake sites with samples analyzed during 1993 through 2014.

[EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; AL, action level; SMCL, secondary maximum contaminant level; --, not available]

Trace metal	Number of sites by analysis fraction type		List of analytical censoring levels for dissolved trace metals, in micrograms per liter	Total number of dissolved analyses	Summary statistics for detected concentration in dissolved fraction, in micrograms per liter				Number of nondetections	EPA (2009, 2012) levels,[1] in micrograms per liter	
	Dissolved	Total			Minimum	Mean	Maximum	Number of dissolved analyses with values reported as detections		MCL or AL	SMCL
Aluminum	66	182	1, 1.6, 1.7, 3.2, 3.4, 10, 10.2, 50	86	1.7	317	6,820	52	34	--	50–200
Arsenic	104	214	0.022, 0.044, 0.06, 0.12, 0.2, 0.6, 1, 1.8	273	5	4.1	516	260	13	10	--
Barium	88	191	0.07, 0.08, 0.14, 0.2, 0.4, 1, 3, 47	236	2.6	51	417	235	1	2,000	--
Chromium	91	191	0.06, 0.12, 0.2, 0.36, 0.8, 0.9, 1, 1.2, 2, 10	244	0.9	6.5	50	35	209	100	--
Copper	87	200	0.23, 0.4, 0.5, 1, 3, 5, 10	243	0.5	16	590	54	189	1,300	1,000
Iron	132	264	3, 3.2, 4, 4, 6, 6, 6.4, 6.4, 7, 8, 8, 9, 10, 10, 12, 16, 18, 30, 260	774	1.7	97	7,220	452	322	--	300
Lead	99	212	0.015, 0.03, 0.08, 0.09, 0.12, 0.2, 0.36, 0.8, 1, 2, 100	263	1	1.6	5	28	235	15	--
Selenium	100	205	0.03, 0.04, 0.08, 0.2, 1, 2	259	2	3.3	33	115	144	50	--
Strontium	20	13	0.2, 0.4, 1	5	202	497	810	5	0	--	--
Zinc	92	200	0.2, 0.6, 1, 1.4, 1.8, 2, 2.8, 6, 8.4, 9, 10, 30	247	9	25	100	143	104	--	5,000

[1]A MCL is the maximum permissible level of a contaminant in water delivered to users of a public-water system and is a health-based enforceable regulation. SMCLs are nonenforceable guidelines regarding cosmetic or aesthetic effects of drinking water. An AL is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

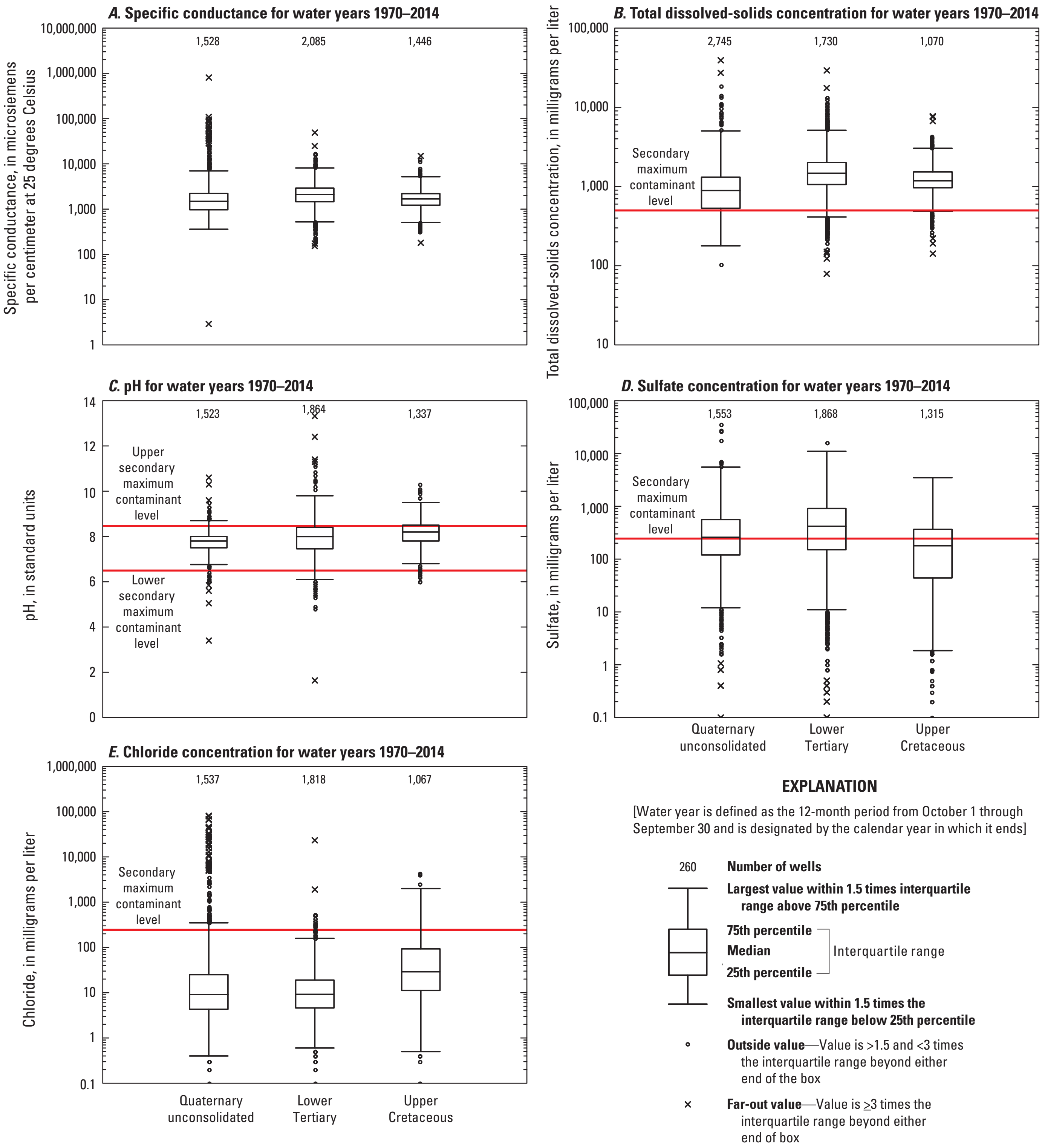
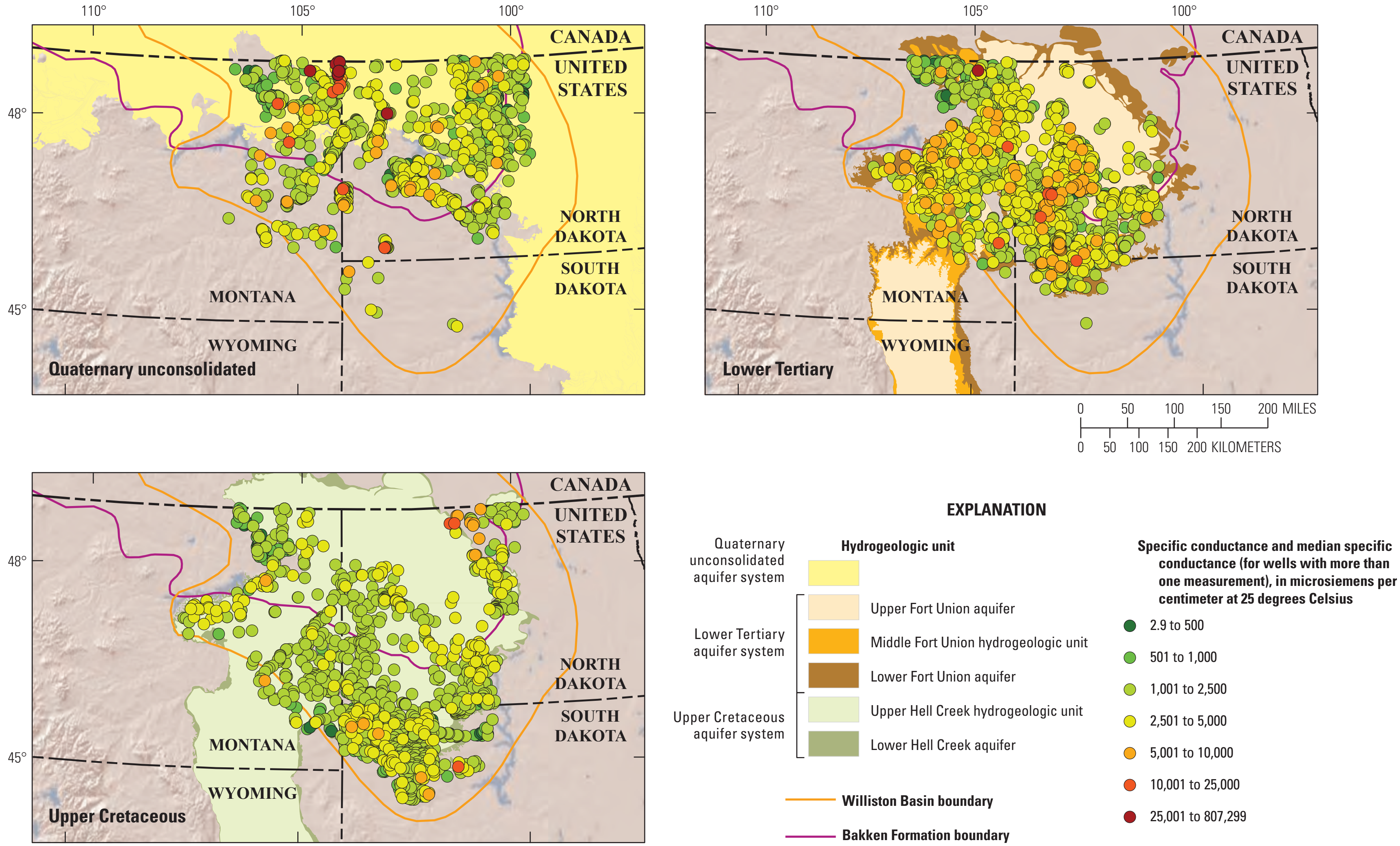


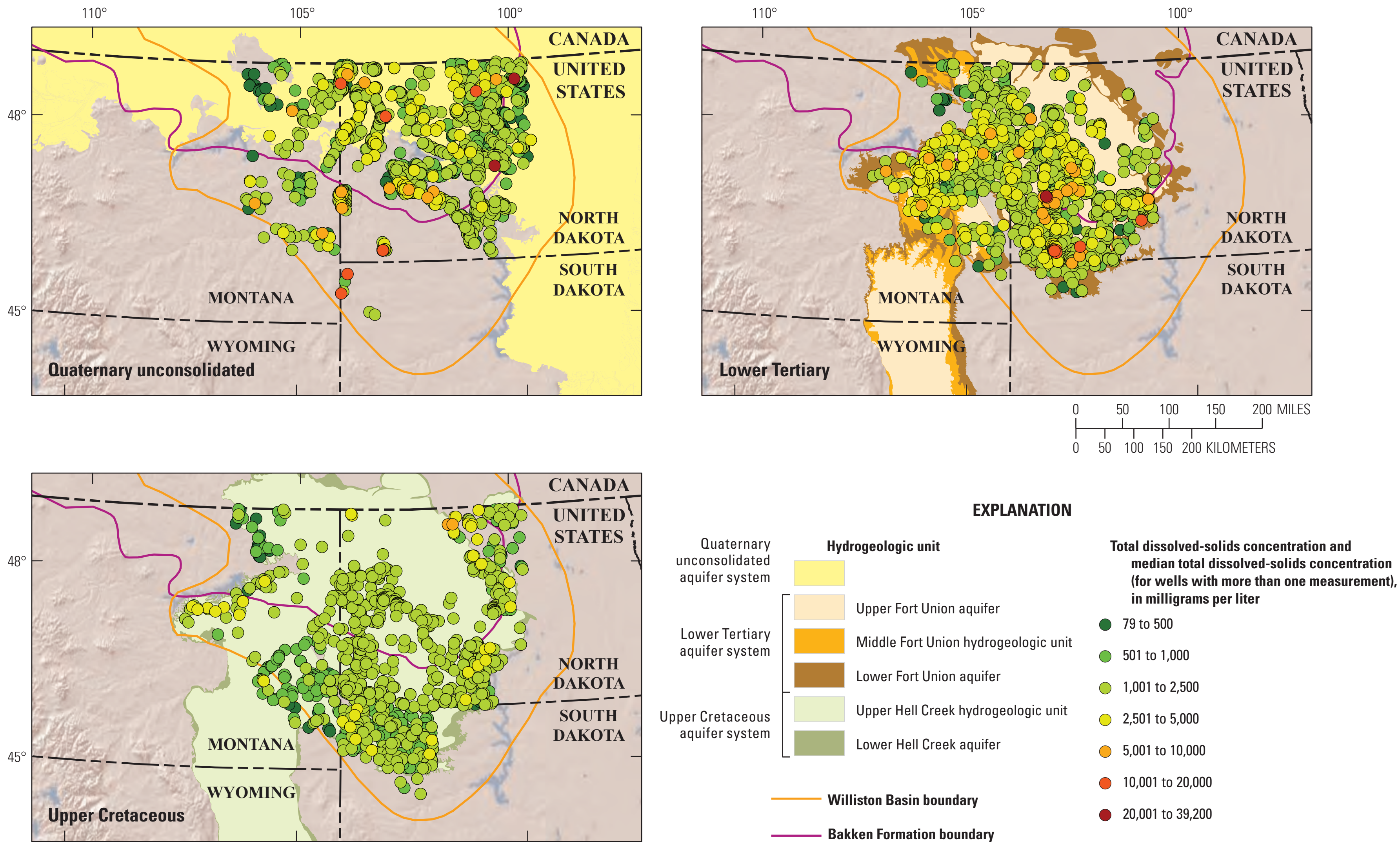
Figure 27. Range and statistical distribution of *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved-solids concentrations, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate concentrations, in milligrams per liter; and *E*, chloride concentrations, in milligrams per liter measured in groundwater samples from the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. A median value was calculated and plotted for wells with more than one sample.



Base map modified from U.S. Geological Survey, Esri, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

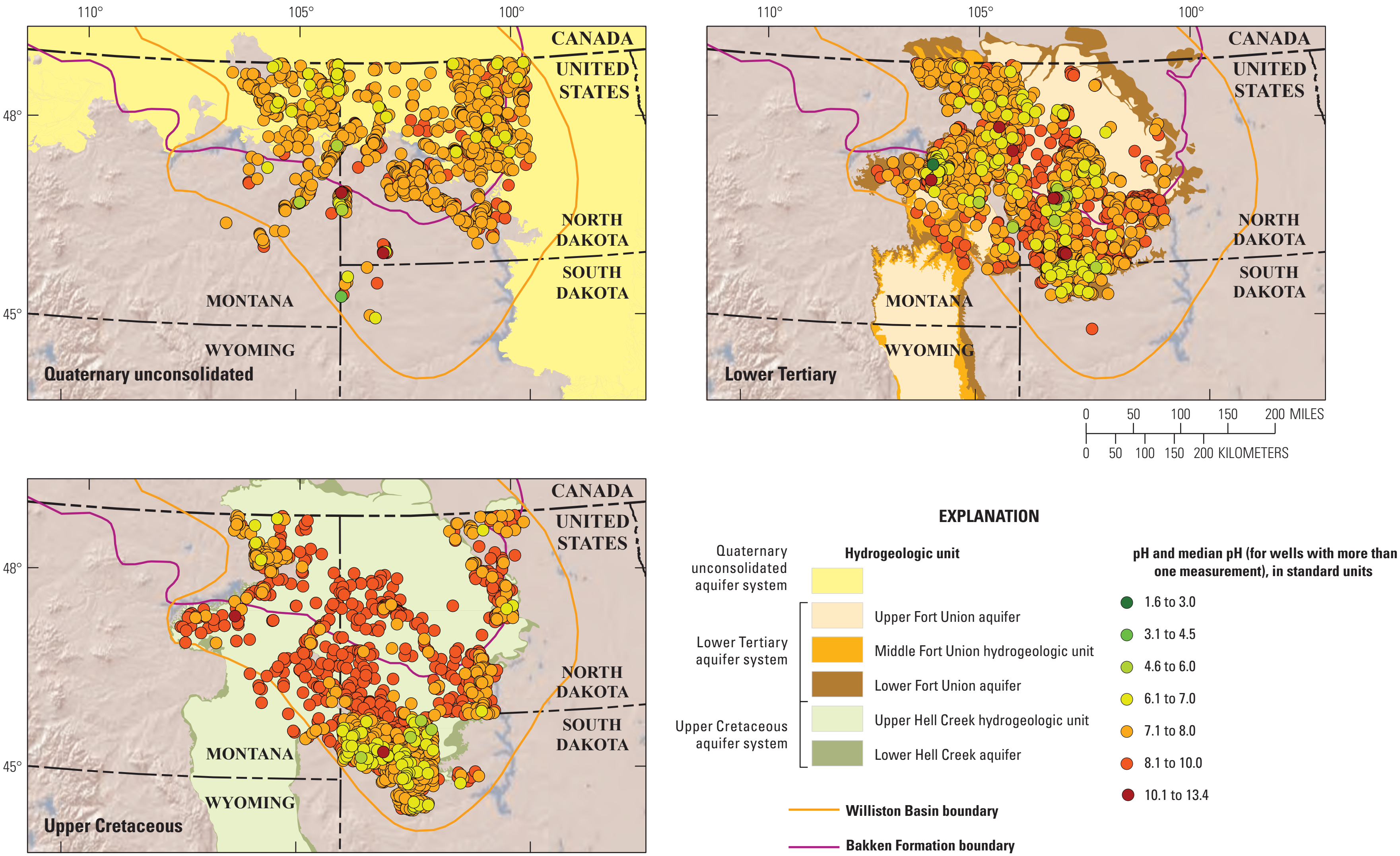
Figure 28. Specific conductance and median specific conductance (for wells with more than one measurement) measured in groundwater samples from wells in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014.



Base map modified from U.S. Geological Survey, Esri, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

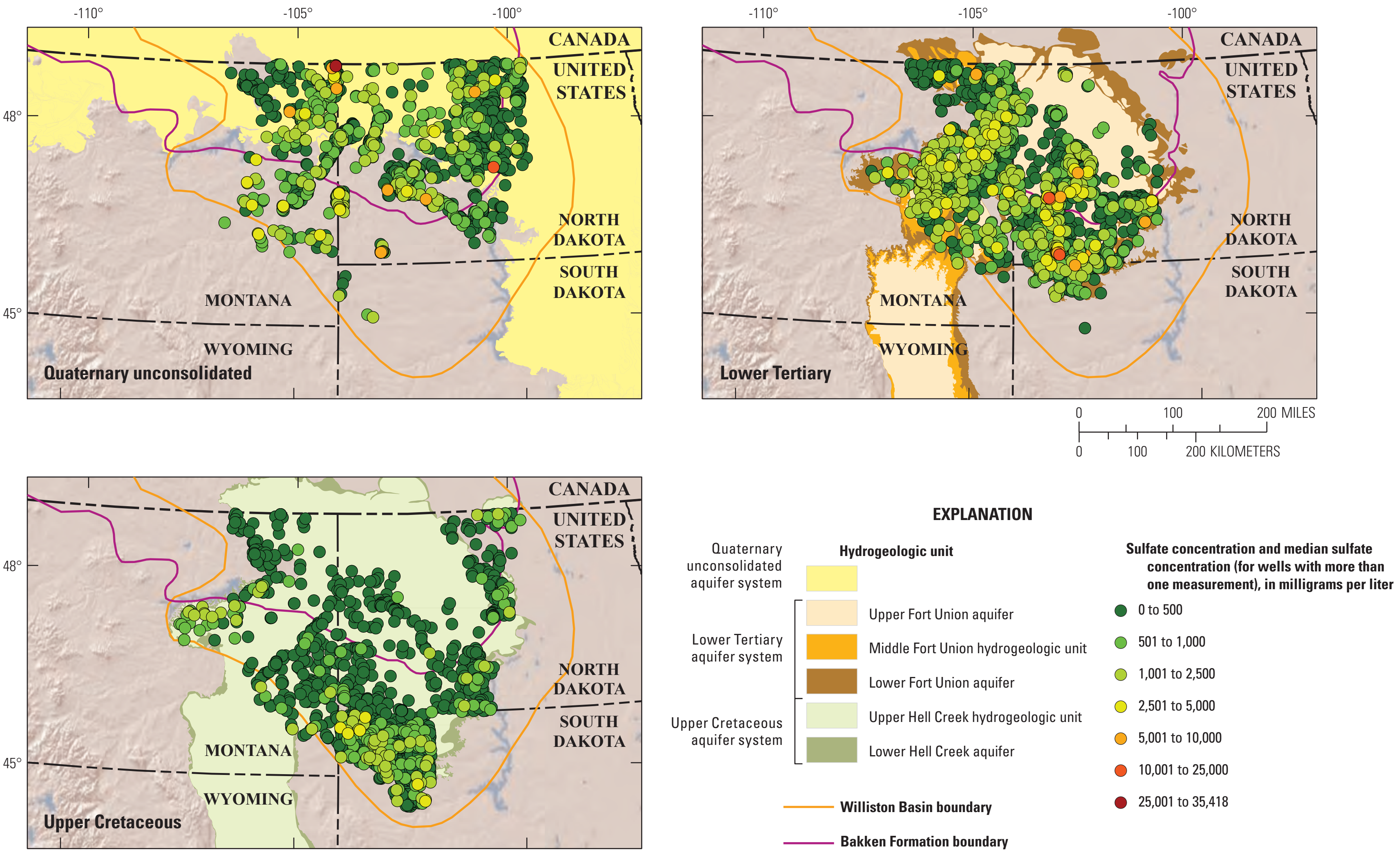
Figure 29. Total dissolved-solids concentrations and median total dissolved-solids concentrations (for wells with more than one measurement) measured in groundwater samples from wells in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014.



Base map modified from U.S. Geological Survey, Esri, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

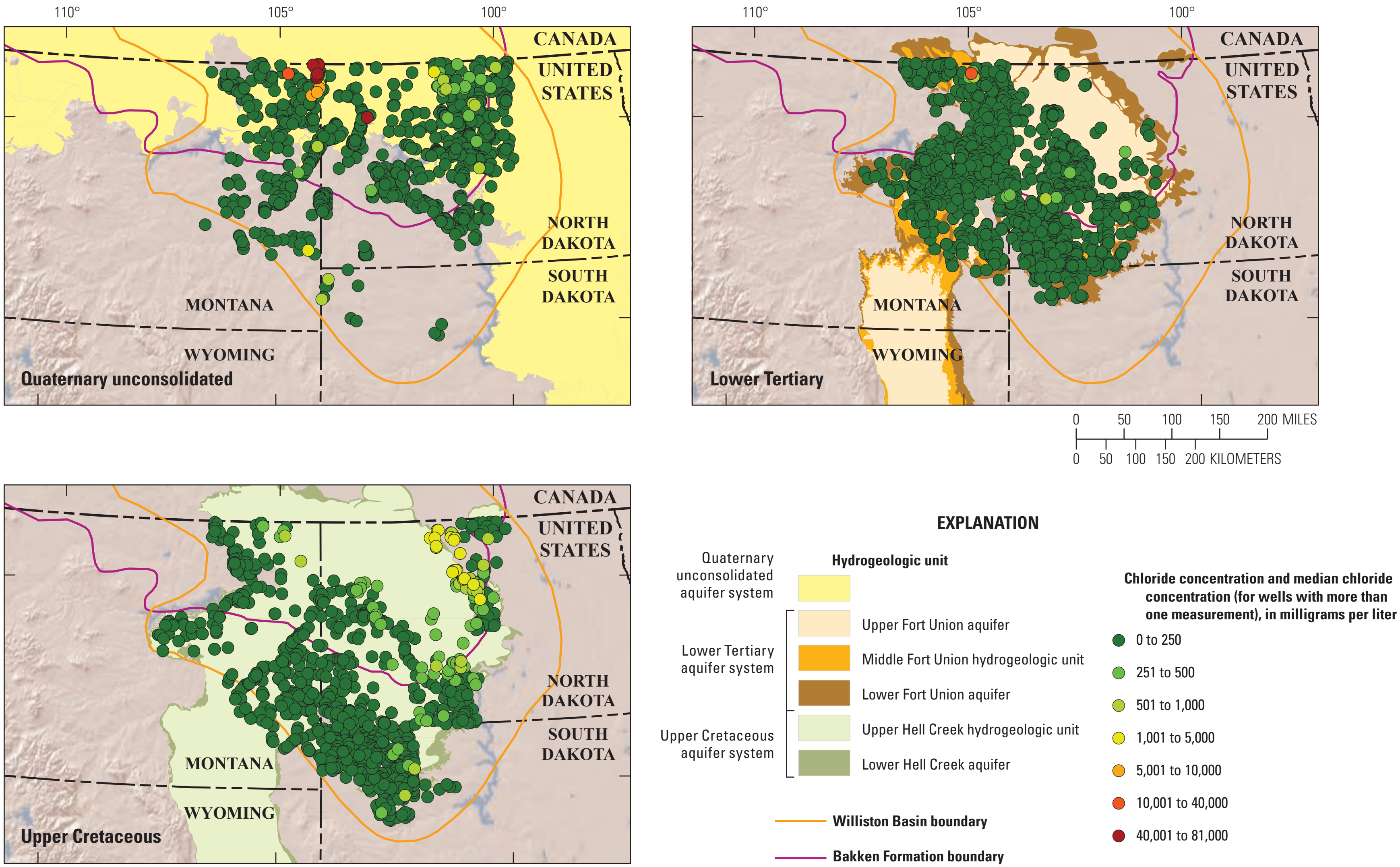
Figure 30. pH and median pH (for wells with more than one measurement) measured in groundwater samples from wells in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 through 2014.



Base map modified from U.S. Geological Survey, Esri, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

Figure 31. Sulfate concentrations and median sulfate concentrations (for wells with more than one measurement) measured in groundwater samples from wells in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 through 2014.



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Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
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Figure 32. Chloride concentrations and median chloride concentrations (for wells with more than one measurement) measured in groundwater samples from wells in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 through 2014.

Values for pH measured in groundwater samples from 4,724 wells in the Williston Basin collected from 1970 to 2014 were summarized for each well. The pH and median pH (for wells with more than one measurement) range from 3.4 to 10.6 standard units for the Quaternary unconsolidated aquifer system, 1.6 to 13.3 standard units for the lower Tertiary aquifer system, and 6.0 to 10.3 standard units for the Upper Cretaceous aquifer system (figs. 27*C*, 30; Boughton and others, 2022, table 3–10). Although the data are publicly available, the minimum and maximum pH values may not be representative of environmental conditions. In general, pH measurements tend to be smaller in the Quaternary unconsolidated aquifer system and larger in the Upper Cretaceous aquifer system (fig. 27*C*).

Sulfate was measured in groundwater samples from 4,774 wells in the Williston Basin (Boughton and others, 2022, table 3–11), but concentrations are only summarized for 4,736 wells with sample concentrations that were above detection levels (figs. 27*D*, 31). Sulfate concentrations and median sulfate concentrations (for wells with more than one measurement) range from 0.1 to 35,418 mg/L in the Quaternary unconsolidated aquifer system, 0.1 to 16,000 mg/L in the lower Tertiary aquifer system, and 0.2 to 3,480 mg/L in the Upper Cretaceous aquifer system (figs. 27*D*, 31). Although the data are publicly available, the minimum sulfate values may not be representative of environmental conditions. In general, sulfate concentrations tend to be smaller in the Upper Cretaceous aquifer system and larger in the lower Tertiary aquifer system.

Chloride was measured in groundwater samples from 4,910 wells in the Williston Basin (Boughton and others, 2022, table 3–12), but concentrations are only summarized for 4,422 wells with sample concentrations that were above detection levels (figs. 27*E*, 32). Chloride concentrations and median chloride concentrations (for wells with more than one measurement) range from 0.1 to 81,000 mg/L in the Quaternary unconsolidated aquifer system, 0.1 to 23,300 mg/L in the lower Tertiary aquifer system, and 0.1 to 4,300 mg/L in the Upper Cretaceous aquifer system (figs. 27*E*, 32). Although the data are publicly available, the minimum chloride values may not be representative of environmental conditions. In general, chloride concentrations are smaller in the lower Tertiary aquifer system and larger in the Upper Cretaceous aquifer system, although some of the largest concentrations were from wells completed in the Quaternary unconsolidated aquifer system (figs. 27*E*, 32).

By aquifer system, the total number of wells with samples analyzed for dissolved trace metals ranges from 83 to 156. The number of wells with sample analytical results was dependent on the trace metal (table 8); for example, aluminum was measured in samples from 83 wells, whereas iron was measured in samples from 156 wells (table 8; Boughton and others, 2022, tables 3–13 to 3–15). In general, more samples from wells completed in the Quaternary unconsolidated aquifer system were analyzed for any 1 of the 10 trace metals (580) as compared to those completed in the lower Tertiary (217) or Upper Cretaceous (236) aquifer systems (Boughton and others, 2022, tables 3–13 to 3–15, respectively). Censoring levels for dissolved trace metal analyses varied considerably, and many analyses had unknown censoring levels. Summary statistics were computed only for detected trace metal concentrations in the dissolved fraction measured in micrograms per liter. Mean concentrations from wells completed in the Quaternary unconsolidated aquifer system were less than EPA MCLs, SMCLs, or ALs (EPA, 2009, 2012) except for arsenic, iron, and lead with mean concentrations of 10.2 micrograms per liter (µg/L) (MCL=10 µg/L), 1,405 µg/L (SMCL=300 µg/L), and 21.3 µg/L (AL=15 µg/L), respectively (table 8). Mean dissolved trace metal concentrations from wells completed in the lower Tertiary aquifer system were less than or equal to EPA MCLs, SMCLs, or ALs except for iron, with a mean concentration of 592 µg/L (SMCL=300 µg/L; table 8). Mean dissolved trace metal concentrations from wells completed in the Upper Cretaceous aquifer system were less than EPA MCLs, SMCLs, or ALs except for aluminum and iron with mean concentrations of 235 µg/L (SMCL range=50–200 µg/L) and 382 µg/L (SMCL=300 µg/L), respectively (table 8).

Water Quality of Streams and Rivers

At least 1 of the 5 commonly monitored constituents was monitored at 329 sites along streams and rivers in the Williston Basin from 1970 to 2014 (Boughton and others, 2022, table 3–6). Most sampling sites for streams and rivers in the Williston Basin are in North Dakota (211 of 329 sites; 64 percent). Water-quality samples for streams and rivers were collected by six State agencies (North Dakota Department of Health [NDDH], NDSWC, Montana Department of Environmental Quality [MDEQ], SDDENR, MBMG, and South Dakota Geological Survey), the Native American Tribes with land holdings in the Williston Basin area (Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation, Three Affiliated Tribes [Mandan, Hidatsa, and Arikara Nation] of the Fort Berthold Indian Reservation, and Turtle Mountain Band of Chippewa Indians of North Dakota), and four Federal agencies (USACE, EPA, USGS, and National Park Service) (Boughton and others, 2022, table 3–6).

The number of stream water-quality samples collected and analyzed for specific conductance at sites in the Williston Basin from 1970 to 2014 is presented in figure 33 and in table 3–16 of the data release (Boughton and others, 2022). Specific conductance was selected from among the five commonly monitored constituents because it was measured in the greatest number of samples and represents the spatial distribution of sampling sites within the Williston Basin. The spatial distribution of surface-water sites sampled for specific conductance was compared with the number of oil and gas wells in the HUC–8 watersheds in the Williston Basin (fig. 33). Overall, the areas with the greatest number of specific conductance samples collected from streams and rivers are not collocated with the areas where the most intensive energy development was present; for example, the Lake Sakakawea HUC–8 (10110101) has the greatest number of oil and gas wells (10,667), but this area has fewer numbers of samples by site in comparison to many other watersheds. The Lower Yellowstone HUC–8 (10100004) has the second most oil and gas wells (3,170) and has fewer samples collected in comparison to many other watersheds. The Yellowstone River near Sidney, Mont. (streamgage 06329500; fig. 17), however, is in the Lower Yellowstone HUC–8 (10100004) and had the third greatest number of samples collected for the period of record (Boughton and others, 2022, table 3–16). Many of the sites with the greatest numbers of samples are in the eastern part of the Williston Basin, in areas that have the least number of oil and gas wells (for example, Lower Heart HUC–8 [10130203]; fig. 33). Areas of the Williston Basin where there is a lack of stream water-quality sampling sites as indicated by the collection of specific conductance samples can be visualized in figure 34, which illustrates minimum, median, and maximum specific conductance values for each site from 1970 to 2014. These underrepresented areas may be targeted for future water-quality sampling programs.

The concentrations of the five commonly monitored constituents are graphically summarized for the Williston Basin (fig. 35) and for one site (fig. 36), the Yellowstone River near Sidney, Mont, (streamgage 06329500; fig. 17). This USGS streamgage was selected because of the sample collection intensity for the period of record, it has substantial streamflow data, it is in the Lower Yellowstone HUC–8 (10100004), and it has the second greatest number of oil and gas wells per HUC-8 (fig. 33). Summary statistics are presented in Boughton and others (2022, tables 3–16 to 3–20).

Specific conductance was measured at stream water-quality sampling sites in the Williston Basin from 1970 to 2014, and values ranged from 1.08 to 13,300 µS/cm (fig. 35*A;* Boughton and others, 2022, table 3–16). In general, median specific conductance values were greater in the western part than in the eastern part of the basin (fig. 34*B*). Median specific conductance values for all sites ranged from 800 to 2,000 µS/cm (fig. 35*A*). From 2003 to 2012, a few questionable measurements that could not be verified were reported as less than 10 µS/cm from smaller tributaries Hell Creek, Horse Creek, Buffalo Springs, and East Redwater River near Circle, Mont. The largest specific conductance (13,300 µS/cm) measured was at streamgage 06177520 (Horse Creek near Circle, Mont.; Boughton and others, 2022, table 3–16). The specific conductance values for streamgage 06329500 were much less variable and ranged from 450 to 850 µS/cm from 1970 to 2014 (Boughton and others, 2022, table 3–16).

Total dissolved solids were measured at 236 sites in the Williston Basin, and values ranged widely from 10 to 19,100 mg/L (Boughton and others, 2022, table 3–17). Although the data are publicly available, the minimum TDS values may not be representative of environmental conditions. Median TDS values generally were greater in the western part of the basin (fig. 37). The median TDS values for all sites and years were between 500 and 1,500 mg/L (fig. 35*B*). Median TDS values exceeded the EPA SMCL of 500 mg/L (EPA, 2009, 2012) at 216 of 236 sites (91 percent) sampled from 2008 to 2014. Annual median TDS values for streamgage 06329500 were between 350 and 600 mg/L from 1970 to 2014 (fig. 36*B*). Very few TDS samples were collected at this site after about 2002.

Values for pH were measured in samples from 275 sites in the Williston Basin, and values ranged widely from 1.78 to 13.14 standard units (Boughton and others, 2022, table 3–18). Although the data are publicly available, the minimum and maximum pH values may not be representative of environmental conditions. Median pH values measured at each site generally were within the EPA SMCL range of 6.5 to 8.5 standard units, but median pH values measured at 50 of 275 sites (18 percent) were greater than the upper EPA SMCL of 8.5 standard units (Boughton and others, 2022, table 3–18). Maximum pH values were greater than 8.5 standard units in samples from 84 percent of the sites. Minimum pH values were less than the lower EPA SMCL of 6.5 standard units at 27 of 275 sites (Boughton and others, 2022, table 3–18). In general, median pH values for all years and sites were between 7.5 and 8.5 standard units (fig. 35*C*). A few pH values that were less than 4 standard units (fig. 38) likely were not reviewed before entry into the WQP. The annual median pH values for Yellowstone River near Sidney, Mont. (USGS streamgage 06329500) also were between 7.5 and 8.5 standard units from 1970 to 2014 (fig. 36*C*).

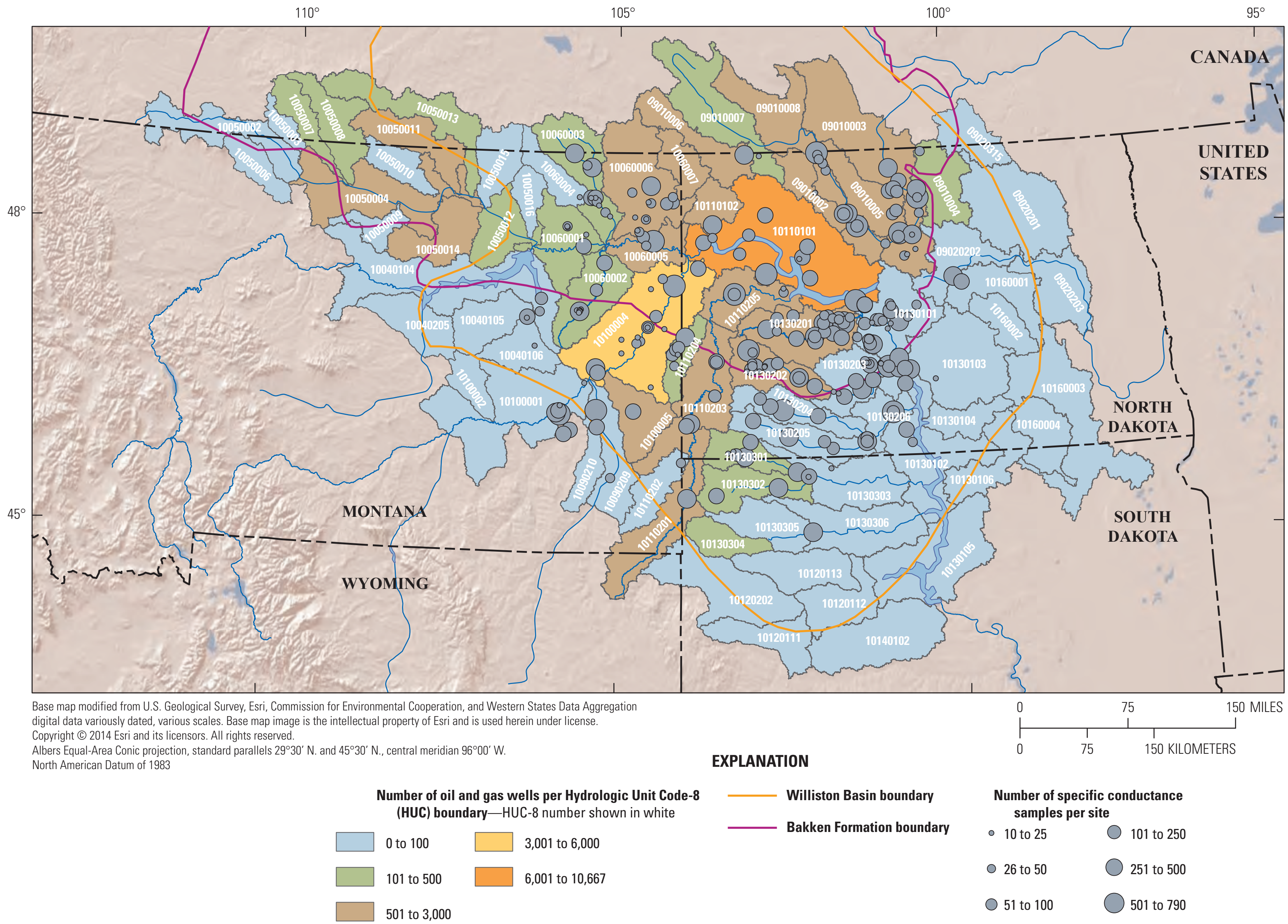
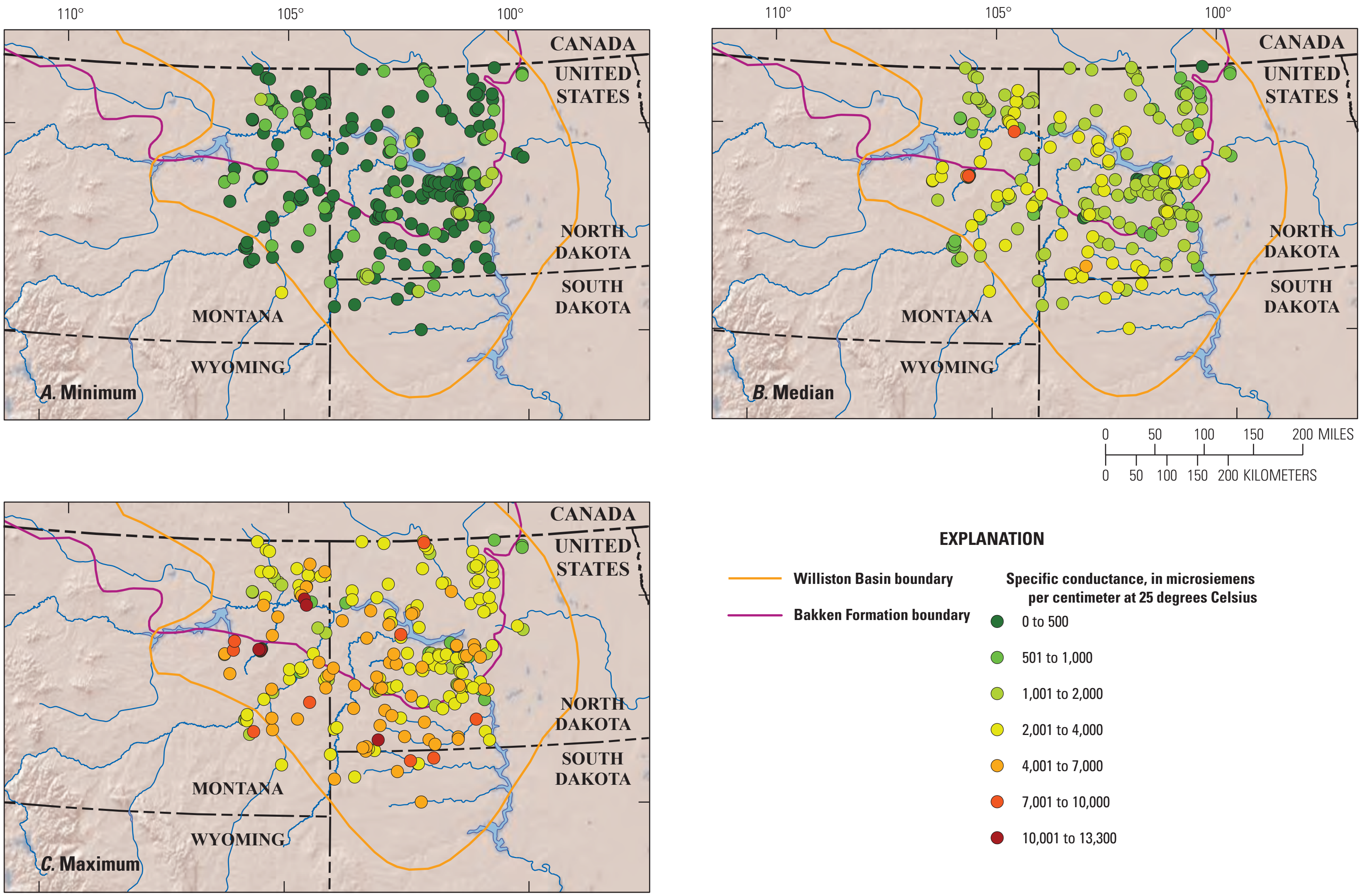


Figure 33. Spatial distribution of specific conductance samples from streams and rivers and numbers of oil and gas wells in HUC-8 watersheds in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014.



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Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
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Figure 34. Specific conductance in streams and rivers in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014.

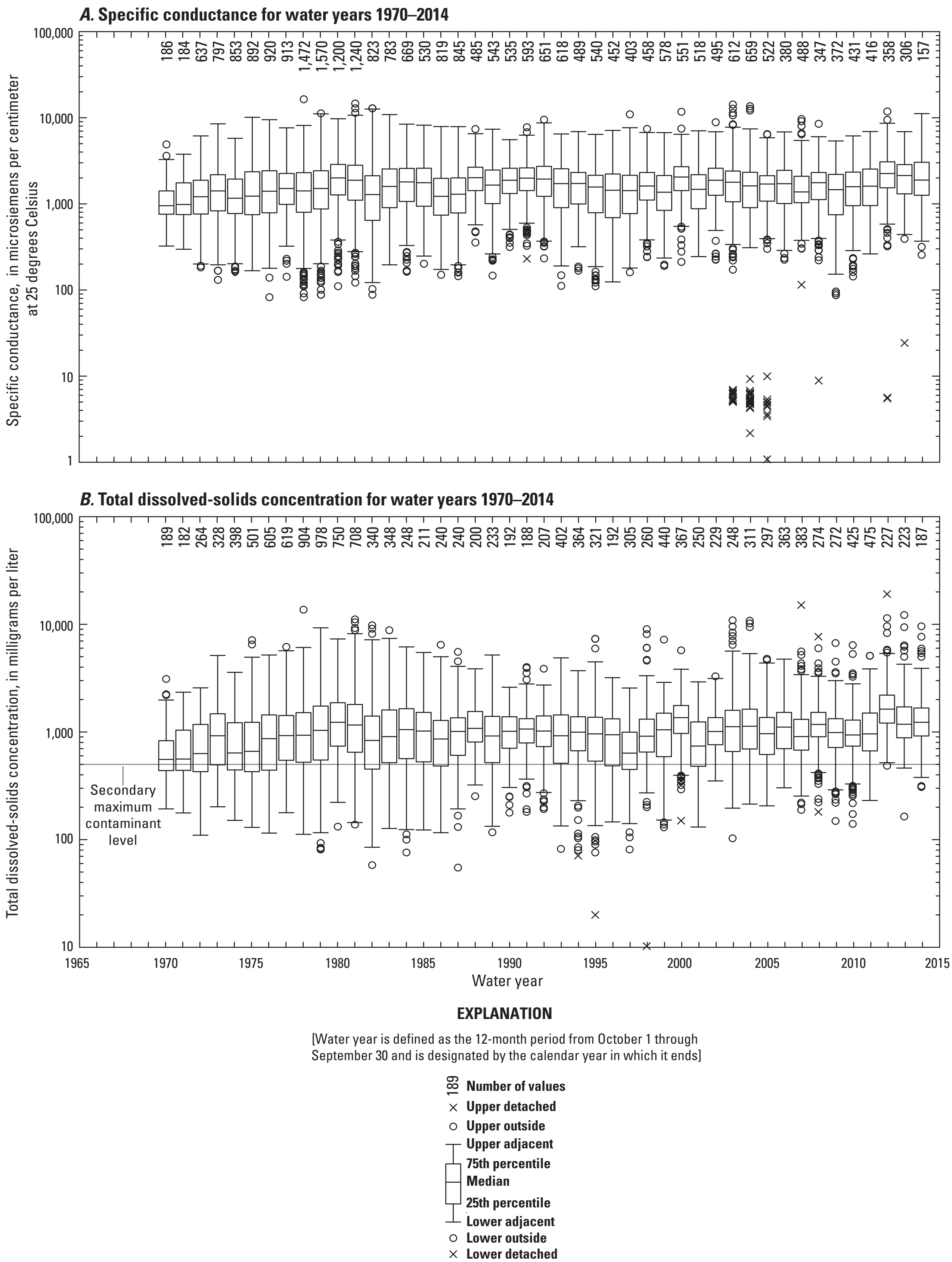
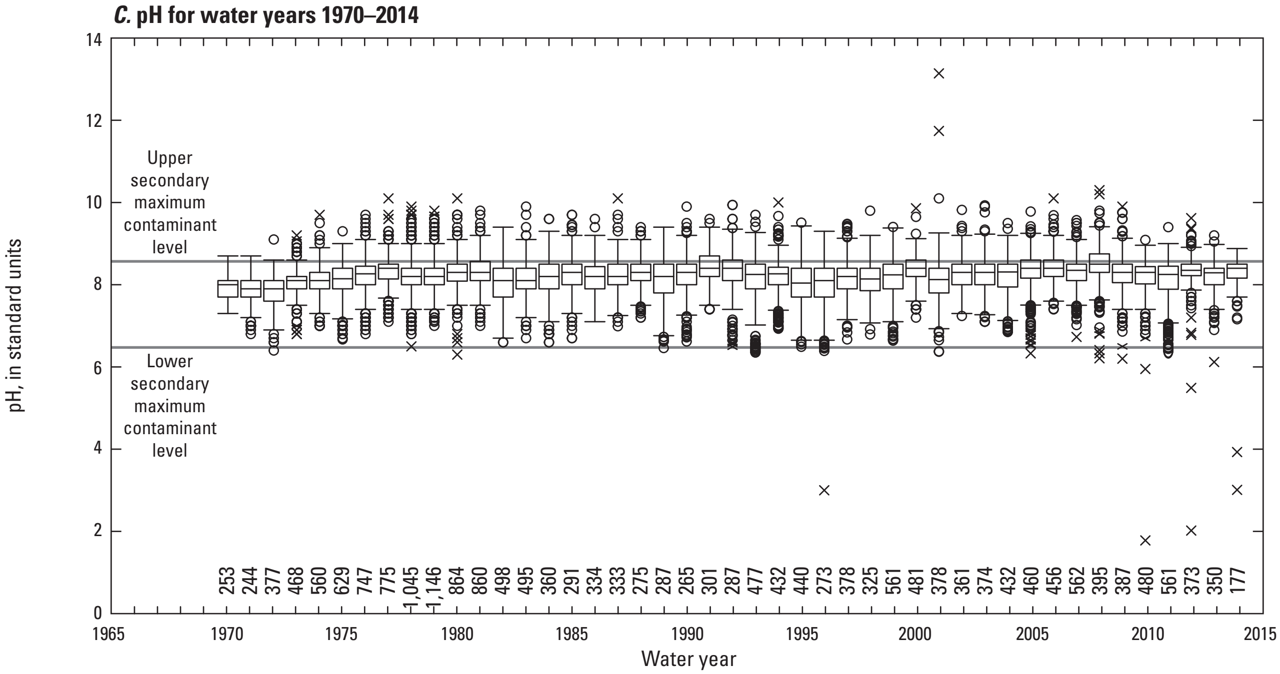


Figure 35. Annual variability in values of constituents for all streams and rivers in the Williston Basin, from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.



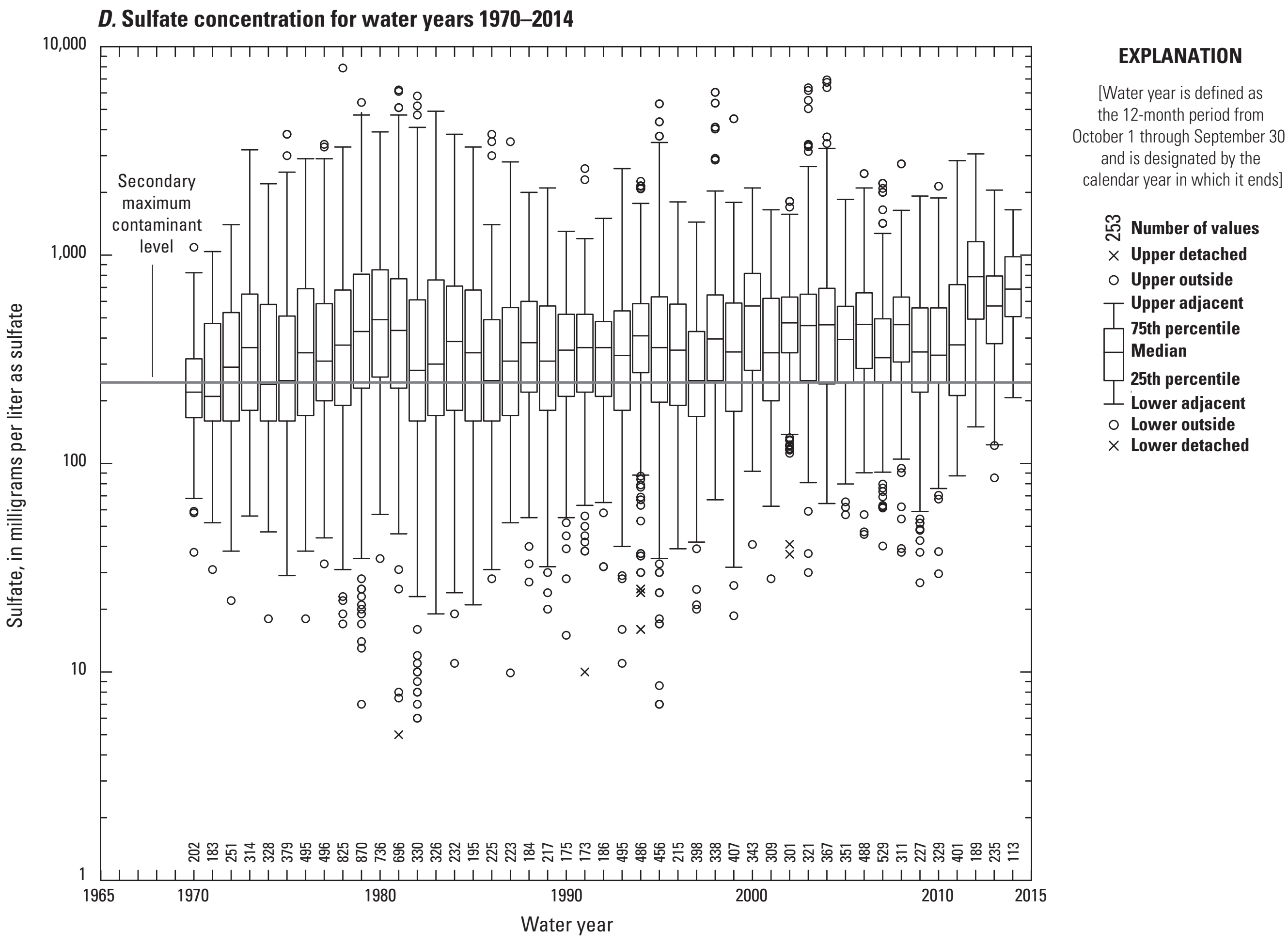


Figure 35. Annual variability in values of constituents for all streams and rivers in the Williston Basin, from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

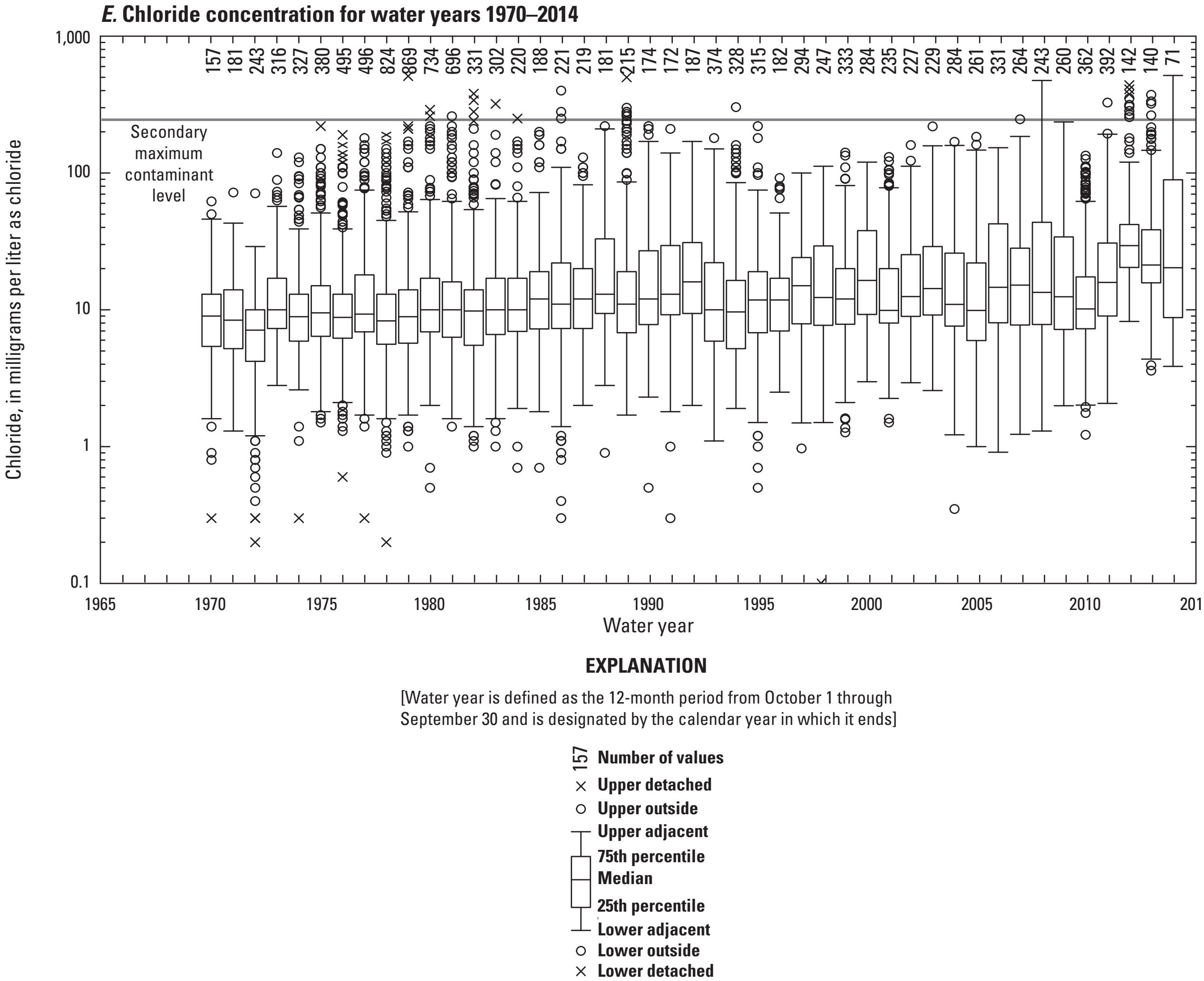


Figure 35. Annual variability in values of constituents for all streams and rivers in the Williston Basin, from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

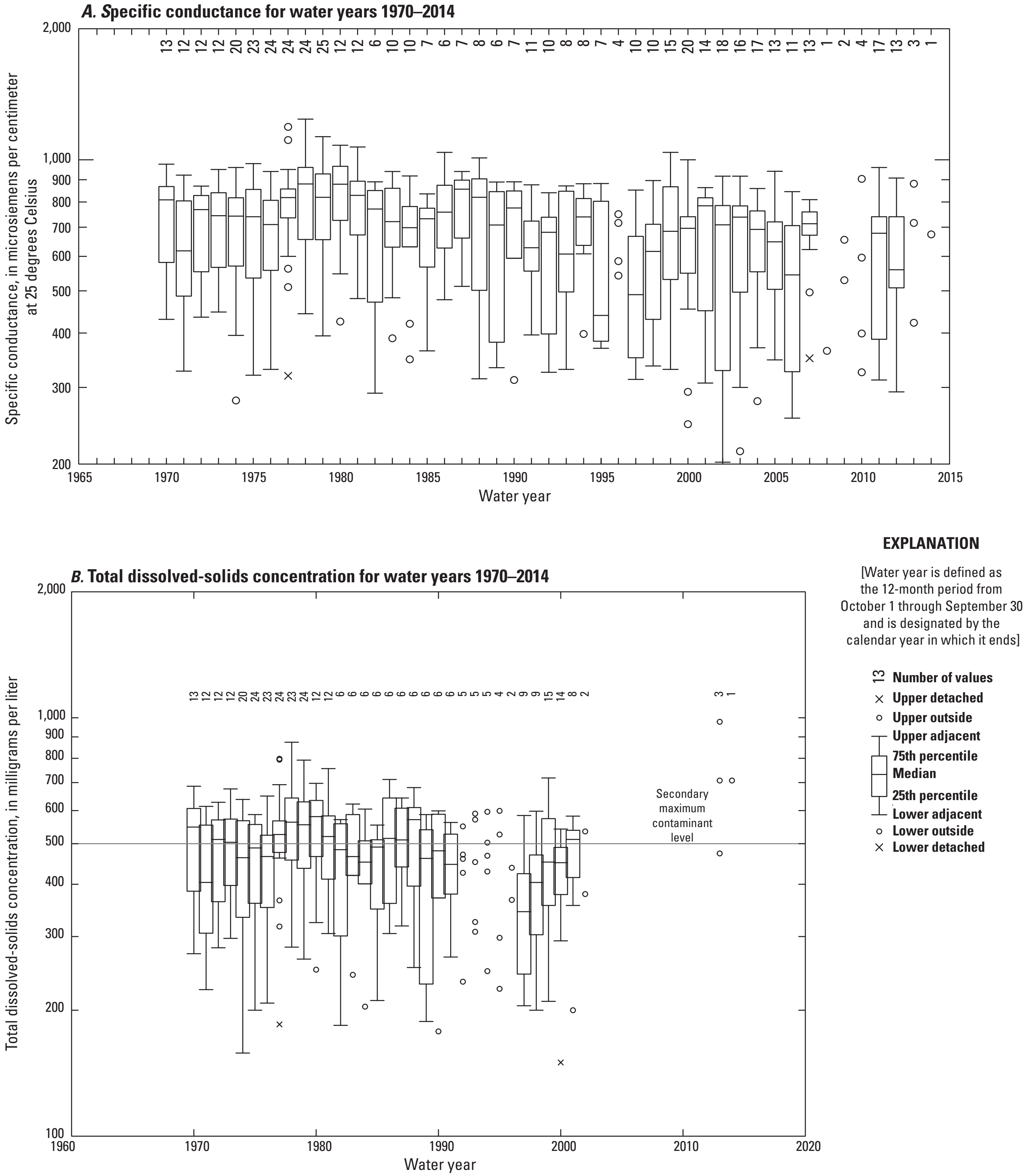


Figure 36. Annual variability in values of constituents for the Yellowstone River near Sidney, Montana (streamgage 06329500), from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.

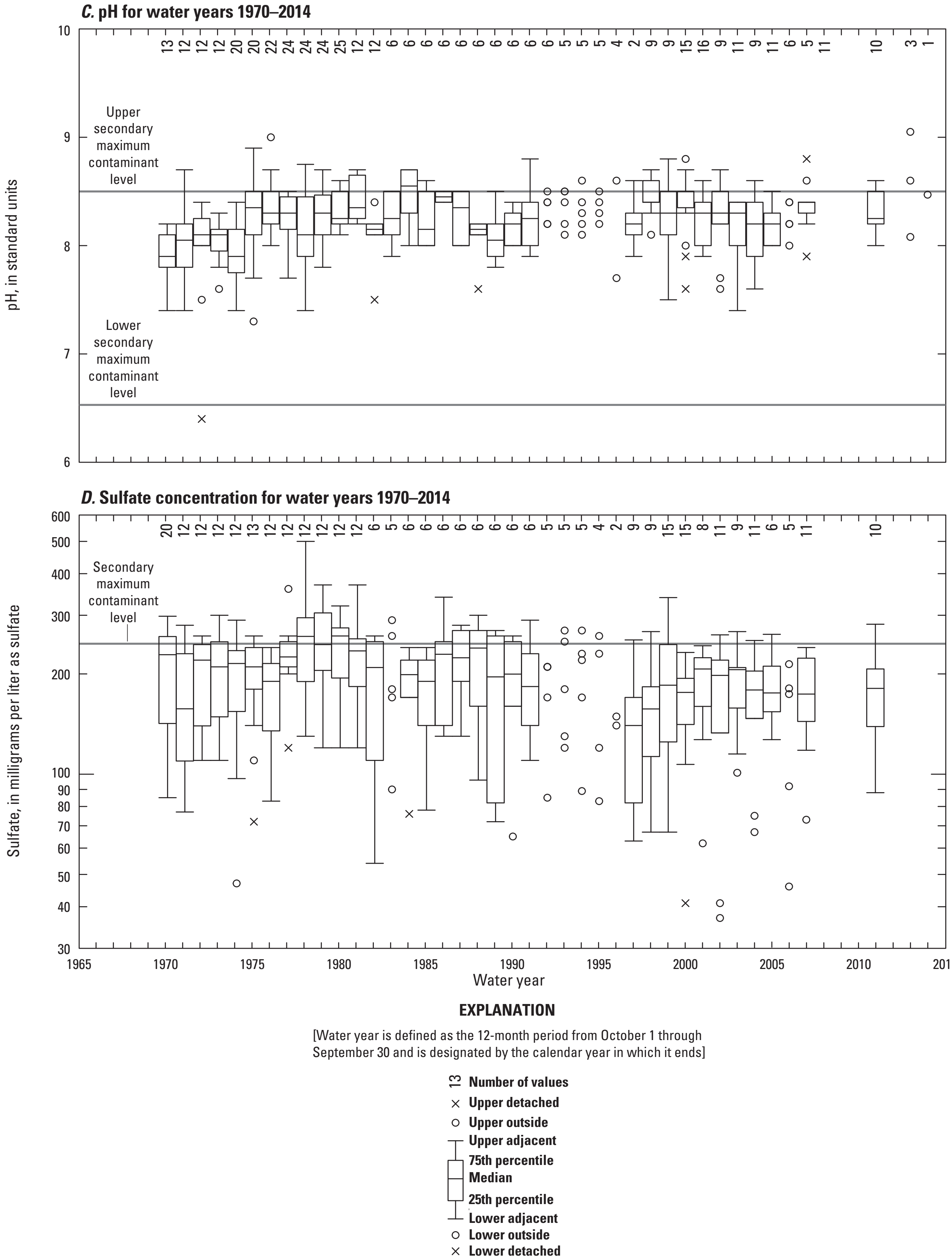


Figure 36. Annual variability in values of constituents for the Yellowstone River near Sidney, Montana (streamgage 06329500), from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

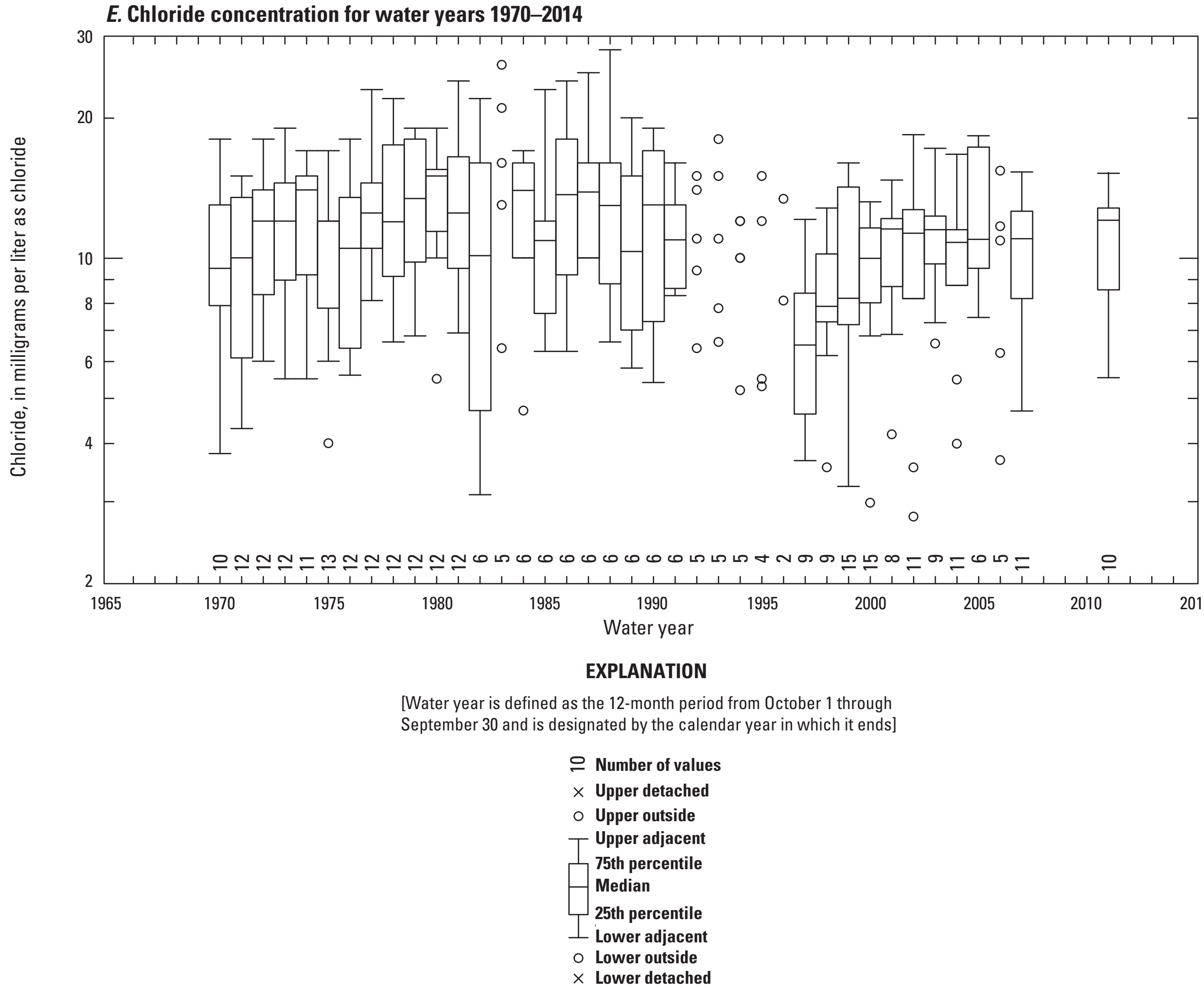


Figure 36. Annual variability in values of constituents for the Yellowstone River near Sidney, Montana (streamgage 06329500), from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

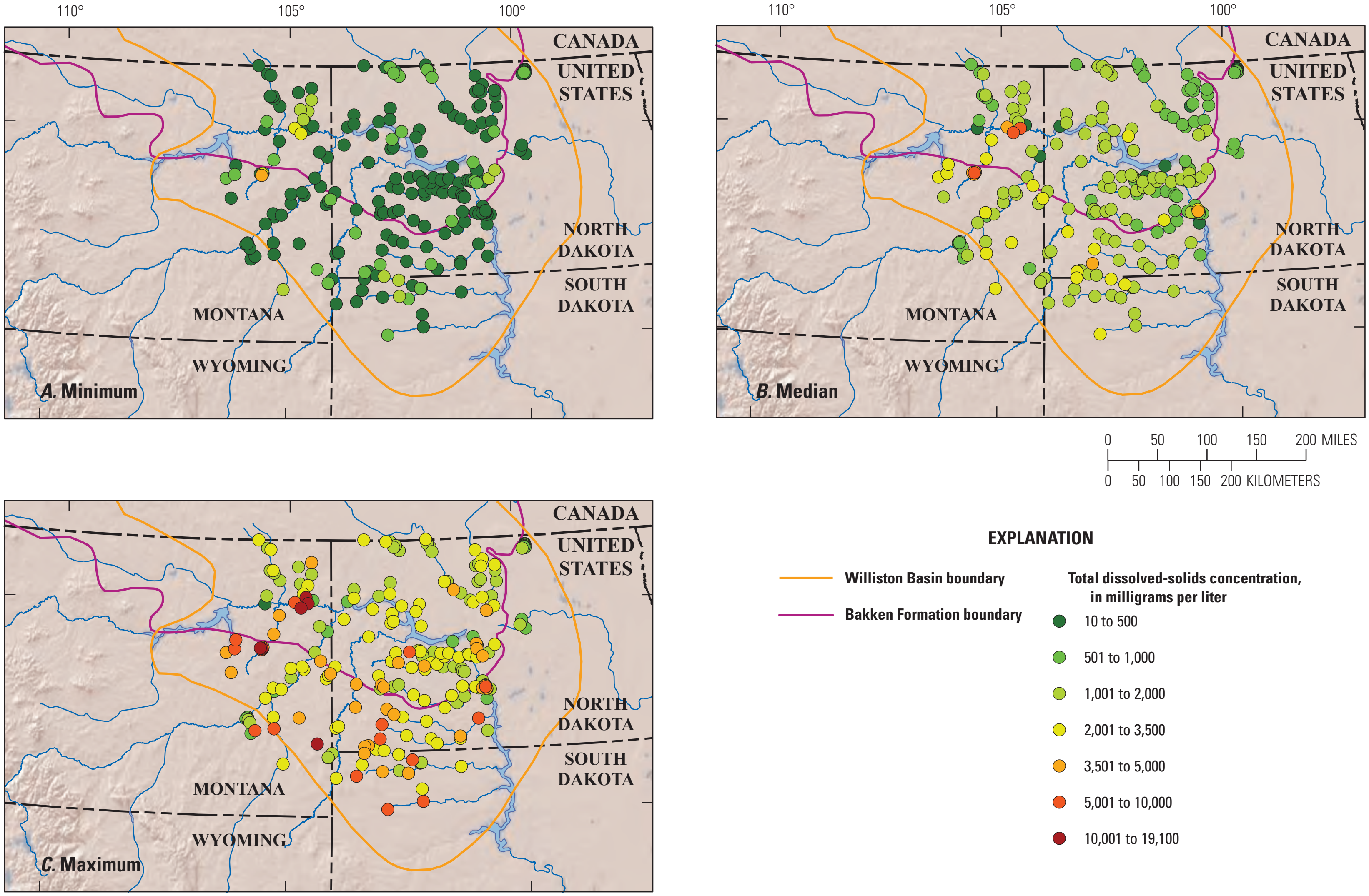


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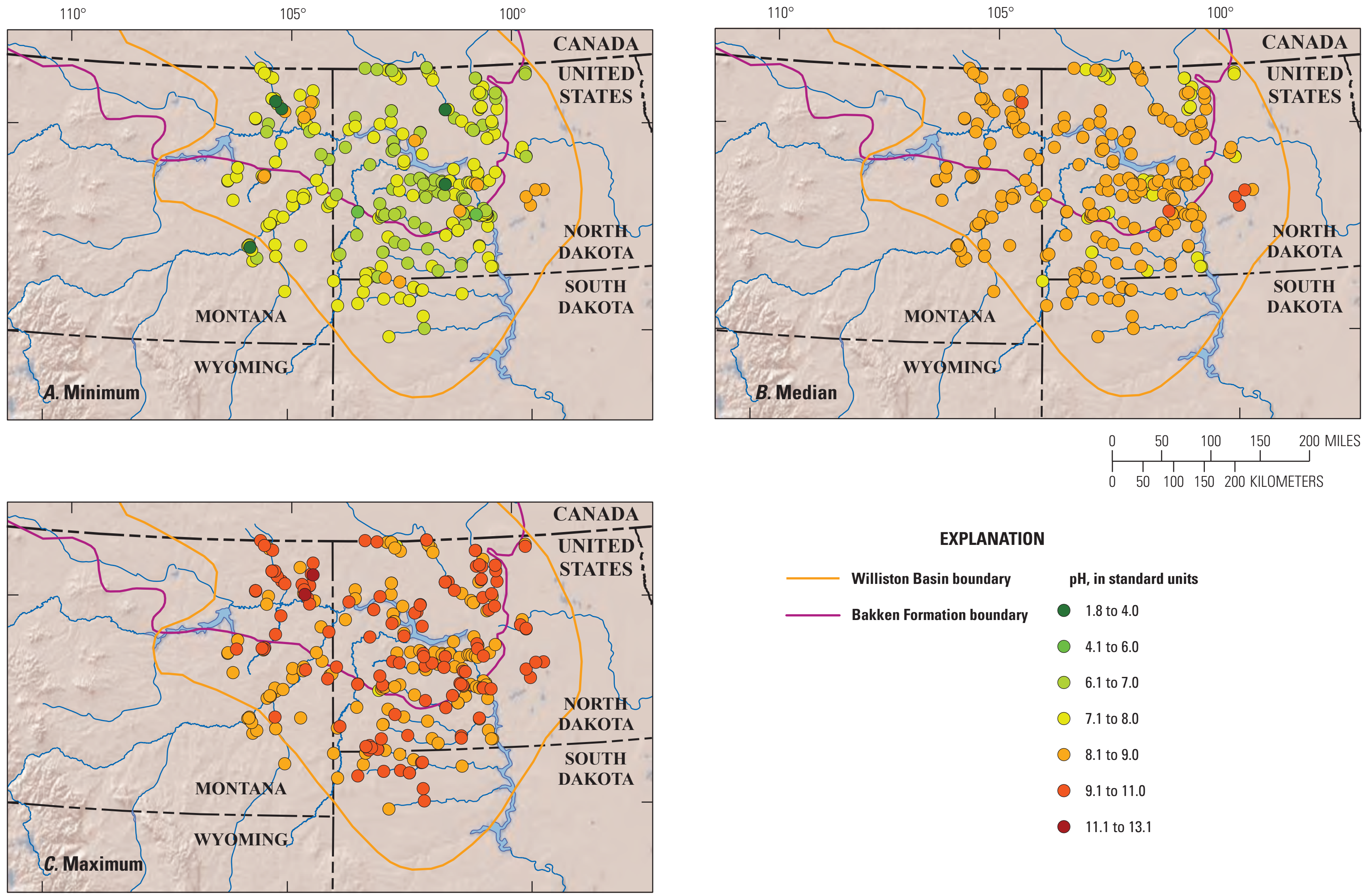
Figure 37. Total dissolved-solids concentrations in streams and rivers in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.



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Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
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Figure 38. pH in streams and rivers in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.

Sulfate was measured at 188 sites in the Williston Basin, and concentrations ranged from 5 to 7,900 mg/L (Boughton and others, 2022, table 3–19). In general, median sulfate concentrations were greater in the western part of the basin and less in the eastern part of the basin (fig. 39*B*). Sulfate concentrations also were modeled in a previous study (Galloway and Vecchia, 2014), and concentrations generally were highest (greater than 750 mg/L) in HUC–8 watersheds in eastern Montana and western North Dakota. Median sulfate concentrations for all sites and years were between 150 and 650 mg/L (fig. 35*D*). Median sulfate concentrations exceeded the EPA SMCL of 250 mg/L at 147 out of 188 sites (78 percent). Since 1978, about one-half of the median sulfate concentrations exceeded the EPA SMCL of 250 mg/L (EPA, 2009, 2012). Minimum sulfate concentrations reported for 21 of the 188 sites (11 percent) were equal to or greater than the EPA SMCL of 250 mg/L; generally, these samples were collected during storm events (Boughton and others, 2022, table 3–19). The annual median sulfate concentrations for Yellowstone River near Sidney, Mont. (streamgage 06329500), generally were between 150 and 250 mg/L from 1970 to 2014 (fig. 36*D*).

Chloride was measured at 214 sites in the Williston Basin, and concentrations ranged from 0.1 to 516 mg/L (Boughton and others, 2022, table 3–20). While the maximum chloride concentrations at seven sites were greater than 250 mg/L, the median chloride concentrations for all sites in the basin were less than the EPA SMCL (fig. 40*B*). The median chloride concentrations across all years ranged from 7 to 30 mg/L (fig. 35*E*). The median chloride concentrations at streamgage 06329500 ranged from 6.5 to 15 mg/L (fig. 36*E*).

Trace metal analyses available for stream and river samples consist of both dissolved and total fractions, but data are presented, and summary statistics are computed, for trace metal concentrations in the dissolved fraction and reported in micrograms per liter (table 9; Boughton and others, 2022, table 3–21). Similarly, samples were analyzed for a wide variety of trace metals, but only information regarding the concentrations of aluminum, arsenic, barium, chromium, copper, iron, lead, selenium, strontium, and zinc are presented in this section (table 9).

Water Quality of Lakes and Reservoirs

At least one of the five commonly monitored constituents was included in analyses from 839 lake sites sampled in the Williston Basin from 1970 through 2014 by six State agencies (NDDH, NDSWC, MDEQ, MBMG, SDDENR, and South Dakota Geological Survey), the Native American Tribes with land holdings in the basin (Assiniboine and Sioux Tribes of the Fort Peck Indian Reservations, Three Affiliated Tribes [Mandan, Hidatsa, and Arikara Nation] of the Fort Berthold Indian Reservation, and Turtle Mountain Band of Chippewa Indians of North Dakota), and three Federal agencies (USACE, EPA, and USGS) (Boughton and others, 2022, table 3–7). Figure 41 shows the distribution of lake and reservoir samples analyzed for specific conductance compared to the number of oil and gas wells by HUC–8 watersheds. Because of the importance of Lake Sakakawea for recreation, four sites in the lake were selected to characterize the water quality and compare with data collected from other sites in the Williston Basin (fig. 42). Physical properties such as temperature, dissolved oxygen, pH, and specific conductance had been collected at these four sites since the 1970s. Chemical constituents had been analyzed periodically at some of these sites since the 1980s, but consistent data collection for these four sites did not begin until 1993. Data from the WQP and NAWQA project's data compilation for the five commonly monitored constituents were supplemented with data collected from the USACE and NDDH (NDDH, 2015) for these four sites because a complete dataset for these sites was not available from the WQP and the NAWQA project's data compilation. Summary statistics for the five commonly monitored constituents at the selected sites on Lake Sakakawea are available in a data release (Boughton and others, 2022, tables 3–27 to 3–31).

Similar to rivers and streams, lakes and reservoirs in the Williston Basin with the greatest number of sites sampled and samples collected are not necessarily near the greatest number of oil and gas wells (fig. 41) as evidenced by the spatial distribution of samples for which specific conductance was measured. Specific conductance was one of the five most commonly monitored constituents in lakes and reservoirs, with the largest number and greatest spatial distribution of samples analyzed. The HUC–8 watershed with second highest number of oil and gas wells (10100004; fig. 41) has few sampling sites and typically less than 10 samples collected per site. The HUC–8 watersheds containing the most oil and gas wells generally have few lakes and lake sampling sites, and few samples per site; however, the HUC–8 watershed containing Lake Sakakawea (10110101) has 10,667 oil and gas wells, several sampling sites along Lake Sakakawea, and several sites with analytical results from more than 50 samples (fig. 41).

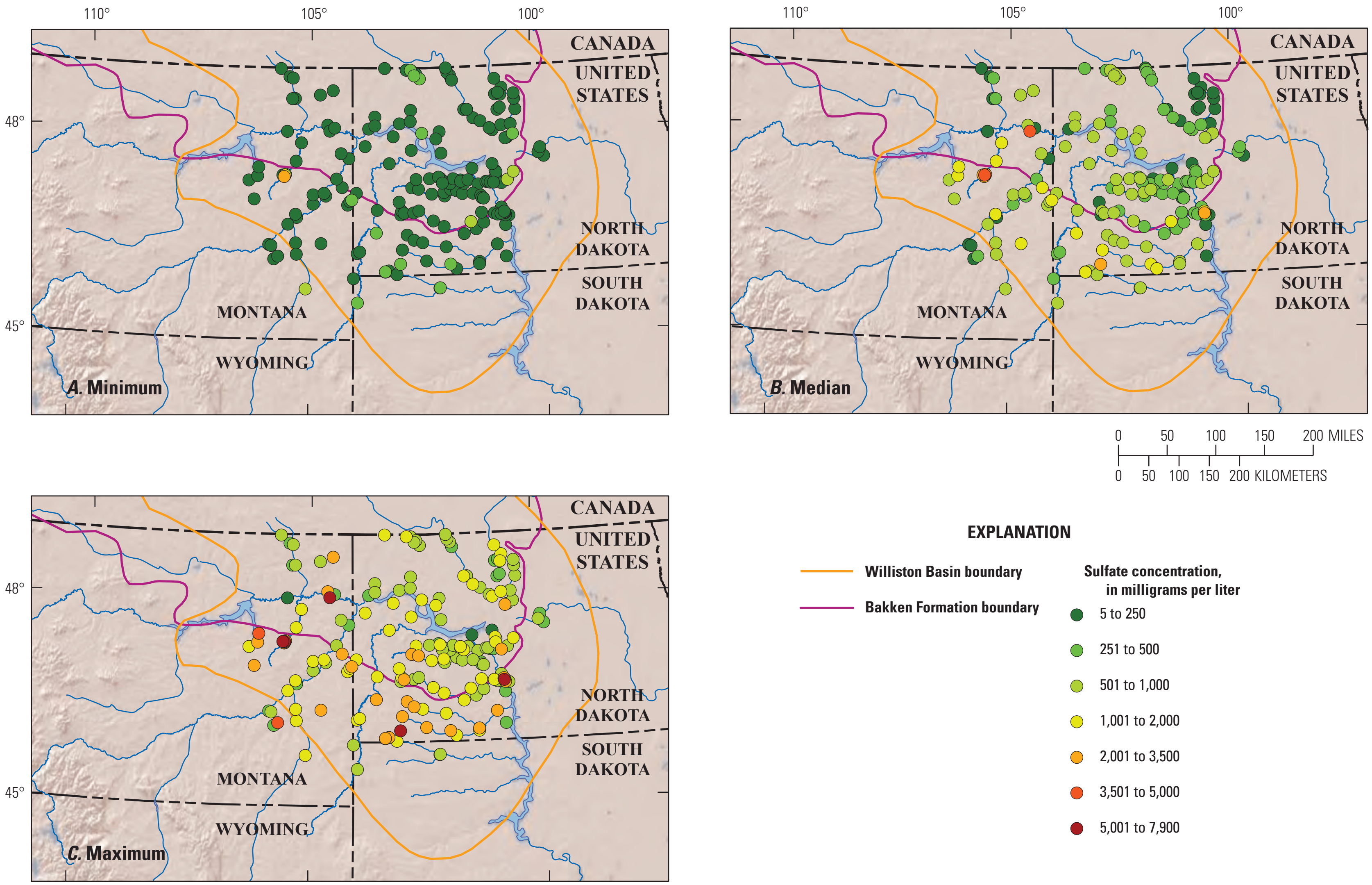

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Figure 39. Sulfate concentrations in streams and rivers in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.

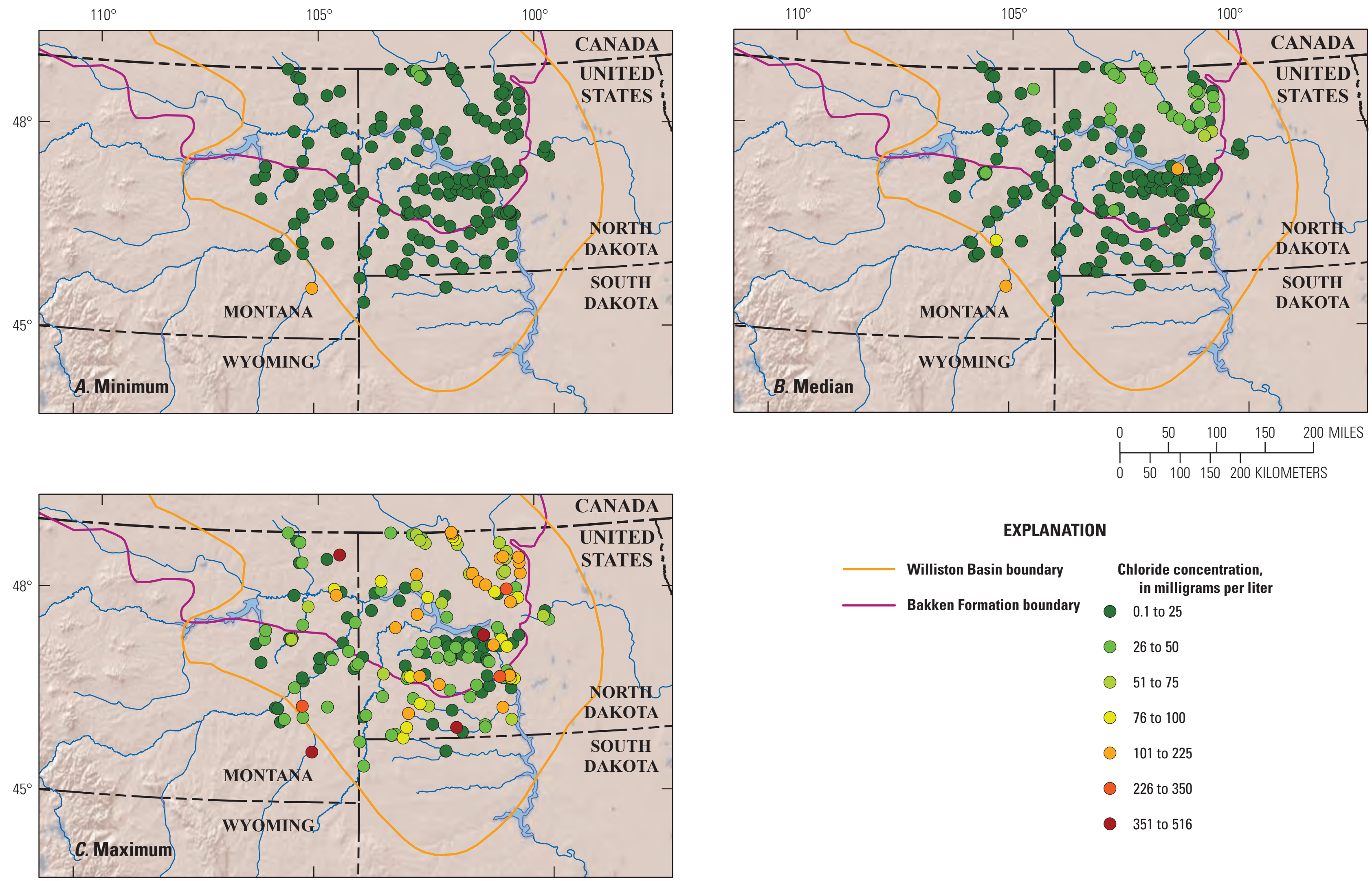

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Figure 40. Chloride concentrations in streams and rivers in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.

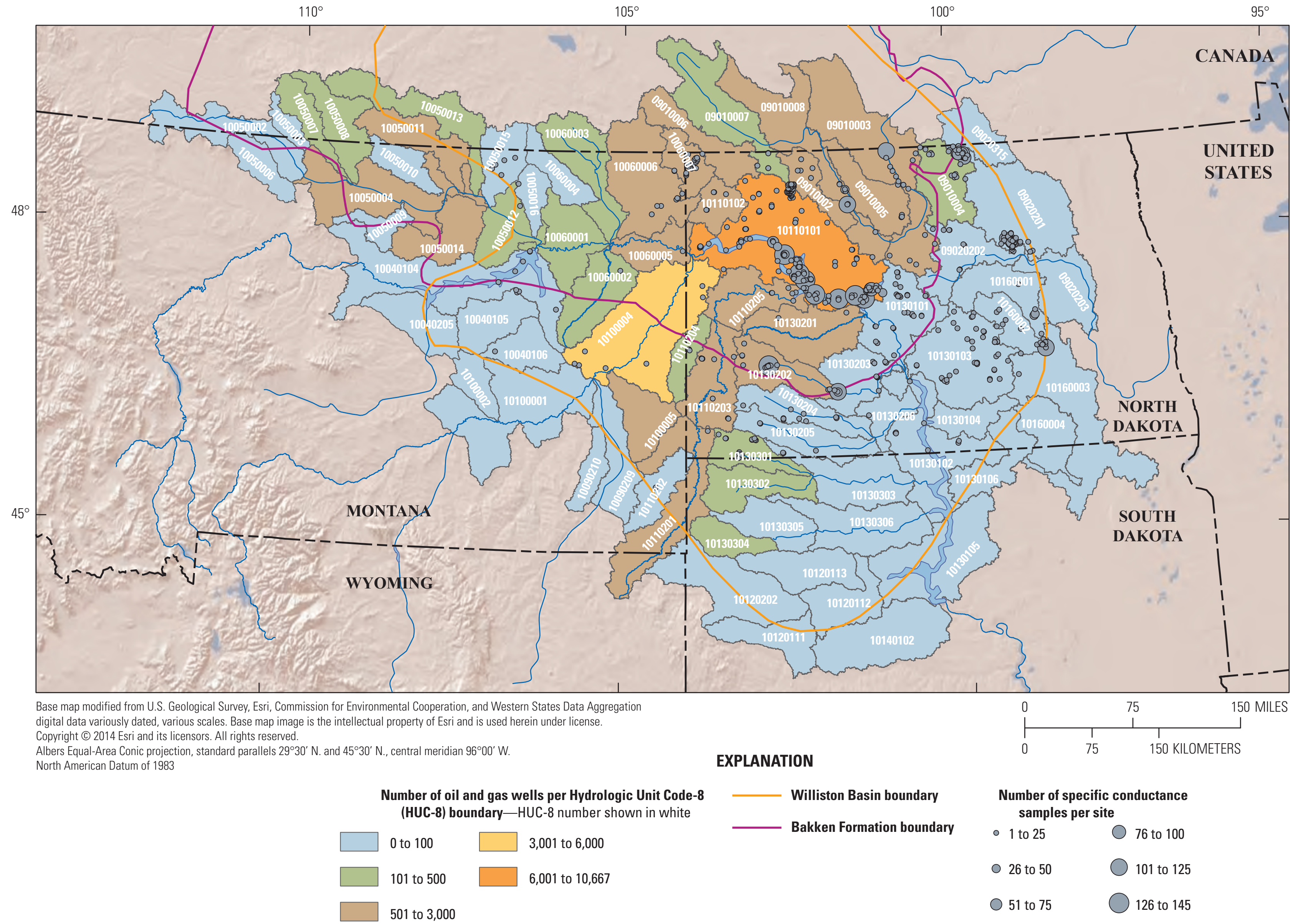


Figure 41. Spatial distribution of specific conductance samples from lakes and reservoirs and numbers of oil and gas wells in hydrologic unit code-8 (HUC-8) watersheds in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014.

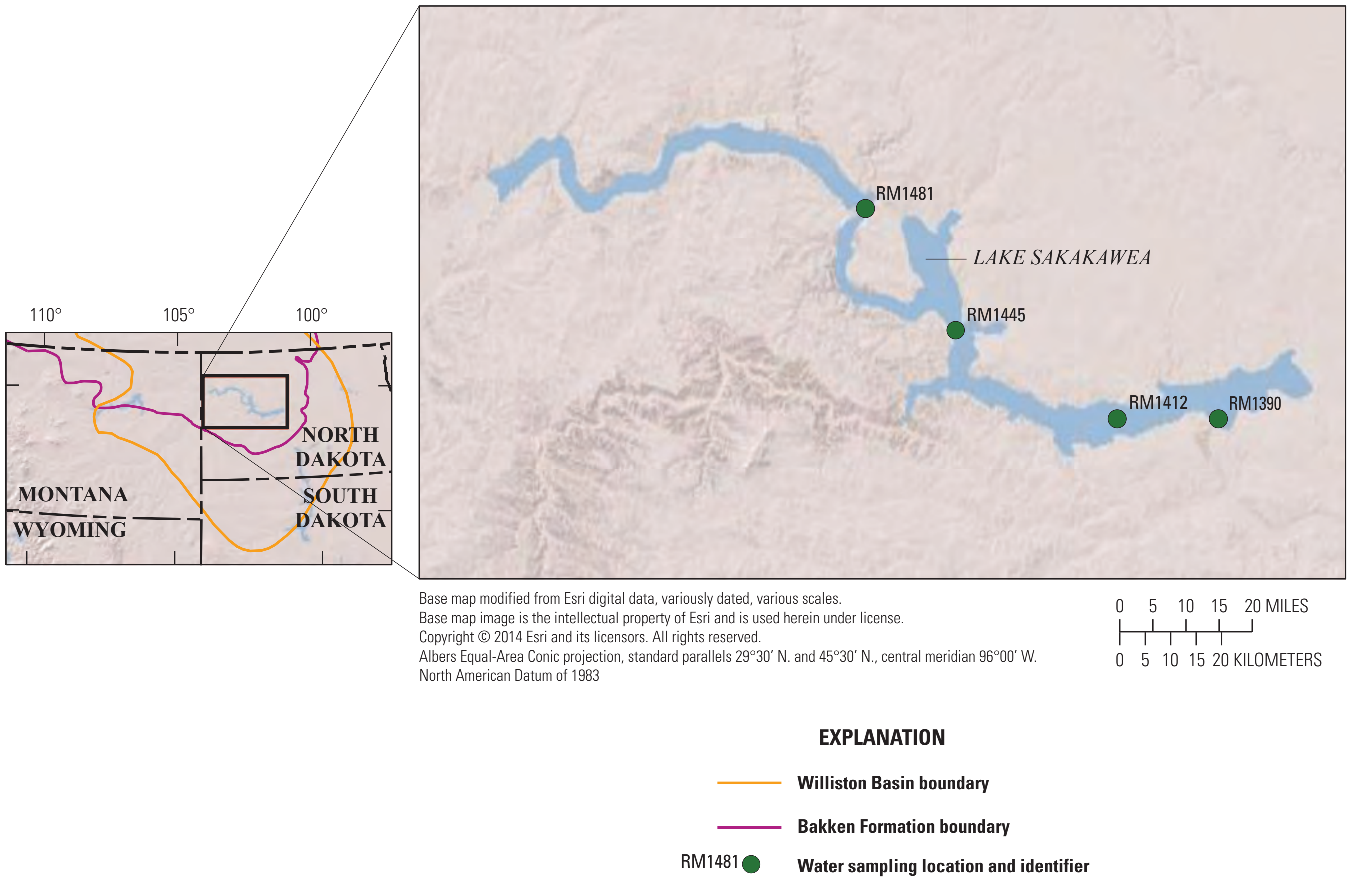


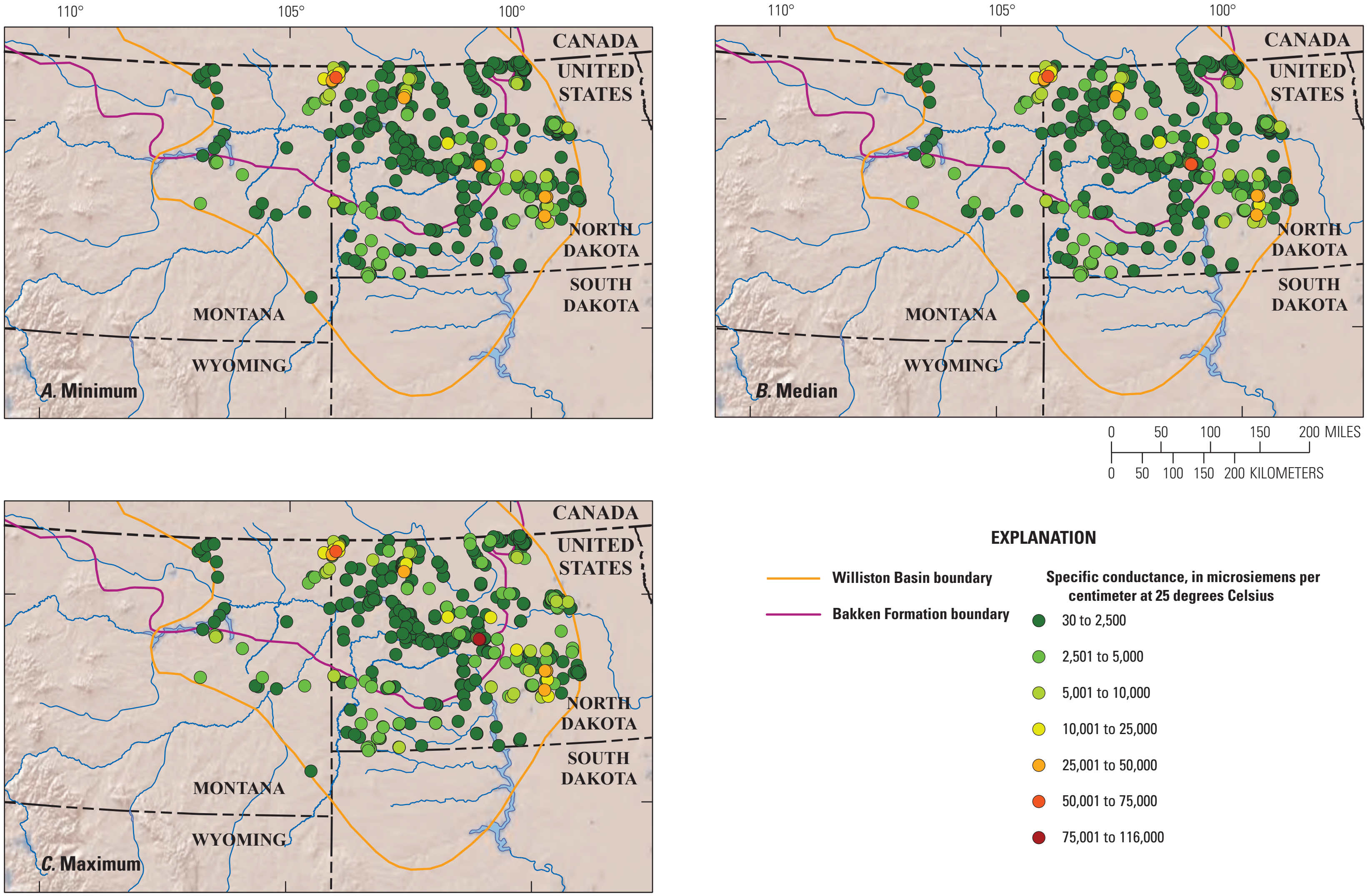
Figure 42. Location of select water-quality sites on Lake Sakakawea sampled from 1993 to 2014.

Across the Williston Basin, specific conductance was measured in lake and reservoir samples from 568 sites from 1970 to 2014 (Boughton and others, 2022, table 3–22). Of the 568 lake sites sampled across the area, 453 sites had fewer than 10 samples (Boughton and others, 2022, table 3–22). Specific conductance was spatially variable for all sites across the Williston Basin (fig. 43). Specific conductance ranged from 30 to 116,000 µS/cm (Boughton and others, 2022, table 3–22), which is consistent with other values reported for lakes and wetlands of the Williston Basin (Gorham and others, 1983; Swanson and others, 1988; Euliss and Mushet, 2004; Tangen and others, 2013; figs. 43, 44*A*). In comparison to other sampling sites in the Williston Basin as a whole, measured specific conductance for the four selected sites on Lake Sakakawea was much less variable, ranging from 339 µS/cm in 2006 to 839 µS/cm in 2012 (fig. 45*A*, Boughton and others, 2022, table 3–27). An area of higher median specific conductance generally is along the northern border of Montana and North Dakota (fig. 43). A closer inspection of the dataset indicates the high median values in this area are a group of 19 sites that were sampled once in October of 1983 (Boughton and others, 2022, table 3–22). A specific conductance value of 116,000 µS/cm was measured in a sample collected in 1990 (fig. 44*A*; Boughton and others, 2022, table 3–22). The sample was collected in an area with no oil or gas wells present (figs. 41, 43*C*), indicating the elevated specific conductance likely was not due to energy development in the immediate area. Two samples collected in 1990 were the highest median and maximum specific conductance values measured in the Williston Basin from 1970 to 2014 (dark red dots in figs. 43*B* and 43*C*, respectively). These high specific conductance measurements are outliers in the boxplots of specific conductance for 1990 (fig. 44*A*).

Even though the range and variability of median specific conductance is substantially less in Lake Sakakawea than for the Williston Basin as a whole, temporal and spatial variability is still present and can primarily be attributed to changes in lake elevation and the effects of inflows and evaporation, respectively (figs. 45*A*, 46). Depending on lake elevation, retention time in Lake Sakakawea ranges from 0.32 year (elevation of 1,775 ft) to 1.54 years (elevation of 1,855 ft; USACE, 2008). Longer retention time of water in the lake results in increased surface-water evaporation from the lake, resulting in elevated TDS and specific conductance. The highest median specific conductance of 757 µS/cm was measured in 2013, and the lowest median specific conductance of 572 µS/cm was measured in 2009 after a 17-ft increase in lake elevation from 2008 to 2009 (figs. 45*A*, 46). Initially, the increase in lake elevation contributed fresher water, but once a higher elevation was reached, the longer retention time contributed to higher specific conductance values in subsequent years (fig. 45*A*). The highest median specific conductance was measured in 2013, which was associated with a period of higher lake elevation followed by a period with a decrease in lake elevation (fig. 46). Spatially, median specific conductance increases slightly from upstream to downstream in Lake Sakakawea, ranging from 568 µS/cm at the upstream end to 644 µS/cm at the downstream end of the reservoir (sites RM1481 and RM1390, respectively; fig. 47*A*). The variability of specific conductance at individual sites decreases from upstream to downstream (fig. 47*A*). Variability in specific conductance is smallest (ranging from 546 to 783 µS/cm) at the most downstream site at RM1390 and largest (ranging from 339 to 839 µS/cm) at the most upstream site at RM1481 (fig. 47*A*; Boughton and others, 2022, table 3–27).

Similar to specific conductance, TDS concentrations varied spatially across the Williston Basin (fig. 48), with the exception of select Lake Sakakawea sites, which had TDS concentrations that were much less variable (fig. 45*B*) than other sites in the basin. TDS was measured at 510 sites in the Williston Basin from 1970 to 2014, and concentrations ranged from 11 mg/L in 1995 to 84,500 mg/L in 1983 (figs. 44*B*, 48; Boughton and others, 2022, table 3–23). In contrast, TDS concentrations in Lake Sakakawea ranged from 211 to 736 mg/L from 1993 to 2014 (fig. 45*B*; Boughton and others, 2022, table 3–28). Of the 510 lake sites sampled across the basin, 384 sites had 10 or fewer samples, and 327 sites had median TDS concentrations that exceeded the EPA SMCL of 500 mg/L (EPA, 2009, 2012; Boughton and others, 2022, table 3–23). Similar to specific conductance, high median TDS concentrations were observed along the northern border of Montana and North Dakota (fig. 48). Consistent with specific conductance, high TDS concentrations were measured in samples collected at sites in the Williston Basin in 1983 (fig. 44*B*).

Within Lake Sakakawea, the same general spatial patterns observed for specific conductance values were observed for TDS concentrations (fig. 45*B*). The highest median TDS concentration of 646 mg/L was measured in 2013, and the lowest median specific conductance of 346 mg/L was measured in 2010 (fig. 45*B*). Generally, before 2010 TDS concentrations did not exceed the 500 mg/L EPA SMCL. Beginning in 2012, median TDS concentrations exceeded the 500 mg/L EPA SMCL. Spatially, median TDS concentrations increase from upstream at RM1481 (364 mg/L) to downstream at RM1390 (406 mg/L), and the variability of specific conductance at an individual site decreases from upstream to downstream (fig. 47*B*). Variability in TDS is smallest (ranging from 276 to 708 mg/L) at the most downstream site RM1390), and largest (ranging from 211 to 736 mg/L) at the most upstream site (RM1481; Boughton and others, 2022, table 3–28).



Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

Figure 43. Specific conductance in lakes in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.

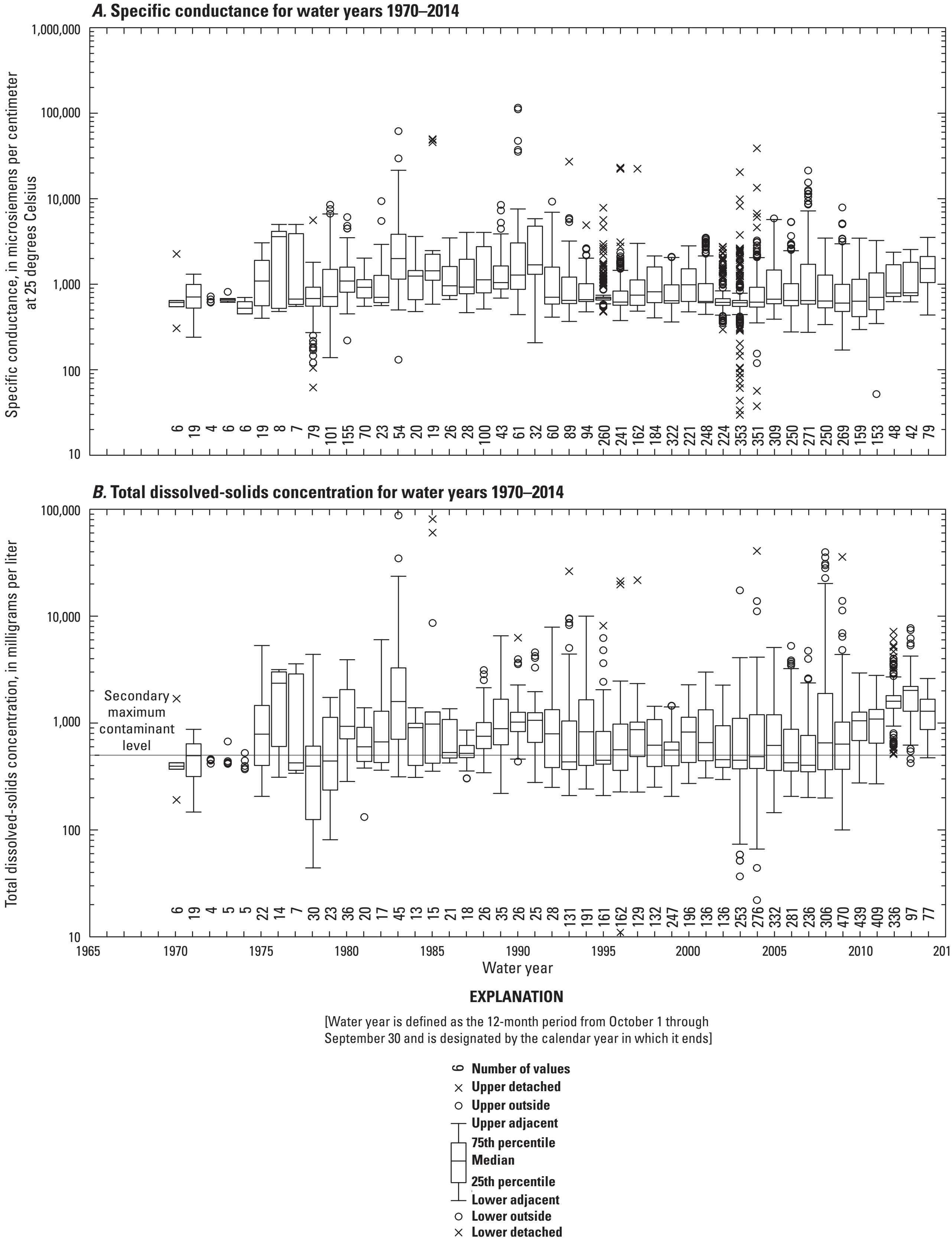


Figure 44. Annual variability in values of constituents in all lakes across the Willison Basin by year from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.

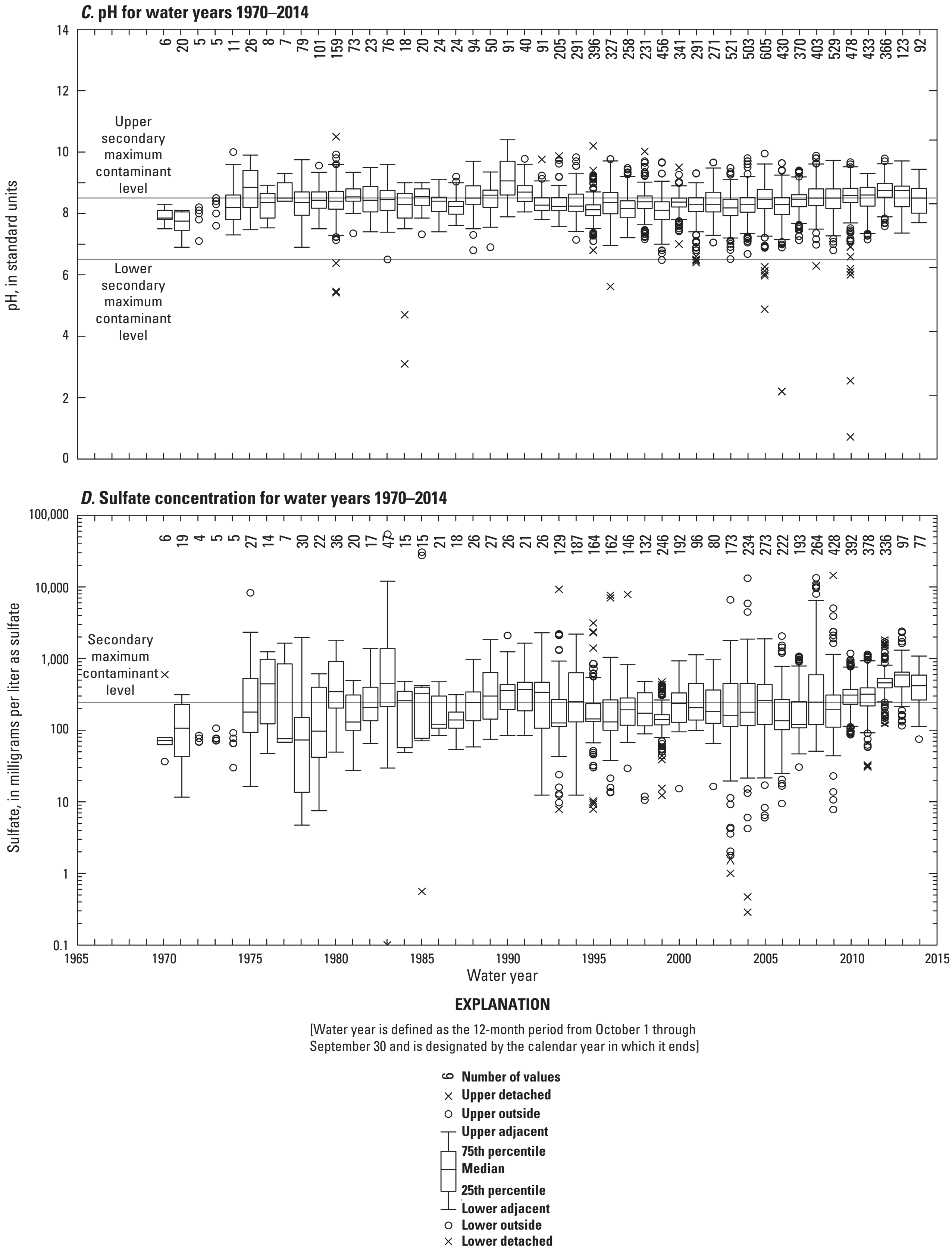
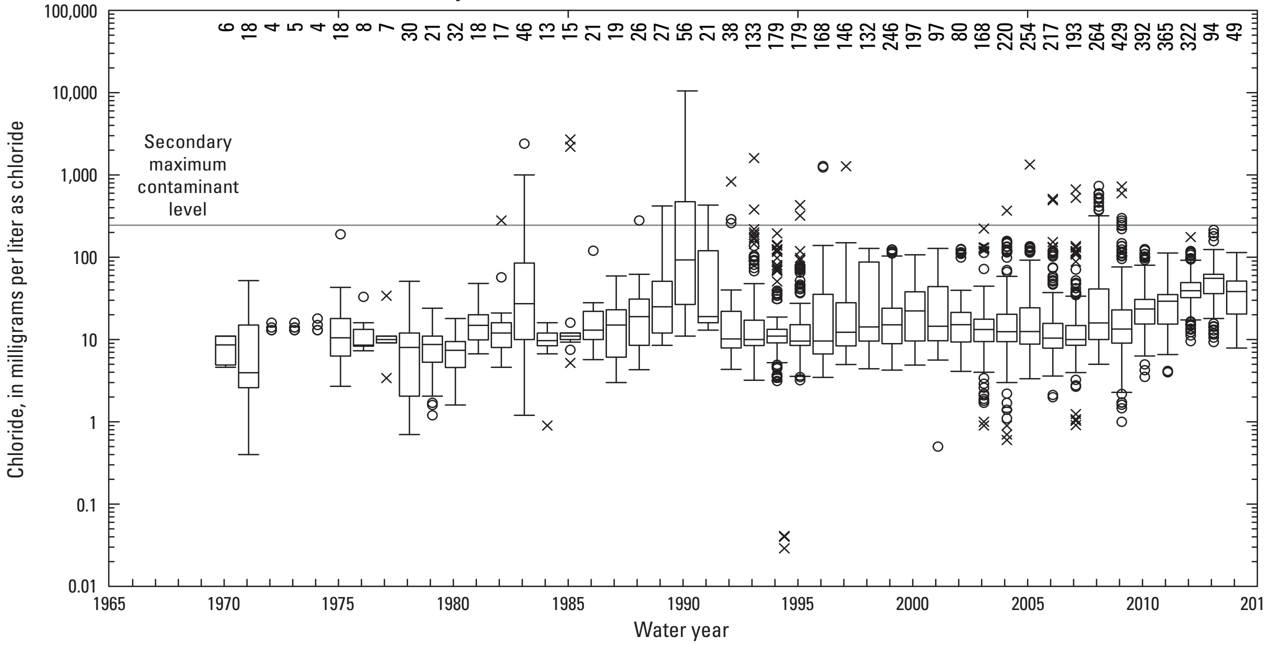


Figure 44. Annual variability in values of constituents in all lakes across the Willison Basin by year from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

E. **Chloride concentration for water years 1970–2014**



EXPLANATION

[Water year is defined as the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends]

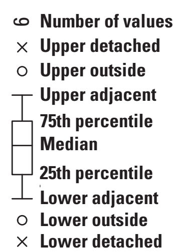


Figure 44. Annual variability in values of constituents in all lakes across the Willison Basin by year from 1970 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.—Continued

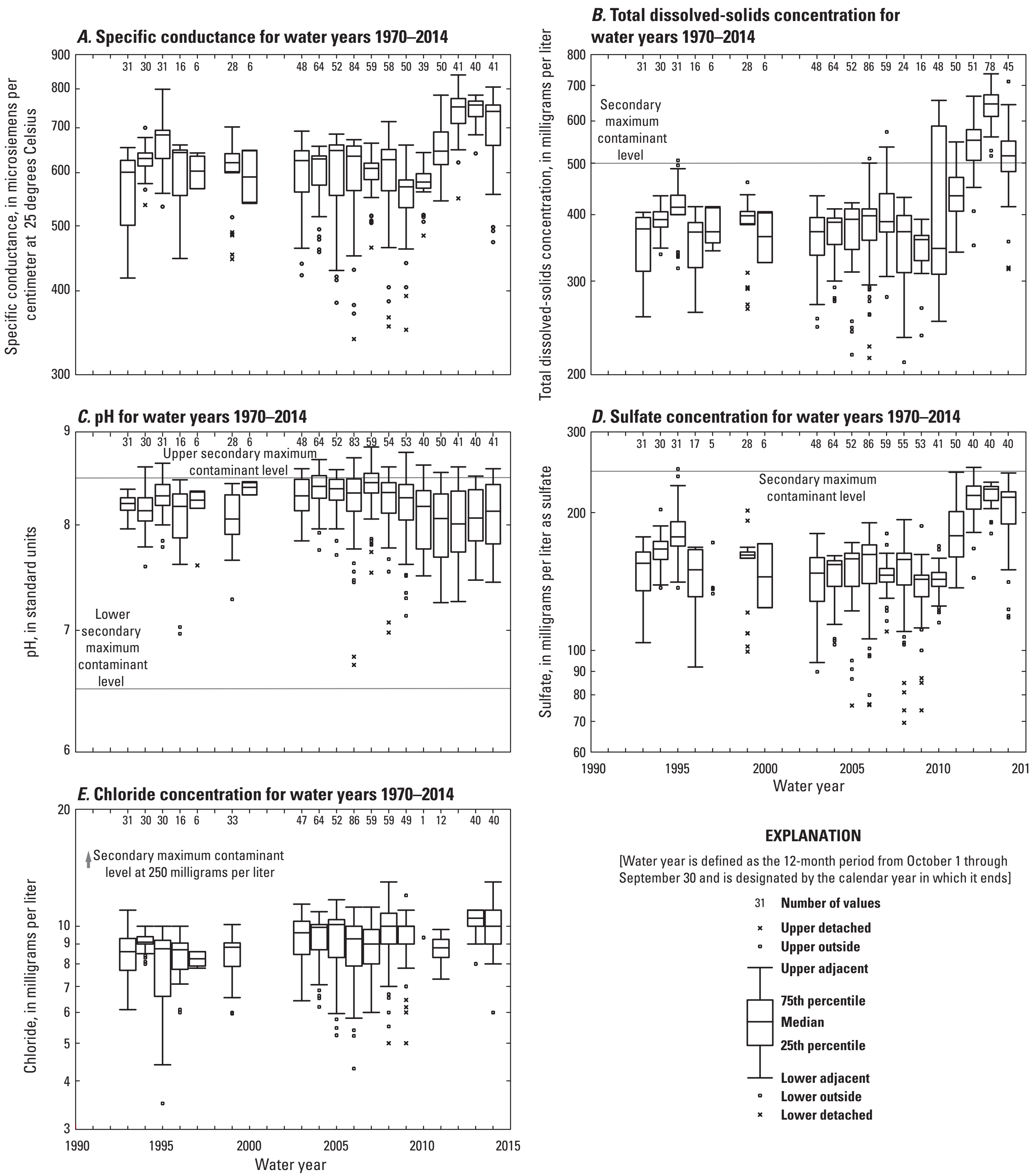


Figure 45. Annual variability in values of constituents in Lake Sakakawea by year from 1993 to 2014. *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter.

Values of pH varied spatially for sites across the Williston Basin (fig. 49), whereas pH variability was minimal for four select Lake Sakakawea sites (fig. 45*C*). Across the Williston Basin, pH was measured at 714 sites from 1970 to 2014 (Boughton and others, 2022, table 3–24). For most years, median pH values were within the EPA SMCL of 6.5 to 8.5 standard units (fig. 44*C*). At the four Lake Sakakawea sites, pH was consistently greater than 6.5 standard units, and 14 percent of the pH values exceeded the upper EPA SMCL of 8.5 standard units (fig. 47*C*). Of the 714 lake sites sampled across the basin, 528 sites had fewer than 10 samples (Boughton and others, 2022, table 3–24). An area of higher median pH was observed along the northern border of Montana and North Dakota (fig. 49). Similar to specific conductance and TDS, these samples were collected in 1983 as part of a special study (Boughton and others, 2022, table 3–24). Another area of high median pH was observed in Montana associated with a sample collected in 1990, which was the highest median concentration for the period (fig. 44*C*). Measured pH values in Lake Sakakawea varied minimally, both temporally and longitudinally (figs. 45*C*, 47*C;* Boughton and others, 2022, table 3–29). Median pH values in Lake Sakakawea ranged from 8.1 standard units in 2010 to 8.5 standard units in 2007 (fig. 45*C*; Boughton and others, 2022). Longitudinally, median pH values in Lake Sakakawea were consistently about 8.3 standard units (fig. 47*C*).

Similar to specific conductance and TDS, sulfate concentrations measured at sites across the Williston Basin were spatially variable (fig. 50), while sulfate concentrations measured at select Lake Sakakawea sites were much less variable (fig. 45*D*). Sulfate was measured at 474 sites in the Williston Basin from 1970 to 2014, and concentrations ranged from 0.1 to 54,000 mg/L (Boughton and others, 2022, table 3–25). In contrast, sulfate concentrations measured at four Lake Sakakawea sites from 1993 to 2014 ranged from 70 to 251 mg/L (Boughton and others, 2022, table 3–30). Of the 474 lake sites sampled across the basin, 351 sites had fewer than 10 samples, and 267 sites had median sulfate concentrations that exceeded the EPA SMCL of 250 mg/L (EPA, 2009, 2012; Boughton and others, 2022, table 3–25). Consistent with specific conductance and total dissolved solids, high median sulfate concentrations were measured in samples along the northern border of Montana and North Dakota collected at several sites as part of a special project in 1983 (figs. 44*D*, 50). The highest single sulfate concentration measured in the Williston Basin was 54,000 mg/L, and this sample was collected from a site associated with this project. Also consistent with specific conductance and TDS, high sulfate concentrations measured at this group of sites resulted in a higher median value in the Williston Basin in 1983 (fig. 44*D*).

Similar temporal and spatial patterns observed for specific conductance values and TDS concentrations were observed for sulfate concentrations within Lake Sakakawea. The highest median sulfate concentration of 225 mg/L was measured in 2013, and the lowest median sulfate concentration of 143 mg/L was measured in 2010 (fig. 45*D*). While an individual measurement at RM1481 (251 mg/L) exceeded 250 mg/L EPA SMCL, the median sulfate concentrations for Lake Sakakawea did not exceed the SMCL from 1993 through 2014. Spatially, median sulfate concentrations increase from upstream at RM1481 (142 mg/L) to downstream at RM1390 (163 mg/L), and the variability of sulfate concentrations at an individual site decreases from upstream to downstream (fig. 47*D*). Variability in sulfate concentrations is smallest (ranging from 121 to 230 mg/L) at the most downstream site (RM1390) and largest (ranging from 70 to 251 mg/L) at the most upstream site (RM1481; fig. 47*D*; Boughton and others, 2022, table 3–30).

Chloride concentrations at sites across the Williston Basin were spatially variable (fig. 51), whereas chloride concentrations at select Lake Sakakawea sites were much less variable (fig. 45*E*). Chloride concentrations measured at 489 sites in the basin from 1970 through 2014 ranged from 0.4 to 10,500 mg/L (Boughton and others, 2022, table 3–26). In contrast, chloride concentrations at four Lake Sakakawea sites ranged from 3.5 to 13 mg/L from 1993 through 2014 (Boughton and others, 2022, table 3–31). Of the 489 lake sites sampled across the basin, 366 sites had fewer than 10 samples, and 36 sites had median chloride concentrations that exceeded the EPA SMCL of 250 mg/L (EPA, 2009, 2012). Samples collected for special projects in 1983 and 1990 identified an area of high median chloride concentrations along the northern border of Montana and North Dakota, potentially resulting in higher median concentrations in the basin for both years (figs. 44*E*, 51).

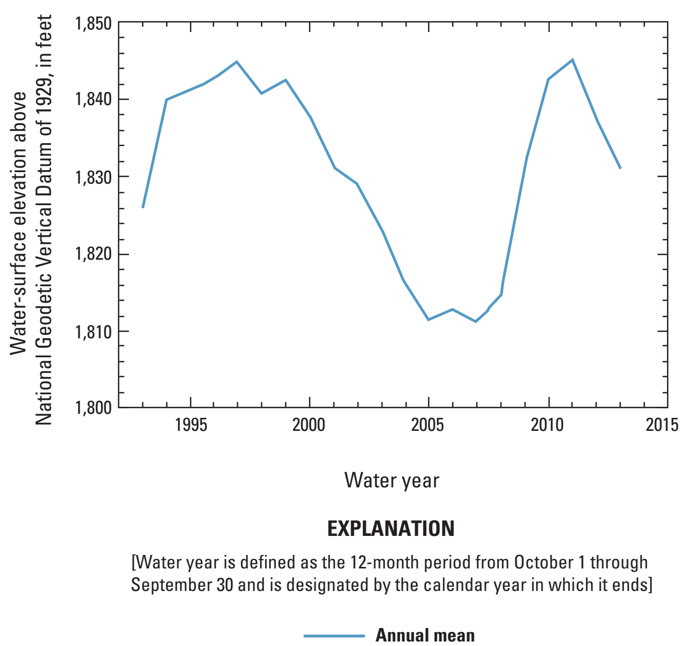


Figure 46. Annual mean water surface elevation in Lake Sakakawea from 1993 to 2014.

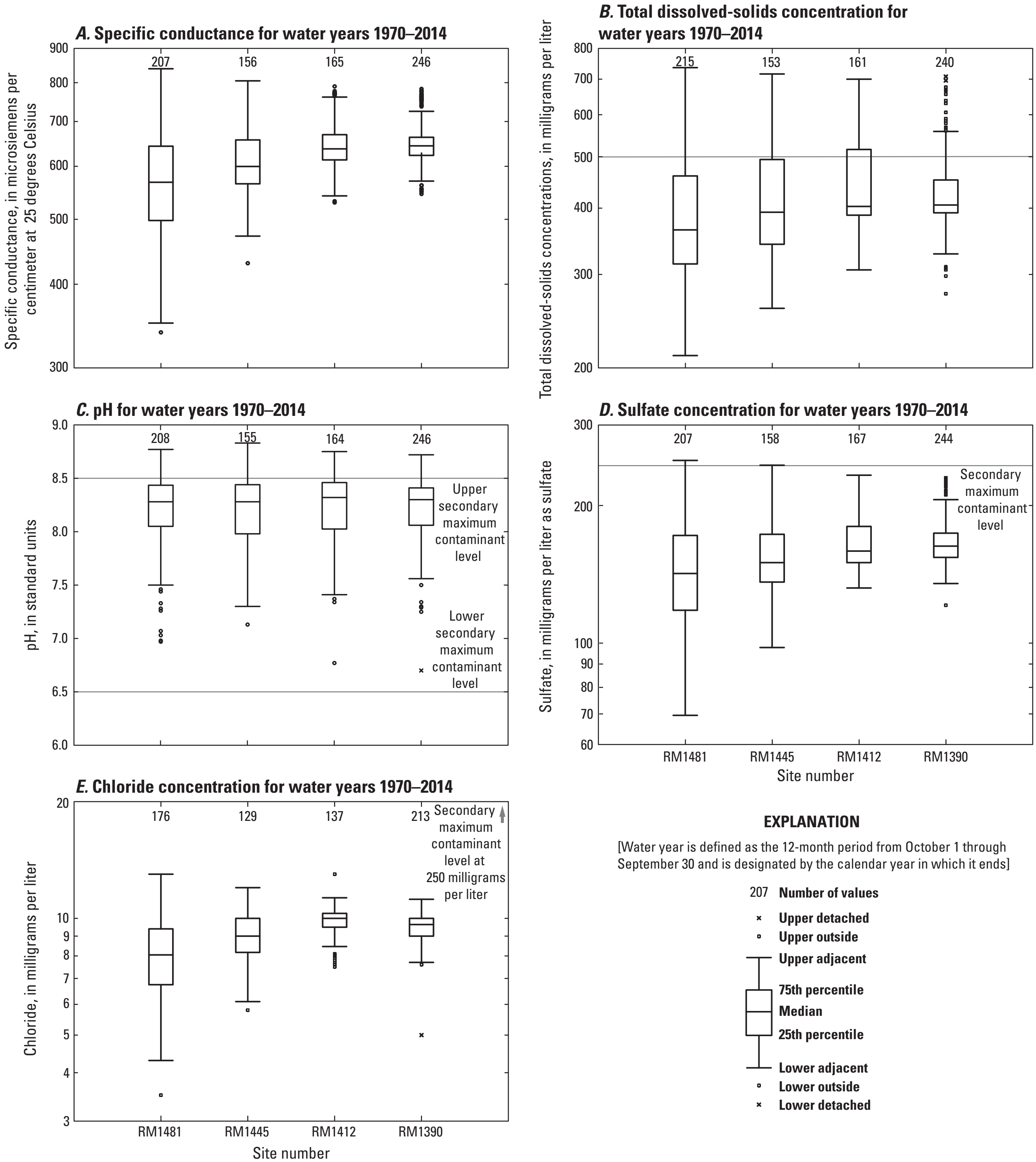
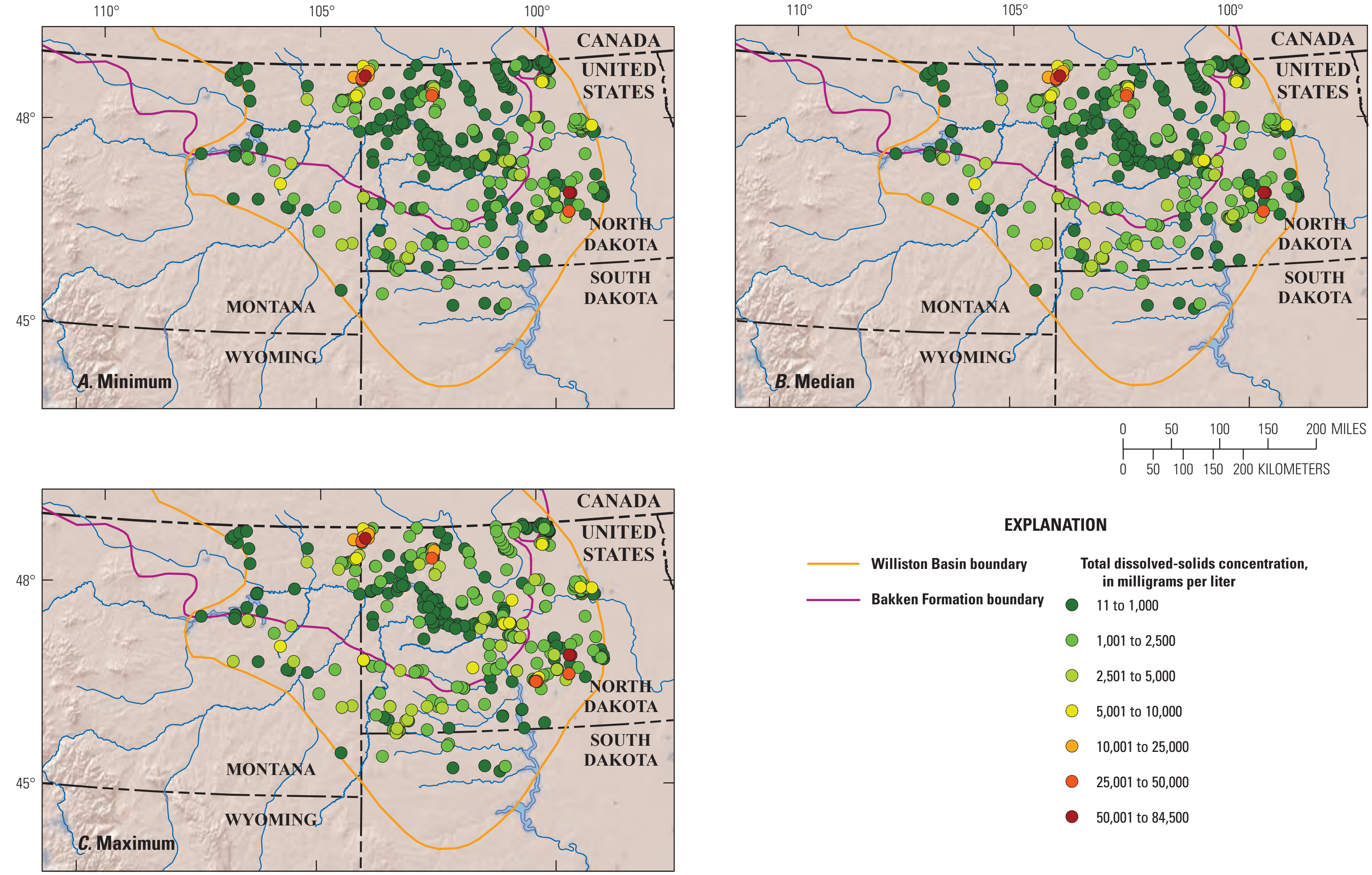


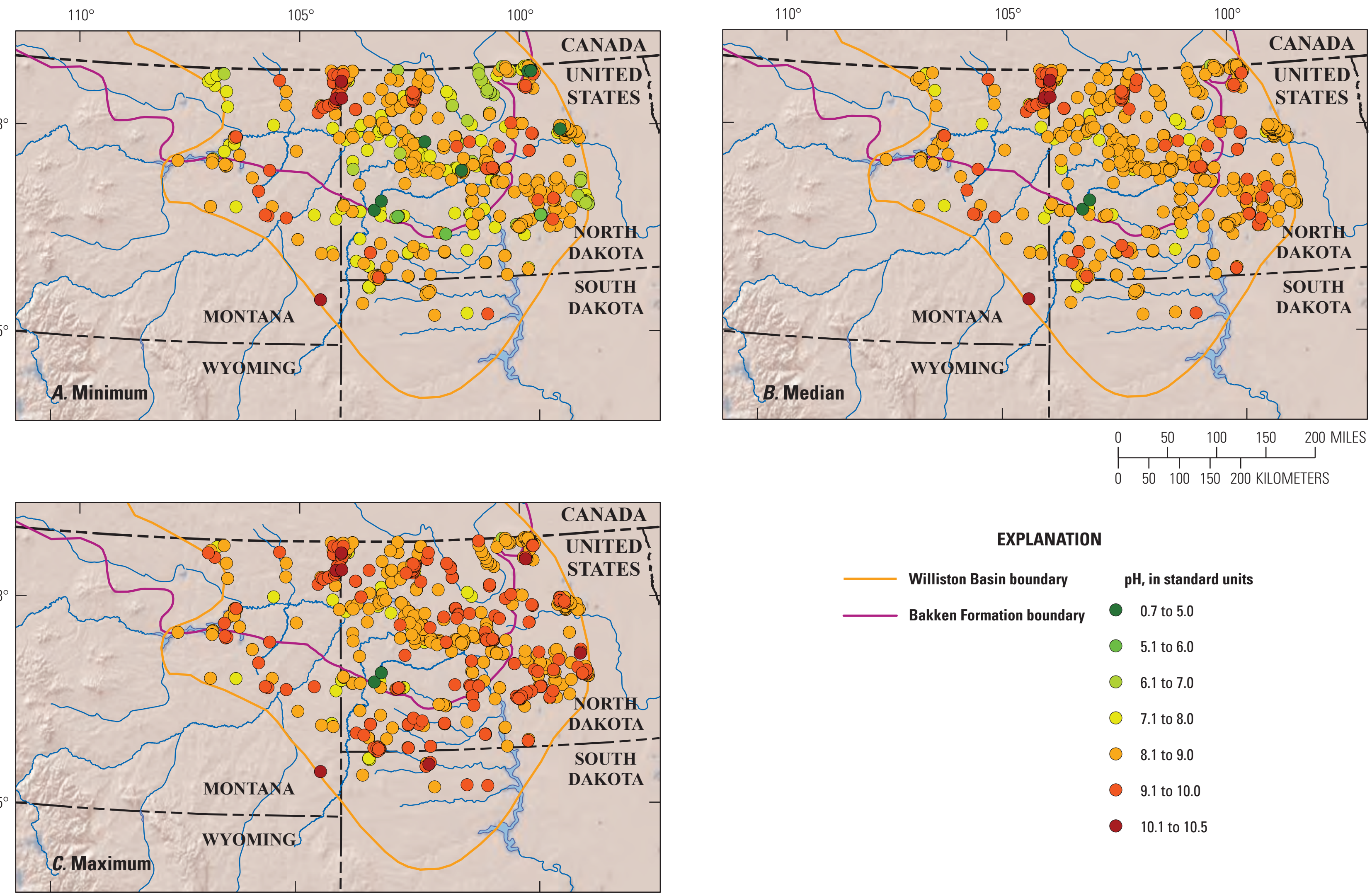
Figure 47. Range and statistical distribution of *A*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; *B*, total dissolved solids, in milligrams per liter; *C*, pH, in standard units; *D*, sulfate, in milligrams per liter; and *E*, chloride, in milligrams per liter, measured at sites in Lake Sakakawea from 1993 to 2014. Sites listed in order from upstream to downstream.



Base map modified from U.S. Geological Survey, Esri, Commission for Environmental Cooperation, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

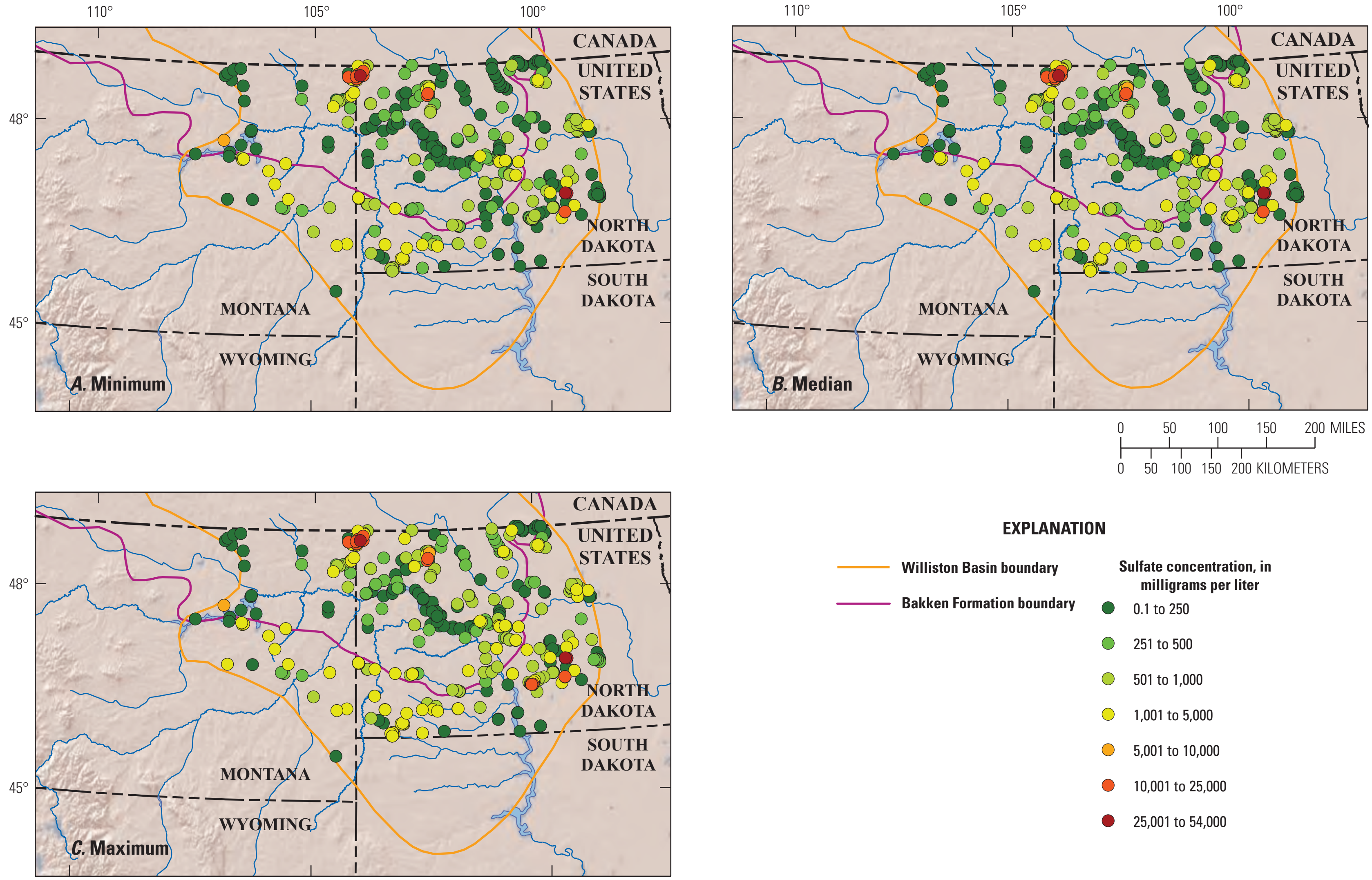
Figure 48. Total dissolved-solids concentrations in lakes in the Williston Basin in Montana, North Dakota, and South Dakota, 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.



Base map modified from U.S. Geological Survey, Esri, Commission for Environmental Cooperation, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

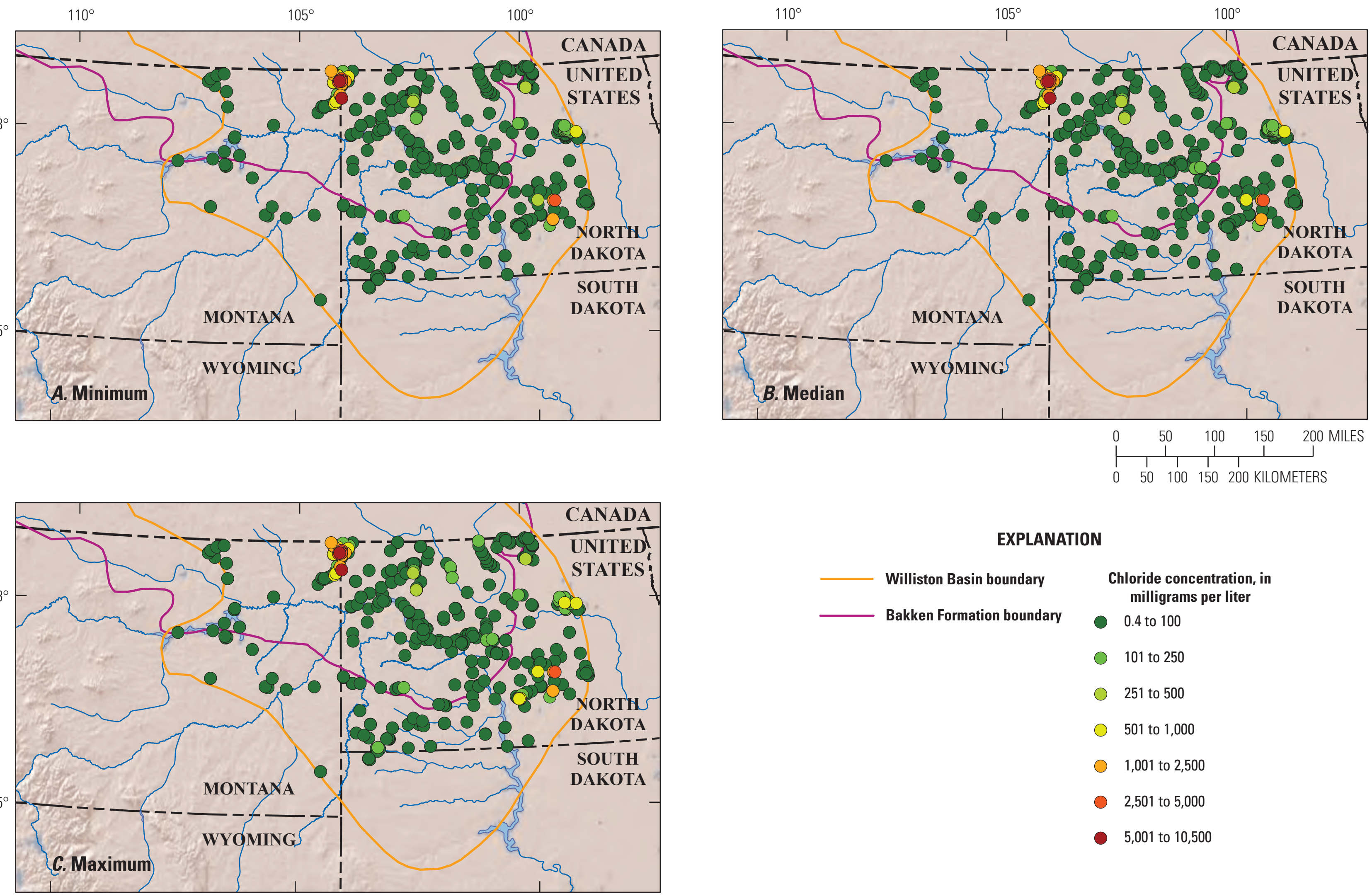
Figure 49. Values of pH in lakes in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 to 2014. *A*, minimum; *B*, median; and *C*, maximum.



Base map modified from U.S. Geological Survey, Esri, Commission for Environmental Cooperation, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

Figure 50. Sulfate concentrations in lakes in the Williston Basin in Montana, North Dakota, and South Dakota, from 1970 through 2014. *A*, minimum; *B*, median; and *C*, maximum.



Base map modified from U.S. Geological Survey, Esri, Commission for Environmental Cooperation, and Western States Data Aggregation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

Figure 51. Chloride concentrations in lakes for Montana, North Dakota, and South Dakota, from 1970 through 2014. *A*, minimum; *B*, median; and *C*, maximum.

Within Lake Sakakawea, there is minimal temporal and spatial variability in measured chloride concentrations (figs. 45*E*, 47*E*); the highest median chloride concentration of 10.5 mg/L was measured in 2013, and the lowest median chloride concentration of 8.25 mg/L was measured in 1997 (fig. 45*E*). Median chloride concentrations for Lake Sakakawea did not exceed the 250 mg/L EPA SMCL from 1993 through 2014. Spatially, median chloride concentrations increase slightly from upstream (8.1 mg/L) at RM 1481 to downstream (9.6 mg/L) at RM 1390, and the variability of chloride at an individual site decreases from upstream to downstream (fig. 47*E*). Variability in measured chloride concentrations is smallest (ranging from 5 to 11 mg/L) at the most downstream site at RM 1390 and largest (ranging from 3.5 to 13 mg/L) at the most upstream site at RM 1481 (fig. 47*E*).

Data for 1 or more of the 10 trace metals were available at 377 lake sites in the Williston Basin from 1993 through 2014 (table 10; Boughton and others, 2022, table 3–32). Chromium, copper, and lead rarely were detected in samples (table 10). The maximum detected concentrations for barium, chromium, copper, lead, selenium, and zinc for each site did not exceed EPA MCLs SMCLs, or ALs (EPA, 2009, 2012). For aluminum, arsenic, and iron, the maximum detected concentrations (6,820, 516, and 7,220 µg/L, respectively) exceeded comparable EPA MCLs or SMCLs of 50 or 200, 10, and 300 µg/L, respectively (table 10). Few trace metal data were available for Lake Sakakawea and are not presented here.

Produced Water

During conventional and unconventional oil and gas development, large volumes of coproduced fluids (hereinafter termed "produced water") are brought to the surface along with the targeted hydrocarbons as part of the oil and gas exploration and extraction processes (fig. 52). Produced water may include formation water (waters that coexist with rock/oil); hydraulic fracturing fluids (predominantly "fresh" waters with chemical additives and proppants used in the hydraulic fracturing process); and other combinations of water and chemicals used during drilling, development, treatments, recompletions, and workovers. Produced water represents waters generated from an oil or gas well, including the fluid retrieved during and after the completion of hydraulic fracturing (flowback waters), water produced immediately after hydraulic fracturing with compositions close to those of the injected fluid, and waters produced after months or years of production, whose compositions resemble formation water (Rowan and others, 2011). Produced water is generated throughout the lifetime of an oil-producing well. The Williston Basin yielded more than 1 million bbl of oil per day in early 2014 and averaged more than 600,000 bbl per day of wastewater produced from wells completed in the Bakken, Three Forks, and Tyler Formations in March 2014 alone (Gordon and Garner, 2014). Produced water to oil ratios, averaged by square-mile section for Bakken and Three Forks wells drilled from 2007 to 2014, ranged from ratios of 0.1:1 to greater than 70:1 for wells during their initial oil production; reportedly, the ratio of produced water to oil typically increases during the life of a well (Gordon and Garner, 2014).

Figure 52. Oil and produced water collected from an unconventional Bakken Formation production well near Sidney, Montana, August 2014. Photograph by Gregory Delzer, U.S. Geological Survey.

The bulk fluid discharged at the oil-production well is separated into oil and water components at local separator facilities. The produced water is typically stored onsite for a period and then hauled by truck or piped to a treatment or disposal facility. Historically, brines were discharged directly into surface water or earthen evaporation pits (McMillion, 1965; Gorman, 1999). North Dakota established rules prohibiting use of reserve pits for storage of fluids generated during well completion (North Dakota Legislative Branch, 2013a); therefore, large volumes of these brines are now injected into deep geologic formations using disposal wells (Gleason and others, 2011).

Development of a Produced Water-Quality Dataset

The water chemistry of produced water of the Williston Basin was evaluated and summarized using two datasets: (1) selected data retrieved from the USGS National Produced Waters Geochemical Database (NPWGD) v2.1 on May 25, 2015 (Blondes and others, 2014), and (2) data specifically collected through USGS efforts to evaluate the chemical and isotopic characteristics of produced waters from the Bakken and Three Forks Formations from 2010 to 2014 (Peterman and others, 2017; Boughton and others, 2022, tables 4–1, 4–2). The water-quality data from the NPWGD and USGS sample-collection efforts are summarized and described in relation to general water-chemistry, source formations, and constituents of concern. These data have been made available in a data release (Boughton and others, 2022, tables 4–1, 4–2).

U.S. Geological Survey National Produced Waters Geochemical Database

The USGS NPWGD includes nearly 162,000 produced water and other deep-formation water samples of the United States (Blondes and others, 2014). The NPWGD data contain a considerable range of reported values for most of the chemical constituents (Blondes and others, 2014). As discussed in Blondes and others (2014), data included within the NPWGD originate from a variety of sources that cannot be verified and are considered provisional. Despite these limitations, the NPWGD may be a source to obtain a general understanding of the geochemistry of produced waters, specifically major ion data associated with oil development processes in the United States.

Data retrieved from the NPWGD were restricted to include only sample sites that included the following: (1) reported locations (latitudes and longitudes) within the boundaries of the Williston Basin and the extent of the Bakken Formation within Montana, North Dakota, and South Dakota; and (2) geologic formation designations. The resulting dataset includes 10,659 samples from 3,361 sites identified with unique American Petroleum Institute numbers. Also included in table 4–1 of Boughton and others (2022) are 106 samples lacking American Petroleum Institute numbers, but that have data for the most commonly reported water-quality constituents or properties (pH, specific conductance, calcium, chloride, magnesium, potassium, sodium, bicarbonate, and sulfate). Although many of these samples have associated well names, it is unclear if they represent unique sites or possibly duplicate sites. The NPWGD also includes the geochemical results of samples collected from a variety of collection points or conditions, including drill-stem tests, well heads, separators, heater treaters, discharge lines, water line, well head samples, water dump, production, swab test, and many others.

Data included in Boughton and others (2022, table 4–1) are shown as retrieved from the NPWGD with the exceptions of the deletions of several columns and the addition of the two columns: generalized geologic unit and comments. The NPWGD data retrieval included “formation” designations (“Formation” column) of the geologic formation associated with the sample. Instead of using the 387 unique “formation” designations included in the original database retrieval, a “generalized geologic unit” designation was developed that primarily was based on the interpretation of formation and age information provided in the database in combination with analysis of the USGS National Geologic Map Database (USGS and the American Association of State Geologists, 2012) and the North Dakota stratigraphic column (Bluemle and others, 1986). The generalized geologic units of several samples were designated as “undifferentiated” within a geologic age if a specific age could not be confidently determined with the available data. The comment column was added at the end of the table and includes remarks related to the analyses.

Data descriptions and summary statistics of the NPWGD were completed using filtered data based on geochemical quality-control criteria stated in Blondes and others (2014). These criteria included culling the data if any of the following conditions were met: (1) magnesium concentration greater than calcium concentration, (2) potassium concentration greater than chloride concentration, (3) potassium concentration greater than five times the sodium concentration, and (4) ion charge balances greater than 5 percent. Resulting samples used for descriptive analysis and summary statistics included 10,178 of the 10,659 samples with formation information retrieved from the NGPWD (Boughton and others, 2022, table 4–1).

U.S. Geological Survey Produced Water Data, 2010 through 2014

The USGS collected samples from 2010 through 2014 to evaluate the chemical and isotopic characteristics of produced waters (Peterman and others, 2017; Boughton and others, 2022, table 4–2) from wells located within the Bakken Formation boundary (fig. 53) that were screened in either the Bakken or Three Forks Formation (figs. 2, 3). These samples were either specifically collected by USGS personnel or by operators that sent the samples directly to the USGS. The data represent site-specific samples collected directly from wellheads or separators at oil-production wells that had typically been in production for at least 6 months. The produced water fraction of samples collected at the wellheads were processed (filtered and acidified) after the oil and water separated. Samples collected directly from separators were processed without the need for oil and water separation. Samples were analyzed for field properties, inorganics (major ions and trace elements), stable isotopes of hydrogen and oxygen, radium isotopes, and strontium isotopes at USGS laboratories or contract laboratories (table 11). Quality-assurance samples, including field replicates and lab replicates, accounted for 10 to 15 percent of the samples collected. These samples analyzed by USGS have linked ancillary information including well logs and analytical procedures, oftentimes production history, and treatment conditions. In general, this ancillary information is not available for sample analyses retrieved from the NPWGD.

Initial reconnaissance samples were collected on June 6, 2010, from separators at two well sites that had been in production for at least 6 months. Produced-water samples were collected on October 15 and 16, 2012, directly from the well heads of six oil-production wells and from separators at three sites. In an attempt to limit the presence of hydraulic fracturing fluid and examine the “end-member” composition of the produced water, sites were selected that had been in production for at least 1 year. A secondary sampling effort on August 12, 2014, was designed to specifically examine safety concerns and produced water sample collection methodology. On August 12, 2014, samples were collected from the wellheads and separators at five oil-production wells (Rodney Caldwell, USGS, written commun., 2015). Efforts were made to ensure that more than 1 year had passed since these wells had been hydraulically fractured, and that they had not been flushed or treated for at least 7 days before sampling. In addition, a series of samples from each site were processed (filtered and acidified) at set periods (about 1 hour, 4 hours, and 24 hours) after the original oil and water composite sample was collected from the wellhead to examine how holding times affect the chemistry of these waters. In 2014, additional samples were collected from the separators by operators and shipped directly to the USGS (Zell Peterman, USGS, written commun., 2015).

General Quality of Produced Water

The TDS in water, commonly termed salinity, is typically expressed in milligrams per liter, and water can be classified by TDS as follows: (1) fresh, 0 to 1,000 mg/L; (2) slightly saline, 1,000 to 3,000 mg/L; (3) moderately saline, 3,000 to 10,000 mg/L; (4) very saline, 10,000 to 35,000 mg/L; and (5) briny, greater than 35,000 mg/L (Heath, 1983). Often, only freshwater is suitable for drinking water, irrigation, and industrial uses. Produced waters are often brines that are more saline than seawater (table 12). Produced waters also can contain dispersed oil, dissolved organic compounds, radionuclides, bacteria, and solids (Veil and others, 2004). In produced waters of the United States, sodium is the most commonly detected cation, and chloride or bicarbonate are the most commonly detected anions (Guerra and others, 2011). Produced waters of the Williston Basin are exceedingly high in dissolved solids concentrations, with some of the highest TDS concentrations measured in the oil and gas production areas of the central and western United States (fig. 54). The generalized water chemistry of samples collected from (1) the top three oil-producing geologic units (Bakken Formation, Madison Group, and Red River Formation) in the Williston Basin (NPWGD); (2) groundwater water-supply wells from the upper Fort Union Formation (McMahon and others, 2014); and (3) mean seawater (Hem, 1989) are presented in table 12. The median TDS concentration of the produced water from units in the Williston Basin is about 278,000 mg/L, about eight times more saline than modern seawater (table 12). In comparison, TDS concentrations of produced water in the Appalachian Basin, which includes the Marcellus Shale, typically range from 100,000 to 300,000 mg/L (Rowan and others, 2015). Median TDS concentration of the produced-water samples (all units; 277,725 mg/L) was about 200 times greater than the median TDS concentration (1,369 mg/L) of

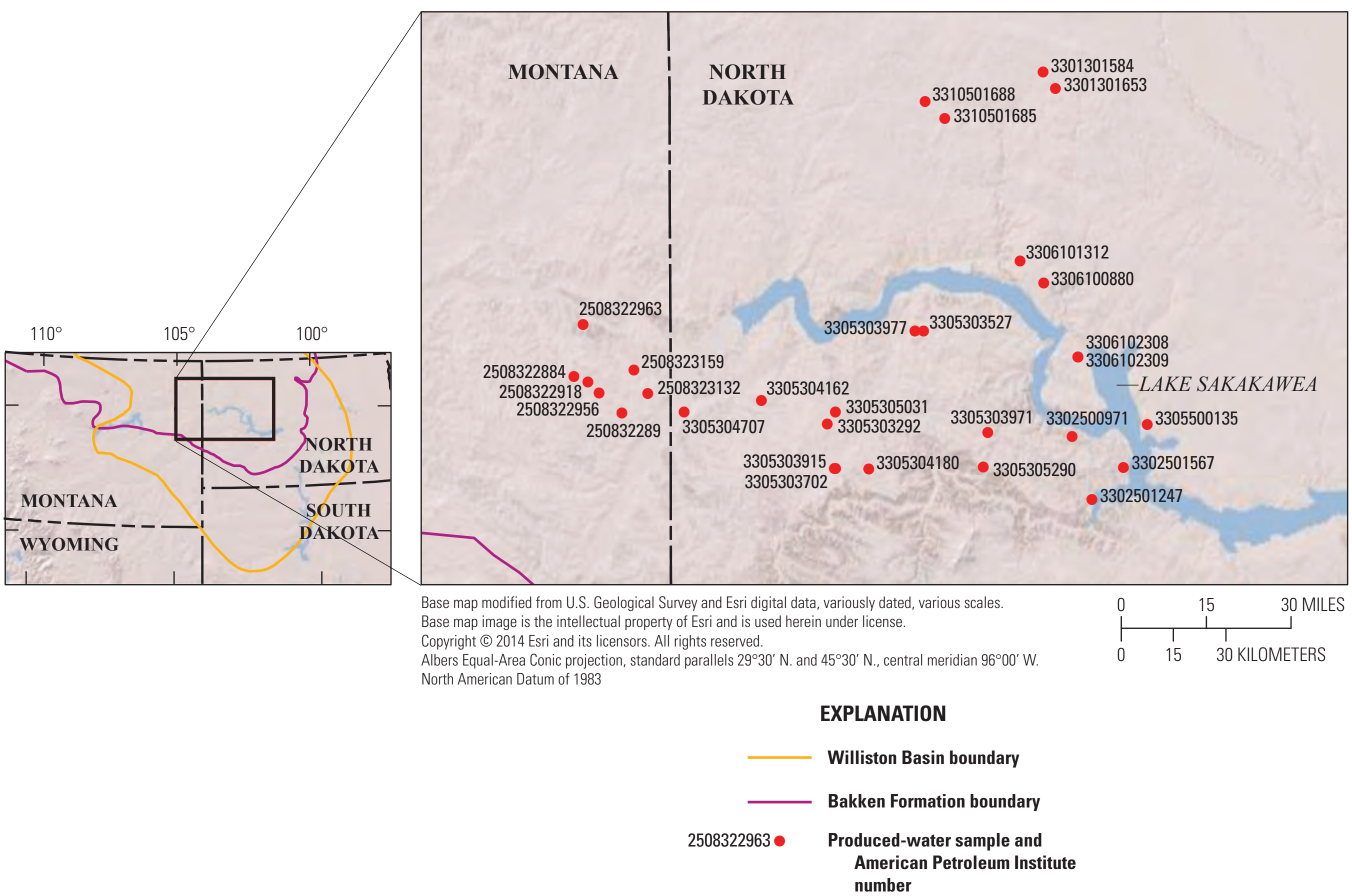


Figure 53. Location of 30 oil-production well sites within the Williston Basin for which the U.S. Geological Survey analyzed samples, 2010 through 2014.

Table 11. Constituent list for characterization of produced waters in the Williston Basin, 2010 through 2014.

[NA, not applicable; CGCSRL, Geophysics and Geochemistry Science Center Laboratory, Lakewood, Colorado; RSIL, U.S. Geological Survey Reston Stable Isotope Laboratory, Reston, Virginia; NWQL, National Water Quality Laboratory]

Analyte group	Analyte class	Laboratory
pH, temperature, specific conductance, specific gravity, and alkalinity	Field parameters	NA
Inorganics—major ions and trace elements	Inorganics	CGCSRL
Hydrogen and oxygen isotopes of water	Isotopes	RSIL
Radium-226 and radium-228	Radiochemical	NWQL contract laboratory.
Strontium-87/strontium-86	Isotopes	CGCSRL

groundwater samples collected from the upper Fort Union Formation (table 12). The major-ion chemistry of produced-water samples are typically dominated by sodium and chloride, whereas domestic and water-supply samples from the upper Fort Union Formation are typically calcium-magnesium bicarbonate type waters (McMahon and others, 2014).

The distribution of USGS NPWGD discrete water-quality samples associated with the Bakken Formation are focused near the center of the Williston Basin, mostly in North Dakota, whereas the greater number of samples identified from wells producing from the Red River Formation, Madison Group, and other or undifferentiated geologic units include sites distributed across the Williston Basin (fig. 55). TDS concentrations of samples collected near the margins of the Williston Basin are typically among the lowest (less than 50,000 mg/L), whereas samples with the highest TDS concentrations (greater than 250,000 mg/L) are typically near the central Williston Basin. Only about 2 percent of the samples from the small number of wells (384) associated with the Bakken Formation have TDS concentrations less than 50,000 mg/L (figs. 55, 56). Samples collected from the Madison Group, Red River Formation, and other or undifferentiated geologic units show a greater variability of TDS concentrations within the central Williston Basin (fig. 56).

General physical properties and major-ion chemistry of produced-water samples collected from wellheads and separators by the USGS or supplied to the USGS from operators within the Williston Basin of Montana and North Dakota were less variable than data from the NPWGD (Boughton and others, 2022, tables 4–1, 4–2). In addition, most major ion and TDS concentrations, measured in samples from Bakken Formation oil-production wells from the USGS studies were higher than the results from the NPWGD (table 13). In general, USGS samples from 2010–2014 were consistently collected, processed, and analyzed, and the sites selected were actively producing wells that were not sampled during periods of drilling and hydraulic fracturing. In addition, an attempt was made to avoid wells that were actively being treated through the addition of scale inhibitors or "freshwater" flushing.

Table 12. Generalized water chemistry of produced waters collected within the Williston Basin, including samples collected from the Bakken Formation, the Madison Group, and Red River Formation; groundwater samples collected from water-supply wells in the upper Fort Union Formation in Montana and North Dakota; and typical seawater.

Constituent	Median concentration, in milligrams per liter (number of results)					Average concentration, in seawater[3], in milligrams per liter
	All units[1]	Bakken Formation[1]	Madison Group[1]	Red River Formation[1]	Upper Fort Union Formation[2]	
Calcium	9,282 (10,178)	12,698 (404)	9,209 (5,490)	6,443 (1,273)	199 (30)	410
Magnesium	1,004 (9,993)	1,004 (404)	1,076 (5,399)	741 (1,213)	97 (30)	1,350
Sodium	82,500 (10,178)	77,953 (404)	93,100 (5,490)	55,061 (1,273)	39 (30)	10,500
Potassium	2,780 (4,473)	4,100 (355)	2,610 (2,257)	2,755 (522)	5 (30)	390
Bicarbonate	236 (9,890)	183 (396)	240 (5,486)	256 (1,205)	534 (30)	142
Sulfate	860 (10,117)	488 (401)	966 (5,659)	945 (1,257)	464 (30)	2,700
Chloride	168,000 (10,178)	153,157 (404)	173,501 (5,490)	125,276 (1,273)	9 (30)	19,000
Total dissolved solids	277,725 (9,968)	251,150 (384)	286,437 (5,376)	219,281 (1,258)	1,369 (30)	34,579

[1]Blondes and others (2014).

[2]McMahon and others (2014).

[3]Hem (1989).

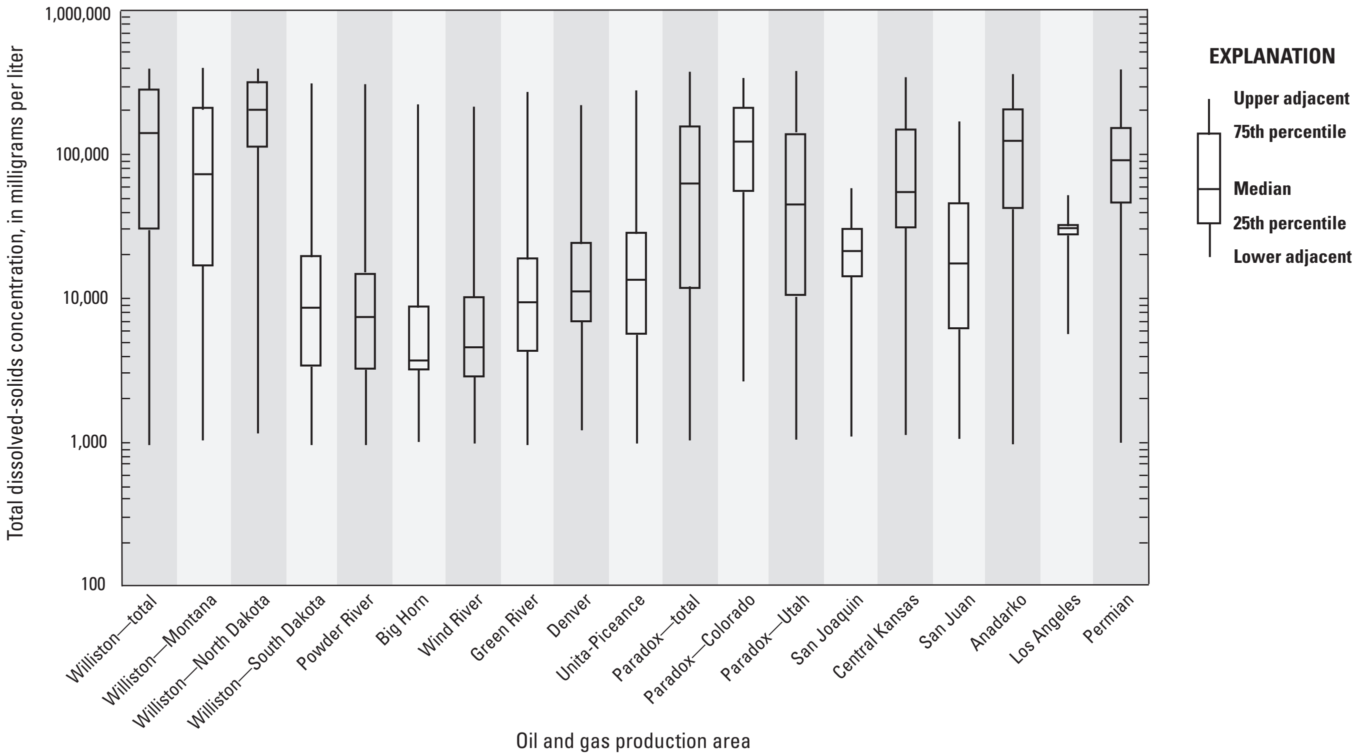


Figure 54. The distribution of total dissolved solids in produced waters from geologic formations in the United States (Benko and Drewes, 2008).

Water-Quality Constituents of Concern in Produced Water

Produced waters can be a resource for several beneficial uses, and constituents in produced waters have been used for their economic value (Guerra and others, 2011; Engle and others, 2014); however, produced waters within the Williston Basin are not considered a viable resource for most uses (drinking water, livestock, irrigation, and so on) because of extreme salinity and other constituent issues. Inadvertent environmental releases of produced waters with extreme salinities and potentially elevated concentrations of constituents could negatively affect groundwater and surface-water resources. Available NPWGD data indicate that produced waters often far exceed EPA MCLs and SMCLs. Major-ion and some trace-element concentrations are commonly elevated in produced waters (table 14). Median values for TDS and chloride concentrations were 555 and 672 times the respective SMCLs. Sulfate concentrations exceeded the SMCL in about 86 percent of samples. Chromium concentrations exceeded the MCL in more than 96 percent of samples, whereas all arsenic concentrations (ranging from 243 to 506 µg/L) exceeded the MCL (table 14). Concentrations of cadmium, fluoride, lead, selenium, and zinc also exceeded drinking-water standards (MCL or AL) in 36 percent or more of the samples.

Water-quality data collected by the USGS within the Williston Basin from 2010 through 2014 include constituents that are not commonly available in the NPWGD (table 15). Major-ion chemistry was similar to that of the NPWGD, although all the USGS samples exceeded SMCL values for TDS and chloride concentrations (table 15). Arsenic concentrations exceeded the MCL, and manganese exceeded the SMCL in samples from all sites analyzed. Barium, cadmium, lead, sulfate, and zinc concentrations exceeded MCLs or SMCLs in samples from 50 percent or more of the sites analyzed. Combined radium-226 and radium-228 activity levels exceeded the MCL for all the USGS samples. The combined radium-226 and radium-228 activity levels in USGS samples ranged from 541 to 6,020 picocuries per liter (pCi/L), with a median of 3,695 pCi/L, which is about 739 times greater than the MCL (table 15). The total ammonia nitrogen (ammonia plus ammonium) aquatic life water quality criteria is 17 mg/L for acute toxicity and 1.9 mg/L for chronic toxicity at pH 7 and 20 degrees Celsius (EPA, 2013a). Ammonium concentrations in samples from two wells ranged from 1,610 to 2,240 mg/L (Boughton and others, 2022, table 4–2).

Characterization of Produced Water

General chemical characteristics of produced-water samples obtained from the geologic units in the Williston Basin indicate that nearly all these waters are extremely saline sodium-chloride brines. With ever-changing extraction and disposal practices in the Williston Basin, it is important to

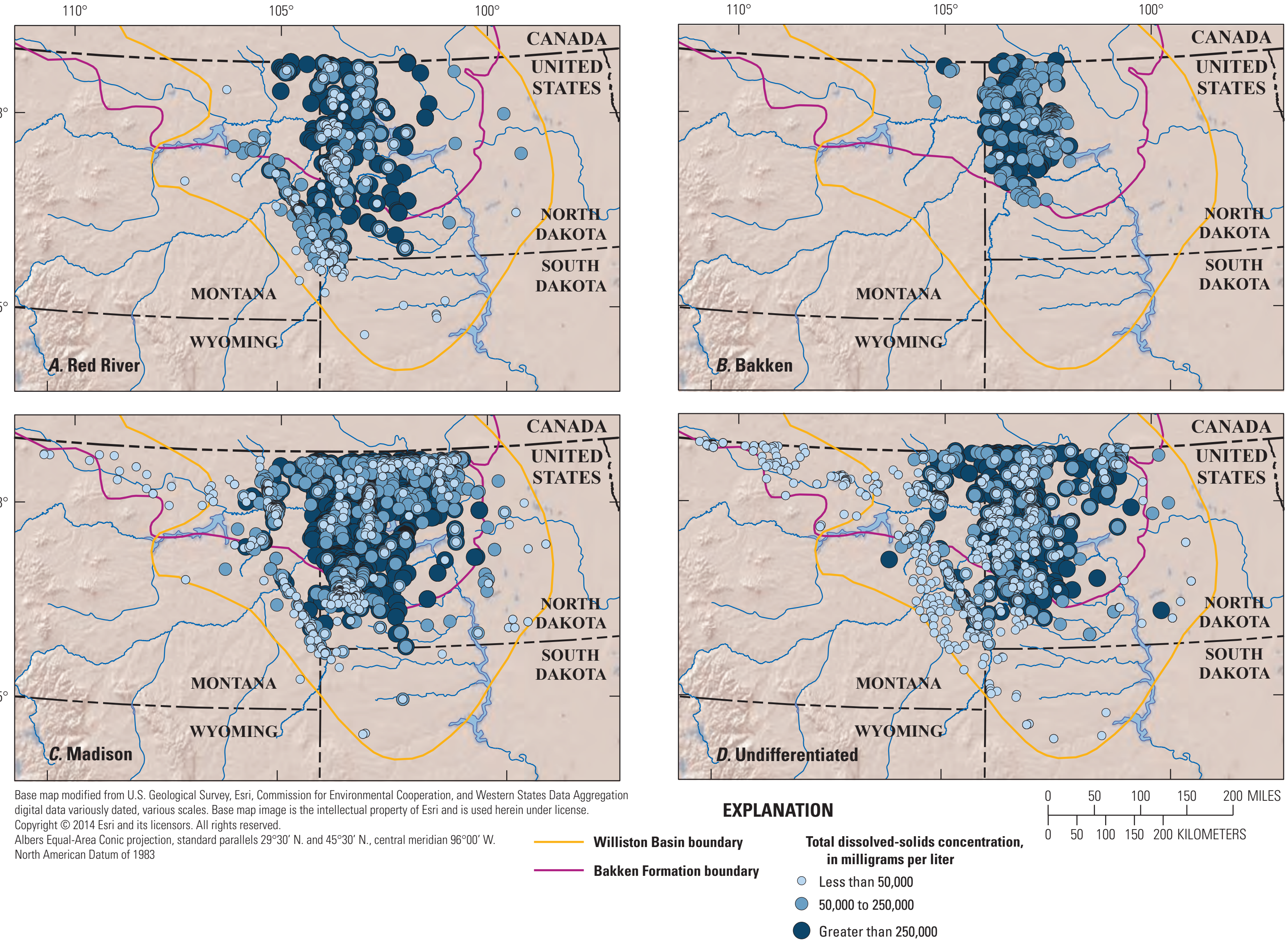


Figure 55. Spatial distribution of total dissolved-solids concentrations, in milligrams per liter, for samples included in the U.S. Geological Survey National Produced Waters Geochemical Database in Montana, North Dakota, and South Dakota. *A*, Red River Formation; *B*, Bakken Formation; *C*, the Madison Group; and *D*, other or undifferentiated geologic units.

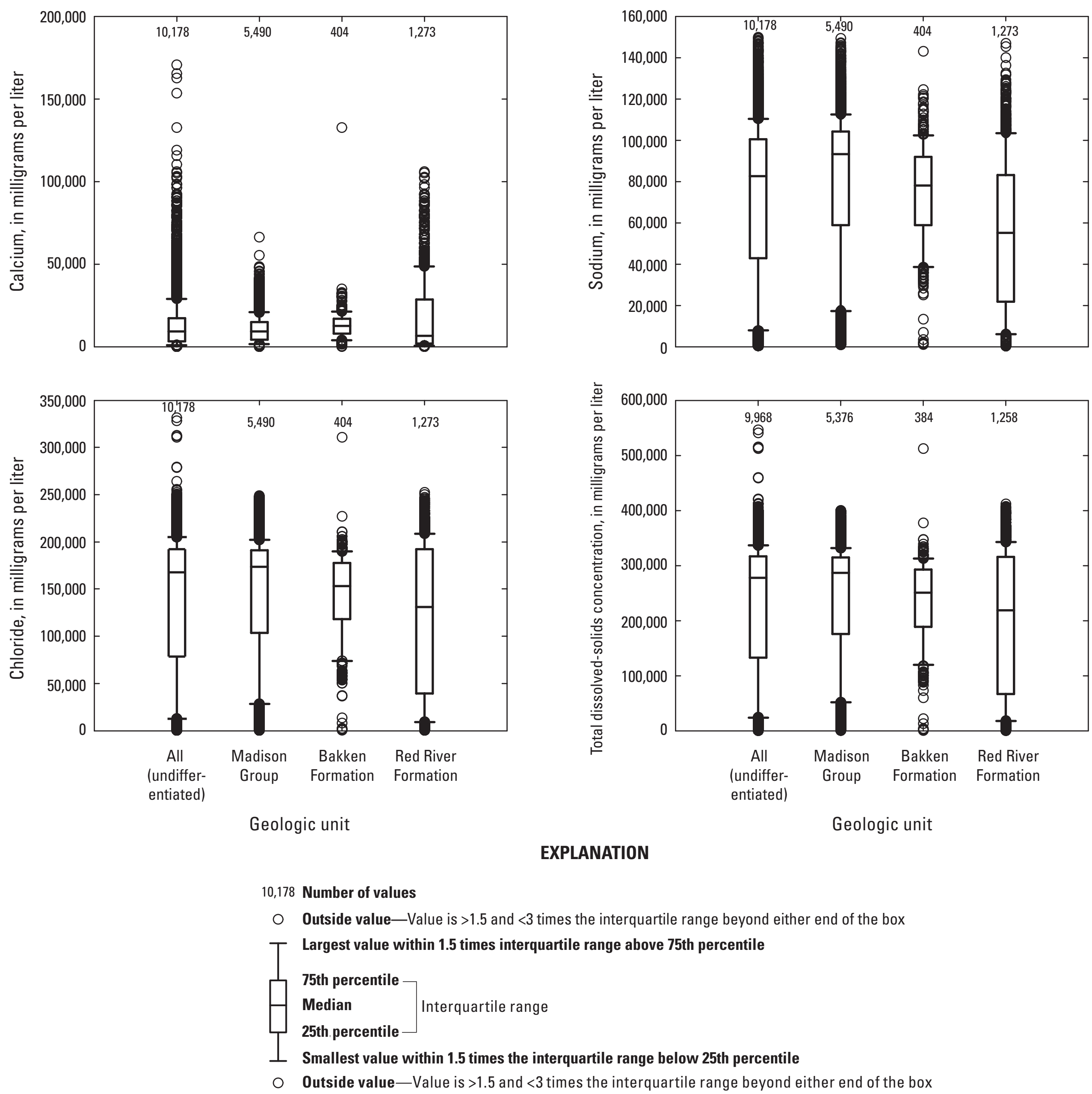


Figure 56. Range and statistical distribution of concentrations of calcium, sodium, chloride, and total dissolved solids in produced-water samples from the Williston Basin, Montana, North Dakota, and South Dakota, including all samples in the U.S. Geological Survey National Produced Waters Geochemical Database (All) as well as from the Madison Group, Bakken Formation, and Red River Formation.

Table 13. Generalized water chemistry of produced-water samples collected from the Bakken and Three Forks Formations, Williston Basin, Montana and North Dakota as part of U.S. Geological Survey study efforts 2010 through 2014 and Bakken Formation samples included in the U.S. Geological Survey Produced Waters Geochemical Database v2.1.

[USGS, U.S. Geological Survey]

Constituent	Median concentration, in milligrams per liter (number of wells)		
	Bakken Formation[1]	Bakken Formation USGS samples 2010–14[2]	Three Forks Formation USGS samples 2010–14[2]
Calcium	12,698 (404)	18,950 (25)	20,600 (3)
Magnesium	1,004 (404)	1,400 (25)	1,400 (3)
Sodium	77,953 (404)	83,100 (25)	84,700 (3)
Potassium	4,100 (355)	6,740 (25)	6,410
Bicarbonate	183 (396)	205 (12)	210 (1)
Sulfate	488 (401)	386 (25)	435 (3)
Chloride	153,157 (404)	187,000 (25)	198,000 (3)
Total dissolved solids	251,150 (384)	299,000 (25)	322,000 (3)

[1]Blondes and others (2014).

[2]USGS data collection efforts during 2010–14. Based on median values of samples from individual wells (Peterman and others, 2017; Boughton and others, 2022, table 4–2).

Table 14. Summary of concentrations of selected chemical constituents in produced-water samples stored in the U.S. Geological Survey Produced Waters Geochemical Database v2.1 for sites within the Williston Basin, Montana, North Dakota, and South Dakota.

[µg/L, microgram per liter; MCL, maximum contaminant level; NQ, not quantified; mg/L, milligram per liter; SMCL, secondary maximum contaminant level]

Constituent (units)	Number of samples	Concentration range[1]	Median concentration[1]	U.S. Environmental Protection Agency drinking-water regulation[2]	Number of samples that exceeded the regulation
Arsenic (µg/L)	5	243 to 506	467	10 (MCL)	5
Barium (µg/L)	508	NQ to 1,400	12.1	2,000 (MCL)	0
Cadmium (µg/L)	11	NQ to 67	NQ	5 (MCL)	4
Chloride (mg/L)	10,178	20 to 331,400	168,000	250 (SMCL)	10,119
Chromium (µg/L)	1,792	NQ to 2,204	1	100 (MCL)	1,730
Fluoride (mg/L)	11	0.81 to 17.0	6.53	4 (MCL)	9
Iron (µg/L)	4,806	NQ to 10,000	7	300 (SMCL)	167
Lead (µg/L)	11	NQ to 1,210	NQ	15 (action level)	4
Manganese (mg/L)	13	NQ to 17.0	0.136	50 (SMCL)	0
Selenium (µg/L)	7	0.04 to 1,560	0.31	50 (MCL)	4
Sulfate (mg/L)	10,117	NQ to 17,751	860	250 (SMCL)	8,693
Zinc (µg/L)	11	NQ to18,100	NQ	5,000 (SMCL)	4
Total dissolved solids (mg/L)	9,968	NQ to 546,300	277,725	500 (SMCL)	9,950

[1]Concentrations were reported as none detected, absent, negative, trace, minor, present, or a qualitative description of some amount and are generalized as NQ. NQ values were ranked the lowest for median calculations.

[2]U.S. Environmental Protection Agency (EPA, 2009, 2012). A MCL is the maximum permissible level of a contaminant in water delivered to users of a public-water system and is a health-based enforceable regulation. SMCLs are nonenforceable guidelines regarding cosmetic or aesthetic effects of drinking water. An action level (AL) is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

Table 15. Summary of selected physical properties and chemical constituents collected within the Williston Basin area of Montana and North Dakota, and analyzed by U.S. Geological Survey, 2010 through 2014.

[µg/L, microgram per liter; MCL, maximum contaminant level; mg/L, milligram per liter; NQ, not quantified; SMCL, secondary maximum contaminant level; pCi/L, picocurie per liter; <, less than]

Constituent (units)	Number of wells	Concentration range[1]	Median concentration[1]	U.S. Environmental Protection Agency drinking-water regulation[2]	Number of wells that exceeded the regulation
Arsenic (µg/L)	7	63 to 566	389	10 (MCL)	7
Barium (µg/L)	30	1,410 to 50,900	24,650	2,000 (MCL)	29
Cadmium (µg/L)	30	NQ to 95	23	5 (MCL)	15
Chloride (µg/L)	28	32,000 to 210,000	187,500	250 (SMCL)	28
Lead (µg/L)[3]	30	NQ to 1,210	77	15 (action level)	20
Manganese (µg/L)	28	1,540 to 35,400	14,850	50 (SMCL)	28
Radium-226 and radium-228 (pCi/L)	8	541 to 6,020	3,695	5 (MCL)	8
Sulfate (mg/L)	28	158 to 579	391	250 (SMCL)	20
Uranium (µg/L)	30	NQ to 3	NQ	30 (MCL)	0
Zinc (µg/L)	30	NQ to 31,000	13,450	5,000 (SMCL)	21
Total dissolved solids (mg/L)	28	51,617 to 346,176	302,073	500 (SMCL)	28

[1]Values were reported as none detected, absent, negative, trace, minor, present, or a qualitative description of some amount and are generalized as NQ. NQ values were ranked the lowest for median calculations. Based on median values of samples from individual wells (Peterman and others, 2017; Boughton and others, 2022, table 4–2).

[2]U.S. Environmental Protection Agency (EPA, 2009, 2012). An MCL is the maximum permissible level of a contaminant in water delivered to users of a public-water system and is a health-based enforceable regulation. SMCLs are nonenforceable guidelines regarding cosmetic or aesthetic effects of drinking water. An action level (AL) is the concentration of copper or lead in drinking water at or above which additional steps are required to reduce the constituent concentration (EPA, 2009, 2012). For regulatory purposes, the AL is applied only to tap water samples, and only if more than 10 percent of the samples exceeded the AL.

[3]Twenty wells had reported lead concentrations greater than the AL of 15 µg/L. Seven additional wells had NQ results (less than values) at levels higher than the AL of 15 µg/L with reported values of <19 to <180 µg/L.

characterize produced waters from the different source formations. Below are descriptions of studies to characterize water sources using standard water chemistry as well additional geochemical tools, such as isotope analysis.

The difference in TDS between potable and produced waters has been used to identify groundwater resources affected by brine within the Williston Basin. As produced waters typically have high TDS concentrations, the measurement of apparent conductivity and resistivity (the inverse of electrical conductivity) differences between potable and produced waters has been used to identify groundwater resources affected by produced waters. Borehole, ground-based, and airborne geophysical surveys have been done in the Williston Basin to map subsurface variations in resistivity (the inverse of electrical conductivity) and electromagnetic readings (expressed as apparent conductivity), particularly in areas that have been developed for energy resources (Murphy and Kehew, 1984; Reiten and Teschmak, 1993; Thamke and Craigg, 1997; Thamke and Smith, 2014). Early geophysical resistivity surveys in northwestern North Dakota were completed by Murphy and Kehew (1984) to map areas of high salinity (low resistivity and high conductivity) around oil and gas well sites. Reiten and Teschmak (1993) completed electromagnetic conductivity surveys (reported as apparent conductivity) in Sheridan County, Mont., to map saline waters near oil and gas well sites. In early 2000s, the USFWS assessed groundwater salinity in several wildlife protection areas that were spatially associated with energy development (Rouse and others, 2013). Maps made from these data to assess possible plumes of high salinity showed that all the sites investigated had areas of anomalously high electrical conductivity. Ground-based geophysical measurements were made by Preston and others (2012, 2014a, b) in several areas near USFWS sites, including areas that had been previously surveyed by Reiten and Teschmak (1993). The survey results were used in association with auxiliary information, such as water chemistry samples or geologic maps, to interpret the source of variations in the geophysical profiles and map areas of variable salinity. Naturally saline and brine-contaminated soil and groundwater can both result in elevated apparent conductivity, so the availability of groundwater chemistry data was important to differentiate between the two types of salinity. In areas that had been previously surveyed, locations of high electrical conductivity values had migrated with time.

The East Poplar oil field on the Fort Peck Indian Reservation in the western Williston Basin is an example of an integrated hydrologic, geologic, and geophysical study of a brine-contaminated area that began in the early 1990s (Thamke and Craigg, 1997). Borehole, ground, and airborne electromagnetic apparent conductivity data were collected in the 106 mi^2 area and used to determine extent of brine contamination (Smith and others, 2006a, b, 2014). These data were collected and interpreted in conjunction with water-quality data collected through 2009 to delineate brine plumes in the shallow aquifers (Thamke and Smith, 2014). Monitoring wells subsequently were drilled in some areas without existing water wells to confirm most of the delineated brine plumes; however, several possible plumes do not contain either existing water wells or monitoring wells.

Clayton and others (1966) analyzed oxygen and hydrogen isotopes of produced water from several basins to show that brines were largely of meteoric origin (precipitation such as rain or snow). Later studies have determined that these waters are complex mixtures of meteoric and marine sources (Hoefs, 2009). As described by Connolly and others (1990), formation waters may originate as meteoric water recharged through and reacting with the rock column or as connate water trapped during sediment deposition. Subsequent isotopic changes may result from dilution by meteoric water, mixing of brines with contrasting chemical and isotopic compositions, or water-rock interaction. Oxygen and deuterium ratio values are important indicators for the origin of the water, whereas strontium (Sr) isotope ratios ($^{87}Sr/^{86}Sr$) can provide information on water mixing and migration, the extent and nature of water-rock interaction, and the chemical evolution of waters (Connolly and others, 1990); therefore, stable isotope geochemistry in combination with major-ion and trace-metal analysis seem to be promising geochemical tools to aid in the determination of the provenance of produced waters.

Wittrup and Kyser (1990) sampled water from potash mineshafts in the northern Williston Basin in Saskatchewan at depths as great as 3,500 ft. Water from these samples was more representative of the formation than produced water, which has undergone chemical changes and possible mixing during translocation from the formation to the surface. The agreement in results between the Wittrup and Kyser (1990) study and a later study by Jensen and others (2006) indicate that the system has reached a dynamic equilibrium. Solute changes relative to depth are illustrated by the concentrations of TDS (fig. 57). The deepest samples in two mines evolved to calcium-chloride brines.

In figure 58, the oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) isotopic composition of the mineshaft water samples collected

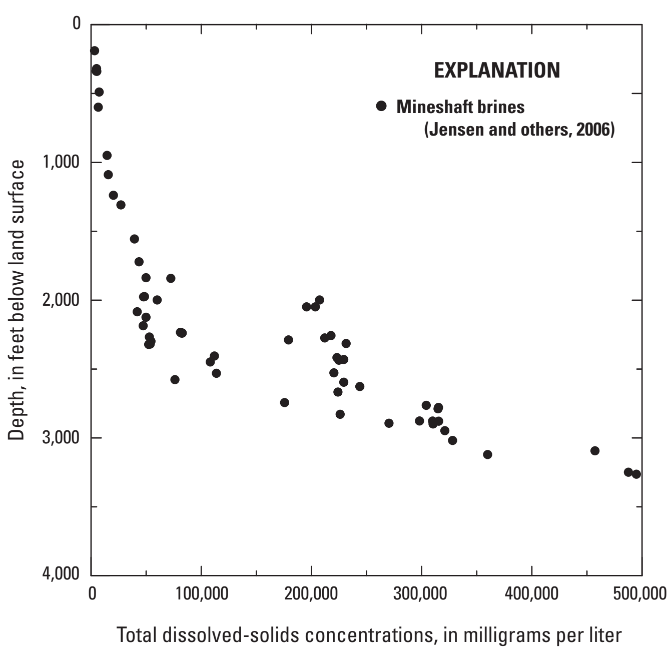


Figure 57. Total dissolved solids in milligrams per liter relative to depth of mineshaft seeps of the northern Williston Basin, Saskatchewan, Canada (modified from Jensen and others, 2006).

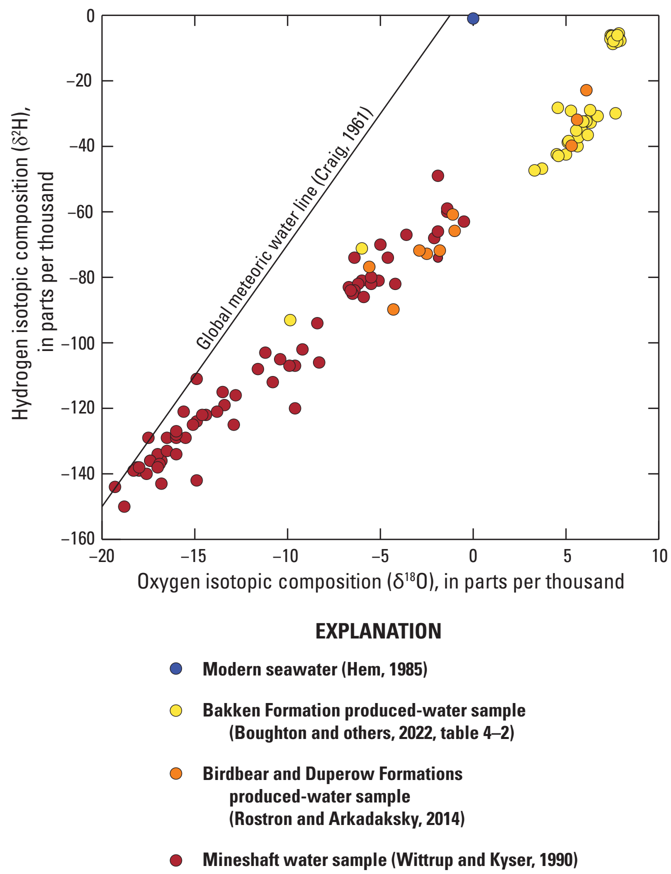


Figure 58. Oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) isotopic composition of modern seawater, produced-water samples from the Bakken, Birdbear, and Duperow Formations, and mineshaft water samples (Wittrup and Kyser, 1990; Rostron and Arkadakskiy, 2014).

by Wittrup and Kyser (1990) indicate mixing of meteoric water with water with $\delta^{18}O$ and $\delta^{2}H$ values similar to those of produced water from the Bakken, Birdbear, and Duperow Formations (fig. 2). Strontium (Sr) isotope ratios ($^{87}Sr/^{86}Sr$) also may be useful in constraining the origin of produced water in some areas (Banner, 2004). Brines with the greater $\delta^{18}O$ and $\delta^{2}H$ values may have formed by evaporation of seawater, which produces a curvilinear hook-like trend (Knauth, 1988; Connolly and others, 1990). Whatever the mode of formation, the $\delta^{18}O$ and $\delta^{2}H$ values, and $^{87}Sr/^{86}Sr$ ratios for brines from the Bakken and Upper Devonian sedimentary rocks may improve the understanding of the provenance of produced water.

In the Williston Basin, many rocks are marine carbonates, evaporites, and clastic rocks (sandstones and shales). Carbonate rocks acquire a marine $^{87}Sr/^{86}Sr$ ratio signature from seawater when they are deposited. The strontium isotopic variation in seawater during Phanerozoic time (about 541 million years to present [Cohen and others, 2019]) is well known (McArthur and others, 2012). Formation water trapped in sediments will acquire the $^{87}Sr/^{86}Sr$ values of the host rocks by long-term water-rock interaction; thus, carbonate-hosted formation water is expected to carry strontium with an $^{87}Sr/^{86}Sr$ value close to marine values (fig. 59). Two groups of Poplar Dome brines mostly from the Mississippian Charles Formation were recognized based on major-ion and trace-metal chemistry and strontium isotopes (Peterman and Thamke, 2016) and are designated as group 1 and group 2. Group 1 brines are consistent with a long residency in carbonate rocks. Group 2 brines are associated with fluid production characterized by large water-to-oil ratios. Peterman and Thamke (2016) interpret these relations to have resulted from cross flow of formation water from younger stratigraphic units and mixing with group 1 brines. Figure 59 shows the strontium and $^{87}Sr/^{86}Sr$ values for the Poplar Dome samples in comparison with values from the Bakken Formation wells.

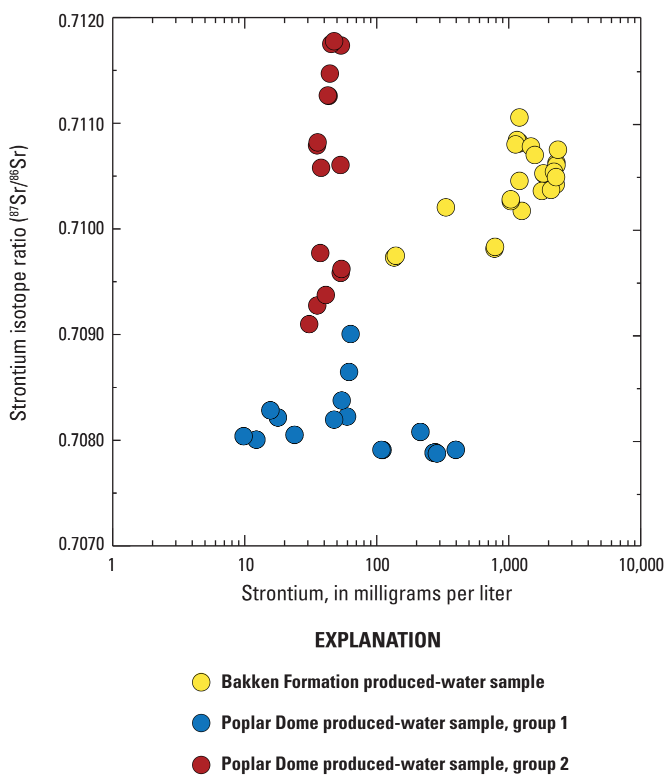


Figure 59. Comparison of strontium (Sr) concentrations and isotope ratios ($^{87}Sr/^{86}Sr$) of produced water in the Poplar Dome of eastern Montana and the Bakken Formation of eastern Montana and North Dakota.

Water-Use Data

Water is a critical component needed to sustain life and is a finite resource. Its availability and use are codependent with the development of energy resources across the Nation. Water cannot be easily accessed by homes, businesses, and industries without delivery systems derived from the development of energy; likewise, most forms of energy development require variably scaled inputs of water to extract energy-rich materials like coal, natural gas, and petroleum. The United States faces two substantial and often competing challenges: (1) to provide sustainable supplies of freshwater for humans and ecosystems, and (2) to ensure adequate sources of energy are available for current and future generations (Healy and others, 2015). Issues associated with water and energy are multifaceted with many variables affecting their supply, demand, and management. Water-resource managers are faced with complex issues because of the increasing demand placed on a small supply of water and energy resources.

During the last 100 years, energy development in the upper Missouri River Basin, specifically in the Williston Basin, has expanded and contracted depending on developments in technology, availability of the energy resource, rising costs to develop and deliver the resource, energy market demands, and the dynamic political climate during the time of the resource's development. In the last decade, the Williston Basin has seen resurgence in unconventional oil and gas development—particularly with new technologies such as horizontal drilling and fracturing of oil-bearing strata with large quantities of water and other fluids.

Energy resources in the Williston Basin have included finite resources such as coal (or lignite), oil and gas, and renewable resources like biofuels and wind (table 16). Each type of energy resource development, and the ancillary infrastructure that helps support that type, has its own unique set of water requirements.

Evaluation and quantification of surface-water and groundwater availability are needed to determine if the water sources can meet the needs of the energy development in an area. Two key components (or "metrics") to consider when evaluating water sources for any type of energy development are water withdrawals (and returns) and consumptive use. Withdrawals are water that is removed from a source and

Table 16. List of energy resources developed in the Williston Basin with U.S. energy consumption (in percent) for 2011 and 2014, and water-use requirements for each energy resource.

[<, less than]

Resource sustainability	Resource (fuel) type	Resource material	Development type	Development process	General water-use requirements for resource	2011/2014 U.S. energy consumption, in percent[1,2]
Nonrenewable	Fossil	Coal (including lignite)	Conventional	Surface/strip or underground mining	Coal washing to improve quality, dust abatement for mine roads, equipment maintenance, revegetation of surface mines, long-distance transport by coal slurry, and use in coal-fired powerplants (once-through and closed loop [or recirculating]/cooling ponds).	20.4/18.3
Nonrenewable	Fossil	Crude oil	Conventional	Primary recovery–vertical well	Drilling, well completion, injection into the reservoir in secondary and enhanced oil recovery, and upgrading and refining into products.	36.2/35.4
Nonrenewable	Fossil	Crude oil	Unconventional	Primary recovery-vertical well, horizontal well, hydraulic fracturing	Drilling, well completion and hydraulic fracturing, injection into the reservoir in secondary and enhanced oil recovery, oil and sands mining and in place recovery, and upgrading and refining into products.	36.2/35.4
Nonrenewable	Fossil	Natural gas	Conventional	Primary recovery-vertical well	Drilling, well completion, injection into the reservoir in secondary and enhanced oil recovery, upgrading and refining into products.	25.5/27.9
Nonrenewable	Fossil	Natural gas	Unconventional (including shale gas, coal bed methane, gas hydrates)	Primary recovery-vertical well, horizontal well, hydraulic fracturing	Drilling, well completion and hydraulic fracturing, injection into the reservoir in secondary and enhanced oil recovery, oil and sands mining and in place recovery, and upgrading and refining into products.	25.5/27.9
Renewable	Hydro	Water	Conventional (dam and reservoir)	Turbines	Electricity generation, storage in a reservoir (for operating hydroelectric dams or energy storage), and discharge through water turbines in dam.	3/2.5
Renewable	Biofuels	Organic matter	Conventional	Crops (ethanol)	Water-use requirements for crops and irrigation for feedstock crop growth, wet milling, washing and cooling in the fuel conversion process.	4.5/4.9
Renewable	Wind	Wind	Conventional	Windmills (wind farm)	Minimal water usage unless in manufacturing of turbine parts in area.	1.5/1.7
Renewable	Geothermal	Geothermal	Conventional	Small scale–homes/schools	Use in heating systems and maintenance.	0.22/0.22
Renewable	Solar	Solar	Conventional	Photovoltaics/concentrated solar power	Use in manufacturing systems and maintenance.	<0.01/<0.01

[1]U.S. Energy Information Administration (2012a, table 1.3; 2014, table 1.3).

[2]Nuclear energy is not present in the Williston Basin; therefore, it is absent from this table. Because of this omission, the percentages do not total 100 percent.

may not be available for reuse, whereas a return is water that was initially unavailable and was returned to the source (may be near the withdrawal point or at a different location near the same source, or to a different source entirely). Returned water may have been treated before returning it to the source. Consumptive use is where the water is "consumed" or used and cannot be returned immediately to any source. These metrics can be used to develop an accurate water budget to fully understand the cycle of water use in an area and the effect that development of the energy resource's role has on that particular water budget. This is critical to determine if water needs for energy development can be met without compromising the water needs of others using the same water sources.

Energy Development and Water Use

Water is a key component in developing the mineral-based energy source. Uses of water in the development of the energy resource include but are not limited to (1) extraction of the raw material, (2) cleaning and processing the material, (3) use of the material in producing the energy, and (4) cleaning and disposing of residual waste from the generation of the energy. The amount of water needed for energy development is based on the type of raw material being used in producing the energy and the method used to generate the energy. The development of energy resources and associated water requirements in the Williston Basin differ with respect to the individual States involved in developing the resource. Comparable energy and water-use data among States may not be available for every type of energy development discussed in this report.

Coal

Lignite coal was one of the first energy resources to be developed in the Williston Basin beginning when the first European settlers arrived in the area, and it continues to be one of the most used energy resources in the area today. Western North Dakota contains the single largest known deposit of lignite in the world (Murphy, n.d.). Lignite is an inferior type of coal when compared to the higher quality coals like anthracite. Lignite is difficult to use because of its high water content (as much as 75 percent water in some varieties), weak cohesiveness, low heat value, and poor storage properties. Although all the lignite coal in North Dakota is low grade, it remains 1 of the 10 top coal-producing States in terms of total tonnage mined at about 30 million short-tons annually since 1988 (U.S. Energy Information Administration [EIA], 2008, 2009). Most users of lignite coal are thermoelectric powerplants and industries near mining sites in North Dakota.

Lignite coal has been mined at hundreds of sites in North Dakota since the 1870s, but it is now recovered from only four surface mines in the west-central part of the State. Two smaller operations in the State mined oxidized lignite (leonardite), which is used in soil stabilization and as a drilling fluid additive (EIA, 2016b). Each of these mines is within the Williston Basin, and relies mostly on nearby surface-water features such as the Missouri River and, to a lesser extent, groundwater. These mines maintain water permits for surface water and groundwater that authorize withdrawals ranging from 50 to several hundred acre-ft per year (acre-ft/yr). Mines in this area typically use water for dust abatement (minimizing dust on nonpaved roads), cleaning and general maintenance of equipment, and to support use by employees. The lignite coal from North Dakota's four larger coal mines is used as fuel for steam boilers at electricity-generating plants in the State. Some of the State's powerplants also receive small amounts of coal from Montana and Wyoming.

The Great Plains Synfuels Plant near Beulah, N. Dak., where lignite coal is converted into pipeline-quality synthetic natural gas (SNG) and a high purity carbon dioxide byproduct (EIA, 2016b), uses about 6 million tons of lignite coal on an annual basis from a nearby mine, surface water from Lake Sakakawea, and electric power from a nearby thermoelectric powerplant to produce 54 billion standard ft^3 of SNG annually. The Synfuels plant has a 17,000 acre-ft/yr surface-water permit for obtaining water from Lake Sakakawea, about 10 mi away.

Montana, with just six mines, produces more than 4 percent of coal in the United States. Most of Montana's coal production comes from several large surface mines in the Powder River Basin in southeastern Montana (fig. 1). The Savage Mine, in the Williston Basin near the State line in northeastern Montana, delivers coal to a nearby thermoelectric powerplant (Lewis and Clark Power Station) southeast of Sidney, Mont., and to a sugar beet processing facility. The coal mine and powerplant are near the Yellowstone River. Similar to North Dakota, nearly all the coal extracted in the Williston Basin in Montana is used to generate electricity (EIA, 2016a).

In contrast, South Dakota does not have any coal reserves in the Williston Basin. Coal brought into the State comes from Wyoming and is used for the generation of electricity. Also, South Dakota has no powerplants in the Williston Basin, but a small part of the coal delivered to South Dakota is used at industrial plants (EIA, 2016c). As a result, water used for energy development in South Dakota is minimal.

Thermoelectric Powerplants

Thermoelectric powerplants that consume coal substantially affect water quantity and quality in the United States. According to the USGS, thermoelectric power is the largest user of water in the United States and accounted for 38 percent of the total freshwater withdrawals and about 91 percent of total saline-water withdrawals in 2010 (Maupin and others, 2014). Water is used by thermoelectric powerplants to (1) extract, wash, and sometimes transport coal; (2) cool the steam used to make electricity in the powerplant; (3) control pollution from the plant; (4) mine and burn coal; and (5) process waste byproducts.

The cooling processes used in a coal-fired powerplant affect not only its water requirement but also the efficiency of the powerplant. While there are four cooling techniques used in thermoelectric power plants, the three major cooling processes utilized in the Williston Basin are (1) once-through, (2) wet-recirculating, and (3) dry cooling; each of these systems withdraw and consume water at different rates (table 17). Once-through cooling, also known as open-loop cooling, is the process where water is withdrawn from a source, circulated through heat exchangers, and then returned to a body of water at a higher temperature. Wet-recirculating cooling, also known as closed-loop cooling, is the process where water is withdrawn from a source, circulated through heat exchangers, cooled, and then reused in the same process. The once-through cooling system withdraws substantially more water than the wet-recirculating process but has a lower consumption rate. Finally, dry cooling is the process of cooling using air rather than water, so this process uses considerably less water than the other processes. Dry cooling still requires water for system maintenance, cleaning, and blowdown (water intentionally wasted to avoid concentration of impurities during continuing evaporation of steam) but uses approximately 95 percent less water than wet systems (Maulbetsch, 2004). On average, water-cooled thermoelectric powerplants in the Williston Basin withdraw less water than most other water-cooled powerplants in the United States in 2008 (fig. 60; Averyt and others, 2001).

Currently, eight powerplants are operating in the Williston Basin: seven in four counties of North Dakota (McLean, Mercer, Morton, and Oliver), and one in Richland County, Montana (table 18). Four of the seven powerplants in North Dakota are considered once-through cooling plants, and the remaining three are wet-recirculating cooling plants. The total water permitted annually for coal-fired powerplants in North Dakota is about 1.8 million acre-ft. This includes withdrawn water (nonconsumed) and consumed water (Schuh, 2010).

Table 17. Water use for thermoelectric power cooling by type for conventional coal-fired powerplants in the Williston Basin, in gallons per megawatthour.

Water use	
Withdrawal, in gallons per megawatthour	**Consumption, in gallons per megawatthour**
Once through[1]	
20,000–50,000	100–317
Wet recirculating[1]	
500–1,200	480–1,100
Dry cooling[2]	
Limited	Limited

[1]Data from Macknick and other (2012).

[2]Data from Electric Power Research Institute and California Energy Commission (2002).

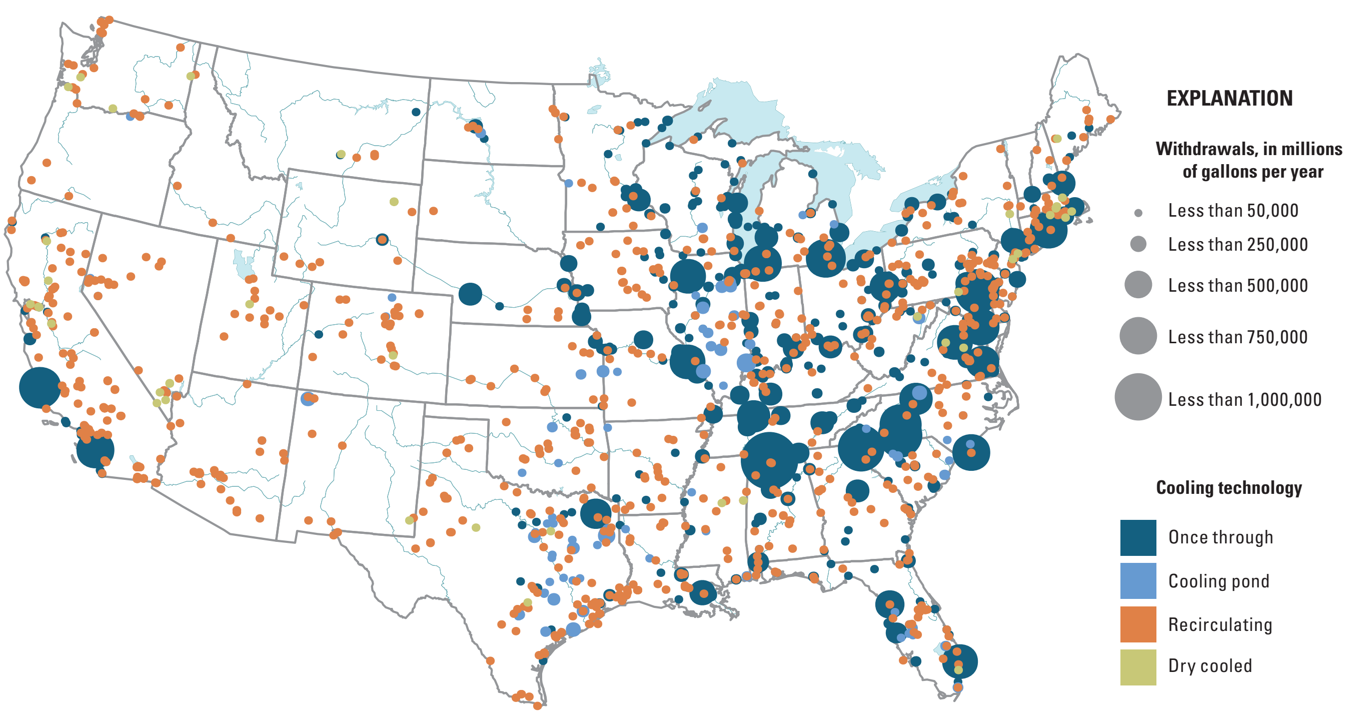


Figure 60. Coal-fired powerplants and water withdrawals in million gallons per year by cooling technology, in the United States, 2008.

Table 18. Total self-supplied water withdrawals and power generated by thermoelectric powerplants for selected counties in North Dakota and Montana for 2005 and 2010.

County (State)	2005		2010	
	Total self-supplied withdrawals, in million gallons per day	Power generated, in gigawatthours	Total self-supplied withdrawals, total, in million gallons per day	Power generated, in gigawatthours
McLean (North Dakota)	12.08	8,708.89	10.68	8,699.71
Mercer (North Dakota)	486.95	15,725.65	354.98	14,680.05
Morton (North Dakota)	55.48	607.34	44.39	471.55
Oliver (North Dakota)	509.46	5,117.83	426.6	4,535.30
Richland (Montana)	20.07	288.04	32.6	315.37

Oil and Gas

Like the development of coal, development of oil and gas resources in the Williston Basin has expanded and contracted depending on the economic market and political climate with the Williston Basin. The last substantial increase was in the late 1970s and early 1980s. In the early 2000s, a resurgence in oil production began, especially in the Bakken Formation. The resurgence may be attributed to new techniques in horizontal drilling and hydrofracturing, the refinement in oil and gas support technologies, higher oil prices, instability in the Middle East, and also in part to reevaluations of the assessment (oil-bearing) units in the Williston Basin by the USGS and others.

According to the North Dakota Department of Mineral Resources (EIA, 2012b), there were 4,141 wells in production the North Dakota Bakken Formation in June 2012. The increasing number of oil rigs underscores the quickening pace of drilling in the area (table 19). Data from the North Dakota Oil and Gas Division indicate that in the Williston Basin, the mean weekly count of active horizontal-drilling rigs totaled 212 in June 2012.

Of concern to water resources managers and others is the large amount of freshwater required to prepare a well for oil and gas production; in some cases, more than 3 to 7 million gallons (Mgal) for each well (Intermountain Oil and Gas BMP Project, 2015). Water is withdrawn from local aquifers, surface waters, or both, and then piped or trucked to the well pad. The withdrawal rate at many of these water sources often exceeds the sustainable recharge rate, particularly if the source is small. Additionally, freshwater supplies are potentially affected by post processing of produced waters through recycling, injection into waste wells, or processing at treatment plants for disposal of wastewater. The EPA estimates that hydraulic fracturing in the Williston Basin uses between 70 and 140 billion gallons (Bgal) of water in total each year (EPA, 2011).

Water also is used for myriad purposes related to ancillary oil and gas extraction. Some of the uses include (1) supplemental fluid in enhanced recovery of petroleum resources; (2) drilling and completion of oil and gas wells; (3) work being done adjacent to or on an oil or gas well; (4) solution of underground salt in brine mining or hydrocarbon storage cavern creation; (5) gas plant cooling and boiler water; (6) hydrostatic test water for pipelines and tanks; (7) rig and vehicle wash water; (8) coolant for internal combustion engines for rigs, compressors, and other equipment; and (9) sanitary and laboratory purposes.

In addition to water used for immediate energy development, the expanded human workforce migrating into the area and other support staff who have moved into the area during the development also use water. The increase in transient and permanent populations has stressed existing infrastructures in the area such that housing and utilities, including water use, are at risk of not being able to keep pace with rapidly expanding needs associated with the development of the energy resources in the Williston Basin.

Table 19. Active drilling rig counts for North Dakota, Montana, and South Dakota based on average count for January, 2005 to 2015.

[Data from Baker Hughes Company (2016)]

Year	Active drilling rigs for the month of January		
	North Dakota	Montana	South Dakota
2005	20	22	0
2006	27	25	0
2007	34	19	0
2008	48	12	1
2009	68	6	0
2010	71	5	0
2011	154	8	0
2012	154	8	0
2013	176	18	1
2014	170	9	1
2015	155	8	0

Hydropower

The primary renewable source of power in the United States is hydropower. The USACE and the Bureau of Reclamation (Reclamation) are the largest producers of electricity from hydropower in the United States (Bureau of Reclamation, 2015b). The USACE has been actively involved in building and operating hydroelectric plants since the 1930s. The USACE has six dams on the upper Missouri River of which three are in or adjacent to the Williston Basin. In contrast, Reclamation has no hydropower plants in the Williston Basin.

The six USACE hydropower projects on the upper Missouri River control runoff from about one-half of the Missouri River Basin and comprise the largest system of dams and reservoirs in the United States. Three of the dams are in or adjacent to the Williston Basin and include Fort Peck Dam in eastern Montana, Garrison Dam in central North Dakota, and Oahe Dam in central South Dakota (fig. 17). These dams were authorized by Congress in the Flood Control Act of 1944 (commonly called the Pick-Sloan Act) and store Missouri River waters to provide flood control, irrigation development, navigation, municipal and industrial water supply, recreation, and hydropower generation (fig. 61).

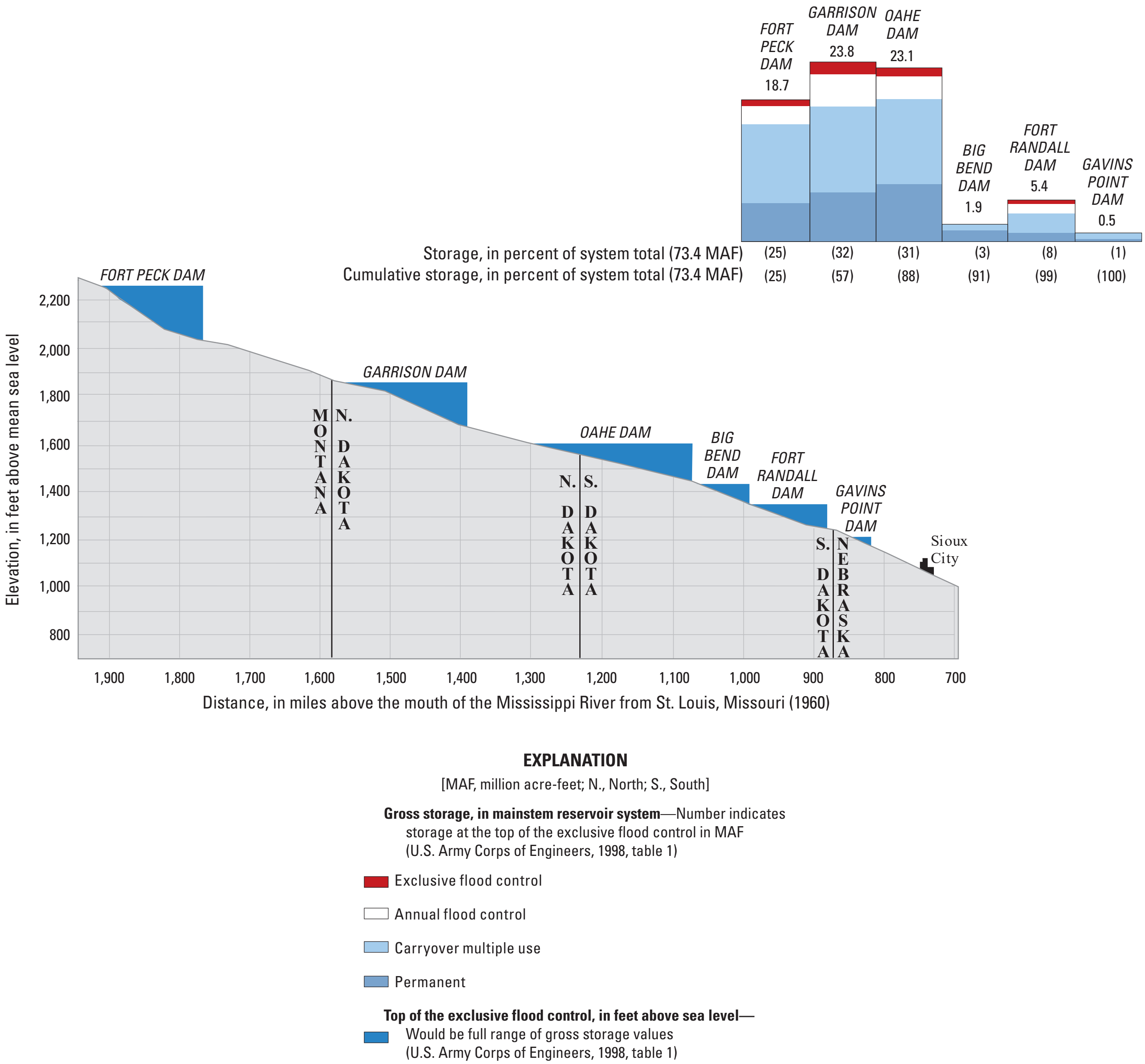


Figure 61. Dams of the Missouri River main-stem system in downstream order according to river miles and the storage capacity of each dam and reservoir complex (U.S. Army Corps of Engineers, 1998, 2007).

The USACE operates the dams and reservoirs with the objective to balance water-use needs within the Missouri River Basin against natural hydrologic effects like precipitation, runoff, and evaporation. Most of the annual water supply is produced by winter snows and spring and summer rains that increase Missouri River Basin storage. The highest mean power generation period extends from mid-April to mid-October, so high peak loads are during the winter heating season (mid-December to mid-February) and the summer air conditioning season (mid-June to mid-August). During the spring and summer period, releases are intended mostly for navigation and flood control requirements and primary power loads are supplied using the four lower dams (USACE, 1998).

The powerplants for the six dams generate a mean of 10.2 million megawatt hours (MWh) of energy annually, and Oahe and Garrison Dams (fig. 17) are typically the biggest power producers in the Missouri River system (USACE, 2006). Oahe and Garrison Dams annually generates 2.9 and 2.5 million MWh of energy, respectively (USACE, 2006).

Biomass and Biofuels

Energy from biomass and biofuels is derived from plant and animal materials that have been converted into a fuel. Biomass can be broken down into two major fuel uses: (1) transportation, and (2) electricity or heat (Healy and others, 2015). Wood is the most common biomass fuel and particularly is used for generating electricity or heat, but normally is not grown commercially as a fuel source. Other biogenic materials that come from private industry, agriculture, or municipal processing also are used for making electricity and heat. Biomass fuel production and use are not particularly large users of water compared to other technologies used to develop energy resources (National Research Council, 2008). The common biofuels ethanol and biodiesel are developed with their own water-usage requirements, which have increased substantially in the area.

Water usage for the biofuels industry reflects a range of efficiencies based on the processes and methods used. Water-use estimates for the biofuels industry have generally decreased with time as water-use efficiency has improved. The processes involved in biofuel production are similar to those present in thermoelectric powerplants in that the largest use of water is for cooling (once-through, wet-recirculating, or dry-recirculating; Schuh, 2010). The amount of water used for each biofuel development is based on the fuel type and the conversion process used in production (table 20).

Biofuel energy development has been on the rise in North Dakota (Great Plains Energy Corridor, 2014a). According to the NDSWC, there have been six ethanol- and two biodiesel-producing plants in operation in North Dakota. Two ethanol plants are within the Williston Basin; one receives Missouri River water from a regional water supplier and the other is co-located with one of the thermoelectric powerplants on the Missouri River. Additionally, there are four facilities currently being considered for development. Based on the current water usage in existing ethanol plants, total water use from current and future ethanol plants would be between 5,600 and 6,500 acre-ft/yr. The only biodiesel plant within the Williston Basin is in north-central North Dakota. The plant uses groundwater, and annual water use is less than 300 acre-ft (Schuh, 2010). Montana and South Dakota have no biomass or biofuel plants within the Williston Basin.

Wind

The development of wind as an energy resource has become one of the most economical renewable energy technologies. Its effects on local or regional water sources are limited to manufacturing of wind technology components and the effect of wind turbine placement on the local environment.

According to the January 2012 report of the American Wind Energy Association, North Dakota is ranked 6th in the United States for available wind resources (Piehl, 2013).

Table 20. National water-use summary estimates for biofuels production.

[Data from National Research Council (2008, table 4). ~, approximately; <, less than]

Fuel type	Conversion process	Processing water-use intensity, in gallons of water per gallon of fuel		Feedstock water-use intensity	
		Process water use	Process water consumption	Feedstock water demand, in acre-feet per acre	Feedstock water consumption, in gallons of water per gallon of fuel
Ethanol (starch or sugar based)	Wet or dry mill	~2–6	~4	~1.0 to 2.3	980–1,360
Ethanol (cellulose based)	Biochemical or thermochemical	~3–12	~2–6	~2.3 to 2.5	Rain-fed
Biodiesel (oil extraction)	Transesterification	~0.3–3	~1	~0.8 to <2.5	6,100–not determined

According to Piehl (2013), the January 2012 report (could not be located) indicated the North Dakota Public Service Commission had issued permits or received letters of intent for more than 6,000 megawatts of additional wind project development in addition to the almost 1,000 wind turbines and projects operating in the State. Most of these projects are in the central one-third of the State and at the southeastern edge of the Williston Basin. The wind turbines do not need water once they are constructed; any water use by a wind company would be for employee use, sanitation, and cleaning. North Dakota has four manufacturing facilities in operation. These facilities are in the eastern one-half of North Dakota and not within the Williston Basin.

In 2015, Montana ranked 22nd for installed wind capacity with 479 wind turbines, and South Dakota ranked 19th for installed wind capacity with 583 wind turbines and 5 manufacturing facilities (American Wind Energy Association, 2015a, b). The wind manufacturing facilities are in the eastern part of South Dakota, and not within the Williston Basin (American Wind Energy Association, 2015b).

Geothermal

Geothermal energy uses heat from the Earth to either heat or cool a structure based on the outside ambient air temperature. Geothermal energy can be drawn from several sources that include the following: (1) hot water or steam reservoirs deep in the Earth that are accessed by drilling, (2) geothermal reservoirs near the Earth's surface (mostly in the western part of the United States), and (3) shallow groundwater near the Earth's surface that maintains a nearly constant temperature of 50 to 60 degrees Fahrenheit (°F) (National Renewable Energy Laboratory, 2016). The amount of water needed is determined by the type of geothermal process used in a system and how much consumptive use, if any, happens within the system over time.

The development of large-scale geothermal energy in the Williston Basin is nonexistent. Montana has 15 geothermal sites identified for possible development but none within the Williston Basin. Large-scale geothermal energy sites need to be in areas where geothermal activity is present, such as Yellowstone National Park (National Resources Defense Council, 2016). Similarly, North Dakota and South Dakota have no major geothermal energy developments, just small geothermal heat exchangers used in domestic and a few commercial settings. Future studies may develop ways to use byproducts from oil and gas development in the western part of North Dakota in geothermal processes. It is interesting to note that the North Dakota Geological Survey does produce geothermal maps for the State of North Dakota (North Dakota Geological Survey, 2016).

Solar

Solar energy use is on the rise in the United States according to the Solar Energy Industries Association (2016). The increase in solar development is a result of advancement in technologies and a reduction in costs associated with solar development. There are two main types of solar energy technology: (1) photovoltaics (PV) use the Sun's rays to create direct current electricity from solar cells, and (2) concentrated solar power uses mirrors typically to concentrate the Sun's rays and create heat that drives turbines. Solar energy in the Williston Basin is limited to domestic uses such as solar panels on homes. No major solar energy development has been done in the Williston Basin, and data on water usage for solar energy development are nonexistent.

An example of industrial/commercial uses of solar energy exist in North Dakota is Verendrye Electric Cooperative (Great Plains Energy Corridor, 2014b). Verendrye Electric Cooperative in north-central North Dakota has the largest solar operation in North Dakota. The cooperative uses more than 240 solar-run water pumps in a six-County area around Minot, N. Dak., to supply water for livestock in remote areas where building power lines are cost prohibitive. In North Dakota, a water permit is not required for watering livestock, so it is difficult to determine the effect these solar pumps have on the local water sources.

State Water-Use Regulations and Permitting Legislation

As energy development, particularly for unconventional oil and gas, expands in the Williston Basin, so do regulations governing the industry with its ancillary infrastructures. In addition, uncertainty exists as to jurisdictions over the water resources (water rights) that often span National, State, local government, private, and Tribal borders.

Water rights are legal entitlements authorizing water to be diverted from a specified source and put to beneficial, nonwasteful use. Water rights guarantee the holder of the right(s) access to the water in question; however, the holder does not own the water itself, only the right to use it, and often with restrictions. Many States view the waters within a State as belonging to the "people of the State" so that all people living in the State can, at some time, use that water. Some States require a permit or license from a State water regulatory agency whose objective is to ensure the State's waters are put to the best possible use, and that the public interest concerning water usage is served. When allocating water rights, a State water regulatory agency must consider developing the water resources in an orderly manner, preventing waste and unreasonable use of water, ensuring water availability in times of stressed conditions (for example, drought), and protecting the environments associated with the water resources.

In the United States, there are two doctrines of water appropriation recognized by the States: (1) riparian and (2) prior appropriation. Riparian doctrine allows property owners to use water that is adjacent to their property, often like a property right. The prior appropriation doctrine evolved wherein the first user (senior) of water from a specific water source had highest senior legal right to continue to use the water. Most States in the eastern and southeastern part of the United States adhere to the riparian doctrine where the climate generally makes water more readily available. Some States in the Midwest and the western part of the United States, where the climate is more arid, follow the prior appropriation doctrine because water, usually from a sustainable source, often has to be diverted some distance before it is used.

Information and web links for surface-water and groundwater withdrawal laws and regulations (including the doctrine of appropriation, administering agency, criteria to consider when determining an individual water right, water withdrawal permit and application requirements, State water withdrawal fees, water withdrawal statutes and administrative codes, and links to other State-specific water withdrawal resources) for North Dakota, Montana, and South Dakota were obtained from the States. Each State has its own methods of regulating and reporting water usage within its jurisdiction. These methods can introduce problems when examining water use from sources, such as the Missouri River or Fox Hills aquifer (part of Upper Cretaceous aquifer system), that are shared across political boundaries. Without the one-to-one match for usage types and amounts used from a water source, it is difficult to develop a comprehensive water budget for the water source being evaluated.

North Dakota

In North Dakota, a permit is required for any surface or groundwater withdrawal, except those for which the amount used is less than 12.5 acre-ft/yr, and the use is for domestic, livestock, fish, wildlife, or recreation (North Dakota Legislative Branch, 2013b). The following questions are considered when a new appropriation of water is requested in North Dakota:

1. Is the use beneficial?
2. Is the amount requested reasonable?
3. What are previous uses for the source?
4. Can all uses be sustained from the source?
5. What are the effects?

Permitted withdrawals must be reported annually on individual response forms. Reports indicating unreasonable amounts of use for a given category or amounts exceeding the permitted amount are investigated by the office of the State Water Engineer. Also, during periods of water stress (for example, droughts), the State has the authority to temporarily suspend or amend the permits to the stressed source. The permitting of water in the State of North Dakota is administered by the NDSWC according to the authority and guidelines contained in the following references:

- North Dakota Legislative Branch (2013b)
- North Dakota State Water Commission (2015a, 2015b)

Montana

In Montana, a new surface-water or groundwater withdrawal requires the filing of an Application for Beneficial Water Use Permit with the Department of Natural Resources and Conservation, Water Resources Bureau. Any new surface-water withdrawal must be permitted with the exception of small livestock pits. Permits for groundwater withdrawal are required only for withdrawals in excess of 35 gallons per minute (gal/min). The following questions are considered when a new appropriation of water is requested in Montana:

1. Is the use beneficial?
2. Is the amount requested reasonable?
3. What are previous uses for the source?
4. Can all uses be sustained from the source?
5. What are the effects?

If the application is approved, the applicant receives a permit. Once a permit is received, the permittee then must construct the project, divert the water, and put the water to the intended use as outlined in the permit. The permitting of water in the State of Montana is administered by the Montana Division of Natural Resources and Conservation, Division of Water Resources according to the authority and guidelines contained in the following references:

- Montana Department of Natural Resources and Conservation (2016)
- Montana Legislature (2011)
- Administrative Code: Water Resources Bureau New Appropriation Rules (Mont. Admin. R. 36.12.101.2001 [2005]) http://www.mtrules.org/gateway/ruleno.asp?RN=36%2E12%2E2001
- Legislative Environmental Quality Council (2008)

South Dakota

In South Dakota, all surface and groundwater withdrawals require a water right permit, except for domestic water uses and water distribution systems that do not pump more than 18 gal/min. The following criteria are considered when a new appropriation of water is requested in South Dakota: (1) if water use requested is available, (2) is the water use beneficial, and (3) the potential for the proposed water use to impair other water rights.

After approval of a water right permit, the permit owner has 5 years to complete any construction. The owner then has an additional 4 years to put the water to beneficial use. A water right permit may be amended to extend the time for completion of construction, or the time may be extended to put the water to beneficial use. Once approved and water is being applied to beneficial use, changes may be made under auspices of the Chief Engineer of the Water Rights Program. Temporary water permits may be issued by the Chief Engineer when small amounts of public water are needed on a temporary basis. The permitting of water in the State of South Dakota is administered by the SDDENR according to the authority and guidelines contained in the following references:

- South Dakota water laws and rules (SDDENR, 2001, 2016a, b)
- South Dakota Legislature (1987)
- South Dakota water rights application (SDDENR, 2016c)

Research and Information Needs

The primary objective of this reporting activity is to characterize the water resources near areas of energy development in the Williston Basin. A secondary objective is the identification of research and information needs that could be relevant in the evaluation of the effects of energy development on water resources. The following summarizes the information and research needs identified during the aggregation and characterization of the scientific information related to groundwater, streams and rivers, water quality, produced water, and water use in the Williston Basin.

Groundwater Resources

Information needs identified during a study of groundwater availability in the lower Tertiary/Upper Cretaceous units include (1) the need for improved potentiometric surface maps for glacial units, (2) the availability of a uniform stream network digital geographic coverage that spans the international boundary with Canada, and (3) enhanced surface-water use information with regards to the gain and loss of streamflow to shallow groundwater, which would increase understanding of groundwater and surface-water interactions. In addition, there are large gaps between smaller areas within the Williston Basin and energy productions areas where geophysical data have been collected. With the exception of the East Poplar oil field study (Thamke and Craigg, 1997; Smith and others, 2006a, b, 2014; Thamke and Smith, 2014), there is a lack of borehole geophysical logging data to tie to specific hydrogeologic settings (lithologies and water chemistry). Though airborne and ground-based geophysical surveys have been used in the East Poplar oil field study and several other energy production areas of the United States, there has been no systematic coverage throughout the Williston Basin, particularly those areas developed for unconventional resources. Prioritization of sites for integrating geophysical, hydrologic, and ecosystem studies can be done in terms of areas of high risk (Preston and Chesley-Preston, 2015) or high vulnerability (Preston and others, 2014a, b), such as those identified in the “Lake and Wetland Resources” section of this report. In addition to these general priorities, land-use managers have specific, site-scale, high priority issues (Farag and Harper, 2014) such as design of remediation for accidents that release saline waters on the landscape. Airborne and ground-based geophysical surveys can provide unique and critical subsurface information needed to understand site- and landscape-scale processes related to salinization of ecosystems by natural and anthropogenic processes.

River and Stream Resources

Ice-jam flooding continues to be a problem within the Williston Basin, as evidenced by oil or gas well flooding (with associated leakage of oil from damaged wells) on the Missouri River downstream from the confluence with the Yellowstone River in 2014 (Associated Press, 2014). The USGS has published peak-flow frequency analyses for streamgages in the Williston Basin (Williams-Sether, 1992; Sando and others, 2008, 2016); however, ice-jam conditions can result in annual peak stages that are substantially higher than the stages associated with annual peak flows. The USGS has not published peak-stage frequency analyses for streamgages in the Williston Basin. The USGS NWIS database contains annual peak-flow data and annual peak-stage data. Detailed analysis and description of annual peak flow and annual peak stage relations for streamgages in the Williston Basin might provide valuable information to assist in better understanding ice-jam issues; furthermore, publication of peak-stage frequency analyses for streamgages in the Williston Basin might assist in structure design activities in the Williston Basin.

In much of the Williston Basin, there are numerous stock dams and diversion dams, and the cumulative effect of these small impoundments on streamflow is understood poorly; furthermore, the locations and characteristics of most of the small dams are not documented in existing datasets. In responding to spills or leakage of oil or produced water, knowledge of the presence and characteristics of small dams could be important in evaluating potential effects on surface-water and groundwater resources. With advancements in remote-sensing technologies, it might be feasible to complete remote-sensing analysis of aerial photography or satellite imagery to produce a dataset that documents locations and characteristics of small dams in the Williston Basin.

Quality of Water Resources

Consistent with findings from Bowen and others (2015), the information provided in this report identifies substantial limitations of the available data to answer water-quality questions related to unconventional oil and gas development in the Williston Basin. Water-quality data collected specifically for energy development investigations are scarce, and a national water-quality monitoring program focused on energy development does not exist. The number of small-scale water-quality studies with data specific to energy development is sparse. A groundwater-quality study, specifically of the Upper Fort Union aquifer, was completed by the USGS in 2014 (McMahon and others, 2014). Results indicated that there was no evidence that energy-development activities affected groundwater quality; however, it is important to consider these results in the context of groundwater age. Most samples were recharged before the early 1950s and had carbon-14 ages ranging from less than 1,000 to greater than 30,000 years; thus, the wells sampled in the McMahon and others (2014) study may not be as well suited for detecting contamination associated with surface spills as compared to shallower wells screened near the water table. Although the deeper aquifers remain an important potential source of water, and monitoring of these resources should continue, future studies focusing primarily on shallower groundwater sources, such as the Quaternary unconsolidated aquifer system and surface-water systems, may better characterize potential effects of unconventional oil and gas development. Additional water-quality data are collected by energy development companies, but generally the data are proprietary and not accessible to the public.

The large water-quality dataset in this report presented several challenges that limit the ability to characterize the status of water quality in the Williston Basin. Challenges with the dataset include duplicate sites from multiple agencies, varied sample collection protocols and analytical methods, differing levels of data-quality reviews, and variations in the reporting processes from the collecting agencies and analytical laboratories. The reported constituent results may not always be reviewed by agencies before entry in the WQP, potentially resulting in errors in reporting and thus contributing to the wide range of reported concentrations. The large range in concentrations also may be attributed to variations in sample design for several of the independent studies. Water-quality data collected for specific studies (for example, studies of water-quality during or after storm events, or in areas of known water-quality issues) may target water-quality constituents not commonly associated with energy development.

Specific gaps in the water-quality dataset for the Williston Basin that have been identified include the following:

- Few water-quality sampling sites in the Montana and South Dakota parts of the Williston Basin.
- Insufficient data on effects of energy development on Lake Sakakawea.
- Insufficient long-term data required for completing trend analyses.
- Insufficient evaluation of groundwater depths for identifying aquifer units.

A complete evaluation of all constituents was beyond the scope for this study. Additional analyses that would help better plan and inform future research needs include the following:

- Evaluating sites monitored after unconventional oil and gas development for differences in water quality based on their distance from oil and gas wells (less than 1 kilometer compared to more than 1 kilometer).
- Comparing groundwater and surface-water quality samples collected from sites near oil and gas wells before and after unconventional oil and gas development.
- Identifying sites and constituents that have enough data to complete trend analyses.
- Comparing trends between sites near and not near oil and gas wells.
- Evaluating water samples with oxygen and sulfate data as a rough indicator of samples that are methanogenic.

Coordination between agencies (State, Tribal, and Federal) and private industry concerning monitoring could improve the design of future assessments of water quality and may reduce overall sampling costs. This coordination could focus on improving cooperative approaches to reduce redundancy in sampling programs and develop a consistent design (sampling and analytical methods) for long-term water-quality assessments. The types of water-quality data included in the assessments could be evaluated to ensure the collection of the supplemental data needed in the Williston Basin. Several considerations for coordinated agency (State, Tribal, and Federal) and private industry water-quality sampling programs for the Williston Basin include the following:

- Designing an efficient Williston Basin water-quality sampling program that requires spatial and temporal components to minimize redundancy.
- Using a systematic approach to identify specific constituents that could be monitored in areas of unconventional oil and gas development, similar to the approach documented by Olsen and others (2013). Constituents that could be considered include boron, chloride, bromide, iodine, fluoride, manganese, lithium, radium, strontium isotopes, volatile organic compounds, and isotopes of inorganic ions (such as hydrogen and carbon).
- Identifying consistent sampling locations for groundwater, streams and rivers, and lakes and reservoirs to generate data to evaluate future water-quality conditions, including comparisons against historical samples.

- Focusing studies on shallower groundwater sources, such as the Quaternary aquifers, and surface-water systems to better characterize potential effects of unconventional oil and gas development. Deeper aquifers remain an important potential resource and should be monitored as well.
- Installing continuous water-quality monitors to potentially determine spills on a real-time basis.

Produced Water

Although the USGS NPWGD is valued as a source of geochemical data for produced waters within the Williston Basin, Blondes and others (2014) have described the limitations, uncertainties, and considerations associated with these data. Specifically, much of the information in the database cannot be independently verified because methods of collection, sample preservation, chemical analysis, assignment of geologic units, and record keeping were not standardized or have changed with time. It also is important to note that minimum reporting levels and quality-assurance information are typically lacking. The distribution and amount of water produced among geologic units may not be represented fully by the samples in the NPWGD. Data collected in the past may not resemble current production because of water flooding, recompletion in other intervals, and workovers within the well. Although criteria were applied to remove the questionable samples, the culling of unrepresentative data is considered preliminary.

It is important to note that the wealth of information available through the NPWGD provides an opportunity for further data mining activities. Although the NPWGD has limitations and missing data, there are opportunities for further analysis to examine site-specific, temporal evaluations of data. Detailed records could be retrieved from the Oil and Gas Information system database (Montana Board of Oil and Gas Conservation, 2015), the North Dakota Industrial Commission (2015), Department of Mineral Resources, Oil and Gas Division (Oil and Gas Division, 2015), and possibly private industry. Further work could be done to compare not only the geochemistry among units, but also the spatial variation of geochemistry within those units. In addition, data could be evaluated to examine chemistry at individual drill sites within sampled geologic units.

Although the USGS has previously examined areas of horizontal drilling combined with hydraulic fracturing of shale gas, the USGS has completed little work in areas of tight-oil reservoirs, such as the Bakken Formation; consequently, there are opportunities for more complete characterization of the quality and quantity of produced waters in the area. The chemical and isotopic composition of produced waters can be further developed to characterize the range of chemical, microbial, and isotopic compositions and quantities of “end-member” produced waters. The chemical and isotopic characterization of produced water from all hydrocarbon reservoirs is needed to assess the potential mixing of produced waters with the freshwater (surface-water and groundwater) resources of an area. In addition, little work has been done to characterize hydraulic fracturing fluids and flowback waters from samples collected immediately after hydraulic fracturing followed by samples collected at fixed numbers of days after hydraulic fracturing. Future sample collection, chemical analysis, and interpretation of produced-water chemistry within the Williston Basin would complement the USGS NPWGD and previously acquired data from oil-production wells by the USGS.

Water-Use Data

The effects of rapid development of new oil and gas resources, and the associated infrastructure, during the last decade on water sources in the upper Missouri River Basin, specifically in the Williston Basin, have caused concerns among government agencies, resource managers, environmentalists, Tribal groups, and the public. Long-term energy development requires sources of high-quality, sustainable, or renewable water supplies, and updated information about water use associated with oil and gas development in the upper Missouri River Basin. To assess the feasibility and desirability of several management options for water resources of the upper Missouri River Basin, an improved understanding of water use is needed to provide a reliable resource from which to make the best management decisions in the future.

Detailed information about water use in the Williston Basin is scant. The Williston Basin spans several political boundaries, and within the boundaries are a variety of regulatory and monitoring controls on water so that water-use data reporting is not seamless across the span of the area; for example, the database FracFocus is a hydraulic fracturing chemical registry website designed to provide information about chemicals and some water used in the hydraulic fracturing of oil and gas wells (Ground Water Protection Council and the Interstate Oil and Gas Compact Commission, 2010). The database is maintained and hosted by the Ground Water Protection Council (http://www.gwpc.org/) and the Interstate Oil and Gas Compact Commission (http://iogcc.publishpath.com/). The FracFocus website provides a means for industry to voluntarily supply hydraulic fracturing chemical data and some water data in a consistent and centralized location. Because the data are voluntarily submitted by industry and the States have differing reporting requirements, FracFocus’ use has to be reviewed on a State-by-State basis rather than by a region or basin that extends beyond State boundaries. A study of water use with data on withdrawals and returns from water users in the Williston Basin, and investigations of trends in the overall water usage in the Williston Basin area with respect to the ongoing energy development, was published by McShane and others (2020).

Although the power sector is responsible for the highest withdrawal volumes of water in the Nation, and certainly within the Williston Basin, statistics on the consumption and withdrawal rates of individual powerplants are inconsistent and scarce (U.S. Government Accountability Office, 2015). Power sector water-use data are collected by State and Federal agencies that may not always use the same methods or definitions in determining water withdrawals (Kenny and others, 2009). Data are not comprehensive and may not contain information on nuclear facilities and some natural gas combined-cycle technologies (EIA, 2015). Additionally, the quality of data is of concern because many powerplants report water withdrawal and consumption values that are considerably less or greater than values cited in general studies of water use in powerplants. The National Energy Technology Laboratory compiled water use data in their 2007 Coal Power Plant Data Base; however, these data are limited by the availability and quality of EIA information. A similar public database has not been developed for natural gas or nuclear power-generating facilities (Macknick and others, 2012).

Water permitting and monitoring for energy development differs by State. One State may require reporting of annual water use as a requirement for keeping a water permit active, whereas another State may not require any annual reporting in the same industry. Lack of compatible water-use data in all sectors of energy development make it difficult to determine the adequacy of water resources for developing and maintaining energy development and for looking at long-term trends.

Summary

The Williston Basin has been a leading domestic oil and gas producing area for more than 50 years. While oil production initially peaked within the Williston Basin in the mid-1980s, production rapidly increased in the mid-2000s, largely because of improved horizontal (directional) drilling and hydraulic fracturing methods. The improvement in extraction methods made oil and gas resources in low-permeability sandstones and shales, or “tight-oil” formations such as the Bakken and Three Forks Formations, accessible.

In 2012, energy development associated with the Bakken Formation was identified as a priority requiring collaboration toward improved timeliness of issuing permits for new wells combined with reasonable measures to maintain environmental quality. Shortly thereafter, the Bakken Federal Executive Group was created to address common challenges associated with energy development. The Bakken Federal Executive Group partner agencies identified a gap in current understanding of the cumulative environmental challenges attributed to energy development throughout the area, resulting in an effort to aggregate scientific data, and identify areas of additional research and information needs related to natural resources within areas of energy development in the Williston Basin. As part of this effort, water resources in the area, including groundwater; streams and rivers; and lakes, reservoirs, and wetlands, were characterized and described in terms of physical presence, flow characteristics, recharge, water quality, and water use. Waters produced during energy-development activities also were discussed even though these waters are not considered usable resources of the area.

Groundwater Resources

Three major hydrogeologic units, the glacial, lower Tertiary, and Upper Cretaceous aquifer systems, supply most of the groundwater used for domestic, stock, agricultural, and industrial purposes. The glacial aquifer system overlies parts of the lower Tertiary and Upper Cretaceous aquifer systems in the northeastern part of the Williston Basin. The glacial aquifer system is highly variable, with multiple, disconnected, but locally productive sand and gravel deposits in the Williston Basin, that are sources of water for thousands of shallow wells. The lower Tertiary aquifer system consists of the upper and lower Fort Union aquifers separated by the middle Fort Union hydrogeologic unit. The upper Fort Union aquifer is present in Montana and North Dakota and is the most used aquifer of the lower Tertiary aquifer system. Because of variable lithology, the middle Fort Union hydrogeologic unit may act as a confining unit or as an aquifer in parts of the Williston Basin. The Upper Cretaceous aquifer system is the deepest and most spatially extensive of the major hydrogeologic units underlying the Williston Basin. The Upper Cretaceous aquifer system consists of the upper Hell Creek hydrogeologic unit, lower Hell Creek aquifer, and Fox Hills aquifer, all of which are present throughout most of the Williston Basin. Although the lower Hell Creek and Fox Hills aquifers are sources of water in much of the Williston Basin, the upper Hell Creek hydrogeologic unit may act as a confining unit in some areas and as an aquifer in other areas.

Groundwater recharge to the glacial, lower Tertiary, and Upper Cretaceous aquifer systems is from stream infiltration, precipitation, and irrigation, and discharge from these aquifer systems is primarily as groundwater discharge to streams (base flow) and reservoirs, but also is due to withdrawals from wells for domestic, irrigation, public-supply, and self-supplied industrial uses. Water in the lower Tertiary and Upper Cretaceous aquifer systems primarily is under confined conditions. Where aquifers in the lower Tertiary and Upper Cretaceous aquifer system are covered by the glacial aquifer system or unconsolidated alluvial deposits, water can percolate downward through these deposits to the bedrock aquifers. South of the glacial aquifer system where the upper Fort Union aquifer is unconfined, localized groundwater flows from topographically high areas toward stream valleys. In the other lower Tertiary and Upper Cretaceous hydrogeologic units, groundwater flow generally is from the west and southwest toward the east, with regional discharge to streams. Potentiometric surfaces for the upper Fort Union and lower Fort Union aquifers are similar in the northern and western parts of the Williston Basin, except for less relief for the lower Fort Union aquifer, indicating probable hydraulic connection between the two aquifers.

In addition to describing groundwater resources for the three major hydrogeologic units, this report included information on the deeper Lower Cretaceous and upper and lower Paleozoic aquifers/aquifer systems. These aquifers/aquifer systems are used rarely and mainly are undeveloped in most of the Williston Basin because of uneconomical drilling depths, poor groundwater quality unsuitable for most uses without treatment, or both; however, within the Williston Basin these units are used or may have potential use as water supplies if treated, reservoirs for injection of produced waters or other anthropogenic wastes, or sources of mineral and energy resources.

River and Stream Resources

The Williston Basin is within two major river systems—about 86 percent of the Williston Basin is in the Missouri River system, and about 12 percent is in the Hudson Bay system. The remaining 2 percent is in the Devils Lake closed basin. Within the Williston Basin, 360 U.S. Geological Survey (USGS) streamgages have 10 or more years of data collection through water year 2014, and 194 of the 360 have year-round or seasonal continuous streamflow data to produce daily streamflow records and also annual peak-flow records that represent the maximum instantaneous discharge for each year of a streamgage's operation. The length of data collection for the 194 streamgages ranges from 10 to 112 years, with a median of about 25 years. A substantial part of the Missouri River Basin upstream from the Williston Basin (hereinafter referred to as the "upstream Missouri River Basin") is mountainous, with about 31 percent of the drainage area being higher than 6,000 feet in elevation. Much of the streamflow generated in the upstream Missouri River Basin results from high-elevation snowmelt that typically is in May and June; however, the upstream Missouri River Basin is somewhat strongly regulated, with four major reservoirs with multipurpose operations that includes flood control; the four reservoirs individually have total storage capacities that exceed 325,000 acre-feet and cumulatively have about 4,300,000 acre-feet of total storage capacity. Similar to the upstream Missouri River Basin, much of the streamflow generated in the upstream Yellowstone River Basin results from high-elevation snowmelt that typically occurs in May and June; however, the upstream Yellowstone River Basin has substantially less major regulation than the upstream Missouri River Basin, with a single major reservoir with multipurpose operations that include flood control.

Streamflow characteristics were described for 17 streamgages in Williston Basin that had greater than 50 years of data collection from water years 1954 through 2014. The selected streamgages were classified as representing either major rivers (the Missouri or the Yellowstone Rivers, with a substantial part of the drainage basin outside the Williston Basin) or large streams (drainage basins from 551 to 22,452 square miles, most of which is within the Williston Basin). Monthly and annual streamflow characteristics were calculated to look at seasonal and interannual variability in streamflow and provide general information on primary drivers of streamflow and reliability of streamflow on seasonal and multiple-year scales. Daily-streamflow and annual-extreme-flow characteristics were calculated to provide information on short-term and extreme streamflow conditions, such as floods or zero-streamflow conditions that happen within short periods. Short-term streamflow statistics provide hydrologic information that might be relevant to infrastructure design and also evaluating potential causes and environmental effects of accidental spills, leaks, or discharges of water or products to the system.

Streamflows for the streamgages on the Missouri River, generally displayed large effects of regulation as evidenced by generally small seasonal and interannual variability in streamflows. Differences in the timing of annual peak flows between Missouri River stations primarily reflect tributary inflows; however, most of the Missouri River streamflow is generated upstream from the Williston Basin, and streamflow inputs generally are small in the reach from below Fort Peck Dam to the confluence with the Yellowstone River. Streamflows for the Yellowstone River sites reflected a high-elevation-snowmelt dominated hydrologic regime within a large predominantly unregulated drainage basin. The snowmelt-dominated hydrologic regime is evidenced by somewhat large seasonal variability in streamflows, but generally small interannual (year-to-year) variability in streamflows. Similar to the Missouri River, most of the Yellowstone River streamflow is generated upstream from the Williston Basin, and streamflow inputs are small within the Williston Basin.

In general, streamflow characteristics of large streams originating in or near the Williston Basin are driven by complex interactions between climatic, geologic, topographic, and land-cover and use characteristics, and interactions of groundwater and surface water. Anthropogenic activities, including reservoir and irrigation operations, also contribute to streamflow variability. Streams in the Williston Basin generally have large seasonal and interannual variability in streamflows. Large-scale spatial differences in streamflow characteristics are substantially affected by spatial variability in precipitation, air temperature, and drainage characteristics (especially the density of depressional storage or percent of area covered by lakes and wetlands). Variability in snowpack accumulation in relation to the frequency and intensity of spring and summer rainfall contributes to differences in seasonal streamflow characteristics among streams.

Lakes and Wetland Resources

State-wide National Wetlands Inventory datasets were acquired for Montana, North Dakota, and South Dakota on March 16, 2015, and used to classify lake, wetlands, and other surface-water features other than streams and rivers. A total of 1,428,501 National Wetlands Inventory palustrine and lacustrine features were identified using the Cowardin system within the Williston Basin, and these features were combined to produce estimates of the numbers of features for four classifications: other, wetland, pond, and lake, which are collectively referred to as surface-water features. Spatial distribution information, specifically number, area, and percent coverage of National Wetlands Inventory features, were calculated for the Williston Basin, the area inside and outside of the multi-State Prairie Pothole Region, and each State and county. The surface-water feature dataset also was analyzed in relation to the State-maintained oil or gas well databases to investigate the proximity of surface-water features to energy-related wells. Proximity analyses to determine the number, area, and percent of surface-water features within 0.4, 0.8, and 1.6 kilometer (km) of at least one oil or gas well were completed for the Williston Basin, the area inside and outside of the Prairie Pothole Region, and each State and county.

Within the Williston Basin, the total number, area, and percent coverage of surface-water features are greater in the Prairie Pothole Region than the area outside of the region; for example, the Prairie Pothole Region covers only 28.9 percent of the Williston Basin yet contains three times the number of surface-water features as the area outside the region. Despite having nearly three-quarters of all surface-water features within the Williston Basin, the area of surface-water features in the Prairie Pothole Region is only 1.2 times greater than the area of surface-water features outside the region, mainly because several large lakes along the Missouri River exist outside the region. Finally, the percent of the landscape covered by surface-water features is 2.9 times greater within the Prairie Pothole Region compared to the area outside the region. The spatial distribution of surface-water features also varied among Montana, North Dakota, and South Dakota and varied among individual counties within the Williston Basin. Although the area of North Dakota in the Williston Basin is only 1.4 times larger than Montana, North Dakota has more than 6.5 times as many surface-water features. Similarly, the area of North Dakota in the Williston Basin is only 2.7 times greater than South Dakota, yet it has 16.6 times as many surface-water features.

Across the Williston Basin, most oil or gas wells (98.7 percent) are within 1.6 km of surface-water features, whereas most surface-water features (69.6 percent) were not proximate to oil or gas wells; however, this number will likely decrease with expected future development. While many surface-water features are proximate to only one oil or gas well, some surface-water features are proximate to numerous oil or gas wells and some oil or gas wells are proximate to numerous surface-water features.

The proximity of surface-water features to oil or gas wells in the Williston Basin was different inside and outside the Prairie Pothole Region. The Prairie Pothole Region covers only 28.9 percent of the Williston Basin and contains only 29.1 percent of the total identified oil or gas wells; however, the Prairie Pothole Region contains about three times as many surface-water features proximate to oil or gas wells in all three buffer distances (0.4, 0.8, and 1.6 km) as compared to the area outside the Prairie Pothole Region. The proximity of surface-water features to oil or gas wells also varied among States and among individual counties within the Williston Basin. North Dakota has about 2.1 and 24.7 times as many oil or gas wells as Montana and South Dakota, respectively; however, it also has 6.5 and 16.6 times as many surface-water features, respectively. Additionally, the total number and area of surface-water features proximate to oil or gas wells in North Dakota are much greater than Montana and South Dakota in all three buffer distances. Similarly, Montana has a much greater number of oil or gas wells and surface-water features compared to South Dakota and, therefore, a greater total number and area of surface-water features proximate to oil or gas wells. Notably, the percentage of surface-water features proximate to oil or gas wells in all three buffer distances was highest in Montana, followed by North Dakota and South Dakota.

Quality of Water Resources

Water-quality data were aggregated from two data sources: (1) the Water-Quality Portal, sponsored by the USGS, U.S. Environmental Protection Agency (EPA), and National Water Quality Monitoring Council; and (2) a data compilation completed as part of the USGS National Water-Quality Assessment project. The Water-Quality Portal integrates publicly available water-quality data from databases maintained by the USGS, EPA, and U.S. Department of Agriculture, including water-quality data from Tribal, State, and local databases. Water-quality data for 15 commonly measured water-quality constituents were aggregated for groundwater, rivers and streams, and lakes and reservoirs. For each aggregated dataset (groundwater, rivers and streams, and lakes and reservoirs), analyses of the water-quality data included summary statistics, maps of spatial distribution of constituent values, boxplots of constituent values by timeframe or hydrogeologic unit, spatial comparisons of site locations and constituent values to petroleum well density, and comparisons of the constituent values measured to EPA drinking-water standards/guidelines.

Produced Water

Produced water includes all fluids brought to the surface along with the targeted hydrocarbons as part of the oil and gas exploration and extraction processes. These fluids may include formation water (waters that co-exist with rock/oil/gas), hydraulic fracturing fluids, and other combinations of water and chemicals used during oil and gas well drilling, development, treatments, recompletions, and workovers. Produced water datasets were aggregated from two sources: the USGS National Produced Waters Geochemical database (ver. 2.1) and a series of projects focused specifically on sampling produced water in the Williston Basin from 2010 to 2014.

The National Produced Waters Geochemical database was useful for a general understanding of produced-water chemistry. Produced waters are characterized by extreme salinity and contain elevated concentrations of other constituents (including arsenic, barium, cadmium, lead, zinc, radium-226/radium-228, and ammonium) that could negatively affect water and aquatic resources if released. Produced waters also have a generally unique chemical (isotopic) signature that may be useful in tracking water from different geologic units; for example, the oxygen/deuterium and strontium ratio values measured in brine waters from the Bakken Formation are distinct from brines collected from other geologic units in the Williston Basin.

Water-Use Data

Water-use information related to energy production in the area was aggregated and summarized. The summary of water use is not limited to oil and gas production but includes water used to produce all types of energy resources in the Williston Basin, including coal/lignite, thermoelectric power, oil and gas, hydropower, biomass and biofuels, wind, geothermal, and solar. Each State has its own methods for regulating and reporting water usage within its jurisdiction. These methods can introduce problems when examining water use from sources, such as the Missouri River or Fox Hills aquifer, that are shared across political boundaries. Without the one-to-one match for usage types and amounts used from a water source, it is difficult to develop a comprehensive water budget for the water source being evaluated. A large amount of freshwater is required to prepare a well for oil and gas well production; in some cases, 3 to 7 million gallons of water are needed per well. The EPA estimates that hydraulic fracturing in the Williston Basin uses between 70 to 140 billion gallons per year. Water also is used for myriad other purposes related to ancillary oil and gas extraction. In addition to water used for immediate energy development, the expanded human workforce migrating into the area and other support staff who have moved into the area during the development also use water.

Research and Information Needs

Research and information needs were identified that could be relevant in the evaluation of the effects of energy development on water resources. Information needs related to the evaluation of groundwater resources include the following: improved potentiometric-surface maps for glacial units; availability of a uniform stream network digital geographic coverage that spans the international boundary with Canada; enhanced surface-water use information with regards to the gain and loss of streamflow to shallow groundwater, which would increase understanding groundwater and surface-water interactions; and expanded geophysical assessments. Gaps in the availability of streamflow data include the lack of information on ice-jam flooding despite potential for effects to infrastructure (pipelines, roads, and facilities) and an understanding of the cumulative effects of largely undocumented stock and diversion dams. Although this study resulted in the aggregation of a large quantity of water-quality data, the availability of consistently collected, systematically processed and reported data over large parts of the Williston Basin is sparse. Few samples have been analyzed for constituents that may indicate the effect of energy development on water resources. Constituents that could be considered include boron, chloride, bromide, iodine, fluoride, manganese, lithium, radium, strontium isotopes, volatile organic compounds, and isotopes of inorganic ions (such as hydrogen and carbon). Collaboration between Tribal, Federal, State, and local entities to identify a common study design, common monitoring constituents, and consistent sampling locations would generate datasets with broad utility and would likely result in overall cost savings for monitoring over time. Similarly, there is a need for standardized sample collection, processing, laboratory analytical methods, and the collection of ancillary data for produced waters sampling. Additional characterization of the range of chemical, microbial, and isotopic compositions and quantities of “end-member” produced waters, and the collection of time-series datasets to document the changes in produced waters during and after well development also were needs identified during this study. Water-use estimates would be improved through the implementation of comprehensive studies of water use from groundwater and surface-water sources using consistent methodologies across the Williston Basin. The submission of chemical and water data related to hydraulic fracturing collected by the oil and gas industry would add to the quantity of available data. Consistent implementation of regulations and monitoring controls across political boundaries (State, county, and international) would further improve the consistency of data available for the estimates of water use.

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Appendix C1

Within the Williston Basin, 360 U.S. Geological Survey streamgages have 10 or more years of data collection through water year 2014. The locations and summary information for these streamgages are presented in figure 1–1 and table 1–1.

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.

The following list of tables are included in the associated data release (Boughton and others, 2022) and are provided here as an aid to readers:

Table 1–2. Summary statistics for monthly and annual streamflows at selected streamgages.

Table 1–3. Summary statistics for annual extreme flows at selected streamgages.

Table 2–1. Total number of surface-water features not including streams and rivers for the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 2–2. Area of surface-water features not including streams and rivers for the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 2–3. Percent coverage of surface-water features not including streams and rivers for the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 2–4. Number of surface-water features not including streams and rivers located within 0.4, 0.8, and 1.6 kilometers of at least one oil well within the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 2–5. Area of surface-water features not including streams and rivers located within 0.4, 0.8, and 1.6 kilometers of at least one oil well within the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 2–6. Percent of surface-water features not including streams and rivers located within 0.4, 0.8, and 1.6 kilometers of at least one oil well within the portions of the 71 counties of Montana, North Dakota, and South Dakota located wholly or partially within the Williston Basin.

Table 3–1. Summary of constituents analyzed in groundwater regardless of constituent fraction type and units reported.

Table 3–2. Summary of constituents analyzed in streams and rivers regardless of constituent fraction type and units reported.

Table 3–3. Summary of constituents analyzed in lakes and reservoirs regardless of constituent fraction type and units reported.

Table 3–4. Aquifers sampled in the Williston Basin.

Table 3–5. Groundwater sites sampled for at least one of the five commonly monitored parameters during 1970 through 2014 and collecting agencies.

Table 3–6. Summary of stream and river sites in the Williston Basin that had ten or more samples of at least one of the five primary parameters during 1970 through 2014 and collecting agencies.

Table 3–7. Lake and reservoir sites in the Williston Basin that had samples of at least one of the five primary parameters during 1970 through 2014 and collecting agencies.

Table 3–8. Summary statistics for specific conductance in groundwater in the Williston Basin from 1970 through 2014.

Table 3–9. Summary statistics for total dissolved solids in groundwater in the Williston Basin from 1970 through 2014.

Table 3–10. Summary statistics for pH in groundwater in the Williston Basin from 1970 through 2014.

Table 3–11. Summary statistics for sulfate in groundwater in the Williston Basin from 1970 through 2014.

Table 3–12. Summary statistics for chloride in groundwater in the Williston Basin from 1970 through 2014.

Table 3–13. Summary statistics for selected trace metals in groundwater in Quaternary aquifers in the Williston Basin for samples analyzed during 1993 through 2014.

Table 3–14. Summary statistics for selected trace metals in groundwater in lower Tertiary aquifers in the Williston Basin for samples analyzed during 1993 through 2014.

Table 3–15. Summary statistics for selected trace metals in groundwater in Upper Cretaceous aquifers in the Williston Basin for samples analyzed during 1993 through 2014.

Table 3–16. Summary statistics for specific conductance at selected stream and river sites in the Williston Basin from 1970 through 2014.

Table 3–17. Summary statistics for total dissolved solids at selected stream and river sites in the Williston Basin from 1970 through 2014.

Table 3–18. Summary statistics for pH at selected stream and river sites in the Williston Basin from 1970 through 2014.

Table 3–19. Summary statistics for sulfate at selected stream and river sites in the Williston Basin from 1970 through 2014.

Table 3–20. Summary statistics for chloride at selected stream and river sites in the Williston Basin from 1970 through 2014.

Table 3–21. Summary statistics for selected trace metals in streams and rivers in the Williston Basin at sites that had 10 or more samples analyzed during 1993 through 2014.

Table 3–22. Summary statistics for specific conductance at selected lake sites in the Williston Basin from 1970 through 2014.

Table 3–23. Summary statistics for total dissolved at selected lake sites in the Williston Basin from 1970 through 2014.

Table 3–24. Summary statistics for pH at selected lake sites in the Williston Basin from 1970 through 2014.

Table 3–25. Summary statistics for sulfate at selected lake sites in the Williston Basin from 1970 through 2014.

Table 3–26. Summary statistics for chloride at selected lake sites in the Williston Basin from 1970 through 2014.

Table 3–27. Summary statistics for specific conductance at selected sites on Lake Sakakawea, North Dakota from 1993 through 2014.

Table 3–28. Summary statistics for total dissolved solids at selected sites on Lake Sakakawea, North Dakota from 1993 through 2014.

Table 3–29. Summary statistics for pH at selected sites on Lake Sakakawea, North Dakota from 1993 through 2014.

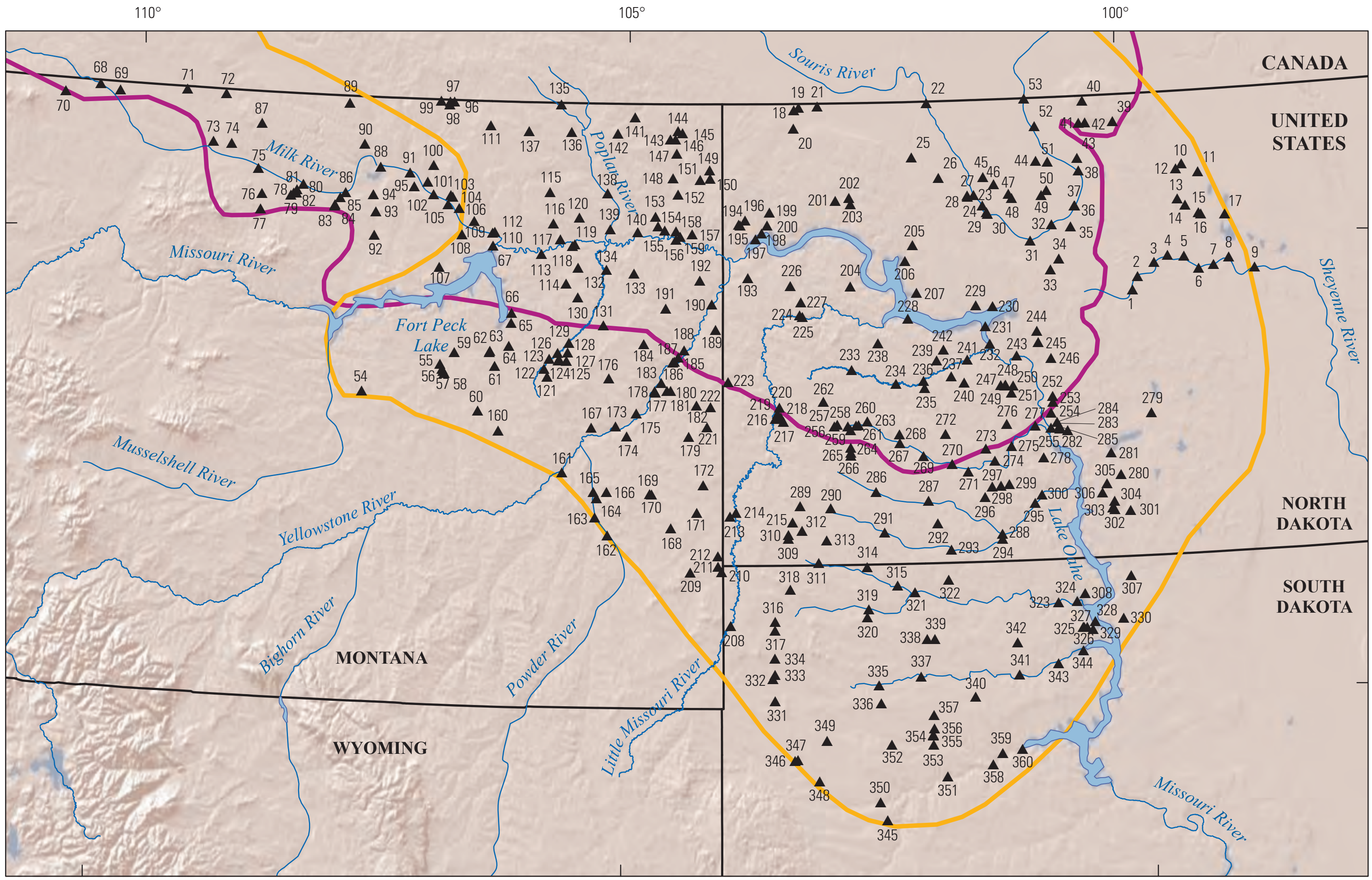
Table 3–30. Summary statistics for sulfate at selected sites on Lake Sakakawea, North Dakota from 1993 through 2014.

Table 3–31. Summary statistics for chloride at selected sites on Lake Sakakawea, North Dakota from 1993 through 2014.

Table 3–32. Summary statistics for selected trace metal data in lakes and reservoirs in the Williston Basin at sites that had 10 or more samples analyzed during 1993 through 2014.

Table 4–1. Geochemical data retrieved from the U.S. Geological Survey National Produced Waters Geochemical Database v.2.1.

Table 4–2. Chemistry of produced waters from Bakken and Three Forks Formation oil-production wells sampled by the U.S. Geological Survey, Montana and North Dakota, 2012–2014.



Base map modified from U.S. Geological Survey, Esri, and Commission for Environmental Cooperation digital data variously dated, various scales. Base map image is the intellectual property of Esri and is used herein under license.

Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W.
North American Datum of 1983

0 25 50 75 100 MILES
0 25 50 75 100 KILOMETERS

EXPLANATION

- Williston Basin boundary
- Bakken Formation boundary
- ▲ U.S. Geological Survey streamgage and identifier (table 1–1)

Figure 1–1. U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
1	5054500	Sheyenne River above Harvey, ND	47.7028	−99.9490	424	154	1956	2014	59	1956	2014
2	5055000	Sheyenne River near Harvey, ND	47.7903	−99.8907	534	174	1943	1956	12	1946	1956
3	5055100	North Fork Sheyenne River near Wellsburg, ND	47.8761	−99.7185	693	207	1958	1967	10	1958	1967
4	5055200	Big Coulee near Maddock, ND	47.9195	−99.5801	140	90	1957	1973	16	1957	1967
5	5055300	Sheyenne River above Devils Lake State Outlet near Flora, ND	47.9078	−99.4156	1,661	591	2005	2014	10	2005	2014
6	5055400	Sheyenne River below Devils Lake State Outlet near Bremen, ND	47.8214	−99.2761	1,716	622	2005	2014	10	2005	2014
7	5055500	Sheyenne River at Sheyenne, ND	47.8392	−99.1251	1,790	660	1930	1951	15	1929	1951
8	5055520	Big Coulee near Fort Totten, ND	47.8825	−98.9676	23.2	7.7	1966	1975	10	1966	1975
9	5056000	Sheyenne River near Warwick, ND	47.8056	−98.7162	2,070	760	1950	2014	65	1950	2014
10	5056020	Mauvais Coulee Tributary near Bisbee, ND	48.5167	−99.3865	--	8.9	1955	1973	19	--	--
11	5056060	Mauvais Coulee Tributary No. 3 near Cando, ND	48.4575	−99.2243	60.2	60.2	1955	2014	45	1986	2014
12	5056080	Mauvais Coulee Tributary No. 4 near Bisbee, ND	48.4861	−99.4476	59.6	53	1955	1973	19	--	--
13	5056300	Little Coulee at Leeds, ND	48.2875	−99.4490	280	140	1956	1973	17	1956	1967
14	5056340	Little Coulee near Leeds, ND	48.2433	−99.3729	320	170	1998	2014	17	1998	2014
15	5056390	Little Coulee near Brinsmade, ND	48.1875	−99.2432	350	--	1976	1997	20	1975	1997

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
16	5056400	Big Coulee near Churchs Ferry, ND	48.1778	−99.2212	1,620	1,462	1950	1997	48	1951	1997
17	5056410	Channel A near Penn, ND	48.1667	−98.9801	930	790	1984	2004	21	1984	1999
18	5113450	Long Creek Tributary No. 2 near Crosby, ND	48.9581	−103.3163	6.69	5.6	1960	1973	14	--	--
19	5113500	Long Creek near Crosby, ND	48.9750	−103.2682	2,080	780	1943	1965	23	1943	1965
20	5113520	Long Creek Tributary near Crosby, ND	48.8364	−103.3224	0.35	--	1960	2009	28	--	--
21	5113600	Long Creek near Noonan, ND	48.9811	−103.0766	1,790	630	1960	2014	55	1960	2014
22	5114000	Souris River near Sherwood, ND	48.9900	−101.9582	8,940	3,040	1904	2014	87	1930	2014
23	5116000	Souris River near Foxholm, ND	48.3722	−101.5054	9,470	3,270	1937	2014	78	1937	2014
24	5116100	Souris River Tributary near Burlington, ND	48.3011	−101.4207	0.13	--	1959	2006	24	--	--
25	5116135	Tasker Coulee Tributary near Kenaston, ND	48.6331	−102.1254	4.62	--	1996	2009	13	--	--
26	5116200	Des Lacs River Tributary near Donnybrook, ND	48.4931	−101.8560	3.82	--	1956	1973	18	--	--
27	5116500	Des Lacs River at Foxholm, ND	48.3706	−101.5702	939	539	1939	2014	70	1904	2014
28	5116550	Fuller Coulee at Foxholm, ND	48.3625	−101.5671	12.8	5.9	1955	1973	19	--	--
29	5117200	Souris River Tributary No. 2 near Burlington, ND	48.2547	−101.3804	2.04	--	1960	1973	14	--	--
30	5117500	Souris River above Minot, ND	48.2458	−101.3713	10,600	3,900	1882	2014	112	1903	2014
31	5119410	Bonnes coulee near Velva, ND	48.0583	−100.9504	53	--	1965	2013	33	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
32	5120000	Souris River near Verendrye, ND	48.1597	−100.7296	11,300	4,400	1937	2014	78	1937	2014
33	5120180	Wintering River Tributary near Kongsberg, ND	47.8625	−100.7596	1.54	--	1998	2009	12	--	--
34	5120200	Wintering River near Bergen, ND	47.9306	−100.6713	176	126	1957	1978	22	1957	1978
35	5120500	Wintering River near Karlsruhe, ND	48.1383	−100.5399	705	285	1937	2014	78	1937	2014
36	5121000	Souris River West Outfall at Eaton Dam near Towner	48.275	−100.4928	--	--	2004	2013	10	2004	2008
37	5121001	Souris River East Outfall at Eaton Dam near Towner	48.2758	−100.4881	--	--	2004	2013	10	2004	2013
38	5122000	Souris River near Bantry, ND	48.5056	−100.4349	12,300	4,700	1937	2014	78	1937	2014
39	5122500	Willow Creek at Dunseith, ND	48.8200	−100.0629	142	91	1954	1973	20	1954	1970
40	5123100	Oak Creek at Lake Metigoshe Outlet near Bottineau, ND	48.9656	−100.3635	59	--	1954	1981	28	1954	1981
41	5123300	Oak Creek Tributary near Bottineau, ND	48.8206	−100.4110	3.1	--	1955	2009	31	--	--
42	5123350	Oak Creek Tributary No. 5 near Bottineau, ND	48.8206	−100.3454	0.73	0.56	1959	1973	15	--	--
43	5123400	Willow Creek near Willow City, ND	48.5889	−100.4421	1,160	730	1957	2014	58	1956	2014
44	5123510	Deep River near Upham, ND	48.5842	−100.8626	975	370	1951	2014	52	1958	2014
45	5123520	Egg Creek near Glenburn, ND	48.4875	−101.4046	20.9	7	1955	1973	19	--	--
46	5123540	Egg Creek near Ruthville, ND	48.4403	−101.2990	108	26	1955	1973	19	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
47	5123560	Egg Creek Tributary near Deering, ND	48.3708	−101.1532	4.25	3.8	1955	1973	19	--	--
48	5123580	Egg Creek near Deering, ND	48.3431	−101.1227	132	41	1955	1973	19	--	--
49	5123600	Egg Creek near Granville, ND	48.3550	−100.8224	289	139	1957	1981	25	1957	1981
50	5123700	Cut Bank Creek at North Lake Outlet near Granville, ND	48.3861	−100.7671	534	244	1957	1980	24	1957	1980
51	5123750	Cut Bank Creek at Upham, ND	48.5747	−100.7446	722	272	1975	2000	12	1975	2000
52	5123900	Boundary Creek near Landa, ND	48.8128	−100.8632	230	170	1958	2000	36	1958	2000
53	5124000	Souris River near Westhope, ND	48.9964	−100.9585	16,900	6,600	1930	2014	85	1929	2014
54	6130610	Bair Coulee near Mosby, MT	47.0541	−107.6126	1.76	--	1974	2013	40	--	--
55	6130700	Sand Creek near Jordan, MT	47.2524	−106.8490	315	--	1958	1986	11	1957	1967
56	6130800	Second Creek Tributary near Jordan, MT	47.1919	−106.8024	0.53	--	1954	1973	17	--	--
57	6130850	Second Creek Tributary No. 2 near Jordan, MT	47.2064	−106.8162	2.19	--	1958	1990	33	--	--
58	6130900	Second Creek Tributary No. 3 near Jordan, MT	47.2193	−106.8260	0.78	--	1958	1972	15	--	--
59	6130915	Russian Coulee near Jordan, MT	47.3327	−106.7114	3.44	--	1974	2013	40	--	--
60	6130925	Thompson Creek Tributary near Cohagen, MT	46.9513	−106.4613	1.22	--	1974	1995	22	--	--
61	6130940	Spring Creek Tributary near Van Norman, MT	47.2492	−106.3062	1.4	--	1974	2013	40	--	--
62	6130950	Little Dry Creek near Van Norman, MT	47.3394	−106.3636	1,223	--	1958	1995	20	1980	1980

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
63	6131000	Big Dry Creek near Van Norman, MT	47.3494	−106.3578	2,551	--	1940	2013	68	1940	2014
64	6131100	Terry Coulee near Van Norman, MT	47.3859	−106.1708	0.46	--	1974	2013	40	--	--
65	6131200	Nelson Creek near Van Norman, MT	47.5366	−106.1535	110	--	1976	2014	26	1976	2014
66	6131300	Mcguire Creek Tributary near Van Norman, MT	47.6054	−106.1530	0.77	--	1974	2013	40	--	--
67	6132000	Missouri River below Fort Peck Dam, MT	48.0444	−106.3563	56,490	--	1934	2014	81	1934	2014
68	6135000	Milk River at Eastern Crossing of international boundary	48.9748	−110.4218	2,496	--	1910	2014	102	1909	2014
69	6136400	Spring Coulee Tributary near Simpson, MT	48.9443	−110.2160	2.76	--	1972	2002	30	--	--
70	6137600	Sage Creek Tributary No. 2 near Joplin, MT	48.9105	−110.7730	2.71	--	1974	2013	40	--	--
71	6150000	Woodpile Coulee near international boundary	48.9832	−109.5311	67	--	1927	1986	47	1927	1977
72	6150500	East Fork Battle Creek near international boundary	48.9711	−109.1303	89.5	86	1927	1986	47	1927	1977
73	6151500	Battle Creek near Chinook, MT	48.6495	−109.2317	1,631	1,485	1905	2014	47	1905	2014
74	6153400	Fifteenmile Creek Tributary near Zurich, MT	48.6454	−109.0457	1.7	--	1974	2013	40	--	--
75	6154100	Milk River near Harlem, MT	48.4896	−108.7590	9,652	9,184	1952	2014	44	1960	2014
76	6154140	Fifteenmile Creek Tributary near Harlem, MT	48.3248	−108.7083	2.11	--	1983	1992	10	1983	1993
77	6154400	Peoples Creek near Hays, MT	48.2237	−108.7141	227	--	1967	2014	48	1967	2014

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
78	6154490	Willow Coulee near Dodson, MT	48.3251	−108.4154	5.53	--	1983	1992	10	1983	1992
79	6154500	Peoples Creek near Dodson, MT	48.3424	−108.3598	680	--	1952	1988	28	1918	1988
80	6154510	Kuhr Coulee Tributary near Dodson, MT	48.3390	−108.3887	1.34	--	1983	2013	31	1983	1996
81	6154550	Peoples Creek below Kuhr Coulee near Dodson, MT	48.3636	−108.3562	688	--	1989	2009	21	1918	2009
82	6155030	Milk River near Dodson, MT	48.4028	−108.2941	11,134	10,666	1983	2014	32	1982	2014
83	6155200	Alkali Creek near Malta, MT	48.2681	−107.9662	190	--	1956	1986	18	--	--
84	6155300	Disjardin Coulee near Malta, MT	48.2760	−107.9643	3.77	--	1956	2002	47	--	--
85	6155400	Taylor Coulee near Malta, MT	48.3262	−107.9147	4.93	--	1956	1986	19	--	--
86	6155500	Milk River at Malta, MT	48.3619	−107.8629	11,654	11,186	1903	2014	21	1902	2014
87	6155600	Murphy Coulee Tributary near Hogeland, MT	48.7886	−108.7479	2.46	--	1974	2013	40	--	--
88	6155900	Milk River at Cree Crossing near Saco, MT	48.5406	−107.5199	13,134	12,560	2000	2009	10	2000	2010
89	6156000	Whitewater Creek near international boundary	48.9526	−107.8622	466	--	1927	1979	52	1927	1980
90	6156100	Lush Coulee near Whitewater, MT	48.6861	−107.6910	8.9	--	1972	2013	41	--	--
91	6164510	Milk River at Juneberg Bridge near Saco, MT	48.5092	−107.2188	17,691	17,117	1978	2014	37	1978	2014
92	6164800	Beaver Creek above Dix Creek near Malta, MT	48.0884	−107.5555	914	--	1967	1986	12	1967	1982
93	6165200	Guston Coulee near Malta, MT	48.2419	−107.5486	2.4	--	1974	2013	40	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
94	6166000	Beaver Creek below Guston Coulee near Saco, MT	48.3568	−107.5822	1,199	--	1982	2014	32	1920	2014
95	6167500	Beaver Creek near Hinsdale, MT	48.4203	−107.1711	1,805	1,678	2005	2014	10	1918	2014
96	6168500	Rock Creek at international boundary	48.9889	−106.7923	239	--	1927	1961	35	1914	1962
97	6169000	Horse Creek at international boundary	48.9884	−106.8352	74.9	--	1915	1961	46	1914	1962
98	6169500	Rock Creek below Horse Creek near international boundary	48.9694	−106.8398	322	--	1917	2014	68	1916	2014
99	6170000	McEachern Creek at international boundary	48.9910	−106.9285	171	--	1924	1976	53	1924	1977
100	6170200	Willow Creek near Hinsdale, MT	48.5650	−106.9825	290	--	1965	1979	10	1965	1973
101	6171000	Rock Creek near Hinsdale, MT	48.4527	−107.0365	1,300	--	1906	1952	11	1906	1920
102	6172000	Milk River near Vandalia, MT	48.3730	−106.9732	21,052	20,351	1915	1987	31	1915	1987
103	6172200	Buggy Creek near Tampico, MT	48.3608	−106.7779	124	--	1958	1982	12	1958	1967
104	6172300	Unger Creek near Vandalia, MT	48.3707	−106.7974	10	--	1958	2013	56	--	--
105	6172310	Milk River at Tampico, MT	48.3079	−106.8223	21,341	20,640	1974	2013	30	1974	2014
106	6172350	Mooney Coulee near Tampico, MT	48.2859	−106.7092	13.8	--	1961	1982	16	--	--
107	6173300	Willow Creek Tributary near Fort Peck, MT	47.8931	−106.8903	0.95	--	1972	1991	19	--	--
108	6174000	Willow Creek near Glasgow, MT	48.1144	−106.6716	531	--	1954	1993	35	1954	1987

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
109	6174300	Milk River Tributary No. 3 near Glasgow MT	48.2047	−106.5523	1.55	--	1974	2013	40	--	--
110	6174500	Milk River at Nashua, MT	48.1301	−106.3643	22,452	20,254	1940	2013	74	1940	2014
111	6174600	Snow Coulee at Opheim, MT	48.8407	−106.4137	3.11	--	1972	2012	40	--	--
112	6175000	Porcupine Creek at Nashua, MT	48.1359	−106.3423	724	--	1909	1993	26	1908	1992
113	6175540	Prairie Elk Creek near Oswego, MT	47.9990	−105.8674	340	--	1976	1985	10	1976	1985
114	6175550	East Fork Sand Creek near Vida, MT	47.8042	−105.6143	8.51	--	1963	1977	15	--	--
115	6175700	East Fork Wolf Creek near Lustre, MT	48.4071	−105.7941	9.98	--	1956	2002	47	--	--
116	6175900	Wolf Creek Tributary No. 2 near Wolf Point, MT	48.2017	−105.7538	0.86	--	1955	1984	30	--	--
117	6176500	Wolf Creek near Wolf Point, MT	48.0972	−105.6802	251	--	1910	1993	37	1908	1992
118	6176950	Missouri River No. 6 near Wolf Point, MT	48.0563	−105.5569	0.55	--	1973	1991	19	--	--
119	6177000	Missouri River near Wolf Point, MT	48.0673	−105.5331	80,647	--	1929	2013	85	1929	2014
120	6177020	Tule Creek Tributary near Wolf Point, MT	48.2446	−105.4927	1.97	--	1974	2013	40	--	--
121	6177050	East Fork Duck Creek near Brockway, MT	47.1872	−105.7856	13.9	--	1955	2002	48	--	--
122	6177100	Duck Creek near Brockway, MT	47.2391	−105.8171	54.6	--	1957	1973	17	--	--
123	6177150	Redwater River at Brock-way, MT	47.3051	−105.7677	240	--	1957	1986	18	--	--
124	6177200	Tusler Creek near Brockway, MT	47.2972	−105.6635	89.4	--	1957	1972	16	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
125	6177250	Tusler Creek Tributary near Brockway, MT	47.2978	−105.6785	3.09	--	1957	1986	18	--	--
126	6177300	Redwater River Tributary Brockway, MT	47.3463	−105.6850	0.26	--	1954	1973	18	--	--
127	6177350	South Fork Dry Ash Creek near Circle, MT	47.2954	−105.5973	6.76	--	1955	1986	19	--	--
128	6177400	McCune Creek near Circle, MT	47.3498	−105.5860	29.7	--	1955	1986	24	1982	1985
129	6177500	Redwater River at Circle, MT	47.4140	−105.5756	551	--	1929	2013	77	1929	2014
130	6177700	Cow Creek Tributary near Vida, MT	47.7158	−105.4945	1.45	--	1963	2013	51	1982	1985
131	6177720	West Fork Sullivan Creek near Richey, MT	47.5322	−105.2351	14.7	--	1972	1992	20	--	--
132	6177800	Gady Coulee near Vida, MT	47.9127	−105.4971	0.83	--	1962	1991	30	--	--
133	6177820	Horse Creek Tributary near Richey, MT	47.8773	−104.9359	0.67	--	1974	2013	40	--	--
134	6177825	Redwater River near Vida, MT	47.9022	−105.2128	1,982	--	1976	2013	12	1976	2012
135	6178000	Poplar River at international boundary	48.9903	−105.6969	358	--	1931	2014	83	1931	2014
136	6179100	Butte Creek Tributary near Four Buttes, MT	48.8094	−105.5861	1.62	--	1972	2013	41	--	--
137	6180000	West Fork Poplar River near Richland, MT	48.8071	−106.0212	454	--	1935	1994	17	1935	1949
138	6180500	Poplar River near Bredette, MT	48.4062	−105.2101	2,921	--	1934	1947	14	1934	1947
139	6181000	Poplar River near Poplar, MT	48.1709	−105.1786	3,140	--	1909	2013	63	1908	2014

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
140	6181200	Missouri River Tributary No. 2 near Brockton, MT	48.1520	−104.9019	0.69	--	1962	1976	15	--	--
141	6182500	Big Muddy Creek at Daleview, MT	48.9109	−104.9391	276	--	1948	1975	26	1947	1972
142	6182700	Middle Fork Big Muddy Creek near Flaxville, MT	48.8022	−105.1139	3.26	--	1972	1983	11	--	--
143	6183000	Big Muddy Creek at Plentywood, MT	48.7661	−104.5781	850	--	1948	1967	19	1948	1953
144	6183100	Box Elder Creek near Plentywood, MT	48.8238	−104.4997	11	--	1956	1976	19	--	--
145	6183300	Marron Creek Tributary near Plentywood, MT	48.8093	−104.4551	6.21	--	1955	2002	48	--	--
146	6183400	Spring Creek at Highway near Plentywood, MT	48.7666	−104.5252	15.4	--	1956	1976	19	--	--
147	6183450	Big Muddy Creek near Antelope, MT	48.6729	−104.5121	955	--	1979	2013	35	1979	2014
148	6183700	Big Muddy Creek diversion canal near Medicine Lake, MT	48.5096	−104.5490	--	--	1987	2009	19	1985	2011
149	6183750	Lake Creek near Dagmar, MT	48.5641	−104.1776	111	--	1986	2010	19	1986	2011
150	6183800	Cottonwood Creek near Dagmar, MT	48.5092	−104.1734	128	--	1986	2010	20	1986	2011
151	6183850	Sand Creek near Dagmar, MT	48.4989	−104.2726	117	--	1986	2010	20	1986	2011
152	6184200	Lost Creek Tributary near Homestead, MT	48.4025	−104.4975	1.92	--	1972	2013	41	--	--
153	6185000	Big Muddy Creek near Culbertson, MT	48.2571	−104.7236	2,670	--	1909	1921	12	1908	1922

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
154	6185100	Big Muddy Creek Tributary near Culbertson, MT	48.1928	−104.6979	7.24	--	1963	1977	15	--	--
155	6185110	Big Muddy Creek near mouth near Culbertson, MT	48.1645	−104.6295	2,37	--	1982	2013	12	1982	2014
156	6185200	Missouri River Tributary No. 3 near Culbertson, MT	48.1042	−104.5158	1.25	--	1963	1977	15	--	--
157	6185300	Missouri River Tributary No. 4 near Bainville, MT	48.1419	−104.3528	32	--	1963	1977	15	--	--
158	6185400	Missouri River Tributary No. 5 at Culbertson, MT	48.1587	−104.5161	3.82	--	1963	2013	51	--	--
159	6185500	Missouri River near Culbertson, MT	48.1235	−104.4733	89,959	89,858	1942	2013	65	1941	2014
160	6309020	Rock Springs Creek Tributary at Rock Springs, MT	46.8222	−106.2544	1.16	--	1963	1987	17	--	--
161	6309080	Deep Creek near Kinsey, MT	46.5568	−105.6207	11.6	--	1962	2013	52	--	--
162	6325950	Cut Coulee near Mizpah, MT	46.1439	−105.1687	2.3	--	1973	2013	41	--	--
163	6326300	Mizpah Creek near Mizpah, MT	46.2607	−105.2934	803	--	1975	1986	12	1975	1986
164	6326400	Meyers Creek near Locate, MT	46.3880	−105.2789	9.35	--	1962	1982	16	--	--
165	6326500	Powder River near Locate, MT	46.4294	−105.3103	13,060	--	1938	2014	77	1938	2014
166	6326510	Locate Creek Tributary near Locate, MT	46.4311	−105.1819	0.9	--	1973	1991	19	--	--
167	6326550	Cherry Creek Tributary near Terry, MT	46.8551	−105.3412	2.6	--	1973	1991	19	--	--
168	6326580	Lame Jones Creek Tributary near Willard, MT	46.1941	−104.5522	0.5	--	1974	2013	40	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
169	6326600	O’Fallon Creek near Ismay, MT	46.4206	−104.7610	663	--	1962	1992	31	1977	1992
170	6326650	O’Fallon Creek Tributary near Ismay, MT	46.4193	−104.7424	0.15	--	1962	1976	15	--	--
171	6326700	Deep Creek near Baker, MT	46.2990	−104.3010	3.8	--	1962	1978	16	--	--
172	6326800	Pennel Creek Tributary near Baker, MT	46.4821	−104.2394	0.84	--	1962	1991	30	--	--
173	6326900	Yellowstone River Tributary No. 4 near Fallon, MT	46.8658	−105.1018	0.8	--	1962	1976	15	--	--
174	6326940	Spring Creek Tributary near Fallon, MT	46.8017	−104.9911	4.05	--	1972	2013	42	--	--
175	6326950	Yellowstone River Tributary No. 5 near Marsh, MT	46.9524	−104.8985	0.95	--	1962	2013	52	--	--
176	6326960	Timber Fork Up Sevenmile Creek Tributary near Lindsay, MT	47.1825	−105.1727	1.1	--	1974	2013	40	--	--
177	6327450	Cains Coulee at Glendive, MT	47.0942	−104.7133	3.64	--	1991	2013	23	1992	2013
178	6327500	Yellowstone River at Glendive, MT	47.1008	−104.7203	66,731	66,039	1903	2014	23	1897	2014
179	6327550	South Fork Horse Creek Tributary near Wibaux, MT	46.8014	−104.3810	1.33	--	1973	2013	41	--	--
180	6327700	Griffith Creek near Glendive, MT	47.1034	−104.5618	16.7	--	1955	1967	12	--	--
181	6327720	Griffith Creek Tributary near Glendive, MT	47.1055	−104.5973	3.5	--	1965	2013	41	--	--
182	6327790	Krug Creek Tributary No. 2 near Wibaux, MT	47.0083	−104.3060	0.42	--	1974	2013	40	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
183	6328100	Yellowstone River Tributary No. 6 near Glendive, MT	47.1569	−104.6546	2.93	--	1974	2013	40	--	--
184	6328400	Thirteenmile Creek Tributary near Bloomfield, MT	47.4128	−104.8316	0.66	--	1972	1991	19	--	--
185	6328700	Linden Creek at Intake, MT	47.2974	−104.5258	3.97	--	1958	1980	17	--	--
186	6328800	Indian Creek at Intake, MT	47.2916	−104.5405	0.26	--	1958	1973	16	--	--
187	6328900	War Dance Creek near Intake, MT	47.3270	−104.4883	3.74	--	1958	1980	17	--	--
188	6329200	Burns Creek near Savage, MT	47.3723	−104.4300	234	--	1958	1986	21	1958	1988
189	6329350	Alkali Creek near Sidney, MT	47.5095	−104.1178	0.81	--	1974	2013	40	--	--
190	6329500	Yellowstone River near Sidney, MT	47.6774	−104.1554	69,099	68,407	1911	2014	102	1911	2014
191	6329510	Fox Creek Tributary near Lambert, MT	47.6493	−104.6149	5.16	--	1972	1996	24	--	--
192	6329570	First Hay Creek near Sidney, MT	47.8359	−104.2748	29.2	--	1963	2004	42	--	--
193	6329597	Charbonneau Creek near Charbonneau, ND	47.8509	−103.7941	149	--	1967	2014	24	1967	2014
194	6329700	Painted Woods Creek Tributary near Williston, ND	48.2056	−103.8838	0.35	--	1955	1973	19	--	--
195	6329800	Painted Woods Creek near Williston, ND	48.1986	−103.8685	17.4	--	1955	1973	19	--	--
196	6329900	Painted Woods Creek Tributary No. 2 near Williston, ND	48.2320	−103.8199	8.3	--	1955	1973	19	--	--
197	6330000	Missouri River near Williston, ND	48.1081	−103.7146	164,500	--	1912	1965	38	1929	1965
198	6330100	Sand Creek at Williston, ND	48.1472	−103.6533	38.2	--	1955	1973	19	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
199	6331000	Little Muddy River below Cow Creek near Williston, ND	48.2845	−103.5730	875	775	1955	2014	60	1954	2014
200	6331500	Little Muddy Creek near Williston, ND	48.1975	−103.5972	920	820	1904	1955	15	1904	1954
201	6331900	White Earth River Tributary near Tioga, ND	48.3556	−102.9060	9.55	--	1960	1973	14	--	--
202	6332000	White Earth River at White Earth, ND	48.3756	−102.7672	780	490	1955	1981	27	1954	2014
203	6332150	White Earth River Tributary near White Earth, ND	48.3320	−102.7532	0.32	--	1960	2009	29	--	--
204	6332515	Bear Den Creek near Mandaree, ND	47.7872	−102.7685	74	--	1967	2014	48	1966	2014
205	6332520	Shell Creek near Parshall, ND	48.0531	−102.1366	465	--	1965	1981	17	1965	1982
206	6332523	East Fork Shell Creek near Parshall, ND	47.9486	−102.2149	360	--	1992	2013	22	1991	2013
207	6332770	Deepwater Creek at Mouth near Raub, ND	47.7378	−102.1077	220	--	1992	2013	22	1991	2013
208	6334500	Little Missouri River at Camp Crook, SD	45.5481	−103.9712	1,974	1,974	1952	2014	60	1904	2014
209	6334625	Coal Creek Tributary near Mill Iron, MT	45.9031	−104.3619	0.88	--	1974	2013	40	--	--
210	6334630	Box Elder Creek at Webster, MT	45.9068	−104.0576	1,097	--	1960	1975	15	1961	1973
211	6334640	North Fork Coal Bank Creek Mill Iron, MT	45.9431	−104.0928	15.5	--	1962	1976	15	--	--
212	6334720	Soda Creek Tributary near Webster, MT	46.0099	−104.0935	2.33	--	1962	1991	30	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
213	6335000	Little Beaver Creek near Marmarth, ND	46.2747	−103.9763	587	--	1939	1979	41	1938	1980
214	6335500	Little Missouri River at Marmarth, ND	46.2978	−103.9175	4,640	--	1939	2014	76	1938	2014
215	6335700	Deep Creek near Bowman, ND	46.2320	−103.3685	0.29	--	1955	1973	19	--	--
216	6336000	Little Missouri River at Medora, ND	46.9195	−103.5282	6,190	--	1904	2014	64	1903	2014
217	6336100	Sheep Creek Tributary near Medora, ND	46.9000	−103.4485	0.29	0.29	1955	1973	15	--	--
218	6336200	Sheep Creek Tributary 2 near Medora, ND	46.9256	−103.4735	0.42	--	1958	1973	16	--	--
219	6336300	Little Missouri River Tributary near Medora, ND	46.9514	−103.5060	0.32	--	1955	2009	34	--	--
220	6336400	Jules Creek near Medora, ND	46.9942	−103.4874	3.8	--	1955	1973	19	--	--
221	6336450	Spring Creek near Wibaux, MT	46.8844	−104.2004	3.91	--	1956	1973	18	--	--
222	6336500	Beaver Creek at Wibaux, MT	46.9899	−104.1838	376	--	1872	1983	40	1938	1984
223	6336600	Beaver Creek near Trotters, ND	47.1631	−103.9927	616	--	1978	2014	37	1978	2014
224	6336980	Little Missouri River Tributary near Watford City, ND	47.6020	−103.2785	2.02	--	1960	1973	14	--	--
225	6337000	Little Missouri River near Watford City, ND	47.5903	−103.2519	8,310	8,310	1935	2014	80	1935	2014
226	6337080	Cherry Creek Tributary near Arnegard, ND	47.7970	−103.3694	13.1	--	1999	2009	11	--	--
227	6337100	Spring Creek near Watford City, ND	47.6884	−103.2652	22.7	--	1960	1973	14	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
228	6337500	Missouri River near Elbowoods, ND	47.5667	−102.2005	179,800	--	1940	1953	14	1940	1954
229	6337600	East Branch Douglas Creek Tributary near Garrison, ND	47.6436	−101.5196	1.39	--	1957	1973	16	--	--
230	6337900	Snake Creek Tributary near Garrison, ND	47.6322	−101.3521	1.22	--	1959	2009	30	--	--
231	6338490	Missouri River at Garrison Dam, ND	47.5022	−101.4310	181,400	181,400	1970	2009	40	1970	2009
232	6339000	Missouri River below Garrison Dam, ND	47.3856	−101.3938	181,400	--	1948	1969	22	1948	1969
233	6339100	Knife River at Manning, ND	47.2361	−102.7699	205	--	1968	2014	47	1967	2014
234	6339300	Knife River at Marshall, ND	47.1381	−102.3338	722	--	1971	1981	11	1971	1982
235	6339490	Elm Creek near Golden Valley, ND	47.1070	−102.0518	82	--	1968	1991	24	1967	1981
236	6339500	Knife River near Golden Valley, ND	47.1545	−102.0599	1,230	--	1943	2014	72	1903	2014
237	6339560	Brush Creek near Beulah, ND	47.1786	−101.7852	23.92	--	1975	1990	16	1975	1991
238	6339890	North Creek near Werner, ND	47.4103	−102.5032	17.6	--	1999	2009	11	--	--
239	6340000	Spring Creek at Zap, ND	47.2861	−101.9257	549	--	1924	2014	70	1924	2014
240	6340200	West Branch Otter Creek near Beulah, ND	47.1347	−101.6602	26.5	--	1965	1991	26	1965	1982
241	6340500	Knife River at Hazen, ND	47.2853	−101.6221	2,240	2,240	1930	2014	81	1929	2014
242	6340528	West Branch Antelope Creek No. 4 near Zap, ND	47.3558	−101.8549	8.46	--	1977	1986	10	1977	1986
243	6340905	Coal Lake Coulee near Hensler, ND	47.3025	−101.1315	70.5	--	1978	1988	11	1978	1989

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
244	6341400	Turtle Creek near Turtle Lake, ND	47.4583	−100.9213	310	115	1957	1976	20	1957	1976
245	6341410	Turtle Creek above Washburn, ND	47.3850	−100.9124	350	155	1987	2003	17	1987	2003
246	6341800	Painted Woods Creek near Wilton, ND	47.2750	−100.7921	427	117	1958	2003	45	1958	2003
247	6342050	Square Butte Creek at Center, ND	47.1111	−101.2990	56.8	--	1956	1973	18	--	--
248	6342100	Square Butte Creek Tributary No. 2 near Center, ND	47.1111	−101.2518	13	--	1955	1976	22	1965	1976
249	6342150	Square Butte Creek Tributary near Center, ND	47.1056	−101.2588	0.19	--	1955	1973	19	--	--
250	6342250	Square Butte Creek Tributary No. 3 near Center, ND	47.1055	−101.1768	1.68	--	1955	1973	19	--	--
251	6342260	Square Butte Creek below Center, ND	47.0575	−101.1957	146	--	1966	2014	49	1965	2014
252	6342300	Burnt Creek Tributary near Baldwin, ND	47.0236	−100.7921	2.98	--	1956	1973	18	--	--
253	6342350	Burnt Creek Tributary No. 2 near Baldwin, ND	46.9847	−100.7907	2.12	--	1956	1973	18	--	--
254	6342450	Burnt Creek near Bismarck, ND	46.9150	−100.8137	108	--	1968	2014	47	1968	2014
255	6342500	Missouri River at Bismarck, ND	46.8142	−100.8214	186,400	--	1881	2014	87	1928	2014
256	6343000	Heart River near South Heart, ND	46.8656	−102.9485	311	--	1947	2014	63	1946	2014
257	6343200	Heart River Tributary near South Heart, ND	46.8764	−102.9199	0.13	--	1955	1973	19	--	--
258	6344000	Heart River below Dickinson Dam near Dickinson, ND	46.8620	−102.8166	404	--	1952	1972	21	1952	1973

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
259	6344200	Heart River Tributary near Dickinson, ND	46.8392	−102.7899	1.72	--	1955	1973	19	--	--
260	6344300	Heart River at Dickinson, ND	46.8672	−102.7352	440	--	1984	1995	12	1984	1996
261	6344500	Heart River at Lehigh, ND	46.8695	−102.7102	443	--	1943	1952	10	1943	1952
262	6344600	Green River near New Hradec, ND	47.0278	−103.0532	152	--	1964	2014	51	1964	2014
263	6345000	Green River near Gladstone, ND	46.8945	−102.6241	356	--	1943	1976	32	1946	1975
264	6345100	Antelope Creek near Dickinson, ND	46.7208	−102.7907	69.2	69	1955	1973	19	--	--
265	6345200	Antelope Creek Tributary near New England, ND	46.6681	−102.7907	13	--	1955	1973	19	--	--
266	6345300	Antelope Creek Tributary Site No. 2 near New England, ND	46.6889	−102.7907	22.4	22	1955	1973	19	--	--
267	6345500	Heart River near Richardton, ND	46.7456	−102.3083	1,240	--	1905	2014	91	1903	2014
268	6345700	Government Creek near Richardton, ND	46.8042	−102.3102	33.4	--	1950	1973	20	--	--
269	6345780	Heart River above Lake Tschida near Glen Ullin, ND	46.6570	−102.0793	1,530	--	1988	2014	27	1988	2014
270	6346500	Heart River below Heart Butte Dam near Glen Ullin, ND	46.5972	−101.8018	1,710	--	1943	1972	29	1943	1972
271	6347000	Antelope Creek near Carson, ND	46.5453	−101.6454	221	--	1943	2014	45	1948	2014
272	6347090	Tavis Creek near Glen Ullin, ND	46.7992	−101.8577	10	--	2000	2009	10	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
273	6347500	Big Muddy Creek near Almont, ND	46.6944	−101.4674	456	--	1946	2014	52	1946	2014
274	6348000	Heart River near Lark, ND	46.6103	−101.3821	2,750	--	1947	1995	49	1946	1995
275	6348300	Heart River at Stark Bridge near Judson, ND	46.7033	−101.2136	2,930	--	1989	2014	26	1989	2014
276	6348500	Sweetbriar Creek near Judson, ND	46.8511	−101.2532	157	--	1950	2014	42	1951	2014
277	6349000	Heart River near Mandan, ND	46.8339	−100.9746	3,310	3,310	1924	2014	84	1924	2014
278	6349083	Southeast Branch Little Heart River at St. Anthony, ND	46.6200	−100.9037	40.2	--	1996	2009	14	--	--
279	6349100	Dead Buffalo Lake Tributary near Steele, ND	46.8842	−99.8265	5.92	--	1960	1973	14	--	--
280	6349200	West Branch Long Lake Creek near Hazelton, ND	46.4861	−100.1559	16.5	--	1955	1973	18	--	--
281	6349215	Long Lake Creek above Long Lake near Moffit, ND	46.6330	−100.2418	280	--	1989	2004	16	1989	2004
282	6349500	Apple Creek near Menoken, ND	46.7944	−100.6573	1,680	1,180	1946	2014	69	2012	2014
283	6349580	Hay Creek at 43rd Avenue near Bismarck, ND	46.8525	−100.7587	20.74	--	2002	2013	12	2002	2007
284	6349590	Hay Creek at Divide Avenue in Bismarck, ND	46.8228	−100.7373	29.9	--	2002	2013	12	2002	2007
285	6349600	Hay Creek at Main Avenue in Bismarck, ND	46.8072	−100.7340	31.2	--	2002	2014	13	2002	2014
286	6350000	Cannonball River at Regent, ND	46.4267	−102.5518	580	--	1950	2014	65	1950	2014

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
287	6351000	Cannonball River below Bentley, ND	46.3583	−102.0421	1,140	--	1943	1981	39	1943	1982
288	6351200	Cannonball River near Raleigh, ND	46.1269	−101.3332	1,640	--	2001	2014	14	2001	2014
289	6351630	Middle Fork Cedar Creek-Tributary near Amidon, ND	46.3381	−103.2935	1.7	--	1998	2009	12	--	--
290	6351680	White Butte Fork Cedar Creek near Scranton, ND	46.3222	−102.9963	42.9	--	1965	1995	31	1965	1995
291	6352000	Cedar Creek near Haynes, ND	46.1553	−102.4757	553	--	1950	2014	65	1951	2014
292	6352380	Timber Creek Tributary near New Leipzig, ND	46.2097	−101.9576	2.8	--	1996	2009	13	--	--
293	6352500	Cedar Creek near Pretty Rock, ND	46.0319	−101.8324	1,340	--	1943	1976	34	1943	1977
294	6353000	Cedar Creek near Raleigh, ND	46.0917	−101.3337	1,750	--	1939	2014	55	1939	2014
295	6353500	Cannonball River near Timmer, ND	46.3231	−101.0043	3,650	--	1903	1934	23	1903	1903
296	6353600	Louise Creek Tributary near Brisbane, ND	46.3736	−101.4893	0.29	--	1955	1973	19	--	--
297	6353700	Louise Creek Tributary near Lark, ND	46.4417	−101.4171	0.76	--	1956	1973	18	--	--
298	6353800	Louise Creek Tributary No. 2 near Lark, ND	46.4431	−101.3324	7.7	--	1956	1973	17	--	--
299	6353900	Louise Creek above Flasher, ND	46.4542	−101.2490	110	--	1955	1973	19	--	--
300	6354000	Cannonball River at Breien, ND	46.3761	−100.9344	4,100	4,100	1906	2014	99	1934	2014

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

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301	6354450	Beaver Creek Tributary near Linton, ND	46.2467	−100.0801	4.07	--	1998	2009	12	--	--
302	6354500	Beaver Creek at Linton, ND	46.2575	−100.2332	717	617	1943	1989	41	1949	1989
303	6354580	Beaver Creek below Linton, ND	46.2686	−100.2526	765	665	1990	2014	25	1990	2014
304	6354700	Spring Creek near Linton, ND	46.3111	−100.2309	22.9	--	1955	1973	19	--	--
305	6354750	Sand Creek Tributary near Hazelton, ND	46.4305	−100.2976	2.96	--	1960	1973	14	--	--
306	6354800	Sand Creek near Temvik, ND	46.3722	−100.3448	23.3	--	1955	1973	18	--	--
307	6354860	Spring Creek near Herreid, SD	45.8144	−100.1082	2,027	565	1963	1997	34	1963	1986
308	6354882	Oak Creek near Wakpala, SD	45.7119	−100.5593	354	354	1985	2014	30	1985	2014
309	6354900	Spring Creek near Bowman, ND	46.1250	−103.4102	51.2	--	1955	1973	19	--	--
310	6354950	Spring Creek Tributary near Bowman, ND	46.1486	−103.4102	15	--	1955	1973	19	--	--
311	6355000	North Fork Grand River at Haley, ND	45.9608	−103.1196	509	--	1909	1995	56	1908	1995
312	6355200	Buffalo Creek Tributary near Buffalo Springs, ND	46.1750	−103.2768	3.39	--	1955	1973	19	--	--
313	6355310	Buffalo Creek Tributary near Gascoyne, ND	46.1111	−103.0393	15.7	--	1975	1987	13	1975	1987
314	6355400	North Fork Grand River Tributary near Lodgepole, SD	45.9292	−102.6515	3.07	3.07	1970	1979	10	--	--
315	6355500	North Fork Grand River near White Butte, SD	45.8022	−102.3624	1,202	1,202	1946	2014	69	1946	2014

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
316	6356000	South Fork Grand River at Buffalo, SD	45.5761	−103.5444	148	148	1908	1994	40	1955	1994
317	6356050	Wide Sandy Creek near Buffalo, SD	45.5167	−103.5457	37.3	38.8	1956	1973	17	--	--
318	6356150	North Jack Creek near Ludlow, SD	45.7875	−103.3957	1.67	1.67	1970	1979	10	--	--
319	6356500	South Fork Grand River near Cash, SD	45.6487	−102.6433	1,305	1,305	1946	2014	65	1946	2014
320	6356600	South Fork Grand River Tributary near Bison, SD	45.5983	−102.6582	1	1	1970	1979	10	--	--
321	6357500	Grand River at Shadehill, SD	45.7564	−102.1960	2,996	2,996	1944	1992	47	1943	1992
322	6357620	Willow Creek near Keldron, SD	45.8333	−101.8678	9.14	9.14	1998	2014	17	--	--
323	6357800	Grand River at Little Eagle, SD	45.6578	−100.8182	5,316	5,316	1959	2014	56	1958	2014
324	6358000	Grand River near Wakpala, SD	45.6611	−100.6393	5,423	5,423	1914	1964	38	1935	1964
325	6358320	Claymore Creek near Mobridge, SD	45.4869	−100.5543	2.15	2.18	1956	1968	12	--	--
326	6358350	Claymore Creek Tributary near Trail City, SD	45.4872	−100.5826	1.96	1.98	1956	1973	18	--	--
327	6358400	Claymore Creek Tributary No. 2 near Trail City, SD	45.4869	−100.5926	0.12	0.15	1956	1973	18	--	--
328	6358500	Missouri River near Mobridge, SD	45.5236	−100.4737	208,700	208,700	1929	1961	33	1928	1962
329	6358520	Deadman Creek Tributary near Mobridge, SD	45.4708	−100.4988	0.3	0.3	1956	1980	25	--	--
330	6358540	Blue Blanket Creek Tributary near Glenham, SD	45.5367	−100.2007	0.61	0.61	1970	1979	10	--	--

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
331	6358550	Battle Creek Tributary near Castle Rock, SD	45.0492	−103.5494	1.57	1.57	1969	1979	11	--	--
332	6358600	South Fork Moreau River Tributary near Redig, SD	45.1958	−103.5696	2.33	2.33	1956	1980	24	--	--
333	6358620	Sand Creek Tributary near Redig, SD	45.2225	−103.5494	0.06	0.06	1956	1972	16	--	--
334	6358750	North Fork Moreau River Tributary near Redig, SD	45.3308	−103.5496	4	4	1956	1972	16	--	--
335	6359000	Moreau River at Bixby, SD	45.1436	−102.5588	1,570	1,570	1949	1973	25	1948	1969
336	6359300	Deep Creek Tributary near Maurine, SD	45.0261	−102.5418	1.26	1.26	1970	1979	10	--	--
337	6359500	Moreau River near Faith, SD	45.1978	−102.1565	2,596	2,596	1944	2014	71	1943	2014
338	6359700	Thunder Butte Creek Tributary near Meadow, SD	45.4441	−102.0896	3	3	1970	1979	10	--	--
339	6359800	Thunder Butte Creek Tributary near Glad Valley, SD	45.4435	−102.0164	11.3	11.3	1970	2014	14	--	--
340	6359850	Elm Creek Tributary near Dupree, SD	45.0533	−101.6446	5	4.16	1970	1979	10	--	--
341	6360000	Moreau River near Eagle Butte, SD	45.1889	−101.2185	4,320	4,320	1944	1958	15	1943	1958
342	6360350	Little Moreau River Tributary near Firesteel, SD	45.4044	−101.2254	2.75	2.09	1970	1979	10	--	--
343	6360500	Moreau River near Whitehorse, SD	45.2558	−100.8429	4,889	4,872	1953	2014	61	1954	2014
344	6361000	Moreau River at Promise, SD	45.3450	−100.6029	5,223	5,223	1929	1958	30	1933	1958
345	6425500	Elk Creek near Elm Springs, SD	44.2483	−102.5032	549	549	1920	2014	66	1949	2014
346	6436760	Horse Creek above Vale, SD	44.6527	−103.3667	461	461	1981	2012	32	1981	2012

Table 1–1. Summary information on U.S. Geological Survey streamgages in the study area that have 10 or more years of data collection through water year 2014.—Continued

[ND, North Dakota; No., Number; MT, Montana; SD, South Dakota]

Map number (fig. 1–1)	Streamgage number	Streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Total drainage area, in square miles	Contributing drainage area, in square miles	Start of annual peak-flow data collection, water year	End of annual peak-flow data collection, water year	Number of years of annual peak-flow data collection	Start of year-round or seasonal continuous streamflow data collection, water year	End of year-round or seasonal continuous streamflow data collection through water year 2014, water year
347	6436800	Horse Creek near Vale, SD	44.6583	−103.3385	522	522	1962	1980	19	1962	1980
348	6437000	Belle Fourche River near Sturgis, SD	44.5130	−103.1368	5,821	5,814	1946	2014	69	1946	2014
349	6437650	Elm Creek near Fairpoint, SD	44.7830	−103.0624	8.8	8.8	1999	2014	16	--	--
350	6438000	Belle Fourche River near Elm Springs, SD	44.3700	−102.5665	7,029	7,022	1927	2014	87	1928	2014
351	6438500	Cheyenne River near Plainview, SD	44.5294	−101.9302	21,425	21,414	1920	2014	53	1951	2014
352	6438800	Elm Creek near Red Owl, SD	44.7511	−102.4491	20.9	20.9	2000	2014	15	--	--
353	6439000	Cherry Creek near Plain-view, SD	44.7430	−102.0535	1,190	1,190	1946	2009	62	1946	2008
354	6439050	Cherry Creek Tributary near Avance, SD	44.8092	−102.0554	0.6	0.6	1956	1980	25	--	--
355	6439060	Cherry Creek Tributary No. 2 near Avance, SD	44.8042	−102.0554	0.11	0.11	1956	1973	18	--	--
356	6439080	Cherry Creek Tributary No. 3 near Avance, SD	44.8508	−102.0438	4.58	4.58	1956	1980	25	--	--
357	6439100	Beaver Creek near Faith, SD	44.9392	−102.0440	37.1	37.1	1956	1980	25	--	--
358	6439300	Cheyenne River at Cherry Creek, SD	44.5997	−101.4979	23,643	23,632	1961	1994	34	1960	1994
359	6439430	Cottonwood Creek near Cherry Creek, SD	44.6744	−101.4049	120	120	1983	1999	17	1982	1999
360	6439500	Cheyenne River near Eagle Butte, SD	44.6964	−101.2174	24,311	24,300	1920	2008	43	1935	2009

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