Prepared in cooperation with the Ute Mountain Ute Tribe

Hydrogeologic Characterization, Groundwater Chemistry, and Vulnerability Assessment, Ute Mountain Ute Reservation, Colorado and Utah

Scientific Investigations Report 2019–5122

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

Cover. Top right: Windmill on the Ute Mountain Ute Reservation. Photograph by Jeannette H. Oden, USGS.
Top left: Mesas in the eastern portion of the Ute Mountain Ute Reservation. Photograph by Jeannette H. Oden, USGS.
Bottom left: Chimney Rock, showing the intertonguing and gradational relations between the Mancos Shale and the lower part of the Point Lookout Sandstone. Photograph by Jeannette H. Oden, USGS.
Bottom right: Spring on the Ute Mountains. Photograph by Nancy J. Bauch, USGS.

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Contents

Figures

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
micrometer (μm)	0.00003937	inch (in.)
	Volume	
liter (L)	0.2642	gallon (gal)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD88) or the National Geodetic Vertical Datum of 1929 (NGVD29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27) or the North American Datum of 1983 (NAD83).

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

Supplemental Information

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

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

Concentrations of total coliform and *Escherichia coli* (*E. coli*) in water are reported as colony-forming units per 100 milliliters (cfu/100 mL).

One milliequivalent per liter (meq/L) is equal to one thousand milligram-equivalents per one thousand milliliters (meq/mL). Chemical analyses of solutes in a sample are expressed in unit concentrations that are chemically equivalent in terms of atomic or molecular weight and electrical charge.

Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope (^{i}E) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Abbreviations

δ^{2}H	hydrogen-2/hydrogen-1 isotopic ratio
δ^{15}N	nitrogen-15/nitrogen-14 isotopic ratio
δ^{18}O	oxygen-18/oxygen-16 isotopic ratio
bls	below land surface
CDPHE	Colorado Department of Public Health and Environment
CFC	chlorofluorocarbon
COGCC	Colorado Oil and Gas Conservation Commission
DEHP	di(2-ethylhexyl) phthalate
DEM	digital elevation model
DO	dissolved oxygen
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GMWL	Global Meteoric Water Line
MVNP	Mesa Verde National Park
NURE	National Uranium Resource Evaluation
NWIS	National Water Information System
per mil	parts per thousand
pmc	percent modern carbon
redox	reduction-oxidation
RPD	relative percent difference
TDS	total dissolved solids
TU	tritium unit
UMUR	Ute Mountain Ute Reservation
UMUT	Ute Mountain Ute Tribe
USGS	U.S. Geological Survey
VOC	volatile organic compound

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Abstract

The U.S. Geological Survey, in cooperation with the Ute Mountain Ute Tribe (UMUT), initiated a study in 2016 to increase understanding of the hydrogeology and chemistry of groundwater within select areas of the Ute Mountain Ute Reservation (UMUR) in Colorado and Utah, identify vulnerabilities to the system and other natural resources, and outline information needs to aid in the understanding and protection of groundwater resources. The results presented for this study can be used to support the UMUT's goal of protecting their vital groundwater resources on the UMUR.

Hydrogeologic conditions were characterized for the surficial aquifer contained in Quaternary-age unconsolidated surficial deposits and the Dakota aquifer contained in the Cretaceous-age Dakota Sandstone. In the surficial aquifer, median depth to water ranges from about 5.4 to 17.2 feet below land surface in the Farm and Ranch Enterprise area and 11 to 34 feet below land surface in the Towaoc area, and the water table slopes generally southwest or south. A map of depth to the top of the Dakota Sandstone was constructed from existing well data. Depths range from zero in outcrop areas to more than 3,000 feet below land surface on mesas in the southeastern part of the UMUR.

Groundwater-chemistry data were collected by the UMUT from 13 springs and 31 wells from 1996 through 2017. Specific conductance was much lower for samples from springs than from wells; median values were 512 and 6,024 microsiemens per centimeter at 25 degrees Celsius, respectively. Spring samples were well oxygenated. A few well samples were anoxic (dissolved oxygen concentrations less than 0.5 milligrams per liter [mg/L]), indicating reducing conditions in the aquifer. About 75 percent of spring samples had fresh water (total dissolved solids concentrations less than 1,000 mg/L), and about 85 percent of well samples had brackish or highly saline water (total dissolved solids concentrations greater than 1,000 mg/L). Water type for springs on the Ute Mountains was calcium bicarbonate. Lower-altitude springs had a calcium-sulfate water type. Most well samples had sodium as the dominant cation, and sulfate, bicarbonate, and chloride as the dominant anions. Fluoride concentrations in about 45 percent of well samples were greater than an agricultural-use standard of 2 mg/L.

Nitrate plus nitrite concentrations in most spring and well samples were less than about 1.6 mg/L per liter. Concentrations in samples from wells in the irrigated agricultural area were elevated; the maximum concentration was 78.5 mg/L. About one-half of the trace-element samples had concentrations that were less than laboratory reporting limits. Only aluminum, arsenic, and selenium in spring samples, and boron and selenium in well samples, were detected at concentrations greater than surface-water standards or water-quality standards for agricultural use of groundwater.

Only three organic compounds, the pesticides alachlor and atrazine and the volatile organic compound di(2-ethylhexyl) phthalate, were detected in well samples. The *Escherichia coli* bacteria was detected in 47 and 23 percent of samples from wells and springs, respectively. The *E. coli* detections included samples from three culturally significant springs, which did not meet the UMUT cultural-use standard of total absence of *E. coli*.

Tritium and carbon-14 were the primary environmental tracers used for interpreting groundwater ages for Lopez 2 Spring and five wells (AP–1, 5000 Block, Cottonwood Spring, Goodknight, and SE Toe). Water from the AP–1 well contained a mixture of pre- and post-1950s recharge. Tritium and carbon-14 recharge ages for Lopez 2 Spring (post-1950s in age), Goodknight and SE Toe wells (pre-1950s in age), and Cottonwood Spring well (primarily pre-1950s in age) are supported by helium-4 data. The helium-4 data for the 5000 Block well are inconsistent with the tritium and carbon-14 age of pre-1950s recharge because of interference caused by high methane concentrations in the water.

Springs and surficial deposits are more vulnerable to contamination from anthropogenic chemicals than deeper bedrock wells. Bedrock aquifers are vulnerable in areas where the geologic formations containing the aquifers are exposed at the land surface. Groundwater in deep bedrock aquifers is likely thousands of years old and is not currently affected by present-day land uses. Both shallow and deep groundwater are vulnerable to naturally occurring salts and minerals, such as of total dissolved solids, major ions, nitrate, and trace elements.

Effects of a changing climate on water resources and other ecological characteristics of the UMUR could include changes in evapotranspiration, a decrease in snowpack, decreased aquifer recharge and flow of springs, a decrease in soil moisture, and increased occurrence of wildfires and forest mortality. Of particular interest for the UMUT are possible effects of a changing climate on medicinal and culturally important plants and springs.

Several information needs were identified during this study that would aid in the understanding and protection of groundwater resources on the UMUR. These include well-completion information for bedrock wells, the collection of environmental tracer data at additional wells, the addition of methane and hydrocarbon analysis to well sampling plans, and the resampling of springs and wells that were last sampled in 2002 or earlier.

Introduction

In the semiarid Colorado Plateau region of Colorado, New Mexico, and Utah, water sustains the cultural, spiritual, and economic health of the Ute Mountain Ute Tribe (UMUT) and the Ute Mountain Ute Reservation (UMUR) (fig. 1). The UMUT has recognized that, whereas current and future land use and business activities on the UMUR are necessary for long-term viability, there could be potential effects of these activities on groundwater resources. With limited availability of surface water and the possibility of drought conditions in future years, protection of groundwater resources on the UMUR is vital for the UMUT.

In 2004, a Groundwater Protection Plan was developed by and for the UMUT (UMUT, 2004) that focused on the vulnerability of aquifers to potential toxic or hazardous chemicals from land-use activities, particularly to pesticide use and management on the UMUR. Previous studies of the water quality of the groundwater system on the UMUR concentrated on New Mexico and specific areas in Colorado and Utah (Irwin, 1966; Geldon, 1985; Naftz and others, 2011; UMUT, 2014).

In 2016, the U.S. Geological Survey (USGS), in cooperation with the UMUT, initiated a study to compile and analyze existing hydrogeologic and groundwater-chemistry information for the UMUR. In addition, in 2017, the USGS assisted the UMUT in developing and implementing a plan to collect water samples from selected springs and wells for analysis of environmental tracers as indicators of groundwater age and sources of recharge. This study was initiated to increase understanding of the hydrogeology and chemistry of groundwater within select areas of the UMUR in Colorado and Utah, identify vulnerabilities to the system and other natural resources, and outline information needs to aid in the understanding and protection of groundwater resources. The results presented for this study can be used to support the UMUT's goal of protecting their vital groundwater resources on the UMUR.

Purpose and Scope

The purposes of this report are to describe the hydrogeologic characterization, groundwater chemistry, and vulnerability assessment of select areas of the UMUR. The report is focused on the Colorado and Utah portions of the UMUR, excluding the White Mesa area in Utah, and includes (1) characterization of hydrogeologic conditions in selected aquifers by determining water-table depth and the direction and gradient of the water-table slope for the surficial aquifer contained in unconsolidated surficial deposits and mapping the depth to the top of the Dakota Sandstone; (2) compilation and analysis of available groundwater-chemistry data for springs and wells as a baseline for future activities, focusing primarily on groundwater-chemistry data collected by the UMUT from 1996 through 2017; (3) interpretation of environmental tracer data collected by the UMUT in 2017; (4) assessments of the vulnerability of groundwater to contamination from anthropogenic and natural sources and the vulnerability of water resources and other ecological characteristics of the UMUR to changes in climate; and (5) identification of information needs to advance the protection and understanding of groundwater resources.

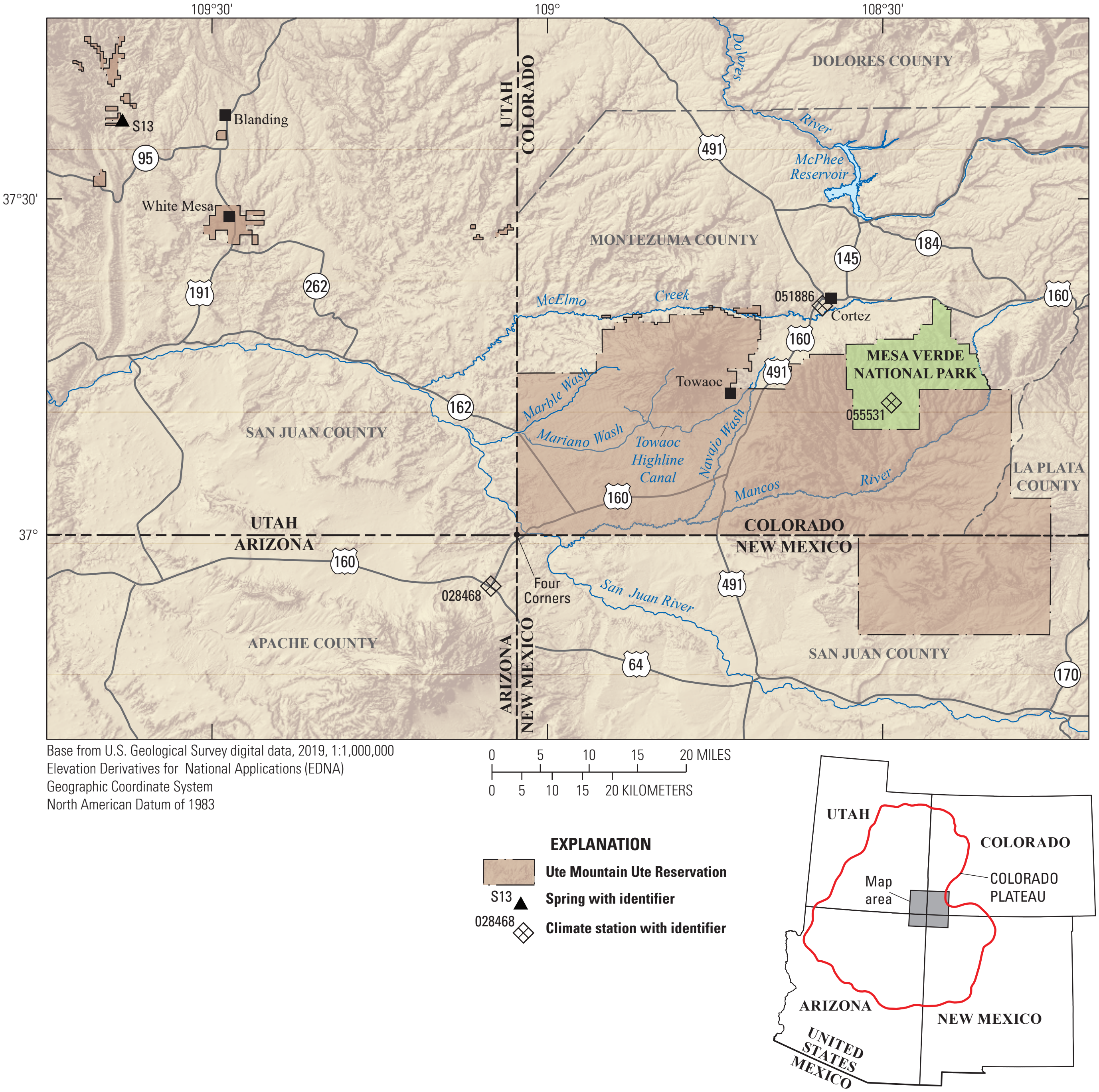
Description of Study Area

The UMUR encompasses about 597,000 acres (933 square miles) of trust land in Colorado, New Mexico, and Utah in the Four Corners region of the Colorado Plateau (fig. 1). Most of the UMUR is in southwestern Colorado. A small contiguous portion is in northwestern New Mexico. Reservation land in southeastern Utah includes the White Mesa community and individual or adjacent parcels of trust land. The UMUT also owns seven off-reservation ranches in Colorado and Utah encompassing about 34,000 acres (UMUT, 2004). The study area for this report consists of reservation lands in Colorado and Utah except for the White Mesa area of Utah. The New Mexico portion of the UMUR is not included in the study area. Water quality of the White Mesa area was previously characterized in Naftz and others (2011), and groundwater resources of the UMUR in New Mexico were previously characterized by the UMUT (UMUT, 2014).

Enrolled Tribal membership is 2,134 (Colorado Commission of Indian Affairs, 2018). Most Tribal members reside in two communities on the UMUR. The community of Towaoc, in Montezuma County, Colorado, is home of the UMUT Tribal government, and the small community of White Mesa is in San Juan County, Utah (fig. 1).

Physiography

The UMUR lies within the Four Corners platform of the Colorado Plateau (Pratt and others, 1976; UMUT, 2005). Reservation land ranges in altitude from 4,590 feet (ft) near the Four Corners (junction of the States of Arizona, Colorado New Mexico, and Utah) to 9,977 ft on Ute Peak in the Ute



Base from U.S. Geological Survey digital data, 2019, 1:1,000,000
Elevation Derivatives for National Applications (EDNA)
Geographic Coordinate System
North American Datum of 1983

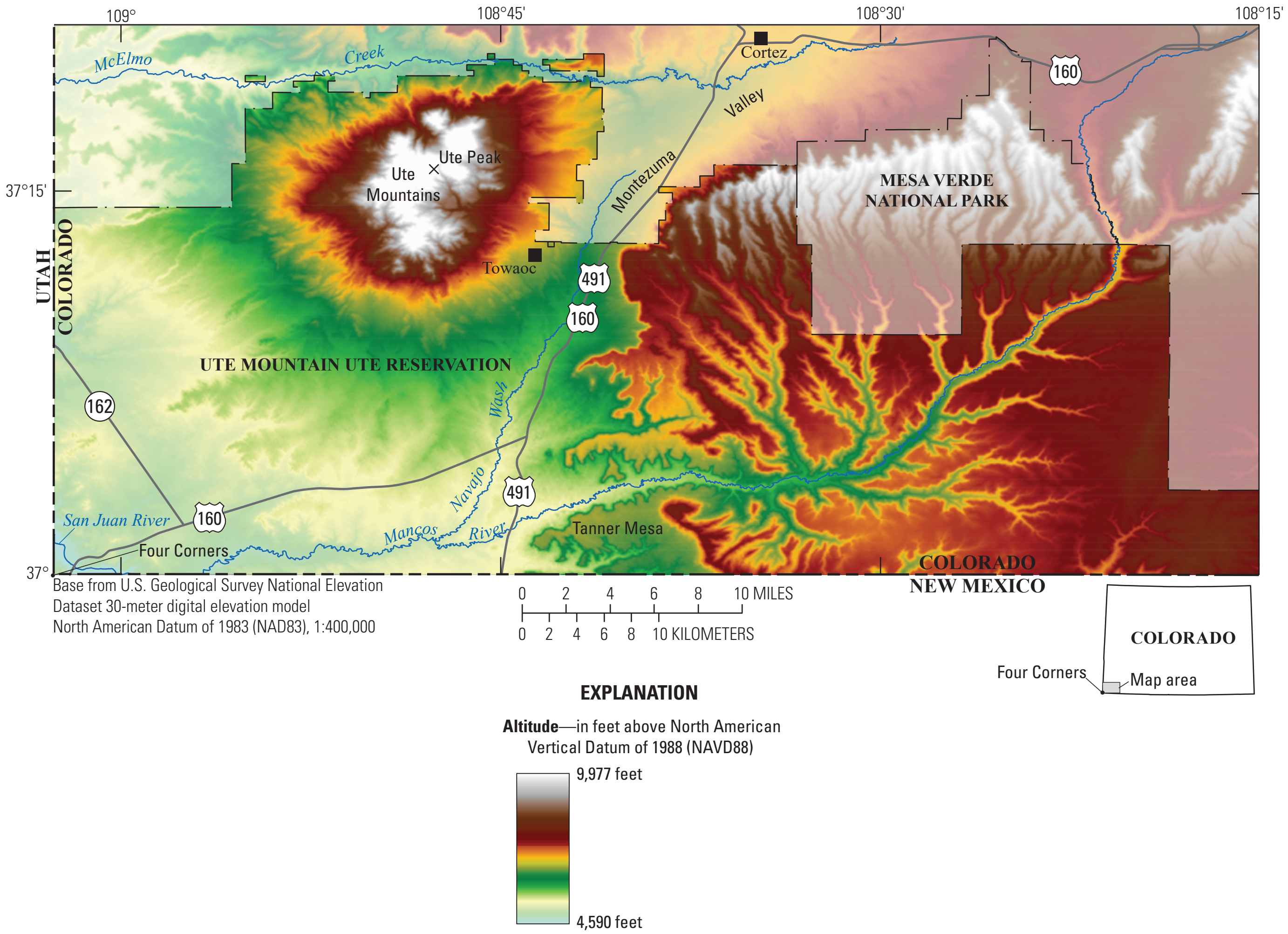
Figure 1. Location and extent of the Ute Mountain Ute Reservation in Colorado, New Mexico, and Utah.

Mountains (fig. 2). The northeastern part of the reservation abuts Mesa Verde National Park (MVNP). The landscape of the Colorado portion of the UMUR is dominated by the Ute Mountains in the northwest and tableland mesas in the eastern portion of the UMUR, similar to those in MVNP (fig. 2). South of the Ute Mountains, a rolling and irregular plain slopes south to the Mancos River (fig. 2). Gullies on the plain cut into the Cretaceous-age Mancos Shale and Quaternary-age unconsolidated surficial deposits (fig. 3). In the eastern portion of the reservation, Mesa Verde and other mesas rise about 1,000 ft above Montezuma Valley and are dissected by deeply cut canyons of the Mancos River and smaller tributaries.

Geology

Most of the UMUR in Colorado is underlain by south and southeast dipping sedimentary rocks of Mesozoic age (Pratt and others, 1976; UMUT, 2005). Surface exposures of bedrock primarily are Cretaceous-age sandstones, shales, and mudstones (fig. 3, table 1). Surface exposures of the oldest sedimentary rock are Late Jurassic-age, possibly Late Triassic-age, rocks along part of the northern boundary of the reservation in McElmo Canyon, defined by McElmo Creek. The youngest sedimentary rocks are Late Cretaceous-age rocks caping the mesas in the eastern portion of the UMUR (Pratt and others, 1976). The most prominent nonsedimentary rocks are the Late Cretaceous- and Tertiary-age igneous rocks that form the Ute Mountains (Irwin, 1966). Unconsolidated surficial deposits include Quaternary-age pediment gravels, landslide deposits, and eolian materials found in areas surrounding the Ute Mountains, and alluvium associated with major tributaries. In-depth discussion of the geology of the UMUR is in Ekren and Houser (1965), Irwin (1966), and Pratt and others (1976).

All geologic units shown within the geologic map of the UMUR in Colorado (fig. 3) are included in the generalized stratigraphic section table (table 1) but may not be discussed herein. In this report, discussion of the geology of the UMUR in Colorado is focused primarily on the units of hydrogeologic and groundwater-chemistry importance.



Base from U.S. Geological Survey National Elevation Dataset 30-meter digital elevation model
North American Datum of 1983 (NAD83), 1:400,000

Figure 2. Altitude of the Ute Mountain Ute Reservation in Colorado.

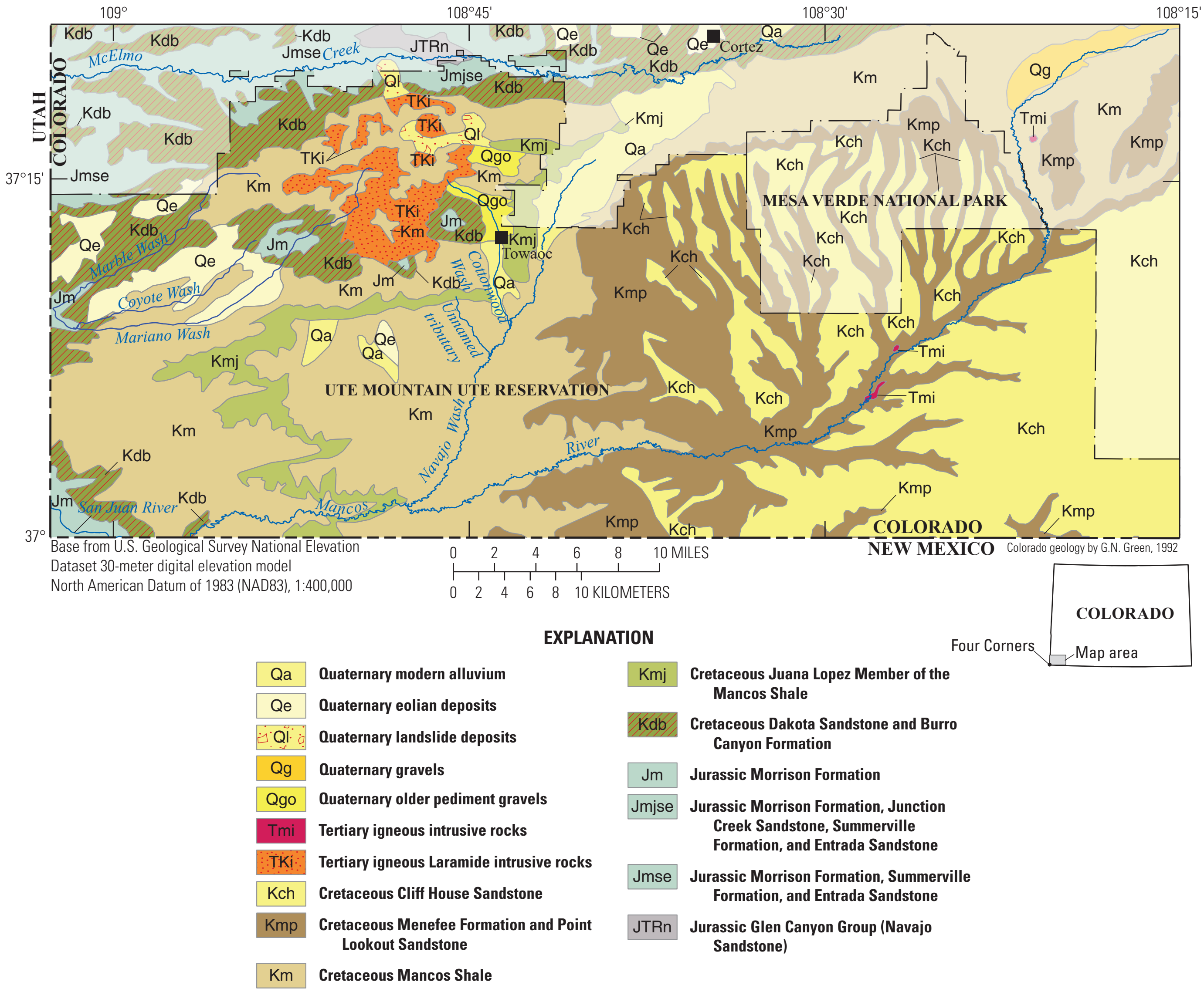


Figure 3. Generalized geology of the Ute Mountain Ute Reservation in Colorado. Because of scale, detail on the map has been simplified from formations shown on the geologic source map (modified from Green, 1992).

Jurassic System

Sedimentary rocks of Jurassic-age crop out in a few areas of the UMUR, most prominently in the McElmo Canyon area. The Navajo Sandstone, the oldest Jurassic-age rocks on the UMUR, is mapped as "JTRn" on figure 3. Other Jurassic-age rocks along McElmo Creek are mapped together on figure 3, including the Entrada Sandstone, Summerville Formation, and Morrison Formation as "Jmse," or with the Junction Creek Sandstone as "Jmjse." Depositional environments were marine, lacustrine, or eolian (Entrada Sandstone), marine and marginal marine (Summerville Formation), shallow marine and eolian (Junction Creek Sandstone), and streams and floodplains (Morrison Formation) (Ekren and Houser, 1965; Pratt and others, 1976; Naftz and others, 2011). The Morrison Formation ("Jm") also outcrops in a few areas in or near the Ute Mountains and the west and southwest boundaries of the UMUR (fig. 3).

Cretaceous System

Cretaceous-age sedimentary rocks that crop out on the UMUR are, in ascending order, the Burro Canyon Formation, Dakota Sandstone, Mancos Shale; and the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone of the Mesaverde Group (table 1). For most of the UMUR, the boundary between the Jurassic and Cretaceous Systems cannot be precisely located because of intertonguing, lithologic gradation, and lack of fossils (Irwin, 1966; Pratt and others, 1976).

Table 1. Generalized stratigraphic section of the geologic formations of the Ute Mountain Ute Reservation in Colorado.

[Modified from Pratt and others (1976) and Irwin (1966). Although mentioned in this report, the Pennsylvanian-age Paradox Formation is not included in table 1 because there are no surface exposures in the study area. na, not applicable; ?, maybe]

System	Series	Group	Formation	Member	Symbol on map	Physical character
Quaternary	Holocene		Modern alluvium	na	Qa	Gravel, sand, silt, clay
	Pleistocene		Eolian deposits	na	Qe	Dune sand, silt, loess
			Landslide deposits	na	Ql	Soil, fine materials, cobbles, boulders, and rock slabs
			Older pediment gravels	na	Qgo	Predominately pebbles, cobbles, and boulders of igneous origin
Tertiary and Tertiary or Cretaceous			Igneous rocks	na	Tmi	Small plugs and dikes of intrusive igneous rocks
			Igneous rocks	na	TKi	Lacoliths, sills, dikes, and stocks intruded into sedimentary rocks forming the Ute Mountains. For this report, TKi includes talus deposits and related block rubble on the slopes of the Ute Mountains.
Cretaceous	Upper Cretaceous	Mesaverde Group	Cliff House Sandstone	na	Kch	Yellowish-orange, massive cliff-forming fine-grained sandstone and some shaly sandstone beds
			Menefee Formation	na	Kmp	Gray to grayish-orange, fine- to medium-grained crossbedded sandstone and gray to black carbonaceous shale and coal beds
			Point Lookout Sandstone	na	Kmp	Yellowish-orange to white, massive cliff-forming fine-grained sandstone. Lower parts contain interbedded thin sandstone and sandy mudstone.
			Mancos Shale	na	Km	Gray to dark-gray/black gypsiferous shaly mudstone with thin beds of grayish-brown sandy limestone and limestone concretions
				Juana Lopez Member	Kmj	Lower member of Mancos Shale. Yellowish-brown sandy fossiliferous limestone and gray to brown shale. Approximately 475 to 525 feet above the Mancos Shale base
			Dakota Sandstone	na	Kdb	Light-gray to yellowish-gray, fine- to medium-grained sandstone interbedded with carbonaceous shale and some thin coal beds
	Lower Cretaceous		Burro Canyon Formation	na	Kdb	Light-gray to white sandstone and conglomeratic sandstone interbedded with grayish-green and some grayish-red mudstone
Jurassic	Upper Jurassic		Morrison Formation	na	Jm, Jmjse, Jmse	Bentontic mudstone with siltstone and siliceous sandstone lenses. Interbedded light-tan to light-gray, fine- to medium-grained sandstone and thin red or green siltstone and mudstone in the middle and lower members
			Junction Creek Sandstone	na	Jmjse	Pale-red to light-brownish-gray, fine- to medium-grained sandstone
			Summerville Formation	na	Jmjse, Jmse	Reddish-brown silty fine-grained sandstone and pale-red to moderate-brown siltstone or mudstone
			Entrada Sandstone	na	Jmjse, Jmse	Upper unit: Grayish-orange-pink to reddish-orange fine-grained sandstone, cliff forming Lower unit: Pale-reddish-brown to grayish-red very fine-grained silty sandstone and siltstone
Triassic(?) and Jurassic		Glen Canyon Group	Navajo Sandstone	na	JTRn	Grayish-orange-pink to reddish-orange fine-grained crossbedded sandstone

The Burro Canyon Formation consists of mudstone interbedded with lenses of conglomerate and conglomeratic sandstone (Pratt and others, 1976); it is grouped with the Dakota Sandstone on figure 3 as "Kdb." The Dakota Sandstone overlies the Burro Canyon Formation or the Morrison Formation if the Burro Canyon Formation is not present or cannot be distinguished. The Dakota Sandstone consists of quarzitic sandstone and conglomeratic sandstone with thin lenticular beds of shale, claystone, carbonaceous sandstone, and impure coal (Haynes and others, 1972). Sediments of the Dakota Sandstone likely were deposited in fluvial, lagoon, and beach environments (Ekren and Houser, 1965). Outcrops of Dakota Sandstone are near McElmo Creek, along the western boundary of the UMUR, and near the Four Corners area (fig. 3). Except for outcrops, the Dakota Sandstone is in the subsurface throughout the UMUR. The formation generally ranges from 100 to160 ft thick with an average thickness of about 135 ft (Irwin, 1966). However, the total thickness of the Dakota Sandstone combined with the underlying Burro Canyon Formation (where present) generally is 200–243 ft (Irwin, 1966). In the eastern half of the UMUR, the Dakota Sandstone lies beneath several thousand feet of younger Cretaceous-age sedimentary rocks. Hydraulic conductivity values specific for the Burro Canyon Formation and Dakota Sandstone on the UMUR could not be discerned. Geldon (1985) reported a maximum hydraulic conductivity of 0.0077 ft per day for the Burro Canyon Formation and Dakota Sandstone in northwestern Colorado and eastern Utah.

Conformably overlying the Dakota Sandstone is the Mancos Shale ("Km" on fig. 3), which was deposited in an inland sea and primarily is marine shale. The Mancos Shale occurs at the land surface across much of the UMUR, especially in the western half where it forms rolling plains and low ridges. Along the mesas in the east, the Mancos Shale forms steep slopes beneath overlying weather-resistant sandstones. The Mancos Shale is composed primarily of gypsiferous mudstone, and there are thin sandy limestone lenses and limestone concretions throughout the formation (Ekren and Houser, 1965; Irwin, 1966). The Juana Lopez Member ("Kmj" on fig. 3) of the Mancos Shale is exposed as a prominent ridge south of the Ute Mountains (Ekren and Houser, 1965; Irwin, 1966). A maximum hydraulic conductivity of 0.028 ft per day was reported by Geldon (1985) for the Mancos Shale in northwestern Colorado.

The youngest sedimentary rocks exposed on the UMUR are the three units of the Mesaverde Group; in ascending order, they are the Point Lookout Sandstone and Menefee Formation ("Kmp" on fig. 3), and Cliff House Sandstone ("Kch" on fig. 3). These outcrops are in the eastern half of the UMUR around the rim of the mesa containing the MVNP and in the canyons dissecting it and other mesas in the east (fig. 3). The upper part of the Point Lookout Sandstone forms the most prominent cliffs on the eastern side of the UMUR (Irwin, 1966).

Late Cretaceous and Tertiary Systems

Northwest of Towaoc, intrusive igneous rocks ("TKi" on fig. 3) form the Ute Mountains (fig. 3; Pratt and others, 1976). The Ute Mountains, also known as Sleeping Ute Mountains because of their profile, are Late Cretaceous- to middle Tertiary-age laccoliths, sills, dikes, and cylinders of igneous rock intruded into and between layers of older Cretaceous sedimentary rocks. Talus deposits and related block rubble of Quaternary age that are common on the slopes of the Ute Mountains are mapped on figure 3 with the Late Cretaceous- to middle Tertiary-age igneous intrusive rocks "TKi." Igneous pebbles, cobbles, and boulders that comprise the talus deposits occur below their source rocks (Pratt and others, 1976). Small plugs and dikes of Tertiary-age igneous rock ("Tmi" on fig. 3) crop out in sedimentary rocks in Mancos Canyon, defined by Mancos River (fig. 3; Pratt and others, 1976).

Quaternary System

Quaternary-age unconsolidated surficial deposits on the UMUR are composed of pediment gravels, landslide deposits, eolian materials, and modern alluvium (fig. 3; Haynes and others, 1972; Condon, 1991). On the land surface, these deposits are much more extensive than those shown on the geology map because of the map scale. The pediment gravels, mapped as "Qgo" on figure 3, are predominately pebbles, cobbles, and boulders of igneous origin (Irwin, 1966). The pediment gravels occur as discontinuous erosion surfaces that extend radially away from the Ute Mountains (Ekren and Houser, 1965). Landslide deposits ("Ql" on fig. 3) on the UMUR are formed when soil, other fine materials, cobbles, boulders, and rock move downward because of the combined effects of gravity and precipitation (Ekren and Houser, 1965). The predominant exposure of landslide deposits is on the north-facing slopes of the Ute Mountains (fig. 3). Eolian materials ("Qe" on fig. 3) are composed of very fine-grained sand, silt, and windblown clay. The materials cover mesa surfaces and pediment deposits and range in thickness from very shallow near the mesa edges to 10–15 ft deep on pediments (Natural Resources Conservation Service, 2008). Eolian materials are primarily exposed in the Farm and Ranch Enterprise area southwest of the Ute Mountains (fig. 4). Eolian materials form an excellent porous soil capable of retaining water for long periods of time (Ekren and Houser, 1965). Modern alluvium ("Qa" on fig. 3, except for the Mancos River alluvium that is not displayed) occurs along the Mancos River, in the Towaoc area, and in a few areas south of the Ute Mountains. Alluvium near Towaoc is composed of silt, clay, sand, and gravel derived from nearby Cretaceous-age shale and sandstone and igneous pebbles and cobbles derived from the Ute Mountains intrusive rocks (Irwin, 1966). Geldon (1985) reported a hydraulic conductivity of 50 ft per day for a well completed in pediment alluvium on the reservation.

Climate

Climate on the reservation is semiarid, with a wide range in temperature and precipitation depending on altitude. Average annual temperatures at three climate stations

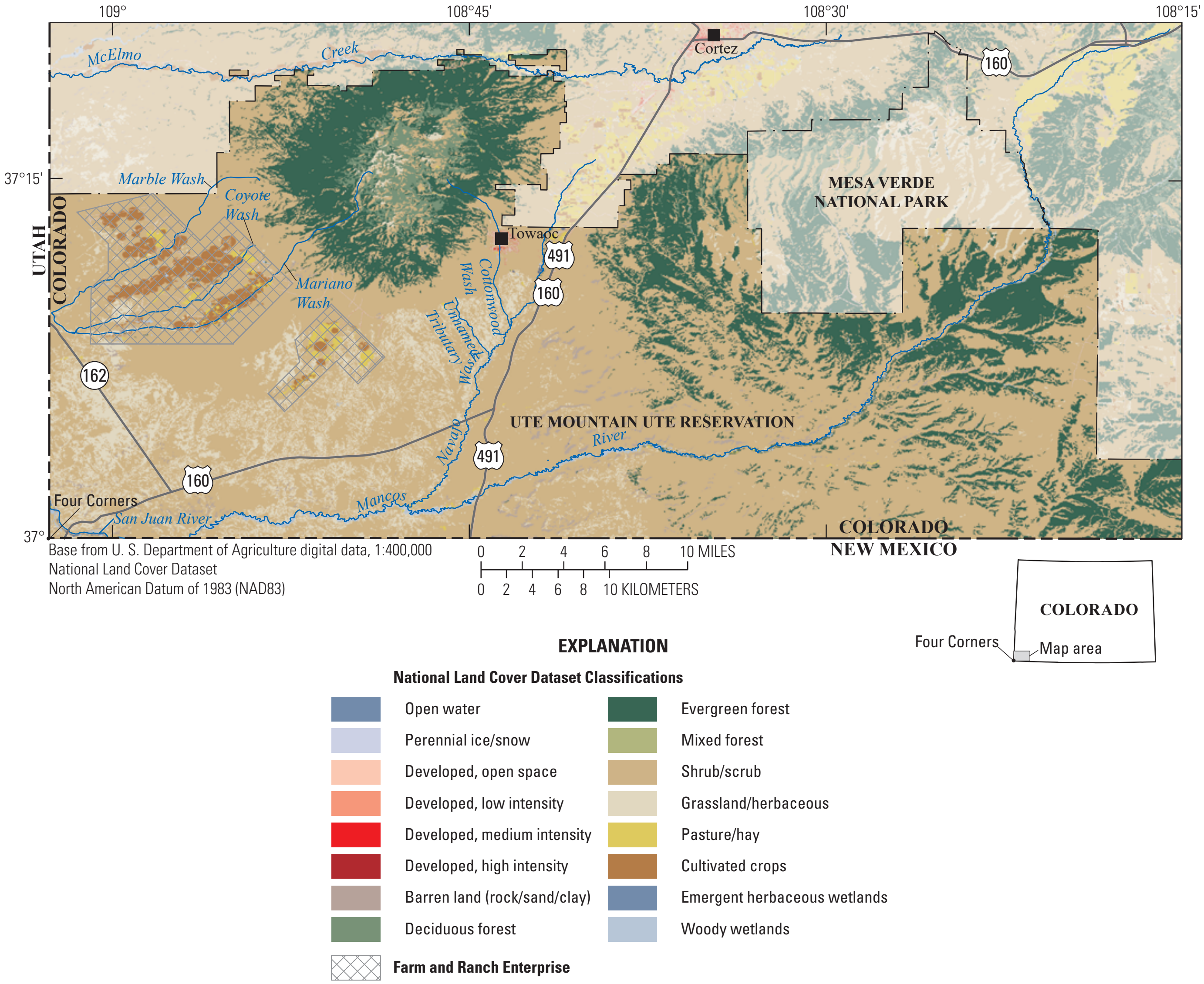


Figure 4. Land cover and land use on the Ute Mountain Ute Reservation in Colorado.

near the UMUR (fig. 1) for 1963–2017 were warmest (55.9 degrees Fahrenheit [°F]) near Four Corners and 49.2 °F at Cortez and MVNP (Western Regional Climate Center, 2018b). During summer, temperatures can fluctuate from daytime highs around 90 °F to nighttime lows around 55 °F (Western Regional Climate Center, 2018a). The mean monthly coldest temperatures occur in January and range from 13.2 °F to 20.0 °F at the three stations (Western Regional Climate Center, 2018a). Average annual precipitation for 1963–2017 was 8.1 inches per year near Four Corners and increased with altitude to 12.5 inches per year at Cortez and 18.1 inches per year at MVNP (Western Regional Climate Center, 2018b). Summer thunderstorms can produce several inches of rain in a few hours or less, and winter storms can drop 1 foot or more of snow at higher altitudes during a single storm event. With hot temperatures during the summer, evapotranspiration rates can exceed precipitation such that only a small fraction of the precipitation infiltrates to the subsurface as groundwater recharge (Irwin, 1966).

Surface-Water Hydrology

Surface-water drainage on the UMUR is characterized by ephemeral stream channels draining toward the Mancos and San Juan Rivers. The ephemeral Navajo Wash and its tributaries drain the area east of the Ute Mountains near Towaoc southward toward the Mancos River. The Mancos River, a perennial stream with headwaters in the mountains northeast of MVNP, flows southwest across the northeast portion of the reservation toward its confluence with the San Juan River in the Four Corners area (fig. 1). A small segment of the San Juan River crosses the southwest corner of the UMUR. The western portion of the UMUR in Colorado is drained by the ephemeral Mariano and Marble Washes and their tributaries (fig. 1), whose waters flow into the San Juan River in Utah. Small tributaries on the northern flanks of the Ute Mountains drain into McElmo Creek, beyond the northwestern boundary of the reservation.

Groundwater Hydrology

Groundwater occurs in confined aquifers contained in sandstone geologic formations and in the surficial aquifer contained in unconsolidated surficial deposits on the UMUR (UMUT, 2005). Bedrock aquifers beneath the UMUR in Colorado include the Dakota aquifer contained in the Dakota Sandstone, which is the main water-bearing unit beneath the UMUR, and aquifers contained in the sandstone units of the Mesaverde Group (primarily the Cliff House Sandstone and the upper part of the Point Lookout Sandstone). Small quantities of groundwater are present in the surficial aquifer contained in unconsolidated surficial deposits such as near-surface alluvium, colluvium, talus, rubble, and pediment deposits (Irwin, 1966; Geldon, 1985; UMUT, 2004).

Sources of recharge to groundwater include rain or snow, irrigation water applied to agricultural areas or landscaping, and seepage of surface water downstream from springs or to the alluvium of streams or washes (Irwin, 1966; Geldon, 1985). Recharge occurs when water percolates downward through the unsaturated zone to the water table where it becomes part of the regional groundwater flow system or is trapped by impervious material and is perched above the regional flow system (Whitfield and others, 1983). Part of the precipitation that moves into the unsaturated zone is evaporated from soils and subsurface material or is transpired by plants.

Groundwater movement in saturated deposits is largely controlled by the hydraulic conductivity of the aquifer material. Shale, mudstone, and siltstone generally have low hydraulic conductivities and transmit little water, whereas sandstones, conglomerate, and gravel have a wide range of conductivities and generally transmit more water than the less permeable rocks (Whitfield and others, 1983). Local movement of groundwater generally is downward, but groundwater may move laterally to discharge into springs when impervious or low-permeability material is encountered or into streams. Flow in the alluvium typically is lateral towards canyons and tributaries of the Mancos and San Juan Rivers. Regionally, groundwater recharged in structurally and topographically high areas, such as the Ute Mountains, moves downdip into structurally low areas toward discharge areas (Irwin, 1966). Regional flow direction for the aquifers contained in sandstone formations is toward the San Juan River (Whitfield and others, 1983).

Outflow of groundwater can occur as evapotranspiration by plants in areas of a shallow water table, discharge to springs and streams, and withdrawal from wells, either through pumping for domestic and livestock supply or naturally because of flowing artesian conditions. Groundwater discharged in springs occurs along canyon walls or lithologic contacts, where generally impervious material impedes the downward movement of water through more permeable material, or in the Ute Mountains, where groundwater emerges as springs at the contact between the intrusive fractured intrusive rocks and underlying low-permeability rocks. Many springs are recharged by snowmelt flow in spring and early summer and are dry by late summer. Discharge of groundwater to perennial streams, such as the Mancos and San Juan Rivers, is a dominant component of streamflow in late summer, fall, and winter when direct runoff from thunderstorms or snowmelt is absent. Some wells that have been drilled on the UMUR are flowing artesian wells and discharge groundwater above the land surface.

Land Cover and Land and Water Use

Most of the reservation is covered by shrubs/scrubs, grassland, and forests (fig. 4). Sagebrush, cacti, and grasses occur on low-altitude areas, and cottonwood trees may be present in washes and along creeks. Forests of mixed conifers and aspen occur on the Ute Mountains and higher-altitude mesas. Land on the UMUR is primarily used for Tribal government facilities, housing for Tribal members, a Tribal park, the Farm and Ranch Enterprise, livestock grazing, oil and gas development, tourism facilities, and other commercial activities (UMUT, 2005). The Farm and Ranch Enterprise (fig. 4) is an irrigated agricultural project where corn, alfalfa, and wheat are grown.

Surface water is imported into the UMUR from the Dolores Project facilities (Bureau of Reclamation, 2019). Water is conveyed from McPhee Reservoir through a pipeline and the Towaoc Highline Canal (fig. 1) and used for municipal supply and for UMUT enterprises around Towaoc. The Dolores Project also supplies irrigation water for the Farm and Ranch Enterprise (UMUT, 2004).

Water pumped from the Dakota aquifer is used primarily for livestock (UMUT, 2005) but also is tapped for the three domestic wells on the UMUR, two private wells near McElmo Canyon on the northern boundary, and a well at the Farm and Ranch Enterprise headquarters. Use of groundwater from aquifers in the Cliff House Sandstone and Point Lookout Sandstone is limited. In the eastern and southeastern part of the UMUR, the Mancos River and its tributaries have cut steep and narrow canyons into the landscape, and the Cliff House Sandstone and Point Lookout Sandstone are drained by seeps and springs on the canyon walls. Groundwater is not a source of irrigation water for the UMUR because of the limited quantity of groundwater (UMUT, 2004).

Springs on the UMUR can be important sources of water for wildlife and vegetation. On steep hillsides or canyons with mostly barren ground or rock, the location of springs can easily be identified by the presence of greenery. Springs on the Ute Mountains (fig. 2) and the Whiskers Draw Spring in Utah (S13 on fig. 1) are spiritually and culturally significant for the UMUT (UMUT, 2004).

Methods of Hydrogeologic Characterization

This section describes methods used to characterize hydrogeologic conditions for the surficial aquifer contained in unconsolidated surficial deposits and the Dakota aquifer contained in the Dakota Sandstone within the UMUR in Colorado. Depth to water below land surface and the direction and gradient of the water-table slope was determined for the surficial aquifer, and the depth to the top of the Dakota Sandstone below land surface was mapped. Hydrogeologic characterization was focused on these two units because of their current or potential use as water supplies and their potential vulnerability to land-use activities.

Surficial Deposits

Because of limited availability of water-level data, characterization of the water-table altitude for the entire UMUR was not possible; instead, the study focused on the Farm and Ranch Enterprise area and an area near Towaoc where some water-level data were available for the surficial aquifer. Water-level data from monitoring wells associated with the Farm and Ranch Enterprise (fig. 5) were compiled from records provided by the UMUT (table 2, table 1.1 in app. 1). Historical water-level data for shallow wells near Towaoc (fig. 6) were compiled from records in the USGS National Water Information System (NWIS; USGS, 2016b), Irwin (1966), and Geldon (1985) (table 1.1 in app. 1).

To estimate direction and gradient of the water-table slope, an effort was made to create lines of equal water-table altitude (water-table contours) for the Farm and Ranch Enterprise and Towaoc areas with consideration of topography, surface geology, and drainage features. Because of the limited data available, a map of the water-table contours is not included in this report, but calculations of the slope direction and gradient were performed using the available data. The method entailed obtaining a land-surface altitude above the North American Vertical Datum of 1988 (NAVD88) for each well from USGS digital elevation models (DEMs) (USGS, 2019). Next, water-level altitudes at each well were determined by subtracting the measured water-level depth below land surface from land-surface altitude. In cases where more than one water-level measurement was available for a well, the median water level was used. The water-table surface was partially contoured manually and reviewed to verify that the water-level altitudes accurately represented the data, progressed in a logical spatial order, and did not exceed land-surface altitudes. Finally, direction of slope and slope gradient (altitude of water table over distance on the ground) were estimated from the data. Because water-level data represent various measurement dates under different hydrologic conditions, these results should be considered representative of generalized water-table conditions rather than precise conditions for a specific time or place.

Dakota Sandstone

A map of the depth to the top of the Dakota Sandstone in feet below land-surface datum in Colorado was developed using well location and lithologic data compiled from Irwin (1966), the Colorado Oil and Gas Conservation Commission (COGCC, 2016), and New Mexico Oil Conservation Division (2012) (compiled data in table 1.2 in app. 1). Lithologic data for wells in New Mexico were included in the dataset to improve interpolation across areas lacking data within Colorado. At each well, the structural altitude at the top of the Dakota Sandstone in feet above NAVD88 was first computed as the difference between the land-surface altitude, determined from the DEM dataset (USGS, 2019) in feet above NAVD88, and the depth to the top of the Dakota Sandstone in feet below land surface based on lithologic data in well construction records. Wells were removed from the dataset in cases where land-surface altitude reported by construction records differed from that of the DEM by more than 50 ft, and the well location could not be confirmed from other sources. Similarly, wells indicating anomalous altitude values for the top of the Dakota Sandstone were removed from the dataset if the values could not be substantiated. Otherwise, conflicting values were retained in the dataset to indicate the variability inherent within the data.

Using outcrop and subcrop areas and structural features digitized from surface geologic maps (Condon, 1991; Haynes and others, 1972), structural-altitude contours of the top of the Dakota Sandstone were drawn by hand to improve interpolation in areas of sparse data. Contours were drawn using an interval of 100 ft and were estimated to have an accuracy of about 50-60 ft where the data provide good structural control. In areas where structural data were unavailable, structural contours representing the base of the Dakota Sandstone were used to infer structural contours for the top of the Dakota, and the accuracy of these contours is unknown.

The depth to the top of the Dakota Sandstone in feet below land surface was determined by using a geographic information system to generate a raster grid of values from the structural-altitude contours and subtracting the raster-based structural altitude from the DEM land surface. The resulting raster-based depth to the top of the Dakota Sandstone was then contoured in a geographic information system using an interval of 100 ft for the western portion of the UMUR and 500 ft for the eastern portion of the UMUR because of the tightness of the 100 ft contours. In areas where the structural altitude of the Dakota Sandstone is well defined, the accuracy of the contours is considered to be 50–60 ft for 100-ft contours and about 250–300 ft for 500-ft contours. All geospatial datasets generated during this process are available in Bauch (2020).

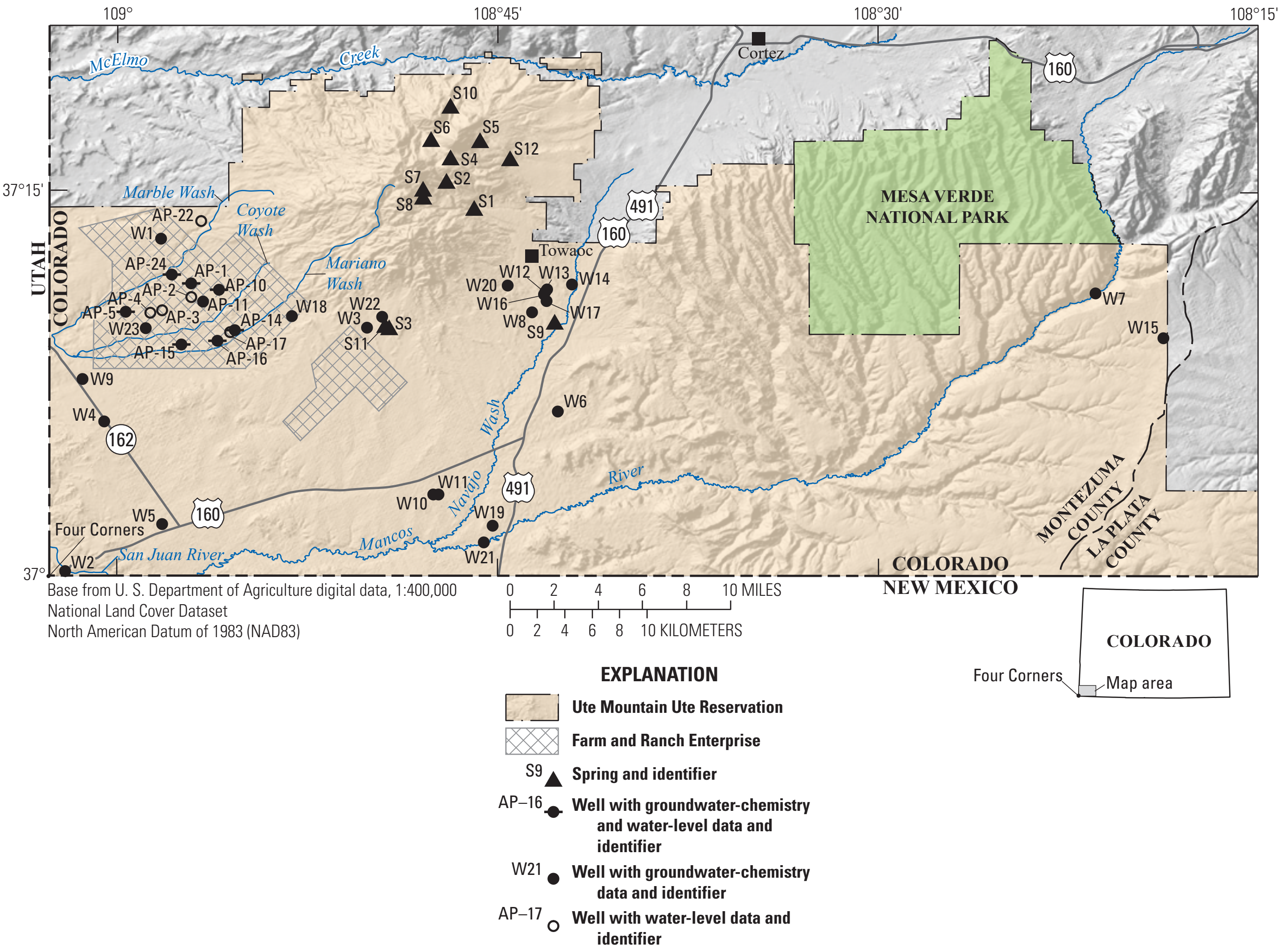


Figure 5. Location of Ute Mountain Ute Tribe wells and springs where water-level and (or) groundwater-chemistry data were collected on the Ute Mountain Ute Reservation in Colorado.

Table 2. Ute Mountain Ute Tribe water-level data for unconsolidated surficial deposits, Ute Mountain Ute Reservation in Colorado.

[Median water level is in bold. ID, identification; fig., figure; ft bls, feet below land surface]

Site ID (see fig. 5)	Date	Water level (ft bls)
AP−1	08/15/2008	10.7
AP−1	03/31/2009	10.1
AP−1	03/01/2010	12.1
AP−1	11/29/2010	10.0
AP−1	06/08/2011	10.7
AP−1	01/04/2012	11.0
AP−1	07/27/2012	12.1
AP−1	04/10/2013	13.6
AP−1	08/14/2013	14.4
AP−1	04/10/2014	24.9
AP−1	08/03/2014	15.6
AP−1	**Median**	**12.1**
AP–2	08/15/2008	12.2
AP–2	11/29/2010	9.9
AP–2	**Median**	**11.1**
AP–3	08/15/2008	9.8
AP–3	03/31/2009	0.9
AP–3	03/01/2010	13.2
AP–3	11/29/2010	9.7
AP–3	**Median**	**9.8**
AP–4	03/31/2009	13.9
AP–4	11/29/2010	11.5
AP–4	06/08/2011	13.2
AP–4	01/04/2012	12.9
AP–4	07/27/2012	12.5
AP–4	**Median**	**12.9**
AP–5	08/11/2008	7.9
AP–5	03/31/2009	6.2
AP–5	03/03/2010	5.8
AP–5	11/29/2010	5.7
AP–5	06/08/2011	3.9
AP–5	01/04/2012	5.3
AP–5	07/27/2012	5.0
AP–5	04/10/2013	6.6
AP–5	08/03/2014	6.0
AP–5	**Median**	**5.8**
AP−10	08/15/2008	11.4
AP−10	04/07/2009	17.2
AP−10	03/03/2010	18.1
AP−10	11/22/2010	16.5
AP−10	06/15/2011	16.9
AP−10	01/04/2012	16.1
AP−10	07/27/2012	17.7
AP−10	04/10/2013	19.3
AP−10	08/14/2013	16.5
AP−10	04/10/2014	19.2
AP−10	08/03/2014	19.7
AP−10	**Median**	**17.2**
AP−14	05/02/2008	5.8
AP−14	04/07/2009	5.4
AP−14	02/22/2010	3.3
AP−14	11/22/2010	4.0
AP−14	06/08/2011	3.3
AP−14	01/03/2012	5.0
AP−14	07/27/2012	4.0
AP−14	04/10/2013	6.0
AP−14	08/14/2013	9.5
AP−14	04/10/2014	12.1
AP−14	08/03/2014	7.3
AP−14	**Median**	**5.4**
AP−15	02/22/2010	5.6
AP−15	11/22/2010	7.8
AP−15	06/08/2011	6.4
AP−15	01/03/2012	7.4
AP−15	07/27/2012	5.0
AP−15	04/10/2013	5.4
AP−15	08/14/2013	10.6
AP−15	04/10/2014	6.6
AP−15	08/03/2014	5.0
AP−15	**Median**	**6.4**
AP−16	05/02/2008	8.3
AP−16	04/07/2009	8.9
AP−16	02/22/2010	6.8
AP−16	11/22/2010	8.4
AP−16	06/08/2011	8.6
AP−16	01/03/2012	9.7
AP−16	07/27/2012	9.1
AP−16	04/10/2013	9.7
AP−16	08/14/2013	5.9
AP−16	04/10/2014	10.4
AP−16	08/03/2014	9.7
AP−16	**Median**	**8.9**
AP−17	05/02/2008	16.2
AP−17	04/07/2009	16.2
AP−17	02/22/2010	14.4
AP−17	11/22/2010	14.2
AP−17	06/08/2011	16.8
AP−17	01/03/2012	15.1
AP−17	04/10/2013	16.0
AP−17	**Median**	**16.0**
AP–22	03/01/2010	6.1
AP–24	01/04/2012	9.2
AP–24	07/27/2012	6.8
AP–24	08/03/2014	4.8
AP–24	**Median**	**6.8**

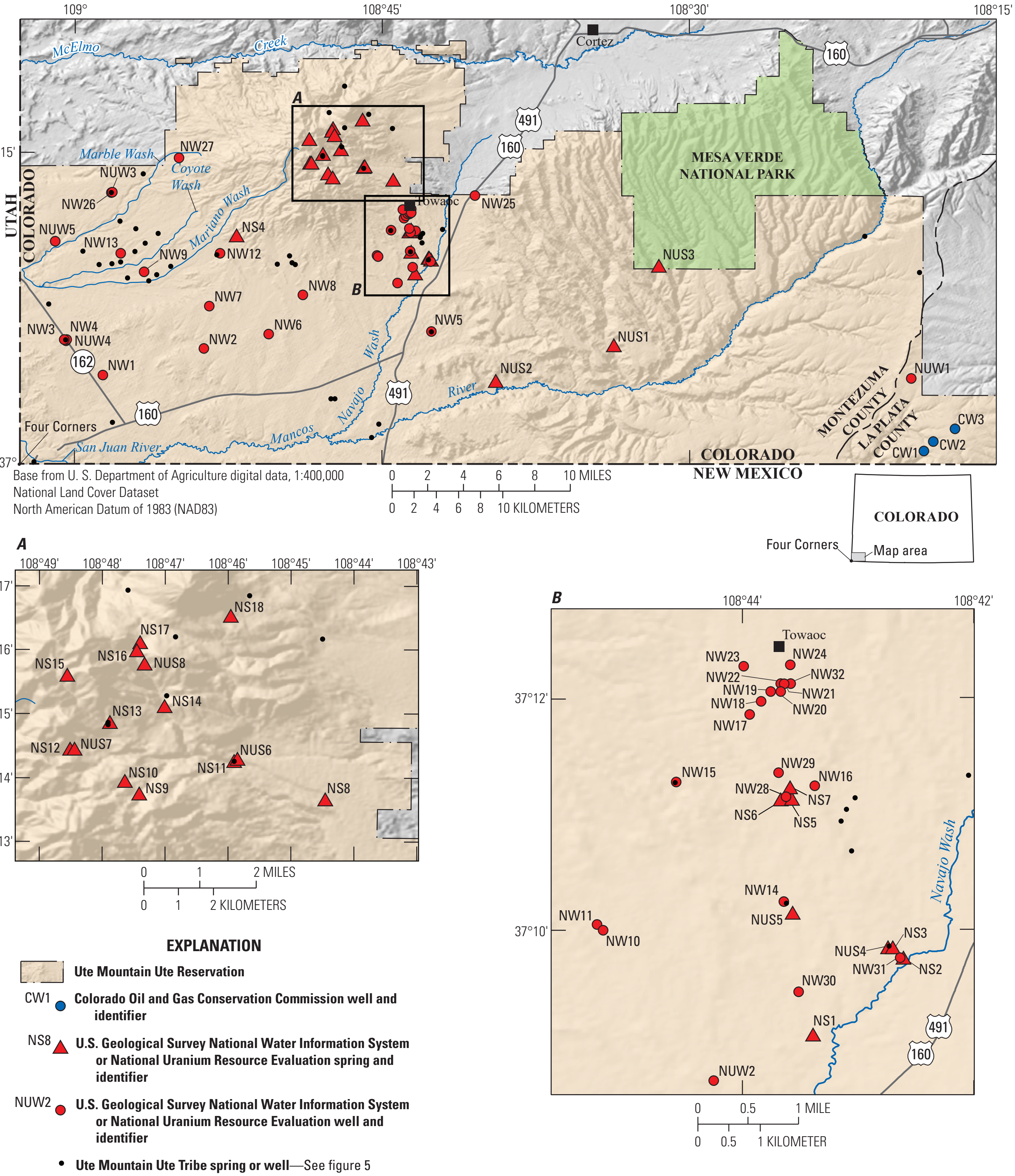


Figure 6. Location of U.S. Geological Survey (USGS) and Colorado Oil and Gas Conservation Commission (COGCC) springs and wells with historical water-level and (or) groundwater-chemistry data on the Ute Mountain Ute Reservation in Colorado. Site labels beginning with "NU" are from USGS National Uranium Resource Evaluation (USGS, 2014); all other site labels beginning with "N" are from USGS National Water Information System (USGS, 2016b), Irwin (1966), and Geldon (1985). Site labels beginning with "CW" are from COGCC (COGCC, 2018).

Methods for Compilation and Analysis of Groundwater-Chemistry Data

This report utilized multiple types of groundwater-chemistry data from multiple sources (table 3). Select chemistry data were compiled, quality assured, aggregated, and summarized as described in the following sections. Comparisons with water-quality standards were used to assess suitability of water for various designated uses. Data collection and laboratory analytical methods for environmental tracer data for select springs and wells collected by the UMUT in 2017 also are described.

Data Sources

The primary groundwater-chemistry data used for this study were collected by the UMUT from 1996 through 2017. Groundwater-chemistry data for 44 sites, 13 springs and 31 wells, were retrieved in an electronic format from the Water Quality Portal (https://www.waterqualitydata.us/) (National Water Quality Monitoring Council, 2017) on September 9, 2017 (fig. 5, table 4). All UMUT sites are in Colorado except for the Whiskers Draw Spring in Utah (S13), which is shown on figure 1. The number of sample days and the number of samples collected at each site varied (table 4).

The groundwater-chemistry data collected by the UMUT are supplemented by older data from the USGS and the COGCC (fig. 6, table 4). The supplemental data were obtained in an electronic format from three databases: the USGS NWIS (USGS, 2016b); National Uranium Resource Evaluation (NURE), hosted by the USGS (USGS, 2014); and COGCC GIS Online (COGCC, 2018). Groundwater-chemistry data for 45 USGS sites, 18 springs and 27 wells, retrieved from NWIS were collected in the 1950s, 1960, 1979, 1982, 1987, and 2003 (tables 3 and 4). These data are described further in Irwin (1966), Geldon (1985), and Wright (2006) (tables 3 and 4). Data for 13 NURE sites, 8 springs and 5 wells, on the UMUR were collected during 1976–78 (tables 3 and 4). Groundwater-chemistry data from the COGCC were collected from three wells during 1971 and 1976 by oil and gas companies at selected COGCC facilities (tables 3 and 4). Detailed analysis of the NWIS, NURE, and COGCC data are not included in this report.

Table 3. Sources of groundwater-chemistry data, number of sampling sites, period of groundwater-chemistry record, and type of groundwater-chemistry data reported by various organizations for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah.

[UMUT, Ute Mountain Ute Tribe; WQP, Water Quality Portal; PP, physical properties; TDS, total dissolved solids; MI, major ions; N, nutrients; TE, trace elements; U, uranium; P, pesticides; VOC, volatile organic compound; CB, coliform bacteria; ET, environmental tracers; U-I, uranium isotopes; RN, radiochemicals; USGS, U.S. Geological Survey; NWIS, National Water Information System; NURE, National Uranium Resource Evaluation; COGCC, Colorado Oil and Gas Conservation Commission; DS, dissolved solids]

Reporting organization	Source	Number of sampling sites (springs/wells)	Period of groundwater-chemistry record	Type of groundwater-chemistry data[1]	Availability of analytical methods	Type of quality-assurance data
UMUT	WQP[2]	13/31	1996–2007, 2009−17	PP, TDS, MI, N, TE, U, P, VOC, CB, ET, U-I, RN, oil and gas	Yes	Field blanks and replicates
USGS	NWIS[3]	18/27	[4]1950–60, 1979, 1982, 1987, 2003	PP, TDS, MI, N, TE, CB	No	None
USGS	NURE[5]	8/5	1976–78	PP, MI, TE	Yes	None
COGCC	COGCC[6]	[7]0/3	1971, 1976	PP, DS, MI	No	None

[1] Not all available data listed were analyzed for the study.

[2] National Water Quality Monitoring Council, 2017.

[3] USGS, 2016b.

[4] No data for 1952 and 1955.

[5] USGS, 2014.

[6] COGCC, 2018.

[7] COGCC wells are environmental sampling sites. The COGCC map of environmental sampling sites shows four wells located within the boundaries of the Ute Mountain Ute Reservation in Colorado. One well, sample site ID 701784, is excluded from the report because there is conflicting information on the location of the well.

Table 4. Description of springs and wells with groundwater-chemistry data on the Ute Mountain Ute Reservation in Colorado and Utah, with sample year, number of environmental sample days and samples, and type of groundwater-chemistry data.

[See table 3 for water-quality data source. Sites sampled for the 2017 environmental tracer study are in bold. ID, identification; figs., figures; LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; ft abv lsd, feet above land surface datum; No., number; env., environmental; UTEMTN, Ute Mountain Ute Tribe; PP, physical properties; CB, coliform bacteria; TDS, total dissolved solids; MI, major ions; N, nutrients; TE, trace elements; U-I, uranium isotopes; R, replicate quality assurance; U, uranium; ET, environmental tracers; RN, radiochemicals; VOC, volatile organic compound; P, pesticides; USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; NURE, National Uranium Resource Evaluation]

Site ID (see figs. 5, 6)	Unique site identifier[1]	Site name used in report	Latitude DD[2]	Longitude DD[2]	Altitude (ft abv lsd)[3]	Sample year	No. of env. sample days	No. of env. samples	Type of groundwater-chemistry data[4]
				Ute Mountain Ute Tribe—Springs					
S1	UTEMTN-Bancroft Spring	Bancroft Spring	37.239	−108.765	[5]6,836	2012	1	5	PP, CB
S2	UTEMTN-Cottonwood Wash Spring	Cottonwood Wash Spring	37.256	−108.783	[5]7,626	2015	1	1	PP, TDS, MI, N, TE, CB, U-I
S3	UTEMTN-EAST_TOE_Spring	East Toe Spring	37.160	−108.821	5,758	1998–2000	4	4	PP, TDS, MI, TE
S4	UTEMTN-Elk Meadows Spring	Elk Meadows Spring	37.271	−108.781	[5]8,149	2012, 2015	2	4	PP, TDS, MI, N, TE, CB, U-I
S5	UTEMTN-Hanna 1	Hanna Spring[6]	37.282	−108.761	[5]7,535	2010–15	9	11	PP, TDS, MI, N, TE, CB, U-I, R
S6	UTEMTN-Last Lake Spring	Last Lake Spring	37.284	−108.793	[5]7,512	2015	1	1	PP, TDS, MI, N, TE, CB, U-I
S7	UTEMTN-Lopez 1	Lopez 1 Spring[6]	37.249	−108.799	[5]7,851	2010, 2011	4	6	PP, MI, TE, CB, U-I, R
S8	**UTEMTN-Lopez 2**	**Lopez 2 Spring[6]**	**37.248**	**−108.799**	**[5]7,812**	**2011–13, 2017**	**5**	**7**	**PP, N, U, CB, ET, R**
S9	UTEMTN-NAVAJO Spring	Navajo Spring	37.164	−108.712	5,461	2001, 2016	3	3	PP, TDS, MI, N, TE, U, CB
S10	UTEMTN-Ute Spring	Ute Spring[6]	37.305	−108.781	[5]6,812	2014, 2015	2	3	PP, TDS, MI, N, TE, CB, U-I, R
S11	UTEMTN-W-TOE-SPG, -WEST_TOE_Spring	West Toe Spring	37.162	−108.824	5,773	1998, 1999	3	3	PP, TDS, MI, TE
S12	Whisky Road Spring	Whisky Road Spring	37.271	−108.742	[5]6,817	2014, 2015	3	3	PP, TDS, MI, N, TE, CB, U-I
S13	UTEMTN-Whiskers Draw	Whiskers Draw Spring[6,7]	37.616	−109.636	[5]5,483	2013	2	2	PP, TDS, MI, N, TE, CB, RN, U-I
				Ute Mountain Ute Tribe—Wells					
W1	UTEMTN-4000B_SOLARWELL	4000B well	[8]37.219	[8]−108.971	5,333	2016	1	1	PP, TDS, MI, N, TE, U, CB
W2	UTEMTN-4C-WELL	4C well	[8]37.000	[8]−109.034	4,641	2002–04, 2006, 2007	7	7	PP, TDS, MI, N, TE, CB, VOC
W3	**UTEMTN-5000 Block Old Windmill**	**5000 Block well**	**37.161**	**−108.836**	**[9]5,659**	**2017**	**1**	**1**	**PP, MI, N, TE, U, ET**
AP−1	**UTEMTN-AP−1**	**AP−1**	**[8]37.190**	**[8]−108.951**	**5,221**	**2001, 2003, 2004, 2009, 2011, 2013, 2014, 2017**	**8**	**8**	**PP, TDS, MI, N, TE, U, CB, P, VOC, ET, U-I**
AP–5	UTEMTN-AP–5	AP–5	[8]37.171	[8]−108.994	5,017	1997, 1998, 2000–02, 2014	9	9	PP, TDS, MI, N, TE, P
AP−10	UTEMTN-AP−10	AP−10	[8]37.186	[8]−108.933	5,305	2001	1	1	PP, MI, TE, P
AP−11	UTEMTN-AP−11	AP−11	[8]37.178	[8]−108.943	5,221	[10]2004	0	0	P
AP−14	UTEMTN-AP−14	AP−14	[8]37.159	[8]−108.923	5,237	1997–2001, [10]2003, 2004, 2005, [10]2007, 2011, 2014	14	14	PP, TDS, MI, N, TE, P, VOC
AP−15	UTEMTN-AP−15	AP−15	[8]37.150	[8]−108.958	5,041	[10]2011, 2012	1	1	PP, TDS, MI, N, TE, CB, P, VOC
AP−16	UTEMTN-AP−16	AP−16	[8]37.152	[8]−108.934	5,150	2001, 2003–05, 2007	6	6	PP, MI, TE, P, VOC
AP–24	UTEMTN-AP–24	AP–24	[8]37.196	[8]−108.964	5,202	2001, 2014	2	3	PP, MI, N, TE, P
W4	UTEMTN-AW HWY 141	[11]AW Hwy 141	37.099	−109.008	4,986	1996, 2000, 2002	3	3	PP, TDS, MI, N, TE, CB
W5	UTEMTN-AW HWY 160/141	[11]AW Hwy 160/141	37.032	−108.970	4,913	1996, 2000, 2002	3	3	PP, TDS, MI, N, TE, CB

Table 4. Description of springs and wells with groundwater-chemistry data on the Ute Mountain Ute Reservation in Colorado and Utah, with sample year, number of environmental sample days and samples, and type of groundwater-chemistry data.—Continued

[See table 3 for water-quality data source. Sites sampled for the 2017 environmental tracer study are in bold. ID, identification; figs., figures; LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; ft abv lsd, feet above land surface datum; No., number; env., environmental; UTEMTN, Ute Mountain Ute Tribe; PP, physical properties; CB, coliform bacteria; TDS, total dissolved solids; MI, major ions; N, nutrients; TE, trace elements; U-I, uranium isotopes; R, replicate quality assurance; U, uranium; ET, environmental tracers; RN, radiochemicals; VOC, volatile organic compound; P, pesticides; USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; NURE, National Uranium Resource Evaluation]

Site ID (see figs. 5, 6)	Unique site identifier[1]	Site name used in report	Latitude DD[2]	Longitude DD[2]	Altitude (ft abv lsd)[3]	Sample year	No. of env. sample days	No. of env. samples	Type of groundwater-chemistry data[4]
W6	UTEMTN- Chimney_Rock_Windmill	Chimney Rock well	[12]37.106	[12]−108.710	[5]5,423	2016	1	1	PP, TDS, MI, N, TE, U
W7	UTEMTN-Corral Well Horse Canyon	HC Corral well	[12]37.183	[12]−108.356	[5]6,065	2012	1	1	PP, TDS, MI, N, TE
W8	**UTEMTN- Cottonwood Spring**	**Cottonwood Spring well[11]**	**37.171**	**−108.727**	**[9]5,561**	**2014, 2017**	**2**	**2**	**PP, TDS, MI, N, TE, U, CB, ET, U-I**
W9	UTEMTN-FW-W	FW-W[11]	37.128	−109.022	[5]4,895	2013	1	1	PP, TDS, MI, N, TE, CB
W10	**UTEMTN- Goodknight Well**	**Goodknight well**	**37.052**	**−108.792**	**[5]5,187**	**2017**	**1**	**1**	**PP, MI, N, TE, U, ET**
W11	UTEMTN-KNIGHT WELL	Knight well	37.052	−108.789	5,100	2000, 2001, 2013	4	4	PP, TDS, MI, N, TE, CB
W12	UTEMTN-LAGOON 1 WELL 1	Lagoon 1 well 1	[8]37.184	[8]−108.718	5,598	2010	2	2	PP, TDS, MI, N, TE
W13	UTEMTN-LAGOON 1 WELL 3	Lagoon 1 well 3	[8]37.186	[8]−108.717	[5]5,601	2003, 2004, 2010	5	5	PP, TDS, MI, N, TE, CB, P, VOC, R
W14	UTEMTN- LAGOON 2 WELL 2	Lagoon 2 well 2	[8]37.189	[8]−108.701	5,560	2002	1	1	PP, CB
W15	UTEMTN-Lewis Well	Lewis well	[12]37.154	[12]−108.312	[5]6,805	2012	1	1	PP, TDS, MI, N, TE
W16	UTEMTN-LF_WELL1	LF well 1	[8]37.182	[8]−108.719	5,596	2009	1	1	TE, R
W17	UTEMTN-LF_WELL3	LF well 3	[8]37.178	[8]−108.718	5,576	2009	1	1	TE
W18	UTEMTN- Mariano-FW	Mariano-FW[11]	37.168	−108.885	[5]5,453	2013	1	1	PP, TDS, MI, N, TE, CB
W19	UTEMTN- MR-FW	MR-FW[11]	37.031	−108.753	[3]5,105	2011	1	1	PP, TDS, MI, TE
W20	**UTEMTN-SE Toe Old Solar**	**SE Toe well**	**37.188**	**−108.743**	**[5]5,862**	**2017**	**1**	**1**	**PP, MI, N, TE, U, ET**
W21	UTEMTN-TF-CORRAL-WELL	TF-Corral well	37.020	−108.759	5,020	2002	1	1	P
W22	UTEMTN-Toe Windmill	Toe well	[12]37.168	[12]−108.826	[5]5,842	2016	1	1	PP, TDS, MI, N, TE, U, CB, RN, U-I, R
W23	WING-WELL, WING WELL	Wing well	37.160	−108.981	4,986	2000, 2001, 2003, 2012	4	4	PP, TDS, MI, N, TE, CB, P, VOC, oil and gas
USGS NWIS—Springs									
NS1	370905108432101	na	37.151	−108.723	5,390	1982	1	1	PP
NS2	370945108423401	S–15 Spring	37.162	−108.710	[13]5,400	1951	1	1	PP, TDS, MI, N
NS3	370950108424201	Spring 16	37.164	−108.712	5,470	1951, 1982	2	2	PP, TDS, MI, N
NS4	371056108520501	na	37.182	−108.869	[13]5,723	1956	1	1	PP, TDS, MI
NS5	371107108433201	na	37.185	−108.726	[13]5,700	1960	1	1	PP, TDS, MI, N, TE
NS6	371107108433801	na	37.185	−108.728	5,670	1950, 1982	3	3	PP, TDS, MI, N, TE
NS7	371113108433301	na	37.187	−108.726	5,680	1960	2	2	PP, TDS, MI, N, TE
NS8	371340108442501	na	37.228	−108.741	6,365	1982	3	3	PP, TDS, MI, N, TE, CB
NS9	371345108472301	na	37.229	−108.790	7,860	1982	3	3	PP, TDS, MI, N, TE
NS10	371357108473701	na	37.232	−108.794	7,960	1982	2	2	PP, TDS, MI, N, TE
NS11	371416108455201	Spring 9	37.238	−108.765	[13]6,850	1951	1	2	PP, TDS, MI, N
NS12	371428108483001	na	37.241	−108.809	8,120	1982	1	1	PP, TDS, MI, N, TE
NS13	371454108475201	Spring 5, S–3 Spring	37.248	−108.798	7,800	1982	3	3	PP, TDS, MI, N, TE, CB
NS14	371508108465901	na	37.252	−108.784	7,400	1982	3	3	PP, TDS, MI, N, TE
NS15	371538108483201	na	37.261	−108.810	8,560	1982	1	1	PP, TDS, MI, N, TE
NS16	371601108472501	na	37.267	−108.791	8,080	1982	3	3	PP, TDS, MI, N, TE, CB
NS17	371610108472201	na	37.269	−108.790	8,160	1982	2	2	PP, TDS, MI, N, TE
NS18	371634108455701	Elbow Spring	37.276	−108.766	7,871	2003	1	1	PP, TDS, MI, N, TE

Table 4. Description of springs and wells with groundwater-chemistry data on the Ute Mountain Ute Reservation in Colorado and Utah, with sample year, number of environmental sample days and samples, and type of groundwater-chemistry data.—Continued

[See table 3 for water-quality data source. Sites sampled for the 2017 environmental tracer study are in bold. ID, identification; figs., figures; LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; ft abv lsd, feet above land surface datum; No., number; env., environmental; UTEMTN, Ute Mountain Ute Tribe; PP, physical properties; CB, coliform bacteria; TDS, total dissolved solids; MI, major ions; N, nutrients; TE, trace elements; U-I, uranium isotopes; R, replicate quality assurance; U, uranium; ET, environmental tracers; RN, radiochemicals; VOC, volatile organic compound; P, pesticides; USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; NURE, National Uranium Resource Evaluation]

Site ID (see figs. 5, 6)	Unique site identifier[1]	Site name used in report	Latitude DD[2]	Longitude DD[2]	Altitude (ft abv lsd)[3]	Sample year	No. of env. sample days	No. of env. samples	Type of groundwater-chemistry data[4]
USGS NWIS—Wells									
NW1	370410108583701	na	37.071	−108.978	4,900	1959	1	1	PP, TDS, MI
NW2	370518108540601	na	37.092	−108.896	5,220	1956	1	1	PP, TDS, MI
NW3	370554109002701	na	37.098	−109.008	4,965	1956, 1959, 1979, 1987	4	4	PP
NW4	370557109003201	B−11	37.099	−109.010	[13]4,989	1959	1	1	PP, TDS, MI
NW5	370612108424001	na	37.106	−108.710	5,400	1959, 1987	2	2	PP, TDS, MI
NW6	370617108504201	na	37.104	−108.843	5,290	1956, 1987	2	2	PP, TDS, MI
NW7	370717108532501	na	37.126	−108.891	5,330	1956	1	1	PP, TDS, MI
NW8	370806108485801	na	37.135	−108.815	5,483	1956	1	1	PP, TDS, MI
NW9	370913108563901	na	37.154	−108.944	5,110	1956, 1987	2	2	PP, TDS, MI
NW10	371000108451001	na	37.167	−108.753	[13]5,680	1956	1	1	PP, TDS, MI
NW11	371003108451301	na	37.167	−108.754	5,690	1956	1	1	PP, TDS, MI
NW12	371006108530401	na	37.169	−108.882	4,440	1959	1	1	PP, TDS, MI
NW13	371007108575101	na	37.169	−108.963	5,078	1956, 1987	2	2	PP, TDS, MI
NW14	371015108433601	na	37.171	−108.727	5,556	1982, 1987	2	2	PP
NW15	371112108443401	na	37.188	−108.743	5,848	1958	2	2	PP, TDS, MI
NW16	371115108432001	na	37.187	−108.723	5,739	1957	1	1	PP, TDS, MI
NW17	371152108435401	na	37.198	−108.732	5,877	1957	1	1	PP, TDS, MI, N
NW18	371159108434801	na	37.200	−108.731	5,885	1954	1	1	PP, TDS, MI, N
NW19	371204108433801	na	37.201	−108.728	[13]5,880	1953	1	1	PP, TDS, MI, N
NW20	371204108434301	na	37.201	−108.729	5,885	1954	1	1	PP, TDS, MI
NW21	371208108433601	na	37.202	−108.727	5,880	1953	2	2	PP, TDS, MI, N
NW22	371208108433801	na	37.202	−108.728	5,885	1954, 1982	3	3	PP, TDS, MI, N, TE
NW23	371217108435701	na	37.205	−108.733	5,922	1953	1	1	PP, MI
NW24	371218108433301	na	37.205	−108.726	5,917	1959	1	1	PP, MI
NW25	371248108402201	na	37.216	−108.674	5,880	1956	2	2	PP, TDS, MI
NW26	371307108581301	A–8	37.219	−108.971	5,320	1956	1	1	PP, TDS, MI
NW27	371443108544701	na	37.247	−108.916	5,755	1956	1	1	PP, TDS, MI
USGS NURE—Springs[12,13]									
NUS1	C24367	na	37.093	−108.561	5,690	1977	1	1	PP, MI, TE
NUS2	C24392	na	37.064	−108.658	5,325	1977	1	1	PP, MI, TE
NUS3	C24434	na	37.158	−108.524	6,283	1977	1	1	PP, MI, TE
NUS4	C24450	na	37.169	−108.726	5,531	1977	1	1	PP, MI, TE
NUS5	C24451	na	37.164	−108.712	5,471	1977	1	1	PP, MI, TE
NUS6	C24456	na	37.238	−108.764	6,813	1977	1	1	PP, MI, TE
NUS7	C24458	na	37.241	−108.808	8,128	1977	1	1	PP, MI, TE
NUS8	C24531	na	37.264	−108.789	8,065	1977	1	1	PP, MI, TE
USGS NURE—Wells[12,13]									
NUW1	C24003	na	37.068	−108.318	6,956	1976	1	1	PP, MI, TE
NUW2	C24448	na	37.145	−108.738	5,442	1977	1	1	PP, MI, TE
NUW3	C24858	na	37.219	−108.970	5,322	1977	1	1	PP, MI, TE

Table 4. Description of springs and wells with groundwater-chemistry data on the Ute Mountain Ute Reservation in Colorado and Utah, with sample year, number of environmental sample days and samples, and type of groundwater-chemistry data.—Continued

[See table 3 for water-quality data source. Sites sampled for the 2017 environmental tracer study are in bold. ID, identification; figs., figures; LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; ft abv lsd, feet above land surface datum; No., number; env., environmental; UTEMTN, Ute Mountain Ute Tribe; PP, physical properties; CB, coliform bacteria; TDS, total dissolved solids; MI, major ions; N, nutrients; TE, trace elements; U-I, uranium isotopes; R, replicate quality assurance; U, uranium; ET, environmental tracers; RN, radiochemicals; VOC, volatile organic compound; P, pesticides; USGS, U.S. Geological Survey; NWIS, National Water Information System; na, not applicable; NURE, National Uranium Resource Evaluation]

Site ID (see figs. 5, 6)	Unique site identifier[1]	Site name used in report	Latitude DD[2]	Longitude DD[2]	Altitude (ft abv lsd)[3]	Sample year	No. of env. sample days	No. of env. samples	Type of groundwater-chemistry data[4]
NUW4	C25005	na	37.099	−109.008	4,979	1978	1	1	PP, MI, TE
NUW5	C25010	na	37.179	−109.017	4,896	1978	1	1	PP, MI, TE
Colorado Oil and Gas Conservation Commission[12,13]									
CW1	213879	213879	37.007	−108.308	6,889	1971	1	1	PP, TDS
CW2	213907	213907	37.017	−108.302	6,945	1976	1	1	PP, TDS
CW3	214329	214329	37.027	−108.283	7,015	1976	1	1	PP, TDS

[1] The term “Unique site identifier” used here is titled differently in the source databases: “MonitoringLocationIdentifier" in the Water Quality Portal, “Site Number” in NWIS, “Prime_ID” in the NURE database, and “Sample Site ID” in the Colorado Oil and Gas Conservation Commission database.

[2] Latitude, longitude datum is North American Datum of 1983, unless otherwise noted.

[3] Altitude datum is National Geodetic Vertical Datum of 1929, unless otherwise noted.

[4] Not all available data listed were analyzed for the study.

[5] Altitude from Google Earth (https://www.google.com/earth/). Altitude datum is unknown.

[6] Culturally significant spring (Larrick and Clow, 2011).

[7] Spring, shown on figure 1, is in Utah. All other sites are in Colorado.

[8] Latitude, longitude datum is North American Datum of 1927.

[9] Altitude from Ute Mountain Ute Tribe. Altitude datum is unknown.

[10] Quality assurance (field blank) sample only.

[11] UMUT flowing artesian well.

[12] Latitude, longitude datum is unknown.

[13] Altitude datum is unknown.

Types of Groundwater-Chemistry Data

The groundwater-chemistry data used by this assessment include physical properties and concentrations of total dissolved solids (TDS), major ions, nutrients, trace elements, uranium, pesticides, volatile organic compounds (VOCs), and coliform bacteria (total coliform and *Escherichia coli*). Concentration data for groundwater-chemistry constituents are reported as filtered (through a 0.45-micrometer filter, described as “dissolved”) and unfiltered (described as “total”). Trace-element and some ammonia data are reported as “total recoverable,” which indicates possible incomplete digestion of particulate matter in the laboratory (Alpers and others, 2000).

Most (47 of 57) TDS concentrations presented in this report were retrieved from the Water Quality Portal (National Water Quality Monitoring Council, 2017) as residue on evaporation at 180 degrees Celsius in milligrams per liter (mg/L, milligrams of a constituent per liter of water). For 10 samples collected in 2016 and 2017, TDS concentrations were calculated as the sum of constituents, which is the sum of the major-ion concentrations retrieved from the Water Quality Portal for each sample.

Samples for environmental tracers, used for assessing recharge, groundwater age, and geochemical conditions, were collected by the UMUT in collaboration with the USGS from one spring and five wells in May 2017 (table 4) and analyzed by USGS laboratories. The environmental tracer samples were analyzed for stable isotope ratios (hydrogen and oxygen in water, nitrogen in nitrate, and carbon in dissolved inorganic carbon), tritium, chlorofluorocarbons (CFCs), dissolved gases (methane, carbon dioxide, nitrogen, oxygen, and argon), and noble gases (helium-4, neon, argon, krypton, and xenon). The nitrogen- and carbon-isotope samples were filtered through disposable, 0.45-micrometer filters, and the rest of the samples were collected as unfiltered or raw water. Sample-collection procedures for stable isotopes of hydrogen, oxygen, and nitrogen are described by USGS (2017b) and for carbon isotopes by USGS (variously dated). Procedures for CFCs and dissolved gases are described by USGS (2017a). Noble gas samples were collected in sealable copper tubes using a back-pressure system to decrease the possibility of bubble formation and degassing of the sample water during collection (Plummer and others, 2012b).

Samples for hydrogen-, oxygen-, and nitrogen-isotope determination were analyzed at the USGS Reston Stable Isotope Laboratory in Reston, Virginia, using methods described in Coplen and others (2012) and Révész and Coplen (2008a, 2008b). Samples for the determination of carbon-14, the radioactive isotope of carbon, and the related isotopic ratio of carbon-13 to carbon-12 were analyzed at the National Ocean Sciences Accelerator Mass Spectrometry Facility in Woods Hole, Massachusetts, following methods specified by the Woods Hole Oceanographic Institution (2011). Samples were analyzed for tritium, the radioactive isotope of hydrogen, at the USGS Tritium Laboratory in Menlo Park, California, using methods described in Thatcher and others (1977) and Östlund and Werner (1962). Analysis of samples for CFCs and dissolved gases were conducted at the USGS Reston Groundwater Dating Laboratory in Reston, Va., following methods described in USGS (2017a), and samples for noble gas determination were analyzed at the USGS Noble Gas Laboratory in Lakewood, Colorado, following methods described in Hunt (2015).

Data-Quality Assurance

Several quality-assurance procedures were applied to the compiled groundwater-chemistry dataset including (1) checks for duplicated results from the same data source, that is, identical measurements and analytical results for an environmental sample collected at the same site and date as another environmental sample; (2) examination of data for zero values, inconsistent results, and outliers; and (3) comparison of total to dissolved concentrations for the same constituent in a sample. Additionally, data for field blanks and field replicates were used to assess the variability and bias of groundwater-chemistry data that may have been introduced by sample collection, processing, shipping, and analysis. Finally, cation-anion charge balance differences were calculated for samples with complete major-ion data to evaluate the accuracy of laboratory analysis. Specific information on quality-control procedures, analysis methods, and analytical or statistical results are presented in appendix 2.

Potential contamination was evaluated using 19 field-blank samples that were collected by the UMUT at 11 sites from 2001 through 2015 and included data for all chemical constituent groups except environmental tracers. About 3 percent (11 of 392) of the field-blank results had concentrations greater than laboratory reporting limits (table 2.1 in app. 2), indicating that the potential for contamination of environmental samples is low. The concentration of dissolved zinc (9 micrograms per liter [µg/L]) in a field blank collected at Lagoon 1 well 3 in 2010 was the same as the concentration in the environmental sample collected on the same day. The environmental result for dissolved zinc was excluded from analysis.

Replicate samples were used to test for variability, which is the degree of random error in independent measurements of the same quantity. Replicate data were available for 185 replicate pairs (environmental concentration and paired replicate concentration for a constituent of interest) for 16 samples at 7 sites collected by the UMUT from 2009 through 2016 (table 4). Constituents included TDS, alkalinity, major ions, nutrients, trace elements, pesticides, VOCs, and coliform bacteria. Of the replicate pairs, 34 percent had both concentrations reported as less than laboratory reporting limits; these data were not included in replicate analysis.

Variability in constituent detection was estimated by calculating the percentage of replicate pairs with inconsistent detections (a pair containing a detected concentration and a concentration less than the laboratory reporting limit) using equation 1 (Mueller and others, 2015).

$$PID = [\text{number of inconsistent detections}/(\text{total number of replicate pairs–the number of replicate pairs with both concentrations less than the reporting limit})] \text{ x } 100, \qquad (1)$$

where

PID is the percentage of replicate pairs with inconsistent detections.

Of the replicate pairs, 14 percent had inconsistent detections. All data were retained for analysis.

Variability in constituent concentrations was estimated as either the standard deviation of the replicate-pair concentrations, used for concentrations less than (<) 1.0 mg/L or 1.0 µg/L (eq. 2), or as the relative percent difference of the replicate-pair concentrations (RPD_{rep}), used for concentrations greater than or equal to (≥) 1.0 mg/L or 1.0 µg/L (eq. 3; Mueller and others, 2015).

$$SD = SQRT[\sum((\text{env sample–replicate sample})/2)/n], \qquad (2)$$

where

SD is the standard deviation,
$SQRT$ is the square root,
$\sum$ is the “sum of,”
env sample is the concentration of the environmental sample, and
n is number of replicate pairs.

$$RPDrep = ABS[(\text{env sample–replicate sample})/((\text{env sample + replicate sample})/2)] \text{ x } 100, \qquad (3)$$

where

RPD_{rep} is the relative percent difference of the replicate-pair concentrations,
ABS is the absolute value, and
env sample is the concentration of the environmental sample.

The mean standard deviation of 17 replicate pairs with both concentrations <1.0 mg/L or 1.0 µg/L was 0.2 or less, and data were retained for analysis. Mean RPD_{rep} values for the 88 replicate pairs with both concentrations of 1.0 mg/L or 1.0 µg/L or more ranged from 0 to 181 percent. Many of the higher RPD_{rep} values were for trace elements. For many trace-element replicate pairs, the environmental concentration was substantially lower than the concentration in the replicate. The environmental sample concentrations in replicate pairs with a RPD_{rep} of 100 percent or more were excluded from analysis.

The accuracy of major-ion results was estimated by calculating the cation-anion balance percent difference for samples with data for dissolved cations (calcium, magnesium, potassium, sodium) and dissolved anions (bicarbonate, carbonate, chloride, sulfate). The difference was calculated for 34 samples collected by the UMUT using equation 4.

$$\text{Cation-anion balance percent difference} = ABS\,[(\sum\text{cations} - \sum\text{anions})/(\sum\text{cations} + \sum\text{anions})] \times 100, \tag{4}$$

where

ABS is the absolute value,

$\sum$cations is the sum of the concentrations of dissolved cations (calcium, magnesium, potassium, sodium) in milliequivalents per liter, and

$\sum$anions is the sum of the concentrations of dissolved anions (bicarbonate, carbonate, chloride, sulfate) in milliequivalents per liter.

For cation or anion concentrations that were less than laboratory reporting limits, one-half of the reporting limit was used in equation 4. For this report, ion balances of 5 percent or less were deemed acceptable. Only three samples had charge-balance percent differences greater than (>) 10 percent, and nine samples had differences between 5 and 10 percent. As described in appendix 2, these charge-balance differences were deemed acceptable, and the major-ion data were retained for analysis.

Data Aggregation and Summarization

Some chemical constituent data retrieved from the Water Quality Portal (National Water Quality Monitoring Council, 2017) used different names for the same constituent; for example, “inorganic nitrogen” (nitrate and nitrite) and “nitrate + nitrite” represent the same constituents. Data for constituents with multiple names were combined under one name (table 5). Methods used for laboratory analysis, also retrieved from the Water Quality Portal, were reviewed to determine or verify chemical forms of constituents; for example, nitrate plus nitrite as nitrogen rather than as nitrate. Review of methods for trace-element analysis confirmed that samples for total analysis were digested in the laboratory; the chemical form of “total” was changed to “total recoverable” as a result. Concentration data for trace element, pesticide, and VOC results that were originally reported as milligrams per liter were converted to micrograms per liter.

Summary statistics were calculated for each chemical constituent and fraction. Estimating the median statistic for groundwater-chemistry data was complicated by the presence of multiple laboratory reporting limits for many of the constituents. When groundwater-chemistry results were reported as less than laboratory reporting limits, estimates of the median (50th percentile) were calculated using (1) the Kaplan-Meier method when fewer than 50 percent of the data were less than laboratory reporting limits or (2) regression of ordered statistics methods when the less-than percentages were 50 to 80 percent (Helsel, 2005). The median was not calculated when more than 80 percent of the data were less-than values. Summary statistics, boxplots, a Piper diagram, and scatter plots are used in this assessment to depict the variability in select groundwater-chemistry properties and constituents.

Water-Quality Standards

Groundwater-chemistry data collected by the UMUT for springs were compared to surface-water quality standards established by the UMUT (table 6) (Larrick and Clow, 2011). Standards are applicable to one or more designated uses for springs including Tribal cultural use, warm-water aquatic life, and agricultural use. Springs specifically designated for the cultural-use standard are Hanna, Lopez 1 and 2, Ute, and Whiskers Draw (Larrick and Clow, 2011). For a stream segment with more than one designated use, the most stringent criterion is considered the applicable water-quality standard (Larrick and Clow, 2011). Aquatic-life standards for some metals are based on hardness; hardness-based formulas are included in table 6.

Groundwater-chemistry data for specific wells in Colorado were compared to basic standards for groundwater established by the Colorado Department of Public Health and Environment (CDPHE) (CDPHE, 2017) (table 6). The CDPHE basic standards for groundwater have been established to protect existing and potential beneficial uses of groundwater. For this assessment, groundwater standards for agricultural use are applied to wells that are or could potentially be used for livestock watering. Comparison of the livestock-water standards is applied to data from all wells except the AP, Lagoon, and LF wells, which were established for specific monitoring purposes. Comparison of data to water-quality standards is used in this report as a guideline for giving qualitative interpretations on the status of groundwater quality on the reservation; the standards are not used in this report for regulatory purposes.

Table 5. Aggregation of constituent names and data retrieved from the Water Quality Portal (WQP).

[See National Water Quality Monitoring Council (2017) for the WQP. µS/cm, microsiemens per centimeter; —, no conversion; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; Ca, calcium; Mg, magnesium; ROE, residue on evaporation at 180 degrees Celsius; SUM, sum of constituents; <, less than; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Consituent name as retrieved from WQP	Sample fraction as retrieved from WQP	Number of samples	Concentration range	Conversion	Constituent name and sample fraction used in report
Specific conductance (µS/cm)					
Conductivity	No fraction	35	3.9–10,520	—	Specific conductance
Specific conductance	No fraction	49	178–9,080	—	
Alkalinity (mg/L)					
Alkalinity, total, as $CaCO_3$	Dissolved	1	328	—	Alkalinity, as $CaCO_3$
Alkalinity, total	Dissolved	30	77–2,000	—	
Alkalinity, total	Total	36	73–1,335	—	
Alkalinity, total, as $CaCO_3$	No fraction	1	428	—	
Alkalinity, total	No fraction	1	290	—	
Hardness (mg/L)					
Hardness, as $CaCO_3$	No fraction	1	3,200	—	Hardness, as $CaCO_3$
Hardness, carbonate	Dissolved	27	7.7–3,793	—	
Hardness, Ca, Mg	Dissolved	7	87–2,903	—	
Hardness, Ca, Mg	Total	2	98; 3,910	—	
Hardness	Dissolved	1	918	—	
Total dissolved solids (mg/L)					
Total dissolved solids (ROE)	Dissolved	45	75–6,860	—	Total dissolved solids
Total dissolved solids (ROE)	Total	2	3,400; 20,000	—	
Total dissolved solids (SUM)	—	10	324–6,318	—	
Major ions (mg/L)					
Alkalinity, bicarbonate, as $CaCO_3$	No fraction	2	302; 428	—	Bicarbonate, as $CaCO_3$
Alkalinity, bicarbonate	Dissolved	10	77–1,290	—	
Alkalinity, bicarbonate	No fraction	5	243–1,760	—	
Bicarbonate	Dissolved	43	85–1,959	—	
Alkalinity, carbonate, as $CaCO_3$	Dissolved	1	26	—	Carbonate, as $CaCO_3$
Alkalinity, carbonate, as $CaCO_3$	No fraction	1	<10	—	
Alkalinity, carbonate	Dissolved	10	<10–240	—	
Alkalinity, carbonate	No fraction	5	<10–280	—	
Carbonate	Dissolved	43	0–240	—	
Nutrients (mg/L)					
Ammonia	Total	4	<0.05–0.08	—	Ammonia, unfiltered, as N
Ammonia	Total recoverable	13	<0.024–1.85	—	
Ammonia as N	Total recoverable	3	<0.043	—	
Ammonia	Unfiltered	2	<0.05; 0.05	—	
Inorganic nitrogen (nitrate and nitrite)	Total	11	<0.011–52.3	—	Nitrate plus nitrite, unfiltered, as N
Nitrate + Nitrite	Total	18	<0.01–45.8	—	
Nitrate/Nitrite as N	Total	3	<0.011–68	—	
Nitrate	Total	4	0.409–78.5	Sum	
Nitrite	Total	4	0.023–0.07		

Table 5. Aggregation of constituent names and data retrieved from the Water Quality Portal (WQP).—Continued

[See National Water Quality Monitoring Council (2017) for the WQP. µS/cm, microsiemens per centimeter; —, no conversion; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; Ca, calcium; Mg, magnesium; ROE, residue on evaporation at 180 degrees Celsius; SUM, sum of constituents; <, less than; N, nitrogen; P, phosphorus; µg/L, micrograms per liter]

Consituent name as retrieved from WQP	Sample fraction as retrieved from WQP	Number of samples	Concentration range	Conversion	Constituent name and sample fraction used in report
Phosphorus	Total	34	<0.011–0.43	—	Total phosphorus, as P
Phosphorus, Total	Total	3	<0.011–0.053	—	
Trace elements (µg/L)					
Aluminum	Total	4	250–10,300	—	Aluminum, total recoverable
Aluminum	Total recoverable	20	<1–817	—	
Antimony	Total	3	<100	—	Antimony, total recoverable
Antimony	Total recoverable	4	<0.4	—	
Arsenic	Total	37	<0.5–224	—	Arsenic, total recoverable
Arsenic	Total recoverable	20	<0.1–7.6	—	
Barium	Total	11	<10–99	—	Barium, total recoverable
Barium	Total recoverable	7	4.8–207	—	
Boron	Total	2	<100		Boron, total recoverable
Boron	Total recoverable	1	<300		
Cadmium	Total	8	<0.09–<50	—	Cadmium, total recoverable
Cadmium	Total recoverable	18	<0.01–<0.1	—	
Chromium	Total	3	<3.7–8.4	—	Chromium, total recoverable
Chromium	Total recoverable	14	<0.1–14	—	
Copper	Total	5	<5–20	—	Copper, total recoverable
Copper	Total recoverable	20	0.2–35.3	—	
Iron	Total	9	<50–6,310	—	Iron, total recoverable
Iron	Total recoverable	22	<24–1,480	—	
Lead	Total	15	<0.2–<100	—	Lead, total recoverable
Lead	Total recoverable	8	<0.03–1.4	—	
Manganese	Total	7	<5–484	—	Manganese, total recoverable
Manganese	Total recoverable	8	4.9–538	—	
Molybdenum	Total	2	<50	—	Molybdenum, total recoverable
Molybdenum	Total recoverable	16	<0.05–14.2	—	
Nickel	Total	4	3–8.1	—	Nickel, total recoverable
Nickel	Total recoverable	13	1–13.4	—	
Selenium	Total	37	<0.5–231	—	Selenium, total recoverable
Selenium	Total recoverable	17	<0.3–212	—	
Silver	Total	1	<0.1	—	Silver, total recoverable
Silver	Total recoverable	7	<0.02–<0.1	—	
Vanadium	Total	2	<20	—	Vanadium, total recoverable
Vanadium	Total recoverable	17	<0.5–5	—	
Zinc	Total	11	<1–<200	—	Zinc, total recoverable
Zinc	Total recoverable	20	<0.4–486	—	

Table 6. Ute Mountain Ute Tribe (UMUT) water-quality standards for surface waters of the Ute Mountain Ute Reservation and Colorado Department of Public Health and Environment (CDPHE) basic standards for agricultural use of groundwater.

[UMUT water-quality standards are from Larrick and Clow (2011). CDPHE basic standards for groundwater are from CDPHE (2017). °C, degrees Celsius; —, no standard; <, less than; mg/L, milligrams per liter; ≤, less than or equal to; dis, dissolved; NH_3, unionized ammonia; N, nitrogen; µg/L, micrograms per liter, trec, total recoverable; cfu/100 mL, colony-forming units per 100 milliliters]

Contaminant	UMUT water-quality standards for surface waters by designated use[1,2]				CDPHE basic standards for agricultural use of groundwater[3]
	Tribal cultural use	Warm water aquatic life		Agriculture, irrigation, and (or) livestock watering	
		Acute	Chronic		
Physical properties					
pH (standard units)	6.5–8.5	6.5–9.0		6.5–9.0	6.5–8.5
Termperature (°C)	—	<30 °C with maximum 3 °C increase		<50 °C	—
Dissolved oxygen (mg/L)	—	(4)		—	—
Total dissolved solids and major ions (mg/L)					
Total dissolved solids	≤500	—	—	Livestock consumption: ≤5,000	Based on background value[5]
Fluoride	—	—	—	—	2 (dis)
Nutrients (mg/L)					
Ammonia, NH_3, as N	0.5 (dis)[6]	Formula (total)[7]	Formula (total)[6,7]	—	—
Nitrite, as N	1.0 (acute)[8]	Formula (total)[9]	Formula (total)[6,9]	10 (acute)[8]	10 (dis)
Nitrate plus nitrate, as N	10 (chronic)[8]	—	—	100 (chronic)[6]	100 (dis)
Trace elements and uranium (µg/L)					
Aluminum	200 (trec)	750 (trec)	87, 750 (trec)[10]	—	5,000 (dis)
Antimony	5.6 (trec)[6]	—	—	—	—
Arsenic	0.018 (trec)[8]	340 (trec)	150 (trec)	100 (trec)[6]	100 (dis)
Barium	1,000 (trec)[8]	—	—	—	—
Beryllium	—	—	—	—	100 (dis)
Boron	—	—	—	750 (dis)	750 (dis)
Cadmium	5 (trec)[8]	Formula (dis)[11,12,13]	Formula (dis)[11,12,13]	10 (trec)[6]	10 (dis)
Chromium	50 (trec)[8]	16 (dis)	11 (dis)	100 (trec)[6]	100 (dis)
Cobalt	—	—	—	—	50 (dis)
Copper	1,000 (trec)[6]	Formula (dis)[12,13,14]	Formula (dis)[12,13,14]	200 (trec)[6]	200 (dis)
Iron	—	—	—	—	5,000 (dis)
Lead	50 (trec)[8]	Formula (dis)[12,13,15]	Formula (dis)[12,13,15]	100 (trec)[6]	100 (dis)
Manganese	—	—	—	—	200 (dis)
Mercury	0.05 (total)[8,16]	1.4 (total)[16]	0.012 (total)[16]	10 (total)[6,16]	10 (dis)
Nickel	100 (trec)[6]	Formula (dis)[12,13,17]	Formula (dis)[12,13,17]	200 (trec)[6]	200 (dis)
Selenium	50 (trec)[6]	20 (trec)	5 (trec)	20 (trec)[6]	20 (dis)
Silver	100 (trec)[8]	Formula (dis)[12,13,18]	Formula (dis)[12,13,18]	—	—
Vanadium	—	—	—	—	100 (dis)
Zinc	5,000 (trec)[6]	Formula (dis)[12,13,19]	Formula (dis)[12,13,19]	2,000 (trec)[6]	2,000 (dis)
Uranium	30 (trec)	—	—	—	—
Pesticides (µg/L)[20]					
Alachlor	[21]2	—	—	—	—
Atrazine	[21]3	—	—	—	—

Table 6. Ute Mountain Ute Tribe (UMUT) water-quality standards for surface waters of the Ute Mountain Ute Reservation and Colorado Department of Public Health and Environment (CDPHE) basic standards for agricultural use of groundwater.—Continued

[UMUT water-quality standards are from Larrick and Clow (2011). CDPHE basic standards for groundwater are from CDPHE (2017). °C, degrees Celsius; —, no standard; <, less than; mg/L, milligrams per liter; ≤, less than or equal to; dis, dissolved; NH_3, unionized ammonia; N, nitrogen; µg/L, micrograms per liter, trec, total recoverable; cfu/100 mL, colony-forming units per 100 milliliters]

Contaminant	UMUT water-quality standards for surface waters by designated use[1,2]				CDPHE basic standards for agricultural use of groundwater[3]
	Tribal cultural use	Warm water aquatic life		Agriculture, irrigation, and (or) livestock watering	
		Acute	Chronic		
Volatile organic compounds (µg/L)[20]					
Di(2-ethylhexyl) phthalate[22]	[21]1.2	—	—	—	—
Bacteria (cfu/100 mL)					
Escherichia coli	0 (absent)	—	—	—	—

[1] For this report, surface-water standards are applied to spring data only. For a water body with multiple use designations, the most stringent criteria will be the goal of its water-quality standard.

[2] For constituents that lack numeric water-quality criteria or for which numeric criteria are not protective or representative of clean water goals, the following narrative water-quality criteria apply. "All Reservation surface waters shall be free from substances, from any pollution source, that:

a) Settle to form objectionable deposits;
b) Float as debris, scum, oil, or other matter forming nuisances;
c) Produce objectionable color, odor, taste, or turbidity;
d) Cause injury to, or are toxic to, or produce adverse physiological responses in humans, animals, or plants; or
e) Produce undesirable or nuisance aquatic life." (Larrick and Clow, 2011, p. 10)

[3] For the purposes of this report, the standard is applied to groundwater that is currently or could potentially be used for livestock watering. This excludes the AP, Lagoon, LF, and Wing wells, which were established for specific monitoring purposes.

[4] Warm-water aquatic life standards. Early life stages: 5.0 mg/L, 1-day mean minimum; 6.0 mg/L, 7-day mean. Other life stages: 3.0 mg/L, 1-day mean minimum; 4.0 mg/L 7-day mean minimum, 5.5 mg/L, 30-day mean. Standards used for comparison purposes are the 1-day mean minimum for early and other life stages.

[5] CDPHE standards for dissolved solids:

a) Background value 0–500 mg/L, standard 400 mg/L or 1.25 times background, whichever is least restrictive.
b) 501–10,000 mg/L, 1.25 times background.
c) 10,001 mg/L or greater, no limit.

[6] 30-day standard.

[7] Ammonia (NH_3). Acute criterion (1-hour): $[0.411/(1+10^{7.204-\mathrm{pH}})]+[58.4/(1+10^{\mathrm{pH}-7.204})]$. Chronic criterion: $[0.0577/(1+10^{7.688-\mathrm{pH}})+(2.487/1+10^{\mathrm{pH}-7.688})]*(1.45*10^{0.028*\mathrm{MAX}(25-T,\ 7)})$.

[8] 1-day standard.

[9] Nitrite. Acute criterion: (1-hour): 0.20(2.00$[Cl^-]$+0.73). Chronic criterion: 0.10(2.00$[Cl^-]$+0.73). $[Cl^-]$ = chloride ion concentration in mg/L, upper Cl^- limit = 22 mg/L.

[10] Chronic criterion is 87 µg/L, unless the pH is 7.0 or greater and the hardness is 50 mg/L as $CaCO_3$ or greater.

[11] Cadmium. Acute criterion: e^(1.0166[ln(hardness)]−3.924)*(1.136672[ln(hardness)(0.041838)]). Chronic criterion: e^(0.7409[ln(hardness)]−4.719)*(1.101672–[ln(hardness)(0.041838)]).

[12] Hardness-dependent criteria are based on hardness expressed as mg/L $CaCO_3$. For waters with a hardness value greater than 400 mg/L as $CaCO_3$, the criterion should be calculated using a hardness value of 400 mg/L, unless a water-effects ratio calculation is to be used.

[13] Not to be exceeded more than once every 3 years on average. The acute criteria has a 1-day averaging period. The chronic criteria has a 4-day averaging period.

[14] Copper. Acute criterion: e^(0.9422[ln(hardness)]–1.700)(0.960). Chronic criterion: e^(0.8545[ln(hardness)]−1.702)(0.960).

[15] Lead. Acute criterion: e^(1.273[ln(hardness)]–1.460)*(1.46203–[ln(hardness)(0.145712)]). Chronic criterion: e^(1.273[ln(hardness)]–4.705)*(1.46203–[ln(hardness)(0.145712)]).

[16] Mercury criteria are µg/L of total mercury.

[17] Nickel. Acute criterion: e^(0.8460[ln(hardness)]+2.255)(0.998). Chronic criterion: e^(0.8460[ln(hardness)]+0.0584)(0.997).

[18] Silver. Acute criterion: e^(1.72[ln(hardness)]−6.52)(0.85). Chronic criterion: e^(1.72[ln(hardness)]−9.06)(0.85).

[19] Zinc. Acute criterion: e^(0.8473[ln(hardness)]+0.884)(0.978). Chronic criterion: e^(0.8473[ln(hardness)]+0.884)(0.986).

[20] Only includes constituents with a detected value; that is, a value greater than the detection level or reporting limits.

[21] Human health criteria (health advisory) 30-day average or chronic value. Criteria applies to water designated as drinking-water source.

[22] Listed as “Bis(2-ethylhexyl) phthalate” in Larrick and Clow, 2011.

Hydrogeologic Characterization of Surficial Deposits and Dakota Sandstone

In the Farm and Ranch Enterprise area, the surficial deposits occur primarily on upland areas separated by the incised drainages of Marble, Coyote, and Mariano Washes, which create local areas of saturation that are largely disconnected by bedrock outcrops (fig. 4). The water table in the surficial aquifer contained in the surficial deposits in the Farm and Ranch Enterprise area ranged from 0.9 to 24.9 ft below land surface (bls), and median values were 5.4 to 17.2 ft bls (table 2). The water surface slopes to the southwest away from the Ute Mountains with a mean gradient of about 94 ft per mile. Because subsurface lithologic information was available for only one well in the Farm and Ranch Enterprise area, the thickness of surficial deposits in the upland areas could not be estimated. However, well depths reported by the UMUT for monitoring wells completed in the surficial aquifer on upland areas range from 6.4 to 26.6 ft bls (table 1.1 in app. 1).

Near Towaoc, the surficial deposits occur primarily along the drainages and associated terraces of Cottonwood Wash, Navajo Wash, and an unnamed tributary of Navajo Wash (fig. 3). Again, local areas of saturation are disconnected by bedrock outcrops. The bedrock near Towaoc, however, generally crops out in upland areas (rather than along incised drainages) that separate lower-lying surficial deposits. Water levels measured in wells completed in the surficial aquifer near Towaoc indicate that the water table ranged from about 11 to 34 ft bls (table 1.1 in app. 1), and the water table slopes generally southward with a mean gradient of about 143 ft per mile. Well records indicate surficial deposits near Towaoc are 30–44 ft thick (Irwin, 1966).

The Dakota aquifer contained in the Dakota Sandstone is the primary bedrock aquifer beneath the UMUR. Where the underlying Burro Canyon Formation is present, it is often difficult to distinguish from the Dakota Sandstone in the subsurface, and the two formations generally are considered a single hydrostratigraphic unit (Irwin, 1966). The structure of the Dakota Sandstone in the UMUR exhibits substantial folding because of past tectonic forces in the region. The predominant dip of the formation generally is to the south and east. However, this general trend is disrupted by uplift related to igneous activity in the vicinity of the Ute Mountains and by other structural features such as basins, domes, faults, synclines, and anticlines.

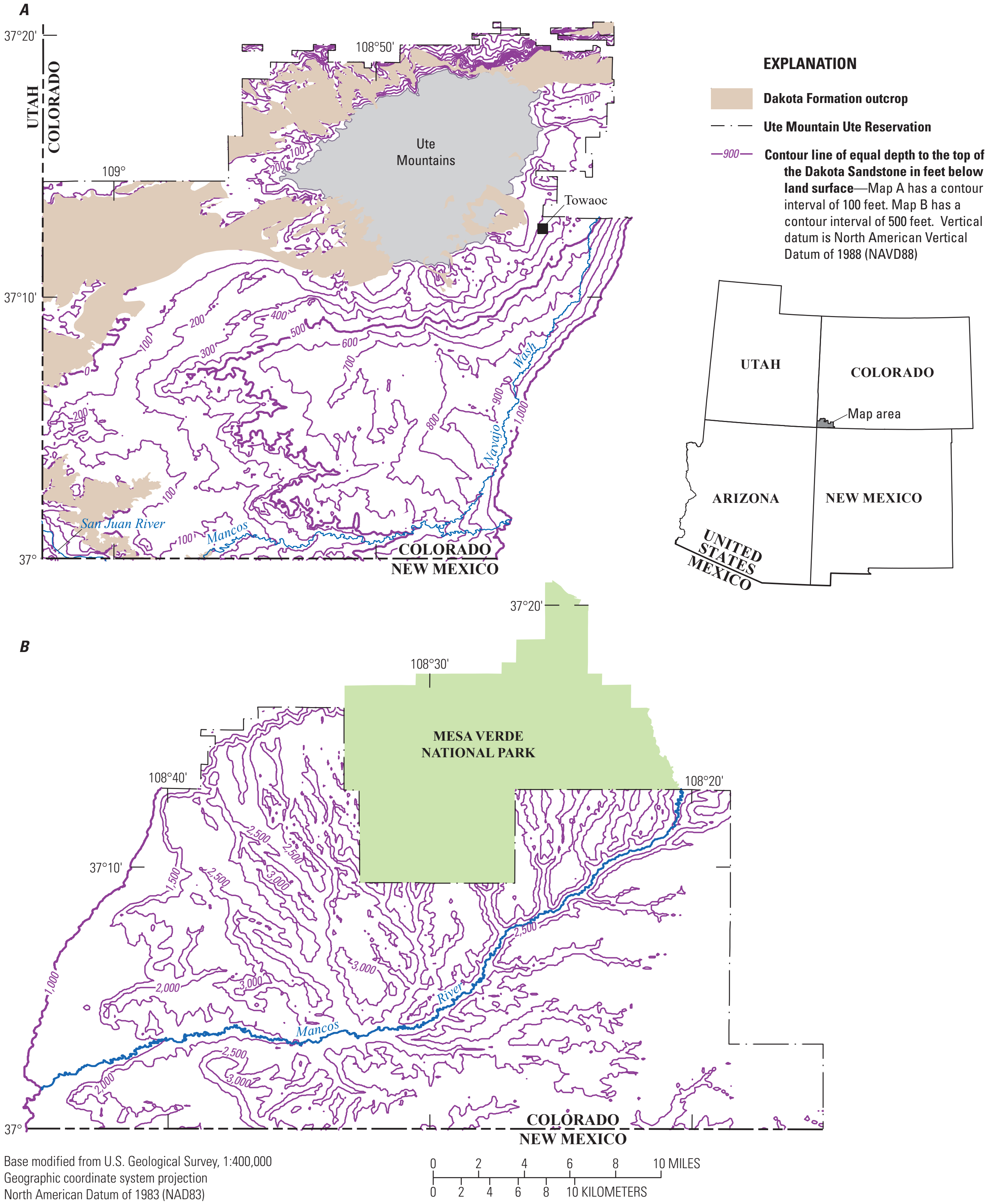
The depth to the top of the Dakota Sandstone is affected by both the subsurface structure of the formation and the topography of the land surface. In the western part of the UMUR, where topography generally has low relief, the depth to the top of the formation in feet below land surface increases somewhat consistently to the east (fig. 7*A*), reflecting the eastward dip direction of the formation in the subsurface. Farther to the east, topographic relief is high with steep slopes and mesas dissected by canyons, and the depth to the top of the Dakota Sandstone primarily is affected by the topography of the land surface. Within the boundaries of the UMUR in Colorado, depths to the top of the Dakota Sandstone range from zero in outcrop areas to 1,000 ft bls in the western part of the UMUR (fig. 7*A*) and >3,000 ft bls on mesas in the southeastern part of the UMUR (fig. 7*B*).

Groundwater Chemistry

The chemical quality of groundwater is determined by natural factors and processes as well as human activities. Primary natural factors and processes that affect groundwater chemistry include source, chemical composition, and amount of recharge water; lithologic and hydrologic properties of geologic materials (sediments, minerals, and rocks); chemical processes affecting geologic materials and groundwater; and the length of time groundwater is in contact with geologic materials. Human activities that change land cover and land use from natural grasslands to agriculture, urbanization, and oil and gas development also can affect groundwater quality. Nutrients and pesticides can be added to groundwater through agricultural practices, and VOCs can be added from chemical and gasoline spills and usage. Contaminants can be released to the environment and groundwater from leaking underground storage tanks and waste ponds, urban runoff, and commercial activities. Because most of the UMUR is undeveloped land, the chemical quality of groundwater is largely determined by natural factors and processes.

A thorough understanding of groundwater chemistry on the UMUR is limited because of incomplete knowledge of spring and well lithology and the lack of well information (well depth and screen location). Where possible, estimations of spring lithology are based on comparisons of groundwater chemistry data of springs assessed in this report to historical spring chemistry data and lithology (Irwin, 1966; Geldon, 1985; USGS, 2016b) and on spring location (fig. 5, table 7). Lithology and well information were sourced from the UMUT (UMUT, 2004), Colorado Division of Water Resources (Colorado Department of Natural Resources, 2019), Irwin (1966), Geldon (1985), and USGS (2016b), and information on depth to the Dakota Sandstone provided in this report (table 7).

Springs on the UMUR likely originate from igneous debris and pediment gravels, weathered Mancos Shale, and alluvium (table 7). High-altitude springs on the Ute Mountains discharge from igneous debris at contacts with less permeable material. Irwin (1966) reports that talus and block rubble on mountain slopes are catchment areas for snowmelt, which discharges as springs at the base of slopes overlying less permeable material, such as Mancos Shale. Similarly, Geldon (1985) reports that block rubble overlies Mancos Shale and igneous rocks. Springs that likely originate from talus and block rubble include Cottonwood Wash, Elk Meadows, Hanna, Last Lake, Lopez 1 and 2, Ute, and Whisky Road (table 7). Bancroft Spring, which is in the same location as Spring 9 in Geldon (1985), likely originates from older pediment gravels (table 7). On the lower-altitude plains, the East and West Toe



EXPLANATION

🟫 **Dakota Formation outcrop**

— · — **Ute Mountain Ute Reservation**

—900— **Contour line of equal depth to the top of the Dakota Sandstone in feet below land surface**—Map A has a contour interval of 100 feet. Map B has a contour interval of 500 feet. Vertical datum is North American Vertical Datum of 1988 (NAVD88)

Base modified from U.S. Geological Survey, 1:400,000
Geographic coordinate system projection
North American Datum of 1983 (NAD83)

Figure 7. Generalized depth to the top of the Dakota Sandstone in feet below land surface on the Ute Mountain Ute Reservation in Colorado. The contour lines are lines of equal depth to the top of the Dakota Sandstone in feet below land surface. The map has been split because of a difference in contour intervals. Map *A* has a contour interval of 100 feet. Map *B* has a contour interval of 500 feet.

Table 7. Estimation of lithology for springs and wells located on the Ute Mountain Ute Reservation in Colorado and Utah and information on select monitoring wells in Colorado.

[Unless stated otherwise, all well and formation depths and screen intervals are assumed to be measured from the land surface. Colorado Division of Water Resources (CDWR) permits are from Colorado Department of Natural Resources (2019). fig., figure; ID, identification; na, not applicable; TDS, total dissolved solids; —, no information; ft, feet; bls, below land surface; UMUT, Ute Mountain Ute Tribe; btoc, below top of casing]

Site (see fig. 5, site ID in parentheses is used on figure)	Lithology	Monitoring-well information
	Springs	
Bancroft Spring (S1)	Older pediment deposits (Geldon, 1985; designated Spring 9)	na
Cottonwood Wash Spring (S2)	Talus and block rubble based on water chemistry and spring location	na
East Toe Spring (S3)	Likely younger pediment deposits and weathered Mancos Shale	na
Elk Meadows Spring (S4)	Talus and block rubble based on water chemistry and spring location	na
Hanna Spring (S5)	Talus and block rubble based on water chemistry and spring location	na
Last Lake Spring (S6)	Talus and block rubble based on water chemistry and spring location	na
Lopez 1 Spring (S7)	Talus and block rubble based on water chemistry and spring location. Block rubble overlying Juana Lopez Member of Mancos Shale (Geldon, 1985; designated Spring 5). Similar location as Juana Lopez Spring of Irwin (1966), designated S–3 Spring	na
Lopez 2 Spring (S8)	Talus and block rubble based on water chemistry and spring location. Block rubble overlying Juana Lopez Member of Mancos Shale (Geldon, 1985; designated Spring 5). Similar location as Juana Lopez Spring of Irwin (1966), designated S–3 Spring	na
Navajo Spring (S9)	Younger pediment deposits (Geldon, 1985, designated Spring 16), alluvium and Mancos Shale (Irwin, 1966; designated S–15 Spring), and weathered Mancos Shale	na
Ute Spring (S10)	Talus and block rubble based on water chemistry and spring location	na
West Toe Spring (S11)	Likely younger pediment deposits and weathered Mancos Shale.	na
Whisky Road Spring (S12)	Talus and block rubble based on water chemistry and spring location	na
Whiskers Draw Spring (S13)[1]	Likely discharges from alluvium and eolian deposits that overlie Jurassic-age rocks; based on location on geologic map of Utah (Utah Geological Survey, 2013)	na
	Wells	
4000B well (W1)	Dakota Sandstone. Similar well location and mostly similar water chemistry (TDS, cations, anions, water type) as Irwin (1966) well A–8. Lithology of A–8 from U.S. Geological Survey, 2016b	na
4C well (W2)	—	na
5000 Block well (W3)	—	na
AP–1	Eolian deposits, weathered Mancos Shale	Shallow (6.4–26.6 ft bls, UMUT) monitoring wells downgradient from irrigation center pivots on Farm and Ranch Enterprise Irrigation project; used to assess effects of agricultural operations and irrigation return flows on water quality
AP–10		
AP–11		
AP–14		
AP–15		
AP–16		
AP–24		
AP–5	Possibly eolian deposits	

Table 7. Estimation of lithology for springs and wells located on the Ute Mountain Ute Reservation in Colorado and Utah and information on select monitoring wells in Colorado.—Continued

[Unless stated otherwise, all well and formation depths and screen intervals are assumed to be measured from the land surface. Colorado Division of Water Resources (CDWR) permits are from Colorado Department of Natural Resources (2019). fig., figure; ID, identification; na, not applicable; TDS, total dissolved solids; —, no information; ft, feet; bls, below land surface; UMUT, Ute Mountain Ute Tribe; btoc, below top of casing]

Site (see fig. 5, site ID in parentheses is used on figure)	Lithology	Monitoring-well information
AW Hwy 141 (W4)	Likely Junction Creek Sandstone. Similar well location and water chemistry (TDS, cations, anions, water type) as Irwin (1966) well B–11. Lithology of B–11 from U.S. Geological Survey, 2016b	na
AW Hwy 160/141 (W5)	—	na
Chimney Rock well (W6)	Dakota Sandstone, based on well depth (1,346 ft bls, UMUT) and well location in relation to depth to top of Dakota Sandstone	na
HC Corral well (W7)	Mancos Shale. CDWR permit 77484–F, Well Construction and Test Report. Well depth 500 ft; Mesaverde Group 7–30 ft, Mancos Shale 30–500 ft, water level 160 ft bls	na
Cottonwood Spring well (W8)	—	na
FW-W (W9)	—	na
Goodknight well (W10)	Mancos Shale, based on well depth (approximately 240 ft bls, UMUT), well location in relation to depth to top of Dakota Sandstone, and geologic log for nearby well (CDWR permit 52885–FR, shale 16–772 ft)	na
Knight well (W11)	na	na
Lagoon 1 well 1 (W12)	Weathered Mancos Shale, Mancos Shale. CDWR permit MH–39051. Well depth 20 ft, screen 10–20 ft in sandy clay and dark shale	Shallow monitoring well used to assess potential migration of constituents into Navajo Wash and groundwater. Well downgradient from wastewater Lagoon 1 system
Lagoon 1 well 3 (W13)	Weathered Mancos Shale. CDWR permit MH–39049. Well depth 28 ft, screen 18–28 ft in clay	Shallow monitoring well used to assess potential migration of constituents into Navajo Wash and groundwater. Well downgradient from wastewater Lagoon 1 system
Lagoon 2 well 2 (W14)	Weathered Mancos Shale, Mancos Shale. CDWR permit MH–39059. Well depth 30 ft, screen 20–30 ft in sandy clay and dark shale	Shallow monitoring well used to assess potential migration of constituents into Navajo Wash. Well downgradient from Lagoon 2 sewer system
Lewis well (W15)	—	na
LF well 1 (W16)	Weathered Mancos Shale, Mancos Shale. CDWR permit MH–39048. Well depth 20 ft, screen 10–20 ft in clay and dark shale	Shallow monitoring well used to assess potential migration of constituents from landfill into Navajo Wash
LF well 3 (W17)	DWR permit MH–39057. Well depth 38 ft, screen 28–38 ft in clay and sandstone	Shallow monitoring well used to assess potential migration of constituents from landfill into Navajo Wash
Mariano-FW (W18)	—	na
MR-FW (W19)	—	na

Table 7. Estimation of lithology for springs and wells located on the Ute Mountain Ute Reservation in Colorado and Utah and information on select monitoring wells in Colorado.—Continued

[Unless stated otherwise, all well and formation depths and screen intervals are assumed to be measured from the land surface. Colorado Division of Water Resources (CDWR) permits are from Colorado Department of Natural Resources (2019). fig., figure; ID, identification; na, not applicable; TDS, total dissolved solids; —, no information; ft, feet; bls, below land surface; UMUT, Ute Mountain Ute Tribe; btoc, below top of casing]

Site (see fig. 5, site ID in parentheses is used on figure)	Lithology	Monitoring-well information
SE Toe well (W20)	Mancos Shale/upper Dakota Sandstone, based on well depth (383 ft btoc, UMUT) and well location in relation to top of Dakota Sandstone	na
TF-Corral well (W21)	—	na
Toe well (W22)	Likely Mancos Shale/upper Dakota Sandstone, based on well depth (128 ft, UMUT) and well location in relation to depth to top of Dakota Sandstone	na
Wing well (W23)	Weathered Mancos Shale	Monitoring well used to assess effects of agricultural operations and irrigation return flows on water quality and use attainment for livestock drinking

[1]Spring is shown on figure 1.

Springs (S3 and S11) likely discharge from pediment gravels and weathered Mancos Shale, whereas the Navajo Spring (S9) likely discharges from pediment gravels, weathered Mancos Shale, and alluvium (fig. 5, table 7). As with higher-altitude springs, the two Toe Springs and the Navajo Spring are contact springs at which water percolating though permeable material discharges at the contact with less permeable shale. Based on the geologic map of Utah (Utah Geological Survey, 2013), Whiskers Draw Spring (S13 on fig. 1) likely discharges from alluvium and eolian deposits that overlie Jurassic-age rocks.

Shallow wells, those with well depths of less than or equal to 38 ft bls, have been installed for specific monitoring purposes and tap different materials depending on monitoring use. The AP and Wing (W23) wells, which were installed in the Farm and Ranch Enterprise area to assess effects of agricultural operations and irrigation return flows on groundwater chemistry, likely tap eolian deposits and (or) weathered Mancos Shale (table 7). Elevated values of specific conductance and concentrations of nitrate plus nitrite and selenium in most samples can be indicative of groundwater in weathered Mancos Shale (U.S. Department of Energy [DOE], 2011). The Lagoon wells (W12, W13, and W14) and LF wells (W16 and W17), installed near Towaoc (fig. 5) to monitor the effects of the wastewater lagoon systems and landfill on groundwater chemistry, are likely completed in weathered Mancos Shale (table 7). The source of water for these wells, however, could also include lagoon and landfill discharges in the underlying shale.

The lithology and source of groundwater at deeper wells were more difficult to determine. A lithologic log was only located for the HC Corral well (Colorado Department of Natural Resources, 2019, permit 77843-F); the log indicated Mancos Shale as the source of water (table 7). Lithology for two wells, 4000B and AW Hwy 141, was estimated based on two wells with a similar location and groundwater chemistry that are described in Irwin (1966) and well information provided for each site in NWIS (USGS, 2016b). The 4000B well likely taps the Dakota Sandstone, similar to A-8 well of Irwin (1966), and AW Hwy 141 well likely taps the Junction Creek Sandstone, similar to B-11 well of Irwin (1966) (table 7). For other wells (Chimney Rock, Goodknight, SE Toe, and Toe), the likely source of water was estimated based on the well depth, well location in relation to depth to the top of the Dakota Sandstone, and (or) lithology of a nearby well (table 7). The specific source of water for the remaining wells (4C, 5000 Block, AW Hwy 160/141, Cottonwood Spring, FW-W, Knight, Lewis, Mariano-FW, MR-FW, and TF-Corral) could not be determined because of the lack of information on well depth, well completion and screen interval, and lithology.

Physical Properties

Physical properties reported herein include specific conductance, pH, water temperature, dissolved oxygen (DO), and hardness. Specific conductance is the ability of a substance to conduct an electrical current (Hem, 1985). In water, it is proportional to the concentration of major dissolved constituents (calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride, and sulfate). In this report, specific conductance is reported as microsiemens per centimeter at 25 degrees Celsius (µS/cm @ 25 °C; henceforth "µS/cm"). The weathering of minerals in soil and bedrock is a primary source of major dissolved constituents in water. Igneous rocks and materials derived from igneous rocks have comparatively slow weathering rates. Sedimentary rocks, which underlie non-Ute Mountains areas of the UMUR, have faster weathering rates, which results in an increase in dissolved constituents and specific conductance in water compared to water sourced from igneous materials.

Specific conductance in 13 springs sampled by the UMUT ranged from 178 to 1,647 µS/cm with a median of 512 µS/cm (table 8). Specific conductance values less than the median typically were measured in water samples from five of the eight springs on the Ute Mountains, including Hanna (S5), Last Lake (S6), Lopez 1 (S7), Lopez 2 (S8), and Ute (S10) (fig. 5). Almost all specific conductance values for Ute Mountain springs were less than those for lower-altitude springs (fig. 8). Specific conductance values >1,000 µS/cm typically were measured in the lower-altitude springs: East Toe (S3), Navajo (S9), and West Toe (S11) (fig. 5). Water for these springs likely is discharged from materials that include the marine Mancos Shale (table 7), where high specific conductance would be expected.

Groundwater samples from 21 wells contained more dissolved materials than spring samples (fig. 8, table 8). Specific conductance values for wells sampled by the UMUT ranged from 646 to 10,520 µS/cm, and the median was 6,024 µS/cm (table 8). For shallow wells, values >4,000 µS/cm (fig. 8) were measured in samples from most AP wells. The interaction of infiltrating irrigation water with minerals in the subsurface has likely increased the amount of dissolved constituents in water that recharges the shallow aquifer system. Only samples from AP–5 and Lagoon 2 wells had values less than about 1,500 µS/cm (fig. 8). The lower values for AP–5 indicate that the water in the well is different than the other AP wells. However, without specific information on lithology thickness and well-screen interval, the difference in specific conductance for the AP wells cannot be confidently explained.

In deeper parts of the groundwater system, dissolved materials can increase because of natural reactions occurring between groundwater and rocks as water slowly (centuries to millennia) flows from shallow to deeper parts of the system. For example, some of the Junction Creek Sandstone was deposited in a marine environment and has minerals that may contribute to increased specific conductance. Specific conductance in deeper wells sampled by the UMUT ranged from 1,010 to 9,080 µS/cm, and the median was 3,670 µS/cm (fig. 8). Groundwater in the Mancos Shale can naturally contain large amounts of dissolved materials, for example, specific conductance ranged from 418 to 70,002 µS/cm in samples from shale beds in Colorado, New Mexico, and Utah (DOE, 2011). Specific conductance in the Goodknight (fig. 8) and HC Corral wells, deep wells identified as likely tapping only the Mancos Shale (table 7), were 9,080 and 2,860 µS/cm, respectively. Wells that likely tap the Dakota Sandstone, the 4000B and Chimney Rock Windmill wells, had a specific conductance of 3,115 and 2,953 µS/cm, respectively (fig. 8). These measurements are well within the range of 347 to 12,100 µS/cm for groundwater in the Dakota Sandstone in the San Juan structural basin, which is mostly in New Mexico (Craigg and others, 1989). Specific conductance values of 7,100 and 7,420 µS/cm for the AW Hwy 141 well were similar to the specific conductance of 7,240 µS/cm reported for well B-11 by Irwin (1966); both wells likely tap the Junction Creek Sandstone (table 7).

A pH value represents the effective concentration (activity) of hydrogen ions in water and is measured as the negative logarithm of the hydrogen ion activity (Hem, 1985). The pH of a water sample is important because the health of aquatic life is susceptible to pH, and the solubility and biological availability of nutrients and trace elements and some chemical processes are pH dependent. The pH for spring samples ranged from 6.4 to 8.6 (table 8), and most of the pH values (33 of 35) were within the ranges established by the UMUT for cultural use of water, aquatic-life criteria, and agricultural uses of surface water (table 9). The pH values for well samples ranged from 6.8 to 9.0 (table 8). The CDPHE standard was exceeded for samples from four wells (table 9).

Water temperature is an important property that controls biological and chemical reaction rates. Temperature often directly affects the life cycles of aquatic organisms and DO concentrations (Hem, 1985). Many spring samples had a lower water temperature than well samples, reflecting the high altitude of many springs on the Ute Mountains and recharge from snowmelt (table 8). There were no exceedances of water-quality standards for water temperature.

Dissolved oxygen is the measurement of the oxygen content in water. Reduction-oxidation (redox) processes, including DO, nitrate, iron, manganese, and sulfate reduction, affect groundwater chemistry in all groundwater systems (Hem, 1985). Understanding redox processes can be a valuable tool in interpreting groundwater-chemistry data and assessing the susceptibility or vulnerability of an aquifer to land-use activities. Groundwater with DO concentrations ≥0.5 mg/L (oxic conditions) can be susceptible to nitrate contamination because nitrate is generally stable and persistent in the presence of oxygen (Dubrovsky and others, 2010). Groundwater with DO concentrations <0.5 mg/L (anoxic, reducing conditions) can be more susceptible to contamination from sulfate, iron, and manganese (Bauch and others, 2014). Concentrations of DO in spring and well samples ranged from <0.01 to 14.6 mg/L (table 8). Most samples were well oxygenated. However, samples from Elk Meadows, Navajo, or Whiskers Draw Springs did not meet a 1-day mean minimum standard of 5.0 mg/L DO for protection of early life stages of aquatic life or a 1-day mean minimum standard of 3.0 mg/L DO for other life stages (table 9). Samples from five wells (5000 Block, Goodknight, Lagoon 1 well 1, Lagoon 1 well 3, and MR-FW) were anoxic. Reducing conditions in groundwater for these wells could affect groundwater chemistry and the types and concentrations of dissolved and noble gases in the groundwater.

Hardness generally is measured by the presence of the cations calcium and magnesium in water and is reported in terms of an equivalent concentration of calcium carbonate (Hem, 1985). Hardness can affect the anthropogenic uses of water and

Table 8. Statistical summary for physical-property measurements collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.

[The UMUT water-quality standards are from Larrick and Clow (2011). The Colorado Department of Public Health and Environment (CDPHE) basic standards for groundwater are from CDPHE (2017). No., number; Min, minimum; Max, maximum; fig., figure; ID, identification; µS/cm, microsiemens per centimeter at 25 degrees Celsius (°C); —, no standard; T, UMUT water-quality standard for Tribal cultural use of surface water; A-WWAL, UMUT acute water-quality standard for warm-water aquatic life; C-WWAL, UMUT chronic water-quality standard for warm-water aquatic life; AG, UMUT water-quality standard for agricultural, irrigation, and (or) livestock watering use of surface water; ne, no exceedance; mg/L, milligrams per liter; WWAL, UMUT water-quality standard for warm-water aquatic life; $CaCO_3$, calcium carbonate; C-GW, CDPHE basic standard for agricultural use of groundwater; <, less than]

Physical property	No. of sites	No. of samples	Measured value or concentration			Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard exceeded (see tables 6, 9)
			Min	Median	Max			
				Springs				
Specific conductance (µS/cm)	13	33	178	512	1,647	Hanna Spring (S5)	Navajo Spring (S9)	—
pH (standard units)	13	35	6.4	7.5	8.6	Hanna Spring (S5)	Navajo Spring (S9)	T, A-WWAL, C-WWAL, AG
Water temperature (°C)	11	28	2.9	9.4	23.6	Last Lake Spring (S6) Whisky Road Spring (S12)	Bancroft Spring (S1)	ne
Dissolved oxygen (mg/L)	11	27	1.4	7.4	11.7	Whiskers Draw Spring (S13)[1]	Last Lake Spring (S6)	WWAL
Hardness, $CaCO_3$ (mg/L)	5	8	87	580	761	Hanna Spring (S5)	Navajo Spring (S9)	—
				Wells				
Specific conductance (µS/cm)	21	45	646	6,024	10,520	AP–5	AP–10	—
pH (standard units)	24	49	6.8	7.7	9.0	Mariano-FW (W18)	Lagoon 1 well 3 (W13)	C-GW
Water temperature (°C)	21	40	14.3	17.4	29.1	AP–5	Mariano-FW (W18)	ne
Dissolved oxygen (mg/L)	15	26	<0.01	4.0	14.6	Goodknight well (W10)	Lagoon 2 well 2 (W14)	—
Hardness, $CaCO_3$ (mg/L)	15	29	7.7	428	3,910	Knight well (W11)	Lagoon 1 well 1 (W12)	—

[1] Spring is shown on figure 1.

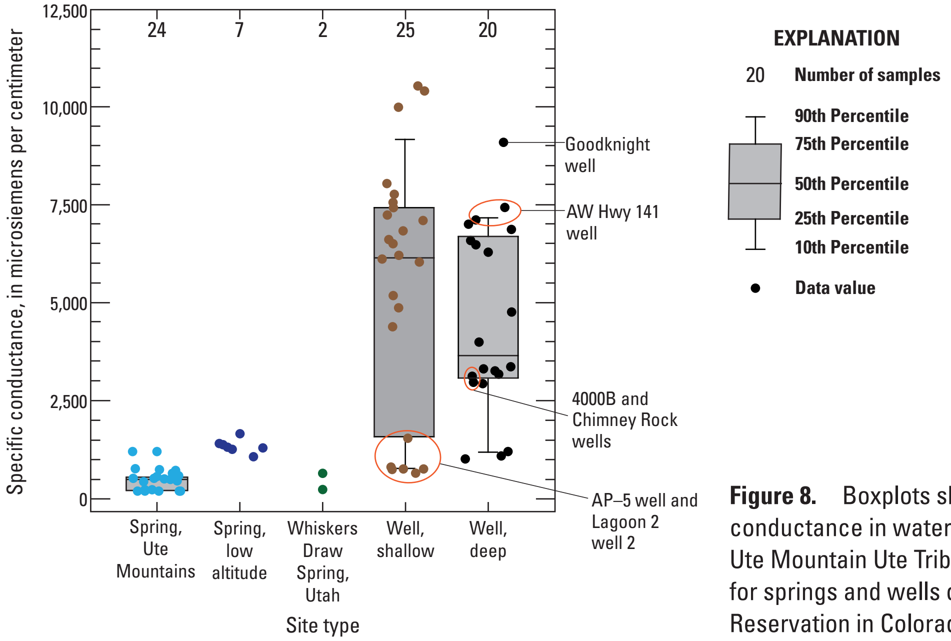


Figure 8. Boxplots showing distribution of specific conductance in water samples collected by the Ute Mountain Ute Tribe in 1998–2002 and 2011–17 for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah.

Table 9. Summary of physical-property measurements and concentrations of groundwater-chemistry constituents in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado that exceed water-quality standards established by the UMUT and the Colorado Department of Public Health and Environment (CDPHE).

[All samples were collected by the UMUT. Water-quality standards are shaded in gray. The measured value or constituent concentration for a sample was compared to the relevant water-quality standard. The UMUT water-quality standards are from Larrick and Clow (2011). The CDPHE basic standards for groundwater are from CDPHE (2017). fig., figure; ID, identification; E, exceedance of standard or standard not met; na, comparison of data value to standard not applicable, —, no standard; ne, no exceedance of standard; mg/L, milligrams per liter; ≤, less than or equal to; bv, based on background value; dis, dissolved; µg/L, micrograms per liter; trec, total recoverable; cfu/100 mL, colony-forming units per 100 milliliters of water]

Site (see fig. 5, site ID in parentheses is used on figure)	Site type	Sample date	Measured value or concentration	UMUT water-quality standards for surface waters by designated use[1]				CDPHE basic standards for agricultural use of groundwater[3]
				Tribal cultural use	Warm water aquatic life		Agriculture, irrigation, and livestock watering[2]	
					Acute	Chronic		
				pH				
			pH	6.5–8.5	6.5–9.0		6.5–9.0	6.5–8.5
Hanna Spring (S5)[4]	Spring	6/13/2011	6.4	E	E	E	E	na
Navajo Spring (S9)	Spring	11/7/2001	8.6	E	—	—	ne	na
AW Hwy 160/141 (W5)	Well	3/1/2000	8.6	—	—	—	na	E
Chimney Rock well (W6)	Well	9/21/2016	8.7	—	—	—	na	E
Cottonwood Spring well (W8)	Well	7/28/2014	8.7	—	—	—	na	E
Cottonwood Spring well (W8)	Well	5/24/2017	8.6	—	—	—	na	E
Knight well (W11)	Well	6/7/2013	8.7	—	—	—	na	E
Knight well (W11)	Well	7/15/2013	8.6	—	—	—	na	E
				Dissolved oxygen (mg/L)				
			Dissolved oxygen (mg/L)	—	([5])	—	—	—
Elk Meadows Spring (S4)	Spring	5/26/2015	1.8	—	E	—	—	—
Navajo Spring (S9)	Spring	9/20/2016	1.8	—	E	—	—	—
Whiskers Draw Spring (S13)[4,6]	Spring	3/5/2013	3.4	—	E	—	—	—
Whiskers Draw Spring (S13)[4,6]	Spring	8/28/2013	1.4	—	E	—	—	—
				Total dissolved solids (mg/L)				
			Total dissolved solids (mg/L)	≤ 500	—	—	[7]5,000	bv[8]
Cottonwood Wash Spring (S2)	Spring	6/22/2015	505	E	—	—	ne	na
East Toe Spring (S3)	Spring	12/22/1998	1,034	E	—	—	ne	na
East Toe Spring (S3)	Spring	2/18/1999	1,040	E	—	—	ne	na
East Toe Spring (S3)	Spring	5/21/1999	994	E	—	—	ne	na
East Toe Spring (S3)	Spring	3/1/2000	986	E	—	—	ne	na
Navajo Spring (S9)	Spring	7/25/2001	1,272	E	—	—	ne	na
West Toe Spring (S11)	Spring	12/22/1998	1,034	E	—	—	ne	na
West Toe Spring (S11)	Spring	2/18/1999	996	E	—	—	ne	na
West Toe Spring (S11)	Spring	5/21/1999	950	E	—	—	ne	na
Whiskers Draw Spring (S13)[4,6]	Spring	3/5/2013	1,439	E	—	—	ne	na
Whiskers Draw Spring (S13)[4,6]	Spring	8/28/2013	570	E	—	—	ne	na

Table 9. Summary of physical-property measurements and concentrations of groundwater-chemistry constituents in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado that exceed water-quality standards established by the UMUT and the Colorado Department of Public Health and Environment (CDPHE).—Continued

[All samples were collected by the UMUT. Water-quality standards are shaded in gray. The measured value or constituent concentration for a sample was compared to the relevant water-quality standard. The UMUT water-quality standards are from Larrick and Clow (2011). The CDPHE basic standards for groundwater are from CDPHE (2017). fig., figure; ID, identification; E, exceedance of standard or standard not met; na, comparison of data value to standard not applicable, —, no standard; ne, no exceedance of standard; mg/L, milligrams per liter; ≤, less than or equal to; bv, based on background value; dis, dissolved; µg/L, micrograms per liter; trec, total recoverable; cfu/100 mL, colony-forming units per 100 milliliters of water]

Site (see fig. 5, site ID in parentheses is used on figure)	Site type	Sample date	Measured value or concentration	UMUT water-quality standards for surface waters by designated use[1]				CDPHE basic standards for agricultural use of groundwater[3]
				Tribal cultural use	Warm water aquatic life		Agriculture, irrigation, and livestock watering[2]	
					Acute	Chronic		
				Fluoride (mg/L)				
			Fluoride (mg/L)	—	—	—	—	2 (dis)
5000 Block well (W3)	Well	5/2/2017	2.3 (dis)	—	—	—	—	E
AW Hwy 141 (W4)	Well	10/16/2002	7.91 (dis)	—	—	—	—	E
AW Hwy 160/141 (W5)	Well	10/16/2002	6.6 (dis)	—	—	—	—	E
Chimney Rock well (W6)	Well	9/21/2016	11.2 (dis)	—	—	—	—	E
FW-W (W9)	Well	2/27/2013	3.7 (dis)	—	—	—	—	E
Goodknight well (W10)	Well	5/10/2017	2.83 (dis)	—	—	—	—	E
Knight well (W11)	Well	7/15/2013	7.22 (dis)	—	—	—	—	E
Mariano-FW (W18)	Well	7/15/2013	7.59 (dis)	—	—	—	—	E
MR-FW (W19)	Well	5/10/2011	6.2 (dis)	—	—	—	—	E
Toe well (W22)	Well	9/20/2016	2.88 (dis)	—	—	—	—	E
				Trace elements (µg/L)				
				Aluminum				
			Aluminum (µg/L)	200 (trec)	750 (trec)	750 (trec)	—	5,000 (dis)
Elk Meadows Spring (S4)	Spring	5/26/2015	815 (trec)	E	E	E	—	na
Ute Spring (S10)[4]	Spring	6/16/2014	258 (trec)	E	ne	ne	—	na
Whiskers Draw Spring (S13)[4,6]	Spring	8/28/2013	817 (trec)	E	E	E	—	na
				Arsenic				
			Arsenic (µg/L)	0.018 (trec, 1-day)	340 (trec)	150 (trec)	100 (trec, 30-day)	100 (dis)
Cottonwood Wash Spring (S2)	Spring	6/22/2015	0.6 (trec)	E	ne	ne	ne	na
Hanna Spring (S5)[4]	Spring	6/16/2014	0.5 (trec)	E	ne	ne	ne	na
Last Lake Spring (S6)	Spring	5/26/2015	1.3 (trec)	E	ne	ne	ne	na
Navajo Spring (S9)	Spring	9/20/2016	1.2 (trec)	E	ne	ne	ne	na
Whisky Road Spring (S12)	Spring	5/26/2015	0.5 (trec)	E	ne	ne	ne	na
Whiskers Draw Spring (S13)[4,6]	Spring	3/5/2013	5.3 (trec)	E	ne	ne	ne	na
Whiskers Draw Spring (S13)[4,6]	Spring	8/28/2013	6.5 (trec)	E	ne	ne	ne	na

Table 9. Summary of physical-property measurements and concentrations of groundwater-chemistry constituents in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado that exceed water-quality standards established by the UMUT and the Colorado Department of Public Health and Environment (CDPHE).—Continued

[All samples were collected by the UMUT. Water-quality standards are shaded in gray. The measured value or constituent concentration for a sample was compared to the relevant water-quality standard. The UMUT water-quality standards are from Larrick and Clow (2011). The CDPHE basic standards for groundwater are from CDPHE (2017). fig., figure; ID, identification; E, exceedance of standard or standard not met; na, comparison of data value to standard not applicable, —, no standard; ne, no exceedance of standard; mg/L, milligrams per liter; ≤, less than or equal to; bv, based on background value; dis, dissolved; µg/L, micrograms per liter; trec, total recoverable; cfu/100 mL, colony-forming units per 100 milliliters of water]

Site (see fig. 5, site ID in parentheses is used on figure)	Site type	Sample date	Measured value or concentration	UMUT water-quality standards for surface waters by designated use[1]				CDPHE basic standards for agricultural use of groundwater[3]
				Tribal cultural use	Warm water aquatic life		Agriculture, irrigation, and livestock watering[2]	
					Acute	Chronic		
				Boron				
			Boron (µg/L)	—	—	—	750 (dis)	750 (dis)
Mariano-FW (W18)	Well	7/15/2013	766 (dis)	na	na	na	E	E
				Selenium				
			Selenium (µg/L)	50 (trec, 30-day)	20 (trec)	5 (trec)	20 (trec, 30-day)	20 (dis)
Cottonwood Wash Spring (S2)	Spring	6/22/2015	5.2 (trec)	ne	ne	E	ne	na
East Toe Spring (S3)	Spring	2/18/1999	9.9 (trec)	ne	ne	E	ne	na
East Toe Spring (S3)	Spring	5/21/1999	10.9 (trec)	ne	ne	E	ne	na
East Toe Spring (S3)	Spring	3/1/2000	30.8 (trec)	ne	E	E	E	na
Navajo Spring (S9)	Spring	11/7/2001	7.4 (trec)	ne	ne	E	ne	na
Navajo Spring (S9)	Spring	9/20/2016	8.7 (trec)	ne	ne	E	ne	na
West Toe Spring (S11)	Spring	5/21/1999	8.4 (trec)	ne	ne	E	ne	na
Goodknight well (W10)	Well	5/10/2017	21.7 (dis)	na	na	na	na	E
				Escherichia coli (cfu/100 mL)				
			Escherichia coli (cfu/100 mL)	0 (absent)	—	—	—	—
Hanna Spring (S5)[4]	Spring	6/16/2014	12.2	E	—	—	—	—
Lopez 2 Spring (S8)[4]	Spring	6/24/2013	1	E	—	—	—	—
Whiskers Draw Spring (S13)[4,6]	Spring	3/5/2013	1	E	—	—	—	—
Whiskers Draw Spring (S13)[4,6]	Spring	8/28/2013	136.4	E	—	—	—	—

[1] For this report, surface-water standards are applied to spring data only. The agricultural-use standards used for springs are for livestock watering. For a water body with multiple use designations, the most stringent criteria will be the goal of its water-quality standard.

[2] For the purposes of this report, the standards are applied to groundwater from springs that is currently or could potentially be used for livestock watering.

[3] For purposes of this report, the standards are applied to groundwater from wells that is currently or could potentially be used for livestock watering. This excludes the AP, Lagoon, LF, and Wing wells, which were established for specific monitoring purposes.

[4] Culturally significant spring.

[5] Warm-water aquatic-life standard: Early life stages: 5.0 mg/L, 1-day mean minimum. Other life stages: 3.0 mg/L, 1-day mean minimum. Standards are not specifically "acute" standards.

[6] Spring is shown on figure 1.

[7] Exceedance of the UMUT standard for dissolved solids is for livestock consumption.

[8] Dissolved-solids standard based on background value. See table 6.

the toxicity of metals to aquatic life (Hem, 1985; Newman, 1995). Hem (1985) reports the following classification system for water hardness in milligrams per liter as calcium carbonate: soft, 0–60; moderately hard, 61–120; hard, 121–180; and very hard, >180. The movement of hard water through pipes can result in scaling, the precipitation of dissolved minerals on the inside surfaces of pipes. Median hardness values of 580 and 428 mg/L (table 8) for UMUT spring and well samples, respectively, indicate very hard water in many samples. Geldon (1985) reported hard to very hard water in spring water sourced from alluvium, colluvium, block rubble, talus, and Mancos Shale, and Irwin (1966) reported soft to very hard water for well samples.

Total Dissolved Solids and Major Ions

Naturally occurring dissolved minerals, or TDS, in groundwater originate when groundwater reacts with geologic materials in the subsurface. In an arid environment such as the UMUR, evapotranspiration of water from plants and evaporation from the water table also can concentrate dissolved solids in the subsurface. The TDS is a measure of inorganic salts (principally the major ions) and organic substances dissolved in water. The most common dissolved solids in water are the major ions—calcium, magnesium, potassium, sodium, chloride, fluoride, sulfate, bicarbonate, and carbonate.

Knowledge of the amount of TDS in water resources on the UMUR is important for the cultural use of springs and, combined with knowledge of major-ion content, for agricultural use to prevent adverse effects on livestock health and soil productivity. Elevated concentrations of some major ions can affect livestock health, and too much salt can affect soil productivity. Water type, calculated from major-ion concentrations, provides information on the chemical quality of water and is used to differentiate the groundwater chemistry of springs and wells.

Total Dissolved Solids

Concentrations of TDS in spring and well samples collected by the UMUT indicated fresh (<1,000 mg/L), brackish (1,000 to 10,000 mg/L), and highly saline water (>10,000 mg/L) according to the classification of Stanton and others (2017) (fig. 9). The UMUT spring samples had fresh and brackish water; TDS concentrations ranged from 75 to 1,439 mg/L (fig. 9, table 10). Well samples had fresh, brackish, and highly saline water; TDS concentrations in wells ranged from 412 to 20,000 mg/L (fig. 9, table 10). All concentrations but one were 6,680 mg/L or less. Only the maximum concentration of 20,000 mg/L, for a sample from Lagoon 1 well 1, was highly saline. Brackish groundwater is commonly detected throughout the Colorado Plateau region, particularly in water from the Mancos Shale (DOE, 2011).

About 72 percent of UMUT spring samples had TDS concentrations <1,000 mg/L (fig. 9), indicating fresh water. The low concentration of 75 mg/L was reported for Hanna Spring. On the Ute Mountains, recharge from rainfall and snowmelt is discharged as spring water from the base of talus deposits derived from igneous rocks (Irwin, 1966). Water discharged from lower-altitude springs south of the Ute Mountains (East Toe [S3], Navajo [S9], and West Toe [S11] Springs; fig.5) in areas underlain by Mancos Shale was more brackish than water discharged from the igneous materials on the Ute Mountains. Total dissolved solid concentrations for the lower-altitude springs were ≥950 mg/L. The increase in TDS in samples from the lower-altitude springs generally is related to an increase in the sulfate concentrations (described further in the “Water Type” section). Samples from five springs, four lower-altitude springs (Cottonwood Wash, East Toe, Navajo, and West Toe Springs) with water sourced from Mancos Shale and Whiskers Draw Spring, had TDS concentrations greater than the Tribal cultural use standard of 500 mg/L (table 9). However, of the five springs, only Whiskers Draw Spring is designated for cultural use.

Overall, well water was more mineralized than spring water. About 85 percent of UMUT well samples had TDS concentrations >1,000 mg/L (fig. 9), indicating brackish or highly saline water. Freshwater samples were collected only from the AP–5 (412-530 mg/L) and Cottonwood Spring (773, 860 mg/L) wells. The highest TDS concentrations, those greater than the 90th percentile concentrations shown in figure 9, were in samples from the shallow Lagoon 1 well 1 (6,860 mg/L) and Lagoon 1 well 3 (20,000 mg/L) and the deep AW Hwy 141 (5,014 mg/L) and Goodknight (5,414 mg/L) wells. Water for the AW Hwy 141 and Goodknight wells likely was sourced from the Junction Creek Sandstone and the Mancos Shale, respectively (table 7).

Historical TDS data for wells likely completed in the Mancos Shale, Dakota Sandstone, Junction Creek Sandstone, and the Pennsylvanian-age Paradox Formation were available for samples collected in the 1950s, 1970s, and some years from 1996 to 2017 (table 11) (Irwin, 1966; USGS, 2016b; COGCC, 2018). Concentrations for samples from wells completed in the Mancos Shale, Dakota Sandstone, and Junction Creek Sandstone ranged from 920 to 6,000 mg/L (table 11). One COGCC sample from a well completed in the Paradox Formation was highly saline with a concentration of 61,500 mg/L. The COGCC wells are in the southeastern portion of the UMUR (fig. 5), where the salt-rich Paradox Formation is at least 5,400 ft beneath the Dakota Formation.

Water Type

The type of water for the major-ion data collected by the UMUT is illustrated using a Piper diagram (see for example fig. 10; Hem, 1985). The diagram shows the relationship between the dominant cations (calcium, magnesium, sodium, potassium) and the dominant anions (bicarbonate, chloride, sulfate) in percent total milliequivalents per liter and is used to classify and compare water types based on ionic composition. The lower left triangle illustrates the water type for cations, and lower right triangle illustrates the water type for anions.

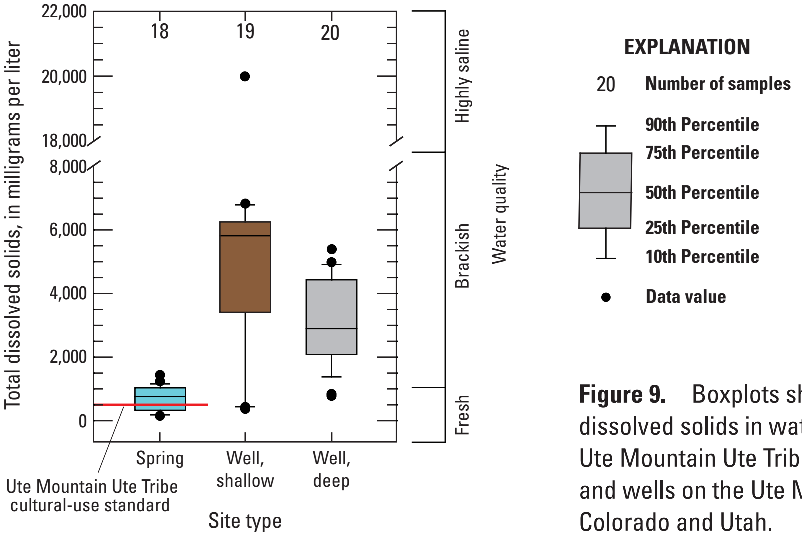


Figure 9. Boxplots showing distribution of total dissolved solids in water samples collected by the Ute Mountain Ute Tribe in 1996–2017 for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah.

Percentage values for the cations and anions are combined on the central graph to show the overall chemical quality of water and define the water type based on cation and anion composition. For sites with more than one sample of applicable data, median concentrations of the cations and anions are plotted on the diagram.

Complete major-ion data were available to calculate water types for nine UMUT springs. Calcium was the dominant cation for 89 percent of the spring samples, and bicarbonate or sulfate were the dominant anions (fig. 10). Springs on the Ute Mountains have a calcium-bicarbonate water type (fig. 10), whereas the lower-altitude East Toe and Navajo Springs south of the Ute Mountains have a calcium-sulfate water type. Whiskers Draw Spring in Utah has a mixed-calcium-magnesium-sulfate water type (fig. 10). The Geldon (1985) study of Cottonwood Wash in Colorado reported that springs with calcium-bicarbonate water type discharged from igneous block rubble and talus and old pediment. Springs with calcium-sulfate water type, such as Navajo Spring, discharged from the Mancos Shale, colluvium, young pediment alluvium, and channel alluvium. The Mancos Shale contains gypsum, which can be an important source of dissolved calcium and sulfate.

The dominant cations and anions in water samples from 21 UMUT wells varied. Unlike the springs, sodium was the dominant cation in 71 percent of wells (fig. 10). This likely indicates dissolved calcium has exchanged for sodium on clays within the aquifer materials. Mixtures of cations were present for other well samples. The dominant anions, and their percentages of well samples, were sulfate (43 percent), bicarbonate (14 percent), and chloride (14 percent) (fig. 10). A mixture of anions was present in about 29 percent of well samples; mixtures included bicarbonate-chloride, bicarbonate-sulfate, chloride-bicarbonate, sulfate-chloride, and sulfate-chloride-bicarbonate.

Numerous water types are present in the water samples from wells (fig. 10). Samples from four wells (AP–1, AP–14, AP–15, and Wing) in the Farm and Ranch Enterprise area, which likely tap eolian deposits and (or) weathered Mancos Shale, are a mixed-cation-sulfate water type (fig. 10). The HC Corral well sample also is a mixed-cation-sulfate water type with water sourced from the Mancos Shale (table 7). The sample for the AP–5 well, also in the Farm and Ranch Enterprise area, has a mixture of cations, similar to the other AP wells, but the dominant anion is bicarbonate. Water types for the remaining well samples are a continuum from sodium-bicarbonate to sodium-sulfate and sodium-chloride (fig. 10). The Goodknight, SE Toe, and Toe wells, which likely tap the Mancos Shale or Mancos Shale/Dakota Sandstone, have predominately a sodium-chloride water type (Goodknight, SE Toe wells) or sodium-mixed-anion (bicarbonate-chloride) water type (Toe well). The 4000B and Chimney Rocks wells, which likely tap the Dakota Sandstone, have sodium as the dominant anion and either sulfate (4000B well) or bicarbonate (Chimney Rock well) as the dominant anion. The sample for The AW Hwy 141 well water, likely sourced from the Junction Creek Sandstone (table 7), is a sodium-mixed-sulfate-chloride water type.

The water types for UMUT wells, likely completed in the Mancos Shale or Dakota aquifer, can be compared to water types for other wells that tap the same formations in nearby areas. Samples from deep unweathered Mancos Shale in southeast Utah, northwest New Mexico, and western Colorado are a sodium-chloride water type and almost all anion content is chloride (DOE, 2011). Similarly, the only UMUT sample likely collected from the Mancos Shale, the Goodknight well, is a sodium-chloride water type. Samples from wells completed in the Dakota aquifer in northwest New Mexico are sodium-bicarbonate or sodium-sulfate water types (Dam, 1995), which are mostly similar to the water types for the UMUT water samples from wells completed in the Dakota aquifer. The sodium-chloride water type has been noted in wells in southern Nebraska completed near the boundary between the Dakota Sandstone and overlying confining shales (Gosselin and others, 2001).

Table 10. Statistical summary for total dissolved solids and major ions in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.

[A censored concentration is a concentration less than the laboratory reporting limit. The UMUT water-quality standards are from Larrick and Clow (2011). The Colorado Department of Public Health and Environment (CDPHE) basic standards for groundwater are from CDPHE (2017). No., number; mg/L, milligrams per liter; Min, minimum; Max, maximum; fig., figure; ID, identification; na, not applicable; T, UMUT water-quality standard for Tribal cultural use of surface water; $CaCO_3$, calcium carbonate; —, no standard; nc, not calculated; <, less than; nd, not detected; C-GW, CDPHE basic standard for agricultural use of groundwater]

Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (mg/L)				Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard with exceedance (see tables 6 and 9)
				Min	Median	Max	Max detected, if censored			
							Springs			
Total dissolved solids	12	18	0	75	760	1,439	na	Hanna Spring (S5)	Whiskers Draw Spring (S13)[1]	T
Alkalinity, as $CaCO_3$	11	22	0	77	178	343	na	Hanna Spring (S5)	Whiskers Draw Spring (S13)[1]	—
Bicarbonate, as $CaCO_3$	12	20	0	77	206	1,722	na	Hanna Spring (S5)	West Toe Spring (S11)	—
Carbonate, as $CaCO_3$	12	20	12	0	nc	<20	nd	Whiskers Draw Spring (S13)[1]	na	—
Calcium	12	21	0	28.4	109	216	na	Hanna Spring (S5)	Navajo Spring (S9)	—
Chloride	11	19	8	<10	10.9	98.6	na	Lopez 1 Spring (S7)	Navajo Spring (S9)	—
Fluoride	10	15	11	<0.019	<0.2	0.384	na	Whiskers Draw Spring (S13)[1]	Whiskers Draw Spring (S13)[1]	—
Magnesium	12	21	0	3.72	19.4	118	na	Last Lake Spring (S6)	Whiskers Draw Spring (S13)[1]	—
Potassium	11	17	14	<0.094	nc	3.75	na	Lopez 1 Spring (S7)	Whiskers Draw Spring (S13)[1]	—
Silica	9	14	0	6.35	18	28.6	na	Whiskers Draw Spring (S13)[1]	Whisky Road Spring (S12)	—
Sodium	12	19	0	3.59	14.4	106	na	Last Lake Spring (S6)	Navajo Spring (S9)	—
Sulfate	12	22	1	<10	111	723	na	Hanna Spring (S5)	Whiskers Draw Spring (S13)[1]	—
							Wells			
Total dissolved solids	23	39	0	412	4,284	20,000	na	AP–5	Lagoon 1 well 1 (W12)	na
Alkalinity, as $CaCO_3$	25	48	0	73	387	2,000	na	AP–14	Toe well (W22)	—
Bicarbonate, as $CaCO_3$	23	41	0	118	434	1,959	na	AP–5	AP–14	—
Carbonate, as $CaCO_3$	22	40	5	0	0	280	na	(2)	Chimney Rock well (W6)	—
Calcium	22	37	0	1.48	37.3	508	na	Mariano-FW (W18)	AP–14	—
Chloride	20	39	1	<10	276	2,180	na	AP–5	Goodknight well (W10)	—
Fluoride	20	23	1	<0.16	1.37	11.2	na	AP–1	Chimney Rock well (W6)	C-GW
Magnesium	22	36	2	<0.019	10.2	580	na	Knight (W11) Mariano-FW (W18)	Lewis well (W15)	—
Potassium	21	39	7	<0.17	1.5	17.5	na	AP–14	AW Hwy 160/141 (W5)	—
Silica	13	14	3	<2.98	11.6	38.6	na	(3)	AP–14	—
Sodium	21	39	0	19.4	864	1,920	na	AP–5	Goodknight well (W10)	—
Sulfate	22	38	3	<1.56	1,173	4,200	na	5000 Block well (W3) Goodknight well (W10)	Lewis well (W15)	—

[1] Spring is shown on figure 1.

[2] Wells AP–1, AP–14, AP–16, AP–24, AP–5, AW Hwy 141 (W4), AW Hwy 160/141 (W5), and Knight (W11).

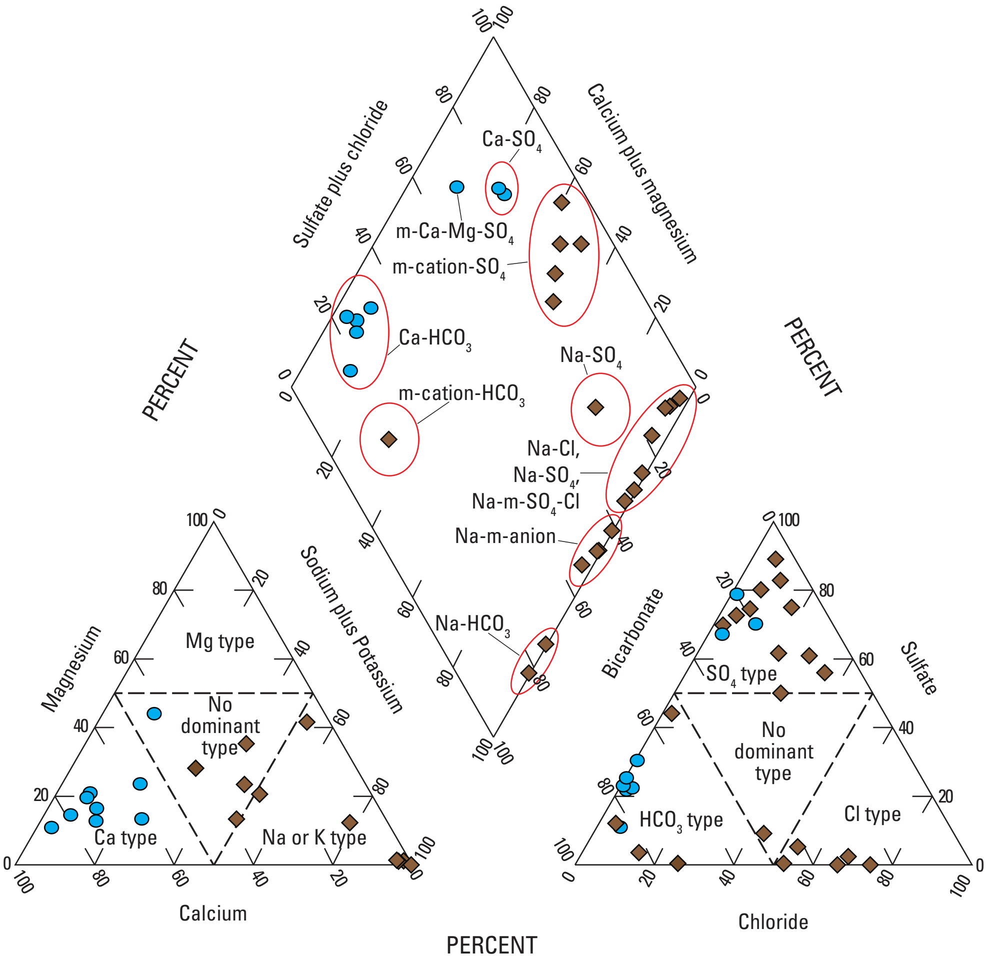
[3] Wells 5000 Block (W3), Goodknight (W10), and SE Toe (W20).

Table 11. Select total dissolved solids data for the 1950s, 1970s, and some years from 1996 to 2017 for Ute Mountain Ute Tribe (UMUT), U.S. Geological Survey (USGS), and Colorado Oil and Gas Conservation Commission (COGCC) wells on the Ute Mountain Ute Reservation in Colorado, sorted by likely lithology.

[Water Quality Portal (WQP) data are from National Water Quality Monitoring Council (2017). National Water Information System (NWIS) data are from USGS (2016b). COGCC data are from COGCC (2018). figs., figures; ID, identification; mg/L, milligrams per liter]

Site (see figs. 5, 6; site ID in parentheses is used on figures)	Total dissolved solids		
	Data source	Sample date	Concentration (mg/L)
	Mancos Shale		
Goodknight well (W10)	WQP	5/10/2017	[1]5,414
HC Corral well (W7)	UMUT	10/2/2012	2,280
370617108504201 (NW6)	Irwin (1966), NWIS	12/5/1956	6,000
371006108530401 (NW12)	Irwin (1966), NWIS	6/24/1959	1,610
371159108434801 (NW18)	Irwin (1966), NWIS	3/15/1954	946
	Mancos Shale/upper Dakota Sandstone		
SE Toe well (W20)	WQP	5/2/2017	[1]3,309
Toe welll (W23)	WQP	9/20/2016	[1]4,668
	Dakota Sandstone		
4000B well (W1)	WQP	9/20/2016	[1]2,597
Chimney Rock well (W6)	WQP	9/21/2016	[1]2,328
370410108583701 (NW1)	Irwin (1966), NWIS	6/24/1959	1,020
370518108540601 (NW2)	Irwin (1966), NWIS	12/5/1956	1,890
370612108424001 (NW5)	Irwin (1966), NWIS	6/25/1959	1,760
370717108532501 (NW7)	Irwin (1966), NWIS	12/5/1956	1,470
370806108485801 (NW8)	Irwin (1966), NWIS	12/5/1956	2,420
370913108563901 (NW9)	Irwin (1966), NWIS	12/6/1956	920
371248108402201 (NW25)	Irwin (1966), NWIS	12/5/1956	1,320
371307108581301 (NW26)	Irwin (1966), NWIS	12/7/1956	2,560
371443108544701 (NW27)	Irwin (1966), NWIS	12/6/1956	5,860
	Junction Creek Sandstone		
AW Hwy 141 (W4)	WQP	8/20/1996	4,612
AW Hwy 141 (W4)	WQP	3/1/2000	5,014
370557109003201 (NW4)	Irwin (1966), NWIS	6/24/1959	4,670
371152108435401 (NW17)	Irwin (1966), NWIS	1/3/1957	1,410
	Paradox Formation		
213879 (CW1)	COGCC	12/1/1971	2,460
213907 (CW2)	COGCC	12/22/1976	5,000
214329 (CW3)	COGCC	1/12/1976	61,500

[1] Sum of constituents.



EXPLANATION

Site Type

● Spring

◆ Well

Major Ions

Ca	Calcium
Cl	Chloride
HCO_3	Bicarbonate
K	Potassium
Mg	Magnesium
Na	Sodium
SO_4	Sulfate

Water Type

Ca-SO_4	Calcium-sulfate
Ca-HCO_3	Calcium-bicarbonate
m-Ca-Mg-SO_4	Mixed-calcium-magnesium-sulfate
m-cation-HCO_3	Mixed-cation-bicarbonate
m-cation-SO_4	Mixed-cation-sulfate
Na-Cl	Sodium-chloride
Na-HCO_3	Sodium-bicarbonate
Na-m-anion	Sodium-mixed-anion
Na-m-SO_4-Cl	Sodium-mixed-sulfate-chloride
Na-SO_4	Sodium-sulfate

Figure 10. Piper diagram showing water type for samples collected by the Ute Mountain Ute Tribe in 1996–2017 for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah. Areas circled in red represent water type. For example, Na-HCO_3 is a sodium-bicarbonate water type.

Major Ions and Fluoride

Summary statistics for major-ion and fluoride data collected by the UMUT from springs and wells are provided in table 10. In general, maximum concentrations of the major ions were less in springs than in wells (table 10). Alkalinity concentrations <100 mg/L (for example, the minimum concentration of 77 mg/L measured in a sample from Hanna Spring [table 10]) indicate that some spring water is not well buffered and could be susceptible to input of acidic water. Some concentrations of bicarbonate in spring samples and bicarbonate, chloride, sodium, and sulfate in well samples were >1,000 mg/L (table 10).

The only major ion with an established water-quality standard is fluoride (table 6). The CDPHE agricultural-use standard for fluoride of 2 mg/L is for the protection of animal skeletal health (CDPHE, 2017). Consumption of water with elevated fluoride levels can adversely affect the teeth and bones of livestock because excess fluoride can cause mottled teeth and skeletal fluorosis, the calcification of joints.

Fluoride was much less common in UMUT spring samples than in well samples (fig. 11, table 10). The CDPHE 2 mg/L agricultural-use standard for dissolved fluoride in groundwater was exceeded in about 45 percent of well samples—one sample each from 10 deep wells (table 9). Concentrations greater than the standard ranged from 2.3 to 11.2 mg/L (table 9). The maximum concentration of 11.2 mg/L, measured in a sample from the Chimney Rock well with water likely sourced from the Dakota aquifer, is slightly higher than the maximum concentration of 10 mg/L reported for the San Juan structural basin, which is mostly in New Mexico (Craigg and others, 1989) and 8 mg/L for the Dakota aquifer in Kansas (Whittemore and others, 2014).

Most dissolved fluoride in groundwater comes from natural sources, including igneous rocks and the minerals fluorite, apatite, micas, and amphiboles (Hem, 1985). Most natural waters contain a small amount of fluoride, generally <1.0 mg/L (Hem, 1985). Concentrations increase because of dissolution of fluoride minerals. Fluoride solubility is limited in the presence of calcium (Edmunds and Smedley, 1996). For UMUT spring samples, the maximum fluoride concentration was 0.384 mg/L (table 10), and the dominant cation was calcium (fig. 10). These samples include spring water discharged from igneous rocks that can be a source of fluoride to groundwater. The UMUT well samples with high concentrations of fluoride all had sodium as the dominant cation and a limited amount of calcium, which allows for higher concentrations of fluoride. Concentrations increase in groundwater where sodium takes the place of calcium in cation exchange (Edmunds and Smedley, 1996).

Although fluoride is the only major ion with an established water-quality standard reported herein, high concentrations of other major ions, such as magnesium and sulfate, can have health implications for livestock. Ayers and Westcot (1994) reported that most major ions that comprise dissolved solids are not very toxic, but magnesium is the exception. A high level of magnesium can cause scouring and diarrhea, and a suggested limit of magnesium in water for beef cattle is 40 mg/L (Ayers and Westcot, 1994). For the UMUT data, magnesium concentrations >40 mg/L were most commonly detected in samples from AP wells, but the maximum magnesium concentration of 580 mg/L in a sample from the Lewis well also exceeded the suggested limit (table 10). A combination of sulfate concentrations >2,000 mg/L in water and high levels of sulfate in feedstock can be associated with neurological disease in cattle (Parker, 2011). As with magnesium, sulfate concentrations in AP wells were commonly >2,000 mg/L, as was the maximum concentration of 4,200 mg/L for the Lewis well (table 10).

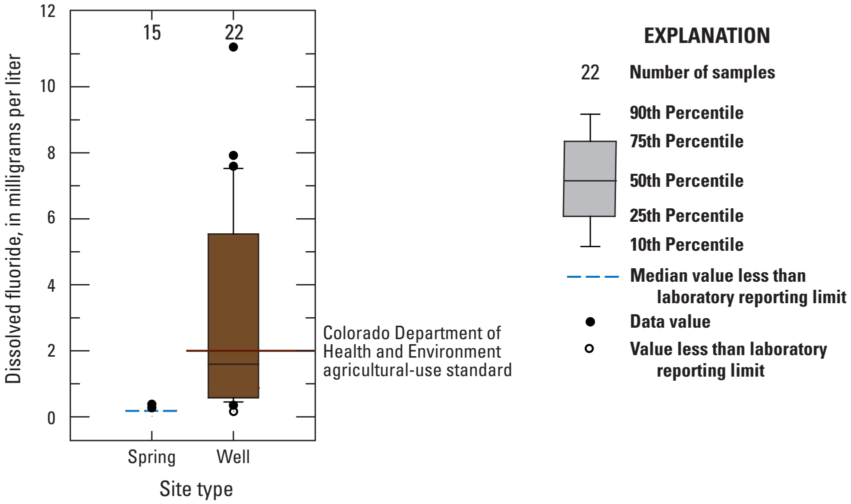


Figure 11. Boxplots showing distribution of fluoride in water samples collected by the Ute Mountain Ute Tribe in 2002 and 2011–17 for springs and wells on the Ute Mountain Ute Reservation compared to the Colorado Department of Public Health and Environment water-quality standard for agricultural use of groundwater.

Nutrients

Nutrients, essential food for plant and animal life, can occur naturally in water from the breakdown of organic matter, weathering and erosion of rocks and minerals, and atmospheric deposition of naturally occurring nitrogen (Dubrovsky and others, 2010). Nutrients also are contributed to the environment by human activities such as the application of fertilizers, runoff and erosion in agricultural and urban areas, animal waste, septic systems, effluent from the wastewater treatment process, atmospheric deposition of nitrogen from fossil fuel combustion, and volatilization of ammonia from fertilizer and manure (Dubrovsky and others, 2010). Once in groundwater, the concentrations and types of nutrients present are affected by factors such as transport mechanisms, availability of oxygen, and geochemical processes. Elevated concentrations of nutrients in surface water and groundwater can have health and environmental effects (Dubrovsky and others, 2010). To better protect the health of organisms and the environment, water-quality standards for nutrients have been established by the UMUT and the State of Colorado (table 6).

Nutrient data included in this assessment are un-ionized ammonia, nitrate plus nitrite, and total phosphorus from 9 UMUT springs and 23 UMUT wells. Only one spring sample had an unfiltered ammonia concentration that was more than 0.2 mg/L (fig, 12*A*, table 12), generally considered the natural background concentration in groundwater (Water Security Agency and Saskatchewan Ministry of Environment, 2012 or later). No concentrations were greater than the UMUT cultural-use standard of 0.5 mg/L for dissolved ammonia (table 6) or aquatic-life criteria for ammonia, which varies depending on the water pH and temperature. Unfiltered ammonia concentrations in about 73 percent (8 of 11) well samples were similar to or <0.2 mg/L (fig. 12*A*). Concentrations >1 mg/L (fig. 12*A*) were only detected in anoxic samples from the 5000 Block, Goodknight, and SE Toe wells. Ammonia is present in low-oxygen environments because of the degradation of naturally occurring organic matter.

Concentrations of unfiltered nitrate plus nitrite were 1.6 mg/L or less in all samples from springs and many samples from wells (fig. 12*B*). Elevated concentrations (9–78.5 mg/L) were only detected in samples from wells in the irrigated areas of the Farm and Ranch Enterprise, the shallow AP wells (AP–1, AP–14, AP–24), and the Wing well (fig. 12*B*). For these wells, it is likely that excess recharge from irrigation has moved naturally occurring nitrate in the soil or nitrate from fertilizers, or both, down to the water table. Nitrate can be released naturally at high concentrations from Mancos Shale (DOE, 2011). Elevated nitrate concentrations have been reported for soils derived from Mancos Shale that have not been irrigated (Mast and others, 2014). Previous studies have shown that the source of elevated nitrate concentrations in areas of western Colorado likely is geologic, probably from the oxidation of organic matter (Morrison and others, 2012; Mills and others, 2016). The small amount of nitrate plus nitrite for AP–5 (0.416 mg/L) is additional evidence, along with low specific conductance and fresh water (figs. 8 and 9 [TDS 412-530 mg/L]), that the source water or processes affecting the AP–5 water are different than those for other AP wells.

Once nitrate is in groundwater, it can be removed naturally only by denitrification, a process that reduces nitrate to harmless nitrogen gas (Dubrovsky and others, 2010). The long amount of time required for water to travel from the water table to deeper parts of an aquifer system provides more time for nitrate to be converted to nitrogen gas by denitrification. The nitrate plus nitrite concentrations in 12 of 13 samples from deep wells were 0.203 mg/L or less (fig. 12*B*), which might reflect denitrification along long groundwater flowpaths or older groundwater that recharged before development occurred.

Total phosphorus concentrations in 37 spring and well samples were low, 0.43 mg/L or less (table 12). Phosphorus often adsorbs to the surface of sediment and organic particles, which reduces phosphorus concentrations in groundwater. Water-quality standards for phosphorus in springs and groundwater have not been established by the UMUT or the States of Colorado or Utah.

Trace Elements and Uranium

For this assessment, trace elements are metallic and nonmetallic elements that generally occur in small (<1 mg/L) concentrations (Hem, 1985). Many trace elements are essential nutrients required by biota in small amounts, but substantial concentrations of trace elements can be toxic to aquatic life and possibly to wildlife, livestock, and people (Ayotte and others, 2011). Some trace elements can bioaccumulate in biota and bioconcentrate in the food chain. Trace-element type and concentration in water are often directly related to natural sources such as soils, geology, geochemical conditions, and the presence of thermal springs. Groundwater in mineralized areas may contain naturally high background concentrations of metals from the oxidation and weathering of minerals in rocks and soils (Bauch and others, 2014). Common anthropogenic sources of trace elements in water are the deposition of metals released to the atmosphere from industrial activities and combustion, industrial water releases, and urban runoff.

Trace-element data collected by the UMUT were available for 11 spring and 28 well samples for 1996 through 2017. Uranium data were available for two springs and eight wells (table 4). Summary statistics are provided in table 13 for total recoverable and dissolved forms of 21 trace elements and uranium. Of the analytical results, 50 percent (338 of 676) were less than laboratory reporting limits, including all results for antimony, beryllium, and mercury (table 13).

Most detected concentrations of trace elements and all uranium concentrations in spring samples were <10 μg/L (table 13). Concentrations >20 μg/L were detected for total recoverable aluminum, barium, iron, manganese, and selenium; and dissolved iron and manganese. Maximum

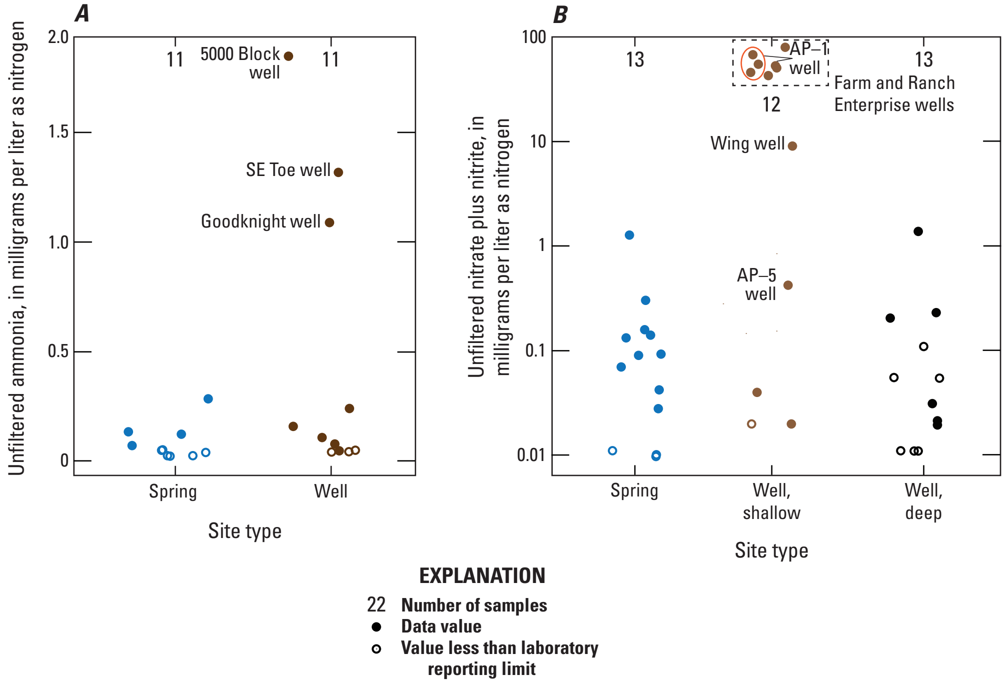


Figure 12. Scatter plots showing distribution of *A*, unfiltered ammonia and *B*, unfiltered nitrate plus nitrite in water samples collected by the Ute Mountain Ute Tribe in 2000–17 for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah.

concentrations of total recoverable aluminum and barium were in samples from Whiskers Draw Spring and West Toe Spring, respectively (table 13). Maximum concentrations of total recoverable iron and manganese were in samples from Navajo Spring (table 13). Concentrations of total recoverable aluminum, arsenic, and selenium were greater than one or more UMUT water-quality standards for surface water (table 9). In particular, exceedances of cultural-use standards for aluminum and arsenic were detected in samples from the culturally significant Hanna, Ute, and (or) Whiskers Draw Springs (table 9).

Many trace elements were detected at higher concentrations in the UMUT samples from wells than from springs. In well samples, 13 trace elements in the total recoverable and (or) dissolved forms were detected at concentrations >20 µg/L compared to 5 trace elements for spring samples (table 13). For uranium, only a sample from AP–1 well had a dissolved concentration >20 µg/L. Concentrations ≥500 µg/L were detected for total recoverable aluminum and iron and dissolved barium, boron, and iron (table 13). Maximum concentrations of total recoverable arsenic and total and dissolved selenium were in samples from AP wells. Both of these trace elements are often present in materials derived from Mancos Shale (Morrison and others, 2012; Tuttle and others, 2014a). The downward flow of irrigation recharge near the AP wells likely has moved arsenic and selenium in weathered Mancos Shale from the subsurface into the shallow groundwater system (Gerla and others, 2011; Tuttle and others, 2014b; Mills and others, 2016). The CDPHE water-quality standards for agricultural use of water have been established for the dissolved form of many trace elements (table 6). The standards for dissolved boron and selenium were exceeded in a sample from the Mariano-FW and Goodknight wells, respectively (tables 9 and 13).

Additional historical trace-element data for the UMUR were available from the USGS NWIS and NURE databases (tables 3 and 4). Ten springs with trace-element data from NWIS for 1982 were sampled as part of a Cottonwood Wash study (Geldon, 1985), and the 1 spring (Elbow Spring on east side of the Ute Mountains) with NWIS data for 2003 was sampled as part of a Yucca House National Monument study (Wright, 2006). About 43 percent of the detected trace-element concentrations for these 11 spring samples were <10 µg/L. Dissolved barium, iron, manganese, and strontium were the only trace elements in these spring samples detected at concentrations of 20 µg/L or more. The one well sample from NWIS, an alluvial well in Towaoc (NW22), had detections of dissolved barium, iron, manganese, and selenium. The NURE data included data for nine trace elements and uranium collected from eight springs and five wells (tables 3 and 4). Concentrations of dissolved chromium, cobalt, copper, lead, iron, manganese, nickel, titanium, zinc, and uranium were >20 µg/L in the spring and (or) well samples.

Table 12. Statistical summary for nutrients in water samples collected by the Ute Mountain Ute Tribe for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 2000–17.

[No., number; mg/L, milligrams per liter; Min, minimum; Max, maximum; fig., figure; ID, identification; N, nitrogen; <, less than;, ne, no exceedance; P, phosphorus, —, no standard]

Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (mg/L)			Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard with exceedance (see tables 6 and 9)
				Min	Median	Max			
Springs									
Ammonia, unfiltered, as N	8	11	7	<0.024	<0.05	0.287	(1)	Ute Spring (S10)	ne
Nitrate plus nitrite, unfiltered, as N	9	13	3	<0.01	0.09	1.26	Cottonwood Wash Spring (S2) Elk Meadows Spring (S4)	Last Lake Spring (S6)	ne
Total phosphorus, as P	9	12	4	<0.018	0.071	0.146	Navajo Spring (S9)	Elk Meadows Spring (S4)	—
Wells									
Ammonia, unfiltered, as N	10	11	3	<0.043	0.108	1.85	AP–1 Cottonwood Spring well (W8)	5000 Block well (W3)	—
Nitrate plus nitrite, unfiltered, as N	20	25	8	<0.011	0.040	78.5	(2)	AP–14	ne
Total phosphorus, as P	19	25	8	<0.011	0.08	0.43	(3)	AP–15	—

[1] Cottonwood Wash (S2), Elk Meadows (S4), Hanna (S5), and Whisky Road (S12) Springs.

[2] Chimney Rock (W6), Cottonwood Spring (W8), and Toe Windmill (W22) wells.

[3] AP–1, Cottonwood Spring (W8), Goodknight (W10), and SE Toe (W20) wells.

Table 13. Statistical summary for total recoverable and dissolved trace elements and total recoverable and dissolved uranium in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.

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Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (µg/L)				Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard exceedance (see tables 6 and 9)
				Min	Median	Max	Max detected, if censored			
Springs (total recoverable)										
Aluminum	8	12	3	<20	89	817	na	Hanna (S5), Last Lake (S6), Navajo (S9) Springs	Whiskers Draw Spring (S13)[1]	T, A-WWAL, C-WWAL
Antimony	1	1	1	<0.4	<0.4	<0.4	na	Navajo Spring (S9)	na	ne
Arsenic	11	20	13	<0.2	nc	<100	6.5	Elk Meadows (S4), Hanna (S5), Ute (S10) Springs	Whiskers Draw Spring (S13)[1]	T
Barium	6	8	0	4.8	22.0	60.9	na	Hanna Spring (S5)	West Toe Spring (S11)	ne
Beryllium	4	4	4	<0.08	nc	<0.5	na	Navajo Spring (S9)	na	—
Boron	2	2	2	<100	nc	<100	na	Hanna (S5), Lopez 1 (S7) Springs	na	—
Cadmium	8	12	12	<0.01	nc	<0.1	na	(2)	na	ne
Chromium	5	5	5	<0.1	nc	<1.1	na	Whiskers Draw Spring (S13)[1]	na	ne
Cobalt	4	4	1	<0.1	0.2	0.8	na	Hanna Spring (S5)	Navajo Spring (S9)	—
Copper	8	12	0	0.2	0.8	2.5	na	Last Lake Spring (S6)	Whiskers Draw Spring (S13)[1]	ne
Iron	9	14	2	<50	108	706	na	Lopez 1 (S7), Whisky Road (S12) Springs	Navajo Spring (S9)	—
Lead	2	4	4	<0.03	nc	<1	na	Whiskers Draw Spring (S13)[1]	na	ne
Manganese	4	4	2	<5	186	538	na	Hanna (S5), Lopez 1 (S7) Springs	Navajo Spring (S9)	—
Mercury, total	7	7	7	<0.02	nc	<0.09	na	(2)	na	ne
Molybdenum	8	8	0	2	4.2	10.1	na	Whiskers Draw Spring (S13)[1]	Last Lake Spring (S6)	ne
Nickel	7	10	0	0.7	2.6	13.4	na	Hanna Spring (S5)	Navajo Spring (S9)	ne
Selenium	11	17	5	<0.3	nc	<200	30.8	Hanna Spring (S5)	East Toe Spring (S3)	A-WWAL, C-WWAL, AG
Silver	4	4	4	<0.02	nc	<0.1	na	Navajo Spring (S9)	na	ne
Thallium	4	4	4	<0.04	nc	<0.1	na	Navajo Spring (S9)	na	—
Vanadium	9	14	3	<0.7	nc	<20	3.3	Cottonwood Wash Spring (S2)	Last Lake Spring (S6)	—
Zinc	10	15	10	<0.4	nc	<50	18.3	Last Lake (S6), Ute (S10) Springs	Hanna Spring (S5)	ne
Uranium	1	1	1	5.5	5.5	5.5	na	Navajo Spring (S9)	Navajo Spring (S9)	ne
Wells (total recoverable)										
Aluminum	12	13	7	<1	<50	10,300	na	Knight well (W11), Mariano-FW (W18)	Lagoon 1 well 3 (W13)	—

Table 13. Statistical summary for total recoverable and dissolved trace elements and total recoverable and dissolved uranium in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.—Continued

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Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (µg/L)				Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard exceedance (see tables 6 and 9)
				Min	Median	Max	Max detected, if censored			
Antimony	6	6	6	<0.4	nc	<100	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	—
Arsenic	20	35	13	<0.1	7.6	224	na	Knight well (W11), Mariano-FW (W18)	AP–16	—
Barium	9	10	2	<6.8	32.9	207	na	4000B well (W1)	Chimney Rock well (W6)	—
Beryllium	3	3	3	<0.04	nc	<0.04	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	—
Boron	1	1	1	<300	<300	<300	na	Cottonwood Spring well (W8)	na	—
Cadmium	11	14	13	<0.04	nc	<50	0.09	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	Lagoon 1 well 1 (W12)	—
Chromium	10	12	7	<0.1	1.0	14	na	Knight well (W11), Mariano-FW (W18)	Lagoon 1 well 1 (W12)	—
Cobalt	3	3	0	0.1	0.1	0.2	na	Chimney Rock well (W6), Toe well (W22)	4000B well (W1)	—
Copper	11	13	4	<20	<20	35.3	na	Cottonwood Spring well (W8)[3]	Toe well (W22)	—
Iron	14	16	2	<24	564	6,310	na	Lewis well (W15)[3]	4C well (W2)	—
Lead	14	18	10	<0.08	nc	<100	13.4	4000B well (W1)	4C well (W2)	—
Manganese	9	10	0	0.19	19.1	484	na	Lewis well (W15)	4C well (W2)	—
Mercury, total	10	11	11	<0.05	nc	<0.2	na	4C well (W2)	na	—
Molybdenum	10	10	7	<0.05	nc	<50	14.2	Knight well (W11), Mariano-FW (W18)	FW-W (W9)	—
Nickel	5	6	0	1	2.8	8.1	na	Toe well (W22)	Lagoon 1 well 3 (W13)	—
Selenium	19	34	12	<0.4	9.6	231	na	Knight well (W11), Mariano-FW (W18)	AP–1	—
Silver	4	4	4	<0.02	nc	<0.02	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	—
Thallium	3	3	3	<0.04	nc	<0.04	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	—
Vanadium	5	5	4	<0.5	nc	<2.5	0.5	Cottonwood Spring well (W8)	AP–1	—
Zinc	14	15	8	<0.5	59.8	486	na	Mariano-FW (W18)	Chimney Rock well (W6)	—
Uranium	3	3	2	<0.02	<0.02	1.3	na	Chimney Rock well (W6), Toe well (W22)	4000B well (W1)	—
Springs (dissolved)										
Aluminum	3	3	3	<1	nc	<20	na	Whiskers Draw Spring (S13)[1]	na	ne
Antimony	1	1	1	<0.07	<0.07	<0.07	na	Navajo Spring (S9)	na	—

Table 13. Statistical summary for total recoverable and dissolved trace elements and total recoverable and dissolved uranium in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.—Continued

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Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (µg/L)				Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard exceedance (see tables 6 and 9)
				Min	Median	Max	Max detected, if censored			
Arsenic	4	4	2	<0.08	nc	<10	6.4	Lopez 2 Spring (S8)	Whiskers Draw Spring (S13)[1]	ne
Barium	2	2	0	15.4	17.5	19.6	na	Lopez 2 Spring (S8)	Navajo Spring (S9)	—
Beryllium	1	1	1	<0.02	<0.02	<0.02	na	Navajo Spring (S9)	na	ne
Boron	2	3	3	<24	nc	<100	na	Whiskers Draw Spring (S13)[1]	na	ne
Cadmium	2	2	2	<0.01	nc	<0.04	na	Navajo Spring (S9)	na	ne
Chromium	1	1	0	4.3	4.3	4.3	na	Navajo Spring (S9)	Navajo Spring (S9)	ne
Cobalt	1	1	0	0.7	0.7	0.7	na	Navajo Spring (S9)	Navajo Spring (S9)	ne
Copper	1	1	0	2.5	2.5	2.5	na	Navajo Spring (S9)	Navajo Spring (S9)	ne
Iron	3	3	2	<4	nc	577	na	Whiskers Draw Spring (S13)[1]	Navajo Spring (S9)	ne
Lead	2	2	2	<0.03	nc	<0.04	na	Whiskers Draw Spring (S13)[1]	na	ne
Manganese	3	3	0	1	208	521	na	Lopez 2 Spring (S8)	Navajo Spring (S9)	ne
Mercury	1	1	1	<0.09	<0.09	<0.09	na	Navajo Spring (S9)	na	ne
Molybdenum	2	2	0	1.8	2.2	2.5	na	Whiskers Draw Spring (S13)[1]	Navajo Spring (S9)	ne
Nickel	1	1	0	9.4	9.4	9.4	na	Navajo Spring (S9)	Navajo Spring (S9)	ne
Selenium	4	4	1	<0.4	6.7	17.3	na	Whiskers Draw Spring (S13)[1]	East Toe Spring (S3)	ne
Silver	1	1	1	<0.03	<0.03	<0.03	na	Navajo Spring (S9)	na	—
Thallium	1	1	1	<0.01	<0.01	<0.01	na	Navajo Spring (S9)	na	—
Vanadium	3	3	1	<0.2	1.8	3.2	na	Lopez 2 Spring (S8)	Whiskers Draw Spring (S13)[1]	ne
Zinc	2	2	0	4.1	7.8	11.5	na	Navajo Spring (S9)	Whiskers Draw Spring (S13)[1]	ne
Uranium	2	2	0	1.5	3.6	5.8	na	Lopez 2 Spring (S8)	Navajo Spring (S9)	—
								Wells (dissolved)		
Aluminum	11	12	10	<1	nc	<201	167	Mariano-FW (W18)	AP–1	ne[4]
Antimony	5	5	5	<0.07	nc	<50	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	—
Arsenic	18	22	8	<0.4	6.1	110	na	Cottonwood Spring well (W8)	LF well 1 (W16), LF well 3 (W17)	ne[4]

Table 13. Statistical summary for total recoverable and dissolved trace elements and total recoverable and dissolved uranium in water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 1996–2017.—Continued

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Constituent	No. of sites	No. of samples	No. of censored samples	Concentration (µg/L)				Site with minimum concentration (see fig. 5, site ID in parentheses is used on figure)	Site with maximum detected concentration (see fig. 5, site ID in parentheses is used on figure)	Water-quality standard exceedance (see tables 6 and 9)
				Min	Median	Max	Max detected, if censored			
Barium	12	11	1	<6.3	72.0	500	na	4000B well (W1)	Goodknight well (W10)	—
Beryllium	5	5	5	<0.02	nc	<4	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	ne
Boron	8	9	4	<426	<851	2,410	na	Cottonwood Spring well (W8)	AP–1	AG, C-GW[4,5]
Cadmium	13	14	13	<0.01	nc	180	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	LF well 3 (W17)	ne[4]
Chromium	8	7	4	<1	<10	48	na	HC Corral well (W7)	LF well 3 (W17)	ne[4]
Cobalt	3	3	0	0.2	0.3	1.1	na	Toe well (W22)	4000B well (W1)	ne
Copper	6	6	1	<5.7	<20	31.4	na	HC Corral well (W7)	Chimney Rock well (W6)	ne
Iron	13	14	10	<3	nc	790	na	4000B well (W1)	4C well (W2)	ne
Lead	11	11	7	<0.04	<0.5	<70	67.8	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	AW Hwy 141	ne
Manganese	10	11	3	<0.7	6.5	69	na	AP–1	4C well (W2)	ne
Mercury	9	9	9	<0.09	nc	<0.2	na	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	na	ne
Molybdenum	5	5	3	<0.02	<0.05	1.9	na	Chimney Rock well (W6)	AP–1	—
Nickel	4	4	0	0.7	2.2	6.6	na	Toe well (W22)	HC Corral well (W7)	ne
Selenium	17	21	10	<0.8	1.5	207	na	Cottonwood Spring well (W8)	AP–1	C-GW[4,6]
Silver	6	6	5	<0.03	nc	<26	0.43	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	AW Hwy 141 (W4)	—
Thallium	5	5	4	<0.01	nc	<50	0.5	4000B well (W1), Chimney Rock well (W6), Toe well (W22)	HC Corral well (W7)	—
Vanadium	8	9	7	<0.04	<3.7	28.4	na	Toe well (W22)	Chimney Rock well (W6)	ne
Zinc	8	8	0	8.4	12.4	178	na	Mariano-FW (W18)	Toe well (W22)	ne
Uranium	8	8	6	<0.008	nc	51.6	na	Chimney Rock well (W6), Toe well (W22)	AP–1	—

[1] Spring is shown on figure 1.

[2] Cottonwood Wash (S2), Elk Meadows (S4), Hanna (S5), Last Lake (S6), Ute (S10), and Whisky Road (S12) Springs.

[3] Minimum detected cconcentration.

[4] Standard applies to wells that are or could potentially be used for livestock watering. This excludes AP and LF wells, which were established for specific monitoring purposes.

[5] Standard is exceeded for Mariano-FW well (766 µg/L). Standard applies to sensitive crops. See Larrick and Clow (2011) and CDPHE (2017).

[6] Standard is exceeded for Goodknight well (21.7 µg/L).

Pesticides and Volatile Organic Compounds

Pesticides and VOCs are organic chemicals that can be present in groundwater because of their release at or near the land surface. Pesticides are chemicals used to prevent or control unwanted plants, insects, fungi, and other pests. Volatile organic compounds are carbon-based compounds that can move between air and water and are used or produced in a variety of industrial, commercial, and domestic applications. The occurrence of pesticides and VOCs in groundwater is of concern because of potential human-health effects (Gilliom and others, 2006; Zogorski and others, 2006). Human-health benchmarks have been established for some but not all pesticides and VOCs (Toccalino and others, 2014).

On the UMUR, 23 samples for pesticide analysis were collected from 10 wells from June 2000 through August 2013 (table 14). Sample collection was most common from AP wells and other monitoring wells in the Farm and Ranch Enterprise area. A total of 499 analytical results were originally available for 74 pesticides. Only the pesticides alachlor and atrazine, selective herbicides used to control grasses and broadleaf weeds, were detected at concentrations greater than or equal to laboratory reporting limits. Alachlor and atrazine were detected once (0.3 and 0.2 µg/L, respectively) in samples from AP–16 well, and atrazine was detected once (1.1 µg/L) in a sample from AP–24 well (table 14). The detections were less than the CDPHE groundwater standards for drinking water for alachlor and atrazine of 2 and 3 µg/L, respectively (CDPHE, 2017).

Ten samples for VOC analysis were collected from 7 wells from June 2000 through August 2012 (table 14). Similar to the pesticide sampling, AP wells were most commonly sampled for VOCs. The analyses for the AP wells only included three VOCs—benzo[a]pyrene, di(2-ethylhexyl) adipate, and di(2-ethylhexyl) phthalate (DEHP). Only DEHP, a manufactured chemical commonly added to plastics to make them flexible (Agency for Toxic Substances and Disease Registry, 2002), was detected at concentrations greater than laboratory reporting limits in one sample each from AP–1 (1.9 µg/L) and AP–14 (0.8 µg/L) (table 14). The only UMUT water-quality standard for DEHP is for cultural use of springs, which is not applicable to the AP wells (table 6). Both detected concentrations of DEHP were less than the U.S. Environmental Protection Agency (EPA) drinking water standard of 6 µg/L (EPA, 2017). A broad suite of VOCs was analyzed in samples from the 4C well and Lagoon 1 well 3; VOCs were not detected (table 14).

Coliform Bacteria

Coliforms are bacteria present in the digestive tracts of warm-blooded animals and in soil and vegetation. The bacteria are not likely to cause illness themselves, but their presence in water indicates that disease-causing pathogens could also be in the water (Bauch and others, 2014). Total coliform consists of a large group of different types of bacteria. Fecal coliform are bacteria that are present in the intestines and feces of warm-blooded animals. Their presence in water indicates recent contamination by animal waste or sewage. The *E. coli* bacterium is a subgroup of fecal coliform bacteria and is the only coliform group with a UMUT water-quality standard. The water-quality standard of total absence of *E. coli* in the water of culturally significant springs is to protect the health of Tribal members during ceremonial use of springs (table 6; Larrick and Clow, 2011).

The UMUT collected water samples from springs and wells for bacterial analysis during most years since 2000 (table 15). The number of sample-collection days varied among the springs and wells. For some sites, more than one sample was collected on a sample day. About 77 percent (44 of 57) of spring and well samples had detections of total coliform bacteria, and 30 percent (18 of 60) of samples had detections of *E. coli*. The *E. coli* detections were more common for well samples (8 of 17, 47 percent) than for spring samples (10 of 43, 23 percent). Concentrations of *E. coli* in the 10 spring samples ranged from 1 to 1,300 colony-forming units per 100 milliliters of water, which exceeded the UMUT cultural-use standard of total absence of *E. coli* in spring water. Exceedances included samples from culturally significant Hanna, Lopez 2, and Whiskers Draw Springs (tables 9 and 15).

Environmental Tracers

Lopez 2 Spring and five wells (AP–1, 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells) were sampled in May 2017 for environmental tracers in the spring and well water (table 4). Tracers included stable isotopes (hydrogen and oxygen of water, nitrogen and oxygen of nitrate, and carbon in dissolved organic carbon), tritium, CFCs, dissolved gases (methane, carbon dioxide, nitrogen and oxygen, argon), and noble gases (helium-4, neon, argon, krypton, xenon). Environmental tracers can provide information on recharge, geochemical conditions, the age of groundwater, and other aquifer processes or conditions. The term “groundwater age” is defined as the time required for a water molecule to travel from a point of recharge to a measurement point such as a spring or well (Shapiro and others, 2012). Therefore, an estimate of the time since a water molecule in a spring or well was recharged can be used as an estimate of groundwater age.

Stable isotope ratios of hydrogen and oxygen of water commonly are used in hydrologic studies to provide information on the source of groundwater and recharge, geochemical history of groundwater, and processes that affect water after it has entered an aquifer, such as water-rock interaction (Gat and Gonfiantini, 1981; Clark and Fritz, 1997; Coplen and others, 2000). Groundwater samples from Lopez 2 Spring and the five wells were analyzed for stable isotopes of hydrogen (hydrogen-2/hydrogen-1 ratio [δ^2H]) and oxygen (oxygen-18/oxygen-16 ratio [$\delta^{18}O$]) in water; the composition of isotopes is reported using delta (δ) notation, which indicates parts per thousand or per mil. Values of δ^2H and $\delta^{18}O$ of water for

Table 14. Summary of sample collection and analysis by the Ute Mountain Ute Tribe for pesticides and volatile organic compounds in wells on the Ute Mountain Ute Reservation in Colorado, 2000–13.

[fig., figure; ID, identification; µg/L, micrograms per liter; —, no detection]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	Number of analytes	Detected compound	Concentration of detected compound (µg/L)
Pesticides				
AP–1	9/18/2003	26	—	—
AP–1	4/1/2004	32	—	—
AP–1	5/27/2009	6	—	—
AP–1	7/25/2011	42	—	—
AP–1	8/29/2013	33	—	—
AP–10	10/30/2001	35	—	—
AP–14	6/13/2000	17	—	—
AP–14	4/1/2004	25	—	—
AP–14	5/11/2004	7	—	—
AP–14	6/15/2005	1	—	—
AP–14	7/25/2011	42	—	—
AP–15	8/15/2012	42	—	—
AP–16	10/30/2001	35	Alachlor	0.3
AP–16	9/19/2003	25	—	—
AP–16	4/1/2004	7	—	—
AP–16	6/15/2005	1	Atrazine	0.2
AP–16	4/3/2007	3	—	—
AP–24	10/31/2001	35	Atrazine	1.1
AP–5	10/31/2001	35	—	—
AP–5	8/5/2002	35	—	—
Lagoon 1 well 3 (W13)	9/15/2010	1	—	—
TF-Corral well (W21)	8/8/2002	7	—	—
Wing well (W23)	3/9/2001	7	—	—
Volatile organic compounds				
4C well (W2)	1/24/2002	43	—	—
AP–1	5/27/2009	2	Di(2-ethylhexyl) phthalate	1.9
AP–1	7/25/2011	3	—	—
AP–14	6/13/2000	2	—	—
AP–14	6/15/2005	3	—	—
AP–14	7/25/2011	3	Di(2-ethylhexyl) phthalate	0.8
AP–15	8/15/2012	3	—	—
AP–16	6/15/2005	3	—	—
Lagoon 1 well 3 (W13)	9/15/2010	65	—	—
Wing well (W23)	8/16/2012	4	—	—

Table 15. Summary of data for total coliform and *Escherichia coli* bacteria for water samples collected by the Ute Mountain Ute Tribe (UMUT) for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 2001–16.

[Culturally significant springs are in bold. The UMUT water-quality standards are from Larrick and Clow (2011). fig., figure; ID, identification; No., number; cfu/100 mL, colony-forming units per 100 milliliters of water; tntc, too numerous to count; na, not applicable; nd, no detection; T, UMUT water-quality standard for Tribal cultural use of surface water; ne, no exceedance; —, no standard]

Site (see fig. 5, site ID in parentheses is used on figure)	Total coliform					*Escherichia coli*					
	Sample years	No. of sample days/No. of sample days with detections[1]	No. of samples	No. samples with detections	Concentration range of detections (cfu/100 mL)	Sample years	No. of sample days/No. of sample days with detections[1]	No. of samples	No. samples with detections	Concentration range of detections (cfu/100 mL)	Water-quality standard exceedance (see tables 6 and 9)
Springs											
Bancroft Spring (S1)	2012	1/1	5	4	1–tntc	2012	1/1	5	3	130–1,300	na[2]
Cottonwood Wash Spring (S2)	2015	1/1	1	1	8.6	2015	1/0	1	0	nd	na[2]
Elk Meadows Spring (S4)	2012, 2015	2/2	4	2	1; 1,120	2012, 2015	2/1	4	1	6.3	na[2]
Hanna Spring (S5)	**2011–15**	**8/8**	**10**	**10**	**2–120**	**2010–15**	**9/1**	**11**	**1**	**12.2**	**T**
Last Lake Spring (S6)	2015	1/0	1	0	nd	2015	1/0	1	0	nd	na[2]
Lopez Spring 1 (S7)	**2011**	**2/2**	**4**	**3**	**7.3–11**	**2010, 2011**	**3/0**	**6**	**0**	**nd**	**ne**
Lopez 2 Spring (S8)	**2011–13**	**5/4**	**6**	**4**	**1–105**	**2011–13**	**5/1**	**6**	**1**	**1**	**T**
Navajo Spring (S9)	2001, 2016	2/2	3	3	58.1–149	2001, 2016	2/1	3	1	4.1	na[2]
Ute Spring (S10)	**2014, 2015**	**2/2**	**2**	**2**	**1**	**2014, 2015**	**2/0**	**2**	**0**	**nd**	**ne**
Whisky Road Spring (S12)	2014, 2015	2/2	2	2	22.8; 51.2	2014, 2015	2/1	2	1	4.1	na[2]
Whiskers Draw Spring (S13)[3]	**2013**	**2/2**	**2**	**2**	**31.5; 2,420**	**2013**	**2/2**	**2**	**2**	**1; 136**	**T**
Wells											
4000B well (W1)	2016	1/1	1	1	2,420	2016	1/1	1	1	8.6	—
4C well (W2)	2002, 2004, 2006	3/2	4	3	tntc	2004, 2006	2/2	4	4	461–687	—
AP–1	2013	1/0	1	0	nd	2013	1/0	1	0	nd	—
AP–15	2012	1/0	1	0	nd	2012	1/0	1	0	nd	—
AW Hwy 141 (W4)	2002	1/0	1	0	nd	2002	1/0	1	0	nd	—
AW Hwy 160/141 (W5)	2002	1/1	1	1	tntc	2002	1/1	1	1	3	—
Cottonwood Spring well (W8)	2014	1/0	1	0	nd	2014	1/0	1	0	nd	—
FW-W (W9)	2013	1/0	1	0	nd	2013	1/0	1	0	nd	—
Knight well (W11)	2013	1/1	1	1	2,420	2013	1/0	1	0	nd	—
Lagoon 1 well 3 (W13)	2010	1/1	1	1	1	2010	1/0	1	0	nd	—
Lagoon 2 well 2 (W14)	2002	1/1	1	1	1,300	2002	1/1	1	1	8.4	—
Mariano-FW (W18)	2013	1/1	1	1	90.5	2013	1/0	1	0	nd	—
Toe well (W22)	2016	1/1	1	1	2,420	2016	1/1	1	1	81.3	—
Wing well (W23)	2012	1/1	1	1	tntc	2012	1/0	1	0	nd	—

[1] For some sites, more than one sample was collected on a sample day.

[2] Spring is not culturally significant.

[3] Spring is shown on figure 1.

Lopez 2 Spring were −99.61 and −13.8 per mil, respectively (table 16). For the five wells, values of δ^{2}H of water ranged from −86.25 to −108.11 per mil, and values δ^{18}O of water ranged from −11.11 to −14.32 per mil (table 16).

The relationship between δ^{2}H and δ^{18}O of water can be used to evaluate sources of recharge to an aquifer and processes that have affected the recharge since it entered the aquifer. The relationship in precipitation measured worldwide is called the Global Meteoric Water Line (GMWL; Craig, 1961). Locally, the δ^{2}H and δ^{18}O composition of groundwater can differ from the GMWL because of different local climatic conditions, geographic differences such as altitude, recharge processes, and evaporation compared to global averages (Gat and Gonfiantini, 1981). Comparison of the stable isotope values for the UMUR groundwater to the GMWL indicate that recharge to groundwater from Lopez 2 Spring and the five wells primarily was derived from precipitation (fig. 13). Isotopic data for four of the five wells plotted slightly below and parallel to the GMWL (fig. 13), indicating that the groundwater was not affected by evaporation at these locations. The composition of the groundwater sample from the AP–1 well was enriched (isotopically heavier) relative to the values of δ^{2}H and δ^{18}O of water for the other wells; accordingly, it plots farther from the GWML than the other wells. The AP–1 well is a shallow well (well depth 26.6 ft bls; table 1.1 in app. 1) in the Farm and Ranch Enterprise area of the UMUR. The Farm and Ranch Enterprise receives irrigation water from McPhee Reservoir through the Dolores Project, and enrichment of δ^{2}H and δ^{18}O of water in the AP–1 sample could result from evaporative processes, possibly evaporation of water from McPhee Reservoir and evaporation of soil water in the irrigated area. Subsequent applications of irrigation water could flush the enriched soil water down to the shallow water table at the AP–1 well, which typically was between 10.0 and 15.6 ft bls for most years between 2008 and 2017 (table 2).

Stable isotope ratios of nitrogen (nitrogen-15/nitrogen-14 ratio [δ^{15}N]) and δ^{18}O of nitrate can be used to differentiate sources of nitrate in groundwater. Only the water sample from the AP–1 well was measured for δ^{15}N and δ^{18}O of nitrate. Values were 6.43 and 2.87 per mil, respectively (table 16). These values are well outside the range of values expected for synthetic fertilizer but fall within the range for manure fertilizer and soil organic matter (Kendall, 1998). Nitrate plus nitrite concentrations as high as 68 mg/L in samples from the AP–1 well (fig. 12*B*) could result from a combination of nitrate from manure-derived fertilizer and nitrate that occurs naturally in soils derived the Mancos Shale.

Tritium, the radioactive isotope of hydrogen, can be used to identify groundwater that has been recharged since the early 1950s ("young" groundwater), groundwater that recharged before the early 1950s ("old" groundwater), and groundwater that contains a mixture of young and old water (McMahon and others, 2013). Prior to the start of above-ground nuclear weapons testing (atomic bomb testing) in 1952, tritium concentrations in precipitation that recharged groundwater probably did not exceed 2–8 tritium units (TUs) (Plummer and others, 1993). Atomic-bomb testing from 1952 to the mid-1960s released large amounts of tritium into the atmosphere where it became incorporated into the water molecules of precipitation and entered groundwater systems as recharge. Because groundwater naturally has very low concentrations of tritium, measurable amounts of tritium in a groundwater sample indicate some portion of recharge occurred since the early 1950s (McMahon and others, 2013).

Unlike tritium, the radioactive isotope carbon-14 is suitable for dating groundwater that recharged around a thousand to tens of thousands of years ago because of its relatively long radioactive half-life of 5,730 years (Clark and Fritz, 1997). Carbon-14 is transported in groundwater as dissolved inorganic carbon or dissolved organic carbon (Clark and Fritz, 1997). To date groundwater using carbon-14, the carbon isotope is measured for dissolved inorganic carbon, and the result is typically expressed as percent modern or percent modern carbon (Plummer and others, 2012a). Carbon-14 values reported from laboratory analysis are typically normalized for carbon-13 fractionation and reported as percent modern. For this assessment, normalized carbon-14 values have been converted to nonnormalized values, reported as percent modern carbon, using techniques of Plummer and others (2012a). The nonnormalized values are the focus for data analysis. Percent modern carbon is the preferred measurement unit for groundwater age dating (Mook and van der Plicht, 1999; Plummer and others, 2012a).

Tritium and carbon-14 were the primary tracers used for interpreting groundwater ages for Lopez 2 Spring and the five wells (table 17). The samples were grouped into three groundwater-age classifications based on tritium and carbon-14 concentrations (fig. 14, table 17). The area of post-1950s water on figure 14 is defined by tritium concentrations >1.8 TU and carbon-14 concentrations >90 percent modern carbon (pmc). Samples plotting in these ranges likely represent groundwater that recharged after the start of above-ground atomic bomb testing in the early 1950s. The area of pre-1950s water on figure 14 is defined by tritium concentrations <0.2 TU and carbon-14 concentrations <90 pmc. Samples plotting is these ranges likely represent groundwater that recharged prior to atomic bomb testing in the early 1950s. Those samples with the lowest carbon-14 concentrations could represent water that recharged thousands of years ago. The tritium boundary of 1.8 TU is the probable current (2018) minimum concentration of tritium remaining from the concentrated atomic bomb testing in the early 1960s, and the boundary of 0.2 TU is the probable current maximum concentration of prebomb tritium because of the radioactive decay of tritium (half-life of 12.32 years) (Michel, 1989; Lucas and Unterweger, 2000; Jurgens and others, 2012). The numbers used for the tritium boundaries vary depending on location. The predominance of test sites in the northern hemisphere and air mass circulation resulted in a latitudinal gradient of tritium concentrations in precipitation (Plummer and others, 2012a). The assumed carbon-14 boundary of 90 pmc for post-1950s recharge is between the values for water samples from Lopez 2 Spring (103 pmc) and the AP–1 well (81.4 pmc) (table 17).

Table 16. Summary of data for stable isotopes of hydrogen and oxygen of water and nitrogen and oxygen of nitrate for water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and five wells on the Ute Mountain Ute Reservation in Colorado.

[Samples were analyzed at the U.S. Geological Survey Reston Stable Isotope Laboratory in Reston, Virginia. fig., figure; ID, identification; δ²H, hydrogen-2/hydrogen-1 isotopic ratio; per mil, parts per thousand; δ¹⁸O, oxygen-18/oxygen-16 isotopic ratio; δ¹⁵N, nitrogen-15/nitrogen-14 isotopic ratio; —, no data]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	Stables isotopes of hydrogen and oxygen of water		Stable isotopes of nitrogen and oxygen of nitrate in water (per mil)	
		δ^2H (per mil)	$\delta^{18}O$ (per mil)	$\delta^{15}N$ (per mil)	$\delta^{18}O$ (per mil)
Lopez 2 Spring (S8)	5/23/2017	−99.61	−13.80	—	—
AP–1 well	5/24/2017	−86.25	−11.11	6.43	2.87
5000 Block well (W3)	5/03/2017	−101.27	−13.52	—	—
Cottonwood Spring well (W8)	5/24/2017	−107.23	−14.32	—	—
Goodknight well (W10)	5/10/2017	−93.58	−12.62	—	—
SE Toe well (W20)	5/02/2017	−108.11	−14.30	—	—

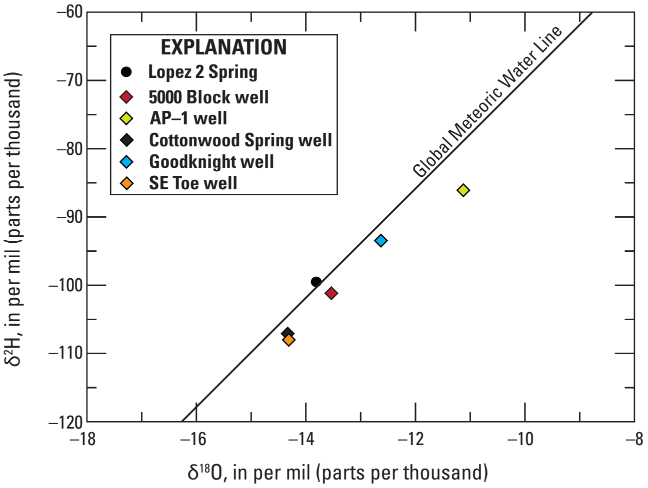

Figure 13. The hydrogen (δ^2H) and oxygen ($\delta^{18}O$) isotopic composition of water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and five wells on the Ute Mountain Ute Reservation in Colorado, plotted in relation to the Global Meteoric Water Line as described by Craig (1961).

The sample from Lopez 2 Spring was the only sample classified as having all post-1950s water (recharge after the early 1950s) (fig. 14). Recharge for samples from the 5000 Block, Goodknight, and SE Toe wells was pre-1950s water. Samples for these three wells had the lowest carbon-14 concentrations (3.90 pmc or less) and were likely recharged thousands of years ago. The Cottonwood Spring well sample also was classified as pre-1950s water, but the higher carbon-14 concentration (18.6 pmc) indicates that recharge probably was not as old as the other three wells. Undetected (that is, less than the laboratory reporting limit) concentrations of tritium for samples from 5000 Block, Goodknight, SE Toe, and Cottonwood Spring wells also indicate that the groundwater has not been affected by recharge since the early 1950s. The sample for the AP–1 well plots outside the pre- and post-1950s boxes in the “mixed” area of figure 14 and contains a combination of groundwater that recharged before and after the early 1950s. Recharge to the AP–1 well was mostly post-1950s, which is consistent with a nitrate plus nitrite concentrations of 45-68 mg/L (fig. 12*B*) and $\delta^{15}N$ and $\delta^{18}O$ values of nitrate of 6.43 and 2.87 per mil, respectively (table 16): this indicates there might be anthropogenic sources of nitrate in the well sample.

Chlorofluorocarbons are synthetic organic compounds that were developed in the early 1930s for refrigeration and have been used in a variety of industrial and refrigeration applications. The presence of CFCs can be used to estimate the apparent age of water that has recharged an aquifer since 1940 and also can be used to estimate the date of recharge (Coplen and others, 2000). To determine apparent CFC ages, measured CFC concentrations in groundwater samples are converted to equivalent air concentrations using known solubility relationships and recharge temperature with corrections made for excess air when needed (USGS, 2016a). The resulting concentrations are compared with the atmospheric concentration curves of CFCs to determine the apparent CFCs ages. Factors affecting the determination of age based on CFCs include transport processes; chemical processes, such as degradation and sorption during transit or redox conditions; excess air in a sample; and estimated recharge altitude or temperature (USGS, 2016a).

Table 17. Summary of tritium and carbon-14 data for water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and five wells on the Ute Mountain Ute Reservation in Colorado.

[The conversion of picocuries per liter (pCi/L) to tritium unit (TU), based on a half-life of 12.32 years (Lucas and Unterweger, 2000), is approximately 1 pCi/L = 0.3135 TU. fig., figure; ID, identification; $\delta^{13}C$, carbon-13/carbon-12 isotopic ratio; DIC, dissolved inorganic carbon; per mil, parts per thousand; pmc, percent modern carbon]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	Tritium (pCi/L)[1]	Tritium (TU)	$\delta^{13}C$-DIC (per mil)[2]	Carbon-14-DIC (nonnormalized) (pmc)[3]	Carbon-14 (normalized) (pmc)[2]	Tritium/cabon-14 category (see fig. 14)[4]
Lopez 2 Spring (S8)	5/23/2017	17.1	5.36	−11.97	103	100.15	Post-1950s
AP-1 well	5/24/2017	12.8	4.01	−12.78	81.4	79.37	Mixed
5000 Block well (W3)	5/03/2017	0.18	0.056	2.65	3.37	3.19	Pre-1950s
Cottonwood Spring well (W8)	5/24/2017	−0.38	−0.119	−12.36	18.6	18.13	Pre-1950s
Goodknight well (W10)	5/10/2017	−0.24	−0.075	−2.69	0.952	0.91	Pre-1950s
SE Toe well (W20)	5/02/2017	−0.11	−0.034	−0.55	3.90	3.71	Pre-1950s

[1] Tritium result reported by the U.S. Geological Survey Tritium Laboratory in Menlo Park, California. Results for 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells are less than laboratory reporting limits, which range from 0.34 to 0.39 pCi/L.

[2] Carbon-13 and carbon-14 results reported by the National Ocean Sciences Mass Spectrometry Facility in Woods Hole, Massachusetts. Although not specifically discussed in the report, the isotopic data for carbon-13 are included in the table for completeness of laboratory results.

[3] Nonnormalized data: data have not been adjusted for isotopic fractionation.

[4] Post-1950s: recharge after the early 1950s. Pre-1950s: recharge before the early 1950s.

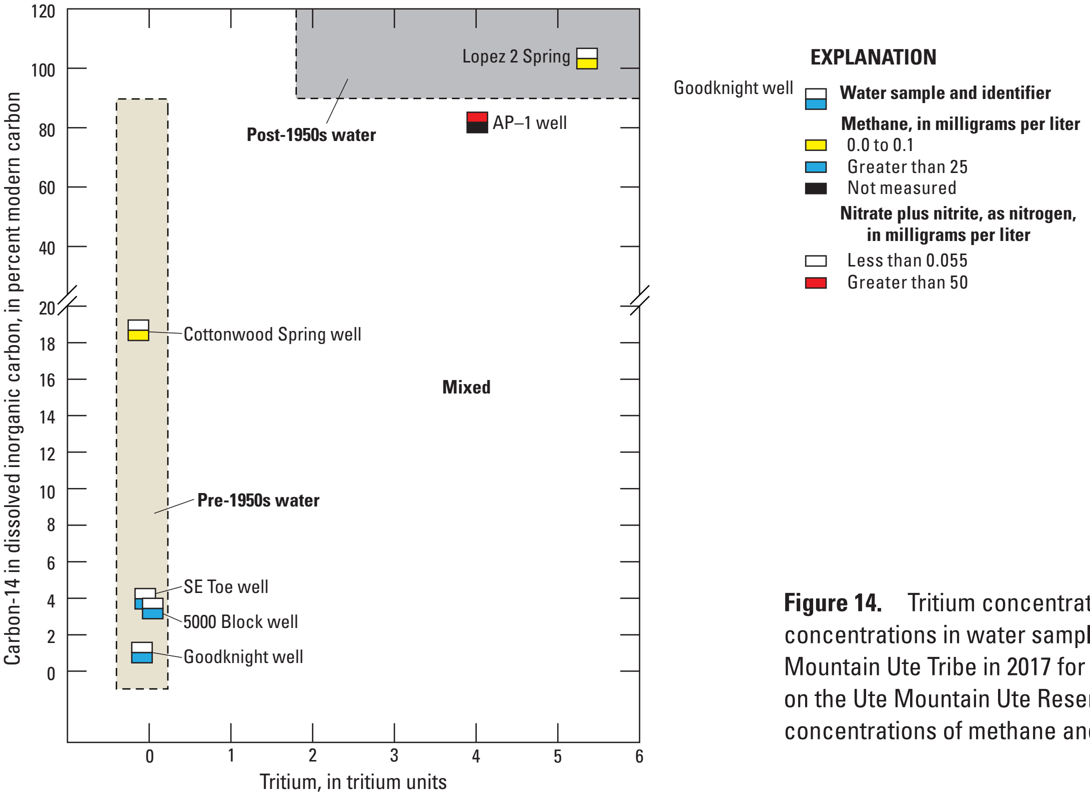

Figure 14. Tritium concentrations in relation to carbon-14 concentrations in water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and five wells on the Ute Mountain Ute Reservation in Colorado, with concentrations of methane and nitrate plus nitrite.

Chlorofluorocarbons were analyzed for groundwater samples collected from Lopez 2 Spring and the 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells (table 18). Elevated CFC concentrations in the Lopez 2 Spring sample and an apparent CFC age of late 1990s or younger are consistent with tritium and carbon-14 results that indicate post-1950s recharge. The CFC results for the Cottonwood Spring well sample indicate that recharge occurred in the mid-1950s (table 18), which is inconsistent with an absence of tritium and an age classification of pre-1950s recharge from the tritium and carbon-14 data. The discrepancy in recharge age could be caused by contamination during CFC sampling, air getting into the well bore, or introduction of air if the water level is within the screened interval of the well. Unlike CFC samples, recharge ages for tritium and carbon-14 samples are not affected by air exposure. Laboratory results for CFC samples from the 5000 Block, Goodknight, and SE Toe wells noted that all CFCs were degraded. Each sample was anoxic (DO concentrations <0.5 mg/L), and numerous studies have reported degradation of CFCs in anaerobic environments (Solomon and others, 1998; Sebol and others, 2007; Chambers and others, 2018). As with the Cottonwood Spring well sample, the presence of CFCs in the three wells, though degraded, are inconsistent with tritium and carbon-14 dating of pre-1950s recharge. Samples from the 5000 Block, Goodknight, and SE Toe wells could also have been contaminated, or air could have been introduced during sampling. The CFC sample results for the Cottonwood Spring, 5000 Block, Goodknight, and SE Toe wells are excluded from evaluation of recharge age.

Samples of groundwater from Lopez 2 Spring and 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells also were analyzed for dissolved and noble gases (tables 19 and 20). Dissolved gas concentrations, as well as the ratios of dissolved gas concentrations, can be used to provide information on geochemical conditions, such as microbial degradation; calculate the recharge temperature of a groundwater sample; and determine excess air. Concentrations of noble gases also are useful for determining the age and source of groundwater and for determining recharge temperature and excess air (Hunt, 2015). For this report, interpretation of dissolved gas and noble gas data is focused on the dissolved gases methane and oxygen and geochemical conditions, and the noble gas helium-4 and groundwater age. Data for other dissolved and noble gases, although not specifically discussed, are included in tables 19 and 20 for completeness of laboratory results.

Concentrations of methane gas were elevated (25.9 mg/L or more) in water samples from the 5000 Block, Goodknight, and SE Toe wells (table 19). Each sample was old (pre-1950s recharge), anoxic (DO water and gas concentrations <0.5 mg/L), enriched with ammonia, and low in sulfate (excluding the SE Toe well) (table 19). These conditions are consistent with what could be expected for methanogenesis, the natural production of methane within aquifers by methanogenic bacteria in low-oxygen environments (McMahon and others, 2017). The cooccurrence of high methane and sulfate concentrations in the SE Toe well sample indicates possible mixing of methanogenic and sulfate-enriched waters (McMahon and others, 2017).

Dates interpreted from helium-4 data for the Lopez 2 Spring and the Cottonwood Spring, Goodknight, and SE Toe wells are consistent with the tritium- and carbon-14-based age classifications (fig. 14). A very low helium-4 concentration like that detected for the Lopez 2 Spring (table 20) occurs when water equilibrates with air, which indicates young water. Helium-4 concentrations, such as those for the Cottonwood Spring, Goodknight, and SE Toe wells (table 20), are greatest in older groundwater, increasing with residence time of water as helium-4 is produced from the decay of uranium and thorium in aquifer materials (Heaton, 1984; Solomon and others, 1998). For the 5000 Block well, the very high methane concentration (table 19) appears to have caused substantial stripping of helium-4 from the sample (table 20), possibly during sample collection. Gases that are in solution within an aquifer because of hydrostatic pressure can come out of solution as pressure is reduced when water is pumped to the surface. When samples with high levels of methane degas, the methane can strip relatively insoluble gases like helium-4 out of solution (Danabalan and others, 2017).

Vulnerability Assessment

The protection of water resources on the UMUR has been an overriding goal of the UMUT. Data collection efforts have been designed to assess the current state of water resources, protect designated uses, assess water-quality trends, and identify potential sources of impairment to water quality and areas vulnerable to land-use activities. The UMUT Groundwater Protection Plan was developed to identify the vulnerability of aquifers to potential toxic or hazardous chemicals, particularly pesticides, from land-use activities, and to organize a protection strategy for the aquifers (UMUT, 2004).

The UMUT specifically focused their assessment of vulnerability on natural risk and land-use susceptibility to contamination (UMUT, 2004). Three classifications of natural risk—low, moderate, and high—were developed by the UMUT; an area's risk is based on its natural conditions, including geology and aquifer properties, and soil properties (leaching and run-off potential) (UMUT, 2004). A high natural risk to contamination occurs, for example, when aquifer properties and leaching through soil favor the movement of a pesticide or other anthropogenic chemical from the land surface to the water table.

The susceptibility of a given area of land to contamination was determined by land-use sensitivity and resource use (UMUT, 2004). The use of land by the UMUT and the level of care required to prevent adverse effects to groundwater affect land-use sensitivity (UMUT, 2004). A high sensitivity ranking, for example, is applied to springs because of their importance for Tribal ceremonial activities, and a low-sensitivity ranking is applied to rangeland because of low pesticide use and

Table 18. Summary of chlorofluorocarbon (CFC) and apparent age for water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and four wells on the Ute Mountain Ute Reservation in Colorado.

[Samples were analyzed at the U.S. Geological Survey Reston Groundwater Dating Laboratory in Reston, Virginia. fig., figure; ID, identification; pptv, parts per trillion by volume; —, no comment; cnbd, could not be determined]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	CFC-11, range of calculated atmospheric mixing ratio (pptv)	CFC-12, range of calculated atmospheric mixing ratio (pptv)	CFC-13, range of calculated atmospheric mixing ratio (pptv)	Piston-flow model age basis	Piston-flow model apparent age	Comment
Lopez 2 Spring (S8)	5/23/2017	243–248	538–556	70.4–73.8	CFC-11, 12, 13	Late 1990s or younger	—
5000 Block well (W3)	5/03/2017	0.0–0.5	93.5–162.2	11.4–13.4	None	cnbd	All CFCs are degraded.
Cottonwood Spring well (W8)	5/24/2017	2.4–5.8	18.9–22.1	0.5–2.0	CFC-11, 12, 13	Mid-1950s[1]	—
Goodknight well (W10)	5/10/2017	0.2–0.5	106.4–120.8	12.3–13.3	None	cnbd	All CFCs are degraded.
SE Toe well (W20)	5/02/2017	0.8–2.2	87.8–95.2	13.4–14.9	None	cnbd	All CFCs are degraded.

[1] Likely anomalous value. Tritium and carbon-14 data indicate that recharge occurred before the early 1950s (see table 17). Tritium was not detected in the sample.

Table 19. Summary of dissolved gas data for water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and four wells on the Ute Mountain Ute Reservation in Colorado, with estimated recharge dates and concentrations of total recoverable ammonia and sulfate.

[Dissolved gas samples were analyzed at the U.S. Geological Survey Reston Groundwater Dating Laboratory in Reston, Virginia. fig., figure; ID, identification; mg/L, milligrams per liter; —, no comment; <, less than]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	Dissolved gases						Estimated recharge date[1]	Ammonia, total recoverable (mg/L)	Sulfate (mg/L)
		Methane (mg/L)	Carbon dioxide (mg/L)	Nitrogen (mg/L)	Oxygen (mg/L)	Argon (mg/L)	Laboratory comment			
Lopez 2 Spring (S8)	5/23/2017	0.0 0.0	11.9 11.2	15.4 15.3	6.0 6.9	0.57 0.56	—	Post-1950s	<0.04	49
5000 Block well (W3)	5/03/2017	39.2 39.6	10.2 10.0	0.62 0.65	0.001 0.0005	0.033 0.036	Gas stripping[2]	Pre-1950s	1.85	<1.56
Cottonwood Spring well (W8)	5/24/2017	0.096 0.094	1.2 1.2	19.9 20.1	0.28 0.29	0.67 0.68	—	Pre-1950s	<0.04	196
Goodknight well (W10)	5/10/2017	27.2 27.6	22.1 23.8	6.4 6.4	0.060 0.050	0.29 0.29	Gas stripping[2]	Pre-1950s	1.09	<1.56
SE Toe well (W20)	5/02/2017	27.0 25.9	1.2 1.2	9.9 9.9	0.060 0.076	0.35 0.36	Gas stripping[2]	Pre-1950s	1.32	52.6

[1] Post-1950s: recharge after the early 1950s. Pre-1950s: recharge before the early 1950s. Estimated dates based on tritium and carbon-14 concentrations. See table 17.

[2] Degassing (separation of a gas from a liquid) of a sample, likely due to high methane concentration.

Table 20. Summary of noble gas data for water samples collected by the Ute Mountain Ute Tribe in 2017 for one spring and four wells on the Ute Mountain Ute Reservation in Colorado.

[Samples were analyzed at the U.S. Geological Survey Noble Gas Laboratory in Lakewood, Colorado. fig., figure; ID, identification; cm^{3}STP/g[H$_2$0], cubic centimeters at standard temperature and pressure per gram of water; R/Ra, measured helium-3/helium-4 isotopic ratio relative to the helium isotopic ratio of air; —, no laboratory comment]

Site (see fig. 5, site ID in parentheses is used on figure)	Sample date	Helium-4 (cm^{3}STP/ g[H$_2$0])	Neon (cm^{3}STP/ g[H$_2$0])	Argon (cm^{3}STP/ g[H$_2$0])	Krypton (cm^{3}STP/ g[H$_2$0])	Xenon (cm^{3}STP/ g[H$_2$0])	R/Ra	Laboratory comment
Lopez 2 Spring (S8)	5/23/2017	4.06E-8	0.000	3.29E-4	8.00E-8	1.24E-8	0.906	—
5000 Block well (W3)	5/03/2017	[1]3.24E-08	1.32E-8	1.64E-5	4.98E-9	9.96E-10	0.197	Hydrocarbons present
Cottonwood Spring well (W8)	5/24/2017	6.29E-7	1.82E-7	3.57E-4	8.75E-8	1.31E-8	0.149	—
Goodknight well (W10)	5/10/2017	3.85E-6	5.62E-8	1.56E-4	4.04E-8	5.97E-9	0.140	Hydrocarbons present
SE Toe well (W20)	5/02/2017	2.03E-7	0.000	1.86E-4	4.24E-8	5.04E-9	0.130	Hydrocarbons present

[1] Value is lower than expected because of gas stripping of the sample (degassing [separation of a gas from a liquid], likely due to high methane concentration).

no irrigation. Some areas are more susceptible to contamination because of resource use. Irrigated land and roadways, for example, are susceptible areas because of a greater potential of a chemical to contaminate water resources as compared to land that is not susceptible because of the lack of development.

Natural risk and land-use susceptibility to contamination were combined by the UMUT to develop an overall groundwater vulnerability ranking of high, moderate, or low (table 21) (UMUT, 2004). A high vulnerability ranking for potential contamination, for example, is given to culturally significant springs because of the short residence time of water in the spring and Tribal ceremonial use. A ranking of low vulnerability is given to rangeland because of the limited amount of recharge to the subsurface and lack of exposure to potential toxic or hazardous chemicals. The groundwater vulnerability ranking is used by the UMUT to focus monitoring, target prevention measures, and implement a strategy for responding to detections of pesticides and other anthropogenic chemicals (UMUT, 2004).

Areas with oil and gas development are given a high vulnerability ranking (table 21). Abandoned wells in the northwest portion of the UMUR have been an issue of concern for several years (Clarren, 2018). Concerns include a legacy of contamination from surface activities and injection wells with casing failure. Hydrocarbons and metals in soils and unlined pits, and other surface contamination at abandoned wells sites, have the potential to migrate farther into in the subsurface, to the water table, or to McElmo Creek during large runoff events. It is estimated that cleanup costs for seven abandoned wells could range from $1 to $5 million or more (Clarren, 2018). Lack of financial and human resources greatly limit the amount of cleanup that can be undertaken (Clarren, 2018).

Vulnerability of groundwater to contamination can also be assessed for different types of groundwater resources. Springs and surficial deposits are more vulnerable to contamination than deeper bedrock wells because of proximity to the land surface, porous aquifer materials, shallow depths to water, young groundwater age, and lack of a confining layer. Based on groundwater-age results, for example, recharge to springs on Ute Mountain and to groundwater in the surficial deposits of the Farm and Ranch Enterprise area has occurred primarily since the early 1950s. These results indicate that contamination at the land surface could potentially affect groundwater quality in springs and surficial deposits in these areas. Chemicals applied or spilled at the land surface can move with recharge water to springs and surficial deposits because of the absence of a confining layer. Similarly, bedrock aquifers are vulnerable to contamination where the geologic formations containing the aquifers are exposed (outcrop) at the land surface. Overlying confining layers and the long residence time of groundwater in deep bedrock aquifers, such as that for the SE Toe well that is likely thousands of years old, minimize the likelihood of contamination from present-day land uses. However, the natural protection offered by overlying, unfractured confining layers may be negated if chemicals on the land surface or poor-quality surficial groundwater contact bedrock aquifers through abandoned wells, as described previously, or through well bores (EPA, 2015). Deeper groundwater could be vulnerable if activity resumes in areas of oil and gas development. Historically, oil and gas development on the UMUR in Colorado has occurred in the far northwest and southeast corners of the reservation and in areas near the confluence of Navajo Wash and the Mancos River. An anthropogenic chemical in deep, old groundwater would not be diluted by new recharge because of the slow rate of infiltration to deep groundwater. The introduction of oxic groundwater to deep anoxic groundwater could change redox conditions and mobilize redox-sensitive contaminants such as uranium.

The vulnerability of the shallow groundwater system in agricultural areas to nitrate is greatly increased with the application of irrigation water and nitrogen-containing fertilizer to the land surface. Downward-flowing irrigation water can transport fertilizers through the subsurface to the water table and can also mobilize and transport naturally occurring nitrate in materials derived from Mancos Shale (Morrison and others, 2012; Mills and others, 2016). Total nitrate concentrations in samples from some AP wells collected in 2011 and 2013–14 were 40 mg/L or more, and depth to water during these sample years was from 3.3 to 24.9 ft bls (table 2). Overall, the deep groundwater system is not vulnerable to nitrate or nitrate plus nitrite because of the absence of a nitrate source, the overlying Mancos Shale confining layer, long residence time, and geochemical processes that would reduce nitrate to nitrogen gas. Most (12 of 13) concentrations of nitrate plus nitrite in samples of deep groundwater were 0.23 mg/L or less (fig. 12*B*). The deep groundwater system, however, may be vulnerable to ammonia when reducing conditions are present. Ammonia concentrations >1 mg/L in the deep groundwater system (fig. 12*A*) were only detected in anoxic samples from the 5000 Block, Goodknight, and SE Toe wells.

Detection of a pesticide or VOCs in well samples collected from the irrigated area, even though concentrations were well below human-health benchmarks, also indicate vulnerability of surficial deposits. The presence of *E. coli* and detections of aluminum and arsenic at concentrations greater than Tribal cultural-use standards in samples from culturally significant

Table 21. Land use and natural risk in groundwater vulnerability for the Ute Mountain Ute Reservation.

[Modified from Ute Mountain Ute Tribe (2004). HV, high vulnerability; MV, moderate vulnerability; LV, low vulnerability]

Land use	High natural risk	Moderate natural risk	Low natural risk
Cultural	HV	HV	MV
Irrigated agriculture	HV	MV	MV
Urban	HV	MV	LV
Highways	HV	MV	LV
Oil and gas	HV	MV	LV
Agriculture	MV	LV	LV
Rangeland	LV	LV	LV

springs indicates vulnerability to contamination from bacteria and trace elements. The UMUT water-quality standards for use of surface water for agriculture, irrigation, and (or) livestock watering, and the CDPHE standards for the agricultural use of groundwater, were exceeded for some constituents.

Groundwater is vulnerable not only to anthropogenic chemicals from various land uses but also to naturally occurring salts and minerals (Focazio and others, 2002). In the absence of anthropogenic influences, detections of dissolved solids, major ions, and trace elements in spring and well samples indicate naturally occurring constituents in groundwater. Groundwater vulnerability to naturally occurring salts and minerals is affected by natural factors such as water movement, rock-water interactions, geochemical processes, and residence time and by the sources, locations, fate, and transport of the salts and minerals. For example, the application of freshwater to irrigate land in the Farm and Ranch Enterprise area likely has dissolved naturally occurring salts in the subsurface and increased their downward movement to the water table where groundwater has become enriched with dissolved solids (Tuttle and other, 2014b, Mills and others 2016). For shallow wells, most (77 percent) TDS concentrations between the 25th (3,456 mg/L) and 90th (6,722 mg/L) percentile concentrations on figure 9 were for samples from AP wells. The trace elements arsenic and selenium, which are often present in materials derived from Mancos Shale (Morrison and others, 2012; Tuttle and others, 2014a), can readily dissolve from surficial deposits when in contact with oxic recharge water. Detected concentrations of total recoverable arsenic and total recoverable and dissolved selenium were greatest in samples from AP wells. Deep groundwater is highly vulnerable to naturally occurring salts and minerals. For example, about 75 percent of samples from deep wells had TDS concentrations >2,000 mg/L (fig. 9).

An area of concern for the UMUT is the effect of climate change on water resources and other ecological characteristics on the UMUR. Climate studies indicate that southwest Colorado warmed by 2 °F between 1977 and 2007 and could warm an additional 2.5–5.5 °F by 2050 (Mountain Studies Institute, 2014). A warmer environment would increase the rate at which water evaporates or transpires from snow, surface water, the water table, soil, and vegetation. Decreases in snowpack and water content of snow and earlier snowmelt and peak streamflow have already been observed in western Colorado as temperatures have warmed (EPA, 2016). It is estimated that snowmelt in western Colorado now occurs 2 weeks earlier than it did in the late 1970s (Clow, 2010). Other potential effects of warmer temperatures include a decrease in groundwater recharge, which results in decreased flow of springs; a decrease in soil moisture for natural vegetation and crops; an increase in invasive vegetation and pests; changes in irrigation and crop production; reduced vegetation coverage; shifts in the altitudinal distribution of plants and animals; and increased occurrence of wildfires and forest mortality (Mountain Studies Institute, 2014; EPA, 2016). Particularly for the UMUT, climate change could potentially affect medicinal and culturally important plants and springs. Climate studies indicate that precipitation could decrease annually, occur more often in winter, and (or) be more variable with more frequent extreme storms (Mountain Studies Institute, 2014). Periods of drought are a natural occurrence in southwest Colorado (fig. 15), but their frequency, length, and intensity are expected to increase throughout the southwestern United States, including Colorado. In MVNP, 90 percent of high-altitude pinyon pines (*Pinus edulis*) have died recently because of drought (National Park Service, 2011).

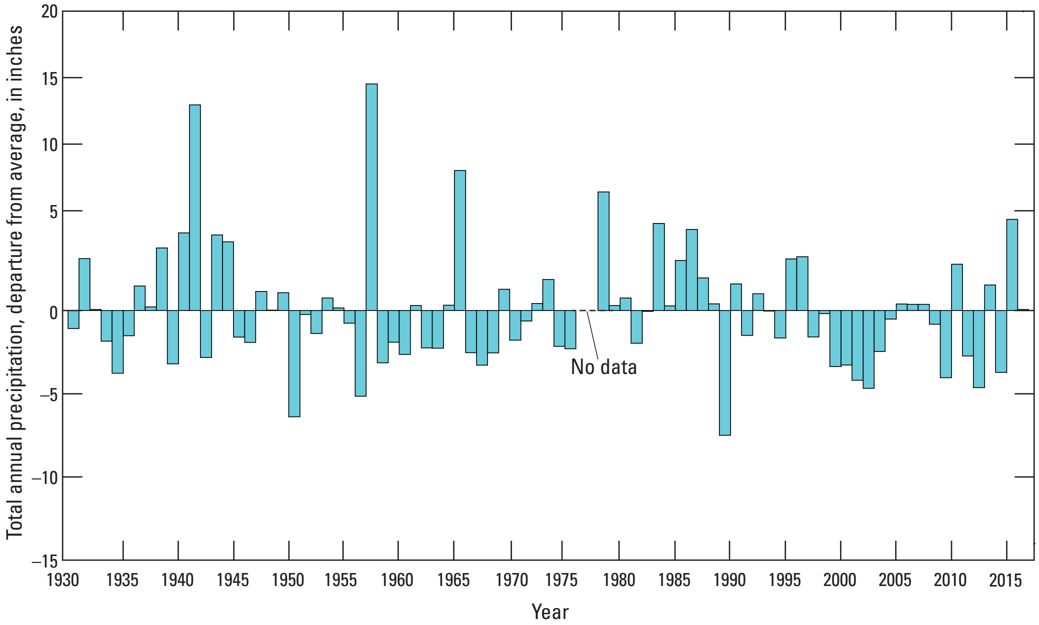

Figure 15. Precipitation departure from average for meteorological station 051886 at Cortez, Colorado, 1930–2016 (Western Regional Climate Center, 2018b). The dashed line indicates no data.

Information Needs

During the compilation and interpretation of data for this report, several items were identified where additional information would aid in understanding the groundwater resources of the UMUR. Some pertain to ancillary information and others pertain to data collection.

The lack of ancillary information for most bedrock wells, including well-completion data such as lithology, lithologic thickness, well depth, and screen interval, limited the interpretation of groundwater-chemistry data for bedrock wells. In most instances, for example, groundwater chemistry could not be correlated to specific geologic formations (aquifers) underlying the UMUR. Information provided by a downhole camera, such as well depth and screen interval, could aid in understanding the source and, therefore, the quality of groundwater.

Collection of environmental tracer data was conducted by the UMUT at six sites in May 2017. The identification of additional sites appropriate for environmental tracer sampling and the sampling of these sites would expand information on recharge, processes affecting groundwater quality, geochemical conditions, groundwater age, methane occurrence, and recharge temperature. This information would increase understanding of where groundwater is old and vulnerable to the effects of human activity occurring in the deep subsurface or younger and vulnerable to human activities occurring at the land surface.

Analysis of elevated dissolved methane concentrations in samples from the 5000 Block, Goodknight, and SE Toe wells indicate that methanogenesis likely has occurred in parts of the groundwater system. Methane can also be introduced into groundwater during oil and gas activities (McMahon and others, 2018). Collection of groundwater samples for analysis of methane and additional hydrocarbons (ethane, propane, butane, and pentane) and analysis of methane isotopes at the three wells and other wells could provide a baseline understanding for the origin of methane, especially if there is Tribal interest in resuming development of hydrocarbon resources in Colorado. Thermogenic gas, which is gas that is produced under high temperature and pressure conditions, is more enriched with ethane, propane, butane, and pentane relative to methane than microbial gas, which is enriched with methane (Kulongoski and others, 2018; McMahon and others, 2018).

The resampling of some sites could aid in further understanding of groundwater resources. Some springs and wells were last sampled in 2002 or earlier, whereas others have been sampled only since 2010. The resampling of springs and wells with data collected from 1996 through 2002, such as that for East Toe Spring and the AW Hwy 141 well, would update the temporal coverage of groundwater-chemistry data.

Summary

Water sustains the cultural, spiritual, and economic health of the Ute Mountain Ute Tribe (UMUT) and the Ute Mountain Ute Reservation (UMUR) in the semiarid Colorado Plateau region of Colorado, New Mexico, and Utah. The U.S. Geological Survey, in cooperation with the UMUT, initiated a study in 2016 to compile and analyze hydrogeologic and groundwater-chemistry information for the UMUR in Colorado and Utah and, in 2017, assisted the UMUT in developing and implementing a sampling plan for environmental tracers in spring and well water that was executed by the UMUT. The study was designed to increase understanding of the hydrogeology and groundwater chemistry of the groundwater system within select areas the UMUR, identify vulnerabilities to the system and other natural resources, and outline information needs to aid in groundwater resource understanding and protection. The results presented for this study can be used to support the UMUT's goal of protecting their vital groundwater resources on the UMUR. This report includes (1) characterization of hydrogeologic conditions for selected aquifers within the UMUR in Colorado; (2) compilation and analysis of groundwater-chemistry data for springs and wells, focusing primarily on data collected by the UMUT in Colorado and Utah from 1996 through 2017; (3) analysis of environmental tracer data collected by the UMUT in Colorado in 2017; (4) assessment of the vulnerability of resources to contamination and climate change; and (5) identification of information needs to advance the protection and understanding of groundwater resources.

The UMUR encompasses about 597,000 acres (933 square miles) of trust land in Colorado, New Mexico, and Utah in the Four Corners region of the Colorado Plateau; most is in southwestern Colorado. Geology of the UMUR includes Cretaceous-age sandstones, shales, and mudstone, prominently the Mancos Shale and Dakota Sandstone; Late Cretaceous- and Tertiary-age igneous rocks that form the Ute Mountains; and Quaternary-age unconsolidated surficial deposits. Groundwater primarily occurs in the surficial aquifer contained in unconsolidated surficial deposits and in aquifers contained in sandstone geologic formations, such as the Dakota Sandstone. Some springs in the Ute Mountains are culturally significant for the UMUT and have ceremonial use.

Characterization of hydrogeologic conditions in Colorado include (1) determining depth to the water table below land surface and direction and gradient of the water-table slope for the surficial aquifer in two areas of the UMUR and (2) mapping depth to the top of the Dakota Sandstone. The median depth to water in the surficial aquifer in the Farm and Ranch Enterprise area ranged from 5.4 to 17.2 feet (ft) below land surface (bls), and the water surface slopes to the southwest away from the Ute Mountains with a mean gradient of about 94 ft per mile. Near Towaoc, the depth to water ranged from about 11 to 34 ft bls, and the water-table slopes generally southward with mean gradient of about 143 ft per mile. Within the boundaries of the UMUR in Colorado, depths to the top of the Dakota Sandstone range from zero in outcrop areas to about 1,500 ft bls in the western part of the UMUR and to more than 3,000 ft bls on mesas in the southeastern part of the UMUR.

Groundwater-chemistry data collected by the UMUT in Colorado and Utah were the focus of the groundwater-chemistry assessment. Analysis was supplemented with historical data from the U.S. Geological Survey and Colorado Oil and Gas Conservation Commission. The UMUT collected data from 13 springs and 31 wells in 1996 through 2017 for physical properties, total dissolved solids (TDS), major ions, nutrients, trace elements, uranium, coliform bacteria, and environmental tracers. Quality-assurance procedures were applied to the data prior to analysis.

Specific conductance values for UMUT data were much lower for samples of spring water than well water; median values were 512 and 6,024 microsiemens per centimeter at 25 degrees Celsius, respectively. Most pH values were within water-quality standards established for cultural use of water, aquatic-life criteria, and agricultural use of surface water and groundwater. Dissolved oxygen concentrations in a few well samples were low, less than 0.5 milligrams per liter (mg/L), which could indicate reducing conditions in the aquifer.

Overall, spring samples collected by the UMUT were less mineralized than well samples. About 72 percent of spring samples had fresh water (TDS concentrations less than 1,000 mg/L), whereas most (85 percent) of well samples had brackish or highly saline water (TDS concentrations greater than 1,000 mg/L). The UMUT cultural-use standard for TDS of 500 mg/L was exceeded for five springs, including the culturally significant Whiskers Draw Spring.

Samples from springs on the Ute Mountains were calcium-bicarbonate type water, whereas lower-altitude springs with more mineralization were a calcium-sulfate type water. Most well samples had sodium as the dominant cation and sulfate, bicarbonate, and chloride as the dominant anions.

Alkalinity concentrations less than 100 mg/L in some UMUT samples from springs on the Ute Mountains indicate that some spring water is not well buffered and could be susceptible to input of acidic water. Of the well samples, about 45 percent had fluoride concentrations greater than the Colorado agricultural-use standard for groundwater of 2 mg/L, which could adversely affect animal health if water were to be used for livestock supply. Most ammonia concentrations in spring and well samples collected by the UMUT were similar to or less than the estimated natural background concentration in groundwater of 0.2 mg/L. Concentrations greater than 1 mg/L were detected in well samples that were anoxic. Most concentrations of nitrate plus nitrite in spring and well samples were 1.6 mg/L or less. Concentrations were elevated (maximum of 78.5 mg/L) in samples from wells in the Farm and Ranch Enterprise area of the UMUR.

About 50 percent of samples collected by the UMUT for trace elements had concentrations less than laboratory reporting limits. Total recoverable aluminum, arsenic, and selenium in spring samples, and dissolved boron and selenium in well samples, were detected at concentrations greater than water-quality standards established by the UMUT or the Colorado Department of Public Health and Environment. Samples from three culturally significant springs, Hanna, Ute, and Whiskers Draw, exceeded the UMUT surface-water cultural-use standards for aluminum and (or) arsenic. Only the pesticides alachlor and atrazine and the volatile organic compound di(2-ethylhexyl) phthalate were detected in well samples. The detected concentrations for wells in the Farm and Ranch Enterprise area were less than drinking-water standards.

Coliform bacteria (total coliform and *E. coli*) were more commonly detected in well samples (77 percent) than in spring samples (30 percent). Detections of *E. coli* were more common for well samples (47 percent) than for spring samples (23 percent). Exceedances of the UMUT cultural-use standard of total absence of the *E. coli* in spring water included samples from the culturally significant Hanna, Lopez 2, and Whiskers Draw Springs.

Water samples from Lopez 2 Spring and AP–1, 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells were analyzed for environmental tracers, including stable isotopes, tritium, chlorofluorocarbons, dissolved gases, and noble gases. Concentrations of the stable isotope of hydrogen and oxygen of water in the spring and well samples indicate that recharge primarily was derived from precipitation. Tritium and carbon-14 were the primary tracers used for interpreting groundwater ages. Recharge to Lopez 2 Spring was post-1950s in age, and recharge to 5000 Block, Cottonwood Spring, Goodknight, and SE Toe wells was pre-1950s in age. Recharge to the AP–1 well was a mixture of pre- and post-1950s water. Helium-4 data support the tritium and carbon-14 ages for Lopez 2 Spring and Cottonwood, Goodknight, and SE Toe wells but not the 5000 Block well because of high methane concentrations in the water.

Springs and surficial deposits are more vulnerable to contamination from anthropogenic chemicals than deeper bedrock wells because of proximity to the land surface, porous aquifer materials, and shallow depths to water. Bedrock aquifers are vulnerable in areas where the geologic formations containing these aquifers are exposed (outcrop) at the land surface. Groundwater in deep bedrock aquifers is likely thousands of years old and is not currently affected by present-day land uses. Deeper groundwater could be vulnerable to contaminants from surface activities or poor-quality shallow groundwater if chemicals can move to deeper groundwater through abandoned wells or through well bores. Both shallow and deep groundwater is vulnerable to naturally occurring salts and minerals, including TDS, major ions, nitrate, and trace elements. Water resources and other ecological characteristics of the UMUR are vulnerable to a changing climate. Possible effects could include changes in evapotranspiration, a decrease in snowpack, decreased aquifer recharge and flow of springs, a decrease in soil moisture, changes in irrigation and crop production, and increased occurrence of wildfires and forest mortality. Of particular interest for the UMUT are possible effects of a changing climate on medicinal and culturally important plants and springs.

Several information needs were identified that would aid in understanding the groundwater resources of the UMUR. Ancillary information for bedrock wells, including well-completion data such as lithology, well depth, and screen interval, would increase understanding of the source and quality of groundwater. The collection of environmental tracer data at additional wells and collection of well samples for methane and hydrocarbon analysis would expand information on recharge, processes affecting groundwater quality, geochemical conditions, groundwater age, and methane occurrence. Resampling of seven springs and wells that were last sampled in 2002 or earlier would update the temporal coverage of groundwater-chemistry data.

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Appendix 1. Hydrogeologic Characterization

Table 1.1. Description of wells used for measuring water levels in the surficial aquifer contained in unconsolidated surficial deposits on the Ute Mountain Ute Reservation in Colorado, with sources of data, period of water-level record, and select water-level measurements.

[ID, identification; figs., figures; USGS, U.S. Geological Survey; LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; DEM, digital elevation model; ft; feet; NAVD88, North American Vertical Datum of 1988; bls, below land surface; UTEMTN, Ute Mountain Ute Tribe; na, not applicable; NAD27, North American Datum of 1927; NWIS, National Water Information System; NAD83, North American Datum of 1983; —, no information]

Site ID (see figs. 5 and 6)	Unique site identifier	USGS station name	Latitude DD	Longitude DD	Datum DD	DEM-derived altitude (ft above NAVD88)[1]	Well depth (ft bls)[2]	Water-level period of record	USGS water level (ft bls)
Ute Mountain Ute Tribe, Farm and Ranch Enterprise wells									
AP–1	[3]UTEMTN-AP–1	na	37.1896	−108.95114	NAD27	5,228	26.6	2008–14	na
AP–2	UTEMTN- AP–2	na	37.181417	−108.96471	NAD27	5,162	15.2	2008, 2010	na
AP–3	UTEMTN- AP–3	na	37.176026	−108.97301	NAD27	5,113	15	2008–10	na
AP–4	UTEMTN- AP–4	na	37.173375	−108.97961	NAD27	5,086	14	2009–12	na
AP–5	[3]UTEMTN- AP–5	na	37.171144	−108.99418	NAD27	5,015	11	2008–14	na
AP–10	[3]UTEMTN- AP–10	na	37.18558	−108.9329	NAD27	5,308	22.6	2008–14	na
AP–14	[3]UTEMTN-AP–14	na	37.159029	−108.92268	NAD27	5,245	14.2	2008–14	na
AP–15	[3]UTEMTN-AP–15	na	37.149655	−108.95784	NAD27	5,059	18.3	2010–14	na
AP–16	[3]UTEMTN-AP–16	na	37.152035	−108.93392	NAD27	5,170	13.4	2008–14	na
AP–17	UTEMTN- AP–17	na	37.163943	−108.91495	NAD27	5,300	18.4	2008–14	na
AP–22	UTEMTN- AP–22	na	37.209428	−108.97165	NAD27	5,273	6.4	3/1/2010	na
AP–24	[3]UTEMTN-AP–24	na	37.195571	−108.96395	NAD27	5,214	11.6	2010, 2012, 2014	na
USGS NWIS, USGS (2016b)									
NW31	[4]370946108423801	NB03301729UDAA	37.16278	−108.71056	NAD83	5,457	36.4	5/25/1982	12.3
USGS, Geldon (1985)									
NW20	[3,4]371204108434301	NB33501707DDA B–15	37.20111	−108.72926	NAD83	5,875	65.8	4/4/1983	26.3
NW29	—	NB03301729UADD	[5]37.18944	[5]−108.72812	—	5,476	36.4	4/7/1983	11.4
NW30	[4]370928108433101	NB03301729UCCA	37.15778	−108.725277	NAD83	5,446	34	4/7/1983	15.2
NW32	[4]371208108433501	NB03301708UCCB	37.20222	−108.72639	NAD83	5,883	36	4/4/1983	17.4
USGS, Irwin (1966)									
NW11	[3,4]371003108451301	NB33501825UABCC B–2	37.16749	−108.75426	NAD83	5,686	77.0	9/3/1956	30.1
NW28	—	B–4	[5]37.186	[5]−108.727	—	5,691	29.5	—	25
NW19	[3,4]371204108433801	NB33501707DDA B–14	37.20111	−108.72787	NAD83	5,873	98	2/7/1954	33.5

[1] Altitude data are from USGS DEMs, which are available at https://www.usgs.gov/core-science-systems/ngp/3dep/about-3dep-products-services (USGS, 2019).

[2] Well depths for the Ute Mountain Ute Tribe wells are approximate.

[3] See table 4.

[4] USGS NWIS site number.

[5] Approximate latitude or longitude.

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
			Colorado Oil and Gas Conservation Commission[1]				
05–067–05038	1 SOUTHERN UTE	37.026	−108.239	NAD83	na	3,094	—
05–067–05063	1 STEWARD	37.014	−108.198	NAD83	na	3,165	—
05–067–05148	9 UTE	37.007	−108.308	NAD83	na	3,002	—
05–067–05176	2 UTE	37.028	−108.332	NAD83	na	2,840	—
05–067–05177	2 UTE	37.017	−108.302	NAD83	na	3,160	—
05–067–05204	1–A UTE	37.026	−108.222	NAD83	na	3,104	—
05–067–05235	1 HUTCHINSON	37.063	−108.172	NAD83	na	3,230	—
05–067–05259	1E GOVT	37.069	−108.292	NAD83	na	3,225	—
05–067–05359	1 NORTH BARKER DOME—GOV	37.088	−108.321	NAD83	na	3,480	—
05–067–05422	1 LLOYD-BENTON	37.106	−108.244	NAD83	na	3,160	—
05–067–05717	5 UTE	37.027	−108.283	NAD83	na	3,215	—
05–067–05727	C−11−1 S. UTE I–22–2818	37.085	−108.184	NAD83	na	3,268	—
05–067–05733	3 UTE MOUNTAIN	37.092	−108.316	NAD83	na	3,310	—
05–067–05734	4 UTE MOUNTAIN	37.092	−108.321	NAD83	na	3,460	—
05–067–05819	3 UTE	37.012	−108.283	NAD83	na	3,128	—
05–067–06011	1 SOUTHERN UTE	37.029	−108.153	NAD83	na	4,001	—
05–067–06034	1 NORTH BARKER UNIT	37.042	−108.331	NAD83	na	3,258	—
05–067–06040	1 AZTEC UTE	37.052	−108.307	NAD83	na	3,273	—
05–067–06044	2 UTE	37.062	−108.315	NAD83	na	3,238	—
05–067–06052	1 BARKER DOME	37.025	−108.330	NAD83	na	3,134	—
05–067–06068	1 FEDERAL ""B""	37.218	−108.231	NAD83	na	3,025	—
05–067–06071	34 UTE 24–D	37.085	−108.315	NAD83	na	3,318	—
05–067–06087	1 STORY A	37.189	−108.252	NAD83	na	3,090	—
05–067–06195	1 BARKER CANYON	37.023	−108.325	NAD83	na	3,160	—
05–067–06245	1 RED HORSE GULCH	37.103	−108.315	NAD83	na	3,426	—
05–067–06273	1 MENEFEE FEDERAL	37.228	−108.270	NAD83	na	3,024	—
05–067–06279	1 UTE MOUNTAIN TRIBAL P	37.002	−108.257	NAD83	na	3,134	—
05–067–06354	1 ROACH	37.157	−108.213	NAD83	na	2,825	—
05–067–06491	1 WEST ALKALI GULCH	37.132	−108.230	NAD83	na	3,156	—
05–067–06493	1 WILDWATER CANYON FEDERAL	37.230	−108.241	NAD83	na	3,034	—
05–067–06562	1 DECKER	37.005	−108.189	NAD83	na	3,790	—
05–067–06782	1 CHERRY CREEK-UTE	37.164	−108.203	NAD83	na	3,090	—
05–067–07820	1 UTE COM	37.020	−108.263	NAD83	na	3,178	—

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.—Continued

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
05–067–07821	16 Ute	37.002	−108.289	NAD83	na	3,028	—
05–067–07920	2R Ute	37.011	−108.299	NAD83	na	3,220	—
05–067–07974	19 UTE	37.007	−108.315	NAD83	na	3,108	—
05–067–07975	9A UTE	37.004	−108.307	NAD83	na	3,065	—
05–067–08010	31 UTE	37.029	−108.294	NAD83	na	3,203	—
05–067–08012	30 UTE	37.022	−108.291	NAD83	na	3,215	—
05–067–08726	58 UTE	37.016	−108.288	NAD83	na	3,208	—
05–067–08786	66 UTE MOUNTAIN UTE	37.021	−108.273	NAD83	na	3,207	—
05–067–08791	63 UTE MOUNTAIN UTE	37.007	−108.292	NAD83	na	3,197	—
05–067–08825	67 UTE MOUNTAIN UTE	37.014	−108.265	NAD83	na	3,153	—
05–067–08861	65 UTE MOUNTAIN UTE	37.002	−108.283	NAD83	na	3,095	—
05–067–09027	64 UTE MOUNTAIN UTE	37.002	−108.298	NAD83	na	3,168	—
05–067–09028	61 UTE MOUNTAIN UTE	37.014	−108.283	NAD83	na	3,130	—
05–067–09029	68 UTE MOUNTAIN UTE	37.027	−108.265	NAD83	na	3,192	—
05–067–09030	62 UTE MOUNTAIN UTE	37.007	−108.283	NAD83	na	3,093	—
05–067–09052	71 UTE MOUNTAIN UTE	37.004	−108.307	NAD83	na	3,071	—
05–067–09053	72 UTE MOUNTAIN UTE	37.008	−108.275	NAD83	na	3,167	—
05–067–09319	86 UTE MOUNTAIN UTE	37.014	−108.273	NAD83	na	3,153	—
05–067–09320	85 UTE MOUNTAIN UTE	37.028	−108.272	NAD83	na	3,226	—
05–067–09321	88 UTE MOUNTAIN UTE	37.002	−108.271	NAD83	na	3,116	—
05–067–09358	87 UTE MOUNTAIN UTE	37.020	−108.282	NAD83	na	3,226	—
05–067–40011	2 UTE	37.044	−108.392	NAD83	na	2,840	—
05–083–05008	2 UTE TRIBE	37.001	−108.484	NAD83	na	2,639	—
05–083–05013	C−1 UTE	37.005	−108.889	NAD83	na	362	—
05–083–05020	1 PHILMO UTE	37.012	−108.698	NAD83	na	1,738	—
05–083–05039	2 UTE MOUNTAIN	37.023	−108.849	NAD83	na	530	—
05–083–05042	5 UTE	37.024	−108.791	NAD83	na	598	—
05–083–05058	1 UTE	37.032	−108.789	NAD83	na	615	—
05–083–05060	B−1 UTE	37.034	−108.821	NAD83	na	675	—
05–083–05065	368 STRAT TEST VA	37.027	−108.852	NAD83	na	515	—
05–083–05068	367 STRAT TEST VA	37.042	−108.834	NAD83	na	667	—
05–083–05072	1 MESA A	37.051	−108.642	NAD83	na	2,360	—
05–083–05073	366 VA STRAT TEST	37.051	−108.822	NAD83	na	720	—
05–083–05081	6 UTE MOUNTAIN TRIBAL	37.067	−108.834	NAD83	na	645	—

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.—Continued

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
05–083–05084	1 MARIANNA WASH	37.078	−108.963	NAD83	na	184	—
05–083–05089	1 UTE MOUNTAIN TRIBAL	37.085	−108.785	NAD83	na	877	—
05–083–05097	1 UTE TRIBAL	37.096	−108.907	NAD83	na	410	—
05–083–05103	D−1 UTE MOUNTAIN INDIAN	37.111	−108.967	NAD83	na	413	—
05–083–05118	1 UTE	37.114	−108.393	NAD83	na	3,220	—
05–083–05125	4 UTE	37.121	−108.803	NAD83	na	714	—
05–083–05141	2 PORTER	37.231	−108.665	NAD83	na	912	—
05–083–05159	1 HARE	37.255	−108.311	NAD83	na	1,474	—
05–083–05177	24−14X MENEFEE MOUNTAIN UNIT	37.284	−108.255	NAD83	na	1,882	—
05–083–05182	1 WILBURN	37.298	−108.363	NAD83	na	854	—
05–083–05184	1 WILLBURN (DAY)	37.300	−108.369	NAD83	na	715	—
05–083–05214	1 STEPHANSON	37.337	−108.402	NAD83	na	745	—
05–083–05222	1 HALLER	37.343	−108.411	NAD83	na	515	—
05–083–05225	2 STEPHANSON	37.345	−108.394	NAD83	na	645	—
05–083–05328	2 PHILMO UTE	37.002	−108.690	NAD83	na	1,746	—
05–083–05356	1 UTE TRIBE	37.003	−108.476	NAD83	na	2,721	—
05–083–05402	1 UTE MTN TRIBAL B	37.102	−108.943	NAD83	na	350	—
05–083–05419	1 LEE W & JAMES C SHEEK	37.269	−108.363	NAD83	na	1,200	—
05–083–06016	1 UTE	37.126	−108.694	NAD83	na	1,485	—
05–083–06027	1 FEDERAL	37.240	−108.281	NAD83	na	1,660	—
05–083–06040	1 MOBIL UTE	37.033	−108.970	NAD83	na	196	—
05–083–06134	1 CITIES SERVICE-FEE	37.330	−108.393	NAD83	na	570	—
05–083–06152	1 BEARD-FEDERAL	37.335	−108.398	NAD83	na	555	—
05–083–06170	3 BEARD-FEDERAL	37.326	−108.367	NAD83	na	470	—
05–083–06178	1 LEULLAN	37.319	−108.388	NAD83	na	815	—
05–083–06192	14–24 UTE MOUNTAIN	37.172	−108.325	NAD83	na	3,198	—
05–083–06276	4 DOERFER	37.301	−108.298	NAD83	na	1,275	—
05–083–06316	2 LEE RATTLER	37.337	−108.495	NAD83	na	70	—
05–083–06317	3 SHEEK	37.282	−108.365	NAD83	na	1,000	—
05–083–06318	2 SHEEK	37.284	−108.368	NAD83	na	985	—
05–083–06319	4 SHEEK	37.295	−108.367	NAD83	na	1,015	—
05–083–06320	1 LUELLEN	37.306	−108.372	NAD83	na	730	—
05–083–06351	1–3 STATE HINDMARSH	37.327	−108.482	NAD83	na	260	—
05–083–06352	1–2 STATE HINDMARSH	37.326	−108.469	NAD83	na	305	—

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.—Continued

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
05–083–06353	1–1 STATE	37.323	−108.453	NAD83	na	510	—
05–083–06354	1–36 STATE	37.328	−108.462	NAD83	na	345	—
05–083–06363	3 MONTEZUMA REVENGE	37.331	−108.364	NAD83	na	455	—
05–083–06394	1–1 FEDERAL	37.324	−108.461	NAD83	na	470	—
05–083–06414	1–30 FEDERAL	37.343	−108.433	NAD83	na	505	—
05–083–06463	30–12 COYOTE WASH	37.163	−108.961	NAD83	na	132	—
05–083–06475	6–11 BADGER	37.140	−108.743	NAD83	na	804	—
05–083–06476	23–32 NIGHTHAWK	37.093	−108.771	NAD83	na	932	—
05–083–06493	6–22 UTE MOUNTAIN TRIBAL	37.050	−108.739	NAD83	na	1,192	—
05–083–06495	31–13 CANYON	37.059	−108.636	NAD83	na	1,660	—
05–083–06498	23–43 NIGHTHAWK	37.089	−108.768	NAD83	na	932	—
05–083–06551	BB 1 STATE - ODOM	37.290	−108.294	NAD83	na	1,200	—
05–083–40032	—	37.002	−108.861	NAD83	na	560	—
New Mexico Oil Conservation Division[2]							
30–045–10963	PRE-ONGARD WELL No. 001	—	—	—	S 10, T 31 N, R 19 W, 1650 ffnl, 1650 ffwl	834	—
30–045–11022	PRE-ONGARD WELL No. 001	—	—	—	S 1, T 31 N, R 16 W, 1650 ffsl, 990 ffel	3,363	—
30–045–11065	PRE-ONGARD WELL No. 001	—	—	—	S 3, T 31 N, R 16 W, 2310 ffsl, 1650 ffwl	2,340	—
30–045–11120	PRE-ONGARD WELL No. 001	—	—	—	SW S 31, T 32 N, R 15 W, 990 ffsl, 910 ffwl of sec 31	3,345	—
30–045–11151	PRE-ONGARD WELL No. 001	—	—	—	S 36, T 32 N, R 18 W, 660 ffsl, 660 ffwl	1,480	—
30–045–11188	PRE-ONGARD WELL No. 001	—	—	—	SW NW S 32, T 32 N, R 18 W, 1980 ffnl, 660 ffwl of S 32	1,425	—
30–045–11276	PRE-ONGARD WELL No. 001	—	—	—	S 25, T 32 N, R 18 W, 2510 ffnl, 1980 ffel	1,544	—
30–045–11322	UTE No. 007	—	—	—	NE SW S 19, T 32 N, R 14 W, 1685 ffsl, 1945 ffwl of sec 19	2,846	—
30–045–11328	PRE-ONGARD WELL No. 001	—	—	—	SE SW S 20, T 32 N, R 13 W, 660 ffsl, 1980 ffwl of sec 20	3,215	—
30–045–11332	PRE-ONGARD WELL No. 001	—	—	—	S 21, T 32 N, R 19 W, 660 ffsl, 660 ffel	735	—
30–045–11392	PRE-ONGARD WELL No. 001	—	—	—	S 14, T 32 W, R 16? W, 800ffsl, 890 ffel	3,312	—
30–045–11413	PRE-ONGARD WELL No. 001	—	—	—	S 15, T 32 N, R 15 W, 1650 ffsl, 790 ffwl of sec 15	3,252	—
30–045–11469	PRE-ONGARD WELL No. 001	—	—	—	S 17, T 32N, R 18 W, 1980 ffnl, 660 ffwl	940	—
30–045–11476	PRE-ONGARD WELL No. 001	—	—	—	S 13, T 32 N, R 17 W,990 ffnl, 1980 ffwl	3,330	—
30–045–11479	UTE No. 004	—	—	—	S 10, T 32 N, R 14 W, 510 ffsl, 2030 ffwl	3,150	—

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.—Continued

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
30–045−13183	PRE-ONGARD WELL No. 001	—	—	—	NW NW S 4, T 31 N, R 18 W, 660 ffnl, 660 ffwl of S 4	1,428	—
30–045−13193	PRE-ONGARD WELL No. 001	—	—	—	NW NW S 33, T 32 N, R 19 W, 660 ffnl, 660 ffwl of S 33	642	—
30–045–20043	PRE-ONGARD WELL No. 002	—	—	—	S 30 T 32 N, R 17 W, 2310 ffsl, 670 ffel	2,255	—
30–045–20354	PRE-ONGARD WELL No. 001	—	—	—	S 36, T 32 N, R 18 W, 990 ffnl, 990 ffel	1,658	—
30–045–20364	PRE-ONGARD WELL No. 001	—	—	—	S 32, T 32 N, R 19 W, 660 ffsl, 1980 ffwl	618	—
30–045–20389	PRE-ONGARD WELL No. 001	—	—	—	S 25, T 32 N, R 18 W, 330 ffsl, 1610 ffwl	1,569	—
30–045–20570	PRE-ONGARD WELL No. 002	—	—	—	S 14, T 32 N, R 15 W, 1980 ffsl, 660 ffel	3,242	—
30–045–20658	PRE-ONGARD WELL No. 003	—	—	—	S 14, T 32 N, R 15 W, 2190 ffnl, 900 ffwl	3,265	—
30–045–20692	PRE-ONGARD WELL No. 001	—	—	—	S 31, T 32 N, R 17 W, 650 ffnl, 1549 ffwl	1,610	—
30–045–22179	PRE-ONGARD WELL No. 001	—	—	—	S 35, T 32 N, R 16 W, 1980 ffsl, 1980 ffwl	3,555	—
30–045–23003	PRE-ONGARD WELL No. 001	—	—	—	NW NE S 27, T 32 N, R 15 W, 1175 ffnl, 1650 ffel	2,939	—
30–045–23237	PRE-ONGARD WELL No. 001	—	—	—	S 13, T 32 N, R 14 W, 1840 ffsl, 1180 ffwl	3,134	—
30–045–23542	PRE-ONGARD WELL No. 001	—	—	—	S 26, T 32 N, R 15 W, 1160 ffnl, 790 ffel	3,218	—
30–045–29262	UTE COM No. 025	—	—	—	S 19, T 32 N, R 14 W, 475 ffsl, 1415 ffwl	3,196	—
30–045–29264	PRE-ONGARD WELL No. 026	—	—	—	S 18, T 32 N, R 14 W, 1270 ffnl, 655 ffel	2,540	—
30–045–29265	UTE COM No. 023	36.976	−108. 34693	—	na	2,550	—
30–045–29395	UTE No. 022	36.990	−108. 32944	—	na	2,403	—
30–045–29547	UTE MOUNTAIN UTE No. 051	36.985	−107. 28000	—	na	3,117	—
30–045–33760	UTE INDIANS B No. 001	—	—	—	S 13 T 32 N, R 14 W, 793 ffnl, 885 ffwl	3,024	—
30–045–34471	UTE MOUNTAIN UTE No. 078	—	—	—	SE SW S 16, T 32 N, R 14 W, 1075 ffsl, 1340 ffwl	2,406	—
30–045–34488	UTE MOUNTAIN UTE No. 084	—	—	—	NW SE NW S 29, T 32 N, R 14 W, 1330 ffnl, 1465 ffwl	2,454	—
U.S. Geological Survey, Irwin (1966)[3]							
370518108540601	NB03301922ADCB A–4	37.092	−108.896	NAD83	na	546	NGVD29
370612108424001	NB03301716BCCC B–7	37.106	−108.710	NAD83	na	1,258	NGVD29
370717108532501	NB03301911BBBB A–3	37.126	−108.891	NAD83	na	659	NGVD29
370806108485801	NB03301804BCDA A−1	37.135	−108.815	NAD83	na	722	NGVD29
371006108530402	NB33501926ABBB2 B–6	37.169	−108.882	NAD83	na	275	NGVD29
371112108443401	NB33501718CCAC B−10	37.188	−108.743	NAD83	na	328	NGVD29

Table 1.2. Description of wells used for determining lithology and depth to the top of the Dakota Sandstone on the Ute Mountain Ute Reservation in Colorado.—Continued

[LatitudeDD, latitude in decimal degrees; LongitudeDD, longitude in decimal degrees; DatumDD, datum for decimal degrees; NAD83, North American Datum of 1983; na, not applicable; —, no data; No., number; S, section; T, township; N, north; R, range; W, west; ffnl, feet from north line; ffwl, feet from west line; ffsl, feet from south line; ffel, feet from east line; SW, southwest; NW, northwest; NE, northeast; SE, southeast; USGS, U.S. Geological Survey; NGVD29, National Geodetic Vertical Datum of 1929]

Well identifier	Well name	Latitude DD	Longitude DD	Datum DD	Township and range	Depth to top of Dakota Sandstone (feet below land surface datum)	Altitude datum
371115108432001	NB33501717CCA B−18	37.187	−108.723	NAD83	na	560	—
371152108435401	NB33501718ABA B−17	37.198	−108.732	NAD83	na	260	—
371159108434801	NB33501707UDDC B−16	37.200	−108.731	NAD83	na	273	—
371217108435701	NB33501707UDBA B−13	37.205	−108.733	NAD83	na	220	—
371218108433301	NB33501708CBB B−19	37.205	−108.726	NAD83	na	320	—
371248108402201	NB33501703DDDA A–9	37.216	−108.674	NAD83	na	986	NGVD29

[1] Colorado Oil and Gas Conservation Commision data are from Colorado Oil and Gas Conservation Commision (2016). Well identifier is the Colorado Oil and Gas Conservation Commision Well API. On the Commission website https://cogcc.state.co.us/data.html, select "Facility" under "Inquiry". On the "Facility Inquiry" page, using well 9 Ute as an example, type 67 as the county code and type 5148 as the sequence code. After entering, select "Well" to obtain well information. Well name is from the Colorado Oil and Gas Conservation Commision (2016).

[2] Well identifier is the New Mexico Oil Conservation Division API number (New Mexico Oil Conservation Division, 2016). Well name is from the New Mexico Oil Conservation Division (2016).

[3] Well identifier and well name for the USGS, Irwin (1966) wells are the National Water Information System site number and site name, respectively (USGS, 2016b).

Appendix 2. Supplemental Information for Data-Quality Assurance

This appendix contains supplemental information for data-quality assurance. Included is information for duplicate sample results, zero values, inconsistent results, data outliers, data pairs with total and dissolved concentrations for the same constituent in a sample, field blanks, field replicates, and cation-anion balance percent difference for samples collected by the Ute Mountain Ute Tribe (UMUT). Data for field blanks and field replicates were not available for the historical U.S. Geological Survey, National Uranium Resource Evaluation, and Colorado Oil and Gas Conservation Commission data.

Groundwater-chemistry data were first checked for duplicate sample results, zero values, inconsistent results, and outliers. The duplicated sample results were excluded; the same analytical result for one of two samples collected on the same date was excluded. Select chemical data with a reported result of zero also were excluded from analysis if the meaning of the zero value could not be determined. Zero values were retained if the laboratory reported limit for a concentration was a zero value or were changed to the known laboratory reporting limit, described as a “less-than” value or concentration. Zero values for physical properties such as specific conductance and pH were assumed erroneous and were excluded. Inconsistent results, such as specific conductance values of 150 microsiemens per centimeter at 25 degrees Celsius or less for Lagoon 1 wells 1 and 3 that were not consistent with related total dissolved solids (TDS) concentrations of 3,400 milligrams per liter (mg/L) or more for the same sample, were excluded from analysis. Data from multiple samples of a constituent at a site were checked for outliers, and extreme outliers were excluded from analysis. For example, a TDS concentration of 66 mg/L for a sample from Navajo Spring was excluded because all other reported TDS concentrations for the spring ranged from 747 to 1,272 mg/L.

Of the trace-element data pairs collected by the UMUT, 40 contained total and dissolved concentrations of the same chemical constituent. Because a total concentration should be greater than a dissolved concentration, a comparison of the two concentrations for each data pair was used as a check on data quality. These data were evaluated by calculating the relative percent difference of concentrations for each data pair (RPD_{td}) using equation 2.1 (modified from Mueller and others [2015], p. 40, table 47):

$$RPDtd = ABS[(\text{total result} - \text{dissolved result})/((\text{total result} + \text{dissolved result})/2)] \times 100, \quad (2.1)$$

where

RPDtd is the relative percent difference of concentrations for each data pair, and

ABS is the absolute value.

The total concentration was less than the dissolved concentration in about 18 percent (7 of 40) of the trace-element data pairs. For six of the data pairs, total concentrations were substantially less than dissolved concentrations; the RPD_{td} values ranged from 27.4 to 81.3 percent. Each of these data pairs was excluded for analysis, including total and dissolved concentrations of arsenic, manganese, nickel, selenium, and zinc for Lagoon 1 well 1 and selenium for Lagoon 1 well 3.

Field-blank data were only available for samples collected by the UMUT. Field-blank samples were processed using inorganic- or organic-free water that contained no detectable concentrations of the constituents of interest. The blank water was processed through the same sampling equipment and handled and analyzed in the same manner as the environmental samples. Data for field blanks retrieved from the National Water Quality Monitoring Council Water Quality Portal were collected at three springs and eight wells, and included data for physical properties (alkalinity, hardness), major ions, nutrients, trace elements, pesticides, volatile organic compounds, and coliform bacteria (National Water Quality Monitoring Council, 2017). Field-blank samples with concentrations greater than laboratory reporting limits were collected from one spring (Whiskers Draw Spring) and four wells (AP–14, AP–15, Lagoon 1 well 3, and Wing well) (table 2.1). Detected constituents in field-blank samples included TDS, nitrate plus nitrite, total phosphate, manganese, nickel, selenium, zinc, and alachlor (table 2.1). Concentrations of unfiltered nitrate plus nitrite (0.02 mg/L), total phosphate (0.082 mg/L), unfiltered selenium (1 microgram per liter [µg/L]), dissolved zinc (5.8 µg/L), and unfiltered zinc (7 µg/L) in field blanks were substantially lower than paired environmental concentrations (9 mg/L, 0.886 mg/L, 15.2 µg/L, 11.5 µg/L, and 32 µg/L, respectively), and the field-blank detections would not affect interpretation of environmental data. Concentrations of dissolved manganese and dissolved nickel (0.5 µg/L for each) in one field-blank sample also were less than the environmental sample concentrations of 1 and 1.4 µg/L, respectively. These blank detections could affect interpretation of environmental data for the sample, and the environmental concentrations were subsequently excluded from analysis because of replicate-sample results. Detections of TDS (24 mg/L), unfiltered selenium (2.4 µg/L), and alachlor (0.3 µg/L) in field blanks could not be evaluated; no environmental samples were collected at the same site and date. A detected concentration of dissolved zinc in a field blank is described in the “Groundwater Chemistry” section.

Replicate data were only available for samples collected by the UMUT. By comparing the analytical results of the first sample (environmental concentration) with the second sample (replicate concentration), replicate data provide information on the variability in constituent detection and concentration. For the 185 replicate pairs, both the environmental and replicate concentrations were greater than the laboratory reporting limit in 105 pairs and less than the laboratory reporting limit in 63 pairs, and 17 pairs had inconsistent detections (a detected concentration and a concentration less than the laboratory

Table 2.1. Select quality-assurance data for field-blank samples collected by the Ute Mountain Ute Tribe for springs and wells on the Ute Mountain Ute Reservation in Colorado and Utah, 2001–13.

[Detected concentrations are in bold. fig., figure; ID, identification; dis, dissolved; mg/L, milligrams per liter; unfil, unfiltered; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; trec, total recoverable; —, no data; <, less than]

Site (see fig. 5, site ID in parentheses is used on figure)	Site type	Sample date	Total dis solids (mg/L)	Nitrate plus Nitrite, unfil (mg/L as N)[1]	Phosphate, total (mg/L as P)	Manga-nese, dis (µg/L)	Nickel, dis (µg/L)	Selenium, unfil trec (µg/L)	Zinc, dis (µg/L)	Zinc, unfil trec (µg/L)	Alachlor, unfil (µg/L)
Whiskers Draw Spring (S13)[2]	Spring	8/28/2013	—	<0.01	**0.082**	<0.4	—	<0.4	**5.8**	<0.8	—
AP–14	Well	10/31/2001	—	—	—	—	—	—	—	—	**0.3**
AP–15	Well	7/25/2011	**24**	<0.6	—	—	—	**2.4**	—	<200	<0.1
Lagoon 1 well 3 (W13)	Well	9/15/2010	<10	—	—	**0.5**	**0.5**	<1	**9**	**7**	—
Wing well (W23)	Well	7/22/2003	—	—	—	—	—	**1**	—	—	—
Wing well (W23)	Well	8/16/2012	<10	**0.02**	—	—	—	<1	—	—	<0.1

[1] Includes "Inorganic nitrogen (nitrate and nitrite), total."

[2] Spring is shown on figure 1.

reporting limit). All concentrations for pesticide and volatile organic compound replicate pairs were less than laboratory reporting limits.

When a sufficient number of replicate pairs have been collected for a particular constituent over a range of concentrations, variability in constituent concentration can be estimated using a two-range model—the mean standard deviation for replicate pairs with low concentrations and the mean relative percent difference for replicate pairs with high concentrations (Mueller and others, 2015). The standard deviation over a range of low concentrations generally is constant but increases at higher concentrations (Mueller and others, 2015), which can overestimate variability. For example, a replicate pair with concentrations of total phosphorus of 0.20 and 0.29 mg/L has a standard deviation of 0.04 and a relative percent difference of the replicate pairs (RPD_{rep}) of 37 percent. For a range of high concentrations, the RPD_{rep} is generally constant (Mueller and others, 2015). Eight replicate pairs had RPD_{rep} values greater than (>) 100 percent. Environmental concentrations for seven pairs were excluded from analysis, including carbonate, unfiltered lead, and dissolved chromium for Toe Windmill (sample date September 2016); dissolved barium for LF well 1 (March 2009); and unfiltered iron, dissolved manganese, and dissolved nickel for Lagoon 1 well 3 (September 15, 2010). For the Hanna Spring sample collected in May 2015, the unfiltered iron concentration of 82 µg/L was retained for analysis because it was similar to other report unfiltered iron concentrations for the spring.

For this report, charge-balance differences of less than 5 percent were deemed acceptable, and the data were retained for analysis. Only 3 of 34 well samples had charge-balance differences of >10 percent. Differences of 11.7 and 11.4 percent for wells AP–5 and AP–14, respectively, may reflect analytical precision at the time of same collection in 2000 or 1999, respectively. The difference of 51.7 percent for a Mariano-FW well sample collected in 2013 reflected a much larger cation sum (27.3 milliequivalents [meq]) than the anion sum (8.7 meq). This is the only sample collected at the well, so it is not known why the difference is so large. Nine samples had charge-balance differences between 5 and 10 percent, four of which had TDS concentrations >2,300 mg/L, and three of which had a total cation-anion sums of less than 5.0 meq per liter. Hem (1985) reports that water with TDS values >1,000 mg/L tend to have a few constituents with high concentrations. For such water, the charge-balance difference does not adequately account for constituents with lower concentrations (Hem, 1985), which can skew the accuracy determination. Hem (1985) also reports that charge-balance differences of more than a few percentages for samples with total sums of less than 5.0 meq per liter are acceptable. All major-ion data collected by the UMUT were retained for analysis.

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