



Inventory and Analysis of Groundwater Resources

Theodore Roosevelt National Park, North Dakota

Natural Resource Report NPS/THRO/NRR—2020/2124



ON THE COVER

Expansive views, Theodore Roosevelt National Park.
Mark Hoffman, NPS.

Inventory and Analysis of Groundwater Resources

Theodore Roosevelt National Park, North Dakota

Natural Resource Report NPS/THRO/NRR—2020/2124

William G. Eldridge and Colton J. Medler

U.S. Geological Survey

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Abstract

Industrial and commercial developments in western North Dakota potentially could affect the sources of water that contribute to wells, spring flow, and seeps within Theodore Roosevelt National Park. Without basic water resources data, accurately predicting the effects of water withdrawals and water-quality concerns related to industrial and commercial developments near the park would be challenging. Water resources in the park include surface water and groundwater. The Little Missouri River and its tributaries cross all three Theodore Roosevelt National Park units and are the primary surface-water features in the park. Groundwater resources include well discharges, springs, and seeps. The geology and hydrogeology of Theodore Roosevelt National Park are defined by the surrounding Williston Basin. Four aquifers are sources of groundwater to the park: unconsolidated aquifers including alluvial systems, the upper Fort Union aquifer, the lower Fort Union aquifer, and the Fox Hills-lower Hell Creek aquifer.

Data used for wells, springs, seeps, and water quality in this report were compiled from the U.S. Geological Survey National Water Information System or from the North Dakota State Water Commission. An inventory of 16 wells was completed for sites within the boundaries of the park. In addition to well data, an inventory of 11 springs and seeps was completed. The groundwater-quality analysis had two objectives: (1) to characterize the groundwater chemistry in aquifers underlying the park and (2) to spatially map selected physical properties and chemical constituents of interest. Groundwater-quality data from the North Dakota State Water Commission were summarized, mapped, and used to characterize groundwater for each aquifer in the study area. Spatial concentration distribution maps were constructed for selected physical properties and chemical constituents using summary statistics and exceedances. Piper diagrams were used to classify and characterize groundwater for each aquifer.

Future research to help fill data gaps in water resources information for Theodore Roosevelt National Park, including recommendations from previous studies, consists of the following: (1) evaluating the variability in discharge from springs and seeps in comparison to changes in precipitation or other recharge sources, (2) evaluating flow control measures for flowing artesian wells, (3) completing a water rights review, and (4) performing routine water-quality monitoring for wells and springs.

Conversion Factors

Table E.1. U.S. customary units to International System of Units.

Unit of measurement	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)
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)
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)
	Acre-foot (acre-ft)	1,233	Cubic meter (m ³)
	Acre-foot (acre-ft)	0.001233	Cubic hectometer (hm ³)
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)
	Gallon per minute (gal/min)	0.063090	Liter per second (L/s)
	Gallon per hour (gal/hr)	0.09085	Cubic meter per day (m ³ /d)
	Gallon per day (gal/d)	0.003785	Cubic meter per day (m ³ /d)
Hydraulic conductivity	Foot per day (ft/d)	0.3048	Meter per day (m/d)
Transmissivity	Foot squared per day (ft ² /d)	0.09290	Meter squared per day (m ² /d)

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

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \div 1.8$$

Datum

Unless otherwise noted, 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).

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness ($[\text{ft}^3/\text{d}]/\text{ft}^2$) ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Acknowledgments

The authors acknowledge the efforts of several people who contributed to this study. Most importantly, the staff of Theodore Roosevelt National Park assisted with site visits, access to records, and background information for the wells, springs, and seeps. Additionally, staff from the National Park Service, Water Resources Division, assisted with site visits, provided access to past reports, and provided a review of this report.

The authors also thank Joel Galloway, Theodore Barnhart, and Galen Hoogestraat of the U.S. Geological Survey for their careful and thoughtful reviews of this report. Their comments were invaluable and greatly improved the accuracy and readability of the report.

Abbreviations

EPA U.S. Environmental Protection Agency

MCL maximum contaminant level

NWIS National Water Information System

TDS total dissolved solids

SMCL secondary maximum contaminant level

USGS U.S. Geological Survey

Introduction

Water is a critical resource for Theodore Roosevelt National Park that is used by all park fauna including free-ranging bison, elk, deer, pronghorn sheep, feral horses, and domestic horses. Additionally, water resources (surface water and groundwater) provide horseback riders, park visitors, and employees drinking water and serve fire protection and other management needs. The Little Missouri River and its tributaries, which cross all three park units (North Unit, Elkhorn Ranch Unit, and South Unit), are the primary surface-water features (Fig. 1). Groundwater resources include well discharges, springs, and seeps with waters that originate from several aquifers. The Theodore Roosevelt National Park Water Resources Management Plan (Iierkley and others, 1998) identified the park water resources as critical to protect riparian and other wildlife habitats and identified deficiencies in its water resource inventories. Industrial and commercial developments in western North Dakota potentially could affect the sources of water that contribute to spring flow and seeps within the park. Without water resources data from inventories and water-quality samples, accurately predicting the effects of water withdrawals and addressing water-quality concerns related to industrial and commercial developments near Theodore Roosevelt National Park would be more challenging.

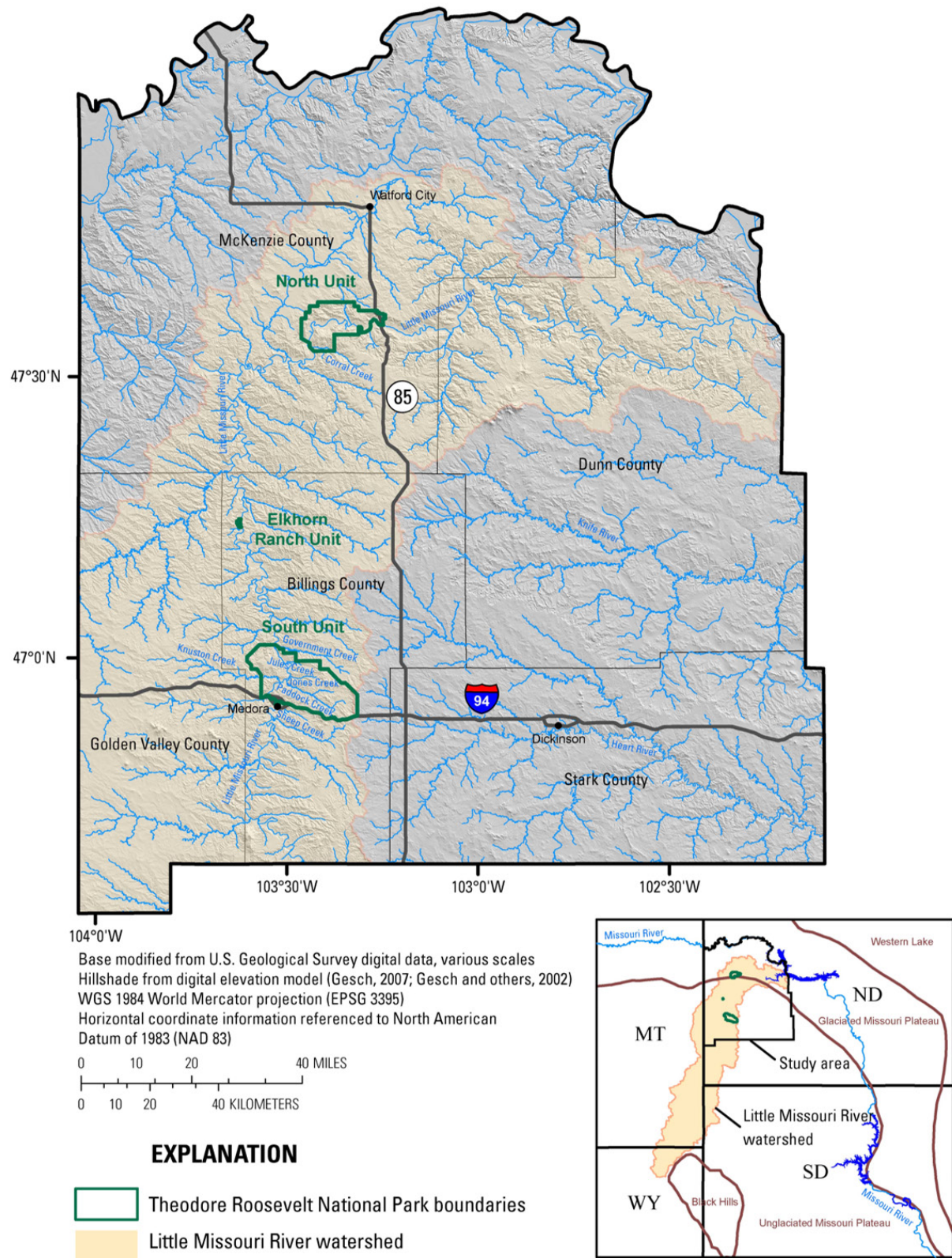


Figure 1. Study area map showing the 3 units of Theodore Roosevelt National Park in western North Dakota and the 5 surrounding North Dakota counties.

Purpose and Scope

The purpose of this report is two-fold. First, it documents past groundwater inventories and describes collection methods for inventorying groundwater resources including wells, springs, seeps, historical water levels, discharge rates, and water quality. The methodologies described in this report could be used as a template for other national parks or agencies seeking to create an inventory and history of groundwater resources. Second, this report provides a summary and analysis of water-quality data from existing databases to characterize the groundwater from aquifers used by the park. Components of this report include a study area description, a description of the geology and hydrogeology, a review of previous hydrologic investigations, data collection methods, inventories, analysis of groundwater flow and water quality, and future research needs. Appendixes include additional water-quality data, site photographs, well log references, water-quality data, and applicable North Dakota water law including permitting processes and water-quality regulation.

The scope of this report is the groundwater resources of Theodore Roosevelt National Park consisting of the wells, springs, and seeps. The scope of the groundwater-quality analysis included two objectives: (1) to characterize the groundwater chemistry for aquifers in the study area and (2) to spatially map selected physical properties and chemical constituents of interest. The groundwater-quality analysis included sampling sites from the 5 counties surrounding Theodore Roosevelt National Park (Billings, Dunn, Golden Valley, McKenzie, and Stark) in 3 aquifers—the upper Fort Union aquifer, the lower Fort Union aquifer, and the Fox Hills-lower Hell Creek aquifer. Water-quality data from alluvial aquifers were not included because of the lack of available data. The 5 counties were selected to provide a large number of sampling sites and to show spatial variation in groundwater quality in the areas surrounding the park. Water-quality data from surface waters were not included in the report but have been previously summarized for Theodore Roosevelt National Park and the surrounding area by the National Park Service (1997), Galloway and others (2012), Amberg and others (2014), and Rockwood and Ashton (2020).

Study Area Description

The study area for this report included Theodore Roosevelt National Park and the five surrounding North Dakota counties (Fig. 1). Theodore Roosevelt National Park encompasses 70,447 acres of land in three separate park units—the South Unit, the North Unit, and the Elkhorn Ranch Unit (National Park Service, 2011a). The three units are in Billings and McKenzie Counties of western North Dakota, and the counties surrounding the park that are included in this study are Dunn, Golden Valley, and Stark Counties (Fig. 1). Theodore Roosevelt National Park was established in 1947 as Theodore Roosevelt National Memorial Park but included only the South Unit and the Elkhorn Ranch Unit (National Park Service, 2014); the North Unit was added in 1948. In 1978, the U.S. Congress designated the three units of Theodore Roosevelt National Memorial Park as Theodore Roosevelt National Park and established 29,920 acres in the North Unit and South Unit as wilderness areas (National Park Service, 2011a).

Geographic Setting

Theodore Roosevelt National Park is mostly within the Little Missouri River watershed in the southwestern part of North Dakota (Fig. 1). The Little Missouri River flows northward through the

South Unit, then adjacent to the Elkhorn Ranch Unit, continues through the North Unit, and finally discharges into the Missouri River (Fig. 1). Theodore Roosevelt National Park contains 21.0 miles (mi) of the Little Missouri River and 268.8 mi of intermittent streams (Amberg and others, 2014).

The Little Missouri River watershed is part of the Missouri Plateau of the Great Plains physiographic province (not shown), and the study area is divided between the Glaciated and Unglaciated Missouri Plateau sections of the Great Plains province (Fig. 1; Wieczorek and LaMotte, 2010). The Missouri River and its tributaries shaped the Missouri Plateau into valleys, leaving terraces and high buttes along the margins of rivers. Continental ice sheets dammed the tributaries, forming large lakes, and subsequent recession of the lakes increased the width of the larger valleys in the region (KellerLynn, 2007). Also, runoff and rapid erosion of the exposed poorly consolidated sediments created the highly dissected topography of the park and parts of western North Dakota.

The town of Medora (population 128 in 2018; U.S. Census Bureau, 2018), North Dakota, is on the southern border of the South Unit (Fig. 1). Interstate 94 runs along the southern part of the South Unit and defines part of the South Unit boundary. Watford City (Fig. 1; population about 7,080 in 2018; U.S. Census Bureau, 2018), N. Dak., is 15 mi north of the North Unit along Highway 85. Overland access to Theodore Roosevelt National Park is predominately by Interstate Highway 94 and Highway 85.

Since the late 1970s, Theodore Roosevelt National Park has experienced an increasing amount of industrial and commercial development along its borders in the form of oil and gas development. Before 1979, oil and gas producing wells in North Dakota numbered less than 2,000; however, the number of wells grew to more than 3,300 in 2005 and to more than 16,000 by 2018 (Fig. 2; North Dakota Department of Mineral Resources, 2019a). Similarly, oil production grew from less than 30 million barrels annually before 1979 to more than 450 million barrels by 2018. Gas production in the 1990s ranged from 45,000,000 to 55,000,000 million cubic feet (MCF) and grew to more than 660,000,000 MCF by 2018. North Dakota oil and gas developments are concentrated in the northwestern region of the State and are near the three units of the park (Fig. 3; North Dakota Department of Mineral Resources, 2019b). At the end of 2018, 96.8 percent of oil production and 98.3 percent of gas production were from more than 12,800 wells completed in the Bakken Formation, which underlies the State's western region (North Dakota Industrial Commission, 2016; North Dakota Department of Mineral Resources, 2019a). The growth of oil and gas wells producing from the Bakken Formation and other formations near the park has increased steadily since the late 1970s (Fig. 4).

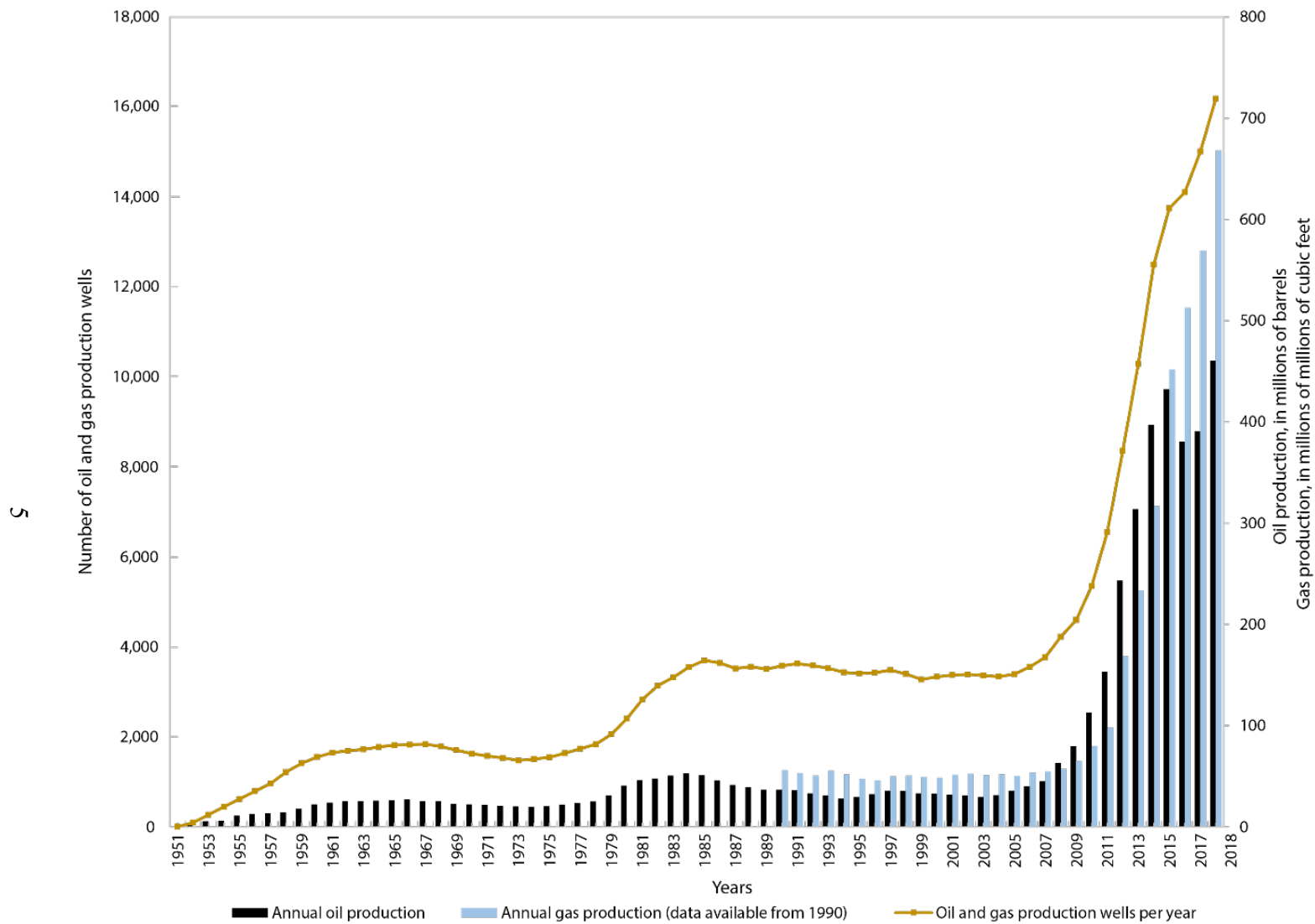


Figure 2. Trends in oil and gas production wells, annual oil production, and annual gas production from 1951 through 2018 in North Dakota (North Dakota Department of Mineral Resources, 2019a, b).

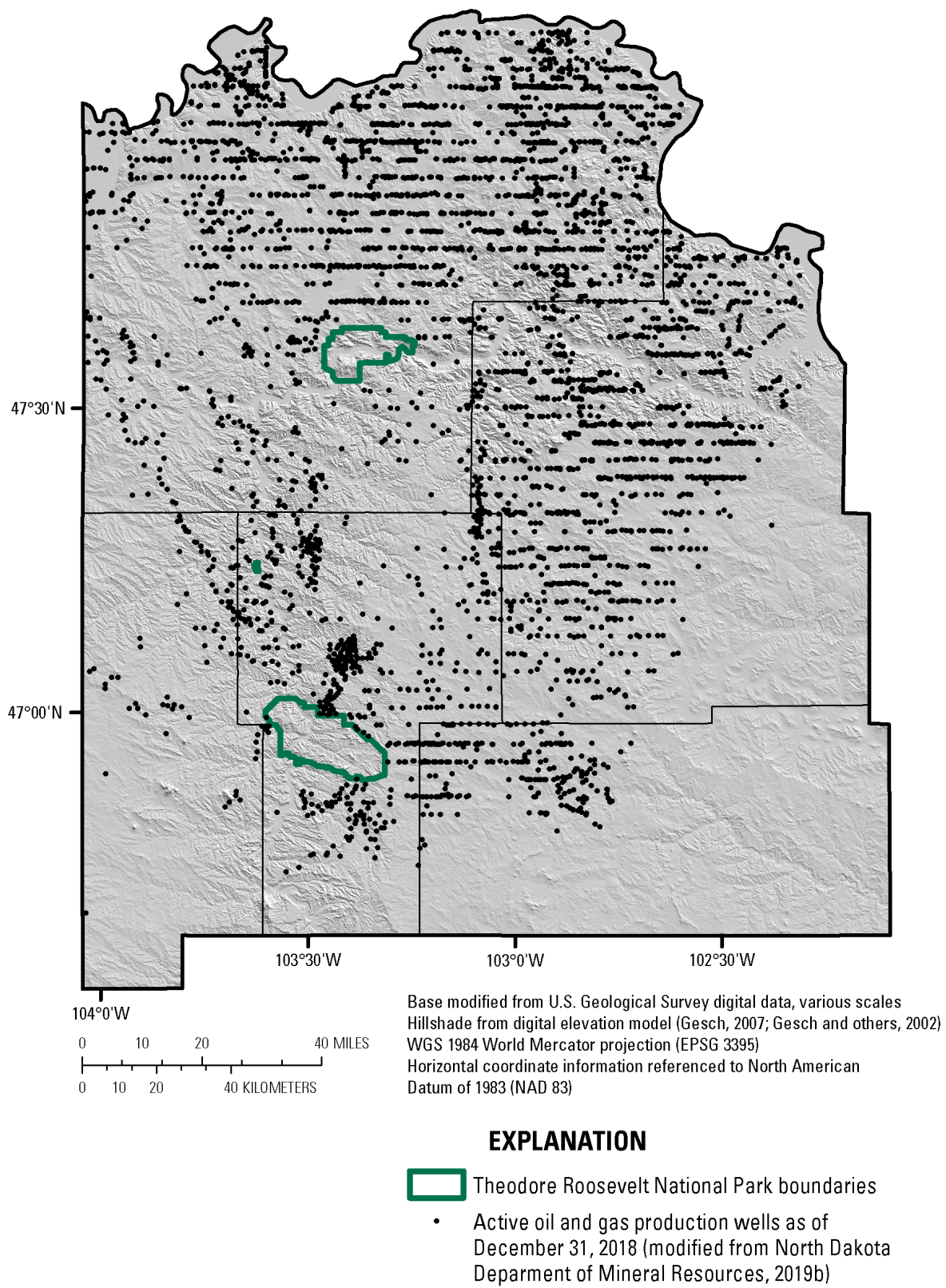


Figure 3. Active oil and gas production wells in western North Dakota as of December 31, 2018.

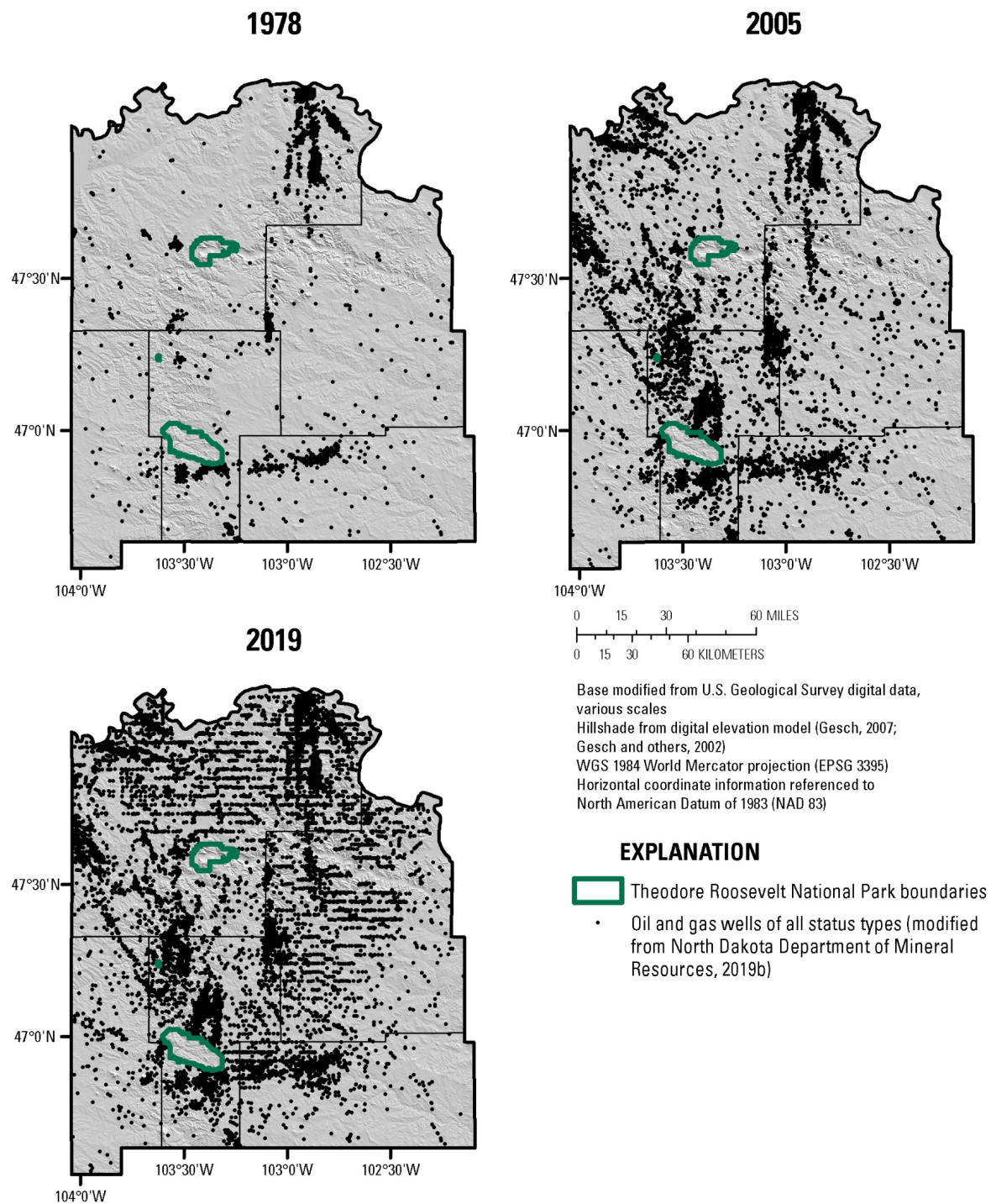


Figure 4. Oil and gas wells of all status types in western North Dakota prior to 1978, 2005, and 2019.

The rapid increase in industrial and commercial growth in western North Dakota could affect the availability of water resources in Theodore Roosevelt National Park because large volumes of water are required to support the sources of growth, such as oil and gas production processes, ethanol production, and irrigation. The North Dakota State Water Commission (2009) estimated that non-Bakken Formation wells require as much as 0.3 acre-foot of fresh water (acre-ft; 100,000 gallons) per well during the drilling process, and Bakken wells use more water, requiring more than 3 acre-ft (1 million gallons) of clean water per well. Based on drilling trends, non-Bakken wells could require as much as 45 acre-ft (15 million gallons) of water per year, and through 2019, new Bakken Formation wells could require as much as 51,000 acre-ft (16 billion gallons) of clean water (North Dakota State Water Commission, 2009). Additionally, water requirements for ethanol production were predicted to increase by 1,500 acre-ft in western North Dakota, and irrigation water requirements are estimated to increase by 35,300 acre-ft (34 million gallons) by 2020 (North Dakota State Water Commission, 2009). Current water needs for industrial and commercial development will not deplete the groundwater sources providing discharge to seeps or springs, or seepage to the Little Missouri River in the park; however, future water needs could stress groundwater resources. For example, an oil refinery is planned near Medora, N. Dak. (Davis Refinery, 2019), and in 2017, the North Dakota State Water Commission began to allow temporary water permits from the Little Missouri River for commercial and industrial uses (Dalrymple, 2017).

Climate

The climate of western North Dakota is semiarid and continental, which is characterized by long, cold winters and short, moderately warm summers (Anna, 1981). Extreme drought conditions were experienced in the 1930s and 1980s. After the mid-2000s, western North Dakota again experienced prolonged drought, but the eastern region of the State faced major flooding (North Dakota State Water Commission, 2009). Monthly mean climate data from 1981 to 2010 (30-year normal) at eight National Oceanic and Atmospheric Administration stations (not shown) in Billings and McKenzie Counties, N. Dak., ranged from 4.6 degrees Fahrenheit (°F) in January to 84.4 °F in July (Table 1; National Oceanic and Atmospheric Administration, 2019). During the same period and at the same eight sites, mean annual precipitation was 15.4 inches (in.). The month of June had the highest mean monthly precipitation at 3.01 in.

Table 1. Monthly 30-year mean temperature and precipitation for Billings and McKenzie Counties, North Dakota. Climate data were obtained from the National Oceanic and Atmospheric Administration (2019). The monthly mean precipitation was computed for a 30-year period from 1981 to 2010 at National Oceanic and Atmospheric Administration sites 00320096, 00322809, 00323705, 00324571, 0094080, 00325814, 00329246, and 00329233.

Month	Mean temperature (degrees Fahrenheit)		Total mean precipitation (inches)
	Monthly minimum	Monthly maximum	
January	4.6	25.3	0.44
February	9.1	30.6	0.33
March	19.5	41.7	0.69
April	30.7	56.9	1.19
May	41.4	67.5	2.27
June	50.8	76.2	3.01
July	56.5	84.4	2.43
August	54.7	84.2	1.54
September	43.8	72.3	1.30
October	32.0	57.2	1.23
November	10.0	39.8	0.57
December	6.7	27.1	0.46
Total	–	–	15.40

Geology and Hydrogeology

The geology and hydrogeology of Theodore Roosevelt National Park are defined by the surrounding Williston Basin, which is a large and roughly circular structural depression underlying parts of North Dakota, South Dakota, Montana, and Canada (Fig. 5). The park is near the center of the basin, which is filled with a nearly complete sequence of Phanerozoic sedimentary rock that can exceed 16,000 feet (ft) in thickness (Anna and others, 2013). Rocks of the Paleozoic era are composed predominantly of limestone, dolomite, sandstone, shale, and evaporites (Croft, 1985). The origin, structural history, stratigraphy, and mineral resources of the Williston Basin are not described in this report but are described by Sandberg (1962), Gerhard and others (1982), and Anna and others (2013). Groundwater from Paleozoic formations often is brackish and uneconomical for many uses containing about 100,000 milligrams per liter (mg/L) of dissolved solids (Croft, 1985). The surface topography of the Williston Basin is flat to gently rolling plains ranging from 1,500 to 3,500 ft above the North American Vertical Datum of 1988 with scattered buttes and badlands (Sandberg, 1962). Rocks at the surface are composed of mostly Tertiary glacial deposits, nonmarine Tertiary sedimentary rocks, and marine Cretaceous sedimentary rocks (Sandberg, 1962; Table 2).

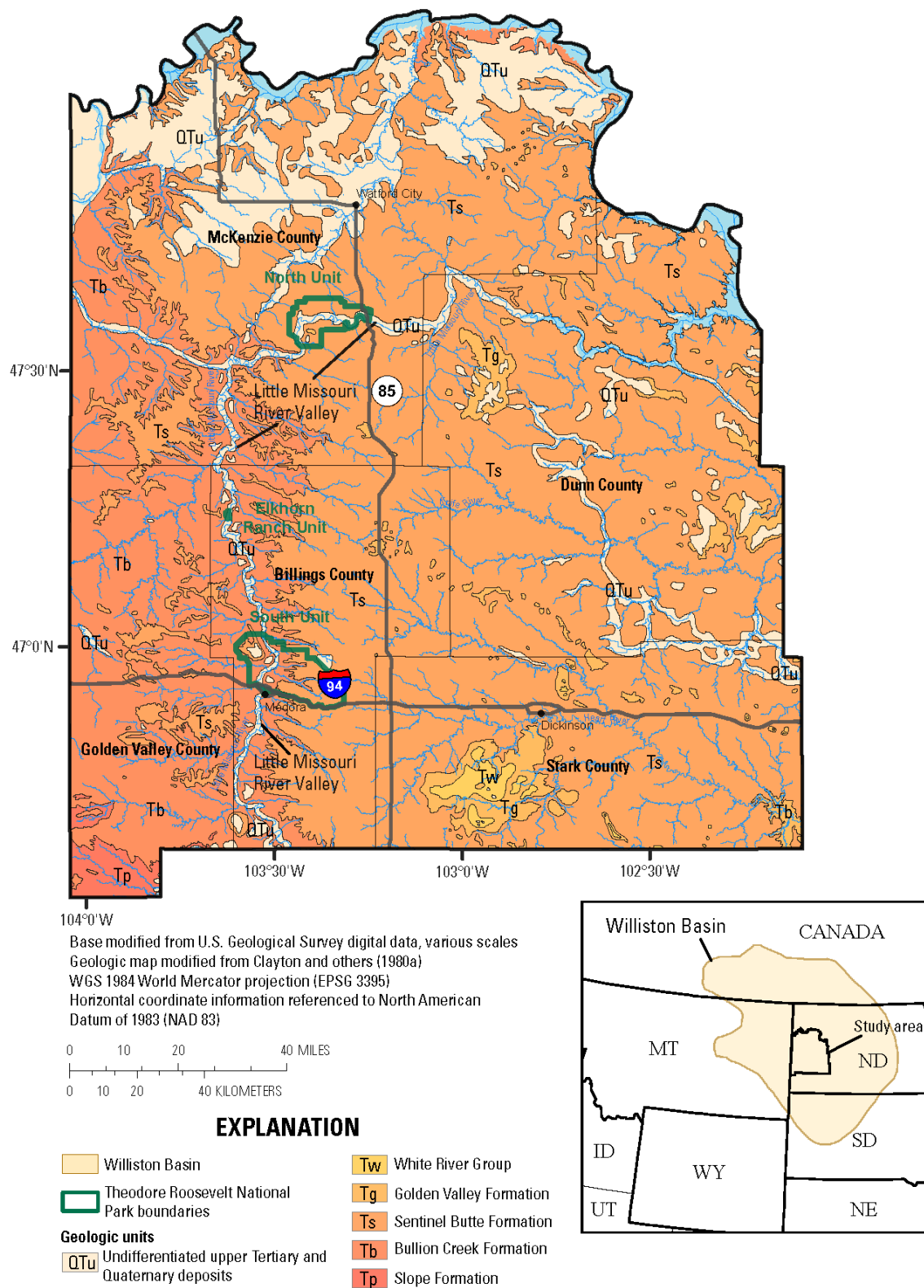


Figure 5. Surficial geology of Theodore Roosevelt National Park and the surrounding area.

Table 2. Generalized stratigraphic column of the geology underlying Theodore Roosevelt National Park listing the era, system, group, formation, maximum thickness, description and lithology, and generalized hydrogeologic unit (modified from Clayton and others, 1980a; Anna, 1981; Murphy and others, 2009).

Era	System	Group	Formation	Maximum thickness (feet)	Description and lithology	Hydrogeologic unit
Cenozoic	Quaternary	–	–	variable	Sand, gravel, silt, and clay from locally derived sources, such as weathering of consolidated rock and terrace gravels	Alluvium/surfacial deposits
	Quaternary	–	Oahe	100	Tan to gray to black clay, silt, sand, and gravel; organic-rich or organic-rich lenses; pebbles consisting of clinker and lignite fragments; paleosols	Not an important source of groundwater in the study area
	Quaternary	Coleharbor	See Murphy and others (2009) for a complete list	1,000	Olive gray to tan clay, silt, sand, gravel, and boulders; glacial till; glaciolacustrine clays; organic rich; plant and animal remains	Not an important source of groundwater in the study area
	Tertiary	–	Unnamed units	300	Gravel, sand, sandstone, silicified wood, concretions; mainly pebbles and cobbles; clay, silt, sand, and gravel	Not an important source of groundwater in the study area
	Tertiary	–	Arikaree	330	Light gray, green, white limestone, sandstone, and siltstone; tuffaceous; green chert nodules in marlstone; contains the burrowed marker unit	Not an important source of groundwater in the study area
	Tertiary	White River*	Brule	200	Brown to pink siltstone, sandstone, and claystone; nodular, siltstones may contain claystone inclusions, mammal fossils common	Not an important source of groundwater in the study area
	Tertiary	White River*	Chadron*	140*	Top: brown, pink, and green claystone; contains silicified zones; bentonitic; popcorn weathering surface Bottom: grayish green to white sandstone and conglomerate; cross-bedded, poorly cemented sandstone; pebbles include volcanic porphyries, quartz, and some petrified wood*	Not an important source of groundwater in the study area

* An unconformity is between the Chadron and Golden Valley Formations, which is an erosional surface that represents missing time from the geologic record (the top part of the Golden Valley Formation is worn down or missing from erosion).

Table 2 (continued). Generalized stratigraphic column of the geology underlying Theodore Roosevelt National Park listing the era, system, group, formation, maximum thickness, description and lithology, and generalized hydrogeologic unit (modified from Clayton and others, 1980a; Anna, 1981; Murphy and others, 2009).

Era	System	Group	Formation	Maximum thickness (feet)	Description and lithology	Hydrogeologic unit
Cenozoic (continued)	Tertiary	–	Golden Valley Formation*	400*	Top: yellow and brown sandstone, siltstone, mudstone, claystone, and thin lignite; poorly to well cemented sandstone; micaceous Bottom: white, gold, purple claystone, siltstone, and sandstone; kaolinitic; small iron spheres*	Not an important source of groundwater in the study area
	Tertiary	Fort Union	Sentinel Butte	650	Gray, blue, and brown sandstone, siltstone, claystone, mudstone, clinker, and lignite; poorly to well cemented sandstone; swelling bentonitic and nonswelling claystones; limestone with nodules and concretions; petrified wood	Upper Fort Union
	Tertiary	Fort Union	Bullion Creek (equivalent to Tongue River Formation pre-1977)	650	Generally bright colored, yellow, brown, gray sandstone, siltstone, claystone, mudstone, clinker, and lignite; poorly to well cemented sandstones; swelling and nonswelling claystones; limestone with nodules and concretions	Upper Fort Union
	Tertiary	Fort Union	Slope (equivalent to Upper Ludlow Formation pre-1977)	270	Generally dark colored, brown and gray sandstone, siltstone, claystone, mudstone, clinker, and lignite; poorly to well cemented sandstone, swelling and nonswelling claystones; limestone with nodules and concretions	Upper Fort Union
	Tertiary	Fort Union	Cannonball	255	Dark gray to black mudstone; greenish gray to yellow sandstone; glauconitic; mudstone contains lenses of siltstone and sandstone; poorly to well cemented sandstone; abundant marine fossils	Lower Fort Union

* An unconformity is between the Chadron and Golden Valley Formations, which is an erosional surface that represents missing time from the geologic record (the top part of the Golden Valley Formation is worn down or missing from erosion).

Table 2 (continued). Generalized stratigraphic column of the geology underlying Theodore Roosevelt National Park listing the era, system, group, formation, maximum thickness, description and lithology, and generalized hydrogeologic unit (modified from Clayton and others, 1980a; Anna, 1981; Murphy and others, 2009).

Era	System	Group	Formation	Maximum thickness (feet)	Description and lithology	Hydrogeologic unit
Cenozoic (continued)	Tertiary	Fort Union	Ludlow (equivalent to Lower Ludlow Formation pre-1977)	300	Brown and gray sandstone, siltstone, claystone, mudstone, clinker, and lignite; poorly cemented to well cemented sandstones; swelling and nonswelling claystones; limestone with nodules and concretions	Lower Fort Union
Mesozoic	Cretaceous	Montana	Hell Creek	330	Gray, brown, and purple sandstone, siltstone, claystone, mudstone and thin discontinuous lignite; moderately to poorly cemented, organic rich, cross-bedded sandstone; bentonitic claystone; tuffaceous beds, limestone with nodules and concretions; dinosaur fossils	Upper part considered Lower Fort Union and lower part considered Fox Hills-lower Hell Creek
	Cretaceous	Montana	Fox Hills	400	Yellowish brown to gray mudstone, siltstone, and sandstone, poorly to well cemented sandstone, organic laminae, tuffaceous beds, abundant fossils	Fox Hills-lower Hell Creek
	Cretaceous	Montana	Pierre	2,300	Light to dark gray shale, generally noncalcareous, fissile to blocky	Not an important source of groundwater in the study area

* An unconformity is between the Chadron and Golden Valley Formations, which is an erosional surface that represents missing time from the geologic record (the top part of the Golden Valley Formation is worn down or missing from erosion).

Alluvial, Surficial, and Other Aquifers

The study area includes alluvial and surficial aquifers. Upper Tertiary and Quaternary alluvial deposits in the study area formed in the Little Missouri River Valley (Fig. 5) and consist of sand, gravel, silt, and clay (Clayton and others, 1980a; Anna, 1981) underlain by 10–15 ft of gravel (Anna, 1981). Recharge to alluvial aquifers that are contained in alluvial deposits is from precipitation infiltrating through surface soils, streamflow losses, and inundation of flood plains (Anna, 1981). The Little Missouri River Valley is typically less than 1 mi wide (Anna, 1981) and is about 200 mi long in the study area (Fig. 5). Some wells exist in the Little Missouri River Valley, but its alluvial aquifer is not considered a major aquifer because of its small spatial extent. Groundwater flow in alluvial aquifers typically follows surface topography. Anna (1981) and Klausing (1979) provided studies on the alluvial aquifers in the Theodore Roosevelt National Park area, and selected hydrologic properties are listed in Table 3.

Other shallow aquifers in the study area include those contained in the Tertiary-age White River Group and the Golden Valley Formation, but neither contain important aquifers in Theodore Roosevelt National Park. The White River Group unconformably overlies the Golden Valley Formation and consists of the Brule and Chadron Formations (Table 2; Murphy and others, 2009). The Brule Formation consists of siltstone, sandstone, and claystone that were deposited in river and lake environments (Table 2; Clayton and others, 1980a; Murphy and others, 2009). The Chadron Formation consists of a conglomerate, sandstone, and claystone that were deposited in river and lake environments (Table 2; Clayton and others, 1980a; Murphy and others, 2009). The Chadron and Brule Formations (part of the White River Group) combine to have a maximum thickness of about 340 ft and are exposed at the surface in the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The Golden Valley Formation conformably overlies the Sentinel Butte Formation and consists of sandstone, siltstone, mudstone, claystone, and thin lignite that were deposited in river, lake, and swamp environments (Table 2; Clayton and others, 1980a; Murphy and others, 2009). The thickness of the Golden Valley Formation is as much as 400 ft, and it is exposed at the surface in the study area as caps to large buttes, especially in Dunn and Stark Counties (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The White River Group and Golden Valley Formation are not considered to contain major aquifers and only a few wells in the study area obtain water from them (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981).

Table 3. Aquifer properties for the alluvial, upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers in or near Theodore Roosevelt National Park by source and county.

Aquifer	Source	County	Depth to aquifer top (feet)	Hydraulic conductivity (ft/d)	Transmissivity (ft ² /d)	Total porosity (percent)	Storage (unitless)	Potential yield (gal/min)	Specific capacity (gal/min/ft) ¹
Alluvial	Trapp and Croft (1975)	Stark	0–30	–	–	–	–	–	–
	Klausing (1979)	Dunn	6 to >100	–	–	–	–	5.0–10.0	–
	Anna (1981)	Billings	0–30	–	–	15	–	<50	–
	Anna (1981)	Golden Valley	–	–	–	15	–	<50	–
	Croft (1985)	McKenzie	0–200	–	–	35	–	<100	–
Upper Fort Union	Trapp and Croft (1975)	Stark	–	0.1–27	70–1,130	–	0.0007–0.008	<100	0.01–7.2; average 0.4
	Klausing (1979)	Dunn	16–750 (sandstone); 15–600 (lignite)	0.057–0.95	1.0–96.0 (sandstone); 49–19,500 (lignite)	–	0.0002–0.007 (lignite)	1–200 (sandstone); 1–200 (lignite)	0.15–2.3 (sandstone); 0.9–68 (lignite)
	Anna (1981)	Billings	0–450	Average 0.4 (sandstone); 94–1,200 (lignite)	220–530	–	–	5–250 (sandstone); 1–200 (lignite)	1.5–4.0
	Anna (1981)	Golden Valley	0–450	Average 0.4 (sandstone); 94–1,200 (lignite)	220–530	–	–	5–250 (sandstone); 1–200 (lignite)	1.5–4.0
	Croft (1985) ²	McKenzie	140–500	0.03–58; average 5	–	27–37	–	<25	–
Lower Fort Union	Trapp and Croft (1975)	Stark	<710	<1.0–19.0	–	35 (assumed for calculations of other aquifer properties)	–	<100	0.2–0.33
	Klausing (1979)	Dunn	570–1,130	0.06–0.45	3.0–4.0	–	–	<50	0.09–0.12
	Anna (1981)	Billings	>0 and <1,400	0.6–0.8	1.5–160; average 77	33.0–34.9	–	<150	0.01–0.3

¹ gal/min/ft = gallon per minute per foot

² Croft (1985) combines the middle Fort Union aquifer (Slope and Bullion Creek Formations) with the upper Fort Union aquifer (Sentinel Butte Formation) because water levels in the Sentinel Butte Formation are higher than in the Slope and Bullion Creek Formations, meaning water must be leaking downward.

Table 3 (continued). Aquifer properties for the alluvial, upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers in or near Theodore Roosevelt National Park by source and county.

Aquifer	Source	County	Depth to aquifer top (feet)	Hydraulic conductivity (ft/d)	Transmissivity (ft ² /d)	Total porosity (percent)	Storage (unitless)	Potential yield (gal/min)	Specific capacity (gal/min/ft) ¹
Lower Fort Union (continued)	Anna (1981)	Golden Valley	>0 and <1,400	0.6–0.8	1.5–160; average 77	33.0–34.9	–	<150	0.01–0.3
	Croft (1985)	McKenzie	>500	0.1–14	–	26–37	0.0006	<25	–
Fox Hills-lower Hell Creek	Trapp and Croft (1975)	Stark	1,120–1,520	–	110–390	–	–	25–75	1
	Klausing (1979)	Dunn	1,150–1,730	0.06–1.2	4.0–71.0	–	–	<100	0.4–1.0
	Anna (1981)	Billings	>0 and <1,900	0.4–7.1; average 1.6	11–600	31.6–40.2; average 35.3	0.0003–0.00042	<300	0.5–3.5
	Anna (1981)	Golden Valley	>0 and <1,900	0.4–7.1; average 1.6	11–600	31.6–40.2; average 35.3	0.0003–0.00042	<300	0.5–3.5
	Croft (1985)	McKenzie	1,100–1,800	Typically <30; average 6	200–350	25–35	0.00022–0.00027	<100	1.9

¹ gal/min/ft = gallon per minute per foot

² Croft (1985) combines the middle Fort Union aquifer (Slope and Bullion Creek Formations) with the upper Fort Union aquifer (Sentinel Butte Formation) because water levels in the Sentinel Butte Formation are higher than in the Slope and Bullion Creek Formations, meaning water must be leaking downward.

Upper Fort Union Aquifer

The upper Fort Union aquifer is contained in the upper part of the Fort Union Formation consisting of the Tertiary-age Sentinel Butte, Bullion Creek, and Slope Formations. The Sentinel Butte Formation consists of sandstone, siltstone, claystone, mudstone, clinker, and lignite that were deposited in river, lake, and swamp environments (Murphy and others, 2009). The thickness of the Sentinel Butte Formation is as much as 650 ft, and it is exposed at the surface in almost the entire eastern two-thirds of the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The Bullion Creek Formation (Tongue River Formation pre-1977) consists of interbedded sandstone, siltstone, claystone, mudstone, clinker, and lignite that were deposited in river, lake, and swamp environments (Moore, 1976; Murphy and others, 2009). The thickness of the Bullion Creek Formation can be as much as 650 ft, and it is exposed at the surface in almost the entire western one-third of the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The Slope Formation (Upper Ludlow Formation pre-1977) consists of interbedded sandstone, siltstone, claystone, mudstone, clinker, and lignite that were deposited in river, lake, and swamp environments (Clayton and others, 1980a; Murphy and others, 2009). The thickness of the Slope Formation is as much as 270 ft, and it is exposed at the surface in the southwestern part of the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009).

Some studies hydrologically exclude the Sentinel Butte Formation from the Bullion Creek and Slope Formations (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981). However, Croft (1985) grouped all three formations into a single aquifer because water levels in the Sentinel Butte Formation were higher than those in the Slope and Bullion Creek Formations, which indicated that groundwater was moving downward. Anna (1981) also reported higher water levels in the Sentinel Butte Formation in western Golden Valley County, whereas other areas either had nearly identical water levels (no leakage) or higher water levels (upward flow). Croft (1985) also showed that water from the Sentinel Butte Formation was chemically similar, except for larger chloride concentrations, to the Slope and Bullion Creek Formations. The downward and upward exchange of water among the Sentinel Butte, Bullion Creek, and Slope Formations and similar water chemistry were used as criteria to consider them as one aquifer.

The regionally extensive upper Fort Union aquifer has a saturated thickness ranging from less than 50 to more than 400 ft thick and consists of sandstone and fractured lignite (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985). All three formations composing the upper Fort Union aquifer are exposed at the surface in the study area and receive recharge from direct precipitation on outcrops, leakage of streams and lakes, and exchange from overlying and underlying aquifers (Anna, 1981; Croft, 1985). Wells completed in the uppermost sandstone units of the Sentinel Butte Formation are generally less than 100 ft deep (Anna, 1981). In topographically high areas, the Sentinel Butte Formation is characterized by perched aquifers above lignite and sandstone beds that cause downward percolating groundwater to travel horizontally until reaching the surface as springs (Anna, 1981).

Trapp and Croft (1975), Klausing (1979), Anna (1981), and Croft (1985) estimated hydrologic properties for the upper Fort Union aquifer for each county in the study area (Table 3). Hydraulic

conductivity and total porosity of the sandstone units were estimated to range from 0.03 to 58 feet per day (ft/d) and from 27 to 37 percent, respectively (Table 3). The average sandstone hydraulic conductivity of about 0.4 ft/d was attributed to the poor sorting and large percentage of clay and silt (20–40 percent) in the samples (Table 3; Anna, 1981). Transmissivity estimates for sandstone units ranged from 1.0 to 1,130 square feet per day (ft²/d; Table 3). Potential well yield for the sandstone units ranged from 1 to 250 gallons per minute (gal/min; Table 3) depending on well depth, particle size distribution, and sorting. Additional hydrologic properties for the upper Fort Union aquifer, including lignite units, are in Table 3.

Lower Fort Union Aquifer

The Tertiary-age Cannonball and Ludlow Formations of the lower part of the Fort Union Formation are the two major units comprising the lower Fort Union aquifer. The Cannonball Formation conformably overlies the Ludlow Formation and consists of mudstone and sandstone that were deposited in a marine/brackish environment (Table 2; Murphy and others, 2009). The thickness of the Cannonball Formation can be as much as 255 ft, and it is thought to be absent or thin in the western part of the State. The Cannonball Formation is not exposed at the surface in the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The Ludlow Formation (Lower Ludlow Formation pre-1977) conformably overlies the Hell Creek Formation and consists of interbedded deposits of sandstone, siltstone, claystone, mudstone, clinker, and lignite that were deposited from terrestrial sources, such as rivers, lakes, and swamps (Table 2; Clayton and others, 1977; Murphy and others, 2009). The thickness of the Ludlow Formation can be as much as 300 ft, and it is not exposed at the surface in the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009).

The Cannonball and Ludlow Formations also are hydrologically connected to the upper sandstone of the underlying Cretaceous-age Hell Creek Formation (Table 2; Trapp and Croft, 1975). These three units form the regionally extensive lower Fort Union aquifer (Table 2). The net thickness of sandstone containing the aquifer ranges from 10 to 600 ft and averages about 80 ft (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985). The depth to the top of the aquifer can be as much as 1,400 ft in the study area (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985). In neighboring Slope, Bowman, and Adams Counties, all three formations are exposed at the surface and, in addition to percolation of precipitation and leakage from overlying or underlying aquifers, the outcrop areas for these formations are a major recharge area to the aquifer (not shown; Trapp and Croft, 1975; Clayton and others, 1980b). Croft (1985) reported that recharge to the lower Fort Union aquifer was from underlying deposits because the hydraulic head in the lower Fort Union aquifer generally is lower than the hydraulic head in the Fox Hills-lower Hell Creek aquifer.

Trapp and Croft (1975), Klausing (1979), Anna (1981), and Croft (1985) estimated hydrologic properties for the lower Fort Union aquifer for each county in the study area (Table 3). Hydraulic conductivity and total porosity were estimated to range from 0.1 to 19 ft/d and from 26 to 37 percent, respectively (Table 3). The low hydraulic conductivity could be attributed to the poor sorting and large percentage of silt in the samples (Anna, 1981). Transmissivity estimates ranged from 1.5 to 160 ft²/d with an average of 77 ft²/d (Table 3). Potential well yields were reported to range from less

than 25 to 150 gal/min depending on the degree of aquifer penetration, particle size distribution, and sorting (Table 3). Additional hydrologic properties for the lower Fort Union aquifer are in Table 3.

Fox Hills-Lower Hell Creek Aquifer

The lowermost freshwater aquifer is contained in the Cretaceous-age Hell Creek and Fox Hills Formations. The Hell Creek Formation consists of interbedded fluvial channel sands and overbank silts/clays (Clayton and others, 1980a). The thickness of the Hell Creek Formation can be as much as 330 ft and is not exposed at the surface in the study area (Fig. 5; Clayton and others, 1980b; Murphy and others, 2009). The Fox Hills Formation consists of reddish-yellow sandstone deposited in a shoreline environment and dark reddish-brown sandy/silty shale deposited in an offshore environment (Table 2; Sandberg, 1962; Clayton and others, 1980a). The thickness of the Fox Hills Formation is as much as 400 ft, and the formation is not exposed at the surface in the study area (Fig. 5; Cvancara, 1976; Murphy and others, 2009).

The uppermost sandstone unit in the Fox Hills Formation is commonly grouped with the lowermost sandstone unit of the Hell Creek Formation to form an extensive aquifer named the Fox Hills-lower Hell Creek aquifer (Table 2). The net thickness of sandstones containing the aquifer ranges from 0 to about 530 ft (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985), and it underlies the entire study area. The aquifer is a major source of water for domestic and livestock use and for municipalities not along the Missouri River (Thorstenson and Fisher, 1979). The main source of recharge likely is from downward percolation of precipitation and leakage of other overlying aquifers, but discharge is thought to be from losses to areas east of the Missouri River and by percolation upward into overlying aquifers (Thorstenson and Fisher, 1979).

Studies by Trapp and Croft (1975), Klausing (1979), Anna (1981), and Croft (1985) estimated hydrologic properties for the Fox Hills-lower Hell Creek aquifer for each county in the study area (Table 3). Hydraulic conductivity and total porosity estimates in the study area ranged from 0.06 to less than 30 ft/d and from 25 to 40.2 percent, respectively. Low hydraulic conductivity could be attributed to the poor sorting and large percentage of silt (28 percent) in the samples (Anna, 1981). Transmissivity estimates ranged from 4 to 600 ft²/d and potential well yields were reported to range from 25 to less than 300 gal/min (Table 3) depending on the depth of aquifer penetration, particle size distribution, and sorting. Additional hydrologic properties for the Fox Hills-lower Hell Creek aquifer in the study area are in Table 3.

The Cretaceous-age Pierre Formation underlies the Fox Hills Formation and separates the lower uneconomical aquifers from the upper productive aquifers (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985). The Pierre Formation is a light- to dark-gray to black shale deposited in an offshore marine environment (Table 2; Gill and Cobban, 1965). The maximum thickness of the Pierre Formation is about 2,300 ft, and it thins towards the edges of the Williston Basin (Sandberg, 1962). Groundwater from aquifers overlying the Pierre Formation is considered the most suitable for industrial, livestock, and domestic use based on common well depths and water quality (Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985). Aquifers underlying the Pierre Formation are outside the scope of this report and are not discussed.

Previous Hydrologic Investigations

Hydrologic investigations in western North Dakota began in the early 1900s. The North Dakota Geological Survey began a series of groundwater studies from 1911 through 1913 that were later published by the U.S. Geological Survey (USGS) in 1929 (Simpson and Riffenburg, 1929). These early studies provided detailed aquifer descriptions, water-quantity estimates, water-quality summaries, and county specific studies. In Billings County, Simpson and Riffenburg (1929) noted two wells near Medora and Sully Springs, N. Dak., that were under flowing artesian conditions and noted that porous beds of sandstone and lignite that were exposed at the land surface below the groundwater level provided the necessary hydrogeologic conditions to form springs. McKenzie County also had low-flowing artesian wells and many springs that were used as water supplies primarily for cattle.

Interest in the geology and water resources of western North Dakota increased in the 1950s and 1970s as regional coal and oil production increased. Anna (1981) listed multiple geologic investigations of southwestern North Dakota and specific geologic studies for Billings and McKenzie Counties dating from 1915 through 1976. Laird (1956a, b) published geologic guides for the North Unit and South Unit of Theodore Roosevelt National Park. Croft (1974) described borehole geology, tested the water quality, and measured hydrologic properties at water supply wells at the Painted Canyon Overlook and the headquarters well in the South Unit of the park. Biek and Gonzalez (2001) mapped and described the geology within the boundaries of Theodore Roosevelt National Park.

Starting in the late 1970s, the North Dakota State Water Commission began publishing county groundwater studies (North Dakota State Water Commission and State Engineer, 2015a). Each study included three parts: part I described geology; part II provided data such as lithologic logs, observation well water levels, and water chemistry; and part III described general hydrogeology. Reports for Billings and McKenzie Counties, which contain Theodore Roosevelt National Park, were included in these studies and were completed by Anna (1981) and Croft (1985), respectively.

The North Dakota Office of the State Engineer and State Water Commission regularly provide water resource reports at the State-level. Starting in 1904, the State Engineer's Office began to publish biennial reports highlighting Office activities, which often focused on water issues (North Dakota State Water Commission and State Engineer, 2015c). Since 1937, North Dakota has published statewide water plans that report on the progress of water developments, outline State water priorities, and provide revenue information (North Dakota State Water Commission and State Engineer, 2015d). Additionally, several groundwater studies dating back to the early 1940s were published for specific locations and aquifers (North Dakota State Water Commission and State Engineer, 2015e). In 2004, both agencies began publishing strategic plans that outlined goals, objectives, and key projects (North Dakota State Water Commission and State Engineer, 2015f). The State Water Commission and Office of the State Engineer also maintain databases for water wells, water well permits, and data for ground and surface water (North Dakota State Water Commission, 2019).

The National Park Service published several reports that provided inventories of the water resources of Theodore Roosevelt National Park. Memorandums from park superintendents from 1949 through

1960 provided lists of springs, seeps, and wells and made recommendations for improvements at those sites (National Park Service, 2011b). Table 4 summarizes the springs and seeps discussed in these memorandums. Some site locations were not maintained nor monitored after 1968. Early reports described the springs (except for Knutson Creek and Jules Creek springs) as receiving their water from the upland prairie recharge areas surrounding the badlands or from remnants of the prairie within the badlands (National Park Service, 2011b). Water resources also were listed in a water-quality study done from the mid- to late 1980s that sampled park wells, springs, seeps, and surface waters for physical properties and chemical constituents (Appendix 1). The water-quality study did not include pesticides or oil and gas production chemical constituents. A baseline water-quality inventory was completed in March 1997 that included locations of springs and surface water sites in the park with water-quality data from October 1949 through March 1996 (National Park Service, 2011b; Appendix 1). A water resources management plan in 1998 inventoried 16 springs, but the list included several flowing artesian wells as springs (Iierkley and others, 1998). A 2006 report inventoried 6 springs and 7 wells as monitored sites or water developments in the South Unit (Oehler and Sexton, 2010).

In addition to springs and seeps, the memorandums provided well inventories. Table 5 is a list of the Theodore Roosevelt National Park wells documented in the memorandums with the park unit (North or South), well depth below land surface, year completed, and reported discharge rates. Numeric discharge rates likely imply that the well was a flowing artesian well at the time of the inventory measurement.

Additional water resource reports were completed by Theodore Roosevelt National Park in 1998 and 2014. Iierkley and others (1998) outlined applicable legislation, policies, and executive orders as well as summarized surface waters, groundwater, and water-quality issues. In 2014, Theodore Roosevelt National Park published its foundation document (National Park Service, 2014) that listed fundamental resources, such as the Little Missouri River, and water resource issues requiring attention. In the same year, Sargeant and others (2014) completed a study on the use of water developments by female elk in the park. Also, Amberg and others (2014) authored the Theodore Roosevelt National Park Natural Resource Condition Assessment that included air and surface-water-quality evaluations. The report by Amberg and others (2014) includes maps of inventoried springs and seeps in the North and South Units.

Table 4. Springs and seeps inventoried by Theodore Roosevelt National Park superintendents from 1953 through 1968. The symbol “x” denotes that the spring or seep was inventoried, and the symbol “–” denotes that the spring or seep was not inventoried or data were not available.

Spring or seep name	Location ¹	Year of document or map showing spring or seep				Flow (1955) ² gal/min
		1953	1955	1960	1968	
Beef Corral Roadside	140N 102W 01 SENE	–	x	x	–	0.1
Big Plateau	140N 102W 02 NESE	x	x	x	x	0.285
Boicourt	140N 101W 02 NWSW	x	x	x	x	0.25
Jules Creek	141N 101W 19 SWSW	x	x	x	–	–
Knutson Creek, Petrified Plateau, or Krudson Creek	140N 102W 03 SWSW	x	x	x	–	0.2
Lone Tree	141N 102W 36 NWSW	–	–	x	x	–
Olsen Seep	140N 100W 31 SWNE	x	x	x	–	–
Painted Canyon	140N 101W 35 SW	x	x	x	–	–
Petrified Forest Plateau	141N 101W 19 NWSW	–	x	x	x	1.0
Sheep Butte	140N 101W 12 NESW	x	x	x	x	0.50
Southeast Corner	140N 100W 32 NWSE	x	x	x	x	0.083
Talkington Pond No. 2	140N 101W 21 NWSW	–	–	x	–	–
Talkington Pond No. 1	140N 101W 14 SESW	–	x	x	–	–
VA Bottom	141N 101W 19 SENW	–	x	x	–	0.083
W. Entrance picnic	140N 102W 16 SENW	x	x	x	–	–
Wannigan Seeps	141N 102W 36 NWNE	x	x	x	–	0.083

¹ Format is range, township, section, quarter section, and quarter-quarter section (if specified); N = North; S = South; W = West; E = East.

² Values listed are as recorded in the original document in gallons per minute (National Park Service, 2011b).

Table 5. Wells inventoried by Theodore Roosevelt National Park superintendents from 1947 through 1959. The symbol “–” denotes that data were not available.

Well Name	Park unit	Well depth below land surface (ft)	Year well completed	Discharge in completion year (gal/min) ¹	Reported well discharge by year (gal/min) ¹				
					1947	1955	1956	1957	1959
Residential and utility area	North	393	1935	–	–	–	Pumped	–	–
Squaw Creek Campground	North	372	1956	–	–	–	Pumped	–	–
Headquarters (renamed Peaceful Valley Ranch by 1960)	South	420	1914	–	5.48	4.0	–	–	–
Chase	South	366	1939	–	–	2.0	–	–	–
Cottonwood	South	360	1914	8	4.92	–	–	–	–
Cottonwood Campground	South	782	1956	–	–	–	5.5	–	4.5
Eklom	South	400	1914	–	5.48	0.3	–	–	–
Halliday	South	593	1924	–	–	2.0	–	–	–
Johnson Plateau	South	759	1922	–	Pumped	–	–	–	–
Jones Creek (CCC ² Camp)	South	443	1939	8	–	6.0	–	–	–
Medora Headquarters	South	1,042	1957	–	–	–	–	75–85	–
Mike Auney	South	350	1914	–	–	3.0	–	–	–
Picnic Site (east entrance)	South	424	1941	7.5	4.95	6.0	–	–	–
Tomamichael	South	640	1928	–	–	0.1	–	–	–
VA Bottom (2 wells)	South	–	–	–	–	0.083	–	–	–
West Entrance (CCC ² Camp)	South	364	1936	–	–	1.5	–	–	–

¹ Discharge assumed to be under flowing artesian conditions unless annotated as “pumped.” Values listed are as recorded in the original document (National Park Service, 2011b).

² Civilian Conservation Corps.

Methods of Collection for Well, Spring, Seep, and Water-Quality Data

Data described in this report for wells, springs, seeps, and water quality were compiled from the USGS National Water Information System database (NWIS; U.S. Geological Survey, 2019a), collected as part of this study in 2018, or acquired from the North Dakota State Water Commission (2015). Well, spring, and seep site locations not already listed in the NWIS database were assigned site identification numbers and added to the NWIS database. This section reviews data collection methods for wells, springs and seeps, and groundwater quality.

Well Data Collection

Well data collection procedures included documenting well locations and identifying missing data elements needed to define a groundwater site in the USGS NWIS database. Wells were defined as sites with well casings, even if park historical records or other studies identified the site as a spring. Data collection methods for the wells used procedures outlined by Cunningham and Schalk (2011). Site information compiled for each well in the inventory included items listed in Table 6.

Table 6. Site information compiled for well sites in Theodore Roosevelt National Park.

Item	Data description
1	USGS assigned well identification number (if none, then assigned identification number)
2	Narrative description of well location and common name of well
3	Latitude and longitude of well, in decimal degrees (including reference coordinate system and measurement device)
4	Land surface elevation, datum used, and measurement method (such a survey or map)
5	Estimate of location quality and accuracy
6	Depth from land surface to bottom of well, in feet
7	Depth from land surface to water level in feet with date and time of measurement
8	Information on surrounding pumping conditions, if any
9	Name of person and agency collecting data
10	Drillers' well log information, such as construction details, if available
11	Water use intended for the well
12	Historical data, such as well construction, well improvements, past aquifer pumping tests, and past water-quality tests

Well location data, including latitude and longitude, were determined, or updated if the location was already known, by a Garmin 64st hand-held global positioning system with an inferred accuracy of 10 ft (U.S. Geological Survey, 2018). If a USGS identification number for a well site was not found in the NWIS database, a 15-digit number was assigned. For each site, photographs were taken and a brief narrative description, including the common well name, was written (Appendix 2). Land-surface elevation was determined from topographic maps or digital elevation models (Gesch and others, 2002). Well log information was from drillers' well logs, if available (Appendix 3) or from

park records. Well depth and water levels were not recorded during the inventory because most wells were drinking supply or production wells with inaccessible well heads or were under flowing artesian conditions.

Springs and Seeps Data Collection

A spring is defined as a place where water naturally issues from the ground and flows or forms pools (Bryan, 1919). Springs commonly form when the side of a hill, a valley bottom, or other excavation intersects flowing groundwater at or below the local water table, below which the subsurface material is saturated with water (U.S. Geological Survey, 2019b). Seeps are a variety of spring in which the water flows from pores in the ground over considerable areas (Bryan, 1919). Seepage occurs from a slow movement of water through small cracks, pores, or interstices of a material into or out of a body of surface or subsurface water (U.S. Geological Survey, 2019b).

Requirements for documenting spring and seep sites data are similar to wells. Procedures outlined in Cunningham and Schalk (2011) were used to establish or determine a site number, location, elevation, and discharge data. Spring locations were recorded with a handheld global positioning system, and site data were entered in the USGS NWIS database (U.S. Geological Survey, 2019a). Spring altitudes were derived from digital elevation data (Gesch, 2007). Discharge was measured using procedures from Turnipseed and Sauer (2010) or by other methods, such as recording the time necessary to fill a container with a known volume, and the measurements also were recorded in the USGS NWIS database. Data compiled for each spring and seep site for the inventory are listed in Table 7.

Table 7. Data compiled for spring and seep sites in Theodore Roosevelt National Park.

Item	Data description
1	USGS assigned identification number (if none, then locally assigned identification)
2	Narrative description of spring or seep location including common name or another identifier
3	Latitude and longitude of site, in decimal degrees (including coordinate system and measurement device)
4	Land surface elevation, datum used, and measurement method (such as survey or map)
5	Estimate of location and elevation quality and accuracy
6	Estimate of discharge in gallons per minute with the date and time of measurement
7	Comment on surrounding well pumping conditions, if any
8	Name of a person and agency collecting data
9	Historical data, such as spring box construction, spring box improvements, historical discharge data, and water-quality tests

Additional data describing springs and seeps include several categories. The type of spring, sphere of discharge, permanence, improvements, number of openings, flow variability, and the basis for variability are data that improve knowledge of the spring or seep resource. Categories of additional descriptive data for seeps and springs, including options for each category, are provided in Table 8.

Table 8. Additional descriptive data for seeps and springs by category with options for each category.

Category	Options or definitions
Spring type (for descriptions of spring type see Bryan, 1919 or U.S. Geological Survey, 2019a)	• Artesian • Artesian and depression • Artesian and seep/filtration • Contact • Depression • Fracture • Fracture and depression • Geyser • Perched • Perched and contact • Perched and depression • Perched and fractured • Perched and seep/filtration • Perched and tubular • Seepage/filtration • Tubular cave • Other
Sphere of discharge	• Subaerial • Subaqueous
Permanence	• Geyser • Intermittent • Perennial • Periodic • Response • Seasonal • Other
Improvements	• Boxed • Concrete tub or basin • Gallery • Lined • Pipe • Pond • Spring house • Trough • None • Other
Number of openings	Number of discharge locations from field observations
Flow variability	Change in spring flow discharge from multiple field measurements
Basis for variability	• Calculated <1 year • Calculated 1–5 years • Calculated >5 years • Calculated intermittent • Estimated • Other

Groundwater-Quality Data

Groundwater-quality data from samples in the study area were summarized and mapped. The groundwater-quality analysis had two objectives: (1) to characterize the groundwater chemistry for aquifers in the study area and (2) to spatially map selected physical properties and chemical constituents of interest. The groundwater-quality data were used to compute summary statistics, construct boxplots (Appendix 4), Piper diagrams, and map the spatial concentration distributions for selected physical properties and chemical constituents.

Water-quality data from 1937 through 2018 were selected from the North Dakota State Water Commission database (North Dakota State Water Commission, 2015) for the five counties in the study area. The North Dakota State Water Commission database was chosen because it provides a large and comprehensive collection of water-quality data in the study area dating to the 1930s. Data included the sampled aquifer; however, inconsistencies in aquifer names and changes in aquifer designations over time in the database required combining the samples into the following three aquifer groups for the study: upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek (Table 9). The hydrogeologic descriptions provided by Trapp and Croft (1975), Klausing (1979), Anna (1981), and Croft (1985) were used to inform the grouped aquifer designations. Glacial and alluvial aquifers were excluded from the analysis because they are not major groundwater resources in Theodore Roosevelt National Park. Surface-water-quality data also were not included in the study, but a summary of surface-water-quality studies in the park was provided by Amberg and others (2014) and McMahon and others (2015).

Table 9. Aquifers groups for Theodore Roosevelt National Park water-quality analysis.

Aquifer group	Aquifer in North Dakota State Water Commission (2015) water-quality database
Upper Fort Union	• Sentinel Butte of Fort Union • Sentinel Butte-Tongue River • Tongue River • Fort Union • Bullion Creek
Lower Fort Union	• Tongue River-Ludlow • Cannonball
Fox Hills-lower Hell Creek	• Hell Creek • Lower Hell Creek • Fox Hills

Water-quality data included physical properties and chemical constituent data from 781 sites. “Physical properties” refer to water-quality properties typically measured in the field, such as water temperature, specific conductance, and pH; “chemical constituents” refer to constituents measured using laboratory methods, such as calcium, chloride, and arsenic. Water-quality samples from the North Dakota State Water Commission database selected for analysis are listed in Table 10. Of the 781 total sites, 520 sites were in the upper Fort Union aquifer, 66 sites were in the lower Fort Union aquifer, and 195 sites were in the Fox Hills-lower Hell Creek aquifer. The number of samples for a

physical property or chemical constituent at each site was not constant because not all sites had recorded data for each constituent or physical property for every sample time and date. Some water-quality samples (such as magnesium and total dissolved solids [TDS]) had many records, but others (such as mercury and alkalinity) had fewer records.

Table 10. Analyzed physical properties and chemical constituents in samples from wells in the Theodore Roosevelt National Park study area, 1937–2018, from data from the North Dakota State Water Commission (2015).

Constituent group	Constituent	Units	Total number of samples in database ¹	Censor levels in database ²	Recensored level	Number of recensored values ³	Number of excluded values ⁴
Physical properties	Alkalinity	mg/L CaCO ₃	299 (170, 9, 120)	–	–	–	–
	Dissolved oxygen	mg/L	1 (1, 0, 0)	–	–	–	–
	Hardness	mg/L	1,001 (610, 86, 305)	–	–	–	–
	Percent sodium	%	939 (553, 85, 301)	–	–	–	–
	pH (field and laboratory) ⁵	Standard units	970 (582, 86, 302)	0	–	–	2 (1, 1, 0)
	Sodium absorption ratio	Unitless	936 (550, 85, 301)	–	–	–	–
	Specific conductance (field and laboratory) ⁶	µS/cm at 25°C	975 (584, 86, 305)	–	–	–	–
	Total dissolved solids (calculated and determined) ⁷	mg/L	1,003 (612, 86, 305)	–	–	–	–
	Water temperature	°C	696 (422, 67, 207)	–	–	–	–
Chemical constituents	Arsenic	µg/L	39 (26, 0, 13)	0, 5, 10*	5	27 (17, 0, 10)	8 (8, 0, 0)
	Bicarbonate	mg/L	997 (609, 86, 302)	0	–	–	4 (4, 0, 0)
	Boron	mg/L	620 (386, 67, 167)	0	–	–	43 (40, 2, 1)
	Bromide	mg/L	0 (0, 0, 0)	–	–	–	–

¹ Total number of samples in the database with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

² A physical measurement or chemical constituent may have multiple censoring levels if the level changed with time or different methods were used to calculate the concentration. Values recorded as zero in the database were excluded because the censor level was unknown or the value was undetermined (Kimberly Fischer, North Dakota State Water Commission, written comm., 2019). The symbol “*” denotes less than five values in dataset and the values were excluded.

³ Total number of recensored values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

⁴ Total number of excluded values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively. Excluded values included database values recorded as zero and censored values in the database greater than the recensored level.

⁵ Laboratory measured pH was used if the pH level was not measured in the field.

⁶ Laboratory measured specific conductance was used if specific conductance was not measured in the field.

⁷ Calculated total dissolved solids were used if determined total dissolved solids were not reported.

Table 10 (continued). Analyzed physical properties and chemical constituents in samples from wells in the Theodore Roosevelt National Park study area, 1937–2018, from data from the North Dakota State Water Commission (2015).

Constituent group	Constituent	Units	Total number of samples in database ¹	Censor levels in database ²	Recensored level	Number of recensored values ³	Number of excluded values ⁴
Chemical constituents (continued)	Cadmium	µg/L	34 (22, 0, 12)	0, 1, 5, 10*	5	34 (22, 0, 12)	1 (1, 0, 0)
	Calcium	mg/L	933 (548, 85, 300)	2	2	67 (4, 3, 60)	0 (0, 0, 0)
	Carbonate	mg/L	994 (605, 86, 303)	0, 1	1	487 (411, 18, 58)	376 (312, 17, 47)
	Chloride	mg/L	972 (584, 86, 302)	0, 10, 15, 60*	15	42 (42, 0, 0)	31 (31, 0, 0)
	Fluoride	mg/L	918 (534, 84, 300)	0	–	–	2 (2, 0, 0)
	Hydroxide	mg/L	265 (137, 9, 119)	1	1	265 (137, 9, 119)	0 (0, 0, 0)
	Iron	mg/L	966 (580, 86, 300)	0, 0.01, 0.05, 0.5*	0.05	117 (60, 3, 54)	71 (54, 2, 15)
	Lead	µg/L	39 (26, 0, 13)	0, 1, 5, 10*	5	33 (21, 0, 12)	11 (11, 0, 0)
	Lithium	µg/L	13 (13, 0, 0)	–	–	–	–
	Magnesium	mg/L	933 (548, 85, 300)	0, 1	1	110 (3, 4, 103)	6 (0, 1, 5)
	Manganese	mg/L	872 (494, 82, 296)	0, 0.01	0.01	213 (47, 16, 150)	93 (33, 10, 50)
	Mercury	µg/L	14 (13, 0, 1)	0, 0.2	.02	10 (9, 0, 1)	9 (8, 0, 1)
	Molybdenum	µg/L	20 (19, 0, 1)	0, 5	5	11 (11, 0, 0)	5 (5, 0, 0)
	Nitrate	mg/L	975 (592, 85, 298)	0, 0.09	0.09	194 (95, 5, 94)	52 (48, 2, 2)

¹ Total number of samples in the database with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

² A physical measurement or chemical constituent may have multiple censoring levels if the level changed with time or different methods were used to calculate the concentration. Values recorded as zero in the database were excluded because the censor level was unknown or the value was undetermined (Kimberly Fischer, North Dakota State Water Commission, written comm., 2019). The symbol “*” denotes less than five values in dataset and the values were excluded.

³ Total number of recensored values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

⁴ Total number of excluded values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively. Excluded values included database values recorded as zero and censored values in the database greater than the recensored level.

⁵ Laboratory measured pH was used if the pH level was not measured in the field.

⁶ Laboratory measured specific conductance was used if specific conductance was not measured in the field.

⁷ Calculated total dissolved solids were used if determined total dissolved solids were not reported.

Table 10 (continued). Analyzed physical properties and chemical constituents in samples from wells in the Theodore Roosevelt National Park study area, 1937–2018, from data from the North Dakota State Water Commission (2015).

Constituent group	Constituent	Units	Total number of samples in database ¹	Censor levels in database ²	Recensored level	Number of recensored values ³	Number of excluded values ⁴
Chemical constituents (continued)	Phosphate	mg/L	2 (2, 0, 0)	–	–	–	–
	Potassium	mg/L	919 (535, 84, 300)	1, 10*	1	16 (7, 0, 9)	1 (1, 0, 0)
	Selenium	µg/L	39 (26, 0, 13)	0, 1, 5, 10*	5	29 (21, 0, 8)	11 (10, 0, 1)
	Silica	mg/L	802 (487, 73, 242)	2	2	1 (1, 0, 0)	0 (0, 0, 0)
	Sodium	mg/L	952 (564, 85, 303)	–	–	–	–
	Strontium	µg/L	13 (13, 0, 0)	4	4	1 (1, 0, 0)	0 (0, 0, 0)
	Sulfate	mg/L	974 (586, 86, 302)	0, 0.3, 5, 10*	5	85 (10, 5, 70)	39 (9, 4, 26)

¹ Total number of samples in the database with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

² A physical measurement or chemical constituent may have multiple censoring levels if the level changed with time or different methods were used to calculate the concentration. Values recorded as zero in the database were excluded because the censor level was unknown or the value was undetermined (Kimberly Fischer, North Dakota State Water Commission, written comm., 2019). The symbol “*” denotes less than five values in dataset and the values were excluded.

³ Total number of recensored values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively.

⁴ Total number of excluded values with values in parentheses denoting the number of upper Fort Union aquifer samples, the number of lower Fort Union aquifer samples, and the number of Fox Hills-lower Hell Creek aquifer samples, respectively. Excluded values included database values recorded as zero and censored values in the database greater than the recensored level.

⁵ Laboratory measured pH was used if the pH level was not measured in the field.

⁶ Laboratory measured specific conductance was used if specific conductance was not measured in the field.

⁷ Calculated total dissolved solids were used if determined total dissolved solids were not reported.

Physical properties and chemical constituents with two or more censoring levels were recensored to a single level to allow for consistent summary statistics and comparison. Censor levels in water-quality analyses are defined as the “less-than” value reported when concentrations are too low to accurately quantify. Censor levels vary based on the type and reliability of the equipment used to measure concentrations (Helsel and Hirsch, 2002; McMahon and others, 2015). The highest censoring level generally was selected as the recensored level; however, the higher censoring level was excluded if the dataset contained less than five values at that censoring level (Table 10). If values were less than the recensoring level, then those values were set equal to the recensoring level for use in statistical analyses. Groundwater-quality data also were screened for zero concentration values before analysis. Zero values were removed from the analysis because the dataset specified zero as the marker for instances when the concentration was either reported as negligible, not recorded, or missing from field records (Kimberly Fischer, North Dakota State Water Commission, written commun., 2019). After screening, groundwater-quality data included 1,003 total water-quality samples categorized in the following aquifers: 612 were in the upper Fort Union aquifer, 86 were in the lower Fort Union aquifer, and 305 were in the Fox Hills-lower Hell Creek aquifer (Table 10).

Summary statistics were computed and included sample size, minimum, 25th percentile, median, 75th percentile, and maximum values for each physical property and chemical constituent listed in Table 10. Recensored data were included in the statistical computations for each physical property and chemical constituent. Some samples from the dataset were combined to simplify summary statistics; laboratory pH and specific conductance values were substituted when field pH and specific conductance values were absent because the two values were similar for nearly all occurrences where laboratory and field values were present. Similarly, calculated TDS values were substituted for determined TDS values when determined TDS values were absent (Table 10).

Samples used in summary statistics were compared to U.S. Environmental Protection Agency (EPA; 2009) drinking-water standards. The drinking-water standards used in this study include maximum contaminant levels (MCL) and secondary maximum contaminant levels (SMCL). The MCL is defined by the EPA as the highest level of a contaminant that is allowed in drinking water, and these are enforceable standards for public water supplies. The SMCL is defined by the EPA as a nonenforceable guideline for contaminants that may cause cosmetic effects (skin or tooth discoloration) or aesthetic effects (taste, odor, or color) in drinking water. The total number of samples exceeding MCL or SMCL drinking-water standards (U.S. Environmental Protection Agency, 2009) was calculated for all applicable physical properties and chemical constituents.

Boxplots were constructed using USGS standards (Helsel and Hirsch, 2002) for selected physical properties and chemical constituents (Appendix 4). Boxplots were used to determine which physical properties and chemical constituents exceeded selected water-quality standards, which were then spatially mapped. Piper diagrams also were constructed using USGS standards (Hem, 1985) to characterize the water chemistry for each aquifer. Piper (1944) developed trilinear diagrams to visualize and classify water types based on six common chemical components, including 3 cation (calcium, magnesium, and sodium plus potassium) and 5 anion (chloride, fluoride, sulfate, nitrate, and carbonate plus bicarbonate) species or groups of species (Ging and others, 1996). Values are

plotted in Piper diagrams by first converting cation and anion concentrations to milliequivalents per liter and then calculating the relative percentages of cation and anion species or groups of species that sum to 100 percent (Ging and others, 1996). Waters are classified by the dominant cation and anion present on the Piper diagram.

Well, Spring, and Seep Inventories

Inventory data were collected for wells, springs, and seeps. The data were used to update the USGS NWIS database (U.S. Geological Survey, 2019a). Water-quality data from National Park Service records for a 1980s study to determine the baseline water quality for Theodore Roosevelt National Park wells, springs, and seeps are included in Appendix 1. The following sections summarize data collected during the inventory, and photographs with additional notes are provided in Appendix 2.

Well Inventory

An inventory of 16 wells was compiled within the boundaries of Theodore Roosevelt National Park (Fig. 6). Some well sites from literature or records were not included in the inventory because the sites were no longer in use or the locations were unknown. Well sites included in the inventory are shown in Figure 6 and Table 11.

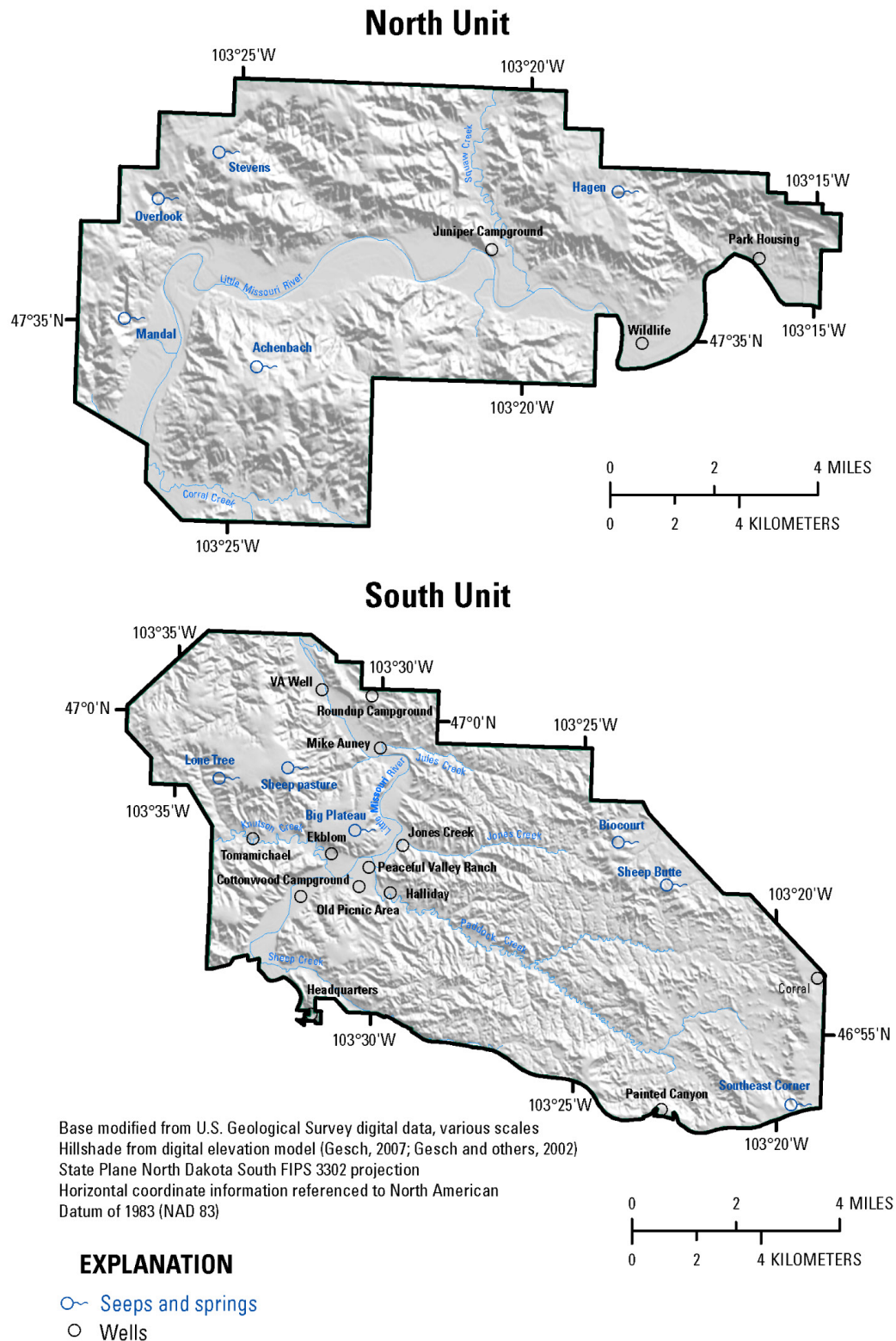


Figure 6. Location of inventoried wells, springs, and seeps in the North and South Units of Theodore Roosevelt National Park.

Table 11. Summary of groundwater well information for Theodore Roosevelt National Park.

Park unit	Well name	USGS NWIS site identification number (applicable NPS well number ¹)	Latitude, decimal degrees	Longitude, decimal degrees	Date constructed	Depth below land surface (ft)	Aquifer ²
North Unit ³	Juniper Campground	473547103200901 (01197)	47.600019	103.34341	2004	430	Bullion Creek (Tongue River)
	Park Housing ⁴	473601103155801 (00193)	47.600152	103.26624	2016	390	Completed in sandstone (likely Bullion Creek)
	Wildlife well	473458103175501	47.582793	103.29908	1976 (estimated)	40	Alluvial
South Unit ⁵	Corral	465601103185801	46.933681	103.31608	1992	951	Fox Hills
	Cottonwood Campground	465700103314801 (03680)	46.950119	103.53012	1984	1,365	Fox Hills
	Ekblom	465744103310601	46.962206	103.51821	1914	400	Tongue River
	Halliday	465707103293801	46.952012	103.49376	1924	593	Tongue River
	Headquarters ⁶	465458103313201 (00193)	46.916052	103.52548	1986	1,343	Fox Hills
	Jones Creek	465755103292201	46.965395	103.48936	1939	443	Tongue River
	Mike Auney	465932103300001	46.992242	103.50009	1914	350	Tongue River

¹ NPS well numbers from Iierkley and others (1998).

² After 1977, the Tongue River Formation was designated the Bullion Creek Formation and for this study was classified as part of the upper Fort Union aquifer. However, driller logs after 1977 may continue to list the Tongue River as a formation.

³ North Unit wells described in records but not inventoried include Squaw Creek well and old Park Housing well.

⁴ Two wells are at this site within 30 feet of each other. Coordinates are provided for the well completed in 2016.

⁵ South Unit wells described in records but not inventoried included Rasmussen (NPS well number 01192), Rough Rider (364 feet depth in Cannonball Member of the Fort Union Formation, flooded and was destroyed), Picnic Site (east entrance), Chase, West Entrance (Civilian Conservation Corps Camp), VA Bottom, and Johnson Plateau (Table 4). The VA well was not visited because of inaccessibility.

⁶ The Headquarters well was capped and plugged in the 2010s and is no longer used. NPS facilities in the South Unit receive water from the city of Medora, North Dakota.

⁷ Well information and data from Croft (1973).

Table 11 (continued). Summary of groundwater well information for Theodore Roosevelt National Park.

Park unit	Well name	USGS NWIS site identification number (applicable NPS well number ¹)	Latitude, decimal degrees	Longitude, decimal degrees	Date constructed	Depth below land surface (ft)	Aquifer ²
South Unit ⁵ (continued)	Old Picnic Area	465708103302201	46.953414	103.50660	1964 (estimated)	424	Tongue River
	Painted Canyon ⁷	465343103225001 (unassigned)	46.894486	103.38035	1973	1,928	Fox Hills (Croft, 1973)
	Peaceful Valley Ranch	465721103300301 (01194)	46.958957	103.50310	1998	1,180	Fox Hills
	Roundup Campground	470024103301601 (05017)	47.00663	103.50453	1996	1,320	Fox Hills
	Tomamichael	465756103330201	46.965611	103.55057	1928	640	Tongue River
	VA well	470028103312901	47.007864	103.52473	1914	350	Tongue River

¹ NPS well numbers from Iierkley and others (1998).

² After 1977, the Tongue River Formation was designated the Bullion Creek Formation and for this study was classified as part of the upper Fort Union aquifer. However, driller logs after 1977 may continue to list the Tongue River as a formation.

³ North Unit wells described in records but not inventoried include Squaw Creek well and old Park Housing well.

⁴ Two wells are at this site within 30 feet of each other. Coordinates are provided for the well completed in 2016.

⁵ South Unit wells described in records but not inventoried included Rasmussen (NPS well number 01192), Rough Rider (364 feet depth in Cannonball Member of the Fort Union Formation, flooded and was destroyed), Picnic Site (east entrance), Chase, West Entrance (Civilian Conservation Corps Camp), VA Bottom, and Johnson Plateau (Table 4). The VA well was not visited because of inaccessibility.

⁶ The Headquarters well was capped and plugged in the 2010s and is no longer used. NPS facilities in the South Unit receive water from the city of Medora, North Dakota.

⁷ Well information and data from Croft (1973).

Theodore Roosevelt National Park maintains wells completed in alluvial aquifers, the upper Fort Union aquifer (before 1977, the Tongue River aquifer), and the Fox Hills aquifer (Table 11). In the study area, wells completed in alluvium had depths of about 40 ft below land surface and historical yields less than 50 gal/min (Anna, 1981). Wells completed in the upper Fort Union aquifer (Tongue River) had depths ranging from about 350 to 640 ft below land surface and often were flowing artesian wells with historical discharge rates generally less than 10 gal/min, but some discharge rates were recorded as high as 250 gal/min (Iierkley and others, 1998). Wells completed in the Fox Hills aquifer generally were about 950 to 1,930 ft below land surface. In the early 1980s, the Fox Hills aquifer had a hydraulic head of about 1,600 ft above land surface near the southern boundary of the South Unit (Anna, 1981) and was classified as artesian with a potentiometric surface above the top of the aquifer. Discharge rates for flowing artesian wells completed in the Fox Hills aquifer historically were less than 150 gal/min.

The North Dakota State Water Commission began recording reported water use from the National Park Service for its permits in North Dakota in 1966 (North Dakota State Water Commission, 2019). Reported water use for permits in Billings and McKenzie Counties began in 1976 and was highest in 1976 at 30.8 acre-ft. The lowest water use was reported in 2011 at 0.1 acre-ft. Records likely are missing data from 1978, and records showed that permit 1197 reported a use of 200 acre-ft in 1989, which was likely in error and changed to 2 acre-ft for Fig. 7, which was the value from the four previous years.

As of 2019, the National Park Service had 12 permits for water rights on record with the North Dakota State Water Commission and State Engineer Office (Table 12; North Dakota State Water Commission, 2019), and 11 of the 12 permits listed groundwater as the water source. All but two permits were in Billings and McKenzie Counties (Table 12). The permits have various priority dates, beneficial use dates, and perfected status. A priority date is defined (Appendix 5) as a water right superior to rights with a later date (North Dakota Legislative Branch, 2019). Priority dates for National Park Service water rights in North Dakota range from 1959 to 1996. Beneficial use dates are defined (Appendix 5) as dates when the use of the water began for its intended use (North Dakota Legislative Branch, 2019). Beneficial use dates were established for six National Park Service permits in North Dakota (Table 12). A perfected permit is defined as a conditionally approved permit with the site developed and inspected by the State Engineer staff to determine that the water was applied to beneficial use; a perfected permit establishes a water right (North Dakota State Water Commission, 2019). Only 6 of the 12 permits were active with a perfected status as of 2019; the other 6 permits were canceled. The domestic water use type was specified for five of the six perfected permits. The water source for all six perfected permits was groundwater, and the Fox Hills aquifer was listed as the aquifer for four of the six perfected permits (two perfected permits listed the aquifer as “undefined”).

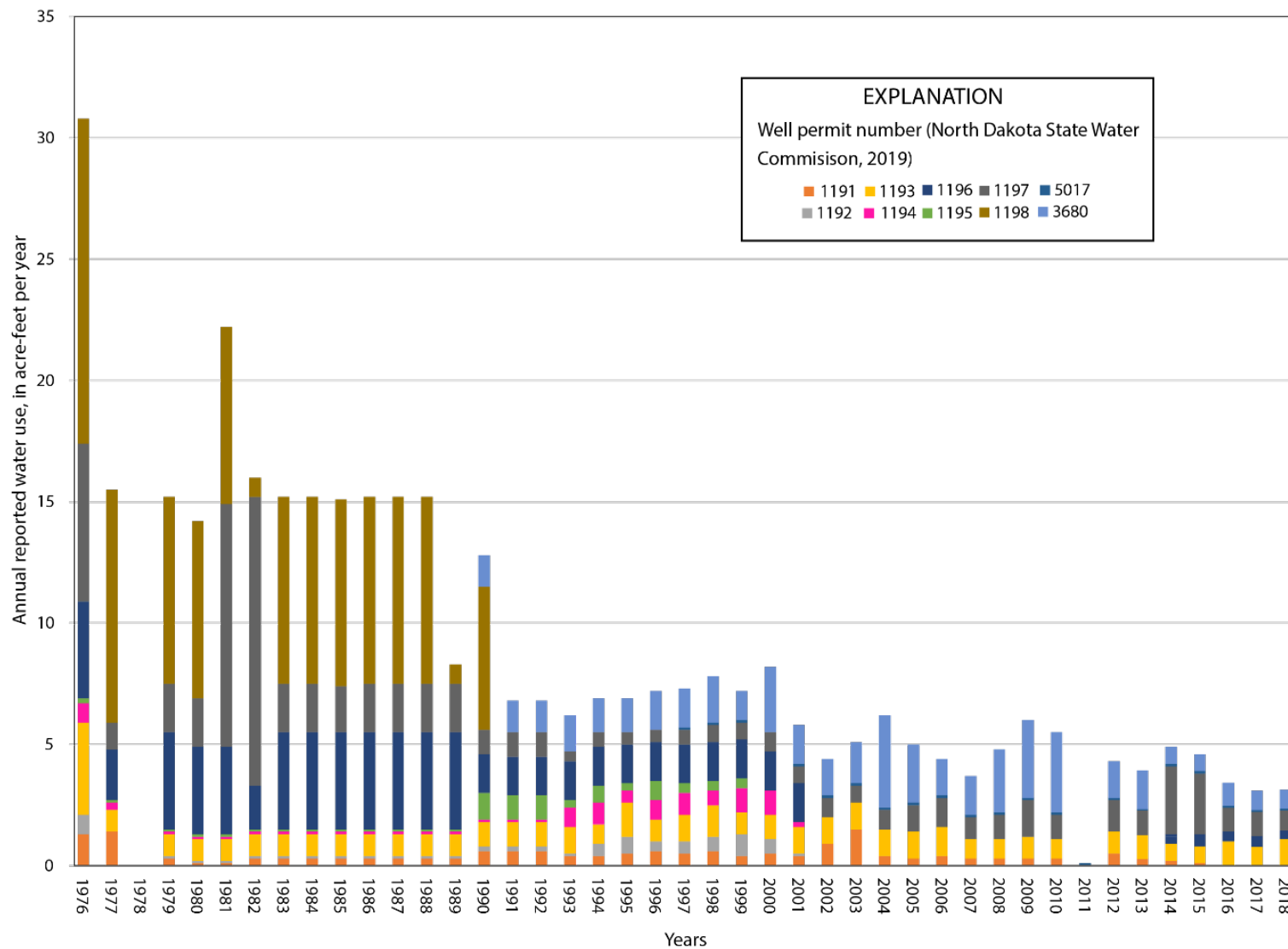


Figure 7. Annual reported water use for National Park Service permits in Billings and McKenzie Counties, North Dakota, 1976–2018 (North Dakota State Water Commission, 2019).

Table 12. Permits for water rights on record as of December 2019 with the North Dakota State Water Commission for the National Park Service (North Dakota State Water Commission, 2019).

Permit number ¹	Well near point of diversion (Table 10)	Priority date (month/day/year)	Beneficial use date (month/day/year)	Status	Use type	County	Water source	Aquifer	Point of diversion ²
789	–	3/11/1959	–	Canceled	Irrigation	Williams	Surface	–	15210408CC
1191	Peaceful Valley Ranch	6/19/1964	7/1/1969	Perfected	Domestic	Billings	Groundwater	Fox Hills	14010212BC
1192	Cottonwood Campground	6/19/1964	–	Canceled	Domestic	Billings	Groundwater	Fox Hills	14010210DC
1193	Park Housing	6/19/1964	–	Perfected	Domestic	McKenzie	Groundwater	Undefined	14809935BB
1194	Old Picnic Area	6/19/1964	–	Canceled	Domestic	Billings	Groundwater	Undefined	14010211DA
1195	Halliday or Old Picnic Area	6/19/1964	–	Canceled	Domestic	Billings	Groundwater	Undefined	14010212AC
1196	Cottonwood Campground	6/19/1964	–	Perfected	Domestic	Billings	Groundwater	Fox Hills	14010211CC
1197	Juniper Campground	6/19/1964	7/1/1969	Perfected	Domestic	McKenzie	Groundwater	Undefined	14809931AB
1198	Headquarters	6/19/1964	7/1/1969	Canceled	Domestic	Billings	Groundwater	Fox Hills	14010226BB
5017	Headquarters	5/22/1996	9/1/1999	Perfected	Industrial	Billings	Groundwater	Fox Hills	14110129A
2501	–	6/3/1976	7/1/1981	Canceled	Industrial	Williams	Groundwater	Tongue River	15210407A
3680	Cottonwood Campground	12/12/1983	4/1/1987	Perfected	Domestic	Billings	Groundwater	Fox Hills	14010210D

¹ Permit number from North Dakota State Water Commission (2019).

² Format is three-digit range, three-digit township, two-digit section, and one- or two-letter quarter section.

Springs and Seeps Inventory

In addition to well data, an inventory of 11 springs and seeps was completed. Springs were inventoried in the North and South Units of the park, and seeps were documented and recorded in the USGS NWIS database as springs. Table 13 provides the location of the major springs and seeps inventoried during the study. Site developments were documented during the site visit inventory and recorded with photographs (Appendix 2). Discharge data were compiled from literature sources, park records, and the USGS NWIS database. The earliest record of a discharge measurement is listed in Table 12.

Spring discharges from the sites were available from Theodore Roosevelt National Park records (John Heiser, Theodore Roosevelt National Park Back Country Ranger, written commun., 2018), information in docket documents listed in Table 4, literature (Iierkley and others, 1998; Amberg and others, 2014), and the USGS NWIS database (U.S. Geological Survey, 2019a). Discharge data were not continuous but were available in various years ranging from 1947 through 2018 (Table 13). In some cases, literature sources included discharge measurements from wells as spring flow (Iierkley and others, 1998; Amberg and others, 2014) and those values were included in Table 14. Discharge measurements from springs in the North Unit were made routinely by park personnel from 1985 through 1998, often three to five times annually (John Heiser, Theodore Roosevelt National Park Back Country Ranger, written commun., 2018). Discharge measurements in the South Unit included some noninventoried sites, and discharge data records for springs ranged from 1955 through 2018. The annual mean spring discharge for sites in the North Unit did not vary substantially from year to year, and the annual mean value was generally within 18 percent of the median annual value, except for Mandal Spring with low recorded discharges in 1976 and 1992. The mean annual discharge was generally within about 23 percent of the median annual discharge for sites in the South Unit, except for Big Plateau Spring and Sheep Butte Spring with the mean annual discharge differing from the median annual discharge by 27 and 47 percent, respectively. Theodore Roosevelt National Park completed studies of the history, background, and recommended management actions for many of the spring and well sites (Oehler and Sexton, 2010). Many of the South Unit sites in designated wilderness areas were recommended for restoration and abandonment because of their proximity to alternative water sources and the difficulty and expense for future maintenance.

Table 13. Summary of spring and seep information for Theodore Roosevelt National Park, 2019.

Park unit	Spring name	USGS NWIS site identifier	Latitude	Longitude	Altitude	Site development	Earliest discharge measurement
North Unit ¹	Achenbach	473432103242801	47.575515	103.407667	2,495	Concrete tub	1976
	Hagen	473644103181901	47.612134	103.305396	2,248	Concrete tub	1976
	Mandal	473509103265101	47.58398	103.446369	2,017	None	1976
	Overlook	473627103261601	47.607618	103.437803	2,085	Concrete tub, flowing stand pipe	1983
	Stevens	473701103251401	47.617025	103.420669	2,360	Concrete tubs	1976
South Unit ²	Big Plateau	465809103302201	46.969183	103.506246	2,438	Concrete tub, spring box	1955
	Boicourt	465807103235601	46.968597	103.398856	2,630	Concrete tub, some protective poles	1955
	Lone Tree	465856103334401	46.98222	103.562341	2,596	Concrete tub	1982
	Sheep Butte	465726103224301	46.957158	103.378626	2,634	None, spring flows from lignite bed	1955
	Sheep Pasture	465909103320401	46.985878	103.53446	2,598	Some protective poles	1992
	Southeast Corner	465350103192901	46.897238	103.324802	2,709	Concrete tub nearby but spring not developed	1955

¹ In the North Unit, Oxbow Spring was described in other sources but not inventoried because the location was unknown.

² South Unit springs or seeps described in other sources but not inventoried because the location was unknown include Olsen Seep, Talkington Ponds No. 1 and No. 2, Painted Canyon, Beef Corral Roadside, Knutson Creek (Petrified Plateau or Krudson Creek), West Entrance Picnic, VA Bottom, Petrified Forest Plateau, Jules Creek, and Wannigan Seeps (see Table 3).

Analysis of Groundwater Flow and Water Quality

Groundwater flow and water quality were analyzed and summarized. Groundwater flow was analyzed using potentiometric maps of the upper Fort Union, lower Fort Union, and Upper Cretaceous (Fox Hills and Hell Creek) aquifers. Water-quality summary statistics were compiled and selected physical properties and chemical constituents were mapped.

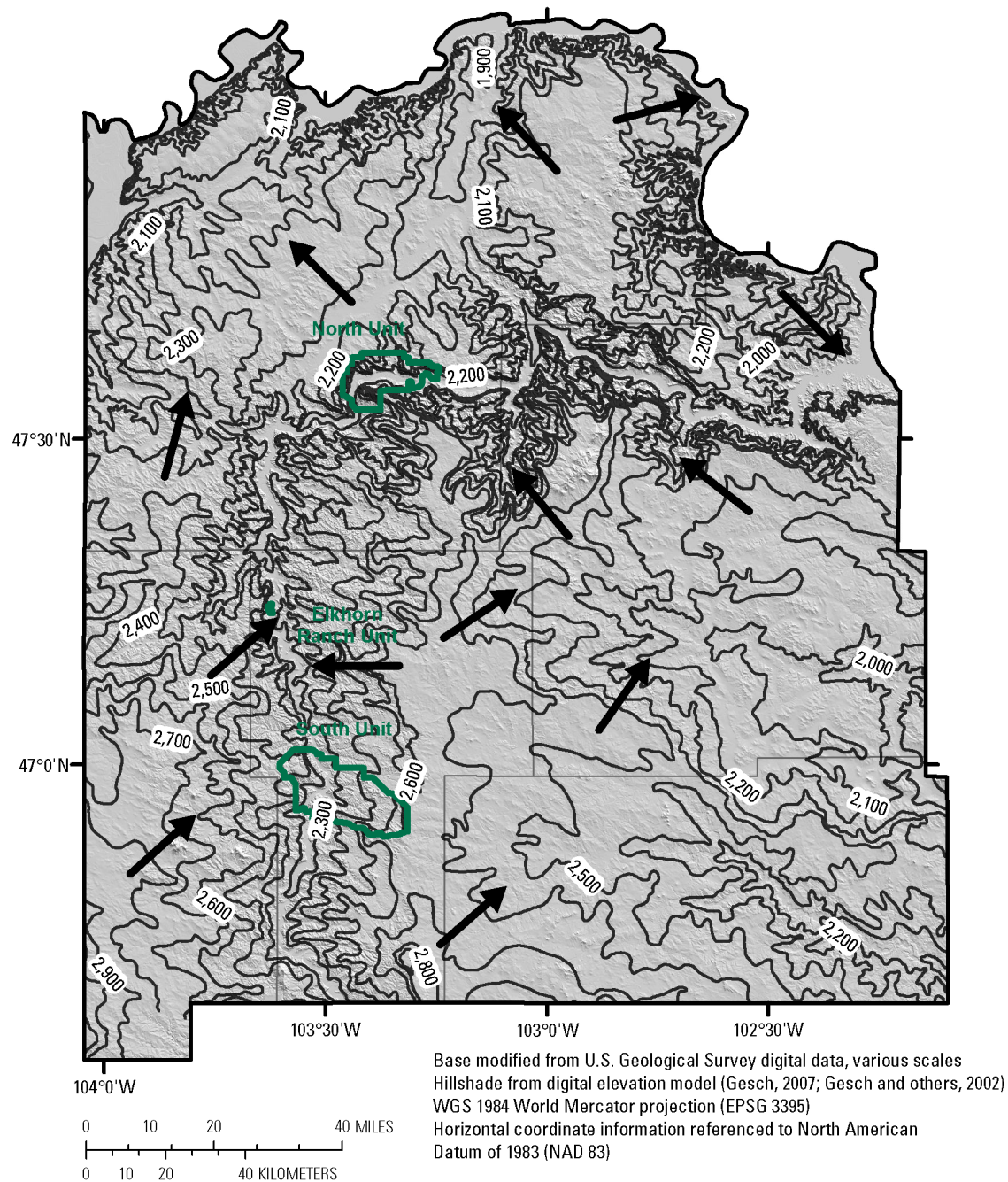
Groundwater Flow in the Theodore Roosevelt National Park Region

Groundwater flow in the Theodore Roosevelt National Park region is through aquifers and saturated alluvium. Potentiometric surface maps, also showing groundwater flow perpendicular to the potentiometric contours, were modified from maps developed for the Williston structural basin representing predevelopment (before 2000) conditions (Thamke and others, 2014). Potentiometric surfaces were mapped for the upper Fort Union aquifer and lower Fort Union aquifer (lower Tertiary), and Upper Cretaceous aquifer (Fox Hills and Hell Creek) in the study area.

The potentiometric surface of the unconfined parts of the upper Fort Union aquifer is topographically controlled and follows land-surface slopes. Groundwater in the upper Fort Union aquifer generally flows from topographically high areas towards streams and valleys (Fig. 8; Thamke and others, 2014). Groundwater flow is highly variable because of topographic control. Potentiometric gradients are higher in steeper terrain and lower in flatter terrains. Previous studies mapped the direction of groundwater flow in the confined parts of the upper Fort Union generally from southwest to northeast (not shown; Trapp and Croft, 1975; Klausing, 1979; Anna, 1981; Croft, 1985).

Groundwater in the lower Fort Union aquifer also generally flows from southwest to northeast in the study area (Fig. 9; Anna, 1981). North of the North Unit, groundwater flows northwest and east. Groundwater gradients were higher in the southwestern part of the study area than the central or northern parts (Fig. 9).

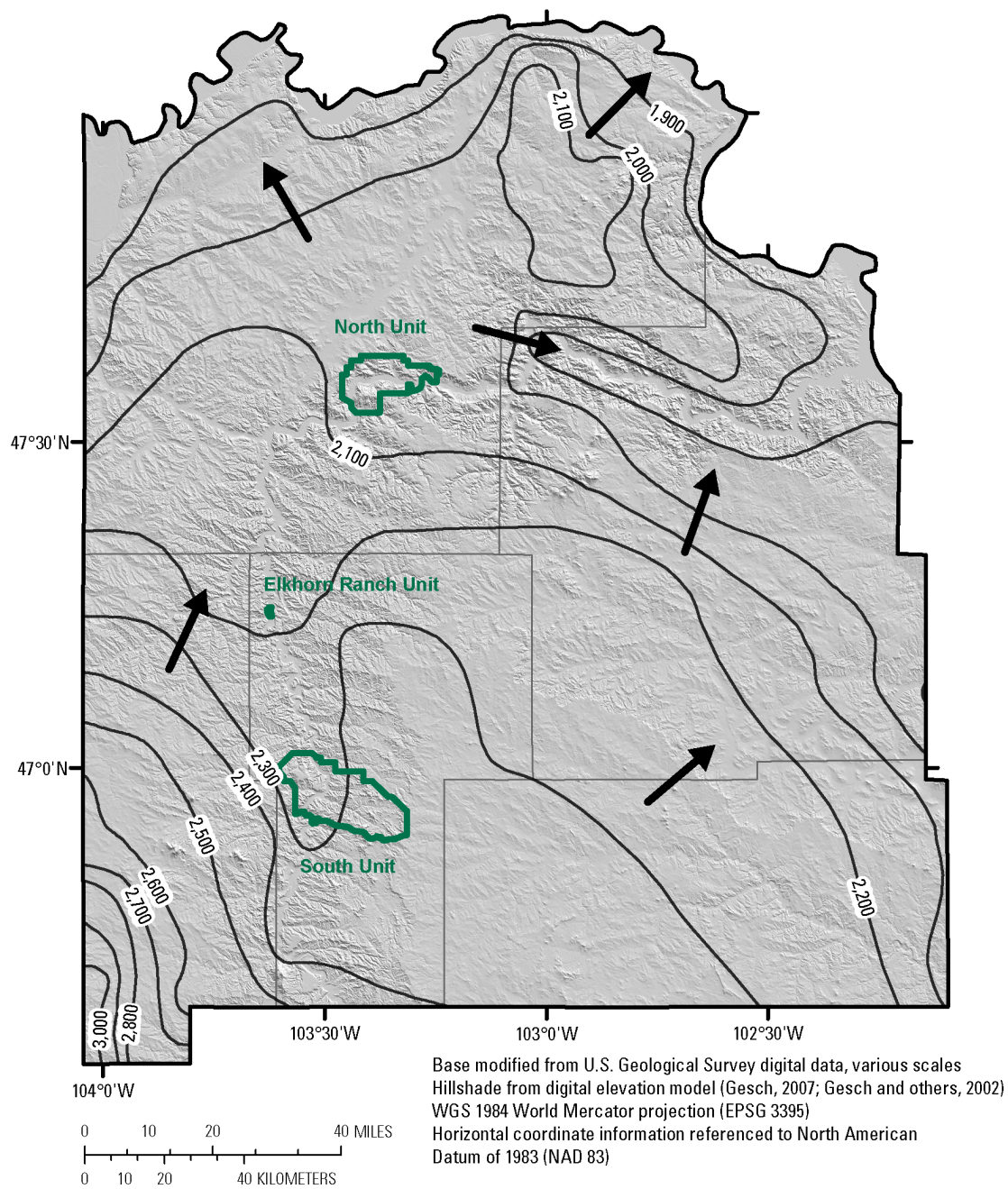
Groundwater flow in the Upper Cretaceous aquifer (Fox Hills and Hell Creek) generally is from southwest to northeast in the study area (Fig. 10). Localized depressions in the potentiometric surface are present causing changes in flow direction that differ from regional trends likely because of pumping from wells completed in the Upper Cretaceous aquifer. Local depressions were mapped about 15 mi east of the North Unit (Fig. 10). Additionally, groundwater flow in the Upper Cretaceous aquifer can vary depending on local structures (Thorstenson and Fisher, 1979; Anna, 1981). The groundwater gradient was shallow in the Upper Cretaceous aquifer compared to the overlying aquifers, meaning groundwater flow is slower in the Upper Cretaceous aquifer than in the overlying aquifers.



EXPLANATION

- Theodore Roosevelt National Park boundaries
- 2,400- Potentiometric contour—Shows average observed elevation at which water level would have stood in tightly cased well, in feet. Modified from Thamke and others (2014). Contour interval is 100 feet. Datum is North American Vertical Datum of 1988.
- Apparent direction of groundwater flow

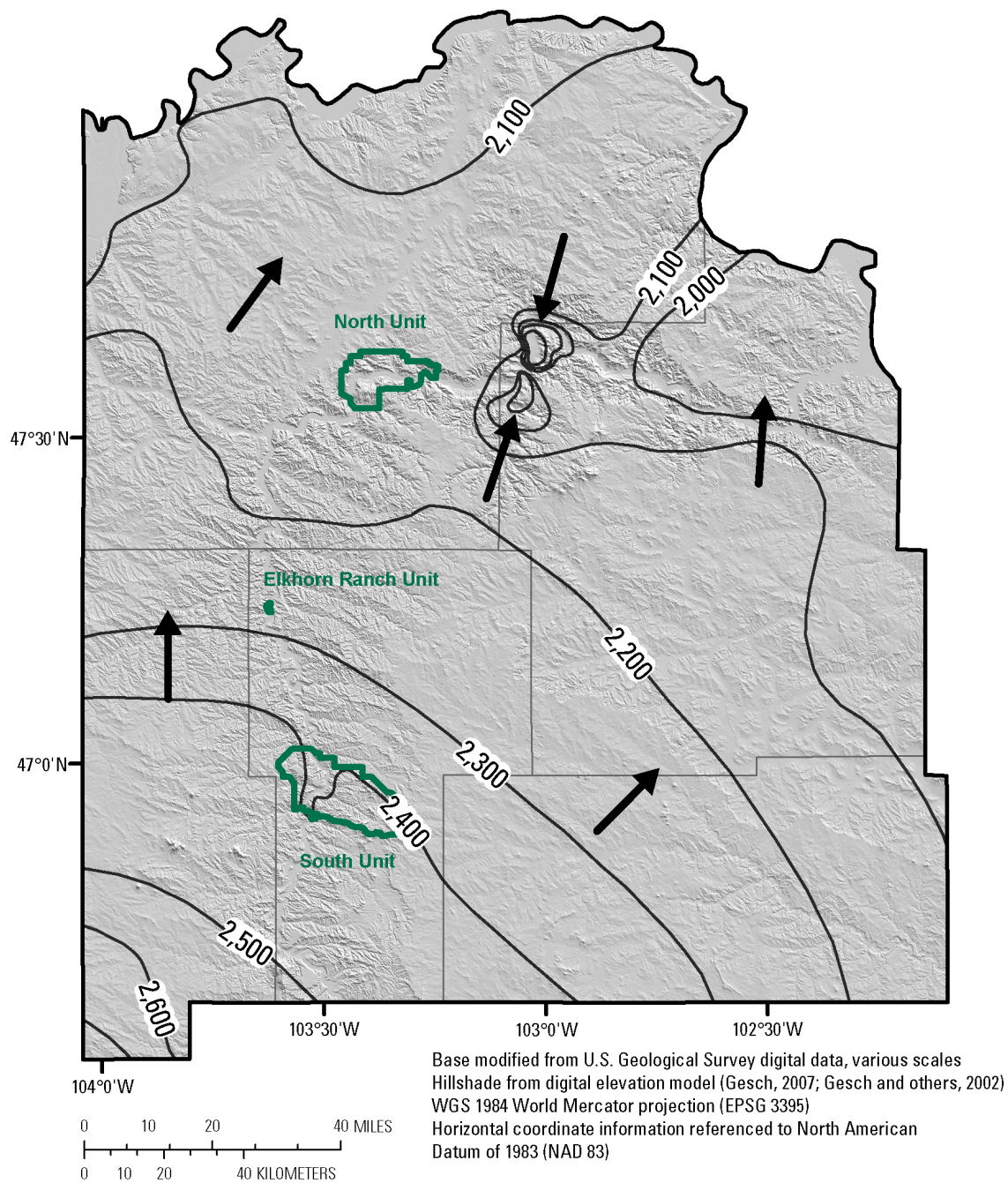
Figure 8. Simulated potentiometric map of the upper Fort Union aquifer.



EXPLANATION

- Theodore Roosevelt National Park boundaries
- 2,400- Potentiometric contour—Shows average observed elevation at which water level would have stood in tightly cased well, in feet. Modified from Thamke and others (2014). Contour interval is 100 feet. Datum is North American Vertical Datum of 1988.
- Apparent direction of groundwater flow

Figure 9. Simulated potentiometric map of the lower Fort Union aquifer.



EXPLANATION

- Theodore Roosevelt National Park boundaries
- 2,400- Potentiometric contour—Shows average observed elevation at which water level would have stood in tightly cased well, in feet. Modified from Thamke and others (2014). Contour interval is 100 feet. Datum is North American Vertical Datum of 1988.
- Apparent direction of groundwater flow

Figure 10. Simulated potentiometric map of the Upper Cretaceous (Fox Hills and Hell Creek) aquifers.

Groundwater Quality

Groundwater-quality data from the North Dakota State Water Commission (2015) were summarized, mapped, and used to characterize groundwater for each aquifer in the study area. Tables 15–17 provide summary statistics, EPA drinking-water-quality standards, and exceedance counts and percentages for physical properties and chemical constituents in the upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers, respectively. Spatial concentration distribution maps were constructed for selected physical properties and chemical constituents using summary statistics and exceedances in Tables 15–17 and boxplots in Appendix 4. Piper diagrams were used to classify and characterize groundwater for each aquifer.

Summary statistics for physical properties and chemical constituents were compared to various drinking-water standards from the EPA (2009). The total number of samples exceeding drinking-water standards and the percentage of exceedances (exceedances divided by the total number of samples) were calculated for each physical property and chemical constituent by aquifer, where applicable, and are listed in Tables 15–17. The upper Fort Union aquifer had samples exceeding drinking-water standards for pH (20 percent), TDS (90 percent), arsenic (6 percent), boron (19 percent), chloride (1 percent), fluoride (26 percent), iron (54 percent), manganese (55 percent), nitrate (12 percent), and sulfate (60 percent) (Table 15). The lower Fort Union aquifer had samples exceeding drinking-water standards for pH (60 percent), TDS (100 percent), boron (28 percent), chloride (1 percent), fluoride (36 percent), iron (38 percent), manganese (31 percent), and sulfate (44 percent) (Table 16). The Fox Hills-lower Hell Creek aquifer had samples exceeding drinking-water standards for pH (72 percent), TDS (100 percent), boron (85 percent), chloride (15 percent), fluoride (89 percent), iron (19 percent), manganese (6 percent), nitrate (0.3 percent), and sulfate (14 percent) (Table 17).

The median concentrations of the seven physical properties and chemical constituents with the highest exceedance percentages common to the three aquifers in the study area were spatially mapped (Figs. 11–17). The mapped physical properties and chemical constituents included the following: TDS, boron, chloride, fluoride, iron, manganese, and sulfate. A spatial map was not constructed for pH even though pH had a high exceedance percentage in the three aquifers. Drinking-water standards (Tables 15–17; U.S. Environmental Protection Agency, 2009) for each physical property and chemical constituent determine map symbol colors: green represents median concentrations less than or equal to the drinking-water standard and red represents median concentrations greater than the standard.

Total Dissolved Solids

Median concentrations of TDS per site showed variable spatial distribution among aquifers (Fig. 11A–C). Nearly all sites in the upper Fort Union aquifer (Fig. 11A) exceeded the SMCL TDS standard with apparent increasing concentrations from south to north and southwest to northeast. Few sites in the study area were in the lower Fort Union aquifer but the SMCL was exceeded in samples from all sites (Fig. 11B). All sites in the Fox Hills-lower Hell Creek aquifer (Fig. 11C) exceeded the standard. The median TDS concentration in all three aquifers (Tables 15–17) was about three times greater than the SMCL standard of 500 mg/L (U.S. Environmental Protection Agency, 2009).

Table 15. Summary of selected physical properties and chemical constituents for the upper Fort Union aquifer in the study area.

Constituent group	Constituent	Units	Number of samples used in statistics	Minimum	25th percentile	Median	75th percentile	Maximum	Standard deviation	Standard ¹	Standard type	Number of exceedances	Percentage exceedance of total samples	Median exceeds standard
Physical property	Alkalinity	mg/L CaCO ₃	170	20	297	539	747	1,870	391	–	–	–	–	–
	Dissolved oxygen	mg/L	1	0.26	0.26	0.26	0.26	0.26	–	–	–	–	–	–
	Hardness	mg/L	610	5.0	28	177	470	9,200	822	–	–	–	–	–
	Percent sodium	%	553	6.0	39	81	98	99.5	31.2	–	–	–	–	–
	pH	Standard units	581	3.3	7.4	8.0	8.4	10.4	0.73	6.5–8.5	SMCL	118	20	No
	Sodium absorption ratio	Unitless	550	0.20	2.6	14.5	50	132	28.4	–	–	–	–	–
	Specific conductance	µS/cm	584	153	1,348	2,140	2,900	44,800	2,432	–	–	–	–	–
	Total dissolved solids	mg/L	612	79	905	1,440	2,020	27,800	1,780	500	SMCL	549	90	Yes
	Water temperature	°C	422	3.9	8.7	10.0	11.3	19.0	2.3	–	–	–	–	–
Chemical constituent	Arsenic	µg/L	18	<5	<5	<5	<5	10	1.37	0.01	MCL	1	6	No
	Bicarbonate	mg/L	605	53.0	402	690	1,100	2,480	520	–	–	–	–	–
	Boron	mg/L	346	0.01	0.16	0.38	0.63	8.4	1.0	² 0.75	–	67	19	No
	Cadmium	µg/L	12	<5	<5	<5	<5	<5	–	5	MCL	0	–	–
	Calcium	mg/L	548	<2	5.4	36	99	2,370	164	–	–	–	–	–
	Carbonate	mg/L	293	<1	<1	14	33	403	47	–	–	–	–	–
	Chloride	mg/L	553	<15	<15	<15	<15	17,500	829	250	SMCL	8	1	No
	Fluoride	mg/L	532	0.082	0.30	0.70	2.1	13	1.7	4.0 and 2.0	MCL and SMCL	140	26	No
	Hydroxide	mg/L	137	<1	<1	<1	<1	<1	–	–	–	–	–	–
	Iron	mg/L	526	<0.05	0.12	0.32	1.1	71	8.0	0.3	SMCL	283	54	Yes
	Lead	µg/L	15	<5	<5	<5	<5	8.6	1.0	15	MCL	0	–	–
	Lithium	µg/L	13	7.1	20	30	100	140	49	–	–	–	–	–
	Magnesium	mg/L	548	<1	3	19	51	1,070	133	–	–	–	–	–
	Manganese	mg/L	461	<0.01	0.02	0.06	0.30	16	1.0	0.05	SMCL	254	55	Yes
	Mercury	µg/L	5	<0.2	<0.2	<0.2	<0.2	<0.2	–	2	MCL	0	–	–
	Molybdenum	µg/L	14	<5	<5	<5	<5	66	16	–	–	–	–	–
	Nitrate	mg/L	544	<0.09	0.49	1.0	2.0	858	71.4	10	MCL	66	12	No
	Phosphate	mg/L	2	0.1	0.45	0.8	1.15	1.5	0.99	–	–	–	–	–
	Potassium	mg/L	534	<1	2.9	4.5	6.8	240	12.9	–	–	–	–	–
	Selenium	µg/L	16	<5	<5	<5	<5	6.8	0.45	50	MCL	0	–	–
	Silica	mg/L	487	<2	8.5	12	16	56	7.4	–	–	–	–	–
	Sodium	mg/L	564	7.4	150	459	660	7,360	465	–	–	–	–	–
	Strontium	µg/L	13	4.0	530	940	5,100	6,900	2,600	–	–	–	–	–
	Sulfate	mg/L	577	<5	117	395	840	5,490	905	250	SMCL	346	60	Yes

¹ U.S. Environmental Protection Agency (2009) unless otherwise noted.
² Concentrations exceeding 0.75 mg/L could affect sensitive agriculture during long-term irrigation (U.S. Environmental Protection Agency, 1986).

Table 16. Summary of selected physical properties and chemical constituents for the lower Fort Union aquifer in the study area.

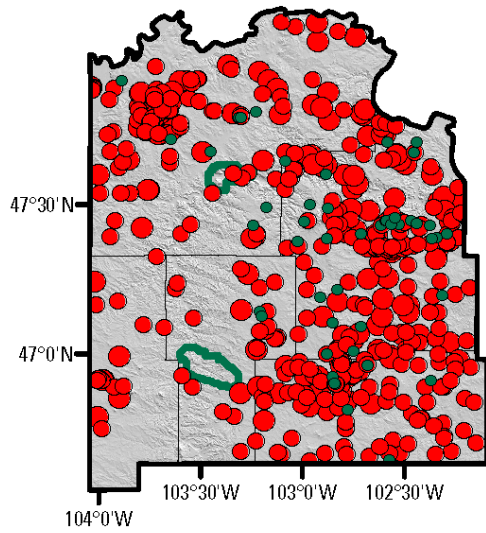
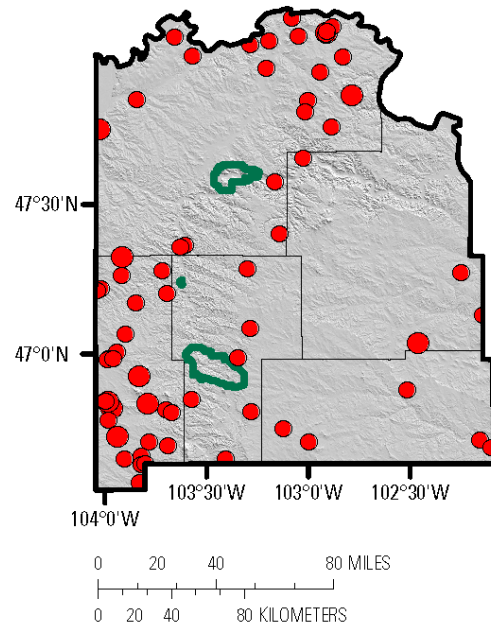
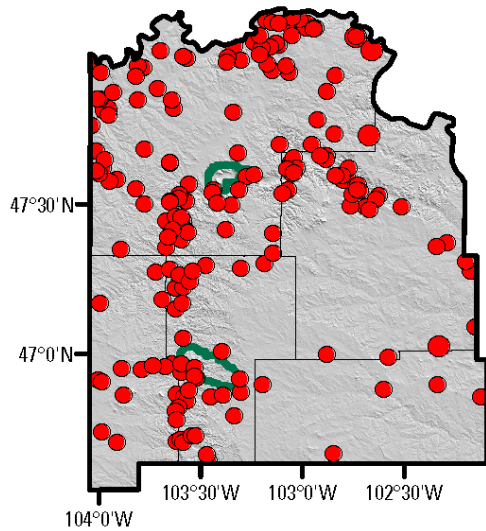
Constituent group	Constituent	Units	Number of samples used in statistics	Minimum	25th percentile	Median	75th percentile	Maximum	Standard deviation	Standard ¹	Standard type	Number of exceedances	Percentage exceedance of total samples	Median exceeds standard
Physical property	Alkalinity	mg/L CaCO ₃	9	382	1,340	1,550	1,660	1,690	432	–	–	–	–	–
	Dissolved oxygen	mg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Hardness	mg/L	86	7.0	16	20	38	1,920	294	–	–	–	–	–
	Percent sodium	%	85	17	97	98	99	100	13	–	–	–	–	–
	pH	Standard units	85	7.1	8.2	8.6	8.8	9.8	0.45	6.5–8.5	SMCL	51	60	Yes
	Sodium absorption ratio	Unitless	85	1.1	39	57	76	124	26	–	–	–	–	–
	Specific conductance	µS/cm	86	984	1,885	2,500	2,948	9,740	1,066	–	–	–	–	–
	Total dissolved solids	mg/L	86	615	1,240	1,700	1,938	8,160	872	500	SMCL	86	100	Yes
	Water temperature	°C	67	7.0	10	12	13	23	2.8	–	–	–	–	–
Chemical constituent	Arsenic	µg/L	0	–	–	–	–	–	–	0.01	MCL	0	–	–
	Bicarbonate	mg/L	86	376	690	1,085	1,740	2,300	565	–	–	–	–	–
	Boron	mg/L	65	0.04	0.43	0.62	0.76	3.0	0.53	² 0.75	–	18	28	No
	Cadmium	µg/L	0	–	–	–	–	–	–	5	MCL	0	–	–
	Calcium	mg/L	85	<2	3.1	4.5	7.8	990	118	–	–	–	–	–
	Carbonate	mg/L	69	<1	22	39	69	467	74	–	–	–	–	–
	Chloride	mg/L	86	<15	<15	<15	57	250	60	250	SMCL	1	1	No
	Fluoride	mg/L	84	0.1	1.1	1.6	2.7	8.0	1.7	4.0 and 2.0	MCL and SMCL	30	36	No
	Hydroxide	mg/L	9	<1	<1	<1	<1	<1	–	–	–	–	–	–
	Iron	mg/L	84	<0.05	0.080	0.16	0.46	10	1.8	0.3	SMCL	32	38	No
	Lead	µg/L	0	–	–	–	–	–	–	15	MCL	0	–	–
	Lithium	µg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Magnesium	mg/L	84	<1	1.3	2.3	5	930	103	–	–	–	–	–
	Manganese	mg/L	72	<0.01	<0.01	0.025	0.060	1.4	0.21	0.05	SMCL	22	31	No
	Mercury	µg/L	0	–	–	–	–	–	–	2	MCL	0	–	–
	Molybdenum	µg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Nitrate	mg/L	83	<0.09	1.0	1.0	1.0	3.7	0.68	10	MCL	0	–	–
	Phosphate	mg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Potassium	mg/L	84	<1	1.8	3.3	5.5	14	2.5	–	–	–	–	–
	Selenium	µg/L	0	–	–	–	–	–	–	50	MCL	0	–	–
	Silica	mg/L	73	<2	5.8	7.9	9.7	37	4.3	–	–	–	–	–
	Sodium	mg/L	85	20.1	440	630	780	2,400	279	–	–	–	–	–
	Strontium	µg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Sulfate	mg/L	82	<5	12	140	385	5,000	658	250	SMCL	36	44	No

¹ U.S. Environmental Protection Agency (2009) unless otherwise noted.
² Concentrations exceeding 0.75 mg/L could affect sensitive agriculture during long-term irrigation (U.S. Environmental Protection Agency, 1986).

Table 17. Summary of selected physical properties and chemical constituents for the Fox Hills-lower Hell Creek aquifer in the study area.

Constituent group	Constituent	Units	Number of samples used in statistics	Minimum	25th percentile	Median	75th percentile	Maximum	Standard deviation	Standard ¹	Standard type	Number of exceedances	Percentage exceedance of total samples	Median exceeds standard
Physical property	Alkalinity	mg/L CaCO ₃	120	384	793	873	981	1,710	196	–	–	–	–	–
	Dissolved oxygen	mg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Hardness	mg/L	305	4.0	9.0	11	14	700	57	–	–	–	–	–
	Percent sodium	%	301	14	99	99	99	99	5.8	–	–	–	–	–
	pH	Standard units	302	6.9	8.4	8.6	8.7	13	0.57	6.5–8.5	SMCL	216	72	Yes
	Sodium absorption ratio	Unitless	301	0.90	59	68	79	106	17	–	–	–	–	–
	Specific conductance	µS/cm	305	1,060	1,700	2,040	2,420	5,070	561	–	–	–	–	–
	Total dissolved solids	mg/L	305	689	1,110	1,270	1,490	3,960	341	500	SMCL	305	100	Yes
	Water temperature	°C	207	–7.2	14	17	20	27	4.4	–	–	–	–	–
Chemical constituent	Arsenic	µg/L	12	<5	<5	<5	<5	5.1	0.03	0.01	MCL	0	–	–
	Bicarbonate	mg/L	302	369	856	1,060	1,210	2,220	304	–	–	–	–	–
	Boron	mg/L	166	0.09	0.92	1.3	1.8	4.7	0.73	² 0.75	–	141	85	Yes
	Cadmium	µg/L	12	<5	<5	<5	<5	<5	–	5	MCL	0	–	–
	Calcium	mg/L	300	<2	<2	2.4	4.0	160	11	–	–	–	–	–
	Carbonate	mg/L	256	<1	22	32	39	400	29	–	–	–	–	–
	Chloride	mg/L	302	<15	55	120	200	520	114	250	SMCL	44	15	No
	Fluoride	mg/L	300	0.10	3.2	4.8	5.3	10	1.5	4.0 and 2.0	MCL and SMCL	264	89	Yes
	Hydroxide	mg/L	119	<1	<1	<1	<1	<1	–	–	–	–	–	–
	Iron	mg/L	285	<0.05	<0.05	0.097	0.23	3.9	0.49	0.3	SMCL	53	19	No
	Lead	µg/L	13	<5	<5	<5	<5	<5	–	15	MCL	0	–	–
	Lithium	µg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Magnesium	mg/L	295	<1	<1	<1	<1	79	6.9	–	–	–	–	–
	Manganese	mg/L	246	<0.01	<0.01	<0.01	0.02	1.3	0.13	0.05	SMCL	15	6	No
	Mercury	µg/L	0	–	–	–	–	–	–	2	MCL	0	–	–
	Molybdenum	µg/L	1	60	60	60	60	60	–	–	–	–	–	–
	Nitrate	mg/L	296	<0.09	<0.09	1.0	1.0	30	1.9	10	MCL	1	0.3	No
	Phosphate	mg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Potassium	mg/L	300	<1	1.5	1.8	2.5	13	1.4	–	–	–	–	–
	Selenium	µg/L	12	<5	<5	<5	9.3	22	5.9	50	MCL	–	–	–
	Silica	mg/L	242	<2	11.0	12.9	14	31	3.0	–	–	–	–	–
	Sodium	mg/L	303	3.6	433	510	600	1,310	144	–	–	–	–	–
	Strontium	µg/L	0	–	–	–	–	–	–	–	–	–	–	–
	Sulfate	mg/L	276	<5	<5	<5	122	1,540	149	250	SMCL	39	14	No

¹ U.S. Environmental Protection Agency (2009) unless otherwise noted.
² Concentrations exceeding 0.75 mg/L could affect sensitive agriculture during long-term irrigation (U.S. Environmental Protection Agency, 1986).

A.**B.****C.****EXPLANATION**

 Theodore Roosevelt National Park boundaries

**Total dissolved solids,
in milligrams per liter**

-  less than 500
-  500–2,000
-  greater than 2,000

Base modified from U.S. Geological Survey digital data, various scales
 Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
 Water quality data from North Dakota State Water Commission (2015)
 WGS 1984 World Mercator projection (EPSG 3395)
 Horizontal coordinate information referenced to North American
 Datum of 1983 (NAD 83)

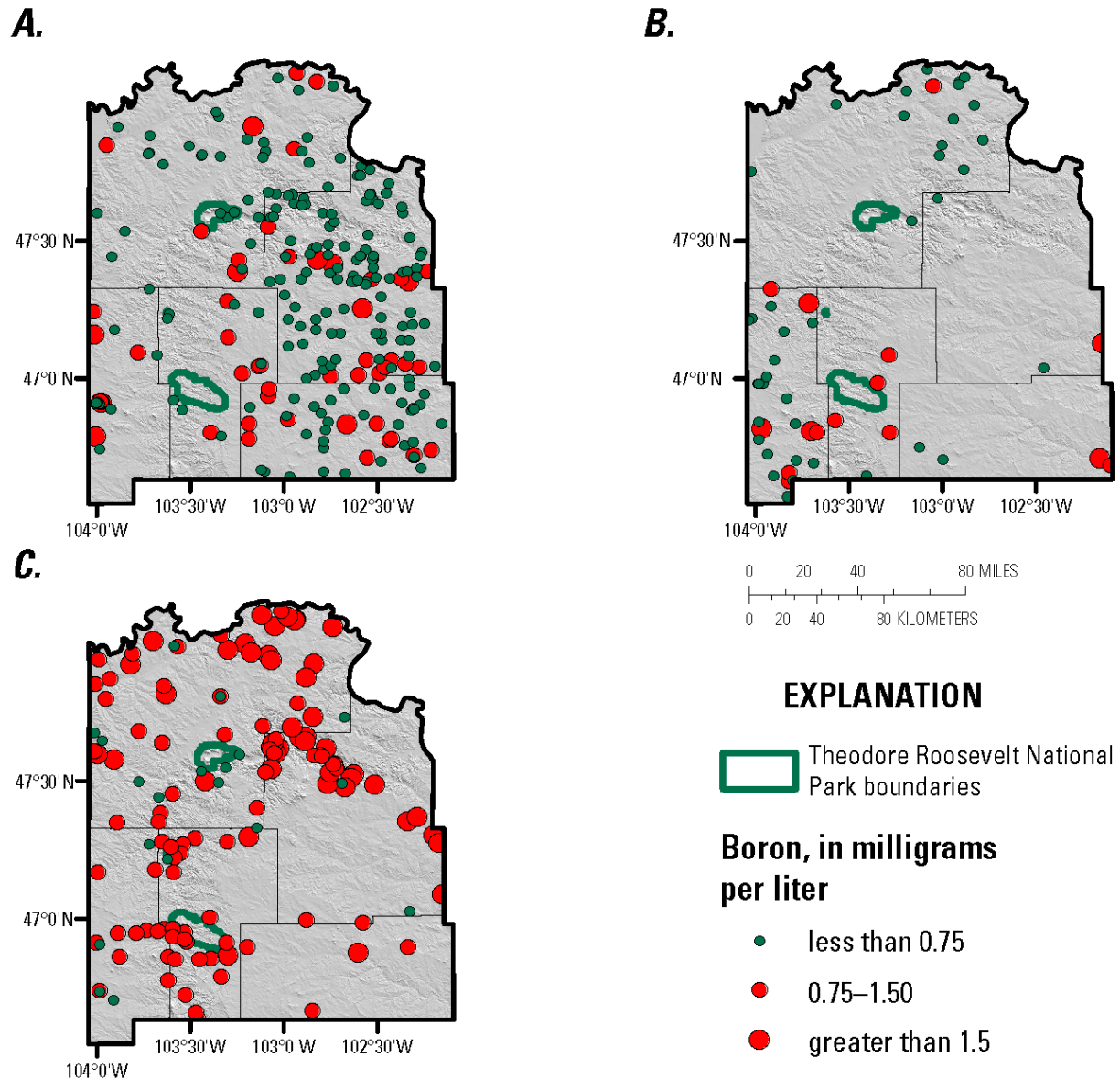
Figure 11. Median total dissolved solids (TDS) concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The secondary maximum contaminant level (SMCL) concentration for drinking water specified by the U.S. Environmental Protection Agency (2009) is 500 milligrams per liter.

High TDS concentrations in the aquifers in the study area likely are naturally occurring and reflect the high concentrations of inorganic salts in the groundwater. The concentration of TDS is a measure of the concentrations of inorganic salts and small amounts of organic matter in solution in water. The principal components of TDS include cations of calcium, magnesium, sodium, and potassium and anions of carbonate, chloride, sulfate, and nitrate (World Health Organization, 2003a). The slow-moving groundwater in the aquifers of the study area dissolves minerals and salts commonly found in the rock formations, and the concentrations of the inorganic salts increase with time. High TDS concentrations can cause cosmetic effects or aesthetic effects in drinking water and can create issues for irrigation or agriculture at concentrations exceeding 1,000 and 5,000 mg/L, respectively (U.S. Environmental Protection Agency, 1986, 2009).

Boron

The spatial distribution of median boron concentrations per site varied among aquifers (Fig. 12A–C). The upper Fort Union aquifer (Fig. 12A) had sites with concentrations greater than and less than the drinking-water standard distributed evenly in the study area. In the lower Fort Union aquifer (Fig. 12B), the greatest number of sites exceeding standard were in the southwestern part of the study area. The Fox Hills-lower Hell Creek aquifer (Fig. 12C) had sites exceeding the standard with increasing concentrations from southwest to northeast in the study area. The median concentration of boron in the Fox Hills-lower Hell Creek aquifer (1.3 mg/L; Table 17) was nearly double the agricultural-use standard of 0.75 mg/L for sensitive crops (U.S. Environmental Protection Agency, 1986). Additionally, Broshears and others (2005) reported that boron concentrations exceeding 1.0 mg/L can be problematic for sensitive crops, and concentrations exceeding 3.0 mg/L are detrimental to more tolerant plants.

High boron concentrations in the Fox Hills-lower Hell Creek aquifer likely are from natural sources. Anthropogenic sources of boron include pesticides or facilities producing ceramics, detergents and soaps, fire retardants, cosmetics, or high energy fuels (U.S. Geological Survey, 2016), but none of these activities likely affect boron concentrations in the study area. The Fox Hills Formation, or the lower part of the Hell Creek Formation, likely contains natural sources of boron concentrated by the slow movement of groundwater in the aquifers.



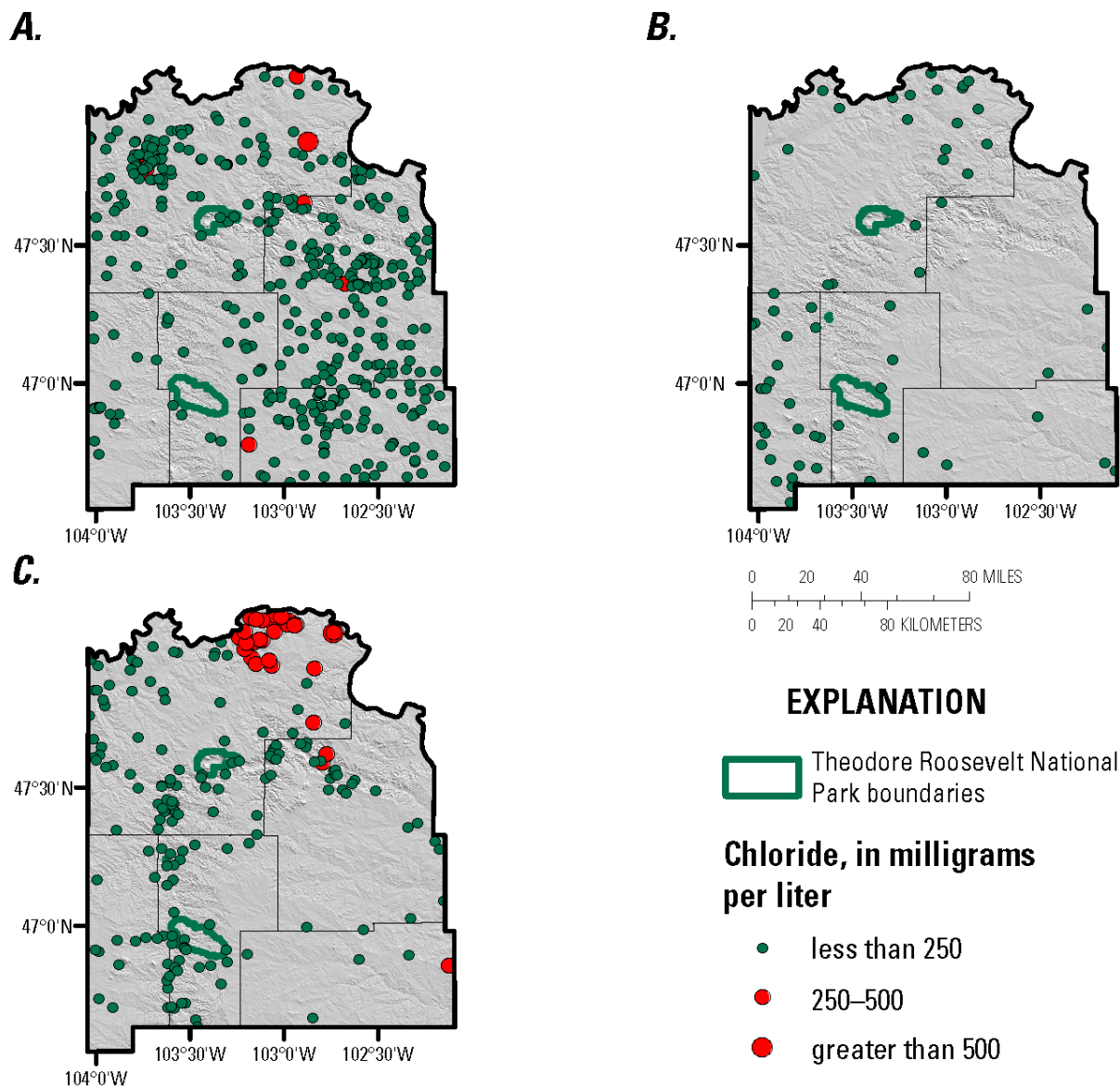
Base modified from U.S. Geological Survey digital data, various scales
Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American
Datum of 1983 (NAD 83)

Figure 12. Median boron concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The maximum concentration for agricultural use specified by the U.S. Environmental Protection Agency (1986) is 0.75 milligram per liter.

Chloride

Median chloride concentrations varied spatially among aquifers (Fig. 13A–C). The upper Fort Union aquifer (Fig. 13A) had few sites with chloride concentrations greater than the standard, and those sites were scattered throughout the study area. The lower Fort Union aquifer (Fig. 13B) had one sample concentration exceeding the standard. The Fox Hills-lower Hell Creek aquifer (Fig. 13C) had an area of high chloride concentrations in the northeastern part of the study area. Although the median concentration of chloride did not exceed the SMCL value of 250 mg/L (Tables 15–17), 15 percent of the samples in the Fox Hills-lower Hell Creek aquifer exceeded the SMCL (Table 17). McMahon and others (2015) also observed elevated chloride concentrations in the Fox Hills-lower Hell Creek aquifer at sites throughout the extent of the Bakken Formation.

High concentrations of chloride in the study area likely are naturally occurring. Chloride is naturally present in salts of sodium (NaCl), potassium (KCl), and calcium (CaCl₂), which are common in clay lenses and claystone interbedded in the aquifers (Table 2). Additionally, chloride is in surface and groundwaters from anthropogenic sources, such as road deicing salts, fertilizers, industrial effluents, and irrigation drainage (World Health Organization, 2003b). Aquifers with high chloride concentrations also could have correspondingly high levels of metals because chloride increases the electrical conductivity and corrosivity of water, enabling reactions with metal ions to form soluble salts (World Health Organization, 2003b).



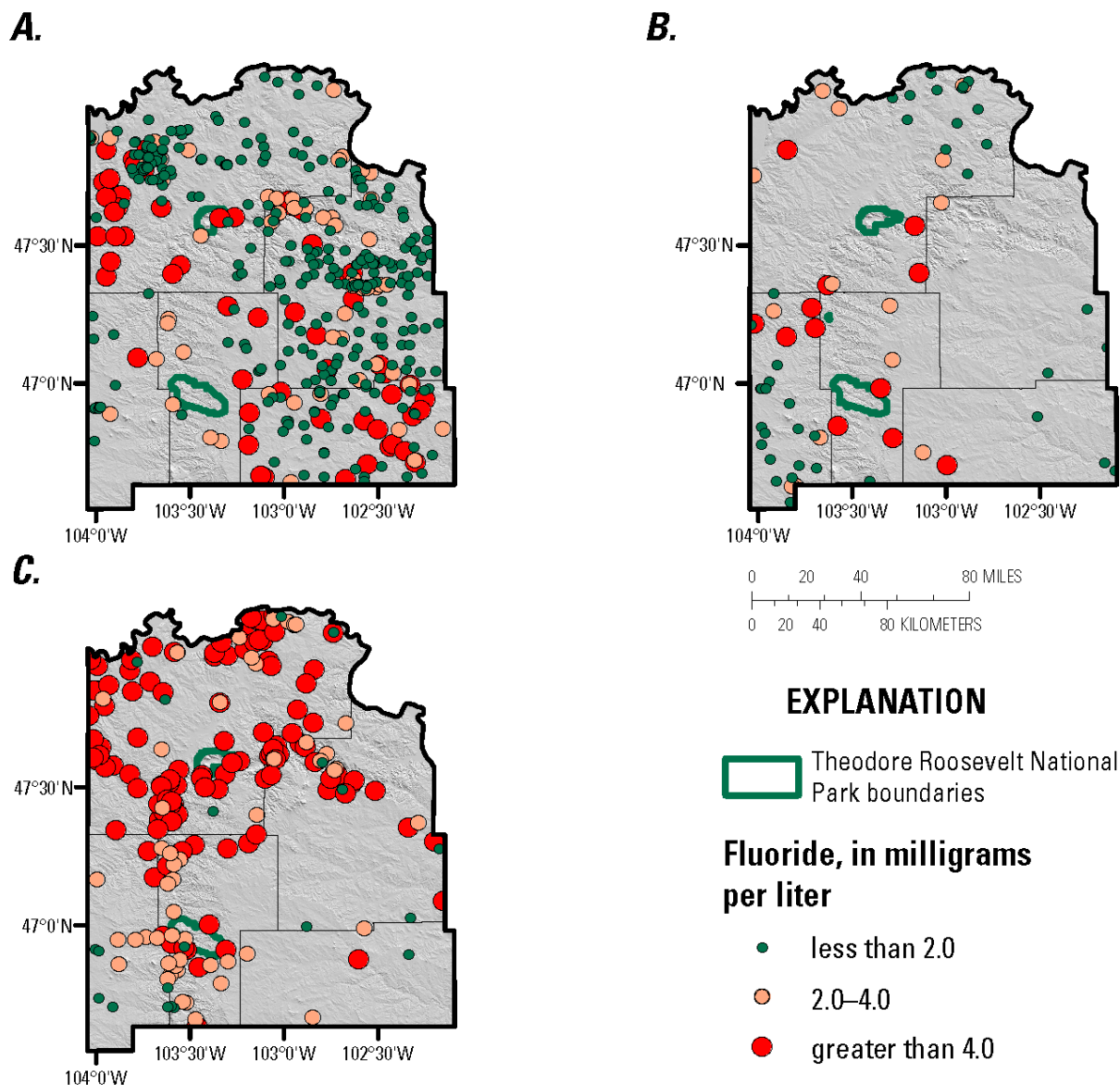
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Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American
Datum of 1983 (NAD 83)

Figure 13. Median chloride concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The secondary maximum contaminant level (SMCL) concentration for drinking water specified by the U.S. Environmental Protection Agency (2009) is 250 milligrams per liter.

Fluoride

The spatial distribution of median fluoride concentrations varied among aquifers (Fig. 14A–C). The upper Fort Union aquifer (Fig. 14A) had sites exceeding the SMCL (2.0 mg/L) and MCL (4.0 mg/L) fluoride standards, but the sites were scattered throughout the study area. The lower Fort Union aquifer (Fig. 14B) also had scattered sites with concentrations greater than the fluoride SMCL and MCL standards. Sites in the Fox Hills-lower Hell Creek aquifer (Fig. 15C) exceeded at least one of the two fluoride standards with increasing concentrations from south to north. The median concentration of fluoride in the Fox Hills-lower Hell Creek aquifer (4.8 mg/L in Table 17) exceeded the MCL of 4.0 mg/L (U.S. Environmental Protection Agency, 2009). McMahon and others (2015) also recorded elevated concentrations of fluoride in the Fox Hills-lower Hell Creek aquifer at wells in the oil and gas production area of the Bakken Formation.

The relatively high concentrations of fluoride in the Fox Hills-lower Hell Creek aquifer likely are natural because of the fluoride-bearing minerals, high pH, low calcium concentration, and slow groundwater movement in the aquifer. Fluorides naturally occur in high concentrations in many minerals, including fluorspar, rock phosphate, cryolite, apatite, mica, and hornblende (Fawell and others, 2006). Fluorite (CaF_2) is a common fluoride mineral of low solubility found in igneous and sedimentary rocks, and waters with high pH are fluoride rich. Also, fluoride often is associated with volcanic activity, and the Fox Hills and Hell Creek Formations likely were affected by volcanic activity as evidenced by the presence of tuffaceous beds in their stratigraphy (Table 2).



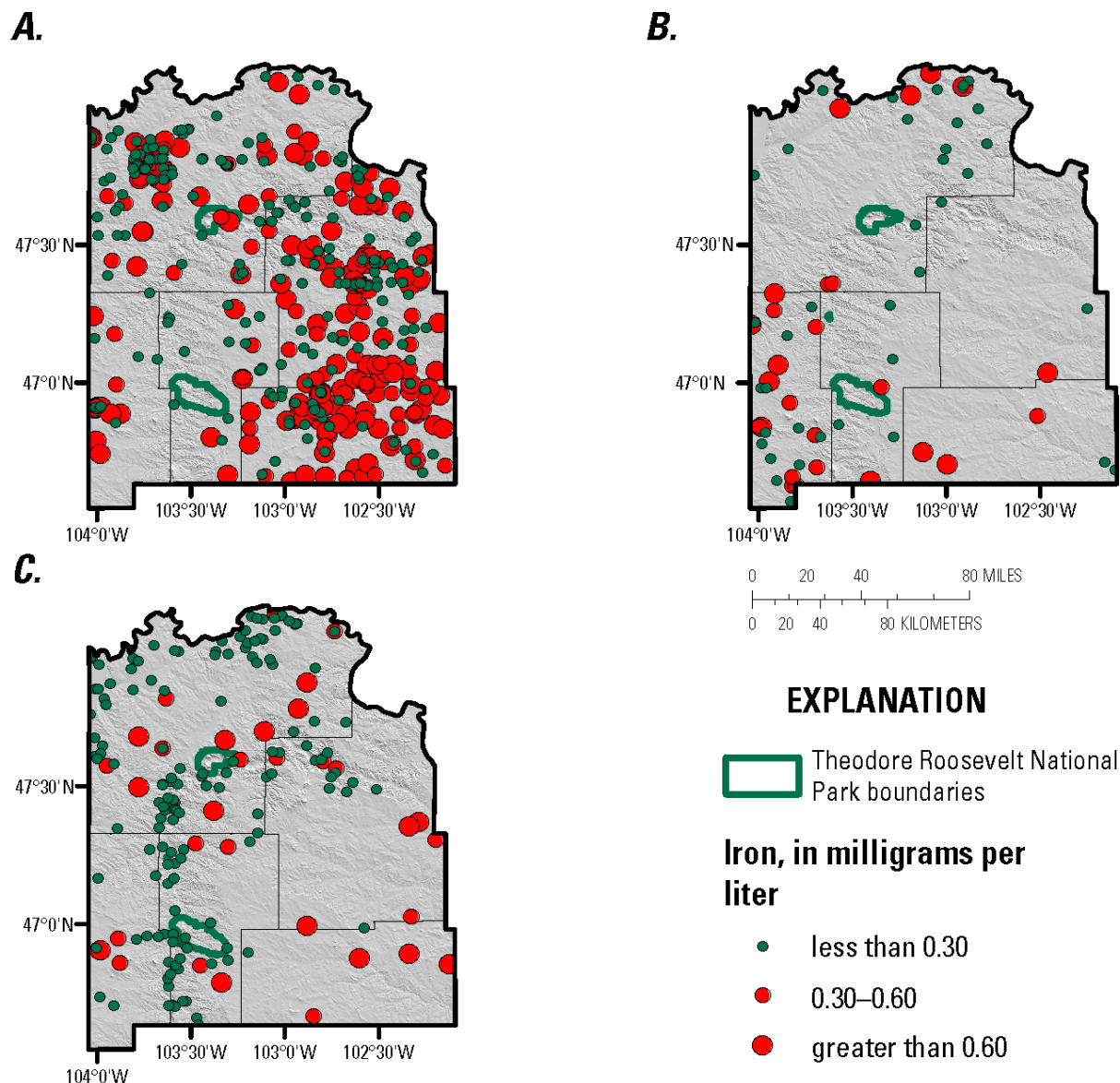
Base modified from U.S. Geological Survey digital data, various scales
Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American Datum of 1983 (NAD 83)

Figure 14. Median fluoride concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The maximum contaminant level (MCL) and secondary maximum contaminant level (SMCL) for drinking water specified by the U.S. Environmental Protection Agency (2009) are 4.0 and 2.0 milligrams per liter, respectively.

Iron

The distribution of median iron concentrations varied spatially among aquifers (Fig. 15A–C). Sites in the upper Fort Union aquifer (Fig. 15A) exceeded the SMCL iron standard with generally increasing concentrations from west to east. The lower Fort Union aquifer (Fig. 15B) and the Fox Hills-lower Hell Creek aquifer (Fig. 15C) had sites with concentrations greater than the standard that were scattered throughout the study area. The median concentration of iron in the upper Fort Union aquifer (0.32 mg/L in Table 15) exceeded the SMCL of 0.30 mg/L (U.S. Environmental Protection Agency, 2009). McMahon and others (2015) also noticed elevated concentrations of iron in the upper Fort Union aquifer at wells in the oil and gas production area of the Bakken Formation.

Iron is an abundant metal and likely is naturally occurring in the formations containing the upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers in the study area. Elemental iron rarely is found naturally because iron easily oxidizes in natural conditions and combines with oxides, hydroxides, carbonates, and sulfides (World Health Organization, 2003c). High iron concentrations can cause cosmetic effects or aesthetic effects in drinking water and will precipitate after oxidation when concentrations exceed 0.1 mg/L (Croft, 1985; U.S. Environmental Protection Agency, 2009).



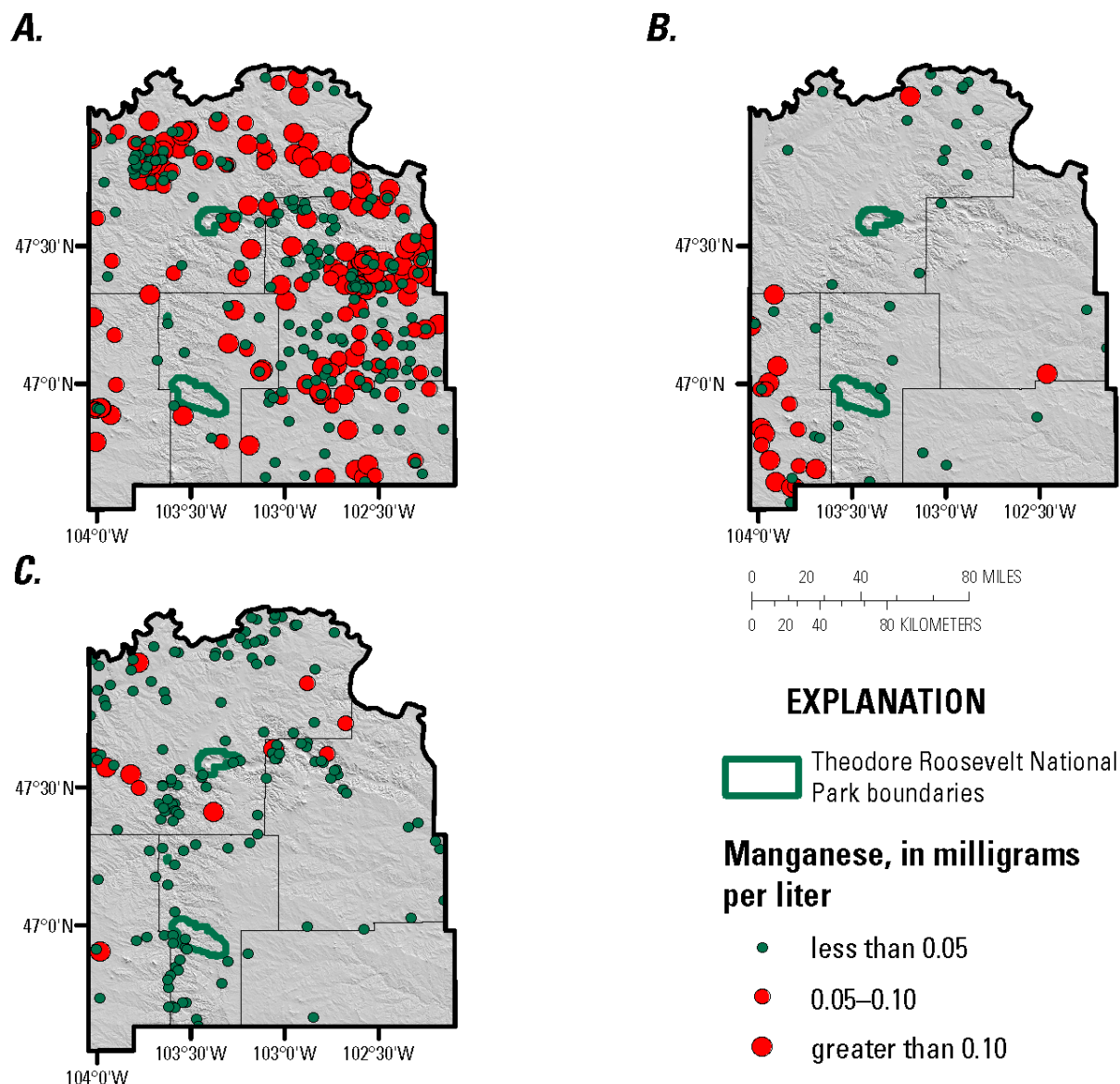
Base modified from U.S. Geological Survey digital data, various scales
Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American
Datum of 1983 (NAD 83)

Figure 15. Median iron concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The secondary maximum contaminant level (SMCL) concentration for drinking water specified by the U.S. Environmental Protection Agency (2009) is 0.30 milligram per liter.

Manganese

Manganese concentrations indicated variable spatial distribution among aquifers (Fig. 16A–C). Sites in the upper Fort Union aquifer (Fig. 16A) exceeded the SMCL manganese standard with generally increasing concentrations from southwest to northeast. Sites in the lower Fort Union aquifer (Fig. 16B) exceeding the standard were mostly in the southwestern part of the study area. The Fox Hills-lower Hell Creek aquifer (Fig. 16C) had sites with concentrations greater than the standard scattered in the study area. The median concentration of manganese in the upper Fort Union aquifer (0.06 mg/L in Table 15) exceeded the SMCL of 0.05 mg/L (U.S. Environmental Protection Agency, 2009). McMahon and others (2015) also recorded elevated concentrations of manganese in the upper Fort Union aquifer at wells throughout the oil and gas production area of the Bakken Formation.

High manganese concentrations in the upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers likely are naturally occurring and concentrated because of slow-moving groundwater. Manganese is an abundant mineral and is common in many surface-water and groundwater sources, especially in anaerobic or low oxidation conditions (World Health Organization, 2011). Manganese is a component of more than 100 minerals and normally is found with relative concentrations similar to iron (World Health Organization, 2011).



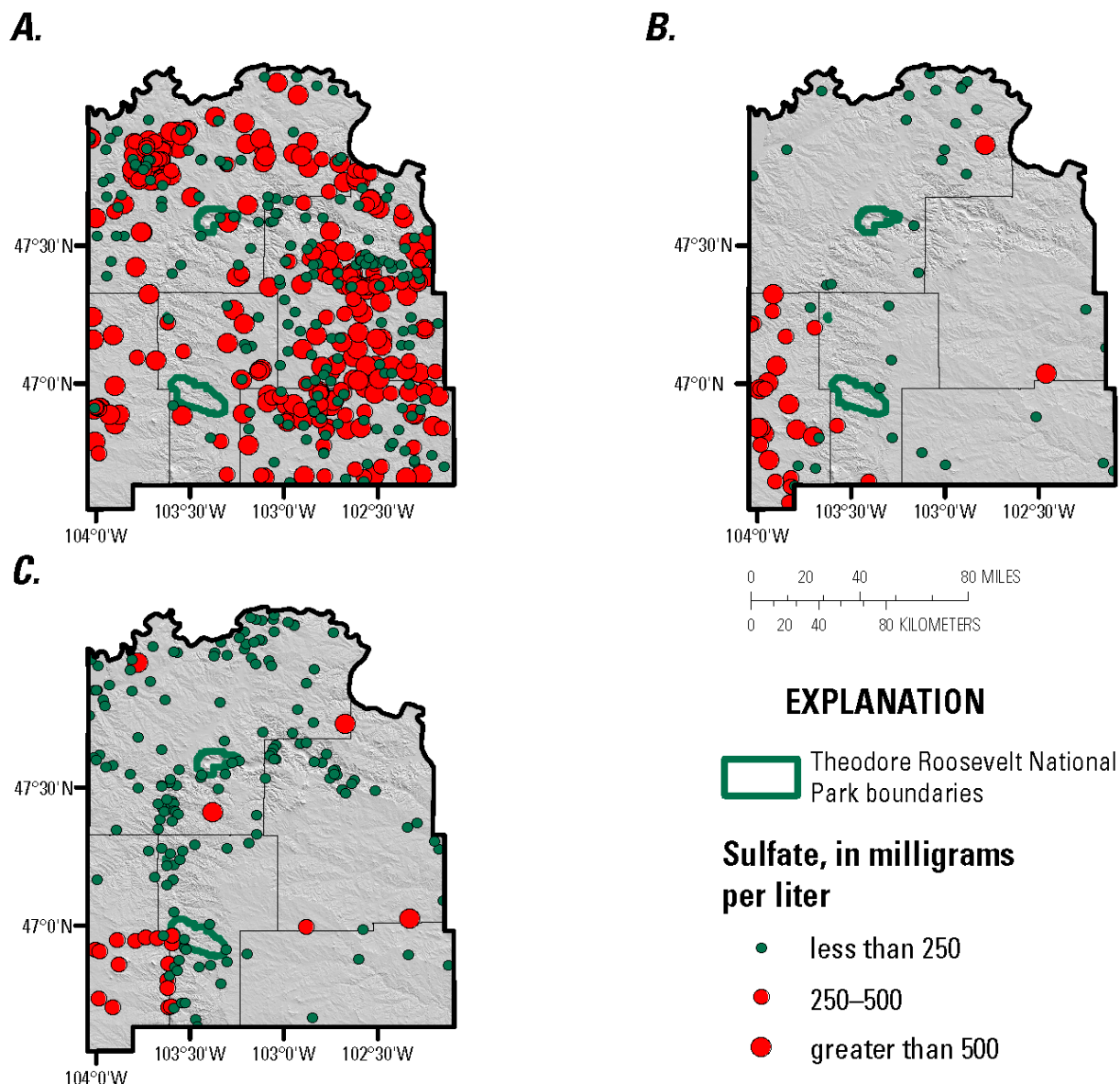
Base modified from U.S. Geological Survey digital data, various scales
Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American
Datum of 1983 (NAD 83)

Figure 16. Median manganese concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The secondary maximum contaminant level (SMCL) for drinking water specified by the U.S. Environmental Protection Agency (2009) is 0.05 milligram per liter.

Sulfate

The distribution of median sulfate concentrations showed spatial variability among aquifers (Fig. 17A–C). Sites in the upper Fort Union aquifer (Fig. 17A) that exceeded the SMCL sulfate standard were scattered throughout the study area. Sites in the lower Fort Union aquifer (Fig. 17B) that exceeded the sulfate standard were mostly in the southwestern part of the study area. Sites in the Fox Hills-lower Hell Creek aquifer (Fig. 17C) with high sulfate concentrations were mostly in the southwestern part of the study area. The median concentration of sulfate in the upper Fort Union aquifer (395 mg/L in Table 15) was about 1.5 times greater than the SMCL of 250 mg/L (U.S. Environmental Protection Agency, 2009).

High sulfate concentrations likely are natural and related to iron concentrations for aquifers in the study area. Sulfates occur naturally in minerals such as barite, epsomite, and gypsum, which contribute to the sulfate content of drinking water (World Health Organization, 2004). High concentrations of sulfate can have a laxative effect and, when in combination with other ions, can give water a bitter taste (Hamilton and Howells, 1996).



Base modified from U.S. Geological Survey digital data, various scales
Hillshade from digital elevation model (Gesch, 2007; Gesch and others, 2002)
Water quality data from North Dakota State Water Commission (2015)
WGS 1984 World Mercator projection (EPSG 3395)
Horizontal coordinate information referenced to North American
Datum of 1983 (NAD 83)

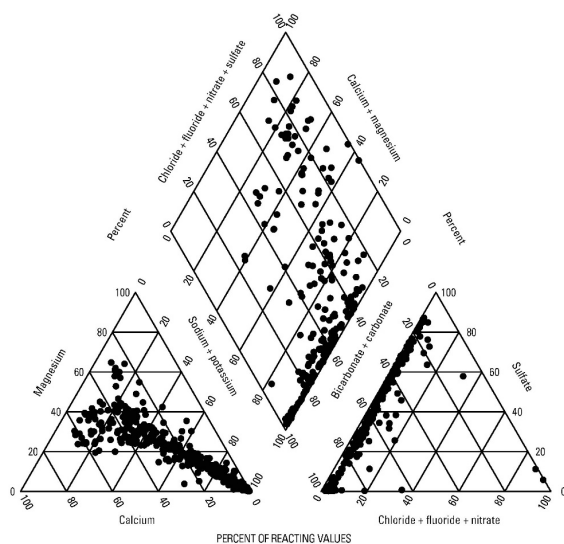
Figure 17. Median sulfate concentration for sites in (A) the upper Fort Union aquifer, (B) the lower Fort Union aquifer, and (C) the Fox Hills-lower Hell Creek aquifer. The secondary maximum contaminant level (SMCL) for drinking water specified by the U.S. Environmental Protection Agency (2009) is 250 mg/L.

Water Classification with Piper Diagrams

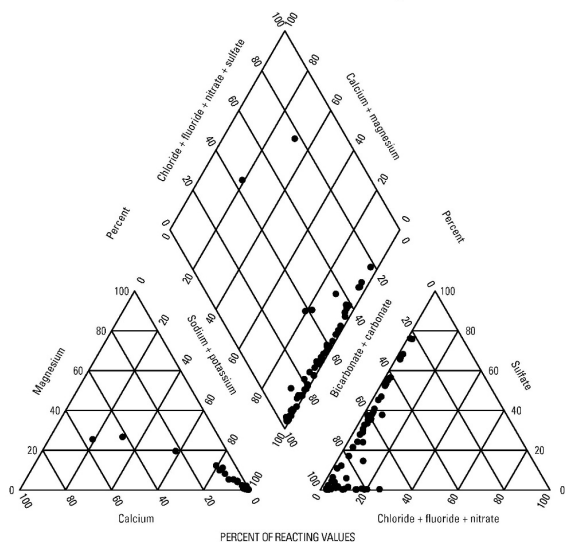
Piper diagrams were constructed to characterize and classify the water type of the aquifers in the study area (Fig. 18A–C). The upper Fort Union aquifer (Fig. 18A) had the most variability in cations and anions compared to the lower Fort Union and Fox Hills-lower Hell Creek aquifers.

Groundwaters in the upper Fort Union aquifer (Fig. 18A) can be classified as several types including sodium bicarbonate, sodium sulfate, magnesium bicarbonate, and magnesium sulfate. McMahon and others (2015) observed similar water-type variability in the upper Fort Union aquifer and concluded the variability was from the residence time of groundwater in the aquifer flow system.

A. Upper Fort Union aquifer



B. Lower Fort Union aquifer



C. Fox Hills-lower Hell Creek aquifer

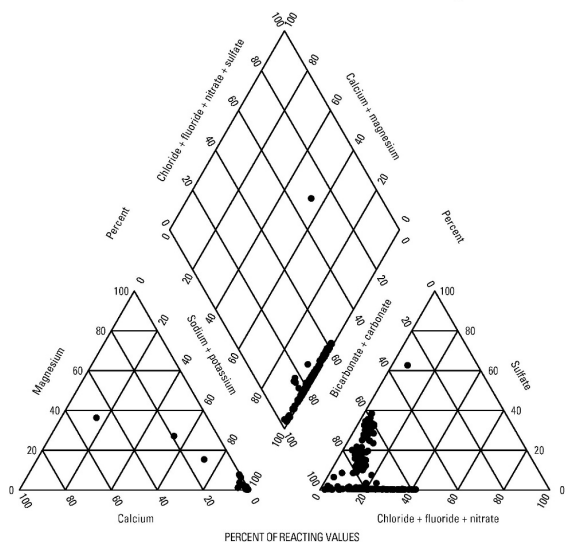


Figure 18. Water characterization with Piper diagrams of the aquifers near Theodore Roosevelt National Park. A, upper Fort Union aquifer; B, lower Fort Union aquifer; C, Fox Hills-lower Hell Creek aquifer.

The lower Fort Union aquifer (Fig. 18*B*) also had groundwaters dominated by sodium bicarbonate and, to a lesser extent, sodium sulfate. The lower Fort Union aquifer had lower concentrations of calcium and magnesium than the upper Fort Union aquifer (Table 15 and Table 16), and calcium and magnesium were not considered to be substantial contributors to the aquifer water type. Additionally, median sulfate concentrations were lower in the lower Fort Union aquifer (Table 15) than the upper Fort Union aquifer (Table 16).

The Fox Hills-lower Hell Creek aquifer (Fig. 18*C*) had the least variability in cations and anions but had greater median concentrations of chloride and fluoride than the upper Fort Union and the lower Fort Union aquifers (Fig. 18*A–C*; Tables 15–17). Groundwater in the Fox Hills-lower Hell Creek aquifer was classified as a sodium-bicarbonate type with minor amounts of chloride and fluoride. McMahon and others (2015) similarly characterized Fox Hills-lower Hell Creek aquifer water as sodium-bicarbonate type. A sodium-bicarbonate water type was expected because the median pH for Fox Hills-lower Hell Creek aquifer was 8.6 (Table 17; Krauskopf, 1979).

Future Research Needs

Several data limitations affected the completeness of the water resources inventory in Theodore Roosevelt National Park including the following: (1) lack of regular or routine flow measurements from springs and seeps to determine discharge response to changes in precipitation or other recharge sources; (2) no continuous measurement of discharge from flowing artesian wells that could be used to plan for the construction of flow control measures or plugging; (3) no recent water rights review to identify other water sources or water rights required for park operations; and (4) lack of regular or routine water-quality data for wells and springs. Iierkley and others (1998) and Amberg and others (2014) suggested future research needs for improving the information and data available to park managers, and some of the following research needs include their recommendations.

To improve knowledge of time-varying discharge from springs and seeps, Iierkley and others (1998) recommended evaluating spring and seep discharge to measure response to changes in precipitation or other recharge sources. Continuous monitoring of spring and seep discharge on monthly, seasonal, and annual periods also could provide information on the origin of water sources for springs and seeps. Springs and seeps recharged by remote or large areas could show delayed discharge responses, but springs and seeps recharged by small areas could have flashy or more immediate responses to changes in precipitation. Monitoring also could be done at flowing artesian well sites to collect data on pressure changes.

A study for the construction of flow control measures or plugging for flowing artesian wells could be considered by park staff. Oehler and Sexton (2010) recommended that five well sites in the South Unit be restored to natural conditions after ceasing flow, and one well (VA well) be restored immediately. Erosion at the Mike Auney well was considerable in 2018 causing that site to not function as intended, and the discharge from that well could be controlled or plugged. The wells recommended by Oehler and Sexton (2010) for restoration discharge from either the Bullion Creek aquifer (Tongue River, pre-1977) or the Fox Hills aquifer (Old Cottonwood well). On August 20, 2013, the North Dakota Office of the State Engineer issued guidance restricting large-scale withdrawals from the Fox Hills-Hell Creek (Fox Hills) aquifer (North Dakota State Water Commission and State Engineer, 2015b) because of decreasing pressure head. The pressure head decrease in Fox Hills wells was highest in McKenzie and Billings Counties. Plugging or controlling discharge from the Old Cottonwood well could help support the State objectives to preserve the pressure head in the Fox Hills aquifer.

Research focused on water rights could include identifying State appropriative rights certified for use on, or diversion from, Theodore Roosevelt National Park lands. A water rights review was recommended by Iierkley and others (1998) that would identify existing State appropriative rights, and registered uses, and identify other water sources or water rights needed within the park. The last water rights assessment was completed in 1964. State-recognized water rights are important for protecting water resources and uses at Theodore Roosevelt National Park; existing water rights should maintain good standing and additional water rights should be secured on water sources

currently without rights. Applicable North Dakota water law on water rights, permitting processes, and water-quality regulations for groundwater are provided in Appendix 5.

Frequent water-quality monitoring of selected well, spring, and stream sites could assist research of the potential effects of industrial and commercial development on Theodore Roosevelt National Park water resources. Amberg and others (2014) recommended regular monitoring of water quality and flood regimes for the Little Missouri River; however, no recommendation for sampling groundwater was provided. The National Park Service Inventory and Monitoring Network collect data of water quality on the Little Missouri River near Medora, N. Dak., that includes temperature, dissolved oxygen, specific conductance, and pH (National Park Service, 2019); however, collection also does not include groundwater sites. Baseline water-quality data from the 1980s for common anions and cations, nutrients, and trace metals from springs and wells are available (Appendixes 3 and 4). In addition to these physical properties and chemical constituents, a future sampling plan could include constituents, such as petroleum distillate hydrocarbons, that measure the effect of industrial and commercial developments that could affect water quality near the park. Additionally, pesticides commonly used in Theodore Roosevelt National Park could be included in the groundwater sampling plan (Iierkley and others, 1998). Monitoring changes in physical properties, chemical constituents, and other chemicals, such as those commonly found in petroleum production byproducts and produced water, could provide insights into possible temporal effects to the aquifers from oil and gas operations or from agricultural developments close to Theodore Roosevelt National Park.

Summary

Water is a critical resource for Theodore Roosevelt National Park that is used by all park fauna including free-ranging bison, elk, deer, pronghorn sheep, and feral and domestic horses. Additionally, water resources provide horseback riders, park visitors, and employees drinking water and serve fire protection and other management needs. Industrial and commercial developments in western North Dakota potentially could affect the sources of water that contribute to wells, spring flow, and seeps within Theodore Roosevelt National Park. Without basic water resources data, accurately predicting the effects of water withdrawals and water-quality concerns related to industrial and commercial developments near the park would be difficult.

This report documents past groundwater inventories and describes collection methods for inventorying groundwater resources including wells, springs, historical water levels, discharge rates, and water quality. Additionally, this report provides a summary and analysis of water-quality data from existing databases to characterize the groundwater from aquifers used by the park. Components of this report include a study area description, a description of the geology and hydrogeology, a review of previous hydrologic investigations, data collection methods, inventories, analysis of groundwater flow and water quality, and future research needs. Appendixes include additional water-quality data, site photographs, well log references, water-quality data, and applicable North Dakota water law including permitting processes and water-quality regulation.

The study area for this report included Theodore Roosevelt National Park and the five surrounding North Dakota counties. Theodore Roosevelt National Park encompasses 70,447 acres of land in 3 separate park units: the South Unit, the North Unit, and the Elkhorn Ranch Unit. The three units are in Billings and McKenzie Counties of western North Dakota and counties near the park include Dunn, Golden Valley, and Stark Counties. Water resources in the park include surface water and groundwater. The Little Missouri River and its tributaries cross all three park units and are the primary surface-water features in Theodore Roosevelt National Park. Groundwater resources include well discharges, springs, and seeps.

The geology and hydrogeology of Theodore Roosevelt National Park are defined by the surrounding Williston Basin, which is a large and roughly circular structural depression underlying parts of North Dakota, South Dakota, Montana, and Canada. Four aquifers are sources of groundwater to the park: unconsolidated aquifers including alluvial aquifers, the upper Fort Union aquifer, the lower Fort Union aquifer, and the Fox Hills-lower Hell Creek aquifer.

Data used in this study for wells, springs, seeps, and water quality were compiled from the U.S. Geological Survey National Water Information System (NWIS) database or from the North Dakota State Water Commission. Site locations and data not recorded in NWIS were assigned site identification numbers and added to the NWIS database. Well location data, including latitude and longitude, were determined, or updated if the location was already known. For each site, photographs were taken and a brief narrative description, including the common well name, was written. Documenting spring and seep sites required data similar to those required for wells. Spring discharge also was measured and recorded. Additional data describing springs and seeps included the type of

spring, sphere of discharge, permanence, improvements, number of openings, flow variability, and the basis for variability.

Groundwater-quality analysis had two objectives: (1) to characterize the groundwater chemistry for aquifers in the study area and (2) to spatially map selected physical properties and chemical constituents of interest. Water-quality data from 1937 through 2018 were selected from the North Dakota State Water Commission database for the five counties in the study area. Water-quality data included physical property and chemical constituent data from 781 sites. All physical properties and chemical constituents in the North Dakota State Water Commission database were selected for analysis. Data included the sampled aquifer but inconsistencies in aquifer names and changes in aquifer designations over time in the database required combining the samples into three aquifer groups for the study: upper Fort Union, lower Fort Union, and Fox Hills-lower Hell Creek aquifers.

Inventory data were collected for wells, springs, and seeps. An inventory of 16 wells was compiled for sites within the boundaries of the park. Wells were defined as sites with well casings at prepared sites (well sites documented in literature or park historical records as having flowing artesian waters often were categorized as springs). Some well sites from literature or records were not included in the inventory because the sites were no longer in use or the locations were unknown. As of 2019, the National Park Service had 12 permits for water rights on record with the North Dakota State Water Commission and State Engineer Office and 11 of the 12 permits listed groundwater as the water source. Priority dates for the water rights range from 1959 to 1996, and beneficial use dates were established for six permits. In addition to well data, an inventory of 11 springs and seeps was completed. Springs were inventoried in the North and South Units of the park. Additionally, if practical, discharge measurements were made by measuring the time to fill a known volume, and the measurements were recorded in the U.S. Geological Survey NWIS database. For this study, seeps were documented and recorded in the NWIS database as springs.

Groundwater flow in the Theodore Roosevelt National Park region is through aquifers and saturated alluvium. Potentiometric surface maps, also showing groundwater flow perpendicular to the potentiometric contours, were modified from maps developed for the Williston structural basin representing predevelopment (before 2000) conditions. Groundwater flow generally is from southwest to northeast in the aquifers underlying the park.

Groundwater-quality data from the North Dakota State Water Commission were summarized, mapped, and used to characterize groundwater for each aquifer in the study area. Spatial concentration distribution maps were constructed for selected physical properties and chemical constituents using summary statistics and exceedances. Piper diagrams were used to classify and characterize groundwater for each aquifer.

Median values for several physical properties and chemical constituents were compared to selected U.S. Environmental Protection Agency drinking-water and other water-quality standards. The median total dissolved solids concentration in all three aquifers was about three times greater than the secondary maximum contaminant level (SMCL) standard of 500 milligrams per liter (mg/L). The median concentration of boron in the Fox Hills-lower Hell Creek aquifer (1.3 mg/L) was nearly

double the agricultural-use standard of 0.75 mg/L for sensitive crops. Although the median concentration of chloride did not exceed the SMCL value of 250 mg/L, 15 percent of the samples in the Fox Hills-lower Hell Creek aquifer exceeded the SMCL. The median concentration of fluoride in the Fox Hills-lower Hell Creek aquifer (4.8 mg/L) exceeded the maximum contaminant level of 4.0 mg/L. The median concentration of iron in the upper Fort Union aquifer (0.32 mg/L) exceeded the SMCL of 0.30 mg/L. The median concentration of manganese in the upper Fort Union aquifer (0.06 mg/L) exceeded the SMCL of 0.05 mg/L. The median concentration of sulfate in the upper Fort Union aquifer (395 mg/L) was about 1.5 times greater than the SMCL of 250 mg/L.

Piper diagrams were constructed to characterize and classify the water type of the aquifers in the study area. All three aquifers investigated were dominated by sodium bicarbonate but had differences in cations and anions. The upper Fort Union aquifer had the largest variability in cations and anions and had many possible water types. The lower Fort Union aquifer had less cation and anion variability than the upper Fort Union aquifer. The Fox Hills-lower Hell Creek aquifer had the least variability in cations and anions but had greater amounts of chloride and fluoride than the upper Fort Union and the lower Fort Union aquifers. The Fox Hills-lower Hell Creek aquifer also had groundwaters dominated by sodium bicarbonate.

Future research to help fill data gaps in water resources information for Theodore Roosevelt National Park, including recommendations from previous studies, consists of the following areas:

(1) evaluating the variability in discharge from springs and seeps in comparison to changes in precipitation or other recharge sources, (2) evaluating flow control measures for flowing artesian wells, (3) completing a water rights review, and (4) performing routine water-quality monitoring for wells and springs.

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Appendix 1. Water-Quality Data from Theodore Roosevelt National Park Records

Theodore Roosevelt National Park maintained paper records in their archives of water quality at several sites in the North and South Units sampled in the 1980s. The water-quality data from the archives were digitized and are recorded in this appendix. The 1984 data included a U.S. Department of the Interior Requisition Form (DI-1) dated October 30, 1984, justifying the water chemistry analysis with the following text: “Justification: Oil and gas well development and production surrounding the park, including injection and saltwater disposal wells, could possibly effect [sic] the chemistry of underground water in the park. This analysis will give us a historical baseline for the chemical comparison of park water sources in future years. In addition, the analysis should tell us why some water sources are used more extensively by wildlife than others” (Theodore Roosevelt National Park, unpub. data, 1984). The water samples were analyzed on November 7, 1984 (Table 1.1); October 30, 1986 (Table 1.2); and November 11, 1988 (Table 1.3). Values reported as zero were included in the tables but assumed to have an actual value less than the minimum detection level of the analysis method at the time of the measurement. Data from surface water and springs from November 7, 1984, and October 30, 1986, were included in a baseline water quality data inventory (National Park Service, 1997).

Table 1.1. Water chemistry analysis at sites in Theodore Roosevelt National Park on November 7, 1984.

Site	pH	Conductivity (µmho/cm ¹)	TDS ² (mg/L)	Iron (mg/L)	Manganese (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total hardness (CaCO ₃ mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulfur (SO ₄ mg/L)	Total alkalinity (CaCO ₃ mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate (N mg/L)	Fluoride (mg/L)	Percent sodium	Turbidity (NTU)	Sodium absorption ratio	Total hardness (CaCO ₃ grains/gal)
Big Plateau	7.1	1,705	1,320	1.55	0.379	200	73.5	802	6.3	130	7.8	632	397	485	0	<2	0.4	26.0	10	2.0	46.9
Boicourt Spring	7.4	1,085	738	1.85	0.162	42.5	41.5	277	2.05	169	7.8	254	351	429	0	<2	0.4	56.9	9	4.41	16.2
Dedication Spring	8	9,328	7,880	0.13	0.04	37.5	25	197	7.25	2,750	6	4,110	1,550	1,900	0	<2	2.0	96.8	<1	85.3	11.5
Ekblom well	8.8	1,848	1,230	0.03	0.003	2.5	0.5	8.0	1.3	452	8	460	501	578	17	<2	1.2	99.2	<1	68.3	0.49
Jones Creek	8.8	1,760	1,190	0.14	0.02	2.5	0	6.0	1.3	457	9.3	395	525	605	18	<2	1.8	99.4	<1	79.5	0.37
Knutson Creek	7	4,345	3,630	0.42	0.545	212	98.5	935	8.6	843	11.2	2,070	636	777	0	<2	0.6	66.1	<1	12.0	54.6
Lone Tree	7.7	550	344	0.09	0.049	17.5	7	73	4.4	108	2.92	30	275	336	0	<2	0.3	76.2	<1	5.49	4.24
Mike Auney	8.8	1,584	1,040	0.13	0	2	0	5.0	1.25	399	10.0	280	558	641	20	<2	2.3	99.4	<1	77.6	0.29
Olson well	7.4	1,043	680	0.16	0.249	114	40.5	450	0.85	86	4.5	134	486	594	0	<2	0.4	29.1	<1	1.75	26.3
Rough Rider well	8.8	1,705	1,080	0.09	0.005	2	0.5	7.0	1.25	430	10.6	345	477	541	20	<2	1.5	99.2	<1	70.3	0.41
SE Corner	7	3,964	3,510	0.07	0.088	265	169	1,360	9.75	602	40.7	2,190	379	463	0	<2	0.3	49.0	<1	7.1	79.3
Sheep Butte	7	1,501	1,070	1.44	0.169	33	38	239	2.4	271	9.6	576	214	261	0	<2	1.2	71.1	<1	7.62	14.0
Sheep Pasture	7.1	856	549	0.41	0.194	34.5	16	152	3.5	152	7.0	120	345	421	0	<2	0.4	38.4	<1	5.36	8.88
Tomamichael	8.6	1,868	1,210	0.13	0.004	2.5	0	6.0	1.65	510	11.5	75	993	1,180	18	<2	3.2	99.4	<1	88.8	0.37
VA wells	8.8	1,642	1,090	0.07	0.003	1.5	0	4.0	1.4	421	11.3	264	627	718	24	<2	2.3	99.6	<1	94.5	0.22

¹ µmho/cm = micromho per centimeter

² TDS = total dissolved solids

Table 1.2. Water chemistry analysis at sites in Theodore Roosevelt National Park on October 30, 1986.

Site	pH	Conductivity (µmho/cm ¹)	TDS ² (mg/L)	Iron (mg/L)	Manganese (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total hardness (CaCO ₃ mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulfur (SO ₄ mg/L)	Total alkalinity (CaCO ₃ mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate (N mg/L)	Fluoride (mg/L)	Percent sodium	Turbidity (NTU)	Sodium absorption ratio	Total hardness (CaCO ₃ grains/gal)
Achenbach Spring	7	858	563	0.17	0.312	103	55	483	4.9	36	2.0	113	416	508	0	0	0.3	13.8	<1	0.71	28.2
Big Plateau	7	1,641	1,100	1.47	0.293	169	63.3	683	4.4	100	7.9	512	401	490	0	0.2	0.3	24.1	5	1.67	39.9
Boicourt Spring (source 4)	8.6	1,083	704	1.18	0.068	41.8	40.2	270	1.7	168	7.2	225	367	416	16	0	0.4	57.4	<1	4.44	15.8
Boicourt Spring (spring A)	8.3	2,300	1,690	0.057	0.002	51.5	44.2	311	4.6	471	12.1	613	809	988	0	1.7	1	76.6	850	11.6	18.1
Buck Hill Spring	8.5	3,746	3,020	0.562	0.006	95.7	74.5	546	5.0	860	12.4	1,530	736	828	35	0	0.5	77.3	3	16	31.9
Dedication Spring	8.6	8,459	6,640	0.02	0.002	21.4	21.4	142	5.0	2,200	4.3	3,440	1,580	1,840	48	0.4	2.1	97.1	<1	80.2	8.27
Ekblom well	8.7	1,847	1,040	0.013	0.002	1.7	0.9	8	1.0	362	8.4	363	512	584	20	0	1.3	99	<1	55.9	0.46
Hagen Spring ³	7.2	3,732	2,980	14.1	0.101	53.5	36.1	282	6.7	996	5.8	1,210	1,120	1,370	0	0	0.6	88.4	13	25.8	16.5
Jones Crk	8.8	1,719	995	0.218	0.002	1.4	0.7	6	0.86	345	10.0	315	532	588	30	0.4	1.9	99.2	<1	59.4	0.37
Knutson Crk	7.4	4,118	3,700	0.483	0.403	228	102	989	7.9	859	6.7	2,110	650	794	0	0	0.6	65.3	<1	11.9	57.8
L. Mo. Knutson	8.3	1,714	1,520	5.4	0.807	79.7	37.9	355	12.0	362	10.2	541	775	946	0	1.7	0.1	68.8	3,600	8.34	20.7
L. Mo. Medora Cmp	8.3	1,541	1,030	0.055	0.001	29.6	13.4	129	7.0	284	9.2	491	321	392	0	1.7	0.1	82.6	2,800	10.8	7.54
L. Mo. N. Boundary	8.2	919	686	1.73	0.122	57.1	22.5	235	6.3	153	7.3	348	148	181	0	0.5	0.3	58.4	48	4.33	13.7
L. Mo. Rvr NU	8.4	1,281	963	2.01	0.082	69.5	28.3	290	8.6	222	8.7	479	245	289	5	0	0.3	62.3	33	5.67	17
L. Mo Rvr NU-E	8.4	1,270	947	2.04	0.093	70.1	27.3	288	8.4	218	8.4	466	249	290	7	0	0.3	62.1	28	5.58	16.8
L. Mo. Rvr NU-SW	8.3	982	700	2.53	0.138	59.8	23.9	248	6.8	154	7.0	350	162	198	0	0	0.3	57.4	38	4.26	14.5
Lone Tree	8.2	537	338	0.018	0.007	14.5	6.9	65	4.3	122	2.9	21	275	336	0	0.2	0.2	80.4	<1	6.61	3.78
Mandal Spring	6.8	1,146	945	0.143	0.357	128	90.3	693	8.2	49	2.9	341	541	660	0	0	0.1	13.3	<1	0.81	40.5
Mike Auney	8.8	1,537	942	0.152	0.007	1.6	0.8	7	0.91	335	10.8	250	570	659	18	0	2.5	99	4	53.9	0.43
Olson well	7.8	918	535	0.037	0.012	69.5	34.1	314	0.82	77	3.0	127	371	453	0	0.3	0.5	34.5	<1	1.88	18.3
Overlook Spring	8.2	2,029	1,430	0.162	0.007	2.6	1.4	12	2.2	559	5.1	372	806	984	0	0	2.3	99	<1	69.4	0.72
Rough Rider well	8.8	1,671	1,020	0.078	0.003	1.7	0.8	8	1.0	366	9.4	299	561	601	41	0.4	1.6	99.1	<1	57.9	0.44
SE Corner	7.8	3,898	3,610	0.026	0.024	279	175	1,420	10	635	17	2,260	396	484	0	0.8	0.3	49.3	<1	7.34	82.7
Sheep Butte	8.1	1,505	1,020	0.558	0.058	33.6	36.2	233	2.0	276	10.2	521	227	277	0	0	1.3	72	2	7.87	13.6
Sheep Pasture	7.4	899	562	0.21	0.153	34.6	17.7	159	3.4	161	7.5	125	354	432	0	0	0.5	68.6	<1	5.55	9.31

¹ µmho/cm = micromho per centimeter
² TDS = total dissolved solids
³ In the records, the site was misnamed Stevens Spring
⁴ In the records, the site was misnamed Hagen Spring

Table 1.2 (continued). Water chemistry analysis at sites in Theodore Roosevelt National Park on October 30, 1986.

Site	pH	Conductivity (µmho/cm ¹)	TDS ² (mg/L)	Iron (mg/L)	Manganese (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total hardness (CaCO ₃ mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulfur (SO ₄ mg/L)	Total alkalinity (CaCO ₃ mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate (N mg/L)	Fluoride (mg/L)	Percent sodium	Turbidity (NTU)	Sodium absorption ratio	Total hardness (CaCO ₃ grains/gal)
Stevens Spring ⁴	7.3	5,120	4,080	0.245	0.087	59.1	32.6	282	6.7	1,430	6.7	1,600	1,570	1,910	0	0.3	1.5	91.6	<1	37	16.5
Tomamichael	8.8	1,849	1,230	0.112	0.002	2.2	1.1	10	1.5	539	11.9	60	1,020	1,130	55	0.6	3.4	99.1	<1	74	0.59
VA wells	8.8	1,629	1,100	0.069	0.002	1.6	0.8	7	1.1	460	11.8	243	638	726	26	0	2.4	99.3	<1	74.1	0.43
Wannagan Seep	8.1	576	344	0.624	0.057	62.7	30.6	283	2.0	29	3.0	44	286	342	4	0	0.4	18.4	<1	0.76	16.5

¹ µmho/cm = micromho per centimeter
² TDS = total dissolved solids
³ In the records, the site was misnamed Stevens Spring
⁴ In the records, the site was misnamed Hagen Spring

Table 1.3. Water chemistry analysis at sites in Theodore Roosevelt National Park on November 11, 1988.

Site	pH	Conductivity (µmho/cm ¹)	TDS ² (mg/L)	Iron (mg/L)	Manganese (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total hardness (CaCO ₃ mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulfur (SO ₄ mg/L)	Total alkalinity (CaCO ₃ mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate (N mg/L)	Fluoride (mg/L)	Percent sodium	Turbidity (NTU)	Sodium absorption ratio	Total hardness (CaCO ₃ grains/gal)
Achenbach Spring	7.4	901	546	0.852	0.338	102	56.7	488	4	35.1	2	96	414	506	0	0.2	0.3	13.5	3	0.69	28.5
Big Plateau	7.7	1,892	1,440	1.47	0.182	253	83.9	977	5.3	134	8.9	711	410	501	0	0.3	0.3	22.9	6	1.86	57.1
Boicourt Spring	8.6	1,016	649	0.702	0.076	34	39.4	247	1.6	146	7.1	216	342	387	15	0	0.4	56.0	3	4.02	14.4
Buck Hill Spring	8.1	441	266	0.199	0.007	27.3	5.1	89	0.2	63.6	2.3	113	91	111	0	0	0.2	60.7	60	2.93	5.21
Dedication Spring	8.6	9,430	7,510	0.16	0.018	38.4	26.7	206	8	2,540	5.3	3,940	1,590	1,830	51	0.8	2	96.4	3	76.8	12
Ekbolm well	8.9	1,866	1,210	0.018	0.015	2.8	1.3	12	1.1	453	8.2	438	517	566	32	0	1.2	98.8	2	56	0.72
Hagen Spring	7.5	1,241	867	0.199	0.013	129	88	684	6.3	47.9	3.2	360	386	471	0	0.1	0.1	13.2	<1	0.8	40
Jones Crk well	9	1,795	1,140	0.091	0.012	2.4	1	10	1.2	433	10.5	369	542	568	46	0	1.8	98.9	<1	59.2	0.59
Knutson Crk Spring	8	4,350	3,420	0.304	0.169	188	97.7	872	7.1	836	6.4	1,930	588	718	0	0.4	0.4	67.5	4	12.3	51
L. Mo. C.G. #9	8.4	3,670	2,750	5.08	0.367	104	65.3	529	14.8	788	27.4	1,470	465	557	5	0.3	0.6	76.3	75	14.9	30.9
L. Mo. Knutson Crk	8.5	4,490	3,440	3.78	0.409	114	91.5	662	21.2	979	30.6	1,970	380	444	10	0.5	0.4	76.2	175	16.5	38.6
L. Mo. No. Boundary	8.5	4,610	3,390	3.4	0.193	118	82.1	633	17	913	19.3	2,020	370	431	10	0.5	0.3	75.8	60	15.8	37
L. Mo. NU Campground	8.3	3,370	2,350	1.17	0.081	73.3	50.2	390	14	626	19	1,250	527	643	0	0.4	0.5	77.7	12	13.8	22.8
L. Mo. NU East	8.3	3,430	2,310	0.798	0.087	63.1	50.1	364	13.7	613	18.6	1,230	525	641	0	0.3	0.5	78.5	60	14	21.3
L. Mo. NU-SW	8.3	3,400	2,400	1.48	0.139	84.1	53.7	431	13.3	623	22	1,270	545	665	0	0.3	0.5	75.8	35	13.1	25.2

¹ µmho/cm = micromho per centimeter.
² TDS = total dissolved solids.

Table 1.3 (continued). Water chemistry analysis at sites in Theodore Roosevelt National Park on November 11, 1988.

Site	pH	Conductivity (µmho/cm ¹)	TDS ² (mg/L)	Iron (mg/L)	Manganese (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Total hardness (CaCO ₃ mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulfur (SO ₄ mg/L)	Total alkalinity (CaCO ₃ mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate (N mg/L)	Fluoride (mg/L)	Percent sodium	Turbidity (NTU)	Sodium absorption ratio	Total hardness (CaCO ₃ grains/gal)
Lone Tree Spring	8.6	599	337	0.023	0.035	13.6	7	63	4.1	116	2.6	27	277	320	9	0.2	0.3	79.9	3	6.34	3.67
Mike Aune well	8.9	1,595	1,020	0.162	0.006	1.5	1	8	0.9	409	10.6	254	571	622	37	0.3	2.2	99.1	2	63.4	0.46
Olsen well	8.4	915	589	0.035	0.014	58.6	46.8	339	2.1	105	5.2	153	338	409	2	3.4	0.5	40.1	4	2.48	19.8
Overlook Spring	8.5	2,260	1,410	0.544	0.008	2.1	1.2	10	2.2	523	5.4	386	809	949	19	0.4	2.3	99.1	2	71.2	0.6
Peck Hill Seep	8.3	1,750	1,240	3.28	0.032	46.4	21.3	204	2.3	347	21.6	486	516	626	2	0.8	0.8	78.7	2,500	10.6	11.9
Rough Rider well	9	1,728	1,090	0.091	0.003	1.7	0.8	8	1	394	9.5	335	570	594	50	0.5	1.4	99.1	2	62.4	0.44
SE Corner	8.1	4,000	3,150	0.3	0.046	216	167	1,230	9.6	550	18.3	2,050	229	279	0	0.9	0.2	49.2	30	6.83	71.6
Sheep Butte	8.6	1,431	960	1.69	0.072	29.8	33	210	1.7	254	9.9	498	223	252	10	0.1	1.3	72.3	3	7.6	12.3
Sheep Pasture Spring	8.6	894	535	0.215	0.037	28.7	14.3	131	2.4	142	7.3	118	369	416	17	0	0.4	70.2	3	5.39	7.63
Stevens Spring	8.4	4,200	3,110	2.04	0.092	50.9	36.1	276	7	980	5.6	1,340	1,150	1,380	9	0.2	0.6	88.5	25	25.7	16.1
Tomamichael well	9.1	2,050	1,180	0.207	0.001	1.7	0.9	8	1.5	466	11.6	78	1,030	1,030	110	0.6	3.2	99.2	3	71.9	0.46
VA well	8.9	1,673	1,100	0.061	0.019	1.7	0.8	8	4.5	436	11.7	261	643	702	41	0.4	2.2	99.2	2	69	0.44
Wannagan Seep	7.9	1,090	615	1.13	0.656	75.9	64.8	456	13.8	86	6.6	4	597	729	0	1.1	0.6	29.0	8	1.75	26.7

¹ µmho/cm = micromho per centimeter.

² TDS = total dissolved solids.

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Appendix 2. Well, Spring, and Seep Sites

In 2018, several well, spring, and seep sites were inventoried by site visits. The inventories included recording coordinates, measuring discharge, and archiving the data in the U.S. Geological Survey (USGS) National Water Information System database (U.S. Geological Survey, 2019). Photographs of the sites are provided in this section and were grouped by the Theodore Roosevelt National Park unit (North or South) with historical and background data from previous reports (Iierkley and others, 1998; Oehler and Sexton, 2010) or observations from the site visits. Well sites not visited in the South Unit and not listed include the VA well (see Oehler and Sexton, 2010), Old Picnic Area well (location unknown), Headquarters well (no longer in use), Painted Canyon well, and Corral well.

Several of the well, spring, and seep sites include developments, or infrastructure to pipe, capture, or store water. In the early 1960s, several 300- to 500-gallon concrete tubs, called dish tanks, were installed at spring locations in the North and South Units (Iierkley and others, 1998). The tanks are at ground level and are filled by springs or wells. The dish tanks were installed to provide water to large ungulates to disperse their grazing ranges. Dish tanks require routine maintenance because grazing ungulates trample the sites and nudge against the pipes and tanks; some of the sites have been severely degraded by ungulate grazing (Iierkley and others, 1998; Oehler and Sexton, 2010).

North Unit

The Theodore Roosevelt National Park North Unit inventory consisted of 3 well sites and 5 spring sites. In 1998, 2 well sites and 4 spring sites in the North Unit were discussed in the Theodore Roosevelt National Park Water Resources Management Plan (Iierkley and others, 1998). North Unit sites were not included in a 2008 management recommendations report by Oehler and Sexton (2010).

Juniper Well

Juniper well (Fig. 2.1) provides drinking water to the Juniper campground in the North Unit. The well was completed on April 7, 2004, with a depth of 430 feet (ft) below land surface (Appendix 3). The well standpipe is about 30 ft southeast of the pump house. The site also is the approximate location of the abandoned Squaw Creek well completed in 1956 at a depth of 372 ft below land surface.



Figure 2.1. Juniper well house in the North Unit of Theodore Roosevelt National Park (May 4, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Park Housing Well

The park housing well (Fig. 2.2) provides water to the North Unit living quarters and workshops. Two well heads are within 30 ft of each other. The newer well was completed March 11, 2016, to a depth of 390 ft below land surface and with a static water level of 21 ft below land surface (Appendix 3). The older well likely was completed on December 19, 1980, to a depth of 358 ft below land surface and with a static water level of 23 ft below land surface. A test hole also was completed near the site on December 17, 1980, to a depth of 400 ft below land surface and was plugged with mud and cement.



Figure 2.2. Park housing well house and well heads in the North Unit of Theodore Roosevelt National Park (May 4, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Wildlife or Roundup Well

The Wildlife well (Fig. 2.3) is in the roundup area of the Theodore Roosevelt National Park North Unit and was completed in the alluvial deposits of the Little Missouri River. The completion date was May 10, 1976, to a depth of 40 ft below land surface (a sand cavity was noted from 30 to 40 ft) and with a static water level of 21 ft below land surface (Appendix 3). The stand pipes were replaced in the mid-2010s.



Figure 2.3. Wildlife or Roundup well in the North Unit of Theodore Roosevelt National Park (May 4, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Achenbach Spring

Achenbach Spring (Fig. 2.4) in the North Unit contains two concrete water collection tubs dish tanks and the site is functional. Known discharge records for the spring began in 1976.



Figure 2.4. Achenbach Spring with concrete collection tubs for site development in the North Unit of Theodore Roosevelt National Park (September 21, 2018; photograph courtesy Kathryn R. Willi, U.S. National Park Service, Water Resources Division).

Hagen Spring

Hagen Spring (Fig. 2.5) in the North Unit contains two collection tubs (dish tanks) and the site is well maintained. Discharge records for the spring began in 1976.



Figure 2.5. Hagen Spring with concrete collection tubs for site development in the North Unit of Theodore Roosevelt National Park (July 9, 2018; photograph courtesy Kathryn R. Willi, U.S. National Park Service, Water Resources Division).

Mandal Spring

Mandal Spring (Fig. 2.6) contributes to a small ephemeral tributary that feeds the Little Missouri River. The site has no developments. Known discharge records for the spring began in 1976.



Figure 2.6. Mandal Spring in the North Unit of Theodore Roosevelt National Park (September 21, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Overlook Spring

Overlook Spring (Fig. 2.7) includes a concrete tub (dish tank) that is not visible at the land surface. The concrete tub dimensions were measured to be about 13 ft long by 5 ft wide by about 2 ft deep. A 1.75-inch (in.) diameter polyvinyl chloride (more commonly known as PVC) pipe discharges water measured with a head of more than 5 ft in October 2019. Known discharge records began in 1986.



Figure 2.7. Overlook Spring in the North Unit of Theodore Roosevelt National Park (September 21, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Stevens Spring

Stevens Spring (Fig. 2.8) includes two concrete tubs (dish tanks) and a spring box. Known discharge records began in 1976.



Figure 2.8. Stevens Spring in the North Unit of Theodore Roosevelt National Park (May 4, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

South Unit

The Theodore Roosevelt National Park South Unit inventory consisted of 8 well sites and 6 spring sites. In 1998, 8 well sites and 12 spring sites in the South Unit were discussed in the Theodore Roosevelt National Park Water Resources Management Plan (Iierkley and others, 1998). South Unit sites in a 2010 management recommendations report by Oehler and Sexton (2010) included 7 wells and 5 springs. Some nomenclature and accounting differences likely were because of differing site classifications; some well sites were classified as springs in the reports.

Cottonwood Campground Well

The Cottonwood Campground well (Fig. 2.9) provides drinking water to the Cottonwood Campground. An “old Cottonwood well” east of the road accessing the campground likely was completed in 1956 (Oehler and Sexton, 2010) and in May 2018 discharged at about 0.75 gallon per minute (gal/min; U.S. Geological Survey, 2019). The new Cottonwood Campground well, currently in use, was completed on June 21, 1984, to a depth of 1,385 ft below land surface, and was a flowing artesian well with a discharge of about 42 gal/min through a 2.5-in. pipe with a closed-in pressure of 50 pounds per square inch at the time of completion (Appendix 3). The site is well maintained and used as a source of drinking water at the campground.



Figure 2.9. Cottonwood Campground well in the South Unit of Theodore Roosevelt National Park (May 3, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Eklom Well

The Eklom well (Fig. 2.10) is a standpipe with flowing water and a concrete tub (dish tank). Records indicate that the well was completed in 1914 (Oehler and Sexton, 2010), but improvements to the site were evident during site visits in 2018. Water quality was considered adequate to use as a domestic supply, and the site is primarily used by bison (Oehler and Sexton, 2010).



Figure 2.10. Eklom well in the South Unit of Theodore Roosevelt National Park (May 21, 2018; photograph courtesy Jeffrey C. Hughes, U.S. National Park Service, Water Resources Division).

Halliday Well

The Halliday well (Fig. 2.11) is near Knutson Creek and was drilled in 1924 to a depth of 593 ft below land surface for domestic, wildlife, and fire protection uses (Oehler and Sexton, 2010). In 1924, the 1.25-in. well provided about 2 gal/min, and in 1994, the well provided about 1 gal/min. In 2018, the well was not flowing but some flow was noted around the well, likely from leakage from the well casing, into a drainage leading to Paddock Creek.



Figure 2.11. Halliday well site in the South Unit of Theodore Roosevelt National Park (May 3, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Jones Creek Well

The Jones Creek well (Fig. 2.12) was completed in 1939 to a depth of 443 ft below land surface. It is a flowing artesian well with historical discharge rates ranging from 2 gal/min to less than 0.2 gal/min in 2010 (Oehler and Sexton, 2010). Bison use the site even though it is less than 0.2 mile from the Little Missouri River. In 1988, the water quality at the site was high in sodium but still rated as a good domestic supply.



Figure 2.12. Jones Creek well site in the South Unit of Theodore Roosevelt National Park (May 21, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Mike Auney Well

The Mike Auney well (Fig. 2.13) was completed in 1914 at a depth of 350 ft below land surface and is one of the oldest wells in the park. Water-quality studies in 1998 reported high sodium levels and classified the well as not suitable for domestic supply (Oehler and Sexton, 2010). The well is a flowing artesian well, and in 2018, considerable erosion was observed around the well casing and along the flow path to a drainage leading to the Little Missouri River.



Figure 2.13. Mike Auney well in the South Unit of Theodore Roosevelt National Park (May 23, 2018; photograph courtesy Jeffrey C. Hughes, U.S. National Park Service, Water Resources Division).

Peaceful Valley Ranch Well

The Peaceful Valley Ranch well (Fig. 2.14) was completed on April 23, 1998, at a depth of 1,290 ft below land surface, and was a flowing artesian well with a closed-in pressure of 56 pounds per square inch or 64 gal/min through a 2-in. pipe. The site provides water to Peaceful Valley Ranch and is well maintained.



Figure 2.14. Peaceful Valley Ranch well in the South Unit of Theodore Roosevelt National Park (May 3, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Roundup Campground Well

The Roundup Campground well (Fig. 2.15) was completed on September 10, 1996, to a depth of 1,325 ft below land surface and has a static water level of 3 ft above land surface. The well provides drinking water to the Roundup Horse Camp and the site is well maintained.



Figure 2.15. Roundup well pump house in the South Unit of Theodore Roosevelt National Park (May 3, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Tomamichael Well

The Tomamichael well (Fig. 2.16) was completed in 1928 to a depth of 640 ft below land surface. Early discharge rates were recorded at 0.2 gal/min, but at 0.1 gal/min in 2010 (Oehler and Sexton, 2010) and 2018. Water-quality reports in 1988 recorded high alkalinity and sodium. The site is used by bison and maintenance is needed to ensure the well discharges into the concrete tub (dish tank) because bison occasionally nudge the well spigot away from the tub.



Figure 2.16. Tomamichael well in the South Unit of Theodore Roosevelt National Park (May 21, 2018; photograph courtesy Jeffrey C. Hughes, U.S. National Park Service, Water Resources Division).

Big Plateau Spring

Records do not provide a history for Big Plateau Spring (Fig. 2.17) or note when it was developed, but discharge recorded in 1953 and afterwards ranged from 0.13–0.5 gal/min. Discharge was measured in 2018 at 0.6 gal/min. Water-quality studies record high iron, manganese, and sulfate levels (Oehler and Sexton, 2010). The site contains a spring box and concrete tubs (dish tanks) but the tubs are filled with mud and the spring box is collapsing.



Figure 2.17. Big Plateau Spring in the South Unit of Theodore Roosevelt National Park (July 8, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Boicourt Spring

The Boicourt Spring (Fig. 2.18) was developed in the mid-1960s to provide a source of water for wildlife. In 1988, the spring discharge was about 2 gallons per hour and the water was considered a good domestic supply but high in sodium, magnesium, and iron (Oehler and Sexton, 2010). Oehler and Sexton (2010) noted that in 2007 the spring “ceased functioning.” In 2018, the concrete tubs (dish tanks) did not contain water and the site was characteristic of a seep rather than a flowing spring.



Figure 2.18. Boicourt Spring in the South Unit of Theodore Roosevelt National Park (July 18, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Lone Tree Spring

Lone Tree Spring (Fig. 2.19) was noted on a 1960 National Park Service map but other sources list 1953 as the first record of development at the spring (Oehler and Sexton, 2010). Discharge from the spring ranged from 0.2 to 0.5 gal/min, and in 2018, discharge was measured at 0.6 gal/min. The development at the site (piping and dish tanks) is not functioning, but spring discharge pools into an extensive seep.



Figure 2.19. Lone Tree Spring in the South Unit of Theodore Roosevelt National Park (September 19, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Sheep Butte Spring

Records for the Sheep Butte Spring site (Fig. 2.20) indicate that the seep functioned in 1953, but the collection system and associated developments were nonfunctioning by 2010 (Oehler and Sexton, 2010). Discharge from the site was recorded from 0.1 to 0.25 gal/min (Oehler and Sexton, 2010), but in 2018, discharge was too low to be measured and water samples were collected by funneling drops into sample bottles. The site provides water as a seep to wildlife.



Figure 2.20. Sheep Butte Spring in the South Unit of Theodore Roosevelt National Park (July 8, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Sheep Pasture Spring

Records of Sheep Pasture Spring (Fig. 2.21) date to 1976 but the first discharge measurement was recorded in 1992. Discharge ranged from 0.2 to 1.25 gal/min, but surface flow was not reported in 2010 (Oehler and Sexton, 2010). The spring box and concrete tubs (dish tanks) at the site are not maintained, and the area was characteristic of a seep in 2018.



Figure 2.21. Sheep Pasture Spring in the South Unit of Theodore Roosevelt National Park (July 8, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

Southeast Corner Spring

Southeast Corner Spring (Fig. 2.22) was noted in a 1953 National Park Service memorandum and historical discharge rates ranged from 0.2 to 0.5 gal/min. The site was not discharging in 2003 but started in 2004 (Oehler and Sexton, 2010). In 2018, discharge was recorded at 0.45 gal/min. Site developments are not maintained, and piping and the concrete tubs (dish tanks) were not in use in 2018. In 2018, the site was characteristic of a seep.



Figure 2.22. Southeast Corner Spring in the South Unit of Theodore Roosevelt National Park (May 23, 2018; photograph courtesy of William G. Eldridge, U.S. Geological Survey, Dakota Water Science Center).

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Appendix 3. Well Logs

The North Dakota State Water Commission maintains well log records filed with the State Board of Water Well Contractor within 30 days of well completion or abandonment (North Dakota State Water Commission, 2017). Well logs for all wells in Theodore Roosevelt National Park were not on record, likely because some wells were completed before record keeping. Well logs were available for the following wells at the following online sites:

North Unit Juniper Campground well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/47077/Log/47077.pdf#view=fitb>

North Unit park housing well (2016 well, 1980 well, and 1980 test hole)

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/73240/Log/73240.pdf#view=fitb>

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/25235/Log/25235.pdf#view=fitb>

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/25233/Log/25233.pdf#view=fitb>

North Unit Roundup well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/25155/Log/25155.pdf#view=fitb>

South Unit Cottonwood Campground well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2432/Log/2432.pdf#view=fitb>

South Unit Corral well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2418/Log/2418.pdf#view=fitb>

South Unit headquarters well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2442/Log/2442.pdf#view=fitb>

South Unit Painted Canyon well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2428/Log/2428.pdf#view=fitb>

South Unit Peaceful Valley well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2435/Log/2435.pdf#view=fitb>

South Unit Roundup Campground well

<https://mapservice.swc.nd.gov/welllink/4dcgi/GetLogPDF/2572/Log/2572.pdf#view=fitb>

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Appendix 4. Water-Quality Boxplots for Theodore Roosevelt National Park

Boxplots were constructed for the physical properties and chemical constituents in tables 14–16. Data were from North Dakota State Water Commission (2015). Boxplots graphically show the distribution of a dataset and assist in comparing several datasets (Helsel and Hirsch, 2002). The physical properties and chemical constituents for the upper Fort Union aquifer, lower Fort Union aquifer, and Fox-Hills-lower Hell Creek aquifer were plotted in boxplot format. The large range of values for some physical properties and chemical constituents required logarithmic y-axes to help visualize the datasets. An explanation of each symbol on the boxplot is in Figure 4.1. Figures 4.2 and 4.3 are boxplots for physical properties and chemical constituents, respectively, in alphabetical order, that were analyzed for the study. The hydroxide boxplot was excluded from Figure 4.3 because all values in the dataset were equal to 1.0 milligram per liter.

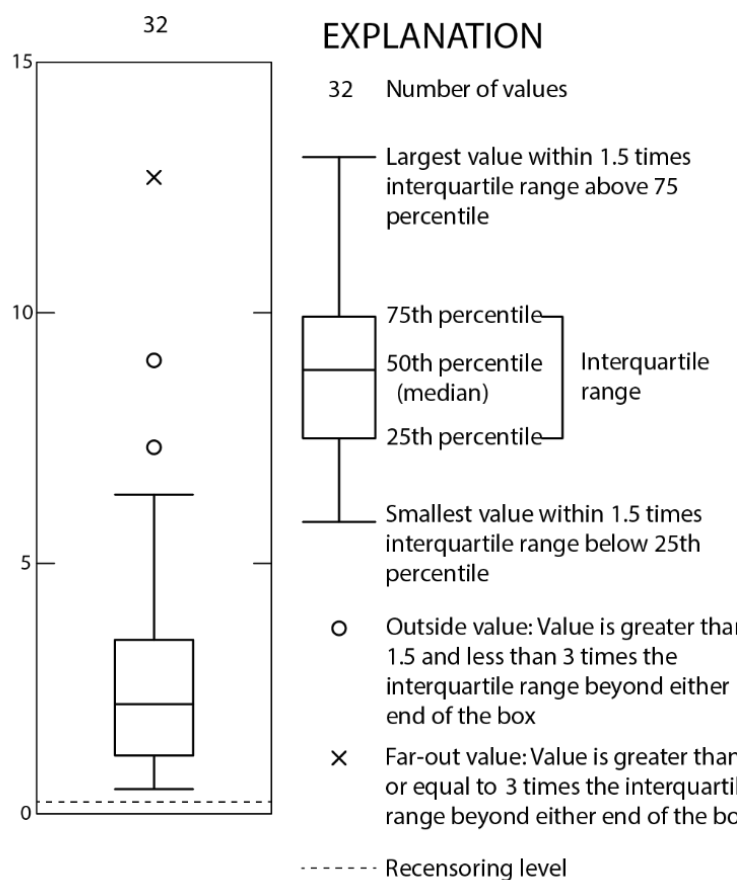


Figure 4.1. Explanation for boxplots showing symbology and annotations.

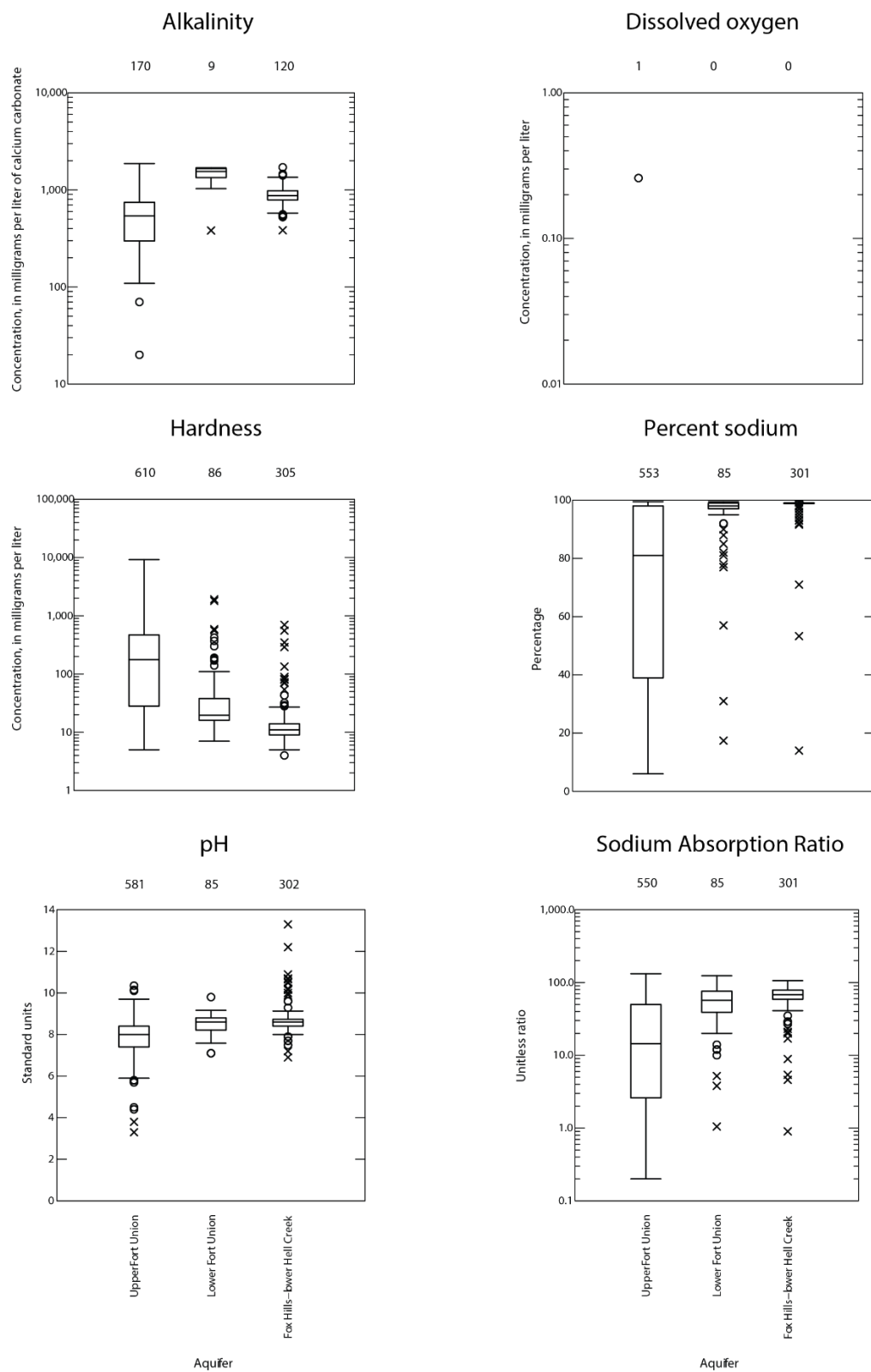


Figure 4.2A. Boxplots of physical properties—alkalinity, dissolved oxygen, hardness, percent sodium, pH, and sodium absorption ratio—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

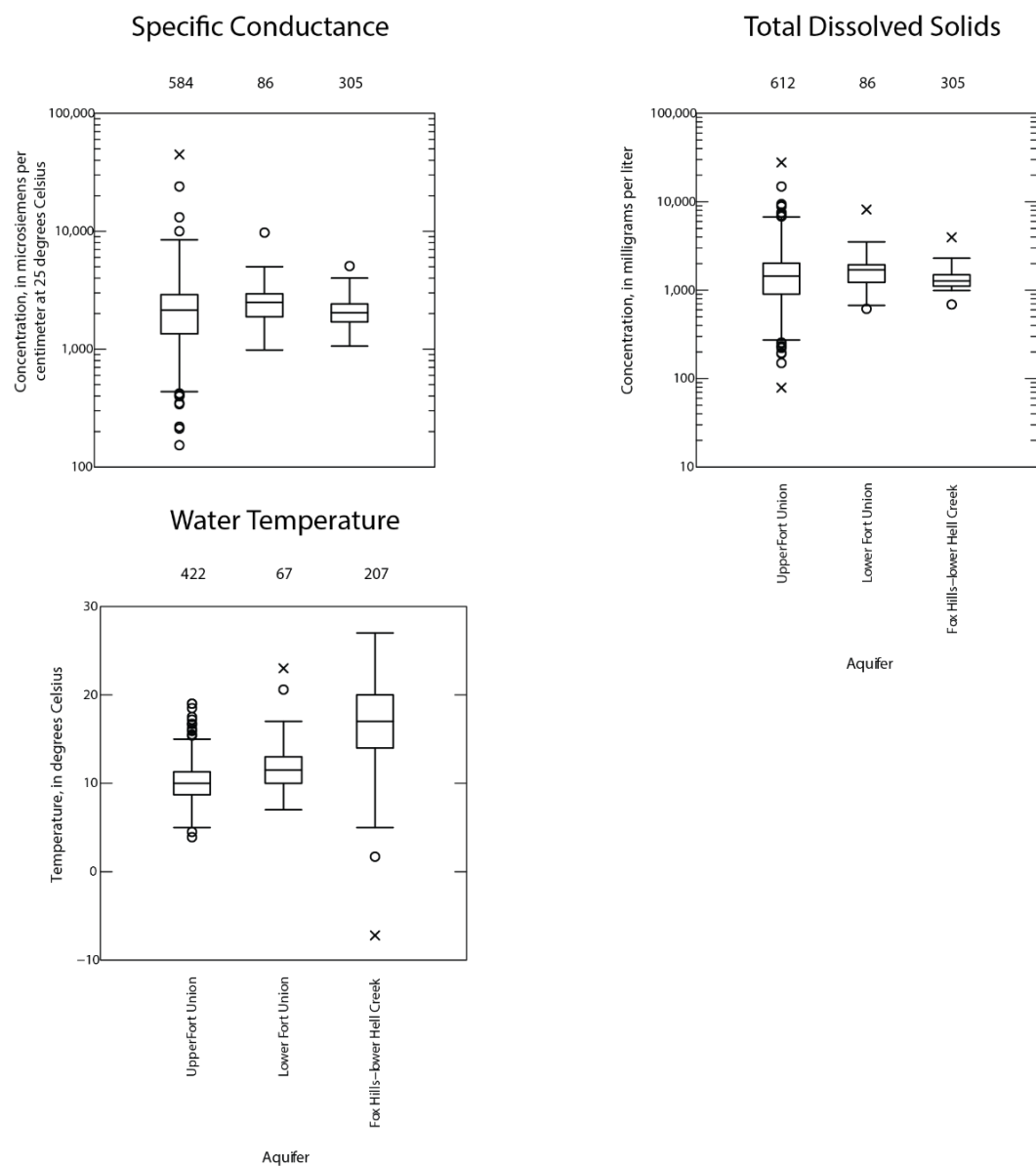


Figure 4.2B. Boxplots of physical properties—specific conductance, total dissolved solids, and water temperature—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

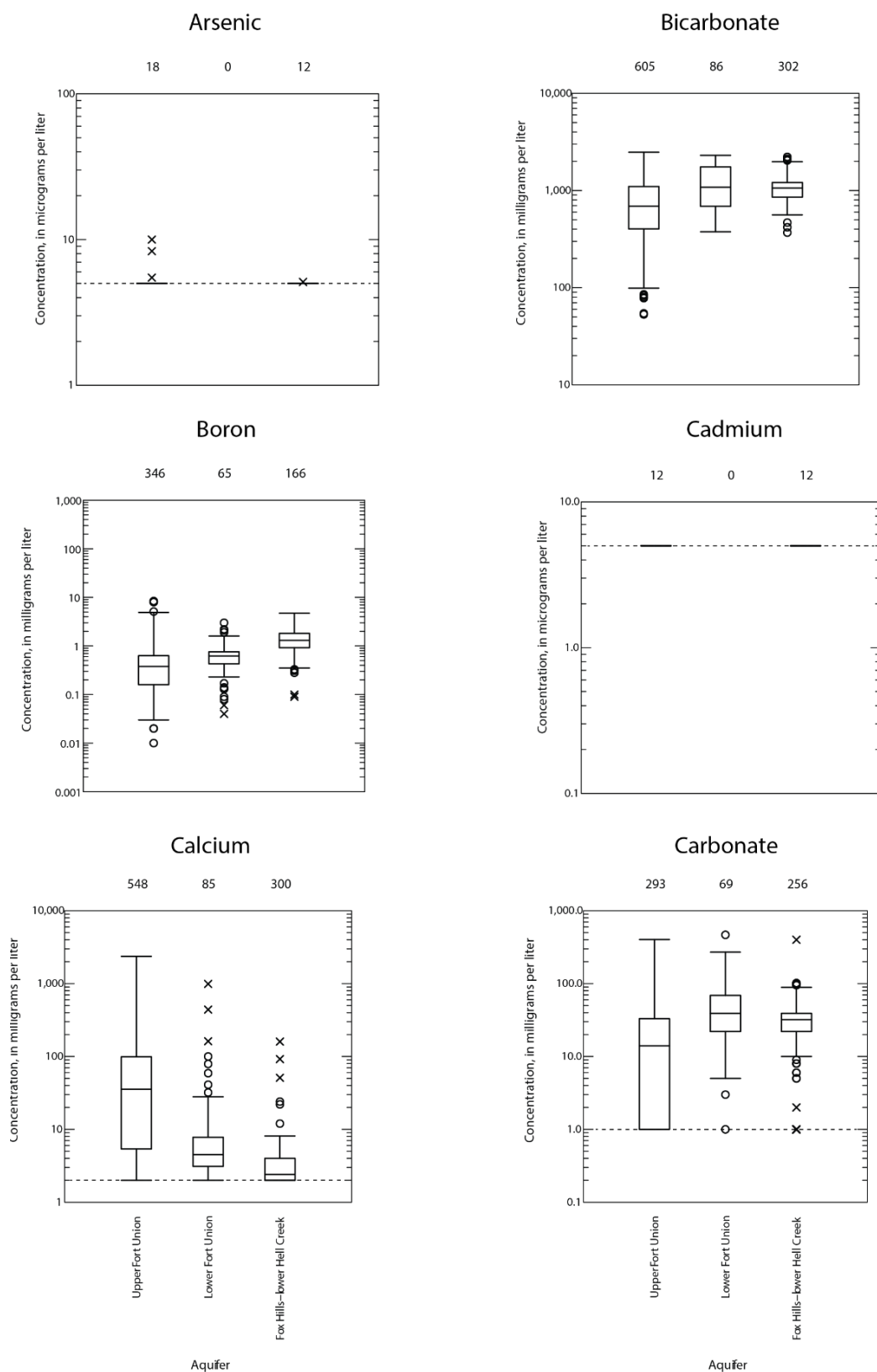


Figure 4.3A. Boxplots of chemical constituents—arsenic, bicarbonate, boron, cadmium, calcium, carbonate—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

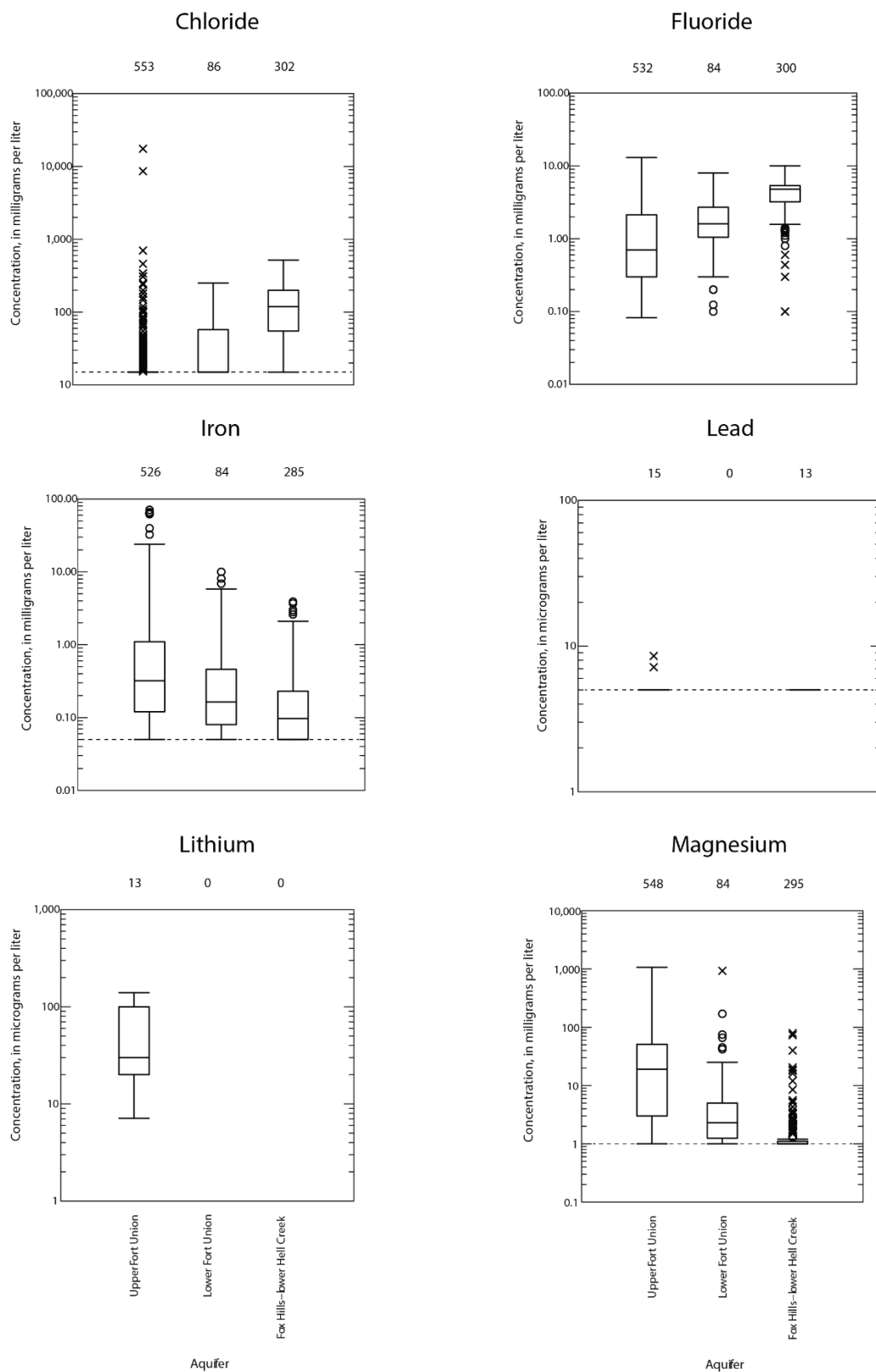


Figure 4.3B. Boxplots of chemical constituents—chloride, fluoride, iron, lead, lithium, magnesium—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

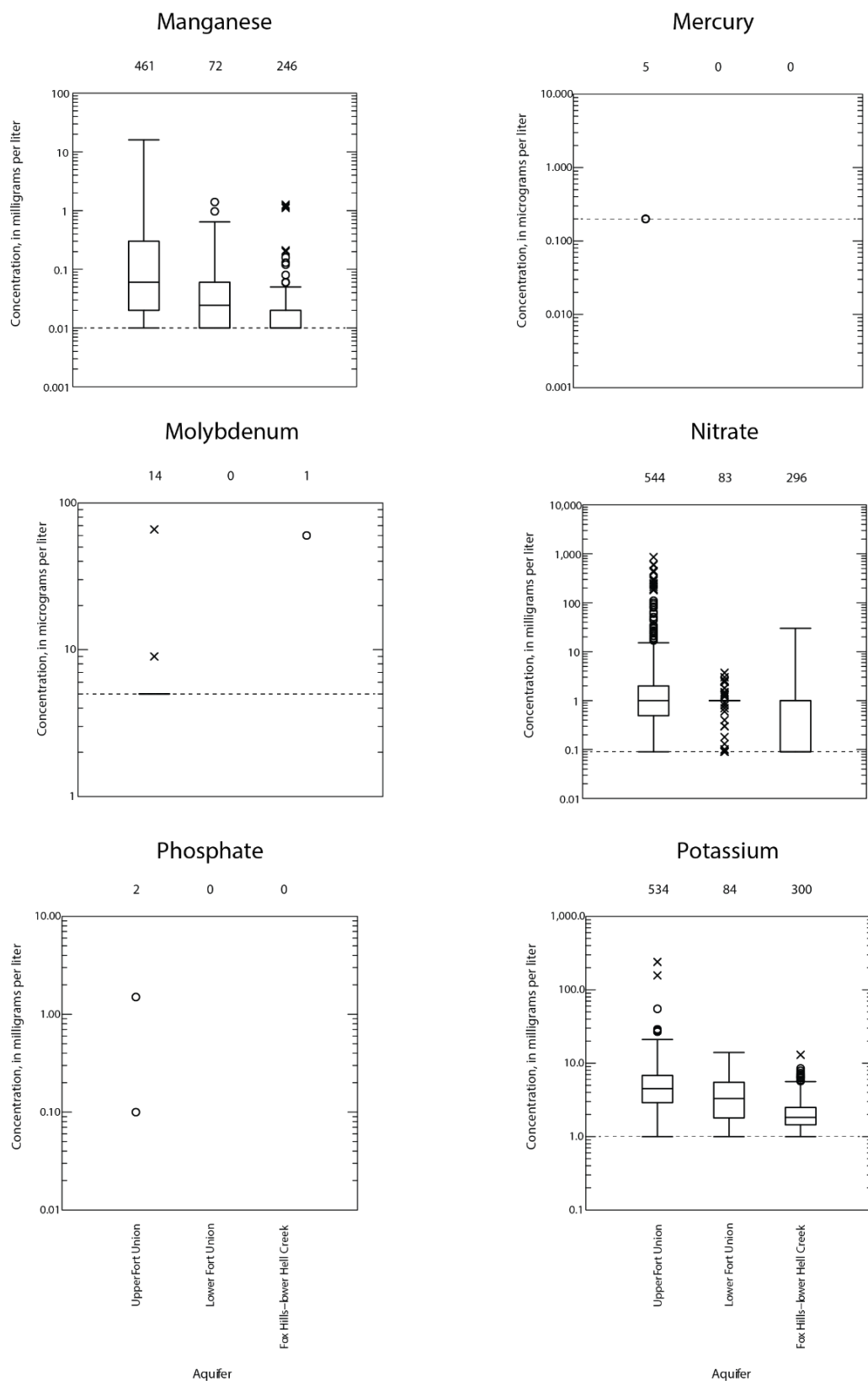


Figure 4.3C. Boxplots of chemical constituents—manganese, mercury, molybdenum, nitrate, phosphate, potassium—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

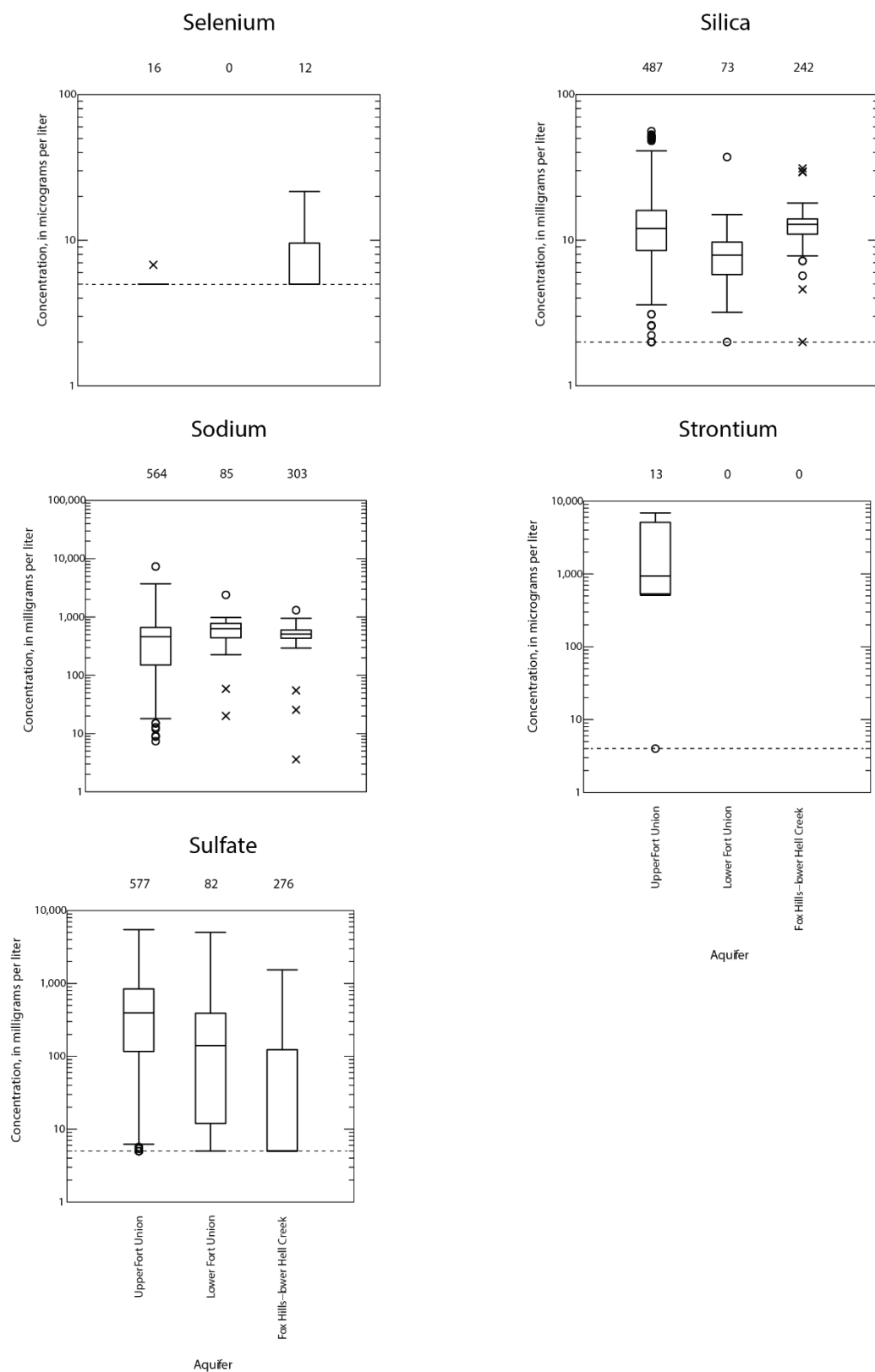


Figure 4.3D. Boxplots of chemical constituents—selenium, silica, sodium, strontium and sulfate—for Theodore Roosevelt National Park with values measured from 1937 through 2018.

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Appendix 5. Applicable North Dakota Water Law, Permitting Process, and Water-Quality Regulations for Groundwater

This appendix provides an overview of North Dakota water law, permitting processes, and water-quality regulations for groundwater as of December 2019. Basic North Dakota water law reviews the legal guidance for waters in the State. Water permitting also is discussed with an emphasis on Federal and State roles in water permitting. Finally, water-quality requirements for groundwaters are reviewed.

Overview of North Dakota Water Law

Legal guidance for North Dakota waters is found in the State Constitution and its codified law in the North Dakota Century Code. The State’s Office of the State Engineer and the North Dakota State Water Commission maintain and enforce water laws and policies.

North Dakota’s Constitution specifies that “all flowing streams and natural watercourses shall forever remain the property of the state for mining, irrigating and manufacturing purposes” (article XI, section 3; North Dakota Legislative Branch, 2019a, 1 p.). However, neither the State nor the State’s court systems have clarified if those water uses are exclusive or preferred (Beck, 2011). Additionally, the definition of watercourses and streams has been refined in the court system, which has ruled that a natural drainage is not a watercourse and that a watercourse must have a definite bed and channel and come from a permanent water source or water supply that is either continuous or periodic (Beck, 2011).

North Dakota’s Century Code broadens the State’s responsibilities and oversight. Century Code chapters 61–01–01 and 61–04.1–01 define State waters as (North Dakota Legislative Branch, 2019b):

1. Waters on the surface of the earth, excluding diffused surface waters but including surface waters whether flowing in well-defined channels or flowing through lakes, ponds, or marshes, which constitute integral parts of a stream system, or waters in lakes;
2. Waters under the surface of the earth, whether such waters flow in defined subterranean channels or are diffused percolating underground water;
3. All residual waters resulting from beneficial use, and all waters artificially drained; and
4. All waters, excluding privately owned waters, in areas determined by the State Engineer to be noncontributing drainage areas. A noncontributing drainage area is any area that does not contribute natural flowing surface water to a natural stream or watercourse at an average frequency more often than once in 3 years over the latest 30-year period.
5. The moisture contained in the clouds and atmosphere within the State boundaries. All water derived as a result of weather modification operations shall be considered a part of North Dakota’s basic water supply and all statutes, rules, and regulations applying to natural precipitation shall also apply to precipitation resulting from cloud seeding.

The North Dakota Century Code states that beneficial use “shall be the basis, the measure, and the limit of the right to the use of water” (chapter 61–04–01.2, North Dakota Legislative Branch, 2019b, p. 2), where beneficial use is defined as the “use of water for the purpose consistent with the best interests of the people of the state” (chapter 61–04–01.1, North Dakota Legislative Branch, 2019b, p. 1).

Water Permitting Processes

In North Dakota, the Office of the State Engineer administers the permit system with oversight and guidance by the North Dakota State Water Commission (formerly called the State Water Conservation Commission; Beck, 2011). North Dakota follows a first in time, first in right method, also called prior appropriation, for allocating water resources (North Dakota State Water Commission, 2009; Beck, 2011). However, the North Dakota Century Code provides that if there are competing applications of water from the same source and the source is insufficient to provide to all applicants, then a specified order or priority is required: domestic; municipal or public use; livestock; irrigation; industrial; and fish, wildlife, and other recreational uses (Beck, 2011; chapter 61–04–06.1, North Dakota Legislative Branch, 2019b). North Dakota appropriates water, meaning the State permits the water right owner to use water but not to own the water. Additionally, North Dakota allows the sale and purchase of water rights; however, the transfer of water rights could be constrained for the following reasons: change of use type, change of location, change of purpose, change of time, or changes in the point of diversion (Iierkley and others, 1998). A water right can be obtained only if the water is for beneficial use, which is defined as using the water for the best interests of the people of the State (North Dakota State Water Commission, 2018).

The State requires a water permit before any construction to appropriate water unless the purpose of the water is for domestic, livestock, fish, wildlife, or other recreational uses and the amount of water to be impounded, diverted, or withdrawn is less than 12.5 acre-feet (North Dakota State Water Commission, 2018). However, even if a permit is not required, a permit may be applied to establish a priority date, and the State engineer may waive fees or hearings for those permit applications. Multiple permit applications usually are considered in the order received (Beck, 2011). If multiple water permits request appropriations from the same source, and the source cannot provide water for all the permits received within 90 days, then the State Engineer allocates the water in the following priority: domestic use; municipal use; livestock use; irrigation use; industrial use; and fish, wildlife, and other outdoor recreational uses (North Dakota State Water Commission, 2018). A permit right can be lost if the holder fails to do the following: comply with the permit’s terms, regularly demonstrate beneficial use, comply with the directives of the State Engineer, or meet the safety standards of the facilities (North Dakota State Water Commission, 2018).

Except for agriculture and recreation, permits from the waters of the Little Missouri River were prohibited by the Little Missouri State Scenic River Act of 1975 (chapter 61–29, North Dakota Legislative Branch, 2019b); however, the law was unused, and since the 1990s the State allowed more than 600 temporary water permits for industrial purposes. In 2017, the State implemented a policy of allowing temporary water permit allocations from the Little Missouri River (chapter 61–29–06, North Dakota Legislative Branch, 2019b) and reinstated the Little Missouri River

commission in an advisory role (chapter 61–29–05, North Dakota Legislative Branch, 2019b). Temporary permits now authorize water use for as many as 12 months, and the State Engineer evaluates and grants the request without a notification requirement (North Dakota State Water Commission, 2018).

Chapter 89–03 of the North Dakota Administrative Code outlines the requirements and processes for obtaining a water permit (North Dakota Legislative Branch, 2019c); however, the North Dakota State Water Commission (2018) summarized the permitting process and updates its guide regularly. Additionally, the State maintains a database of permitting policies, applications, and permit statuses (North Dakota State Water Commission and State Engineer, 2015). As of December 2019, the National Park Service held six perfected permits for waters in the Fox Hills aquifer, except for permits 1193 and 1197, which are undefined (North Dakota State Water Commission and State Engineer, 2015).

The Federal Government generally obtains water rights when land is reserved by Federal action, such as establishing a national park. The land reservation generally includes enough unappropriated water to support the purposes of the land that was reserved but without restrictions or limitations imposed by the laws of the hosting State (Iierkley and others, 1998). Federal water rights may include water for consumptive uses, such as domestic and irrigation, or for the maintenance of *in-situ* purposes such as instream flow to support the purposes of the reserved land. Generally, the Federal Government cannot be involuntarily required to adjudicate water rights in courts. However, the McCarran Amendment in 1952 allowed for involuntary Federal Government adjudication of water rights for general streams but not for private court cases to decide water right priorities between the United States and a claimant (Davenport, 2001; U.S. Department of Justice, 2015). A court ruling in 1971 (United States v. District Court in and for Eagle County, 401 U.S. 520) decided that some Federal water rights can be involuntarily adjudicated. After the ruling, litigation over the existence and quantity of Federal reserved water rights held for national parks, national forests, national wildlife refuges, and other Federal lands greatly increased (U.S. Department of Justice, 2015). As of 1998, none of the Theodore Roosevelt National Park water rights have been adjudicated (Iierkley and others, 1998).

Water-Quality Regulations and Requirements

North Dakota water-quality standards are regulated by chapter 33–16–02.1 of the North Dakota Administrative Code (North Dakota Legislative Branch, 2019c). The purpose of the code is to classify State waters, provide standards for water quality, and protect existing and potential uses of State waters. The State’s policy requires maintaining or improving the quality of water and protecting existing uses. General water-quality standards apply to all waters, except for some classes of groundwaters (chapter 33–16–02.1–08, North Dakota Legislative Branch, 2019c). Additionally, North Dakota requires minimum streamflow for major rivers to ensure public health and welfare. The minimum streamflow requires considering present and future use for public supply; propagation of fish and aquatic life; and wildlife, recreation, agricultural, industrial, and other uses (chapter 33–16–02.1–08(1d), North Dakota Legislative Branch, 2019c).

Water-quality standards in North Dakota vary based on the type of water: surface waters and groundwater. Surface waters are classified into stream classes (I, IA, II, and III), wetlands, and lakes and reservoirs. Groundwater is classified into two classes: class I groundwaters have a total dissolved solids concentration of less than 10,000 milligrams per liter, and class II groundwaters have a total dissolved solids concentration of 10,000 milligrams per liter or greater. Class II groundwaters are exempt under the North Dakota underground injection control program. Surface or groundwaters used for drinking water could be required to meet specific water-quality standards.

The North Dakota Department of Environmental Quality–Groundwater Protection Program maintains two groundwater sampling programs to monitor the quality of water from aquifers (North Dakota Department of Environmental Quality, 2019). The first program, the Agricultural Groundwater Sampling Program, began in 1992 with the purpose of assessing groundwater quality related to agricultural activities. The second program, the Western Groundwater Sampling Program, began in 2013 to monitor the quality of groundwater in oil-producing areas of northwestern North Dakota. Both programs monitor 85 aquifers ranked by vulnerability. The Tobacco Garden aquifer, about 10 miles west of the Theodore Roosevelt National Park North Unit, is part of the Western Groundwater Sampling Program and two wells are routinely sampled. One of the wells tested greater than 10 parts per billion for arsenic (the federally mandated maximum contaminant level) during the testing period from 1993 to 2015 (North Dakota Department of Environmental Quality, 2019). The part of the Little Missouri River aquifer in North Dakota from the border with South Dakota to the Missouri River is not sampled as a part of the program.

Drinking-water standards in North Dakota are regulated by chapter 33.1–17–01 of the North Dakota Administrative Code (North Dakota Legislative Branch, 2019c). Drinking-water standards apply to all public water systems except for those that consist only of distribution and storage facilities, obtain all water from a public water system, do not sell water, and are not a passenger carrier in interstate commerce. A public water system includes at least 15 service connections or regularly serves at least 25 individuals 60 or more days of the year.

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