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Water-Quality Characteristics in the Black Hills Area, South Dakota

By Joyce E. Williamson and Janet M. Carter

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CONTENTS

CONTENTS—Continued

Water-Quality Characteristics—Continued

Water-Quality Characteristics of Selected Surface-Water Sites—Continued

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
inch	2.54	centimeter
inch	25.4	millimeter
mile	1.609	kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

°F = 9/5 (°C) + 32
°C = 5/9 (°F-32)

Chemical concentrations: Chemical concentrations of substances in water are given in metric units of milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water. Micrograms per liter is a unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of water. Micrograms per liter are equivalent to milligrams per liter divided by 1,000.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water year: Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 1992, is called the “1992 water year.”

OTHER ABBREVIATIONS, SYMBOLS, AND ACRONYMS USED:

mg/L	milligrams per liter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
pCi/L	picocuries per liter
TU	tritium units
<	less than

DENR	South Dakota Department of Environment and Natural Resources
MCL	Maximum Contaminant Level
NURE	National Uranium Resource Evaluation
NWIS	U.S. Geological Survey National Water Information System
NWQL	U.S. Geological Survey National Water Quality Laboratory
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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ABSTRACT

This report summarizes the water-quality characteristics of ground water and surface water in the Black Hills area. Differences in ground-water quality by aquifer and differences in surface-water quality by water source are presented. Ground-water characteristics are discussed individually for each of the major aquifers in the Black Hills area, referred to herein as the Precambrian, Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Characteristics for minor aquifers also are discussed briefly. Surface-water characteristics are discussed for hydrogeologic settings including headwater springs, crystalline core sites, artesian springs, and exterior sites.

To characterize the water quality of aquifers and streams in the Black Hills area, data from the U.S. Geological Survey National Water Information System water-quality database were examined. This included samples collected as part of the Black Hills Hydrology Study as well as for other studies within the time frame of October 1, 1930, to September 30, 1998. Tables of individual results are not presented in this report, only summaries. Constituents summarized and discussed include physical properties, common ions, nutrients, trace elements, and radionuclides. Comparisons of concentration levels are made to drinking-water standards as well as beneficial-use and aquatic-life criteria.

Ground water within the Black Hills and surrounding area generally is fresh and hard to very hard. Concentrations exceeding various Secondary and Maximum Contaminant Levels may affect the use of the water in some areas for many aquifers within the study area. Concentrations that exceed Secondary Maximum Contaminant Levels (SMCL's) generally affect the water only aesthetically. Radionuclide concentrations may be especially high in some of the major aquifers used within the study area and preclude the use of water in some areas. The sodium-adsorption ratio and specific conductance may affect irrigation use for some wells.

High concentrations of iron and manganese are the only concentrations that may hamper the use of water from Precambrian aquifers. The principal deterrents to use of water from the Deadwood aquifer are the high concentrations of radionuclides as well as iron and manganese. Iron, manganese, and hardness may deter use of water from the Madison aquifer as well as dissolved solids and sulfate in downgradient wells (generally deeper than 2,000 feet). Iron, manganese, and hardness may also deter use of the Minnelusa aquifer. Water from the Minnekahta aquifer generally is suitable for all water uses although it is hard to very hard. High concentrations of dissolved solids, iron, sulfate, and manganese may hamper the use of water from the Inyan Kara aquifer. In the southern Black Hills, radium-226 and uranium concentrations also may preclude use of water from the Inyan Kara aquifer. Suitability for irrigation may be affected by high specific conductance and sodium-adsorption ratio for the Inyan Kara.

Surface-water quality within the Black Hills and surrounding area generally is very good but the water is hard to very hard. Concentrations of some constituents in the study area tend to be higher exterior to the Black Hills, primarily due to influences from the Cretaceous-age marine shales, including dissolved solids, sodium, sulfate, selenium, and uranium. Headwater springs have relatively constant discharge, specific conductance, dissolved solids, and concentrations of most other constituents.

Concentrations at crystalline core sites are very similar to those found in samples from Precambrian aquifers. Some high nitrate concentrations greater than the Maximum Contaminant Level (MCL) of 10 mg/L (milligrams per liter) have occurred at Annie Creek near Lead, which have been attributed to mining impacts. Trace elements generally are low with the exception of arsenic, for which 60 percent of samples exceed the proposed MCL of 10 µg/L (micrograms per liter) and one sample exceeds the current MCL of 50 µg/L. The SMCL's for iron and manganese also have been exceeded in some samples. Artesian springs have very constant discharge and specific conductance at each site but show some variability between sites. Dissolved solids concentrations exceeding the SMCL of 500 mg/L and sulfate concentrations exceeding the SMCL of 250 mg/L are common for these sites.

Low dissolved oxygen concentrations in surface waters only occur at sites exterior to the Black Hills where high temperature and low flow occasionally are problematic. About 66 percent of the samples from sites exterior to the Black Hills exceed 1,000 mg/L sulfate. Concentrations exceeding the arsenic MCL, the selenium aquatic-life criterion, and the iron and manganese SMCL's occasionally occur at these sites. Radionuclide data are limited, but higher uranium concentrations are found for the areas exterior to the Inyan Kara Group outcrop.

Occasionally very low pH levels are recorded immediately downstream from abandoned mine sites but generally are within acceptable ranges once they mix with additional stream water. Changes in specific conductance, sodium, and sulfate in Bear Butte Creek occurred after additional mining activities in a tributary basin. Bear Butte Creek also had exceedances of the acute and chronic copper aquatic-life criteria for several samples between 1992-94. Within-basin changes for Rapid Creek follow the general trend of increasing concentrations for most constituents. Nutrient levels are low but do show an increase, indicating that land-use practices, both urban and agricultural, may be affecting the stream.

INTRODUCTION

The Black Hills area is an important resource center for the State of South Dakota. The Black Hills provide an economic base for western South Dakota through tourism, agriculture, the timber industry, and mineral resources. In addition to these resources, one of the most important natural resources in the Black Hills is water. Water originating from the area is used for municipal, industrial, agricultural, and recreational purposes throughout much of western South Dakota and is important recharge for aquifers in the northern Great Plains.

Population growth and resource development have the potential to affect the quantity, quality, and availability of water within the Black Hills area. Because of this concern, the Black Hills Hydrology Study was initiated in 1990 to assess the quantity, quality, and distribution of surface water and ground water in the Black Hills area of South Dakota (Driscoll, 1992). This long-term study is a cooperative effort between the U.S. Geological Survey (USGS), the South Dakota Department of Environment and Natural Resources (DENR), and the West Dakota Water Development District, which represents various local and county cooperators.

Ground-water quality in the area is heavily influenced by the mineralogy of the specific geologic unit containing the aquifer. Surface-water quality is heavily influenced by underlying geology and streamflow. Both ground-water and surface-water quality may be influenced by human effects related to land use. An assessment of the quality of ground and surface water is important for managing the water resources in the Black Hills area and providing a baseline for comparison of future water-quality data.

Purpose and Scope

The purpose of this report is to summarize the water-quality characteristics of ground water and surface water in the Black Hills. Comparisons of water quality by aquifer and comparisons of surface-water quality by water source are presented. Ground-water-quality characteristics are discussed individually for each of the major aquifers in the Black Hills area, referred to in this report as the Precambrian, Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Characteristics for minor aquifers, referred to in this report as the Spearfish, Sundance, Morrison, Pierre, Graneros, Newcastle, and alluvial aquifers, are discussed briefly. Surface-water-quality characteristics are discussed for various hydrogeologic settings including headwater springs, crystalline core basins, artesian springs, and exterior basins (downgradient of the outcrop of the Inyan Kara Group). For some comparisons or descriptions, surface-water characteristics are discussed for selected basins, groups of sites, or selected sites. Comparisons are made for physical properties, major-ion chemistry, nutrients, trace elements, and radionuclide concentrations. Where sufficient data are available, spatial variations are presented.

Description of Study Area

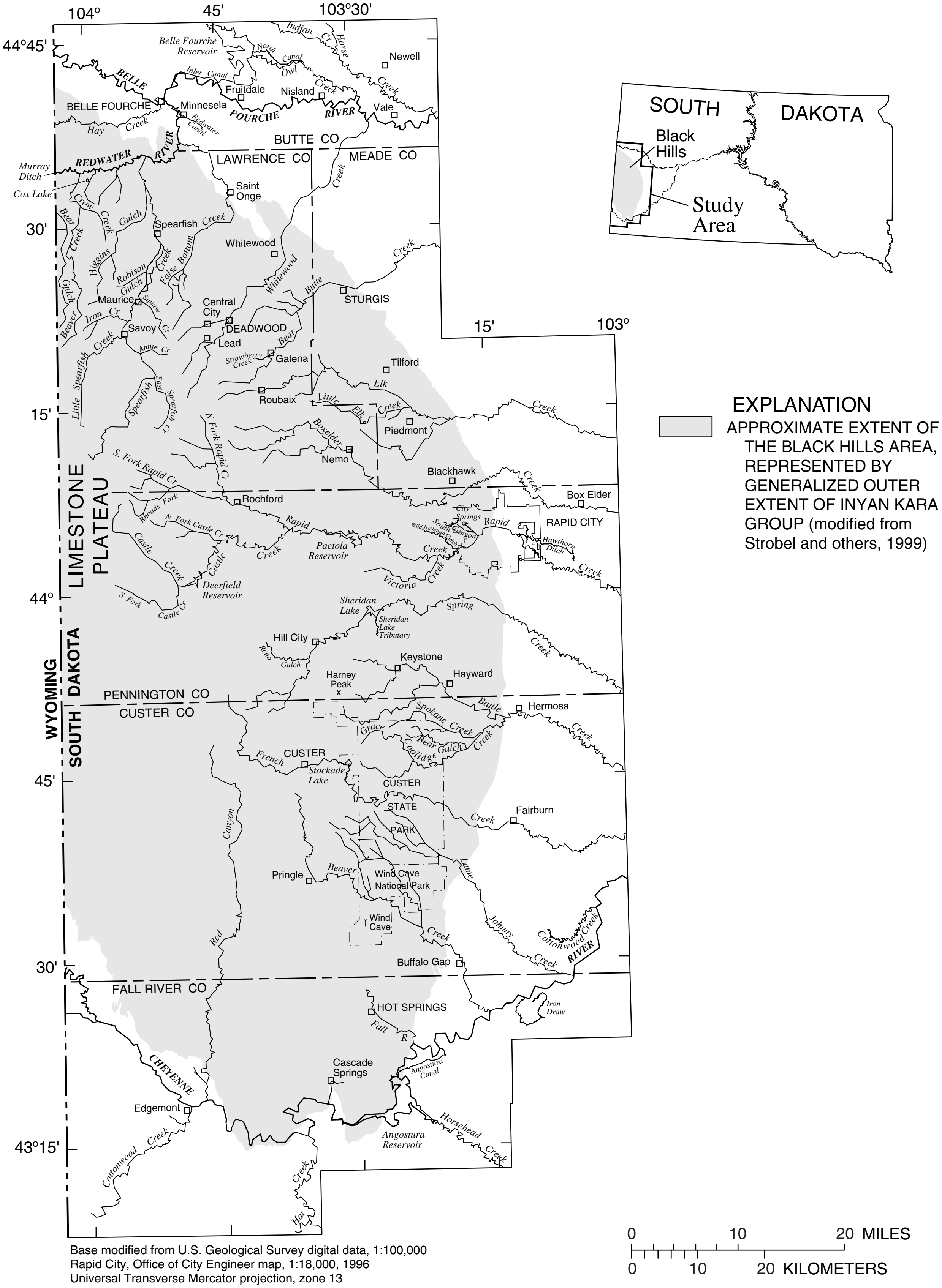
The study area consists of the topographically defined Black Hills and adjacent areas located in western South Dakota (fig. 1). The generalized outer extent of the Inyan Kara Group, which approximates the outer extent of the Black Hills area, also is shown in figure 1. About 32 percent of the study area is within the boundaries of the Black Hills National Forest, which was created in 1897. The Black Hills are situated between the Cheyenne and Belle Fourche Rivers. The Belle Fourche River is the largest tributary to the Cheyenne River. The study area includes most of the larger communities in western South Dakota and contains about one-fifth of the State's population.

Physiography and Climate

The Black Hills uplift formed as an elongated dome about 60 to 65 million years ago (DeWitt and others, 1986). The dome trends north-northwest and is about 120 miles long and 60 miles wide. Elevations range from 7,242 feet above sea level at Harney Peak to about 3,000 feet in the adjacent plains. Most of the higher elevations are heavily forested with ponderosa pine, which is the primary product of an active timber industry. White spruce, quaking aspen, paper birch, and other native trees and shrubs are found in cooler, wetter areas (Orr, 1959). The lower elevation areas surrounding the Black Hills primarily are urban, suburban, and agricultural. Numerous deciduous species such as cottonwood, ash, elm, oak, and willow are common along stream bottoms in the lower elevations. Rangeland, hayland, and winter wheat farming are the principal agricultural uses for dryland areas. Alfalfa, corn, and vegetables are produced in bottom lands and in irrigated areas. Various other crops, primarily for cattle fodder, are produced in both dryland areas and in bottom lands.

Beginning in the 1870's, the Black Hills have been explored and mined for many commodities including gold, silver, tin, tungsten, mica, feldspar, bentonite, beryl, lead, zinc, uranium, lithium, sand, gravel, and oil (U.S. Department of Interior, 1967). Mines within the study area have utilized placer mining, small surface pits, underground mines, and open-pit mines.

The overall climate of the study area is continental, with generally low precipitation, hot summers, cold winters, and extreme variations in both precipitation and temperatures (Johnson, 1933). Local climatic conditions are affected by topography, with generally lower temperatures and higher precipitation at the higher elevations. The average annual precipitation for the study area (1931-98) is 18.61 inches, and has ranged from 10.22 inches for water year 1936 to 27.39 inches for water year 1995 (Driscoll, Hamade, and Kenner, 2000). The largest precipitation amounts typically occur in the northern Black Hills near Lead, where average annual precipitation (1950-98) exceeds 29 inches. Annual averages (1931-98) for counties within the study area range from 16.35 inches for Fall River County to 23.11 inches for Lawrence County. The average annual temperature is 43.9°F (U.S. Department of Commerce, 1999) and ranges from 48.7°F at Hot Springs to approximately 37°F near Deerfield Reservoir. Average evaporation generally exceeds average annual precipitation throughout the study area. Average pan evaporation for April through October is about 30 inches at Pactola Reservoir and about 50 inches at Oral.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 1. Area of investigation for the Black Hills Hydrology Study.

Geologic Setting

The geologic units that contain aquifers for which water-quality characteristics are presented are described in this section from oldest to youngest. The oldest geologic units in the study area are the Precambrian crystalline (metamorphic and igneous) rocks (fig. 2), which form a basement under the Paleozoic, Mesozoic, and Cenozoic rocks and sediments. The Precambrian rocks are exposed in the central core of the Black Hills. These Precambrian rocks range in age from 1.7 to about 2.5 billion years, and were eroded to a gentle undulating plain by the beginning of the Paleozoic Era (Gries, 1996). The Precambrian rocks are highly variable, but are composed mostly of metasediments, such as schists and graywackes. The Paleozoic and Mesozoic rocks were deposited as nearly horizontal beds. Subsequent uplift during the Laramide orogeny and related erosion exposed the Precambrian rocks in the central core of the Black Hills with the Paleozoic and Mesozoic sedimentary rocks exposed in roughly concentric rings around the core. Deformation during the Laramide orogeny contributed to the numerous fractures, folds, and other structural features present throughout the Black Hills. Tertiary intrusive activity also contributed to rock fracturing in the northern Black Hills where numerous intrusions exist.

Surrounding the crystalline core is a layered series of sedimentary rocks including limestones, sandstones, and shales. The distribution of hydrogeologic units in the Black Hills area is shown in figure 3. The bedrock sedimentary units typically dip away from the uplifted Black Hills at angles that can approach or exceed 15 to 20 degrees near the outcrops, and decrease with distance from the uplift to less than 1 degree (Carter and Redden, 1999a, 1999b, 1999c, 1999d, 1999e) (fig. 4).

The oldest sedimentary unit in the study area is the Cambrian- and Ordovician-age Deadwood Formation, which is composed primarily of brown to light-gray glauconitic sandstone, shale, limestone, and local basal conglomerate (Strobel and others, 1999). These sediments were deposited on the generally horizontal plain of Precambrian rocks in a coastal- to near-shore environment (Gries, 1975). The thickness of the Deadwood Formation increases from south to north in the study area and ranges from 0 to 500 feet (Carter and Redden, 1999e). In the northern and central Black Hills, the Deadwood Formation is disconformably overlain by Ordovician-age rocks that include the Whitewood and Winnipeg Formations. The Winnipeg Formation is absent in the southern Black Hills, and the Whitewood Formation has eroded to the south and is not present south of the approximate latitude of Nemo (DeWitt and others, 1986). In the southern Black Hills, the Deadwood Formation is unconformably overlain by the Devonian- and Mississippian-age Englewood Formation because of the absence of the Ordovician-age sequence. The Englewood Formation is overlain by the Madison Limestone.

The Mississippian-age Madison Limestone, deposited as a marine carbonate, is a massive, gray to buff limestone that is locally dolomitic (Strobel and others, 1999). The thickness of the Madison Limestone increases from south to north in the study area and ranges from almost zero in the southeast corner of the study area (Rahn, 1985) to 1,000 feet east of Belle Fourche (Carter and Redden, 1999d). The Madison Limestone was exposed above land surface for approximately 50 million years. During this period, significant erosion, soil development, and karstification occurred (Gries, 1996). Numerous caves and fractures occur within the upper part of the formation (Peter, 1985). Because the Madison Limestone was exposed to erosion and karstification for millions of years, the formation is unconformably overlain by the Minnelusa Formation.

The Pennsylvanian- and Permian-age Minnelusa Formation consists mostly of yellow to red cross-stratified sandstone, limestone, dolomite, and shale (Strobel and others, 1999). In addition to sandstone and dolomite, the lower part of the formation consists of shale and anhydrite (DeWitt and others, 1986). The upper part of the Minnelusa Formation also may contain anhydrite, which generally has been removed by dissolution at or near the outcrop areas, forming collapse features filled with breccia (Bowles and Braddock, 1963). The thickness of the Minnelusa Formation increases from north to south and ranges from 375 feet near Belle Fourche to 1,175 feet near Edgemont in the study area (Carter and Redden, 1999c). On the southwest side of the study area, there is a considerable increase in thickness of clastic units as well as a thick section of anhydrite. In the southern Black Hills, the upper part of the Minnelusa Formation thins due to leaching of anhydrite. The Minnelusa Formation is disconformably overlain by the Permian-age Opeche Shale, which is overlain by the Minnekahta Limestone.

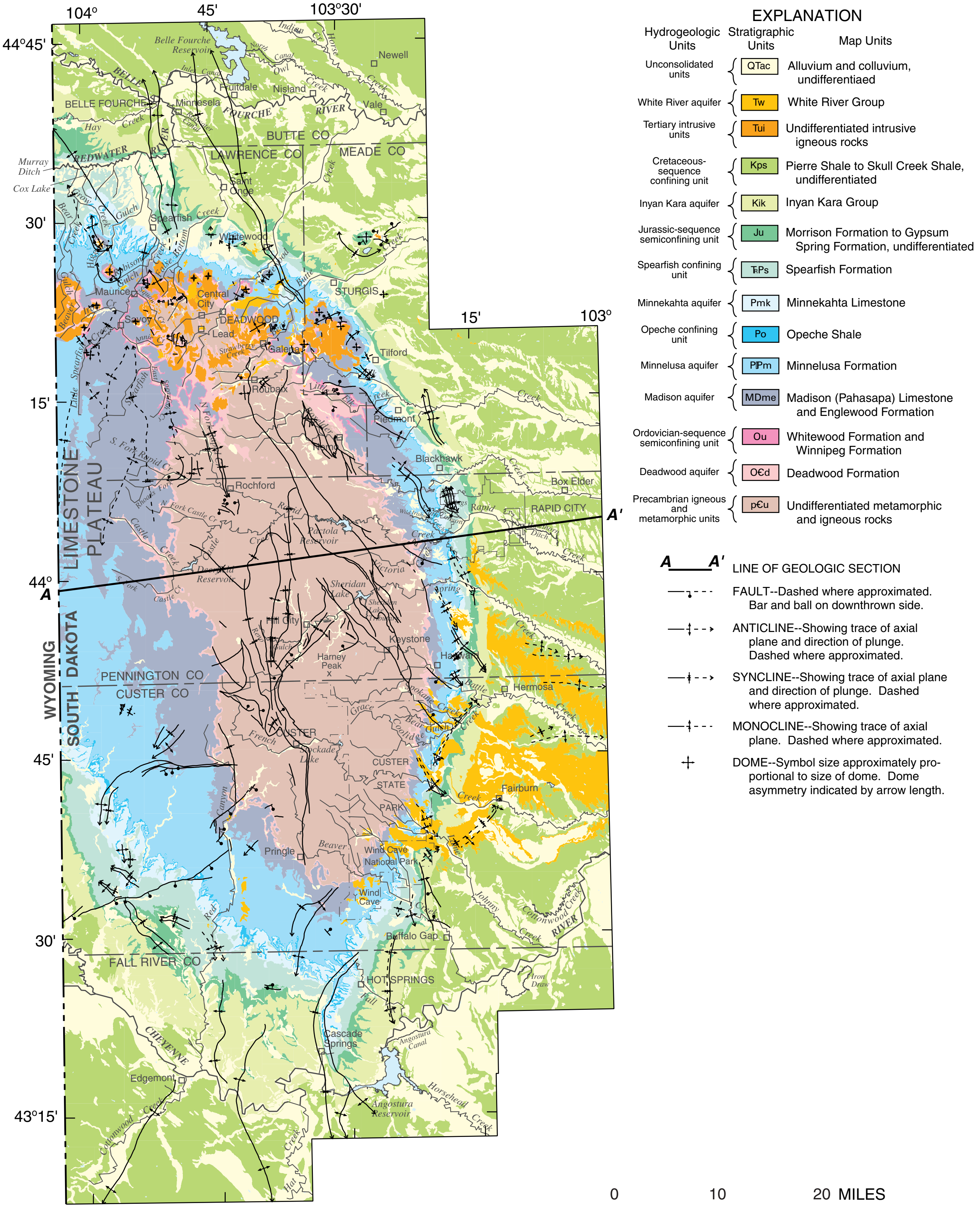
The Permian-age Minnekahta Limestone is a fine-grained, purple to gray laminated limestone with thicknesses ranging from 25 to 65 feet in the study area (Strobel and others, 1999). The Minnekahta Limestone is overlain by the Triassic- and Permian-age Spearfish Formation.

ERATHEM	SYSTEM	ABBREVIATION FOR STRATIGRAPHIC INTERVAL	STRATIGRAPHIC UNIT	THICKNESS IN FEET	DESCRIPTION
CENOZOIC	QUATERNARY & TERTIARY (?)	QTu	UNDIFFERENTIATED SANDS AND GRAVELS	0-50	Sand, gravel, and boulders
		Tw	WHITE RIVER GROUP	0-300	Light colored clays with sandstone channel fillings and local limestone lenses.
	TERTIARY	Tui	INTRUSIVE IGNEOUS ROCKS	--	Includes rhyolite, latite, trachyte, and phonolite.
MESOZOIC	CRETACEOUS	Kps	PIERRE SHALE	1,200-2,700	Principal horizon of limestone lenses giving teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses, giving small teepee buttes. Black fissile shale with concretions.
			NIOBRARA FORMATION	[1]80-300	Impure chalk and calcareous shale.
			CARLILE SHALE: Turner Sandy Member Wall Creek Member	[1]350-750	Light-gray shale with numerous large concretions and sandy layers. Dark-gray shale
			GREENHORN FORMATION	225-380	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale, with thin Orman Lake limestone at base.
			GRANEROS GROUP: BELLE FOURCHE SHALE	150-850	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
			GRANEROS GROUP: MOWRY SHALE	125-230	Light-gray siliceous shale. Fish scales and thin layers of bentonite.
			GRANEROS GROUP: MUDDY SANDSTONE / NEWCASTLE SANDSTONE	0-150	Brown to light yellow and white sandstone.
			GRANEROS GROUP: SKULL CREEK SHALE	150-270	Dark gray to black siliceous shale.
		Kik	INYAN KARA GROUP: FALL RIVER FORMATION	10-200	Massive to slabby sandstone.
			INYAN KARA GROUP: LAKOTA FM: Fuson Shale Minnewaste Limestone Chilson Member	10-190 0-25 25-485	Coarse gray to buff cross-bedded conglomeratic sandstone, interbedded with buff, red, and gray clay, especially toward top. Local fine-grained limestone.
	JURASSIC	Ju	MORRISON FORMATION	0-220	Light-gray claystone and shale. Thin sandstone.
			UNKPAPA SS	0-225	Massive fine-grained sandstone.
			SUNDANCE FORMATION: Redwater Member Lak Member Hulett Member Stockade Beaver Mem. Canyon Spr Member	250-450	Greenish-gray shale, thin limestone lenses. Glauconltic sandstone; red sandstone near middle.
			GYPSUM SPRING FORMATION	0-45	Red siltstone, gypsum, and limestone.
	TRIASSIC	TRPs	SPEARFISH FORMATION Goose Egg Equivalent	375-800	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PALEOZOIC	PERMIAN	Pmk	MINNEKAHTA LIMESTONE	[1]25-65	Thin to medium-bedded finely-crystalline, purplish gray laminated limestone.
		Po	OPECHE SHALE	[1]25-150	Red shale and sandstone.
	PERMIAN PENNSYLVANIAN	ℙPm	MINNELUSA FORMATION	[1]375-1,175	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
	MISSISSIPPIAN	MDme	MADISON (PAHASAPA) LIMESTONE	[1]250-1,000	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
	DEVONIAN		ENGLEWOOD FORMATION	30-60	Pink to buff limestone. Shale locally at base.
	ORDOVICIAN	Ou	WHITEWOOD (RED RIVER) FORMATION	[1]0-235	Buff dolomite and limestone.
			WINNIPEG FORMATION	[1]0-150	Green shale with siltstone.
	CAMBRIAN	OꞒd	DEADWOOD FORMATION	[1]0-500	Massive to thin-bedded brown to light-gray sandstone. Greenish glauconitic shale flaggy dolomite and flat-pebble limestone conglomerate. Sandstone, with conglomeratelocally at the base.
PRECAMBRIAN		pꞒu	UNDIFFERENTIATED METAMORPHIC AND IGNEOUS ROCKS		Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

[1] Modified based on drill-hole data

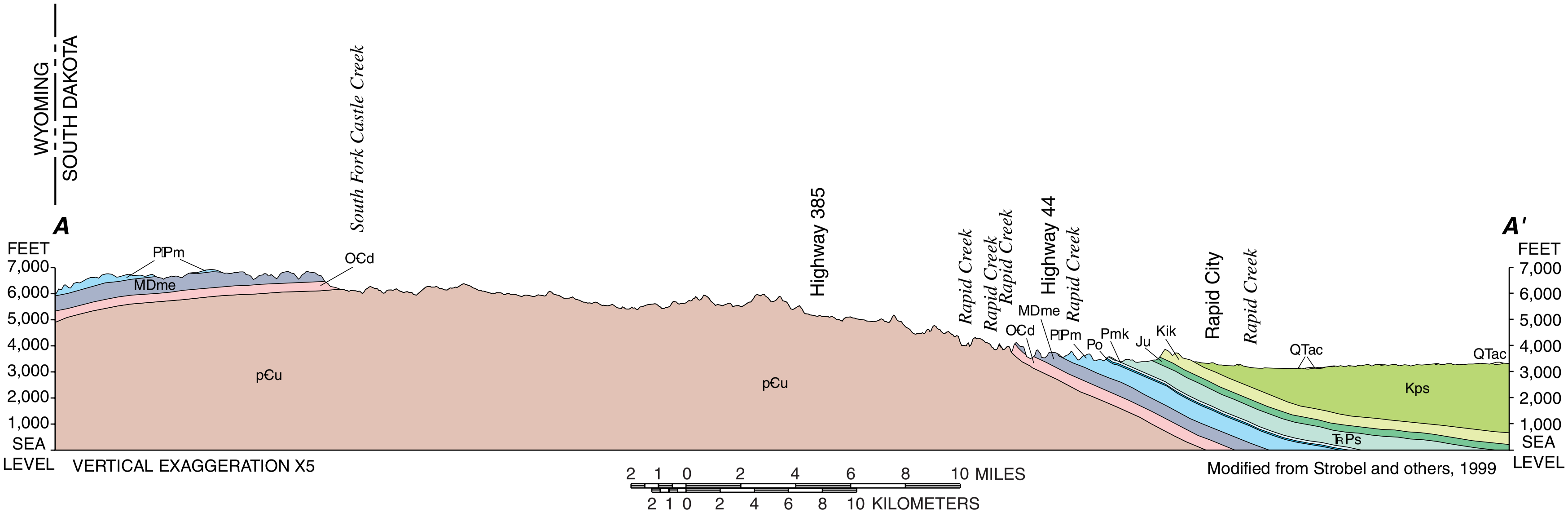
Modified from information furnished by the Department of Geology and Geological Engineering, South Dakota School of Mines and Technology (written commun., January 1994)

Figure 2. Stratigraphic section for the Black Hills.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 3. Distribution of hydrogeologic units in the Black Hills area (modified from Strobel and others, 1999).



Modified from Strobel and others, 1999

Figure 4. Geologic cross section A-A' (Location of section is shown in figure 3. Abbreviations for stratigraphic intervals are explained in figure 2.).

The Permian- and Triassic-age Spearfish Formation consists of red, silty shale interbedded with friable, red sandstone and siltstone, and sparse limestone layers (Strobel and others, 1999). The lower portion of the Spearfish Formation contains massive gypsum (Robinson and others, 1964). The thickness of the Spearfish Formation ranges from 375 to 800 feet (Gries and Martin, 1985).

Jurassic-age units consisting of shale and sandstone with some limestone and gypsum overlie the Spearfish Formation and include the Sundance and Morrison Formations. The Sundance Formation consists of reddish-gray to light-gray siltstone, sandstone, limestone, and glauconitic sandstone and shale (DeWitt and others, 1989) and is 250 to 450 feet thick in the study area (Strobel and others, 1999). The Morrison Formation is a light-gray siliceous claystone and shale (DeWitt and others, 1989) with a thickness that ranges from 0 to 220 feet (Strobel and others, 1999).

The Cretaceous-age Inyan Kara Group consists of the Lakota Formation and overlying Fall River Formation. The Lakota Formation consists of the Chilson, Minnewaste Limestone, and Fuson Shale members. The Lakota Formation consists of yellow, brown, and reddish-brown massive to thin-bedded sandstone, pebble conglomerate, siltstone, and claystone of fluvial origin (Gott and others, 1974); lenses of limestone and coal are present locally. The Fall River Formation is a brown to reddish-brown, fine-grained sandstone, thin bedded at the top and massive at the bottom (Strobel and others, 1999). The thickness of the Inyan Kara Group ranges from 135 to 900 feet in the study area (Carter and Redden, 1999a).

The Cretaceous-age Graneros Group includes the Skull Creek Shale, Newcastle Sandstone, Mowry Shale, and Belle Fourche Shale. The Skull Creek Shale is a dark gray to black siliceous shale and is 150 to 270 feet thick (DeWitt and others, 1989). The Newcastle Sandstone is 0 to 100 feet thick and is a gray to light-brown sandstone and siltstone that contains beds of bentonite and lignite (DeWitt and others, 1989). The Mowry Shale consists of light-gray siliceous shale with thin bentonite layers and is 125 to 230 feet thick (DeWitt and others, 1989). The Belle Fourche Shale is a dark-gray bentonitic shale that contains minor limestone lenses and large concretions and is 150 to 850 feet thick (DeWitt and others, 1989).

The Cretaceous-age Pierre Shale is a dark-gray to black shale containing minor limestone lenses and concretions. The thickness of the Pierre Shale ranges from 1,200 to 2,700 feet (Strobel and others, 1999).

For purposes of this report, alluvial deposits refer to Quaternary-age alluvium, gravel deposits, and windblown deposits and Tertiary-age gravel deposits. Generally, the thickness of these deposits ranges from 0 to 50 feet.

Hydrologic Setting

The hydrologic setting of the Black Hills area is schematically illustrated in figure 5. The major aquifers in the Black Hills area are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Aquifers in the Precambrian rocks also were considered as a major aquifer in this report because numerous wells are completed in this unit. In some local areas, wells are completed in strata that generally are considered semiconfining or confining units. These local water-bearing strata are referred to as minor aquifers in this report. This section describes the hydrologic setting for the major and minor aquifers considered in this report.

Major Aquifers

The Precambrian basement rocks generally have low permeability and form the lower confining unit for the series of sedimentary aquifers in the Black Hills area. Localized aquifers occur in Precambrian rocks at many locations in the central core of the Black Hills, where enhanced secondary permeability results from weathering and fracturing. These localized aquifers are referred to as the Precambrian aquifers in this report. In the Precambrian aquifers, water-table (unconfined) conditions generally prevail and land-surface topography can strongly control ground-water flow directions. Many wells completed in the Precambrian aquifers are located along stream channels.

Many of the sedimentary units contain aquifers, both within and beyond the study area. Within the Paleozoic rock interval, aquifers in the Deadwood Formation, Madison Limestone, Minnelusa Formation, and Minnekahta Limestone are used extensively. These aquifers are collectively confined by the underlying Precambrian rocks and the overlying Spearfish Formation. Individually, these aquifers are separated by minor confining layers or by relatively impermeable layers within the individual units. In general, ground-water flow in these aquifers is radially outward from the central core of the Black Hills. Although the lateral component of flow predominates, extremely variable leakage (vertical component of flow) can occur between these aquifers (Peter, 1985; Greene, 1993).

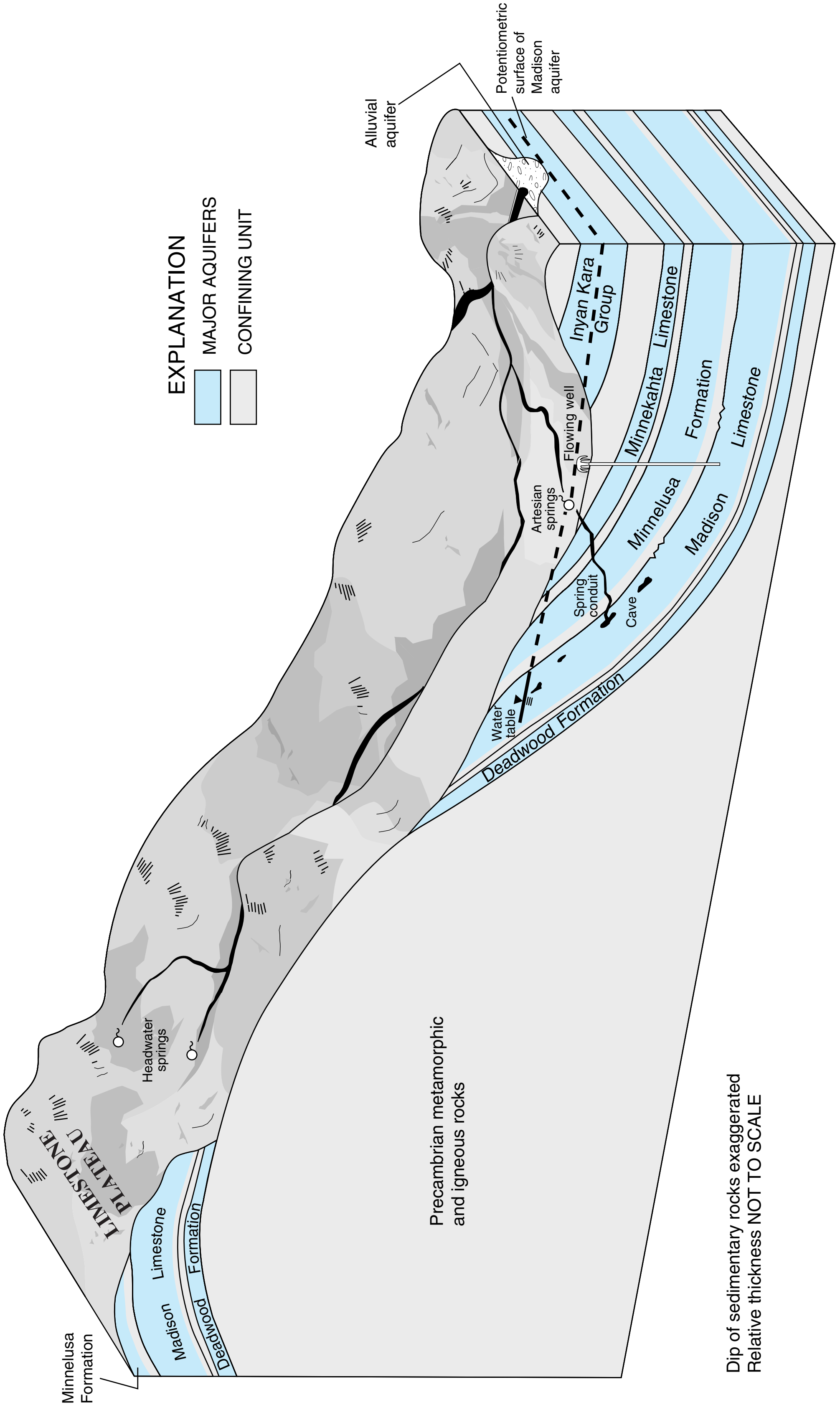


Figure 5. Schematic showing simplified hydrogeologic setting of the Black Hills area.

The Deadwood Formation contains the Deadwood aquifer, which overlies the Precambrian rocks. In general, the Deadwood aquifer serves as a source of water mainly for domestic and municipal users near its outcrop area. There may be some hydraulic connection between the Deadwood and the underlying weathered Precambrian rocks, but regionally the Precambrian rocks act as a lower confining unit to the Deadwood aquifer. Where present, the Whitewood and Winnipeg Formations act as a semiconfining unit overlying the Deadwood aquifer (Strobel and others, 1999). These units locally may transmit and exchange water with the Deadwood aquifer, but regionally are not considered aquifers. Where the Whitewood and Winnipeg Formations are absent, the Deadwood aquifer is in contact with the overlying Englewood Formation, which Strobel and others (1999) included as part of the Madison aquifer.

The Madison aquifer generally occurs within the karstic upper part of the Madison Limestone; however, Strobel and others (1999) included the entire Madison Limestone and underlying Englewood Formation in their delineation of the aquifer. Numerous fractures and solution openings in the Madison Limestone provide extensive secondary porosity in the aquifer. The Madison aquifer generally is confined by low permeability layers in the overlying Minnelusa Formation.

The Minnelusa aquifer occurs within layers of sandstone, dolomite, and anhydrite in the lower portion of the Minnelusa Formation and sandstone and anhydrite in the upper portion. The Minnelusa aquifer has primary porosity in the sandstone units and secondary porosity from collapse breccia associated with solution of interbedded evaporites and fracturing. The Minnelusa aquifer is confined by the overlying Opeche Shale and by low-permeability layers within the Minnelusa Formation.

The Minnekahta aquifer, which overlies the Opeche Shale, typically is very permeable, but well yields are limited by the aquifer thickness. The overlying Spearfish Formation acts as a confining unit to the aquifer.

Within the Mesozoic rock interval, the Inyan Kara Group contains an aquifer that is used extensively. As much as 4,000 feet of Cretaceous shales act as the upper confining layer to the Inyan Kara aquifer.

Artesian (confined) conditions generally exist within the aforementioned aquifers where an upper confining layer is present. Under artesian conditions, water in a well will rise above the top of the aquifer in which it is completed. Flowing wells will result when drilled in areas where the potentiometric surface is above the land surface. Flowing wells and artesian springs that originate from confined aquifers are common around the periphery of the Black Hills.

Numerous headwater springs originating from the Paleozoic units at high elevations on the western side of the study area provide base flow for many streams. These streams flow across the central core of the Black Hills, and most streams generally lose all or part of their flow as they cross the outcrops of the Madison Limestone (Rahn and Gries, 1973; Hortness and Driscoll, 1998). Karst features of the Madison Limestone, including sinkholes, collapse features, solution cavities, and caves, are responsible for the Madison aquifer's capacity to accept recharge from streamflow. Large streamflow losses also occur in many locations within the outcrop of the Minnelusa Formation (Hortness and Driscoll, 1998). Large artesian springs occur in many locations downgradient from these loss zones, most commonly within or near the outcrop of the Spearfish Formation. These springs provide an important source of base flow in many streams beyond the periphery of the Black Hills (Rahn and Gries, 1973; Miller and Driscoll, 1998).

Minor Aquifers

In addition to the major aquifers, many other aquifers, such as the Newcastle and alluvial aquifers, are used throughout the study area. In addition, many of the semiconfining and confining units shown in figure 3 may contain local aquifers. These other and local aquifers are considered minor aquifers in this report. This section provides a brief overview from Strobel and others (1999) of the minor aquifers for which water-quality data are available.

Local aquifers may exist in the Spearfish confining unit where gypsum and anhydrite have been dissolved, increasing porosity and permeability; these aquifers are referred to as the Spearfish aquifer in this report. The Jurassic-sequence semiconfining unit consists of shales and sandstones. Overall, this unit is semiconfining because of the low permeability of the interbedded shales; however, local aquifers do exist in some formations such as the Sundance and Morrison Formation. These aquifers are referred to as the Sundance and Morrison aquifers in this report.

The Cretaceous-sequence confining unit mainly includes shales of low permeability, such as the Pierre Shale; local aquifers within the Pierre Shale are referred to as the Pierre aquifer in this report. Within the Graneros Group, the Newcastle Sandstone contains an important minor aquifer. Because water-quality characteristics are very different between the Newcastle aquifer and the other units within the Graneros Group, water-quality data are presented for the Newcastle aquifer separately from the other units within the Graneros Group, known as the Graneros aquifer in this report.

Gravel deposits of Tertiary age and unconsolidated units of Quaternary age, including alluvium, colluvium, gravel deposits, and wind-blown deposits, all have the potential to provide water where these units are saturated. In this report, these units are collectively referred to as alluvial aquifers.

Previous Investigations

Numerous reports from previous investigations contain information on the water quality of ground and surface water in the Black Hills area. The investigations described in this section are not exhaustive, but rather are those that either provide regional water-quality information or were done as part of the Black Hills Hydrology Study.

Various investigations have addressed the quality of ground water in the Black Hills area. Water-quality data collected from the Inyan Kara aquifer in the southern Black Hills were presented by Gott and others (1974). Radium concentrations collected from wells completed in the Madison aquifer in western South Dakota were presented by Carda (1975). Numerous water-quality data were collected in western South Dakota during the National Uranium Resource Evaluation (NURE) Program established by the U.S. Department of Energy. Some of the NURE data collected in the Black Hills area were presented by Union Carbide Corporation (1979, 1980). Water-quality data collected from the Madison aquifer in Montana, South Dakota, and Wyoming were presented in Busby and others (1983). The quality of ground water in western South Dakota was summarized for 17 aquifers by Meyer (1984), and ground-water pollution problems were summarized in Meyer (1986). Summaries of water-quality samples collected from the Inyan Kara, Minnelusa, and Madison aquifers were presented by Peter (1985) for the Rapid City area and by Kyllonen and Peter (1987) for the northern Black Hills of South Dakota and Wyoming. Water-quality data with emphasis on selenium in the Inyan Kara aquifer in the Black Hills were presented by Behal (1988). Water-quality data with emphasis on radionuclides for the Deadwood aquifer in the Black Hills were presented by Rounds (1991). Major ion and isotope data for the Madison aquifer in Montana, South Dakota, and Wyoming were presented by Busby and others (1991).

Many investigations on the quality of surface water have been conducted. The general water quality of streams within South Dakota has been reported every 2 years in 305(b) assessment reports prepared by the South Dakota Department of Environment and Natural Resources (1975-99). Water-quality data and results from the Rapid City National Urban Runoff Program were presented by Harms (1983), Harms and others (1983), and Goddard and others (1989). The water-quality effects of contaminated sediments on Whitewood Creek and the Belle Fourche and Cheyenne Rivers were addressed by Cherry and others (1986a, 1986b, 1986c), Goddard (1988, 1989a, 1989b, 1990), and Fuller and others (1988, 1989). Water-quality data, including major ions, properties, trace elements, and pesticides, that were collected during 1988 as part of irrigation drainage programs were presented by Greene and others (1990) for the Angostura Reclamation Unit and by Roddy and others (1991) for the Belle Fourche Reclamation Project. The water quality of streams in Custer State Park following the Galena Forest Fire was presented by Gundarlahalli (1990). Freeman and Komor (1991) presented a compilation of water-quality data along Rapid Creek for the period 1946-90, and Williamson and others (1996) presented data on selected trace elements in Rapid Creek. Additional summaries of sources of water-quality data in the Rapid Creek Basin were presented by Zogorski and others (1990). Information about arsenic loads and concentrations in Spearfish Creek were presented by Driscoll and Hayes (1995). Water-quality impacts on surface water from mining were presented by Rahn and others (1996).

Several reports contain water-quality data that were specifically collected as part of the Black Hills Hydrology Study. Water-quality data for selected wells, streams, and springs have been published by Driscoll and Bradford (1994), Driscoll and others (1996), and Driscoll, Bradford, and Moran (2000). Water-quality data for selected streams in Lawrence

County were presented by Torve (1991), Williamson (1999), and Williamson and Hayes (2000). Nutrient, chloride, and bacteria data collected during 1988-90 for the Spearfish Creek Basin in Lawrence County were presented by Johnson (1992). Water-quality data from large-discharge springs and selected wells completed in the Madison and Minnelusa aquifers in the southern Black Hills were presented by Whalen (1994) and in northwestern Lawrence County by Klemp (1995). Water-quality data with emphasis on field properties of selected headwater springs in the Black Hills were presented by Wenker (1997).

Acknowledgments

The authors acknowledge the efforts of the West Dakota Water Development District for helping to develop and support the Black Hills Hydrology Study. West Dakota's coordination of various local and county cooperators has been a key element in making this study possible. The authors also recognize the numerous local and county cooperators represented by West Dakota, as well as the numerous private citizens who have helped provide guidance and support for the Black Hills Hydrology Study. The South Dakota Department of Environment and Natural Resources has provided support and extensive technical assistance to the study. In addition, the authors acknowledge the input and technical assistance from many faculty and students at the South Dakota School of Mines and Technology.

WATER-QUALITY CHARACTERISTICS

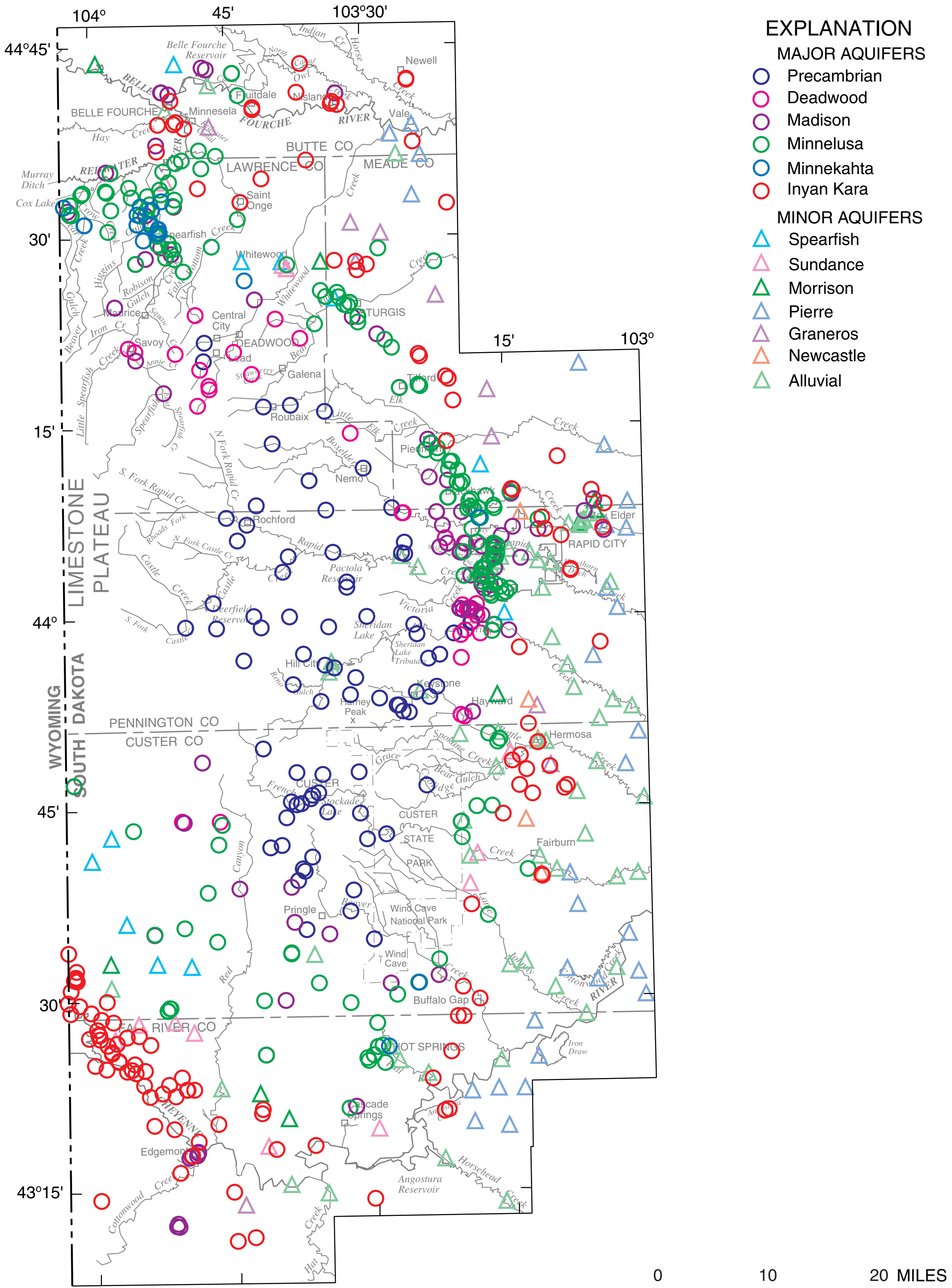
Data from the USGS National Water Information System (NWIS) water-quality database, QWDATA, were examined to characterize the water quality of aquifers, streams, and springs in the Black Hills area. QWDATA stores data primarily collected and analyzed by USGS. The data also are transferred to the U.S. Environmental Protection Agency (USEPA) water-quality database, STORET.

Data summarized in this report include samples collected from October 1, 1930, to September 30, 1998. A selection criterion for including a sample as part of this analysis was to have a cation/anion balance within 10 percent. Tables of individual results are not presented in this report, only summaries. Site specific data can be requested from the USGS or USEPA. For some of the constituents summarized in this report, multiple laboratory reporting limits were used, resulting in censored values at various levels. If the majority of detectable levels were less than some of the censored values, those censored values were removed because they do not provide additional information for describing the data set. For the censored data, boxplots and summary statistics were estimated using a log-probability regression procedure (Helsel and Gilliom, 1985).

Sampling Sites and Methods

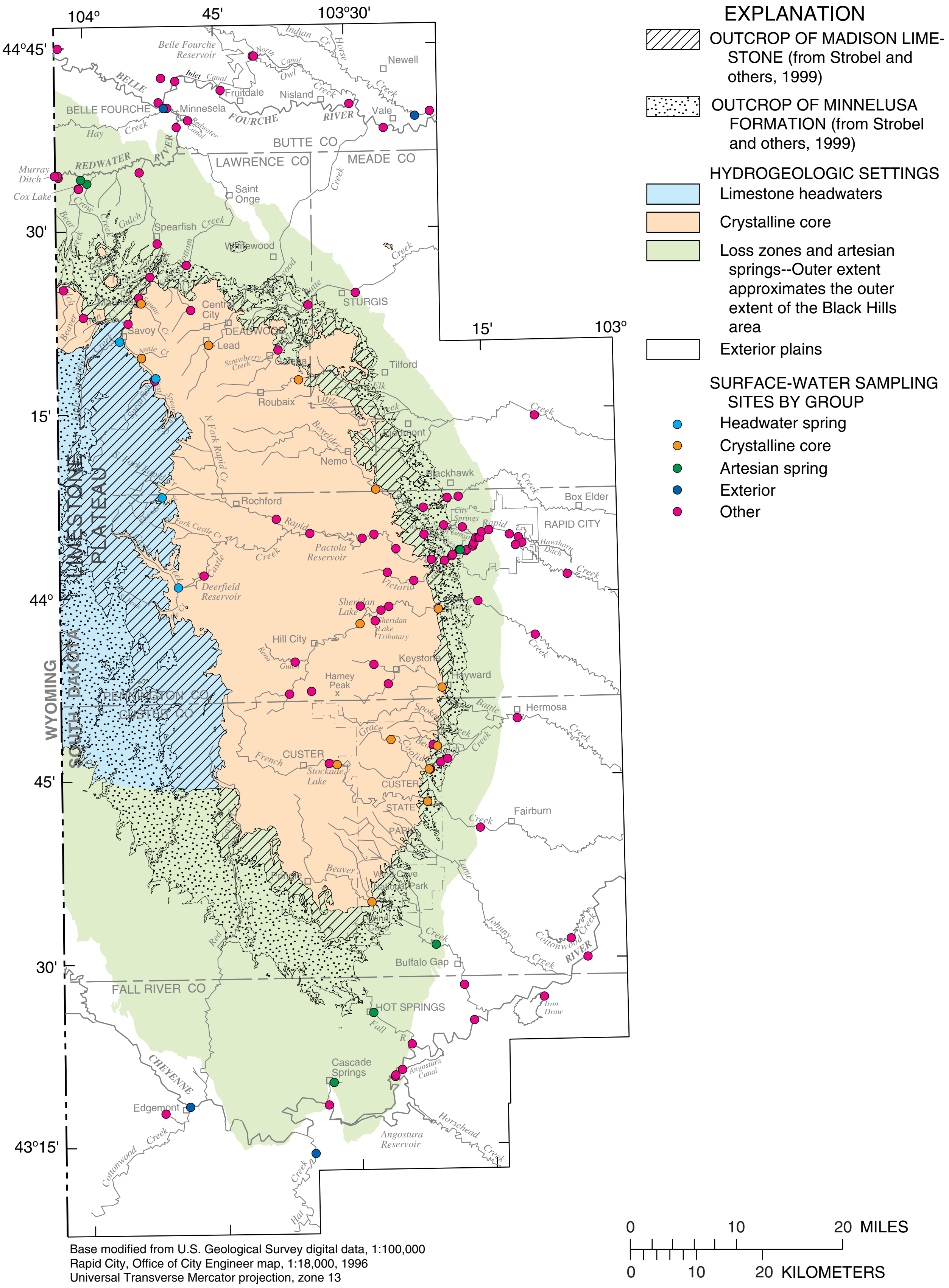
Ground-water and surface-water samples collected as part of studies along Whitewood Creek have been summarized in previous reports (Goddard, 1988, 1989a; Fuller and Davis, 1989; Fuller and others, 1988, 1989; Goddard and others, 1989) and are not included in this summary. In addition, samples from wastewater treatment plant effluents, some miscellaneous measurement sites, and samples from sites obviously affected by abandoned mines are not included. Sampling locations for ground water and surface water are presented in figures 6 and 7, respectively. The location of selected surface-water sites in the Rapid Creek Basin is presented in figure 7a. Lists of the ground-water and surface-water sampling sites are presented in tables 15 and 16 in the Supplemental Information section at the end of the report.

For the majority of the samples collected prior to the Black Hills Hydrology Study and for all samples collected during the study, all water-sampling equipment was presoaked in a Liquinox solution, thoroughly scrubbed, rinsed with tap water, and then rinsed with deionized water prior to sampling. Samples were collected using acceptable methods at the time; most methods are described by Hem (1985) and Ward and Harr (1990). Field measurements of streamflow, air and water temperature, pH, dissolved oxygen, and specific conductance usually were collected. When more than one site was sampled on a given day, equipment cleaning between sites consisted of a deionized water rinse and thoroughly rinsing with well or stream water. After samples were collected, filtered and preserved, if applicable, they were shipped to the USGS National Water Quality Laboratory (NWQL) for analysis.



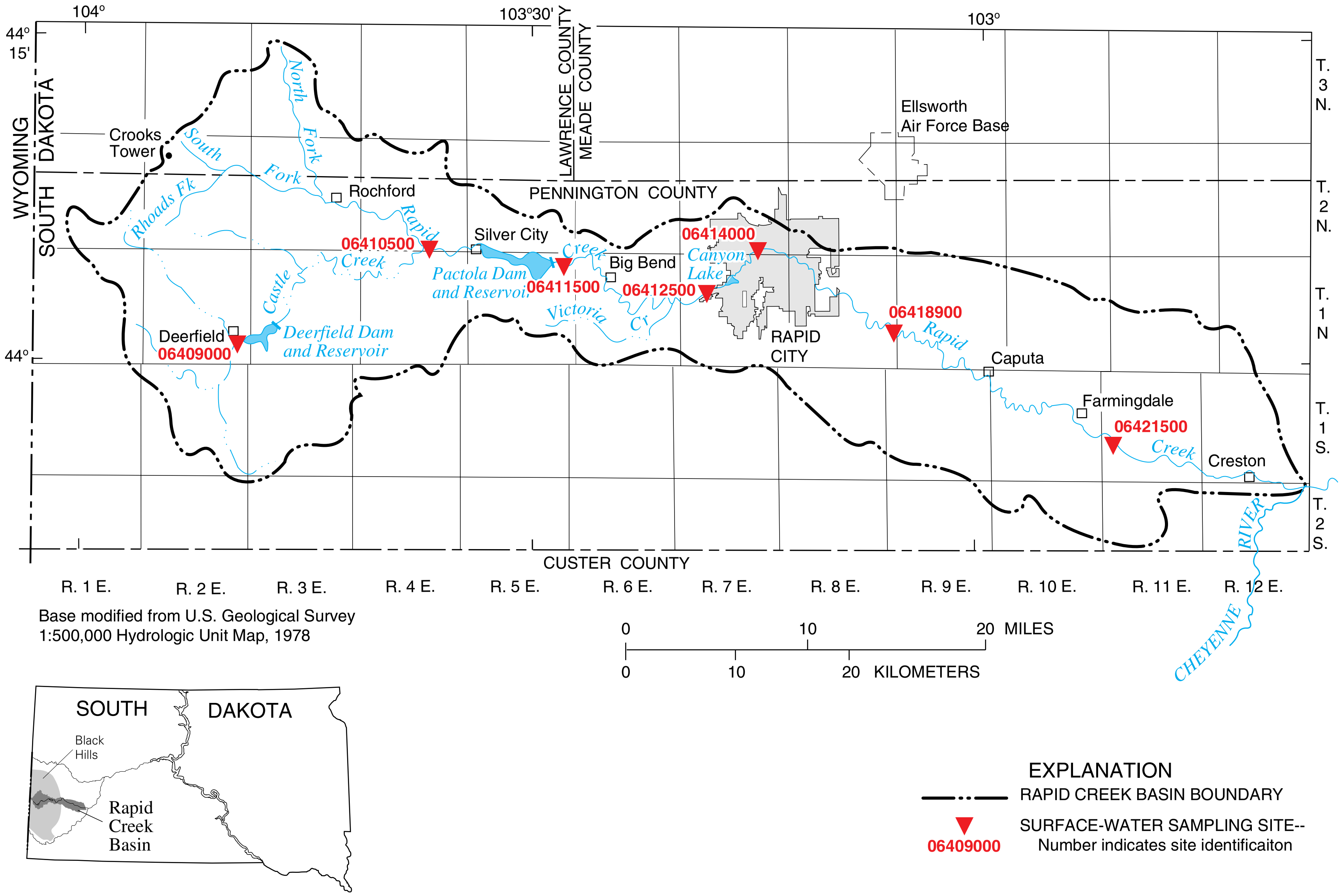
Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 6. Location of ground-water sampling sites.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 7. Location of selected surface-water sampling sites by group.



Base modified from U.S. Geological Survey 1:500,000 Hydrologic Unit Map, 1978

Figure 7a. Location of selected surface-water sampling sites in the Rapid Creek Basin.

Water-Quality Criteria

Under the authority of the Safe Drinking Water Act in 1974, the USEPA established a public drinking-water system program. The State of South Dakota received USEPA approval to administer their own drinking-water program in 1984. Under the Safe Drinking Water Act and the 1986 Amendments, both USEPA and the State of South Dakota set limits for contaminant levels in drinking water to ensure the safety of public drinking water.

Maximum Contaminant Levels (MCL's) are established for contaminants that, if present in drinking water, may cause adverse human health effects; MCL's are enforceable health-based standards (U.S. Environmental Protection Agency, 1994a). Secondary Maximum Contaminant Levels (SMCL's) are established for contaminants that can adversely affect the taste, odor, or appearance of water and may result in discontinuation of use of the water; SMCL's are nonenforceable, generally non-health-based standards that are related to the aesthetics of water use (U.S. Environmental Protection Agency, 1994a). Action levels are concentrations that determine whether treatment requirements may be necessary (U.S. Environmental Protection Agency, 1997). Water-quality criteria, standards, or recommended limits and the general significance for the physical properties and constituents discussed in this report are presented in table 1.

Concentrations of constituents are compared to drinking-water standards set by the USEPA. Although USEPA standards apply only to public-water supplies, local residents using water from private wells for domestic purposes may want to be aware of the potential health risks associated with drinking water that exceeds drinking-water standards. Drinking-water standards established by the USEPA are based on total constituent concentrations, which refer to the combined concentrations of both dissolved and suspended phases of the water sample. Results reported by the USGS as dissolved constituent concentrations may be less than those obtained for similar samples analyzed for total constituent concentrations.

In an effort to control water pollution, Congress passed the Federal Water Pollution Control Act (Public Law 92-500) in 1972. Congress amended the law in 1977, changing the name to the Clean Water Act, which requires States to classify surface waters with regard to beneficial use and to establish water-quality criteria to meet those uses (South Dakota Department of Water and Natural Resources, 1987). The Clean Water Act also require States to review and revise these standards every 3 years. The current beneficial-use and aquatic-life criteria are presented in table 2.

The beneficial-use criteria are designed to protect and ensure that a stream can support the specified beneficial uses. All streams in South Dakota are classified for irrigation and wildlife propagation and stock watering. Additional beneficial uses are assigned to stream segments as applicable. Some of the more common beneficial uses for the Black Hills area include domestic water supply, fish life propagation waters, and immersion recreation waters. Specific stream segment beneficial uses can be found in "Surface Water Quality," Administrative Rules of South Dakota 74:51 (1998). Aquatic-life criteria are estimates of the highest concentrations in surface water that aquatic life can be exposed to without a resulting unacceptable or harmful effect. The chronic criteria is based on a concentration that the aquatic life can be exposed to for an indefinite period without an unacceptable or harmful effect. The acute criteria is based on a concentration that the aquatic life can be exposed to for very short periods without an unacceptable or harmful effect. The aquatic criteria for several trace elements vary with stream hardness (fig. 8). Generally, as stream hardness increases, the toxicity of the trace element decreases.

Table 1. Water-quality criteria, standards, or recommended limits and general significance for selected properties or constituents

[Modified from Hamilton and Howells, 1996. All standards are from U.S. Environmental Protection Agency (1994a) unless noted. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; USEPA, U.S. Environmental Protection Agency; mL, milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no limit established]

Constituent or property	Limit	Significance
Specific conductance	--	A measure of the ability of water to conduct an electrical current; varies with temperature. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids. Values are reported in microsiemens per centimeter at 25°Celsius.
pH	6.5-8.5 units SMCL	A measure of the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values smaller than 7.0 indicate acidity, pH values larger than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water also may be corrosive.
Temperature	--	Affects the usefulness of water for many purposes. Generally, users prefer water of uniformly low temperature. Temperature of ground water tends to increase with increasing depth to the aquifer.
Dissolved oxygen	--	Required by higher forms of aquatic life for survival. Measurements of dissolved oxygen are used widely in evaluations of the biochemistry of streams and lakes. Oxygen is supplied to ground water through recharge and by movement of air through unsaturated material above the water table (Hem, 1989).
Carbon dioxide	--	Important in reactions that control the pH of natural waters.
Hardness and noncarbonate hardness (as mg/L $CaCO_3$)	--	Related to the soap-consuming characteristics of water; results in formation of scum when soap is added. May cause deposition of scale in boilers, water heaters, and pipes. Hardness contributed by calcium and magnesium, bicarbonate and carbonate mineral species in water is called carbonate hardness; hardness in excess of this concentration is called noncarbonate hardness. Water that has a hardness less than 61 mg/L is considered soft; 61-120 mg/L, moderately hard; 121-180 mg/L, hard; and more than 180 mg/L, very hard (Heath, 1983).
Alkalinity	--	A measure of the capacity of unfiltered water to neutralize acid. In almost all natural waters alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate. Typically expressed as mg/L $CaCO_3$.
Dissolved solids	500 mg/L SMCL	The total of all dissolved mineral constituents, usually expressed in milligrams per liter. The concentration of dissolved solids may affect the taste of water. Water that contains more than 1,000 mg/L is unsuitable for many industrial uses. Some dissolved mineral matter is desirable, otherwise the water would have no taste. The dissolved solids concentration commonly is called the water's salinity and is classified as follows: fresh, 0-1,000 mg/L; slightly saline, 1,000-3,000 mg/L; moderately saline, 3,000-10,000 mg/L; very saline, 10,000-35,000 mg/L; and briny, more than 35,000 mg/L (Heath, 1983).
Calcium plus magnesium	--	Cause most of the hardness and scale-forming properties of water (see hardness).
Sodium plus potassium	--	Large concentrations may limit use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally large concentrations may indicate natural brines, industrial brines, or sewage.
Sodium-adsorption ratio (SAR)		A ratio used to express the relative activity of sodium ions in exchange reactions with soil. Important in irrigation water; the greater the SAR, the less suitable the water for irrigation.
Bicarbonate	--	In combination with calcium and magnesium forms carbonate hardness.
Sulfate	250 mg/L SMCL	Sulfates of calcium and magnesium form hard scale. Large concentrations of sulfate have a laxative effect on some people and, in combination with other ions, give water a bitter taste.
Chloride	250 mg/L SMCL	Large concentrations increase the corrosiveness of water and, in combination with sodium, give water a salty taste.

Table 1. Water-quality criteria, standards, or recommended limits and general significance for selected properties or constituents—Continued

[Modified from Hamilton and Howells, 1996. All standards are from U.S. Environmental Protection Agency (1994a) unless noted. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; USEPA, U.S. Environmental Protection Agency; mL, milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no limit established]

Constituent or property	Limit	Significance
Fluoride	4.0 mg/L MCL 2.0 mg/L SMCL	Reduces incidence of tooth decay when optimum fluoride concentrations present in water consumed by children during the period of tooth calcification. Potential health effects of long-term exposure to elevated fluoride concentrations include dental and skeletal fluorosis (U.S. Environmental Protection Agency, 1994b).
Bromide	--	Not known to be essential in human or animal diet. Not known to have any ecologic significance when it occurs in small concentrations typically found in fresh waters of the United States.
Iodide	--	Essential and beneficial element in metabolism; deficiency can cause goiter.
Silica (as SiO_2)	--	Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Nitrite (mg/L as N)	1.0 mg/L MCL	Commonly formed as an intermediate product in bacterially mediated nitrification and denitrification of ammonia and other organic nitrogen compounds. An acute health concern at certain levels of exposure. Nitrite typically occurs in water from fertilizers and is found in sewage and wastes from humans and farm animals. Concentrations greater than 1.0 mg/L, as nitrogen, may be injurious when used in feeding infants.
Nitrite plus nitrate (mg/L as N)	10 mg/L MCL	Concentrations greater than local background levels may indicate pollution by feedlot runoff, sewage, or fertilizers. Concentrations greater than 10 mg/L, as nitrogen, may be injurious when used in feeding infants.
Ammonia	--	Plant nutrient that can cause unwanted algal blooms and excessive plant growth when present at elevated levels in water bodies. Sources include decomposition of animal and plant proteins, agricultural and urban runoff, and effluent from waste-water treatment plants.
Ammonia plus organic	--	Organic species are unstable in aerated water and generally are considered to be indicators of pollution through disposal of sewage or organic waste (Hem, 1989). Nitrogen in reduced (ammonia) or organic forms is converted by soil bacteria into nitrite and nitrate (nitrification). See also ammonia.
Phosphorus, orthophosphate	--	Dense agal blooms or rapid plant growth can occur in waters rich in phosphorus. A limiting nutrient for eutrophication since it is typically in shortest supply. Sources are human and animal wastes and fertilizers.
Aluminum	50-200 µg/L SMCL	No known necessary role in human or animal diet. Nontoxic in the concentrations normally found in natural water supplies. Elevated dissolved aluminum concentrations in some low pH waters can be toxic to some types of fish (Hem, 1989).
Arsenic	[1]50 µg/L MCL	No known necessary role in human or animal diet, but is toxic. A cumulative poison that is slowly excreted. Can cause nasal ulcers; damage to the kidneys, liver, and intestinal walls; and death. Recently suspected to be a carcinogen (Garold Carlson, U.S. Environmental Protection Agency, written commun., 1998).
Barium	2,000 µg/L MCL	Toxic; used in rat poison. In moderate to large concentrations can cause death; smaller concentrations cause damage to the heart, blood vessels, and nerves.
Boron	--	Essential to plant growth, but may be toxic to crops when present in excessive concentrations in irrigation water. Sensitive plants show damage when irrigation water contains more than 670 µg/L and even tolerant plants may be damaged when boron exceeds 2,000 µg/L. The recommended limit is 750 µg/L for long-term irrigation on sensitive crops (U.S. Environmental Protection Agency, 1986).
Cadmium	5 µg/L MCL	A cumulative poison; very toxic. Not known to be either biologically essential or beneficial. Believed to promote renal arterial hypertension. Elevated concentrations may cause liver and kidney damage, or even anemia, retarded growth, and death.
Chromium	100 µg/L MCL	No known necessary role in human or animal diet. In the hexavalent form is toxic, leading to intestinal damage and to nephritis.

Table 1. Water-quality criteria, standards, or recommended limits and general significance for selected properties or constituents—Continued

[Modified from Hamilton and Howells, 1996. All standards are from U.S. Environmental Protection Agency (1994a) unless noted. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; USEPA, U.S. Environmental Protection Agency; mL, milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no limit established]

Constituent or property	Limit	Significance
Cobalt	--	Importance to human nutrition is not known but the element is essential in plant and animal nutrition. Concentrations of cobalt in the Earth's crust are generally very low. Uncontaminated natural water should generally contain no more than a few micrograms per liter of cobalt (Hem, 1989, p. 139).
Copper	1,300 µg/L (action level)	Essential to metabolism; copper deficiency in infants and young animals results in nutritional anemia. Large concentrations of copper are toxic and may cause liver damage. Moderate levels of copper (near the action level) can cause gastro-intestinal distress. If more than 10% of samples at the tap of a public water system exceed 1,300 µg/L, the USEPA requires treatment to control corrosion of plumbing materials in the system.
Iron	300 µg/L SMCL	Forms rust-colored sediment; stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing. Can promote growth of certain kinds of bacteria that clog pipes and well openings.
Lead	15 µg/L (action level)	A cumulative poison, toxic in small concentrations. Can cause lethargy, loss of appetite, constipation, anemia, abdominal pain, gradual paralysis in the muscles, and death. If 1 in 10 samples of a public supply exceed 15 µg/L, the USEPA recommends treatment to remove lead and monitoring of the water supply for lead content (U.S. Environmental Protection Agency, 1991).
Lithium	--	Reported as probably beneficial in small concentrations (250-1,250 µg/L). Reportedly may help strengthen the cell wall and improve resistance to genetic damage and to disease. Lithium salts are used to treat certain types of psychosis.
Manganese	50 µg/L SMCL	Causes gray or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria that clog pipes and wells.
Mercury (inorganic)	2 µg/L MCL	No known essential or beneficial role in human or animal nutrition. Liquid metallic mercury and elemental mercury dissolved in water are comparatively nontoxic, but some mercury compounds, such as mercuric chloride and alkyl mercury, are very toxic. Elemental mercury is readily alkylated, particularly to methyl mercury, and concentrated by biological activity. Potential health effects of exposure to some mercury compounds in water include severe kidney and nervous system disorders (U.S. Environmental Protection Agency, 1994b).
Molybdenum	--	In minute concentrations, appears to be an essential nutrient for both plants and animals, but in large concentrations may be toxic.
Nickel	--	Very toxic to some plants and animals. Toxicity for humans is believed to be very minimal.
Selenium	50 µg/L MCL	Essential to human and animal nutrition in minute concentrations, but even a moderate excess may be harmful or potentially toxic if ingested for a long time (Callahan and others, 1979). Potential human health effects of exposure to elevated selenium concentrations include liver damage (U.S. Environmental Protection Agency, 1994b).
Silver	100 µg/L SMCL	Causes permanent bluish darkening of the eyes and skin (argyria). Where found in water is almost always from pollution or by intentional addition. Silver salts are used in some countries to sterilize water supplies. Toxic in large concentrations.
Strontium	--	Importance in human and animal nutrition is not known, but believed to be essential. Toxicity believed very minimal—no more than that of calcium.
Vanadium	--	Not known to be essential to human or animal nutrition, but believed to be beneficial in trace concentrations. May be an essential trace element for all green plants. Large concentrations may be toxic.
Zinc	5,000 µg/L SMCL	Essential and beneficial in metabolism; its deficiency in young children or animals will retard growth and may decrease general body resistance to disease. Seems to have no ill effects even in fairly large concentrations (20,000-40,000 mg/L), but can impart a metallic taste or milky appearance to water. Zinc in drinking water commonly is derived from galvanized coatings of piping.

Table 1. Water-quality criteria, standards, or recommended limits and general significance for selected properties or constituents—Continued

[Modified from Hamilton and Howells, 1996. All standards are from U.S. Environmental Protection Agency (1994a) unless noted. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; USEPA, U.S. Environmental Protection Agency; mL, milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no limit established]

Constituent or property	Limit	Significance
Gross alpha-particle activity	15 pCi/L MCL	The measure of alpha-particle radiation present in a sample. A limit is placed on gross alpha-particle activity because it is impractical at the present time to identify all alpha-particle emitting radionuclides due to analytical costs. Gross alpha-particle activity is a radiological hazard. The 15 pCi/L standard also includes radium-226, a known carcinogen, but excludes any uranium or radon that may be present in the sample. Thorium-230 radiation contributes to gross alpha-particle activity.
Beta-particle and photon activity (formerly manmade radionuclides)	4 millirem/yr MCL (under review)	The measure of beta-particle radiation present in a sample. Gross beta-particle activity is a radiological hazard. See strontium-90 and tritium.
Radium-226 & 228 combined	5 pCi/L MCL	Radium locates primarily in bone, however, inhalation or ingestion may result in lung cancer. Radium-226 is a highly radioactive alkaline-earth metal that omits alpha-particle radiation. It is the longest lived of the four naturally occurring isotopes of radium and is a disintegration product of uranium-238. Concentrations of radium in most natural waters are usually less than 1.0 pCi/L (Hem, 1989).
Radon[2]	300 or 4,000 pCi/L proposed MCL	Inhaled radon is known to cause lung cancer (MCL for radon in indoor air is 4 pCi/L). Injested radon also is believed to cause cancer. A radon concentration of 1,000 pCi/L in water is approximately equal to 1 pCi/L in air. The ultimate source of radon is the radioactive decay of uranium. Radon-222 has a half life of 3.8 days and is the only radon isotope of importance in the environment (Hem, 1989).
Strontium-90 (contributes to beta-particle and photon activity)	Gross beta-particle activity (4 millirem/yr) MCL	Strontium-90 is one of 12 unstable isotopes of strontium known to exist. It is a product of nuclear fallout and is known to cause adverse human health affects. Strontium-90 is a bone seeker and a relatively long-lived beta emitter with a half-life of 28 years. The USEPA has calculated that an average annual concentration of 8 pCi/L will produce a total body or organ dose of 4 millirem/yr (U.S. Environmental Protection Agency, 1997).
Thorium-230 (contributes to gross alpha-particle activity)	15 pCi/L MCL	Thorium-230 is a product of natural radioactive decay when uranium-234 emits alpha-particle radiation. Thorium-230 also is a radiological hazard because it is part of the uranium-238 decay series and emits alpha-particle radiation through its own natural decay to become radium-226. The half-life of thorium-230 is about 80,000 years.
Tritium (^3H) (contributes to beta-particle and photon activity)	Gross beta-particle activity (4 millirem/yr) MCL	Tritium occurs naturally in small amounts in the atmosphere, but largely is the product of nuclear weapons testing. Tritium can be incorporated into water molecules that reach the Earth's surface as precipitation. Tritium emits low energy beta particles and is relatively short-lived with a half-life of about 12.3 years. The USEPA has calculated that a concentration of 20,000 pCi/L will produce a total body or organ dose of 4 millirem/yr (CFR 40 Subpart B 141.16, revised July 1997, p. 296).
Uranium[3]	30 µg/L MCL (under review)	Uranium is a chemical and a radiological hazard and carcinogen. It omits alpha-particle radiation through natural decay. It is a hard, heavy, malleable metal that can be present in several oxidation states. Generally, the more oxidized states are more soluble. Uranium-238 and uranium-235, which occur naturally, account for most of the radioactivity in water. Uranium concentrations range between 0.1 and 10 µg/L in most natural waters.

[1] Whereas the drinking water MCL currently remains at 50 µg/L, USEPA is currently reviewing a proposed standard of 10 µg/L (U.S. Environmental Protection Agency, 2000a).

[2] USEPA currently is working to set an MCL for radon in water. The proposed standards are 4,000 pCi/L for States that have an active indoor air program and 300 pCi/L for States that do not have an active indoor air program (Garold Carlson, U.S. Environmental Protection Agency, oral commun., 1999). At this time, it is not known whether South Dakota will participate in an active indoor air program (Darron Busch, South Dakota Department of Environment and Natural Resources, oral commun., 1999).

[3] Although USEPA has finalized the MCL of 30 µg/L for uranium, this regulation does not take effect until December 8, 2003 (U.S. Environmental Protection Agency, 2000b).

Table 2. Surface-water-quality standards for selected physical properties and constituents

[All constituents in milligrams per liter unless otherwise noted. µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; mL, milliliters; °F, degrees Fahrenheit; °C, degrees Celsius; ≥, greater than or equal to; --, no data available]

Property or constituent	Beneficial-use criteria[1]										Aquatic-life criteria for fisheries[1] (acute/ chronic) (µg/L)
	Domestic water supply (mean/daily maximum)	Coldwater permanent fisheries	Coldwater marginal fisheries	Warmwater permanent fisheries	Warmwater semi-permanent fisheries	Warmwater marginal fisheries	Immersion waters	Limited contact waters	Wildlife propagation and stock-watering waters	Irrigation waters	
Specific conductance (µS/cm)	--	--	--	--	--	--	--	--	4,000/[2]7,000	2,500/[2]4,375	--
pH (standard units)	6.5-9.0	6.6-8.6	6.5-8.8	6.5-9	6.5-9	6.5-9	--	--	6.0-9.5	--	--
Temperature (°F) (maximum)	--	65 (18.3°C)	75 (24°C)	80 (27°C)	90 (32°C)	90 (32°C)	--	--	--	--	--
Dissolved oxygen	--	≥6.0 ≥7 during spawning	≥5.0	≥5.0	≥5.0	≥4.0	≥5.0	≥5.0	--	--	--
Total alkalinity as ($CaCO_3$)	--	--	--	--	--	--	--	--	750/[2]1,313	--	--
Total dissolved solids	1,000/[2]1,750	--	--	--	--	--	--	--	2,500/[2]4,375	--	--
Total suspended solids	--	30/[2]53	90/[2]158	90/[2]158	90/[2]158	150/[2]263	--	--	--	--	--
Sodium-adsorption ratio	--	--	--	--	--	--	--	--	--	10	--
Chloride	250/[2]438	100/[2]175	--	--	--	--	--	--	--	--	--
Fluoride	4.0	--	--	--	--	--	--	--	--	--	--
Sulfate	500/[2]875	--	--	--	--	--	--	--	--	--	--
Nitrate (as N)	10	--	--	--	--	--	--	--	50/[2]88	--	--
Un-ionized ammonia (as N)	--	0.02	0.02	0.04	0.04	0.04	--	--	--	--	--
Cyanide (free)	--	--	--	--	--	--	--	--	--	--	22/5.2
Dissolved antimony	[3]0.014	[4]4.3	[4]4.3	[4]4.3	[4]4.3	[4]4.3	--	--	--	--	--
Dissolved arsenic	[3]0.000018	[4]0.00014	[4]0.00014	[4]0.00014	[4]0.00014	[4]0.00014	--	--	--	--	360/190 (340/[5]150)

Table 2. Surface-water-quality standards for selected physical properties and constituents—Continued

[All constituents in milligrams per liter unless otherwise noted. µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; mL, milliliters; °F, degrees Fahrenheit; °C, degrees Celsius; ≥, greater than or equal to; --, no data available]

Property or constituent	Beneficial-use criteria[1]										Aquatic-life criteria for fisheries[1] (acute/ chronic) (µg/L)
	Domestic water supply (mean/daily maximum)	Coldwater permanent fisheries	Coldwater marginal fisheries	Warmwater permanent fisheries	Warmwater semi-permanent fisheries	Warmwater marginal fisheries	Immersion waters	Limited contact waters	Wildlife propagation and stock-watering waters	Irrigation waters	
Dissolved barium	1.0	--	--	--	--	--	--	--	--	--	--
Dissolved cadmium	--	--	--	--	--	--	--	--	--	--	[6]3.7/[6]1.0 (4.3/[5]2.2)
Dissolved copper	[3]1.3	--	--	--	--	--	--	--	--	--	[6]17/[6]11 (13/[5]9)
Dissolved lead	--	--	--	--	--	--	--	--	--	--	[6]65/[6]2.5
Dissolved mercury	[3]0.00014	[4]0.00015	[4]0.00015	[4]0.00015	[4]0.00015	[4]0.00015	--	--	--	--	2.1/[7]0.012 (1.4/[5]0.77)
Dissolved selenium	--	--	--	--	--	--	--	--	--	--	20/5 (--/[5]5)
Dissolved silver	--	--	--	--	--	--	--	--	--	--	[6]3.4/--
Dissolved zinc	[3]0.0017	--	--	--	--	--	---	--	--	--	[6]110/[6]100 (120/[5]120)

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[1] South Dakota Department of Environment and Natural Resources, 1998a, unless indicated otherwise.

[2] 30-day average/daily maximum.

[3] Based on two routes of exposure—ingestion of contaminated aquatic organisms and drinking water.

[4] Based on one route of exposure—ingestion of contaminated aquatic organisms only.

[5] U.S. Environmental Protection Agency, 1998.

[6] Hardness-dependent criteria; value given is an example based on hardness of 100 milligrams per liter as $CaCO_3$.

[7] Chronic criteria based on total recoverable concentration.

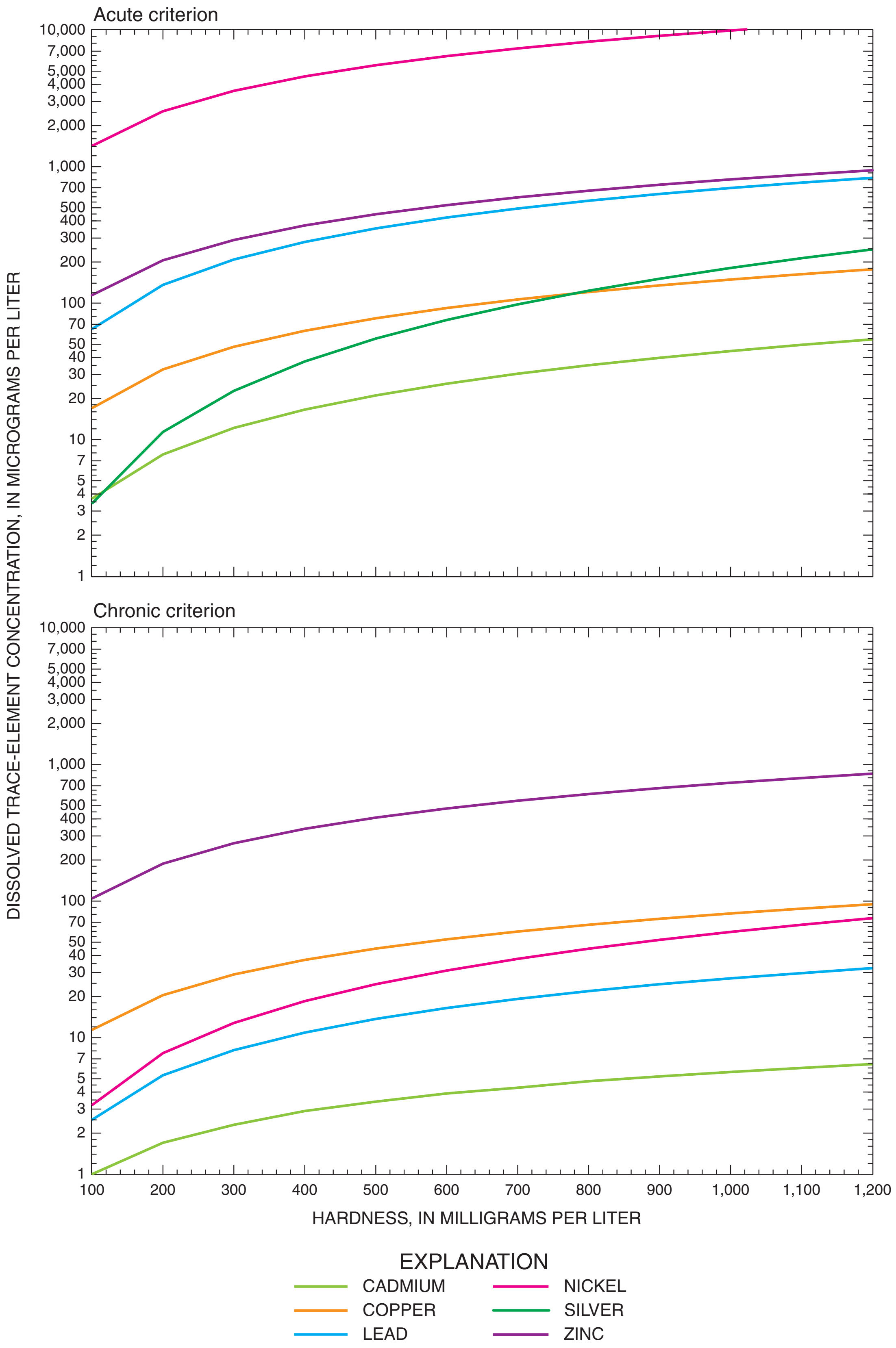


Figure 8. Relations between water hardness and freshwater aquatic-life standards for acute and chronic toxicity of selected trace elements (South Dakota Department of Environment and Natural Resources, 1998a).

Water-Quality Characteristics of Selected Aquifers

Water-quality characteristics are described for selected aquifers within the study area. Summaries are provided for various physical properties and constituents, which are grouped by common ions, nutrients, trace elements, and radionuclides. The effect that water-quality characteristics have on water use for selected aquifers in the study area is summarized at the end of this section.

The major aquifers are those that regionally are used for water supply and include the Precambrian, Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Minor aquifers include formations that typically are not considered aquifers, but may be used locally to supply water; these include the Spearfish, Sundance, Morrison, Pierre Shale, Graneros, and Newcastle aquifers. Numerous wells are completed in alluvial deposits in the Black Hills area, but these aquifers are considered minor because they are not regionally extensive. Water-quality characteristics are presented for aquifers for which at least eight samples were available in the USGS NWIS water-quality database. Multiple samples were collected from some ground-water sites; all sites and the number of valid samples considered are presented in table 15 in the Supplemental Information section.

Comparisons were made for selected aquifers between well depth and variations of selected properties and constituents to provide a general description of how properties and constituents vary with increasing distance from the outcrop. Linear and logarithmic regressions were performed on all properties and constituents with at least eight valid measurements. If the associated R^2 value, which is the fraction of variability in the dependent variable that is explained by the regression equation, was greater than 0.1 and the associated p-value, which is based on the ratio of the explained variance to the unexplained variance, was less than 0.1, the regression was considered statistically significant. Plots of the properties or constituents versus well depth are presented for all significant regressions. Sometimes higher R^2 values were obtained by using the logarithmic value for a particular property or constituent. In these cases, the plot presented contains the logarithmic values of the property or constituent versus well depth.

Because the bedrock formations dip away from the core of the Black Hills, the depth to these formations increases with increasing distance from the outcrop. Therefore, well depth can be used as an indication of distance from the outcrop for four of the aquifers (Deadwood, Madison, Minnelusa, and Inyan Kara aquifers). Well depth is easily quantifiable (as compared to distance from the outcrop) and is available for almost every well sampled. The well depths for samples collected from these aquifers vary from less than 50 feet to greater than 1,500 feet. For the Precambrian, Minnekahta, and all minor aquifers considered, wells generally are located either on or very near the outcrop and, therefore, well depth is relatively constant; water-quality variations with well depth for these aquifers were not determined.

Water quality in individual aquifers may be affected by leakage from other aquifers and by surface contamination in poorly constructed wells. Also, some samples may be incorrectly included with summaries of a specific aquifer due to difficulties in identifying the source aquifer for some wells in areas of complex hydrogeologic conditions.

Physical Properties

The physical properties measured for samples include specific conductance, pH, temperature, dissolved oxygen, carbon dioxide, hardness, noncarbonate hardness, and alkalinity. Summary statistics are presented in table 3, and boxplots are presented in figure 9 for each of these properties.

Relations between various properties and well depth are shown in figure 10. Water temperature generally increases with increasing well depth due to increases in ground temperature with depth, as shown for the Madison, Minnelusa, and Inyan Kara aquifers (fig. 10). Minimum water temperatures for all the aquifers are similar (fig. 9). Water from the Precambrian aquifers has the lowest mean and median temperature of the major aquifers, which is expected due to generally shallow well depths in the Precambrian aquifers. The highest water temperatures are from samples from the Madison and Minnelusa aquifers, which have the deepest wells in the study area (fig. 10). In the Madison aquifer, the water temperature of samples collected from wells located on or near the outcrop is less than 20°C (fig. 11), with some samples less than 10°C; the warmest water sampled (greater than 50°C) was from wells located near Edgemont.

Table 3. Summary of physical properties in ground water

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per million; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, not analyzed or not determined]

Property or dissolved constituent	Number of samples	Mean	Median	Minimum	Maximum
Precambrian aquifers					
Specific conductance (µS/cm)	92	387	350	73	1,130
pH (standard units)	110	6.8	7.1	5.4	8.3
Temperature (°C)	64	11	10	5.0	23
Dissolved oxygen	51	5.5	5.7	1.0	14
Carbon dioxide	110	39	18	1.0	571
Hardness, as $CaCO_3$	112	172	175	22	480
Noncarbonate hardness	13	65	9.0	0	342
Alkalinity	87	144	144	20	349
Deadwood aquifer					
Specific conductance (µS/cm)	37	460	453	83	831
pH (standard units)	36	7.5	7.7	6.8	8.4
Temperature (°C)	32	13	12	7.5	31
Dissolved oxygen	25	4.2	3.5	0.2	11
Carbon dioxide	35	12	8.4	1.2	45
Hardness, as $CaCO_3$	37	210	210	37	460
Noncarbonate hardness	3	6.7	0	0	20
Alkalinity	34	225	207	129	409
Madison aquifer					
Specific conductance (µS/cm)	110	632	460	290	3,360
pH (standard units)	126	7.4	7.6	6.1	8.5
Temperature (°C)	74	19	15	7.0	63
Dissolved oxygen	39	5.9	7.0	0	11
Carbon dioxide	124	17	9.9	1.1	558
Hardness, as $CaCO_3$	127	284	250	22	1,600
Noncarbonate hardness	18	114	95	0	460
Alkalinity	82	203	181	136	363
Minnelusa aquifer					
Specific conductance (µS/cm)	196	783	490	208	3,300
pH (standard units)	237	7.4	7.6	6.1	8.6
Temperature (°C)	106	16	14	7.7	53
Dissolved oxygen	53	5.3	5.7	0	15
Carbon dioxide	234	16	10	1.1	341
Hardness, as $CaCO_3$	249	453	270	8.0	2,200
Noncarbonate hardness	44	497	287	0	1,810
Alkalinity	138	206	205	108	400
Minnekahta aquifer					
Specific conductance (µS/cm)	26	640	550	270	2,330
pH (standard units)	27	7.4	7.5	6.9	8.3
Temperature (°C)	8	13	12	8.2	31
Dissolved oxygen	3	4.7	4.2	2.6	7.2

Table 3. Summary of physical properties in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per million; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, not analyzed or not determined]

Property or dissolved constituent	Number of samples	Mean	Median	Minimum	Maximum
Minnekahta aquifer—Continued					
Carbon dioxide	27	18	17	3.2	62
Hardness, as $CaCO_3$	28	398	310	190	1,500
Noncarbonate hardness	3	554	297	265	1,100
Alkalinity	20	253	250	180	338
Inyan Kara aquifer					
Specific conductance (µS/cm)	150	1,242	1,060	297	4,350
pH (standard units)	175	7.3	7.5	6.2	9.5
Temperature (°C)	107	15	14	1.4	33
Dissolved oxygen	68	4.0	3.2	0	10
Carbon dioxide	174	20	12	0.1	253
Hardness, as $CaCO_3$	176	377	280	6.0	2,000
Noncarbonate hardness	34	185	105	0	990
Alkalinity	117	213	204	30	551
Spearfish aquifer					
Specific conductance (µS/cm)	13	1,384	610	260	5,725
pH (standard units)	12	7.1	7.4	6.3	8.0
Temperature (°C)	10	11	12	4.4	18
Dissolved oxygen	9	6.9	5.0	2.4	17
Carbon dioxide	12	30	17	1.4	195
Hardness, as $CaCO_3$	13	727	360	130	2,100
Noncarbonate hardness	0	--	--	--	--
Alkalinity	12	199	199	78	282
Sundance aquifer					
Specific conductance (µS/cm)	12	1,857	2,045	700	3,160
pH (standard units)	14	7.0	7.2	6.5	8.1
Temperature (°C)	12	14	13	9.0	20
Dissolved oxygen	4	2.9	1.1	0	9.5
Carbon dioxide	14	43	29	3.6	153
Hardness, as $CaCO_3$	14	737	740	190	1,800
Noncarbonate hardness	8	424	450	20	773
Alkalinity	12	229	215	150	341
Morrison aquifer					
Specific conductance (µS/cm)	13	1,345	821	432	4,910
pH (standard units)	15	7.2	7.7	6.3	8.0
Temperature (°C)	10	20	17	10	33
Dissolved oxygen	6	7.7	7.8	2.0	12
Carbon dioxide	15	25	6.8	3.3	233
Hardness, as $CaCO_3$	15	576	270	11	2,200
Noncarbonate hardness	5	114	170	0	202
Alkalinity	10	192	189	130	268

Table 3. Summary of physical properties in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per million; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, not analyzed or not determined]

Property or dissolved constituent	Number of samples	Mean	Median	Minimum	Maximum
Pierre aquifer					
Specific conductance (µS/cm)	28	2,082	1,840	300	6,090
pH (standard units)	28	7.3	7.4	6.6	7.9
Temperature (°C)	28	11	11	7.9	18
Dissolved oxygen	28	5.2	4.0	1.3	12
Carbon dioxide	28	32	22	6.9	142
Hardness, as $CaCO_3$	28	772	560	160	2,800
Noncarbonate hardness	0	--	--	--	--
Alkalinity	28	292	291	170	740
Graneros aquifer					
Specific conductance (µS/cm)	10	1,358	1,060	495	2,650
pH (standard units)	10	7.1	7.0	6.7	7.8
Temperature (°C)	10	13	12	9.7	19
Dissolved oxygen	10	4.4	3.6	1.3	8.2
Carbon dioxide	10	43	37	6.7	91
Hardness, as $CaCO_3$	10	642	540	120	1,500
Noncarbonate hardness	0	--	--	--	--
Alkalinity	10	258	261	142	368
Newcastle aquifer					
Specific conductance (µS/cm)	8	679	595	480	1,290
pH (standard units)	8	7.2	7.7	6.5	7.8
Temperature (°C)	5	14	11	10	23
Dissolved oxygen	0	--	--	--	--
Carbon dioxide	8	34	9.1	5.0	185
Hardness, as $CaCO_3$	8	274	265	33	560
Noncarbonate hardness	4	28	6.5	0	98
Alkalinity	5	257	234	180	359
Alluvial aquifers					
Specific conductance (µS/cm)	95	1,128	650	280	6,500
pH (standard units)	112	7.3	7.5	6.3	8.9
Temperature (°C)	49	14	13	7.7	30
Dissolved oxygen	29	6.4	6.0	2.0	12
Carbon dioxide	101	21	13	0.5	158
Hardness, as $CaCO_3$	116	464	280	57	2,000
Noncarbonate hardness	9	367	220	16	760
Alkalinity	75	222	220	23	539

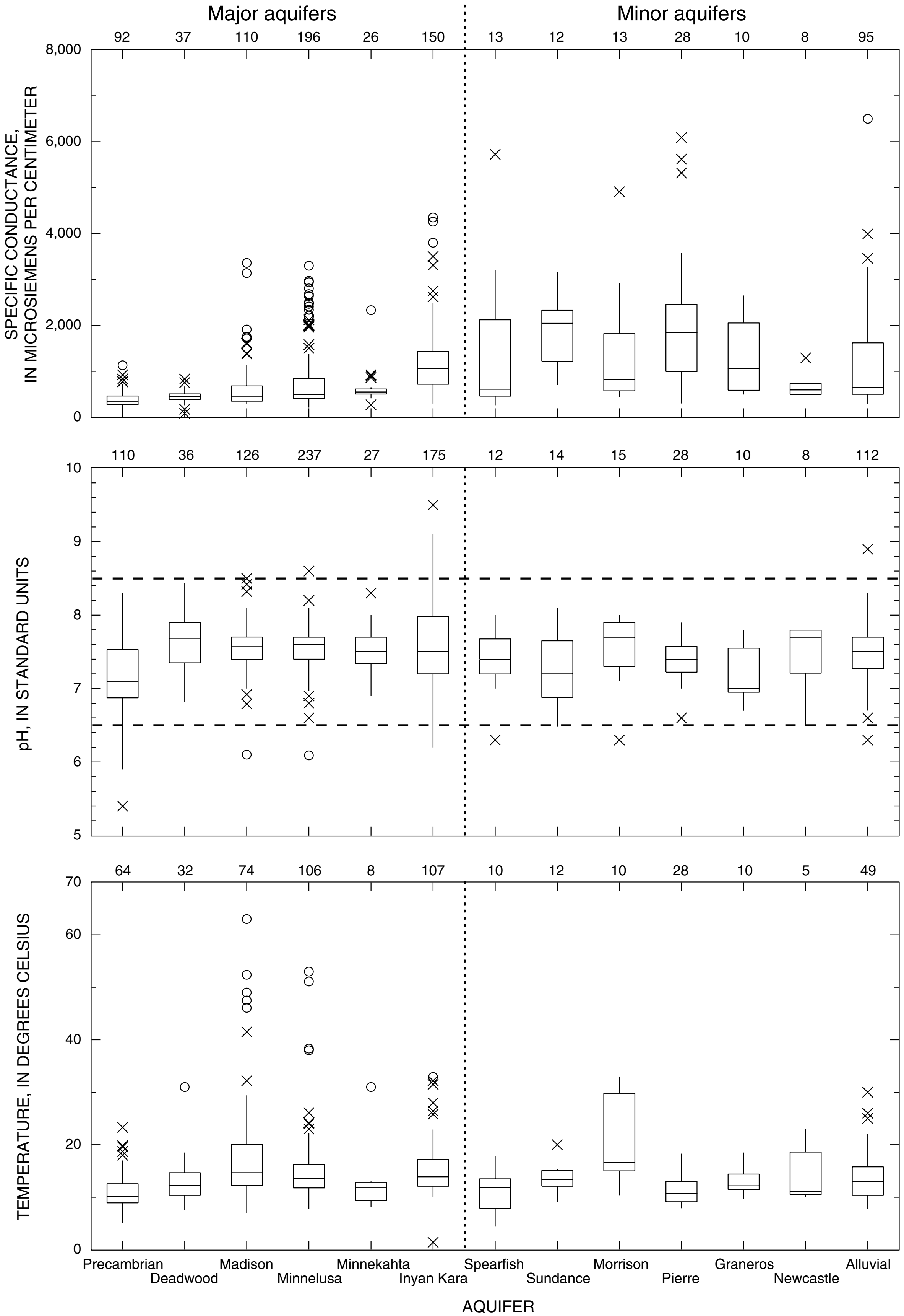


Figure 9. Boxplots of physical properties for selected aquifers.

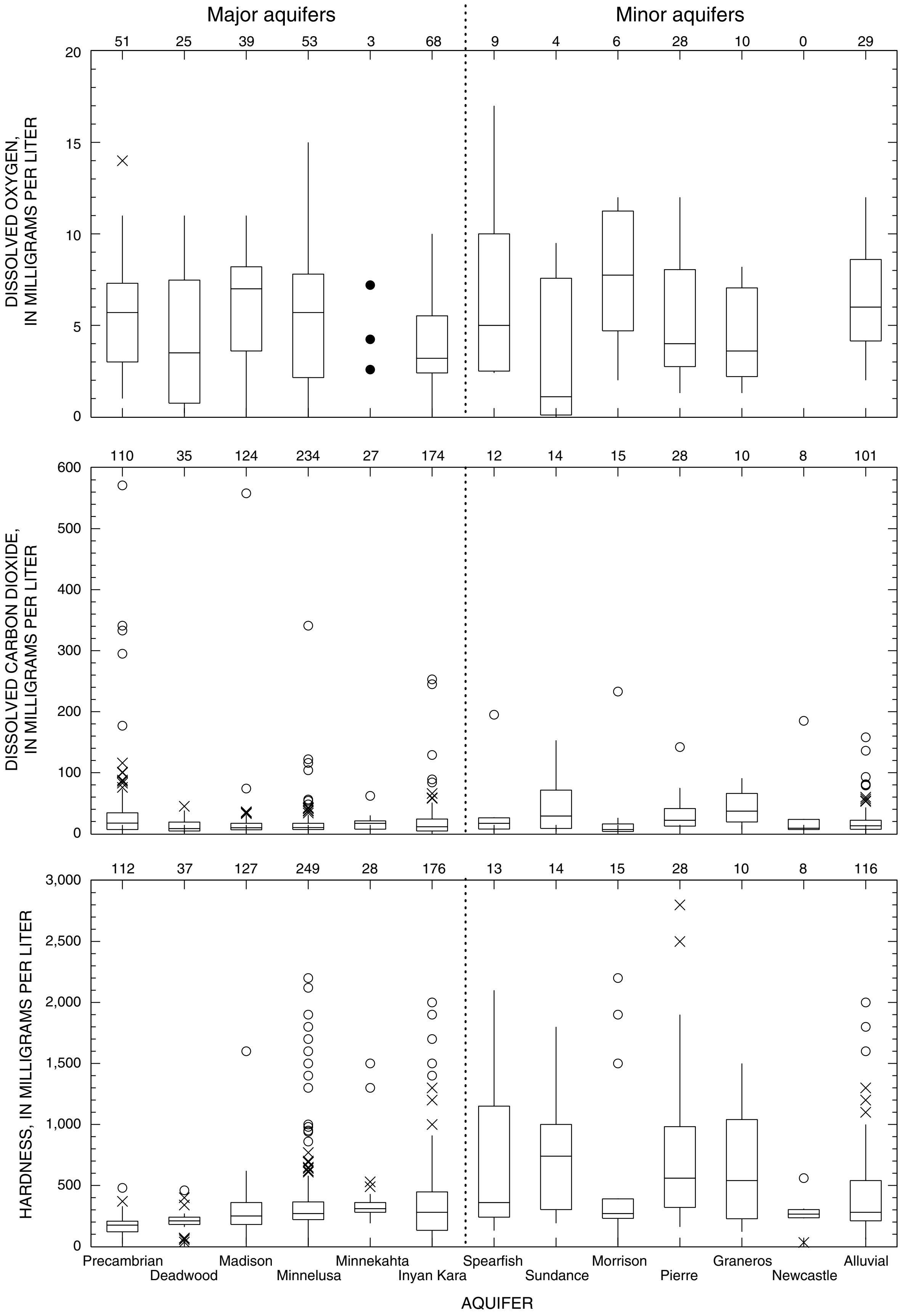


Figure 9. Boxplots of physical properties for selected aquifers.--Continued

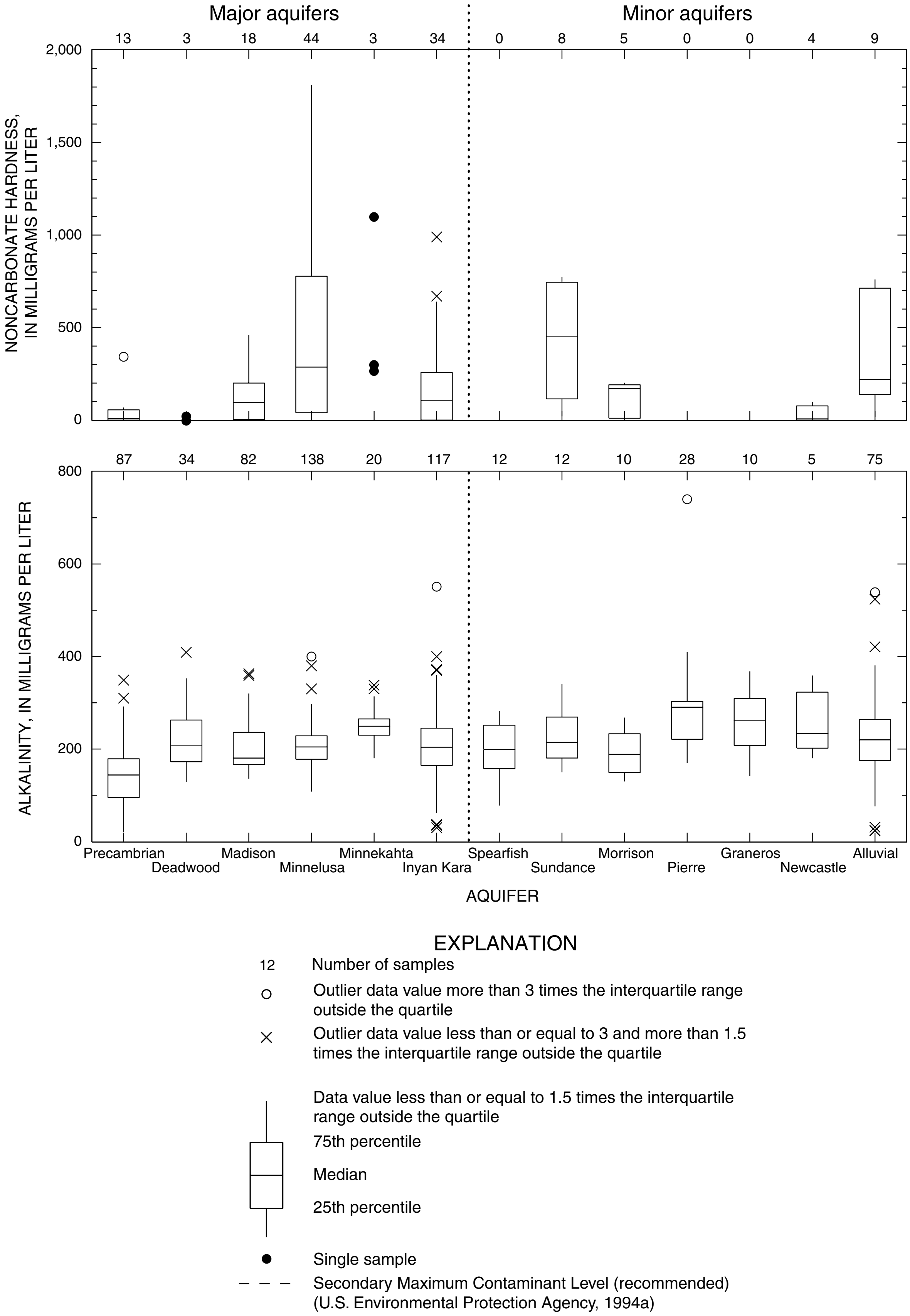
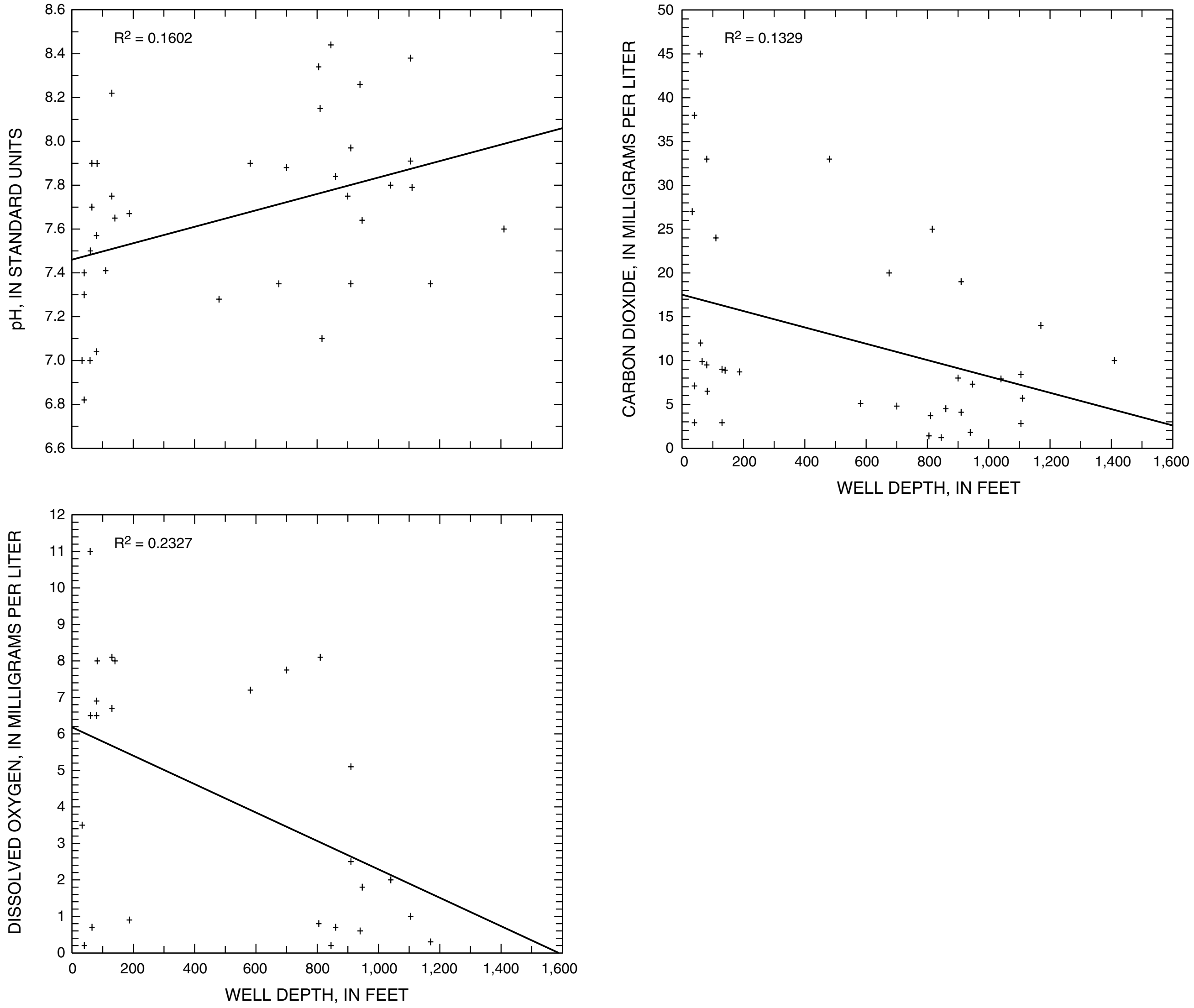


Figure 9. Boxplots of physical properties for selected aquifers.--Continued



DEADWOOD AQUIFER

Figure 10. Selected relations between physical properties and well depth for selected aquifers.

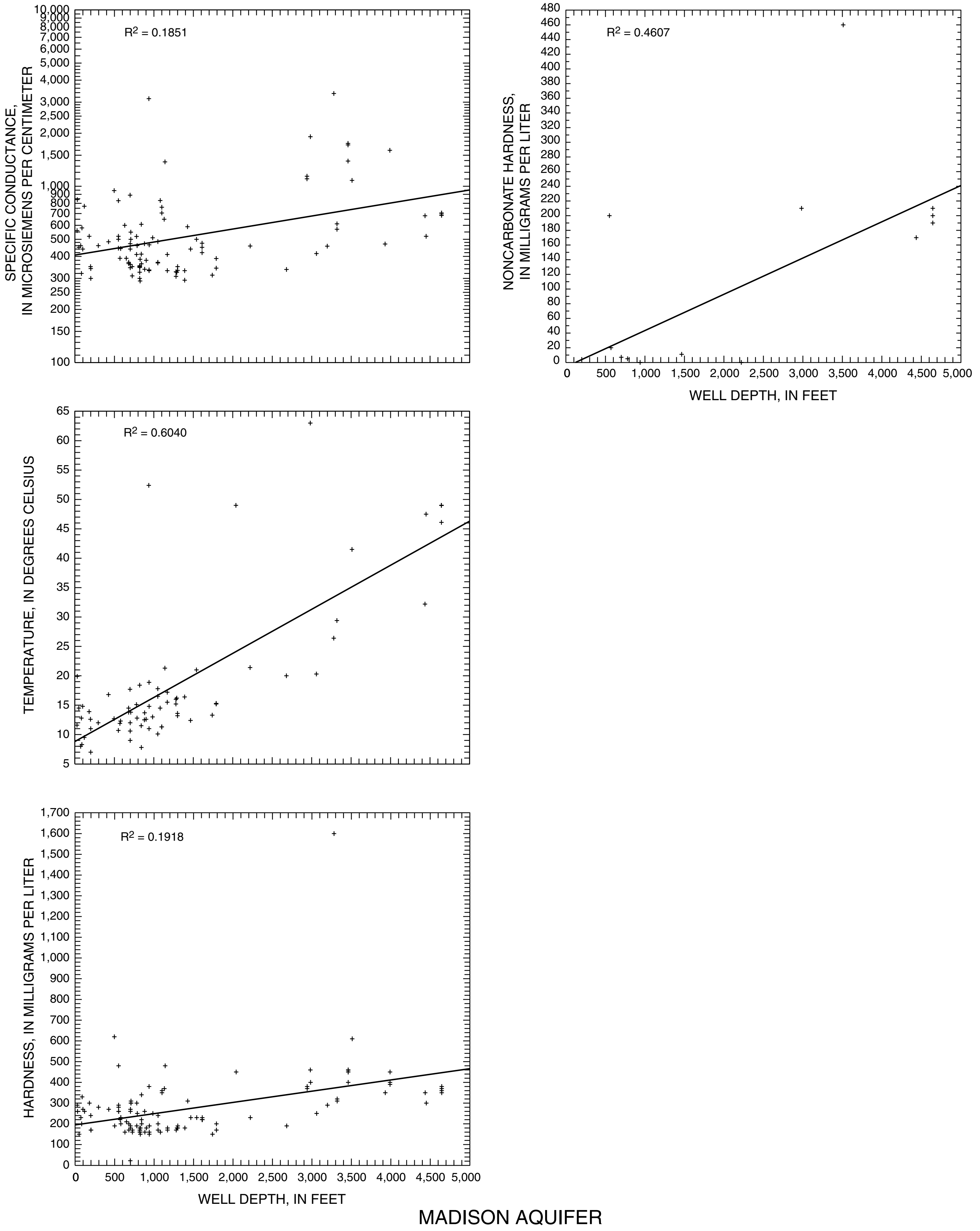
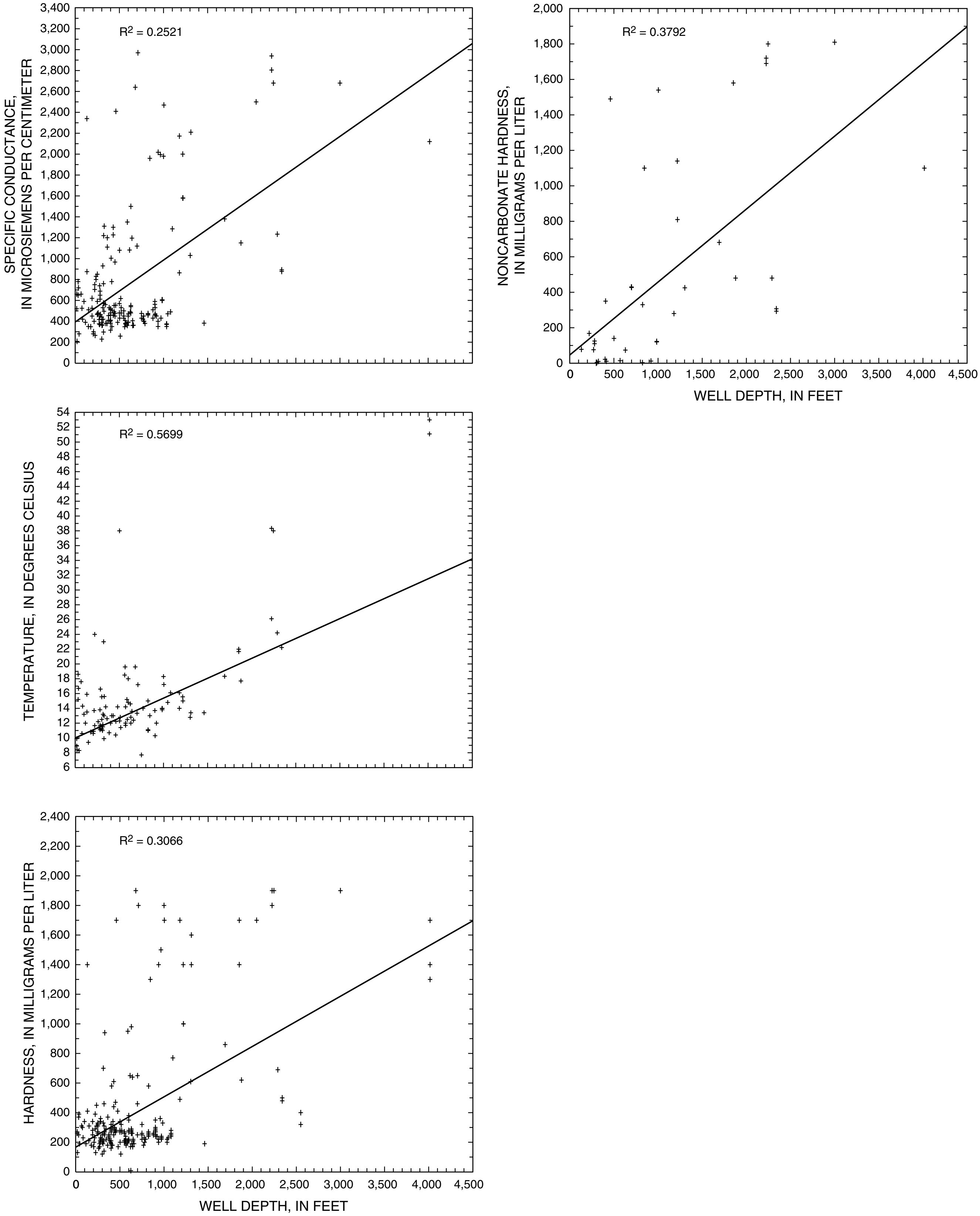
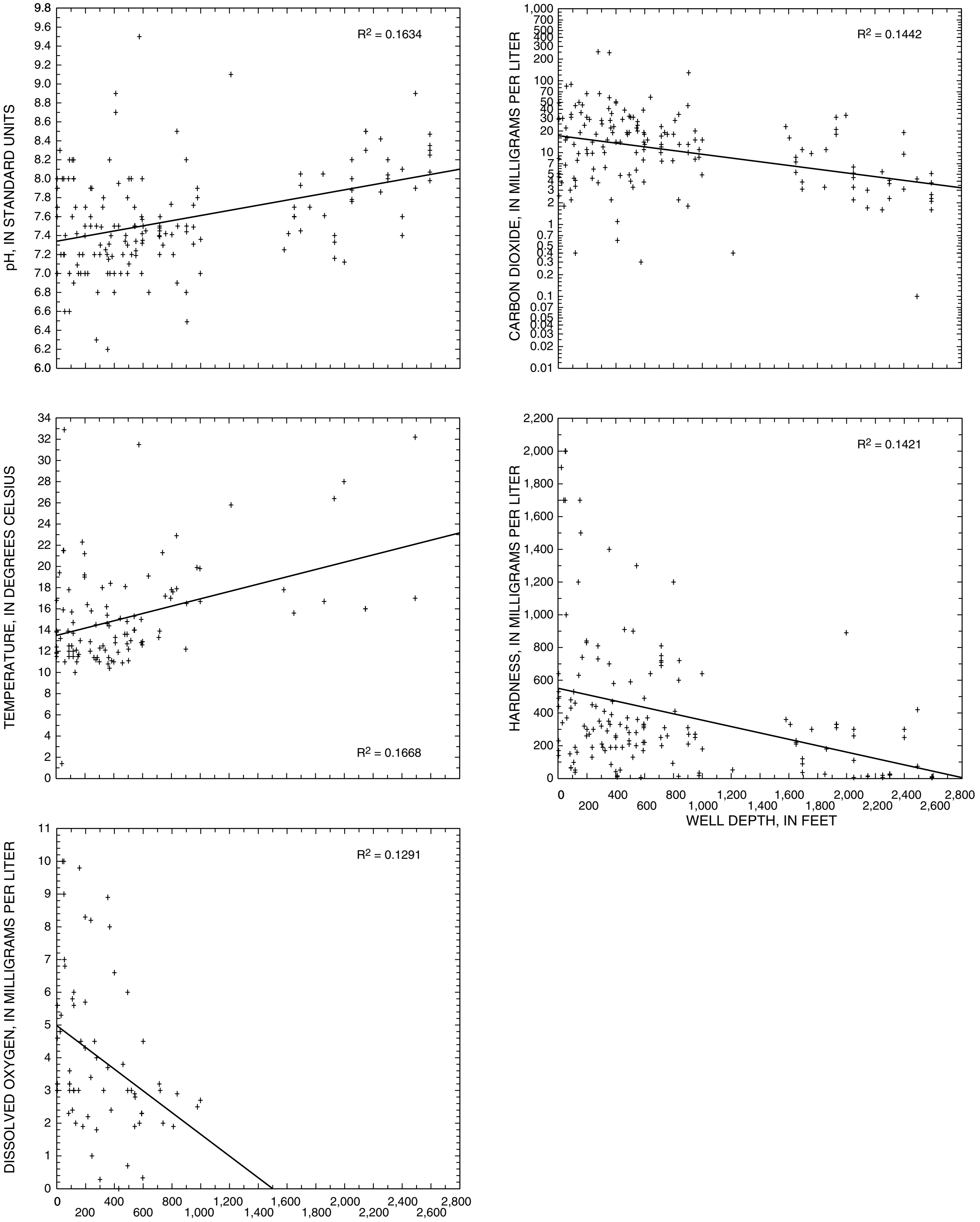


Figure 10. Selected relations between physical properties and well depth for selected aquifers.--Continued



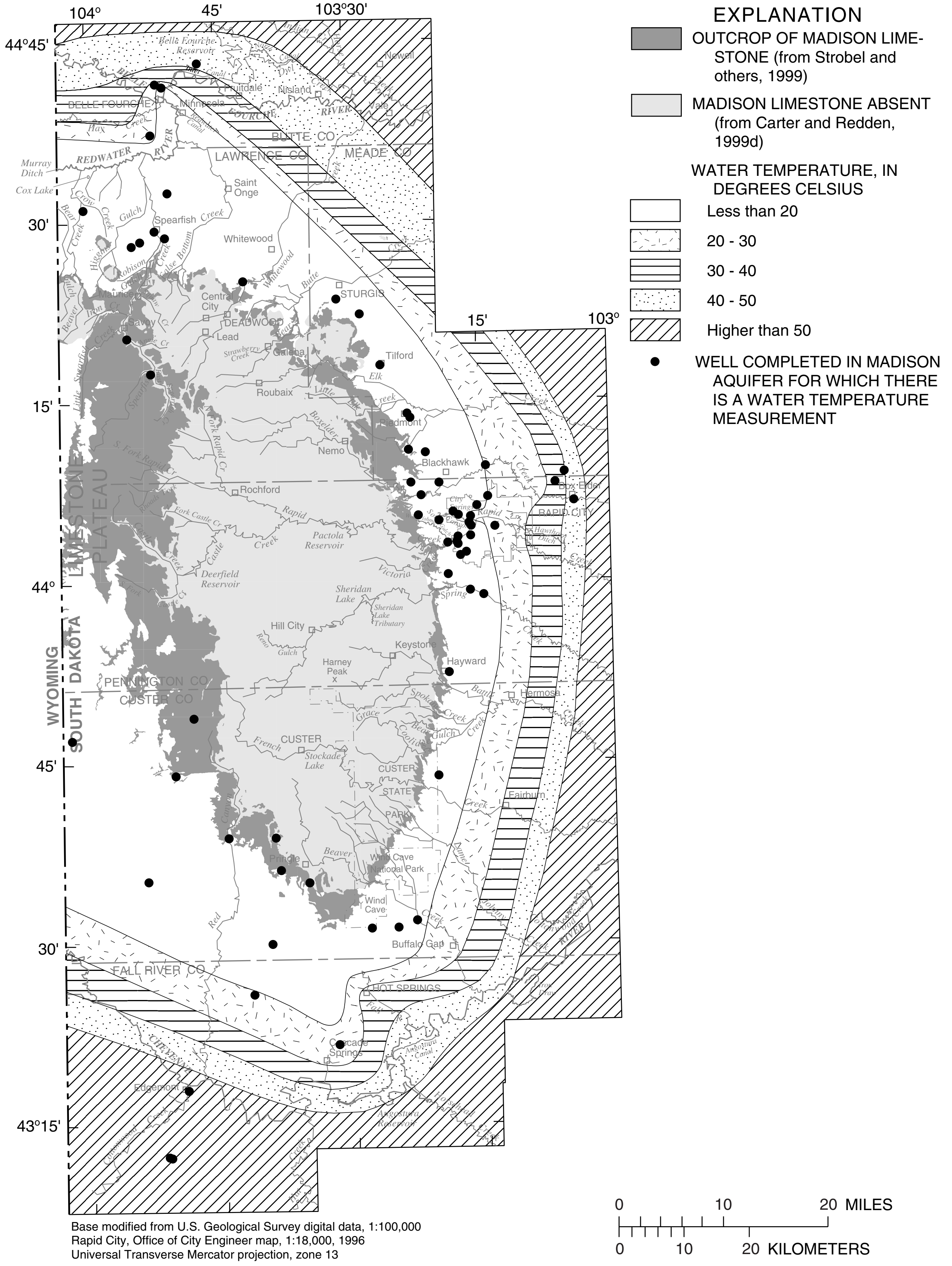
MINNELUSA AQUIFER

Figure 10. Selected relations between physical properties and well depth for selected aquifers.--Continued



INYAN KARA AQUIFER

Figure 10. Selected relations between physical properties and well depth for selected aquifers.--Continued



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 11. Distribution of water temperature in the Madison aquifer.

Most pH values for the aquifers are within the range specified by the SMCL (6.5 to 8.5 standard units). In the Precambrian aquifers, 14 of 110 samples are below the lower limit specified by the SMCL, which indicates acidity. The lowest mean and median pH values are from samples from the Precambrian aquifers, which is indicative of a formation with few carbonate rocks. Samples from the Inyan Kara aquifer have the greatest variability in pH (fig. 9). The pH increases with increasing depth for both the Deadwood and Inyan Kara aquifers. In addition to samples from the Precambrian aquifers, a few samples from other aquifers also are outside the SMCL range for pH: 2 of 126 samples from the Madison aquifer, 3 of 237 samples from the Minnelusa aquifer, 11 of 175 samples from the Inyan Kara aquifer, 1 of 12 samples from the Spearfish aquifer, 1 of 15 samples from the Morrison aquifer, and 2 of 112 samples from alluvial aquifers.

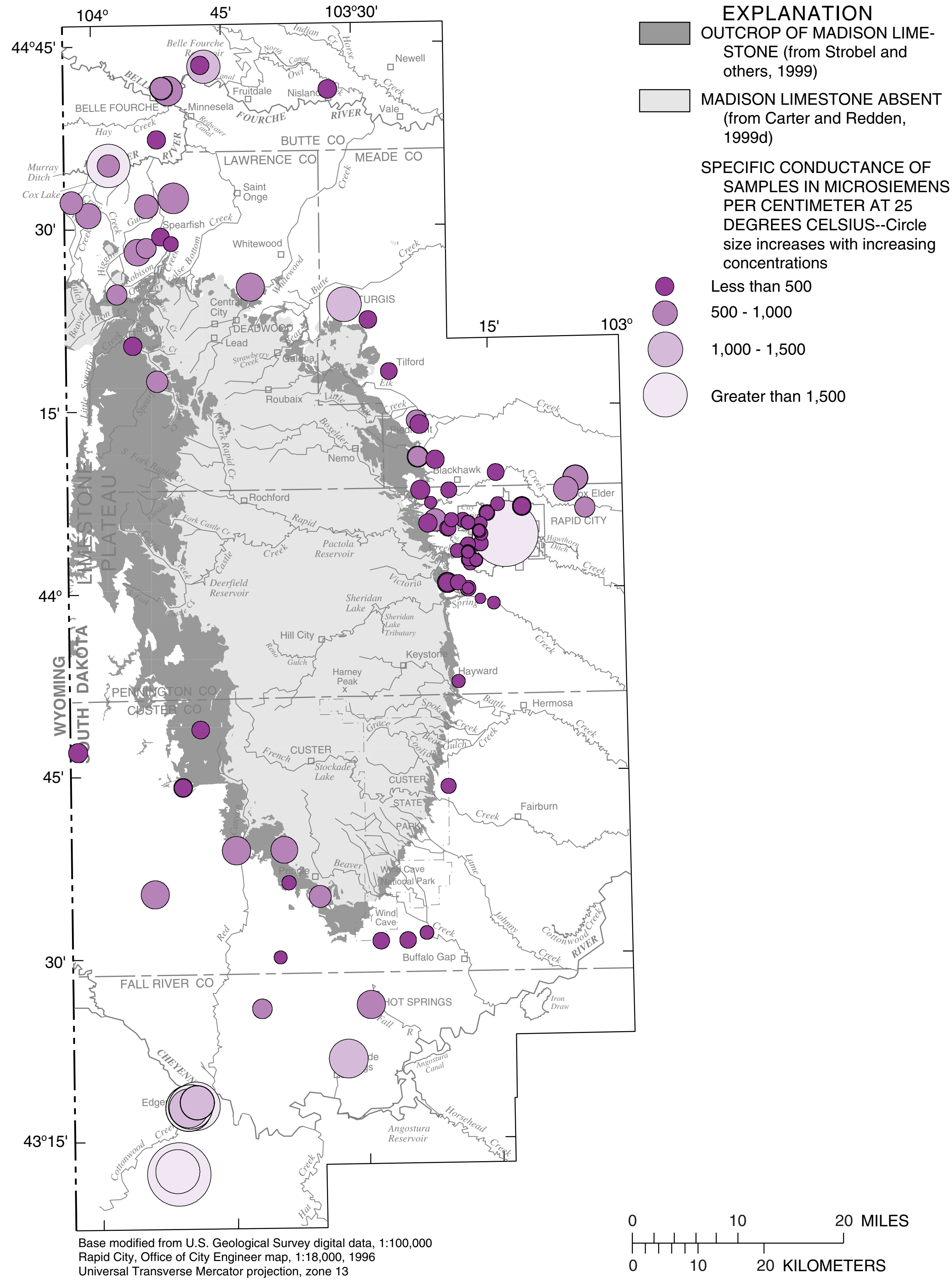
Specific conductance is related to dissolved solids concentrations as discussed in the following section. Specific conductance generally is low for the Precambrian, Deadwood, and Minnekahta aquifers. Dissolved constituents tend to increase with residence time as indicated by the increase in specific conductance with well depth in the Madison and Minnelusa aquifers (fig. 10). Ranges in specific conductance in the Madison and Minnelusa aquifers are similar, and the highest values generally are from wells located at distance from the outcrops as shown in figures 12 and 13, respectively. Samples from the Inyan Kara aquifer have the highest mean and median specific conductance of the major aquifers. The distribution of specific conductance in the Inyan Kara aquifer is shown in figure 14. Generally, water from the Inyan Kara aquifer and from the minor aquifers (with the exception of the Newcastle aquifer) is higher in specific conductance than the other major aquifers due to larger amounts of shale within the formations. Water obtained from shales may contain rather high concentrations of dissolved solids (Hem, 1985) and, hence, high specific conductance. Generally, the specific conductance of alluvial aquifers increases with increasing distance from the core of the Black Hills as streams flow across formations with increasing amounts of shale.

Hardness contributed by calcium, magnesium, and bicarbonate and carbonate species is called carbonate hardness. Additional hardness in excess of this concentration, such as associated with sulfate, is called noncarbonate hardness. The definitions of varying degrees of hardness are listed in table 1. Like carbonate hardness, alkalinity results from dissolved bicarbonate and carbonate species. Thus, formations that contain few carbonate rocks generally contain water with lower carbonate hardness and alkalinity than formations that are composed primarily of carbonate rocks. Samples from the Precambrian aquifers have the lowest mean and median hardness and alkalinity of the aquifers, which again is indicative of a formation containing few carbonate rocks.

Water from the Deadwood, Madison, Minnelusa, and Minnekahta aquifers generally is hard to very hard and is higher in alkalinity than the Precambrian aquifers. The source of carbonate hardness and alkalinity in these aquifers is the dissolution of limestone and dolomite. The dissolution of anhydrite in the Minnelusa Formation, and possibly in the Madison Limestone, contributes calcium sulfate and increases the noncarbonate hardness in these aquifers (Kyllonen and Peter, 1987). Samples from the Minnelusa aquifer have the highest mean hardness of the major aquifers; the softest water in the Minnelusa aquifer is from wells located on the inside of the sulfate transition zone, which is described in the following section. In the Madison and Minnelusa aquifers, hardness and noncarbonate hardness increase with increasing well depth (fig. 10). Samples from the Minnekahta aquifer have the highest median hardness and the highest mean and median concentrations of noncarbonate hardness and alkalinity of the major aquifers.

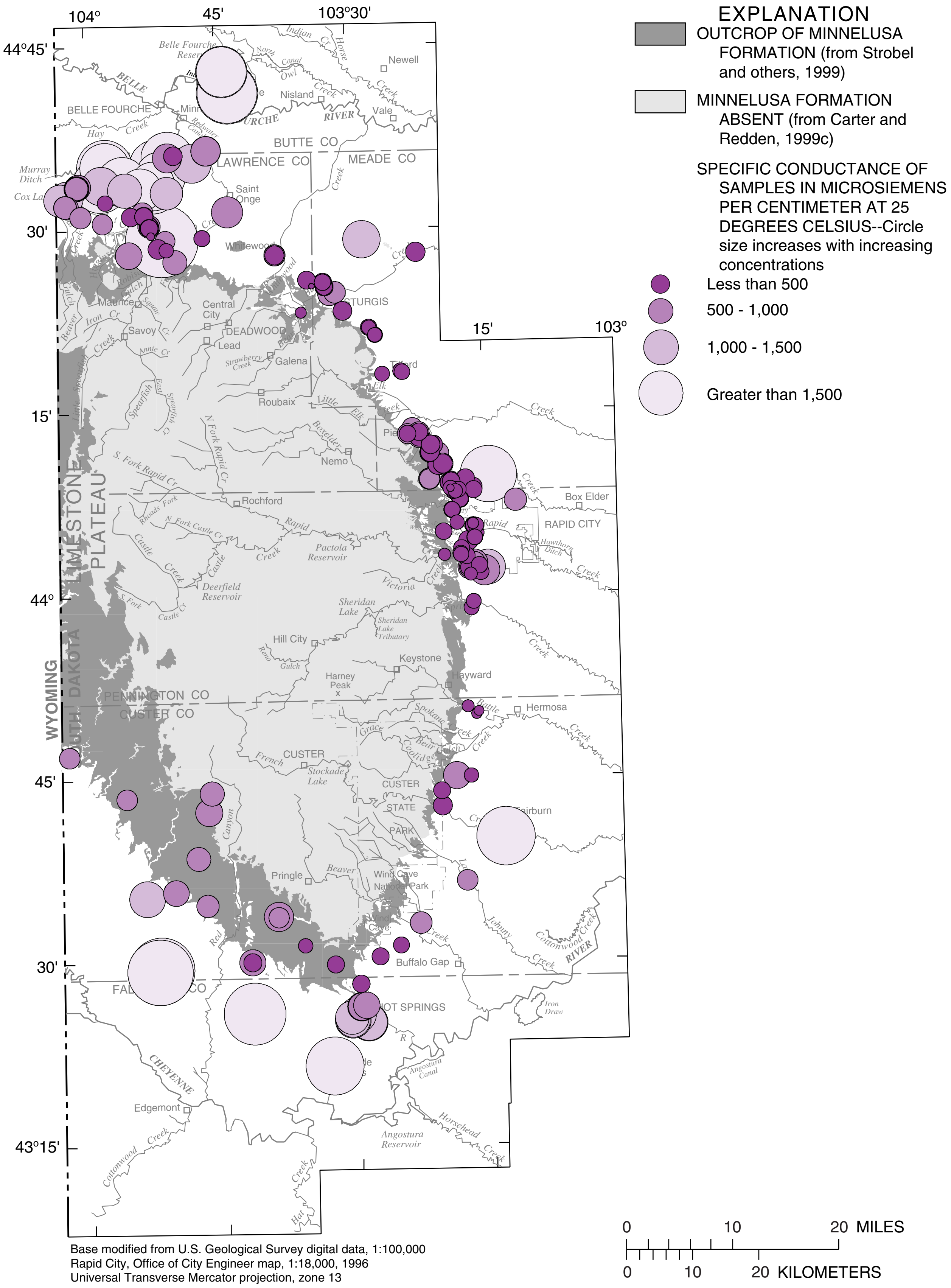
The hardness of water from the Inyan Kara aquifer ranges from soft to very hard. Hardness in the Inyan Kara aquifer decreases with increasing well depth, or distance from the outcrop (figs. 10 and 15). The softening of water downgradient is due to the precipitation of calcium and magnesium as water moves downgradient, which is described in the following section. Water from the minor aquifers generally is very hard.

Variability in dissolved oxygen and carbon dioxide concentrations generally is similar among the aquifers; however, in the Sundance aquifer, dissolved oxygen concentrations are notably lower and dissolved carbon dioxide concentrations notably higher than the other aquifers (fig. 9). Dissolved oxygen and carbon dioxide concentrations in samples from the Deadwood and Inyan Kara aquifers decrease with increasing well depth. Samples from alluvial aquifers indicate that dissolved oxygen concentrations generally decrease with increasing distance from the core of the Black Hills, which is due to low dissolved oxygen concentrations in streams in the exterior plains, as discussed in the surface-water section.



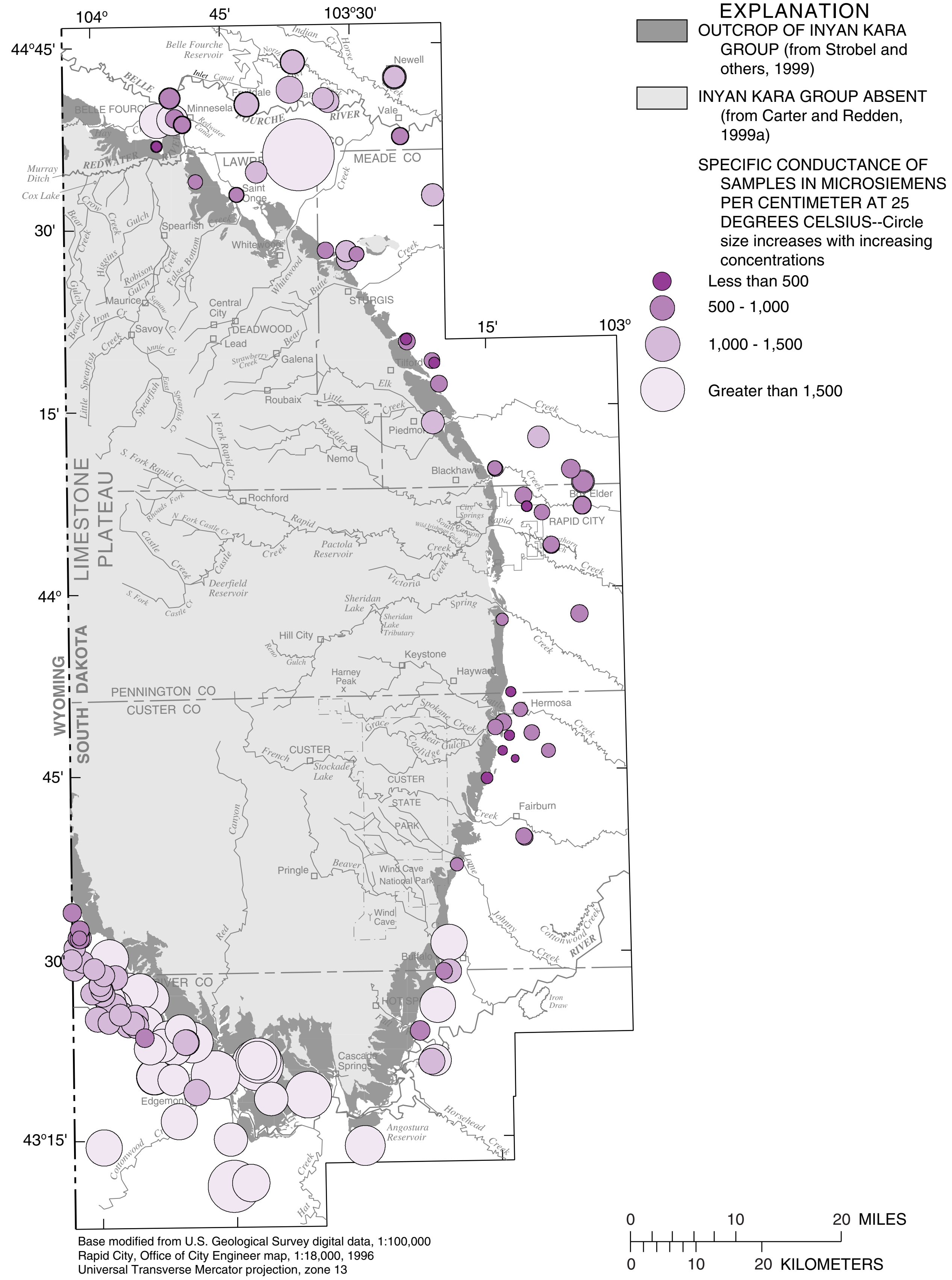
Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 12. Distribution of specific conductance in the Madison aquifer.



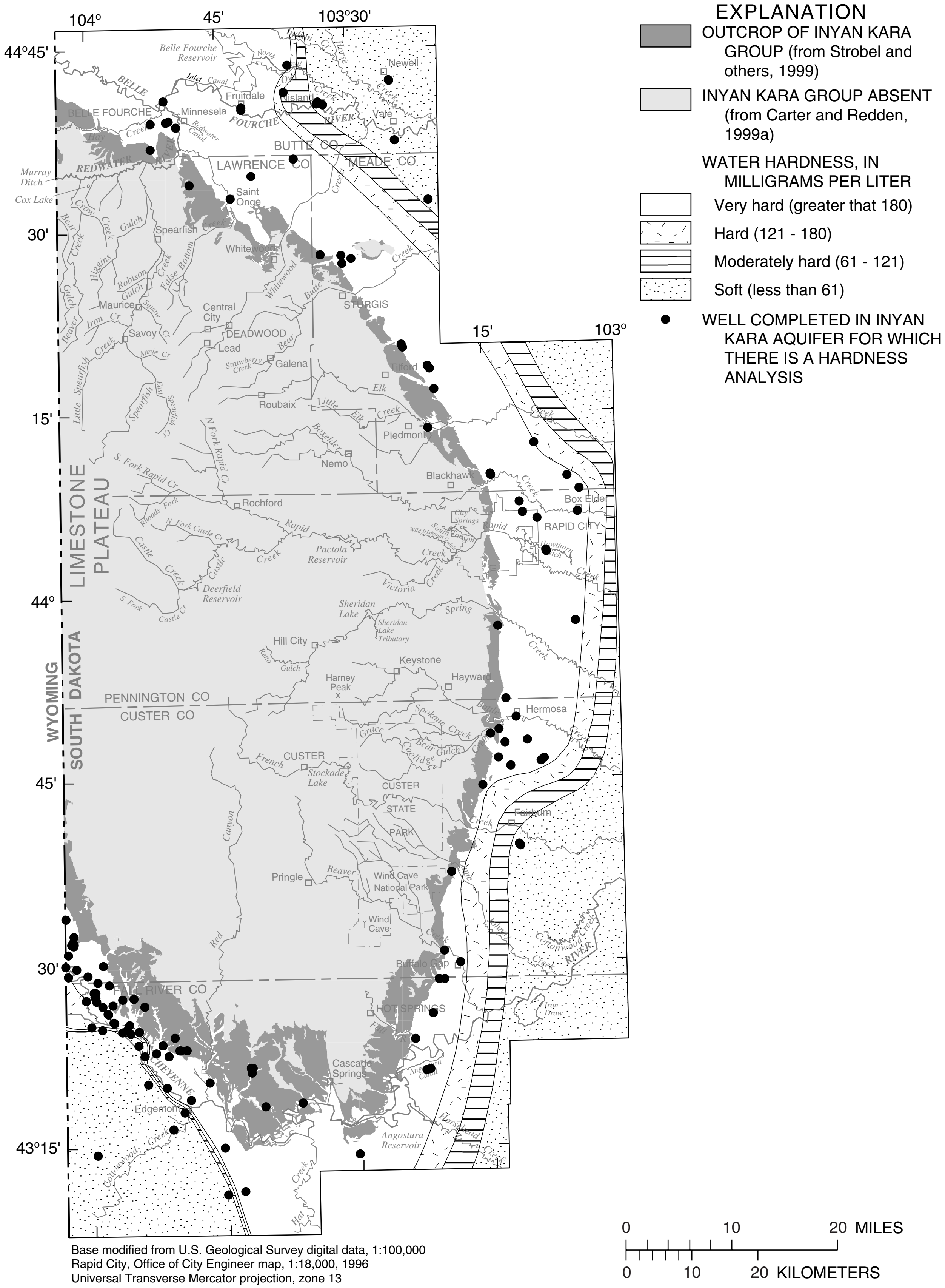
Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 13. Distribution of specific conductance in the Minnelusa aquifer.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 14. Distribution of specific conductance in the Inyan Kara aquifer.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 15. Distribution of hardness in the Inyan Kara aquifer.

Common Ions

Summary statistics for selected common ions, including dissolved solids, calcium, magnesium, sodium, percent sodium, sodium-adsorption ratio (SAR), potassium, bicarbonate, carbonate, sulfate, chloride, fluoride, bromide, iodide, and silica, are presented in table 4. The significance of the various common ions is described in table 1. Boxplots are presented in figure 16 for each of the common ions, except for carbonate. The water type for the various aquifers also is discussed in this section. Trilinear diagrams (fig. 17) are presented for each of the aquifers. Changes in water type as ground water flows downgradient are discussed for the Madison, Minnelusa, and Inyan Kara aquifers.

Specific conductance can be used to estimate the concentration of dissolved solids using the equations presented in table 5. Linear regression was performed using specific conductance and concentrations of dissolved solids (sum of constituents or residue) for each aquifer having sufficient measurements of both to indicate the strength of the relation between specific conductance and dissolved solids concentration.

The general suitability of water for irrigation from the aquifers in the study area can be determined by using the South Dakota irrigation-water diagram (fig. 18). The diagram is based on South Dakota irrigation-water standards (revised January 7, 1982) and shows the State's water-quality and soil-texture requirements for the issuance of an irrigation permit. For each aquifer, the adjusted SAR, which is used to classify South Dakota irrigation waters, was calculated according to Koch (1983) from the mean concentrations of calcium, magnesium, sodium, and bicarbonate (or alkalinity from table 3) presented in table 4 for each aquifer. Based on mean concentrations, water from all aquifers, with the exceptions of the Pierre and Sundance aquifers, generally is suitable for irrigation, but may not be in specific instances if either the specific conductance or the SAR is high.

A strong relation exists between specific conductance and dissolved sulfate concentrations for samples from the Madison, Minnelusa, and Inyan Kara aquifers (fig. 19). Linear regression was performed using specific conductance and sulfate concentrations for each of these aquifers. Sulfate concentrations for these aquifers can be estimated using the equations presented in figure 19.

Precambrian Aquifers

Generally, water from the Precambrian aquifers is fresh (less than 1,000 mg/L dissolved solids concentration). Calcium and bicarbonate generally are dominant among the common ions. Water from the Precambrian aquifers has the highest median chloride concentration, lowest mean and median concentrations of calcium, magnesium, and bicarbonate, and the lowest median sulfate (equal to the Deadwood aquifer) of the major aquifers.

The water type of the Precambrian aquifers generally is a calcium bicarbonate or a calcium magnesium bicarbonate type but also can be a mixed type (fig. 17). The original rock mineralogy, degree of metamorphism, and degree of weathering all can contribute to the variations in water type.

Two of 56 samples from Precambrian aquifers exceed the SMCL of 500 mg/L for dissolved solids. Two of 112 samples exceed the SMCL of 250 mg/L for sulfate; both were collected from the same well. Three of 55 samples exceed the SMCL of 2.0 mg/L for fluoride; all three samples were collected from the same well. None of the samples exceeded the MCL of 4.0 mg/L for fluoride.

Deadwood Aquifer

Water from the Deadwood aquifer generally is fresh. Generally, calcium and bicarbonate are dominant among the common ions. Of samples collected from the major aquifers, the Deadwood aquifer has the lowest mean and median sulfate concentration (equal to the Precambrian aquifers). Variability in sulfate concentrations in the Deadwood aquifer is low.

The Deadwood aquifer generally has a calcium magnesium bicarbonate water type (fig. 17) in wells located on or near the outcrop. This water type results from the dissolution of calcite and dolomite. The downgradient water type is not known because no samples were collected from wells located more than 5 miles from the outcrop of the Deadwood Formation. Samples collected from three wells located about 3 miles from the outcrop have either a sodium bicarbonate or calcium sodium bicarbonate water type. Sodium may become the dominant cation in the Deadwood aquifer as the water flows downgradient.

Relations between various common ions and well depth are shown in figure 20. Fluoride and sodium concentrations, percent sodium, and SAR generally increase with increasing well depth. Two of 33 samples equal or exceed the MCL for fluoride; both of these samples were collected from a well with a depth of 1,105 feet.

Table 4. Summary of concentrations of common ions in ground water

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Precambrian aquifers						
Solids, residue at 180°C	58	0	293	249	60	1,970
Solids, sum of constituents	56	0	230	221	54	642
Calcium	112	0	44	44	6.0	108
Magnesium	112	0	15	14	1.7	52
Sodium	108	0	10	8.1	1.5	70
Sodium, percent	57	0	13	10	6.0	41
Sodium-adsorption ratio	108	0	0.3	0.3	0	2.0
Potassium	58	0	4.0	3.8	1.0	16
Bicarbonate	22	0	165	168	21	268
Carbonate	0	0	--	--	--	--
Sulfate	112	9	35	21	<5.0	345
Chloride	109	41	11	5.6	0.5	161
Fluoride	55	3	0.5	0.3	0.1	2.5
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	64	0	10	8.6	3.5	27
Deadwood aquifer						
Solids, residue at 180°C	31	0	254	248	65	528
Solids, sum of constituents	32	0	262	248	48	469
Calcium	37	0	46	50	8.6	70
Magnesium	37	0	23	20	2.5	78
Sodium	37	0	17	5.9	1.2	160
Sodium, percent	32	0	14	7.0	1.0	85
Sodium-adsorption ratio	37	0	0.7	0.2	0	9.0
Potassium	32	0	2.8	2.2	0.1	10
Bicarbonate	3	0	249	260	220	268
Carbonate	2	0	0	0	0	0
Sulfate	37	2	27	21	3.4	88
Chloride	37	4	5.2	2.0	0.5	40
Fluoride	33	1	0.7	0.3	<0.1	5.4
Bromide	1	0	--	--	0.3	0.3
Iodide	0	0	--	--	--	--
Silica	33	0	11	10	3.3	18
Madison aquifer						
Solids, residue at 180°C	80	0	490	260	162	2,300
Solids, sum of constituents	99	0	428	260	161	1,820
Calcium	127	0	70	54	5.6	430
Magnesium	127	0	26	25	2.0	120
Sodium	122	0	39	5.4	0.8	260
Sodium, percent	103	0	14	6.0	1.0	57
Sodium-adsorption ratio	122	0	1.0	0.2	0	18
Potassium	103	0	6.0	2.8	0.7	55
Bicarbonate	41	0	250	222	166	454
Carbonate	24	0	0.3	0	0	6.0

Table 4. Summary of concentrations of common ions in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Madison aquifer—Continued						
Sulfate	127	10	96	23	<1.0	453
Chloride	124	15	55	3.5	0.2	1,000
Fluoride	89	0	0.7	0.4	0.1	18
Bromide	4	0	0.18	0.10	0.1	0.4
Iodide	2	0	0.03	0.03	0.01	0.04
Silica	62	0	11	11	3.4	34
Minnelusa aquifer						
Solids, residue at 180°C	190	0	619	296	128	5,055
Solids, sum of constituents	176	0	512	271	120	2,700
Calcium	250	0	127	68	2.2	695
Magnesium	248	0	32	23	0.6	194
Sodium	245	0	18	3.8	0.05	731
Sodium, percent	196	0	4.4	2.0	0	37
Sodium-adsorption ratio	243	0	0.3	0.1	0	21
Potassium	197	0	3.0	2.0	0.7	19
Bicarbonate	86	0	252	249	149	370
Carbonate	15	0	--	0	0	10
Sulfate	249	15	257	32	<2.0	3,438
Chloride	236	38	12	2.0	<0.1	230
Fluoride	185	8	0.5	0.3	0.01	2.8
Bromide	5	0	0.3	0.1	0.1	0.8
Iodide	3	0	0.01	0.01	0.01	0.01
Silica	104	0	9.8	11	2.2	33
Minnekahta aquifer						
Solids, residue at 180°C	24	0	509	346	228	2,255
Solids, sum of constituents	24	0	410	330	233	1,920
Calcium	28	0	109	80	45	425
Magnesium	28	0	30	26	12	105
Sodium	26	0	7.9	4.0	1.1	100
Sodium, percent	25	0	3.2	2.0	1.0	15
Sodium-adsorption ratio	26	0	0.1	0.1	0	1.0
Potassium	25	0	2.4	1.9	1.1	12
Bicarbonate	21	0	321	316	230	412
Carbonate	2	0	0	0	0	0
Sulfate	28	1	139	32	<1.0	1,385
Chloride	28	2	7.5	3.0	0.5	119
Fluoride	25	4	0.3	0.2	<0.1	1.0
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	7	0	12	12	4.8	24
Inyan Kara aquifer						
Solids, residue at 180°C	111	0	760	682	174	3,170
Solids, sum of constituents	102	0	742	673	170	3,300
Calcium	177	0	95	71	1.6	505

Table 4. Summary of concentrations of common ions in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Inyan Kara aquifer—Continued						
Magnesium	174	1	34	24	<1.0	279
Sodium	171	0	145	127	1.0	1,000
Sodium, percent	103	0	45	37	1.0	99
Sodium-adsorption ratio	169	0	8.9	2.0	0	79
Potassium	105	0	6.4	6.2	0.1	19
Bicarbonate	31	0	254	258	167	438
Carbonate	0	0	--	--	--	--
Sulfate	177	0	462	330	5.0	2,030
Chloride	176	42	11	5.0	0.1	140
Fluoride	105	1	0.6	0.5	0.1	4.0
Bromide	9	0	0.2	0.1	0.1	0.7
Iodide	10	0	0.04	0.01	0.01	0.26
Silica	112	1	6.1	4.6	<0.1	17
Spearfish aquifer						
Solids, residue at 180°C	3	0	294	286	274	322
Solids, sum of constituents	3	0	257	259	247	266
Calcium	13	0	223	116	36	661
Magnesium	13	0	42	23	10	109
Sodium	13	0	63	5.0	2.0	608
Sodium, percent	4	0	3.3	2.0	2.0	7.0
Sodium-adsorption ratio	13	0	0.9	0.2	0.1	8.0
Potassium	4	0	3.9	2.1	1.5	10
Bicarbonate	2	0	224	224	221	227
Carbonate	0	0	--	--	--	--
Sulfate	13	0	635	98	10	2,338
Chloride	13	7	11	4.4	1.5	50
Fluoride	4	0	0.6	0.3	0.2	1.6
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	9	0	5.5	4.8	3.5	9.4
Sundance aquifer						
Solids, residue at 180°C	12	0	1,264	1,440	414	1,930
Solids, sum of constituents	12	0	1,202	1,365	399	1,820
Calcium	14	0	155	150	56	352
Magnesium	14	0	86	89	10	220
Sodium	14	0	144	118	6.7	512
Sodium, percent	12	0	29	24	3.0	84
Sodium-adsorption ratio	14	0	3.3	2.0	0.2	16
Potassium	12	0	8.2	6.9	3.9	14
Bicarbonate	2	0	305	305	283	326
Carbonate	0	0	--	--	--	--
Sulfate	14	0	780	1,000	99	1,724
Chloride	14	0	13	8.2	1.1	65
Fluoride	12	0	2.5	0.5	0.1	25

Table 4. Summary of concentrations of common ions in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Sundance aquifer—Continued						
Bromide	2	0	0.15	0.15	0.1	0.2
Iodide	2	0	0.03	0.03	0.01	0.05
Silica	13	0	10	9.7	2.2	26
Morrison aquifer						
Solids, residue at 180°C	8	0	460	383	256	751
Solids, sum of constituents	7	0	443	340	234	793
Calcium	15	0	146	74	2.5	519
Magnesium	15	0	52	23	1.1	268
Sodium	13	0	77	30	2.7	357
Sodium, percent	8	0	22	15	5.0	81
Sodium-adsorption ratio	13	0	2.8	0.8	0	19
Potassium	8	0	6.4	6.7	2.9	9.0
Bicarbonate	1	0	--	--	208	208
Carbonate	0	0	--	--	--	--
Sulfate	15	0	489	208	46	2,056
Chloride	15	5	7.8	3.0	0.4	56
Fluoride	9	0	0.5	0.5	0.2	0.9
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	11	0	8.9	5.3	3.8	17
Pierre aquifer						
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	0	0	--	--	--	--
Calcium	28	0	164	144	41	365
Magnesium	28	0	88	49	10	508
Sodium	28	0	227	176	8.7	757
Sodium, percent	0	0	--	--	--	--
Sodium-adsorption ratio	28	0	3.6	3.0	0.3	11
Potassium	0	0	--	--	--	--
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	28	0	964	659	15	4,126
Chloride	28	7	52	26	<10	222
Fluoride	0	0	--	--	--	--
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	28	0	6.9	6.3	2.0	13
Graneros aquifer						
Solids, residue at 180°C	0	0	---	--	--	--
Solids, sum of constituents	0	0	--	--	--	--
Calcium	10	0	168	133	25	459
Magnesium	10	0	54	51	12	122
Sodium	10	0	91	66	3.6	289
Sodium, percent	0	0	--	--	--	--

Table 4. Summary of concentrations of common ions in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter (mg/L) is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Graneros aquifer—Continued						
Sodium-adsorption ratio	10	0	1.6	1.5	0	4.0
Potassium	0	0	--	--	--	--
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	10	0	539	286	87	1,598
Chloride	10	7	41	39	<10	57
Fluoride	0	0				
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	10	0	4.7	4.7	3.7	6.4
Newcastle aquifer						
Solids, residue at 180°C	8	0	460	400	279	1,010
Solids, sum of constituents	8	0	415	355	277	862
Calcium	8	0	80	76	10	170
Magnesium	8	0	18	18	1.9	32
Sodium	8	0	35	13	8.0	164
Sodium, percent	8	0	20	11	6.0	90
Sodium-adsorption ratio	8	0	1.9	0.4	0.2	12
Potassium	8	0	8.0	7.1	4.1	17
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	8	0	128	103	23	410
Chloride	8	0	3.4	2.6	1.1	8.7
Fluoride	8	0	0.6	0.6	0.3	1.4
Bromide	0	0	--	--	--	--
Iodide	0	0	--	--	--	--
Silica	5	0	8.4	8.6	6.9	10
Alluvial aquifers						
Solids, residue at 180°C	78	0	559	329	127	2,380
Solids, sum of constituents	81	0	503	323	100	2,280
Calcium	116	0	121	77	13	536
Magnesium	116	0	39	25	3.2	274
Sodium	115	0	62	10	2.0	778
Sodium, percent	85	0	13	6.0	1.0	87
Sodium-adsorption ratio	115	0	1.1	0.3	0	12
Potassium	85	0	5.0	4.0	0.9	42
Bicarbonate	21	0	266	244	158	458
Carbonate	3	0	0	0	0	0
Sulfate	116	0	360	99	2.9	3,000
Chloride	114	15	19	6.1	1.0	194
Fluoride	73	1	0.4	0.3	0.1	1.5
Bromide	3	0	0.09	0.08	0.06	0.13
Iodide	0	0	--	--	--	--
Silica	51	0	7.7	7.1	0.7	25

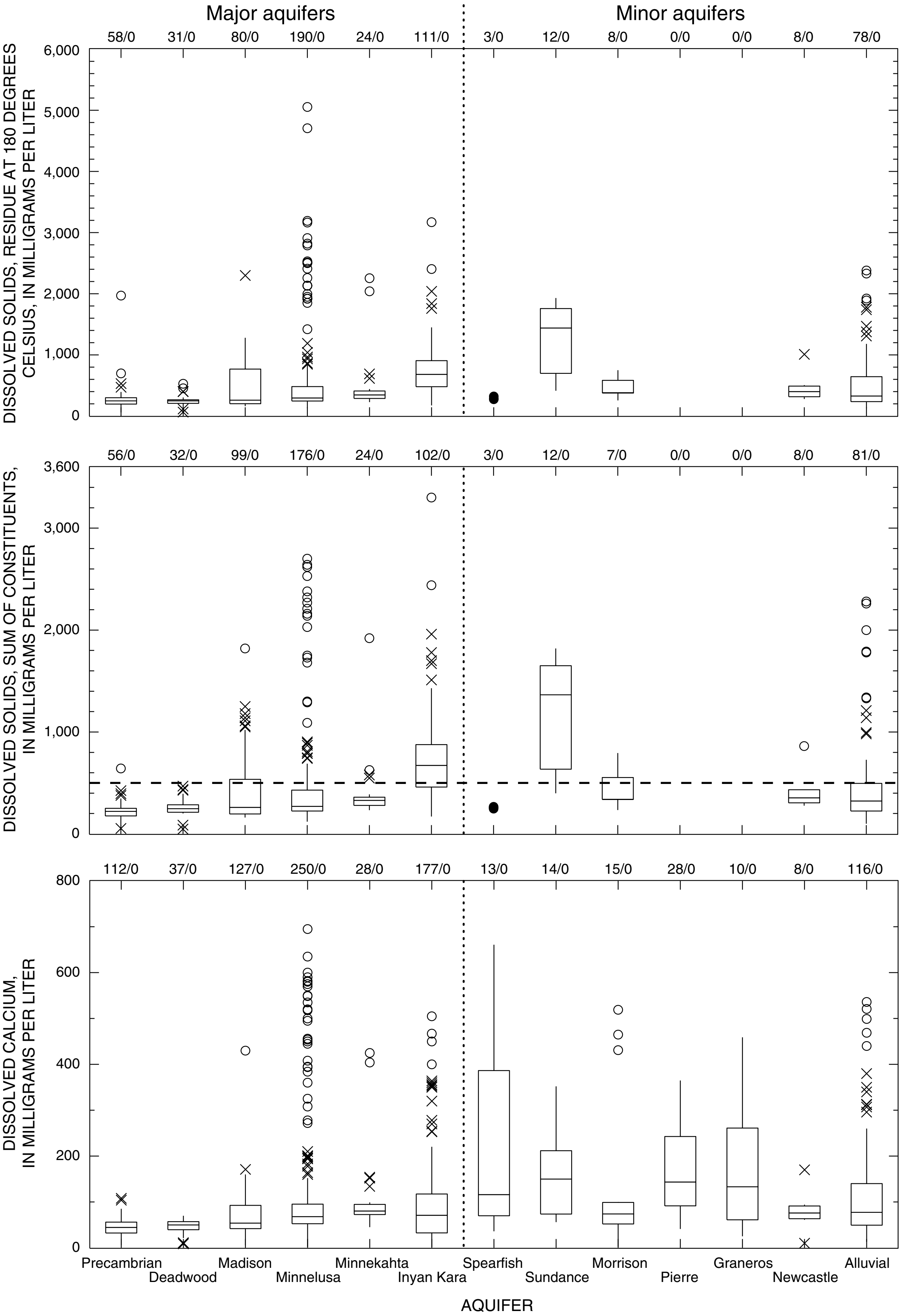


Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.

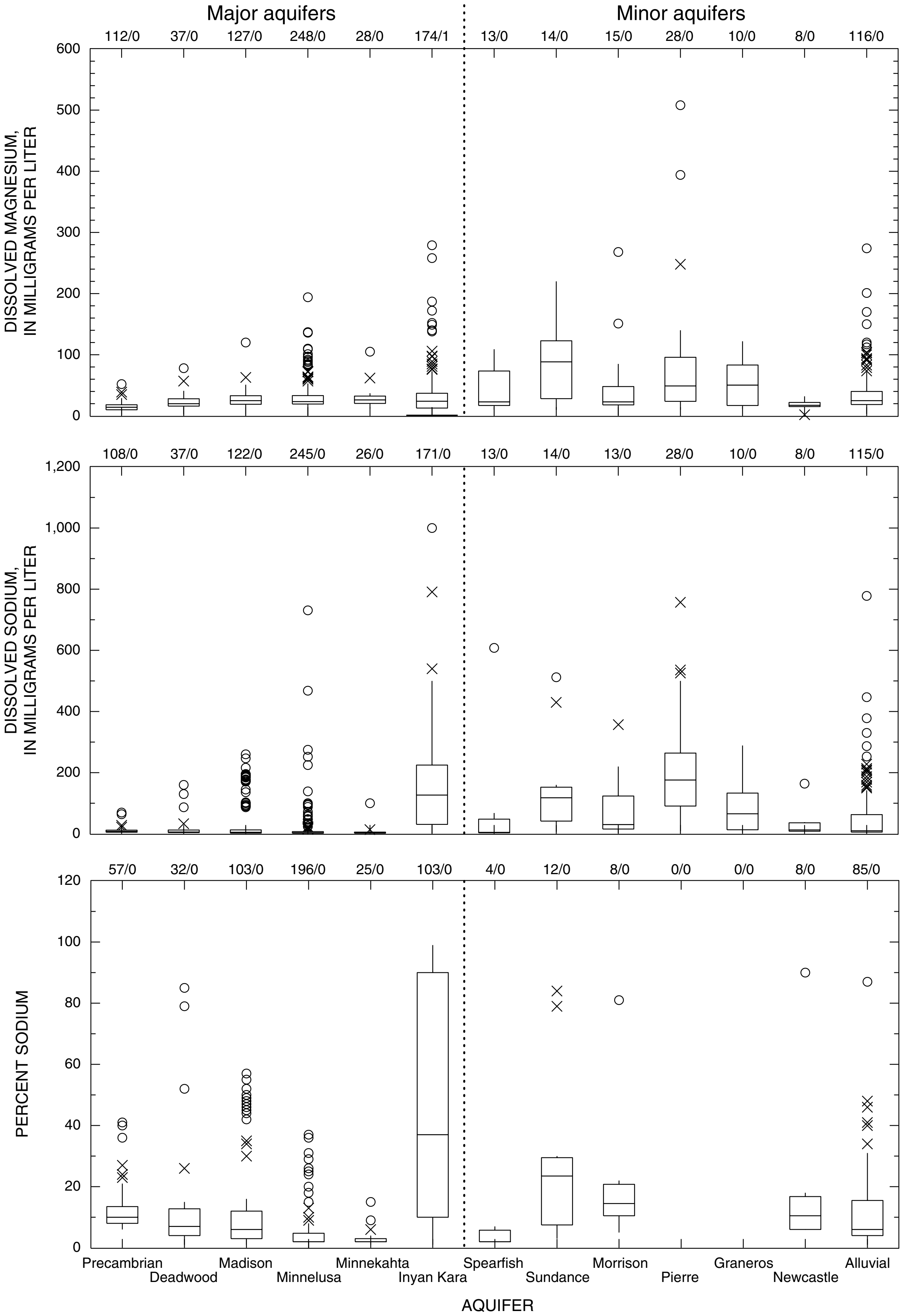


Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.--Continued

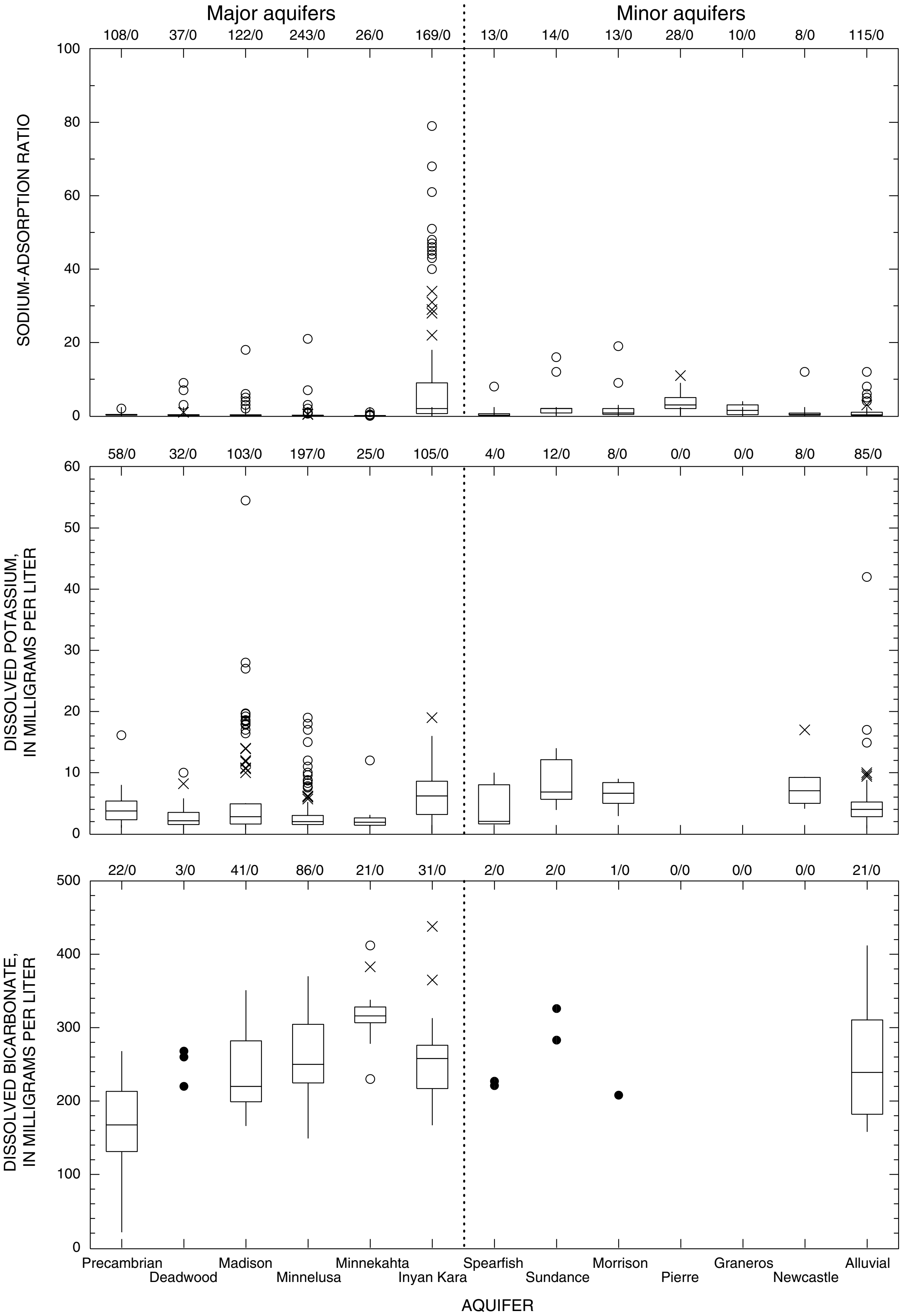


Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.--Continued

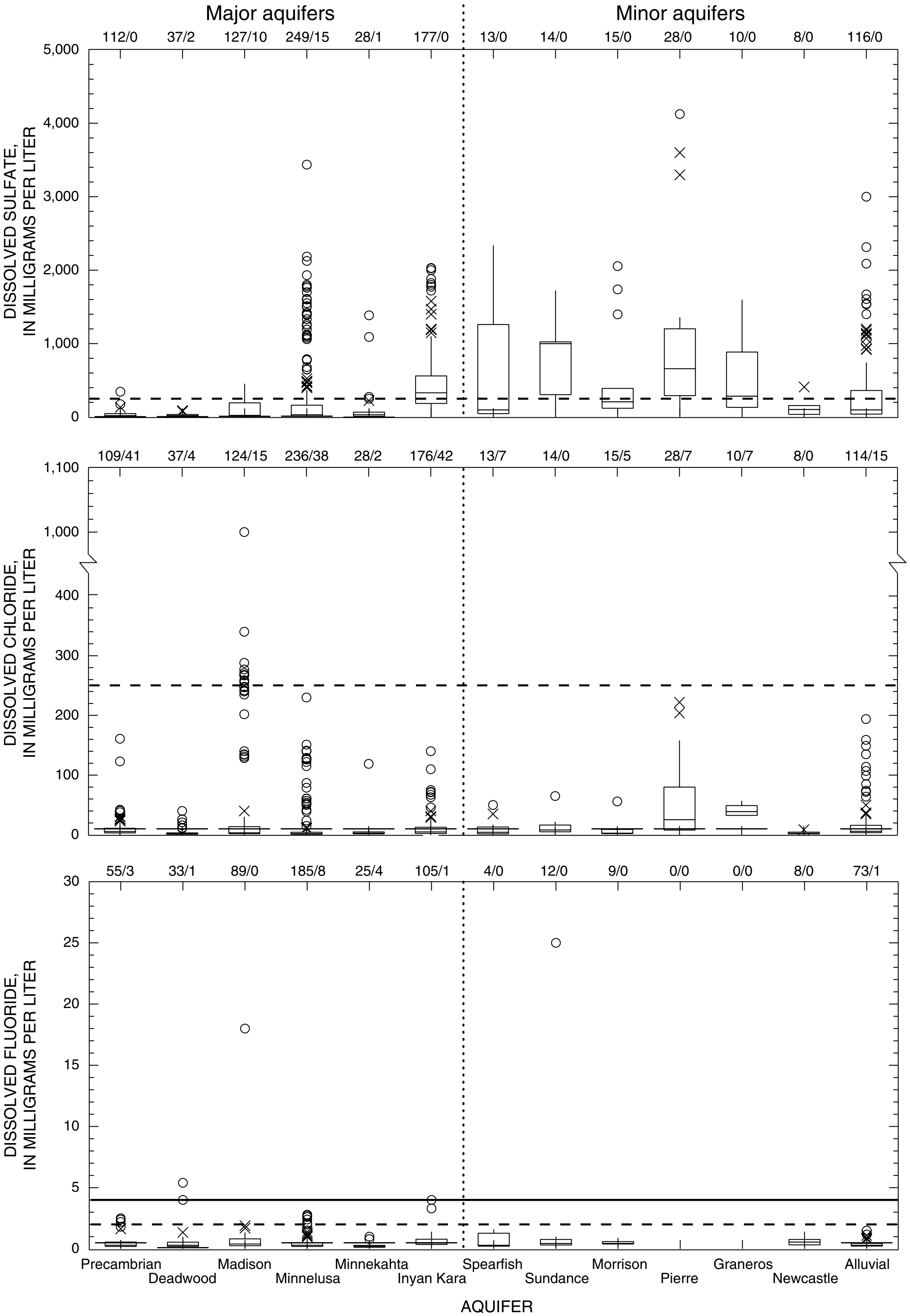


Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.--Continued

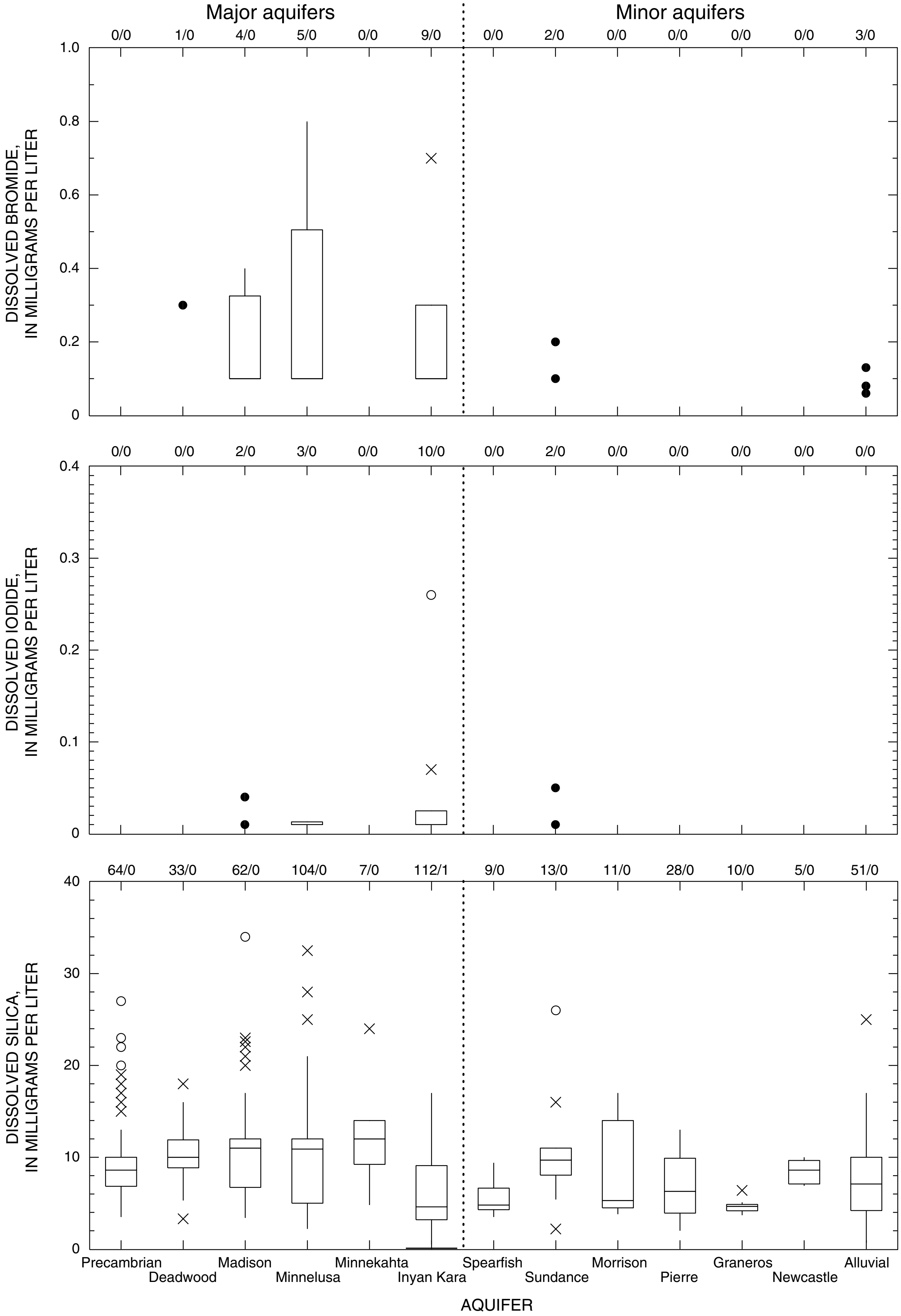


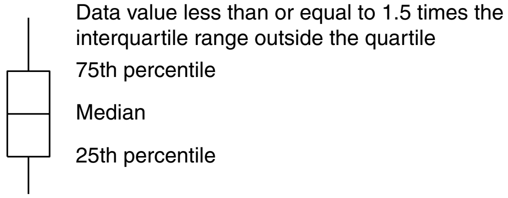
Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.--Continued

EXPLANATION

114/15 Number of samples/Number of samples with concentrations below the laboratory reporting limit

○ Outlier data value more than 3 times the interquartile range outside the quartile

× Outlier data value less than or equal to 3 and more than 1.5 times the interquartile range outside the quartile



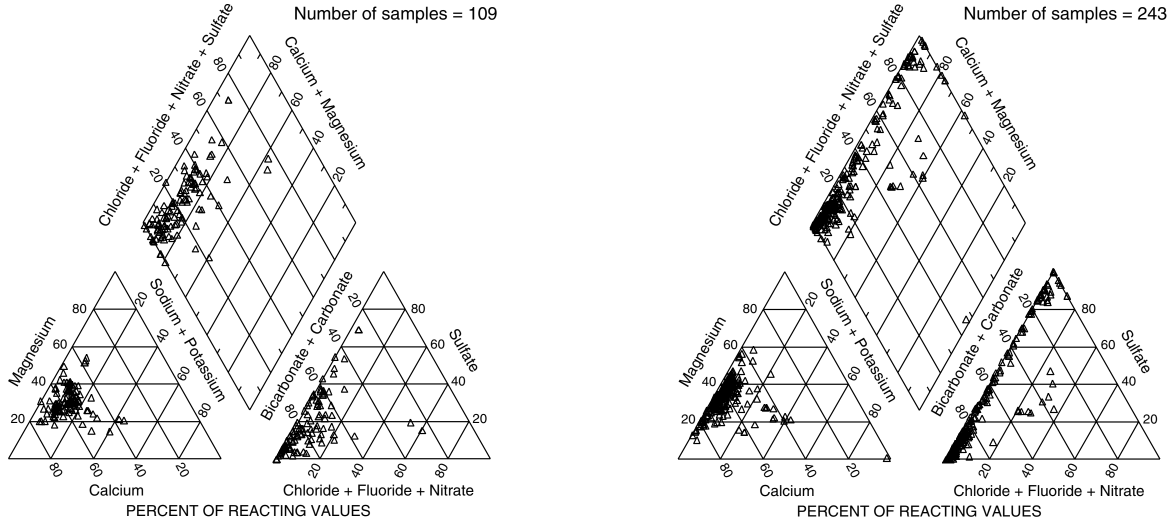
● Single sample

——— Highest detection limit

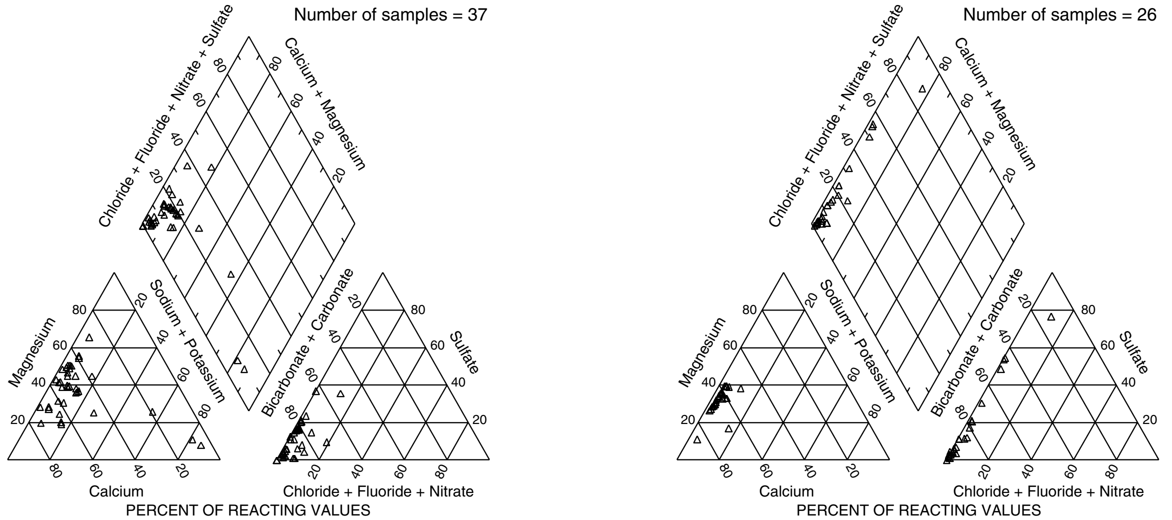
━━━ Maximum Contaminant Level (mandatory (U.S. Environmental Protection Agency, 1994a)

– – – Secondary Maximum Contaminant Level (recommended) (U.S. Environmental Protection Agency, 1994a)

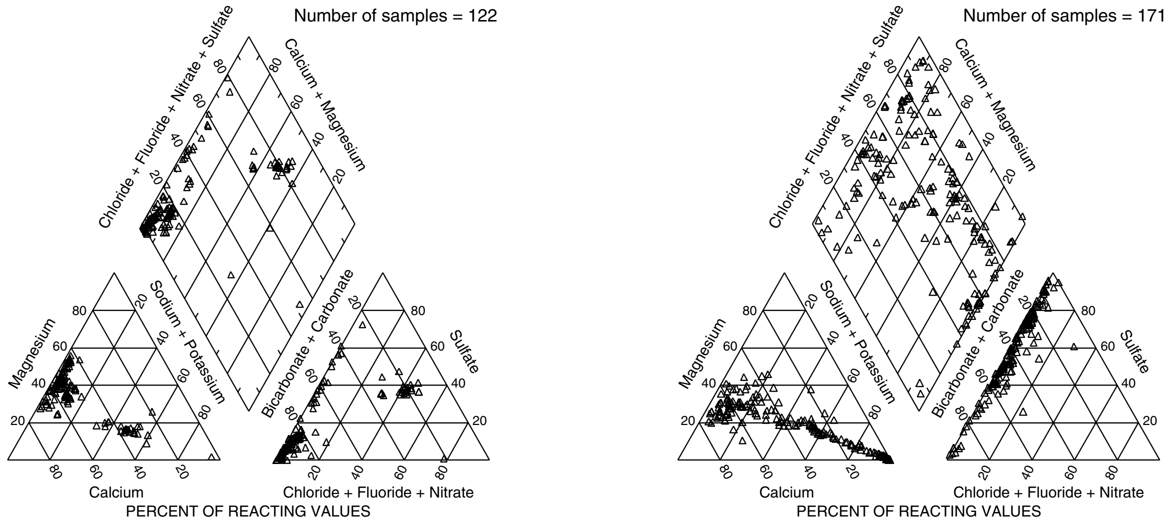
Figure 16. Boxplots of concentrations of selected common ions for selected aquifers.--Continued



PRECAMBRIAN AQUIFERS **MINNELUSA AQUIFER**

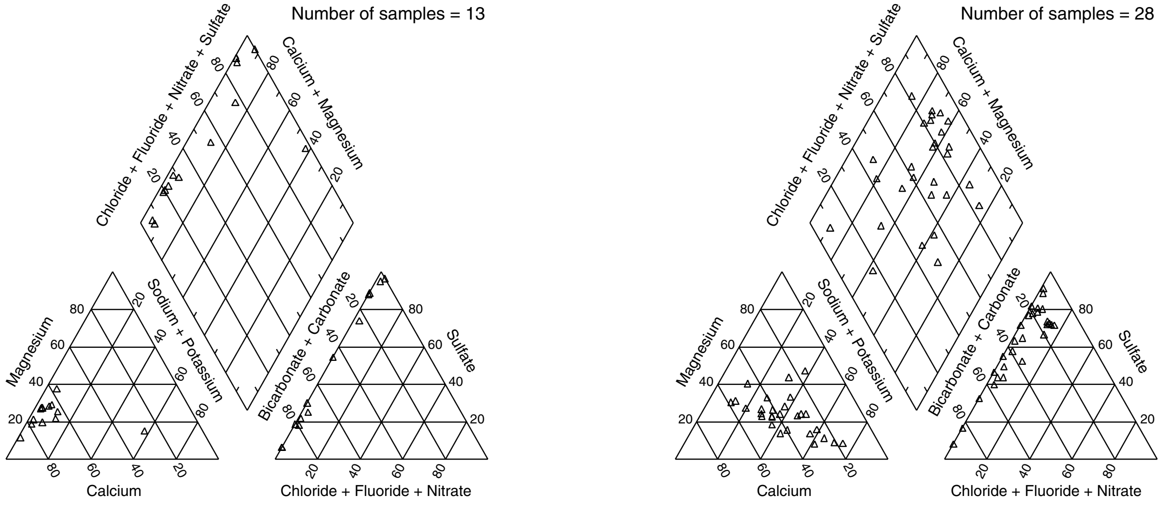


DEADWOOD AQUIFER **MINNEKAHTA AQUIFER**



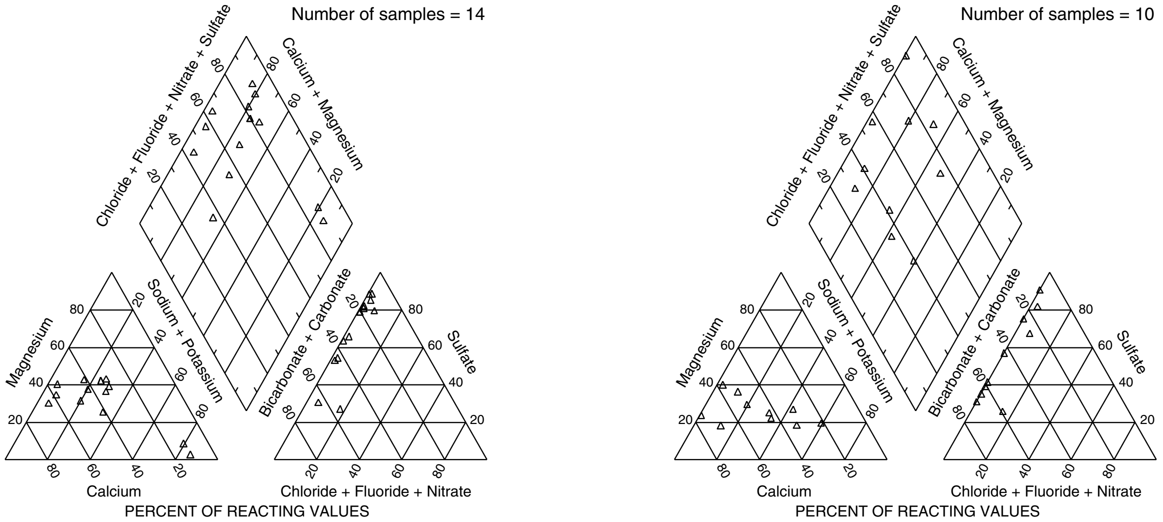
MADISON AQUIFER **INYAN KARA AQUIFER**

Figure 17. Trilinear diagrams showing proportional concentrations of major ions in selected aquifers.



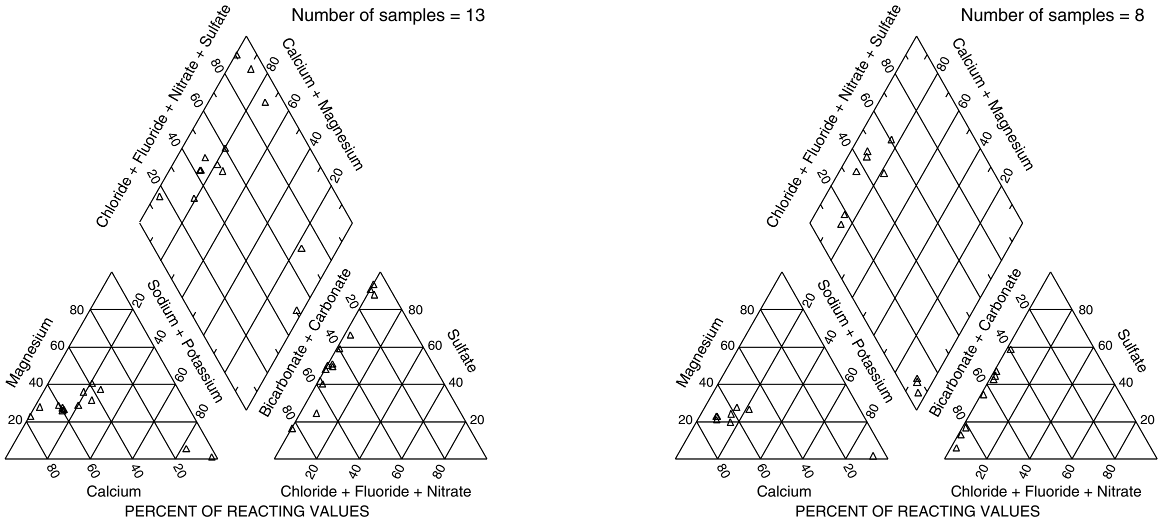
SPEARFISH AQUIFER

PIERRE AQUIFER



SUNDANCE AQUIFER

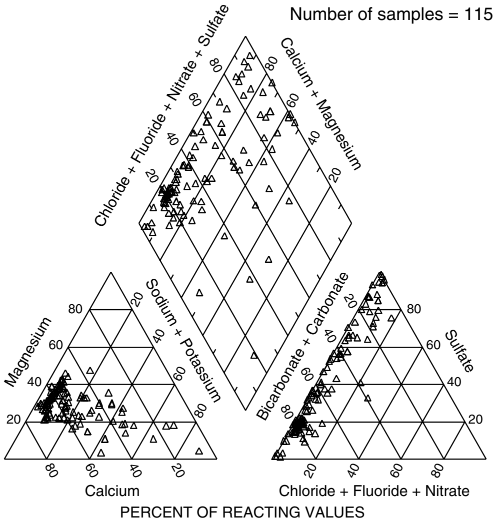
GRANEROS AQUIFER



MORRISON AQUIFER

NEWCASTLE AQUIFER

Figure 17. Trilinear diagrams showing proportional concentrations of major ions in selected aquifers.--Continued



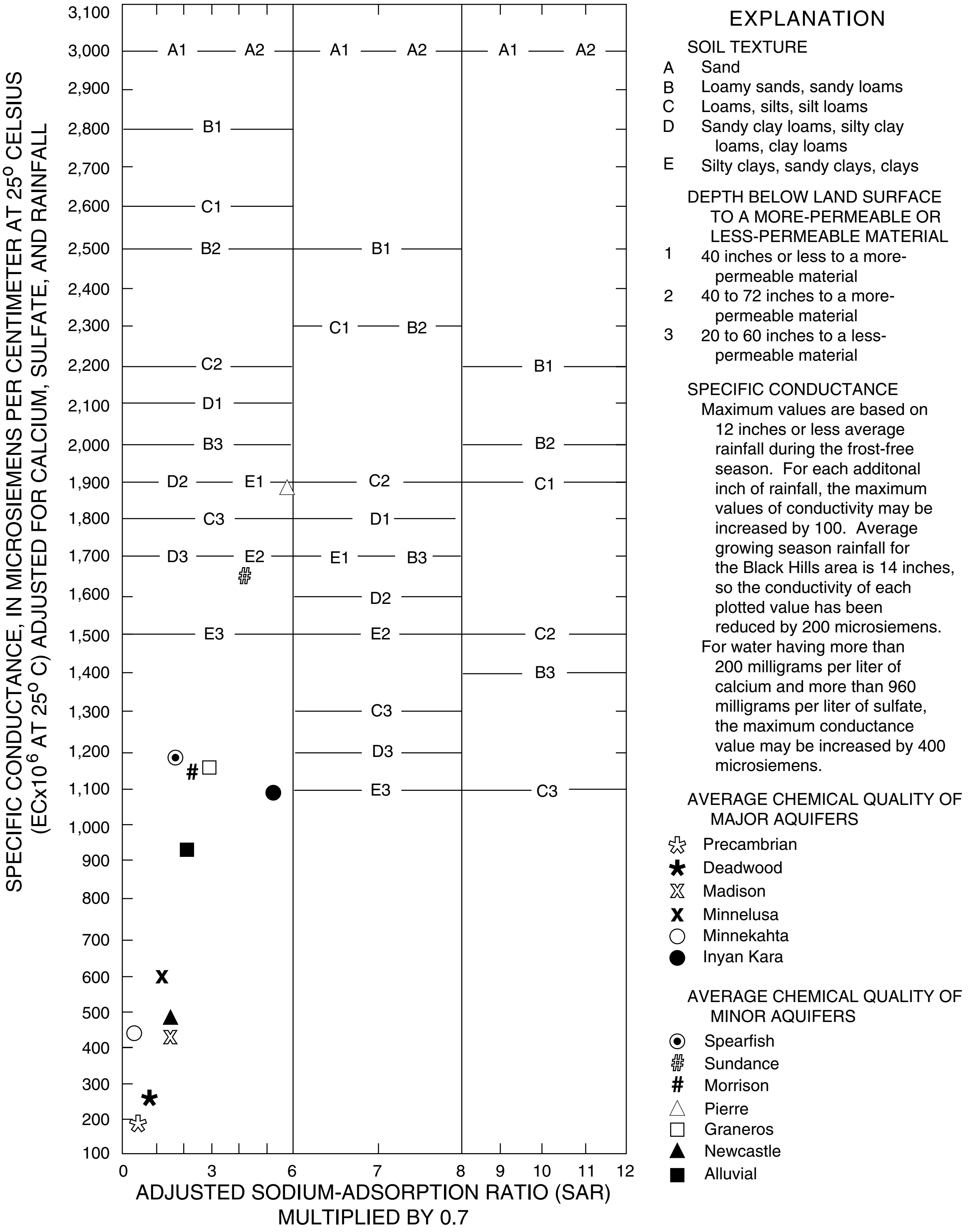
ALLUVIAL AQUIFERS

Figure 17. Trilinear diagrams showing proportional concentrations of major ions in selected aquifers.--Continued

Table 5. Relation between specific conductance and dissolved solids for selected aquifers

[*S* = dissolved solids, in milligrams per liter; *K* = specific conductance, in microsiemens per centimeter]

Aquifer	Equation of line	R^2	Number of samples
Precambrian	$S = 0.6151K - 14.42$	0.9108	39
Deadwood	$S = 0.5792K - 1.93$	.9687	33
Madison	$S = 0.6091K - 3.73$	.9793	91
Minnelusa	$\mathrm{S} = 1.0070K - 215.09$	.9777	159
Minnekahta	$S = 0.8860K - 177.62$	.9912	25
Inyan Kara	$S - 0.7842K - 98.49$	.9479	85
Sundance	$S = 0.7986K - 129.34$	.9750	10
Morrison	$S = 0.7601K - 66.71$	.9781	7
Newcastle	$S = 0.7105K - 67.20$	.9817	8
Alluvial	$S = 0.8302K - 105.62$	.9601	64



EXPLANATION

SOIL TEXTURE

A Sand
B Loamy sands, sandy loams
C Loams, silts, silt loams
D Sandy clay loams, silty clay loams, clay loams
E Silty clays, sandy clays, clays

DEPTH BELOW LAND SURFACE TO A MORE-PERMEABLE OR LESS-PERMEABLE MATERIAL

1 40 inches or less to a more-permeable material
2 40 to 72 inches to a more-permeable material
3 20 to 60 inches to a less-permeable material

SPECIFIC CONDUCTANCE

Maximum values are based on 12 inches or less average rainfall during the frost-free season. For each additonal inch of rainfall, the maximum values of conductivity may be increased by 100. Average growing season rainfall for the Black Hills area is 14 inches, so the conductivity of each plotted value has been reduced by 200 microsiemens.

For water having more than 200 milligrams per liter of calcium and more than 960 milligrams per liter of sulfate, the maximum conductance value may be increased by 400 microsiemens.

AVERAGE CHEMICAL QUALITY OF MAJOR AQUIFERS

✲ Precambrian
✱ Deadwood
⧖ Madison
✖ Minnelusa
○ Minnekahta
● Inyan Kara

AVERAGE CHEMICAL QUALITY OF MINOR AQUIFERS

⊙ Spearfish
Sundance
Morrison
△ Pierre
□ Graneros
▲ Newcastle
■ Alluvial

Figure 18. South Dakota irrigation-water classification diagram. This diagram is based on South Dakota standards (revised Jan. 7, 1982) for maximum allowable specific conductance and adjusted sodium-adsorption-ratio values for which an irrigation permit can be issued for applying water under various soil-texture conditions. Water can be applied under all conditions at or above the plotted point, but not below it, provided other conditions as defined by the State Conservation Commission are met (from Koch, 1983).

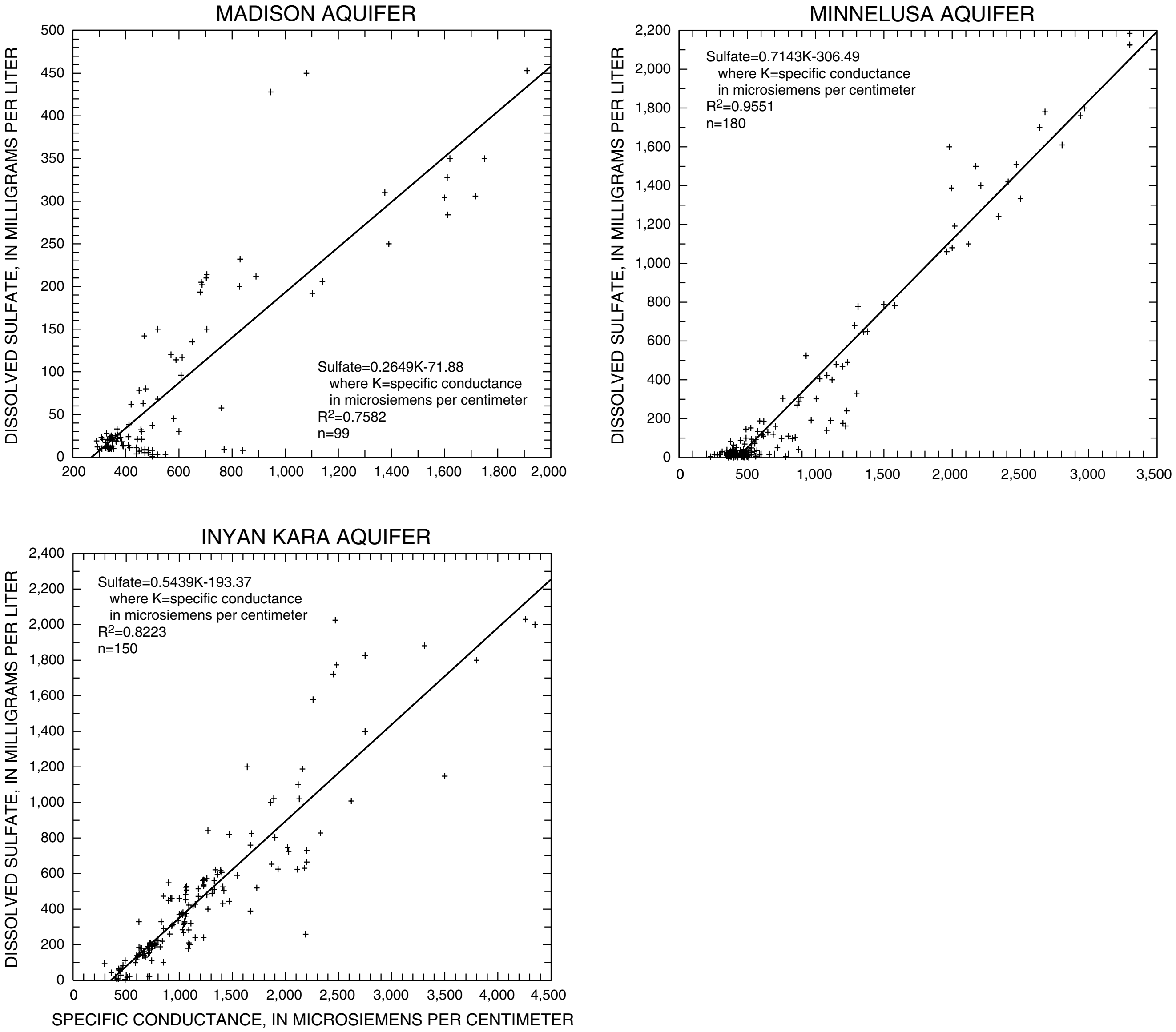
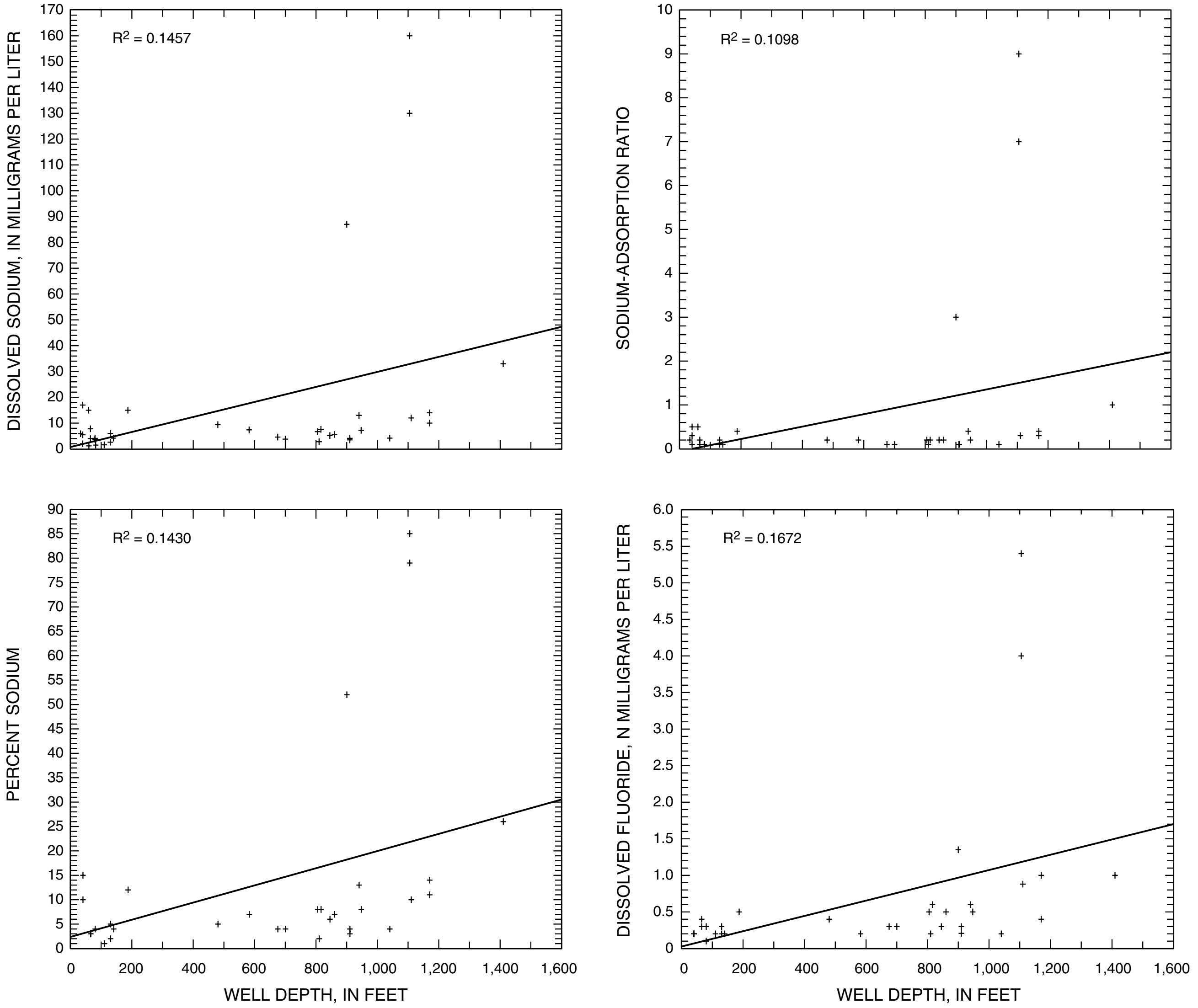


Figure 19. Relations between sulfate and specific conductance in the Madison, Minnelusa, and Inyan Kara aquifers.



DEADWOOD AQUIFER

Figure 20. Selected relations between common ions and well depth for selected aquifers.

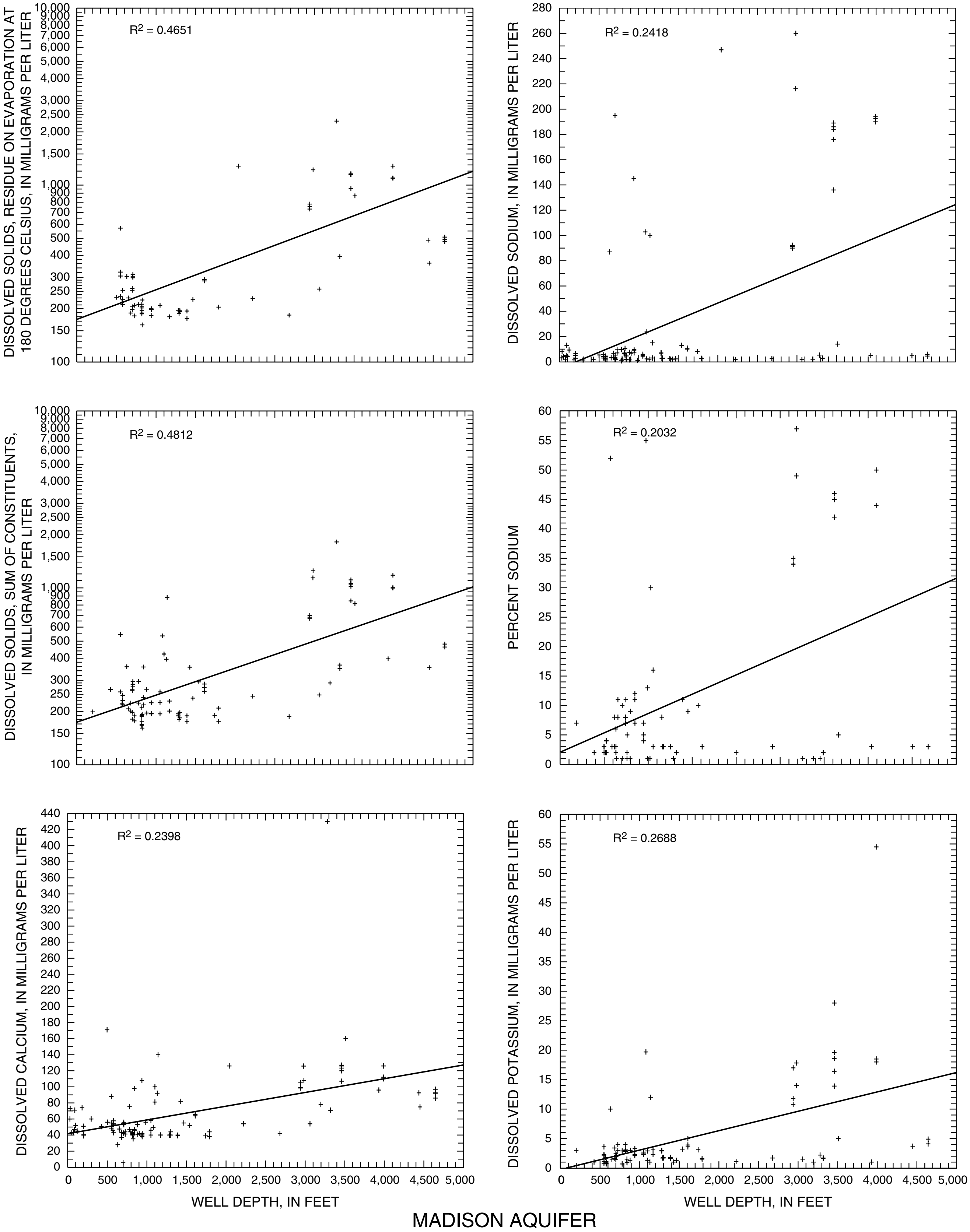
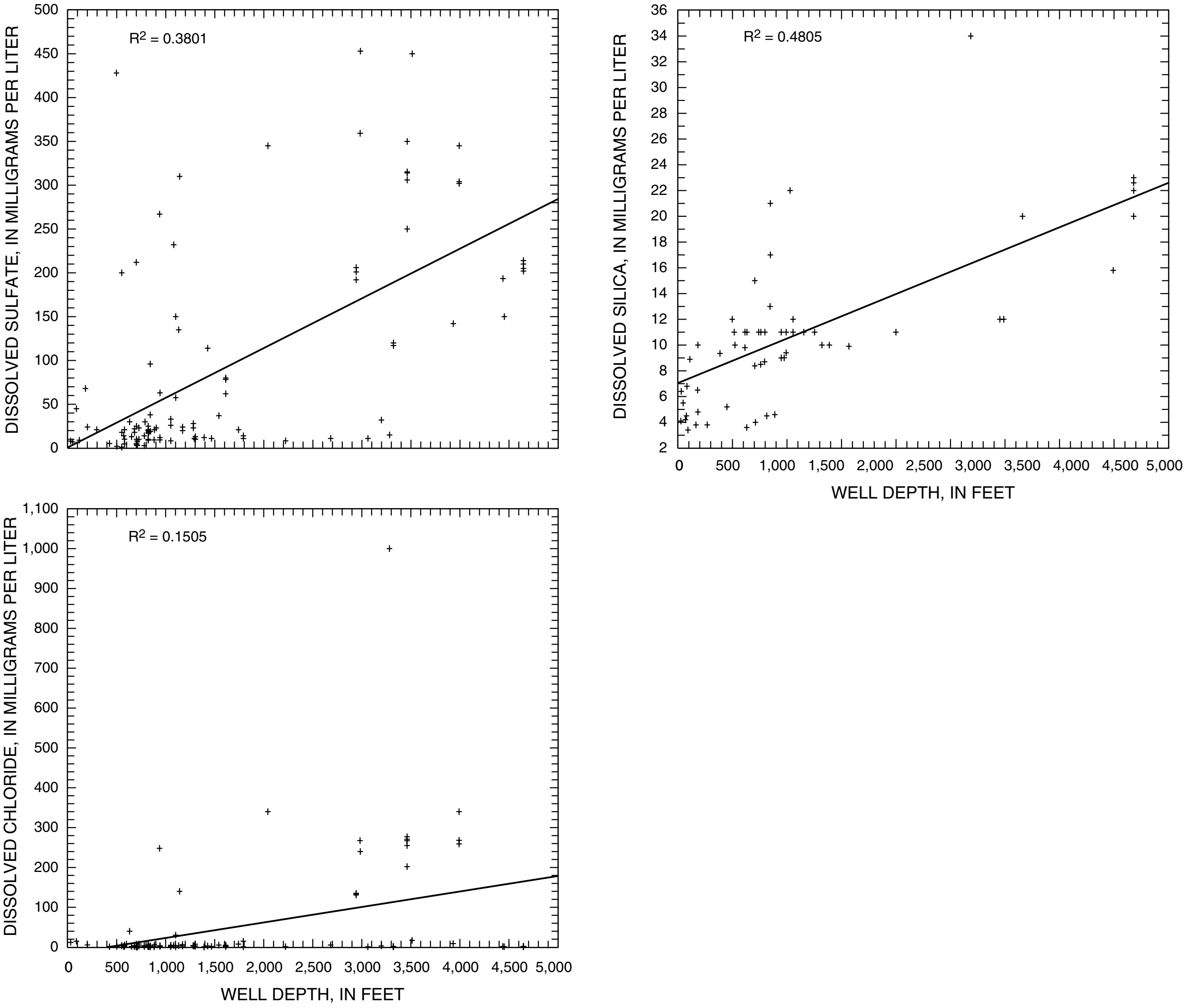


Figure 20. Selected relations between common ions and well depth for selected aquifers.--Continued



MADISON AQUIFER

Figure 20. Selected relations between common ions and well depth for selected aquifers.--Continued

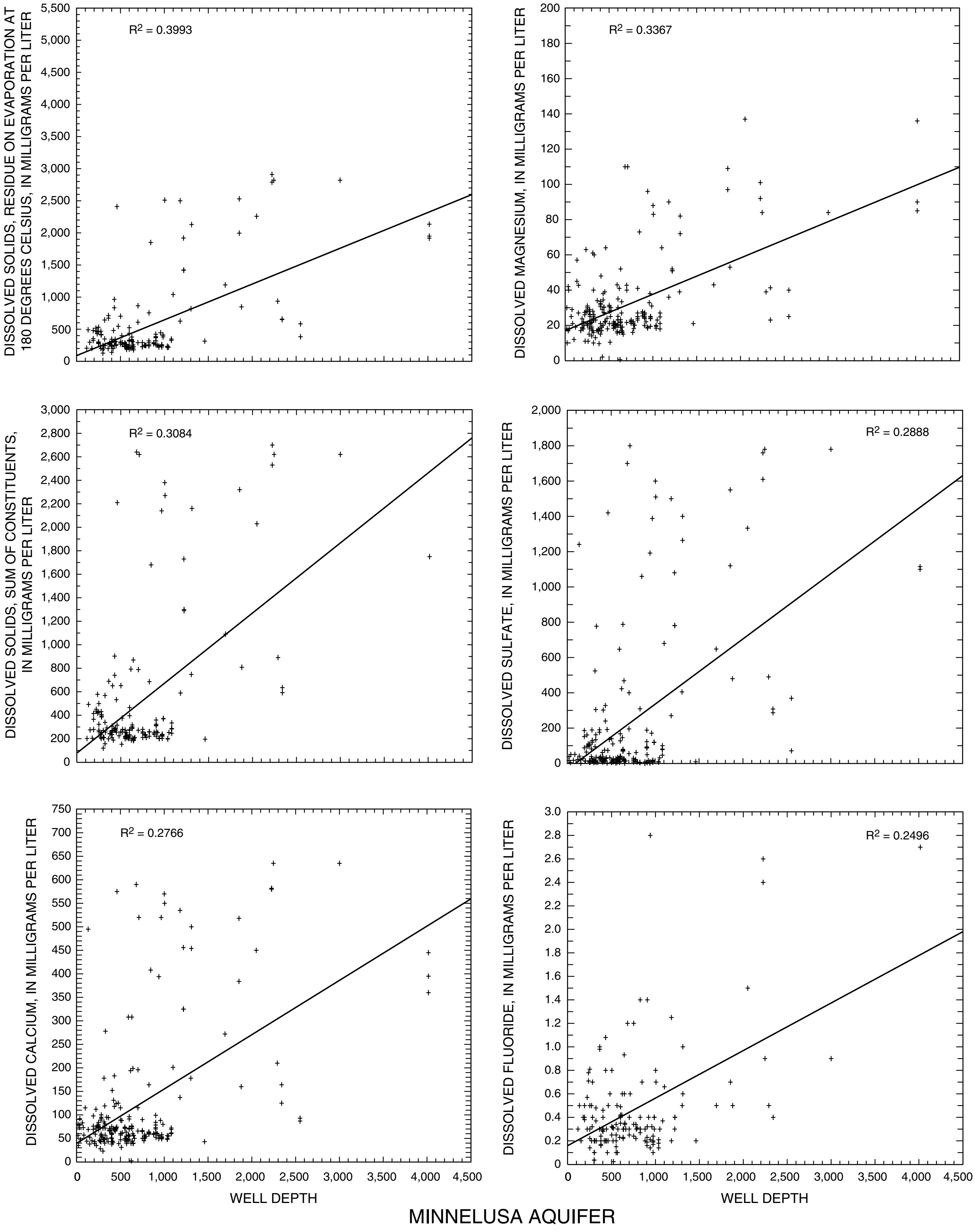
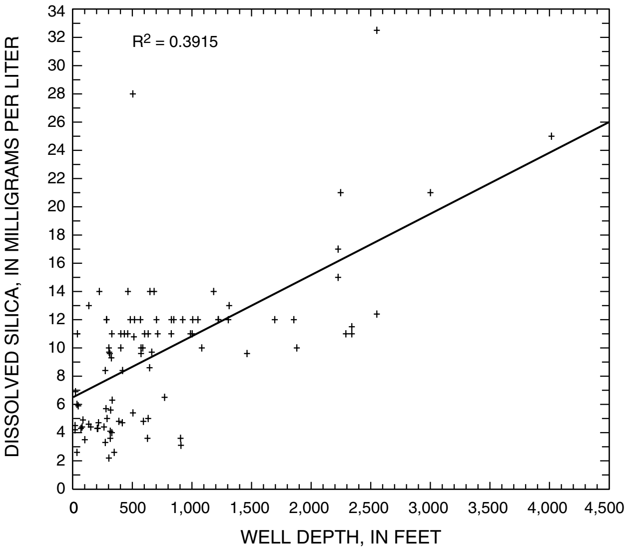


Figure 20. Selected relations between common ions and well depth for selected aquifers.--Continued



MINNELUSA AQUIFER

Figure 20. Selected relations between common ions and well depth for selected aquifers.--Continued

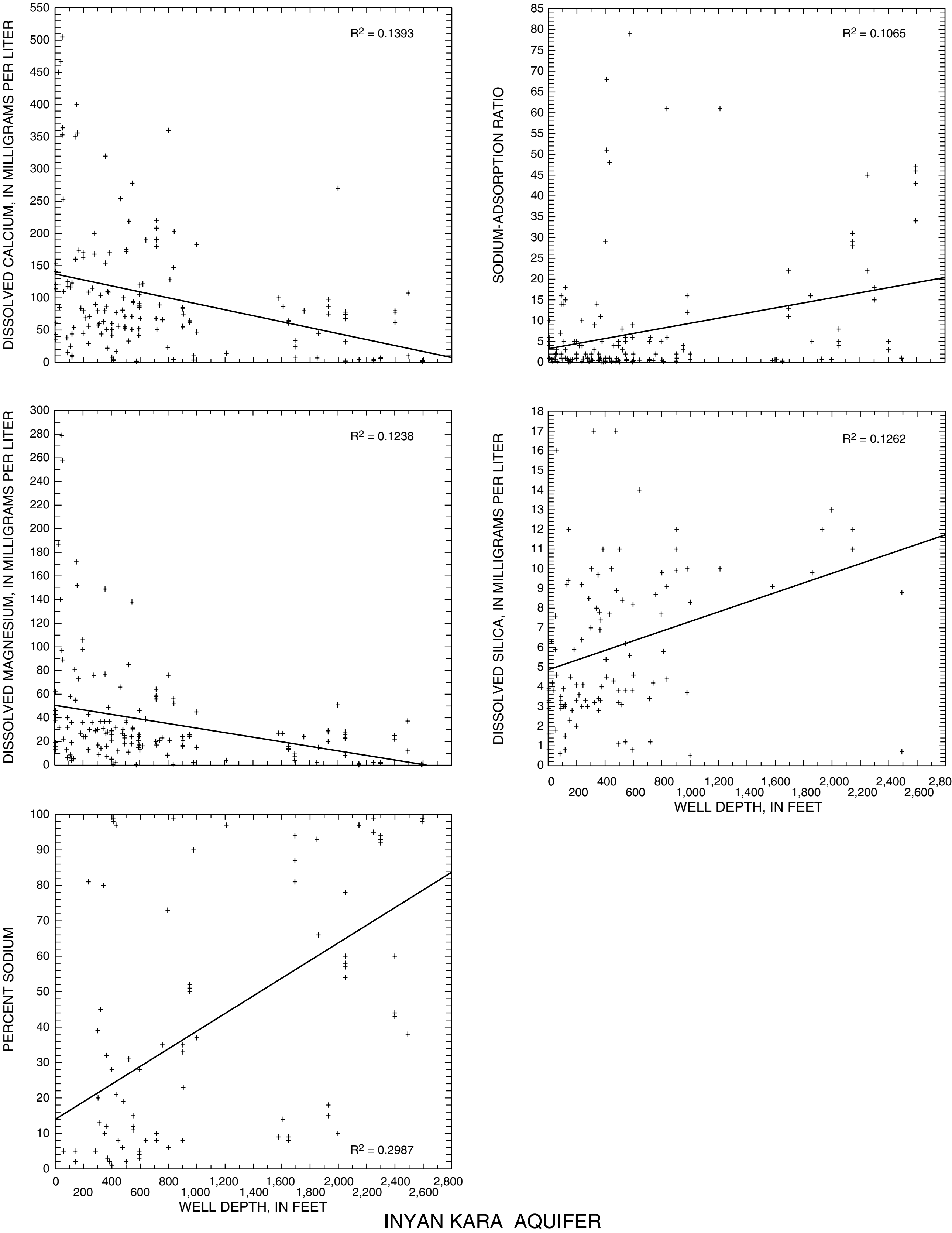


Figure 20. Selected relations between common ions and well depth for selected aquifers.--Continued

Madison Aquifer

Water from the Madison aquifer generally is fresh, but can be slightly saline (dissolved solids concentration of 1,000 to 3,000 mg/L) near Edgemont, Rapid City, and northwest of Spearfish. Samples from the Madison aquifer have the highest mean chloride concentration of the major aquifers.

The two main water types in the Madison aquifer are calcium magnesium bicarbonate type and calcium sodium chloride sulfate type (fig. 17). Calcium, magnesium, and bicarbonate are dominant among the common ions throughout most of the study area due to the dissolution of calcite and dolomite. The latter water type exists only in the southwestern part of the study area (Naus and others, in press). The high concentrations of chloride, sulfate, and sodium in the southwestern part of the study area relative to the rest of the study area probably reflect the presence of more evolved ground water and regional flow from the west, and/or the presence of evaporite minerals available for dissolution (Naus and others, in press).

In the Madison aquifer, calcium, sodium, potassium, sulfate, chloride, and silica concentrations and percent sodium generally increase with increasing well depth (fig. 20). Although there were not enough values of bicarbonate concentrations with a corresponding well depth for a statistical correlation, a visual check of the well locations in relation to the outcrop showed that bicarbonate concentrations decrease with increasing distance from the outcrop and, hence, probably decrease with increasing well depth. Generally, chloride concentrations, sodium concentrations, and percent sodium are higher in Fall River County than in other counties in the study area.

About 25 percent of the samples (25 of 99) exceed the SMCL for dissolved solids (sum of constituents); all but one of these samples were collected from wells located downgradient from the outcrop with depths greater than 2,000 feet. About 16 percent of the samples (21 of 127 samples) equal or exceed the SMCL for sulfate, and about 12 percent of the samples (15 of 124 samples) equal or exceed the SMCL of 250 mg/L for chloride. All of the samples that exceed these SMCL's were collected from wells located downgradient of the outcrop and most of the wells were in Fall River County. The higher sulfate concentrations in the Madison aquifer may be caused by the dissolution of anhydrite or leakage of water from the Minnelusa aquifer (Kyllonen and Peter, 1987). One of 89 samples exceeds the MCL for fluoride.

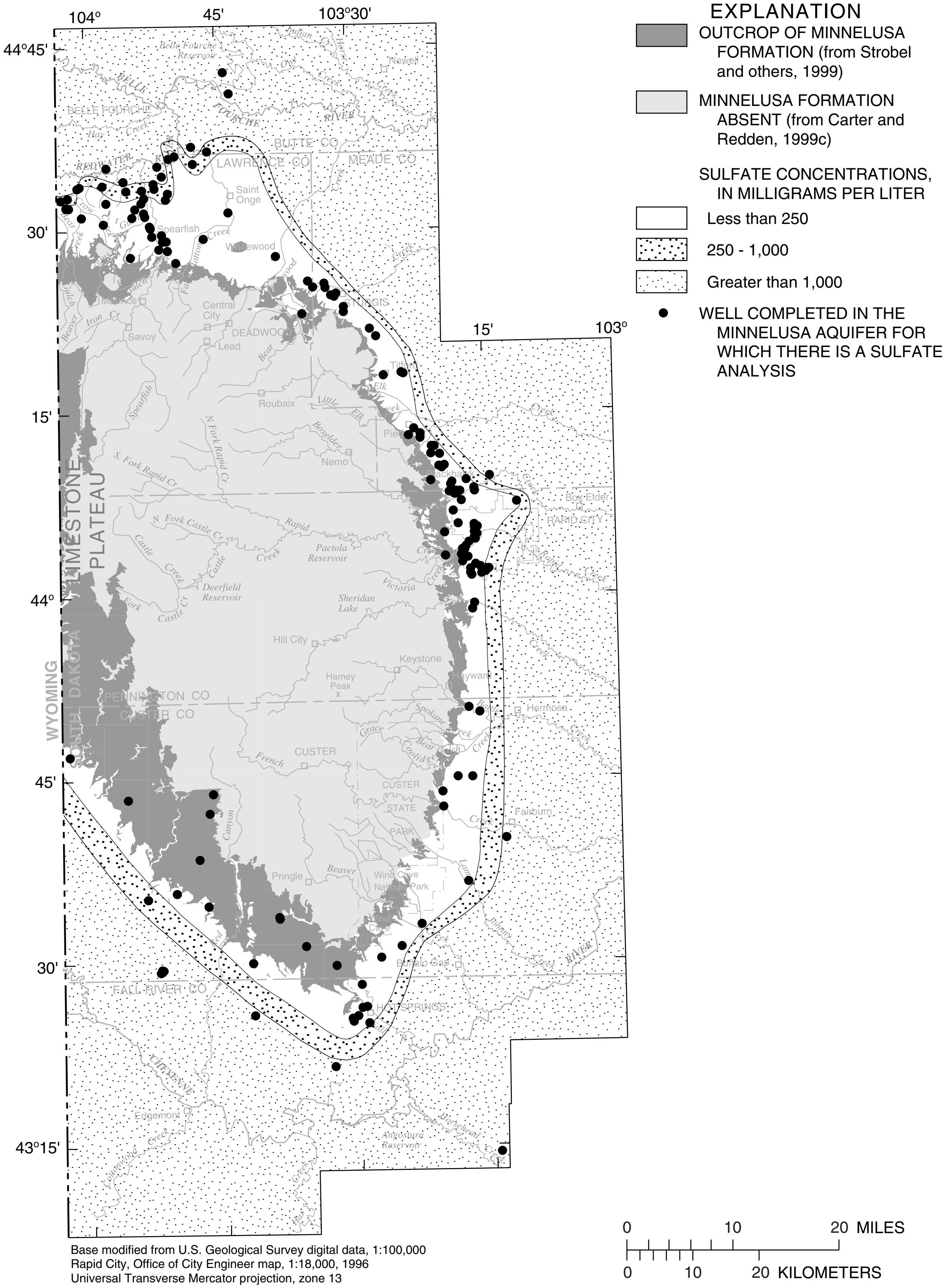
Minnelusa Aquifer

Water from the Minnelusa aquifer typically is fresh, but can be slightly saline at some locations greater than about 5 miles from the outcrop. Generally, calcium, bicarbonate, and sulfate are dominant among the common ions in the Minnelusa aquifer. Of all the major aquifers, the Minnelusa aquifer had the highest mean calcium concentration and the lowest median sodium concentration, percent sodium (equal to samples from the Minnekahta aquifer), and SAR (equal to samples from the Minnekahta aquifer).

The three main water types in the Minnelusa Formation are calcium magnesium bicarbonate type, calcium magnesium sulfate type, and calcium magnesium bicarbonate sulfate chloride type. Water in the Minnelusa aquifer generally evolves downgradient from a calcium magnesium bicarbonate type to a calcium magnesium sulfate type due to dissolution of anhydrite. In the southern part of the study area, ground water is characterized by higher concentrations of sodium and chloride. The higher chloride concentrations in this area could reflect hydraulic connection between the Madison and Minnelusa aquifers (Naus and others, in press). The dissolution of evaporite minerals and the presence of more evolved ground water also may contribute toward the occurrence of this water type in the Minnelusa aquifer (Naus and others, in press).

In the Minnelusa aquifer, calcium, magnesium, sulfate, fluoride, and silica concentrations generally increase with increasing well depth (fig. 20). The increasing concentrations reflect the dissolution of many minerals as the water flows downgradient from the outcrop of the Minnelusa Formation. Concentrations of chloride and sodium vary with geographic location and do not show a relation to well depth (or distance from outcrop). The chloride and sodium concentrations are higher in the southern Black Hills than in other areas.

The concentration of sulfate in the aquifer is dependent on the amount of anhydrite present in the Minnelusa Formation. Near the outcrop, anhydrite has been dissolved and removed; hence, sulfate concentrations near the outcrop are low (less than 250 mg/L). Surrounding the core of the Black Hills and downgradient from the Minnelusa Formation outcrop is a sulfate transition zone (Kyllonen and Peter, 1987), within which the sulfate concentrations range from 250 to 1,000 mg/L. The transition zone is approximately 2 to 10 miles wide (fig. 21) and marks an area of active



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 21. Distribution of sulfate concentrations in the Minnelusa aquifer (from Naus and others, in press).

removal of anhydrite by dissolution. The transition zone probably is shifting downgradient over geologic time as the anhydrite in the formation is dissolved (Kyllonen and Peter, 1987). Downgradient from the transition zone, sulfate concentrations are greater than 1,000 mg/L, which represents a zone in which thick anhydrite beds remain in the formation.

More than 20 percent of the samples (38 of 176) exceed the SMCL for dissolved solids (sum of constituents); most of these samples were collected from wells located downgradient from the outcrop with depths greater than 1,000 feet. About 20 percent of the samples (51 of 249) collected exceed the SMCL for sulfate; generally most of these samples are from wells located downgradient from the outcrop. Seven of 185 samples equal or exceed the SMCL for fluoride; all 7 of these samples were located downgradient from the outcrop. None of the samples exceed the MCL for fluoride.

Minnekahta Aquifer

Water from the Minnekahta aquifer generally is fresh. Generally, calcium and bicarbonate are dominant among the common ions, although a few samples also had high sulfate concentrations. Of the major aquifers, the Minnekahta aquifer had the highest median calcium and magnesium concentrations and the highest mean and median bicarbonate and silica concentrations (table 4). The Minnekahta aquifer also had the lowest mean sodium concentration and the lowest mean and median potassium concentration, percent sodium (equal to the median of the Minnelusa aquifer), and SAR (equal to the median of the Minnelusa aquifer).

The Minnekahta aquifer generally yields a calcium bicarbonate water (fig. 17) due to the dissolution of calcite. In samples from four wells completed in the Minnekahta aquifer, the water type is calcium sulfate. The four wells with a substantial sulfate component generally are farther from the outcrop than the wells dominated by bicarbonate. A possible source for the sulfate is leakage from or through the underlying Minnelusa aquifer.

Four of 24 samples exceed the SMCL for dissolved solids (sum of constituents). Four of 28 samples exceed the SMCL for sulfate; all of these samples were collected from wells that are farther from the outcrop than the other wells that were sampled.

Inyan Kara Aquifer

Water from the Inyan Kara aquifer is fresh to slightly saline, with the highest salinity occurring in the southern Black Hills. Generally, sodium and sulfate are dominant among the common ions, although calcium and bicarbonate concentrations also can be high depending on well depth and geographic location. Of the major aquifers, the Inyan Kara aquifer had the highest mean and median sodium concentration, percent sodium, SAR, and sulfate concentration and the highest mean magnesium concentration (table 4). The Inyan Kara aquifer also had the lowest mean and median silica concentration.

The Inyan Kara aquifer may yield a sodium sulfate, calcium sulfate, calcium bicarbonate, or sodium bicarbonate water type (fig. 17) depending on geographical location and distance from the outcrop. The initial water types are similar to those of the Minnelusa aquifer—calcium sulfate or calcium bicarbonate—possibly because the Inyan Kara aquifer receives recharge from the underlying aquifers. Wells located on and near the outcrop of the Inyan Kara Group in the southern Black Hills generally yield a calcium sulfate water type, whereas wells in the eastern and northern Black Hills generally yield a calcium bicarbonate water type. In the southern Black Hills, the water evolves as it moves downgradient to a sodium sulfate water type or, locally, to a sodium bicarbonate water type (Gott and others, 1974). In the eastern and northern Black Hills, the water evolves to a sodium sulfate water type as it moves downgradient.

Percent sodium, SAR, and silica concentrations generally increase with increasing well depth, whereas calcium and magnesium concentrations decrease with increasing well depth. The change in concentrations indicates that sodium and silica are dissolving and calcium and magnesium are precipitating as the water flows downgradient from the outcrop of the Inyan Kara Group. The source of high sulfate concentrations on or near the outcrop may be from upward leakage of water from the Minnelusa aquifer or gypsiferous formations (Gypsum Spring or Spearfish Formations) or from the oxidation of sulfide minerals in the Inyan Kara aquifer (Kyllonen and Peter, 1987).

Chloride concentrations vary with geographic location as opposed to distance from outcrop. In the southern Black Hills, chloride concentrations generally are higher than those in other areas. Sulfate concentrations generally are higher in the southern Black Hills than those in other areas, whereas silica concentrations generally are lower in the southern Black Hills.

More than 60 percent of the samples (65 of 102 samples) analyzed for dissolved solids (sum of constituents) exceed the SMCL for dissolved solids; most of these samples were collected from wells in the southern Black Hills or from wells located downgradient from the outcrop with depths greater than 500 feet. More than 60 percent of the samples (110 of 177 samples) collected exceed the SMCL for sulfate; almost every sample collected in the southern Black Hills exceeds the SMCL for sulfate. Two of 105 samples equal or exceed the SMCL for fluoride, and one of these samples equals the MCL for fluoride.

Minor Aquifers

Only three samples were analyzed for dissolved solids from the Spearfish aquifer. However, at least 25 percent of the total number of samples probably would exceed the SMCL for dissolved solids, based on sulfate concentrations that are greater than 500 mg/L. Calcium, sulfate, and bicarbonate are dominant among the common ions in the Spearfish aquifer. About 45 percent of the samples (6 of 13 samples) exceed the SMCL for sulfate. Water from the Spearfish aquifer generally is a calcium bicarbonate or calcium sulfate type (fig. 17). The dominance of sulfate increases with the amount of gypsum present in the formation.

Most samples (10 of 12 samples) from wells completed in the Sundance aquifer and some samples (3 of 7 samples) from wells completed in the Morrison aquifer exceed the SMCL for dissolved solids. In the Sundance aquifer, calcium, sodium, sulfate, and bicarbonate are dominant among the common ions. Almost all of the samples from the Sundance aquifer (12 of 14 samples) exceed the SMCL for sulfate, and 1 of 12 samples exceeds the MCL for fluoride. Most samples from the Sundance aquifer are slightly saline. Calcium, sulfate, and bicarbonate are dominant among the common ions in the Morrison aquifer. About 45 percent of the samples (7 of 15 samples) exceed the SMCL for sulfate in water from the Morrison aquifer.

No samples from the Pierre aquifer were analyzed for dissolved solids; however, it is likely that most would exceed the SMCL for dissolved solids, based on sulfate concentrations. Sodium, calcium, sulfate, and bicarbonate (based on alkalinity) are dominant among the common ions in the Pierre aquifer. The mean bicarbonate concentration is about 360 mg/L and was determined by dividing the mean alkalinity (table 3) by 0.8202 (Hem, 1985). Almost all of the samples (24 of 28 samples) exceed the SMCL for sulfate.

Water from the Sundance, Morrison, and Pierre aquifers generally is a mixed type that includes dominant cations of sodium, calcium, and magnesium, and the dominant anions of sulfate and bicarbonate (fig. 17). The dominance of sodium and sulfate increases with increasing amounts of shale present in the formations due to the large cation-exchange capacities of clay minerals (generally sodium concentrations increase) and due to the reduced circulation of water through the shale (Hem, 1985). The dominance of calcium, magnesium, and bicarbonate increases with increasing amounts of sandstone (where calcium carbonate commonly is the cementing material) and carbonate rocks present in the formations.

No samples from aquifers in the Graneros Group (excluding the Newcastle aquifer) were analyzed for dissolved solids; however, at least 25 percent of the samples probably would exceed the SMCL for dissolved solids, based on sulfate concentrations. Wells completed in the Newcastle aquifer generally yield water that is low in specific conductance and dissolved solids, although one of eight samples from the Newcastle aquifer did exceed the SMCL for dissolved solids. Calcium, bicarbonate (based on alkalinity), and sulfate are the dominant common ions in the Graneros aquifer. Calcium and bicarbonate (based on alkalinity) are the dominant common ions in the Newcastle aquifer. None of the samples for either the Graneros or Newcastle aquifers were analyzed for bicarbonate. The mean bicarbonate concentration of the samples for both aquifers is about 300 mg/L based on the mean alkalinity (table 3). Fifty percent of the samples (5 of 10 samples) collected from the Graneros aquifer exceed the SMCL for sulfate, and one of eight samples collected from the Newcastle aquifer exceeds the SMCL for sulfate. Of the minor aquifers, the Newcastle aquifer generally has the lowest sulfate concentrations and has the lowest dissolved solids concentrations.

The water type yielded from the Graneros aquifer varies from a calcium bicarbonate sulfate type to a mixed type (fig. 17), depending on the formation in which the well is completed. Most wells completed within the Graneros Group are completed in the Newcastle aquifer, which generally yields a calcium bicarbonate or calcium bicarbonate sulfate water type.

Generally, calcium, sulfate, and bicarbonate are dominant among the common ions in the alluvial aquifers. The concentrations of all of the common ions increase with distance from the central core of the Black Hills, which is largely due to the increasing dissolved ions in the streams and in the geologic formations that underlie the alluvial deposits. About 25 percent of the samples (20 of 81 samples) exceed the SMCL for dissolved solids (sum of constituents); almost all those samples are from wells completed in alluvial deposits that overlie the Cretaceous-age shales. More than 30 percent of the samples (38 of 116 samples) from alluvial aquifers exceed the SMCL for sulfate, and most of these are from wells completed in alluvial deposits that overlie the Cretaceous-age shales.

The water type yielded from wells completed in alluvial aquifers varies greatly (fig. 17) and largely is dependent on the geologic formation that underlies the alluvial deposit. Generally, wells completed in alluvial deposits that do not overlie Cretaceous-age shales yield fresh water with a calcium bicarbonate or calcium magnesium bicarbonate water type. Wells that are completed in alluvial deposits that overlie the Cretaceous-age shales generally yield slightly saline water with a mixed water type or a water type in which sodium is the dominant cation and/or sulfate is the dominant anion.

Nutrients

Nitrogen and phosphorus are essential nutrients for plant growth. The major form of nitrogen in ground water is nitrate, although it also can occur in other forms including ammonium, ammonia, nitrite, and as part of organic solutes. Nitrate is very mobile in ground water, and it moves with little or no retardation (Freeze and Cherry, 1979). Elevated nitrate concentrations in ground water can originate from natural processes or as contamination from nitrogen sources, such as fertilizers and sewage. Nitrate concentrations above 10 mg/L (U.S. Environmental Protection Agency, 1994a) can cause methemoglobinemia (blue-baby syndrome) in small children.

In ground water, phosphorus generally occurs as phosphate. Orthophosphate generally is the most stable phosphate species that occurs. Phosphorus has a low solubility and, therefore, dissolved concentrations in ground water generally are no more than a few tenths of a milligram per liter (Hem, 1985). Concentrations above this level may indicate contamination by fertilizer or sewage. Concentrations of orthophosphate that were reported as phosphate were converted to concentrations as phosphorus for this report.

Summary statistics for selected nutrients, including nitrite, nitrite plus nitrate, ammonia, ammonia plus organic, phosphorus, and orthophosphate, are presented in table 6, and the significance of the various nutrients is described in table 1. Boxplots are presented in figure 22 for each of the nutrients.

Generally, concentrations of nitrogen and phosphorus are low in water from the major aquifers. Two of 40 samples collected from wells completed in Precambrian aquifers exceed the MCL of 10 mg/L for nitrite plus nitrate. No samples from the Deadwood, Madison, or Minnekahta aquifers exceed the MCL for any regulated nutrient constituent. A sample from the Madison aquifer has the highest concentration of ammonia plus organic (5.0 mg/L) of all the samples from all of the aquifers considered in this study. In the Minnelusa aquifer, 2 of 157 samples exceed the MCL for nitrite plus nitrate. A sample from the Minnelusa aquifer has the highest phosphorus concentration (2.1 mg/L) of all the samples from all aquifers considered in this study.

Nitrogen and phosphorus concentrations generally are low in water from the Inyan Kara aquifer. Of the samples collected from wells completed in the Inyan Kara aquifer, 1 of 41 samples equalled the MCL of 1.0 mg/L for nitrite, and 1 of 81 samples exceeds the MCL for nitrite plus nitrate. Three individual samples from the Inyan Kara aquifer have the highest concentration of nitrite (1.0 mg/L), nitrite plus nitrate (60 mg/L), and ammonia (2.2 mg/L) of all the samples from all aquifers considered in this study (fig. 22). The extreme values for nitrite and nitrite plus nitrate are unusually high and may reflect poor well construction and surface contamination as opposed to aquifer conditions.

With the exception of alluvial aquifers, few samples from the minor aquifers were analyzed for nitrogen or phosphorus. Of the samples analyzed, nitrogen and phosphorus concentrations are low and none exceed the MCL for nitrite or for nitrite plus nitrate.

Table 6. Summary of concentrations of nutrients in ground water

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter. One milligram per liter is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Precambrian aquifers						
Nitrite, as N	18	17	--	--	<0.01	0.01
Nitrite plus nitrate, as N	40	8	1.6	0.7	<0.1	12
Ammonia, as N	0	--	--	--	--	--
Ammonia plus organic, as N	0	--	--	--	--	--
Phosphorus, as P	51	44	[1]--	[1]--	<0.04	0.12
Orthophosphate, as P	0	--	--	--	--	--
Deadwood aquifer						
Nitrite, as N	5	5	--	--	<0.01	<0.01
Nitrite plus nitrate, as N	8	4	0.2	<0.1	<0.1	0.5
Ammonia, as N	2	0	0.025	0.025	0.02	0.03
Ammonia plus organic, as N	3	1	--	--	<0.2	0.6
Phosphorus, as P	7	5	--	--	<0.01	0.25
Orthophosphate, as P	1	1	--	--	<0.001	<0.001
Madison aquifer						
Nitrite, as N	56	50	[1]--	[1]--	<0.01	0.03
Nitrite plus nitrate, as N	74	14	0.4	0.2	<0.05	2.6
Ammonia, as N	31	12	0.2	0.01	<0.01	1.9
Ammonia plus organic, as N	36	23	0.4	0.1	0.05	5.0
Phosphorus, as P	59	42	0.01	<0.01	<0.01	0.22
Orthophosphate, as P	28	14	<0.01	<0.01	<0.01	0.02
Minnelusa aquifer						
Nitrite, as N	61	49	[1]--	[1]--	<0.01	0.05
Nitrite plus nitrate, as N	157	29	0.6	0.3	0.01	16
Ammonia, as N	22	6	0.04	0.02	<0.01	0.3
Ammonia plus organic, as N	28	16	0.2	0.2	<0.1	0.8
Phosphorus, as P	68	54	0.04	<0.01	<0.01	2.1
Orthophosphate, as P	19	11	<0.01	<0.01	<0.01	0.03
Minnekahta aquifer						
Nitrite, as N	10	9	--	--	<0.01	0.01
Nitrite plus nitrate, as N	23	4	1.5	0.7	<0.1	9.5
Ammonia, as N	3	1	--	--	<0.02	0.07
Ammonia plus organic, as N	3	1	--	--	<0.2	0.2
Phosphorus, as P	4	3	--	--	<0.01	<0.04
Orthophosphate, as P	3	1	--	--	<0.01	0.03

Table 6. Summary of concentrations of nutrients in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter. One milligram per liter is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
		Inyan Kara aquifer				
Nitrite, as N	41	31	0.06	<0.01	<0.01	1.0
Nitrite plus nitrate, as N	81	29	1.1	0.1	0.01	60
Ammonia, as N	17	2	0.5	0.25	<0.01	2.2
Ammonia plus organic, as N	18	1	0.8	0.5	<0.1	2.7
Phosphorus, as P	81	74	--	--	<0.01	0.03
Orthophosphate, as P	0	0	--	--	--	--
		Spearfish aquifer				
Nitrite, as N	3	3	--	--	<0.01	<0.01
Nitrite plus nitrate, as N	4	0	1.8	0.8	0.5	5.0
Ammonia, as N	0	--	--	--	--	--
Ammonia plus organic, as N	0	--	--	--	--	--
Phosphorus, as P	9	9	--	--	<0.04	<0.04
Orthophosphate, as P	0	--	--	--	--	--
		Sundance aquifer				
Nitrite, as N	3	0	0.02	0.02	0.02	0.02
Nitrite plus nitrate, as N	9	0	0.4	0.1	0.02	2.1
Ammonia, as N	3	0	0.2	0.03	0.02	0.5
Ammonia plus organic, as N	3	0	0.5	0.5	0.3	0.6
Phosphorus, as P	5	4	--	--	<0.01	<0.04
Orthophosphate, as P	0	--	--	--	--	--
		Morrison aquifer				
Nitrite, as N	2	2	--	--	<0.01	<0.01
Nitrite plus nitrate, as N	7	0	0.5	0.5	0.2	0.7
Ammonia, as N	0	--	--	--	--	--
Ammonia plus organic, as N	0	--	--	--	--	--
Phosphorus, as P	6	6	--	--	<0.04	<0.04
Orthophosphate, as P	0	--	--	--	--	--
		Pierre aquifer				
Nitrite, as N	0	--	--	--	--	--
Nitrite plus nitrate, as N	0	--	--	--	--	--
Ammonia, as N	0	--	--	--	--	--
Ammonia plus organic, as N	0	--	--	--	--	--
Phosphorus, as P	28	26	--	--	<0.04	0.10
Orthophosphate, as P	0	--	--	--	--	--

Table 6. Summary of concentrations of nutrients in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter. One milligram per liter is approximately equal to one part per million; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Graneros aquifer						
Nitrite, as N	0	--	--	--	--	--
Nitrite plus nitrate, as N	0	--	--	--	--	--
Ammonia, as N	0	--	--	--	--	--
Ammonia plus organic, as N	0	--	--	--	--	--
Phosphorus, as P	10	10	--	--	<0.04	<0.04
Orthophosphate, as P	0	--	--	--	--	--
Newcastle aquifer						
Nitrite, as N	4	4	--	--	<0.01	<0.01
Nitrite plus nitrate, as N	6	4	--	--	<0.1	<0.1
Ammonia, as N	1	0	--	--	0.01	0.01
Ammonia plus organic, as N	1	1	--	--	<0.1	<0.1
Phosphorus, as P	1	0	--	--	0.01	0.01
Orthophosphate, as P	0	--	--	--	--	--
Alluvial aquifers						
Nitrite, as N	18	17	--	--	<0.01	0.01
Nitrite plus nitrate, as N	70	9	0.7	0.4	0.01	3.1
Ammonia, as N	14	5	0.01	<0.01	<0.01	0.02
Ammonia plus organic, as N	4	3	--	--	<0.2	0.2
Phosphorus, as P	33	29	[1]--	[1]--	<0.01	0.77
Orthophosphate, as P	23	13	<0.01	<0.01	<0.001	0.02

[1] Boxplot for constituent is shown in figure 22, although percent of censored values is greater than 80 percent. Mean and median are not reported because they are unreliable.

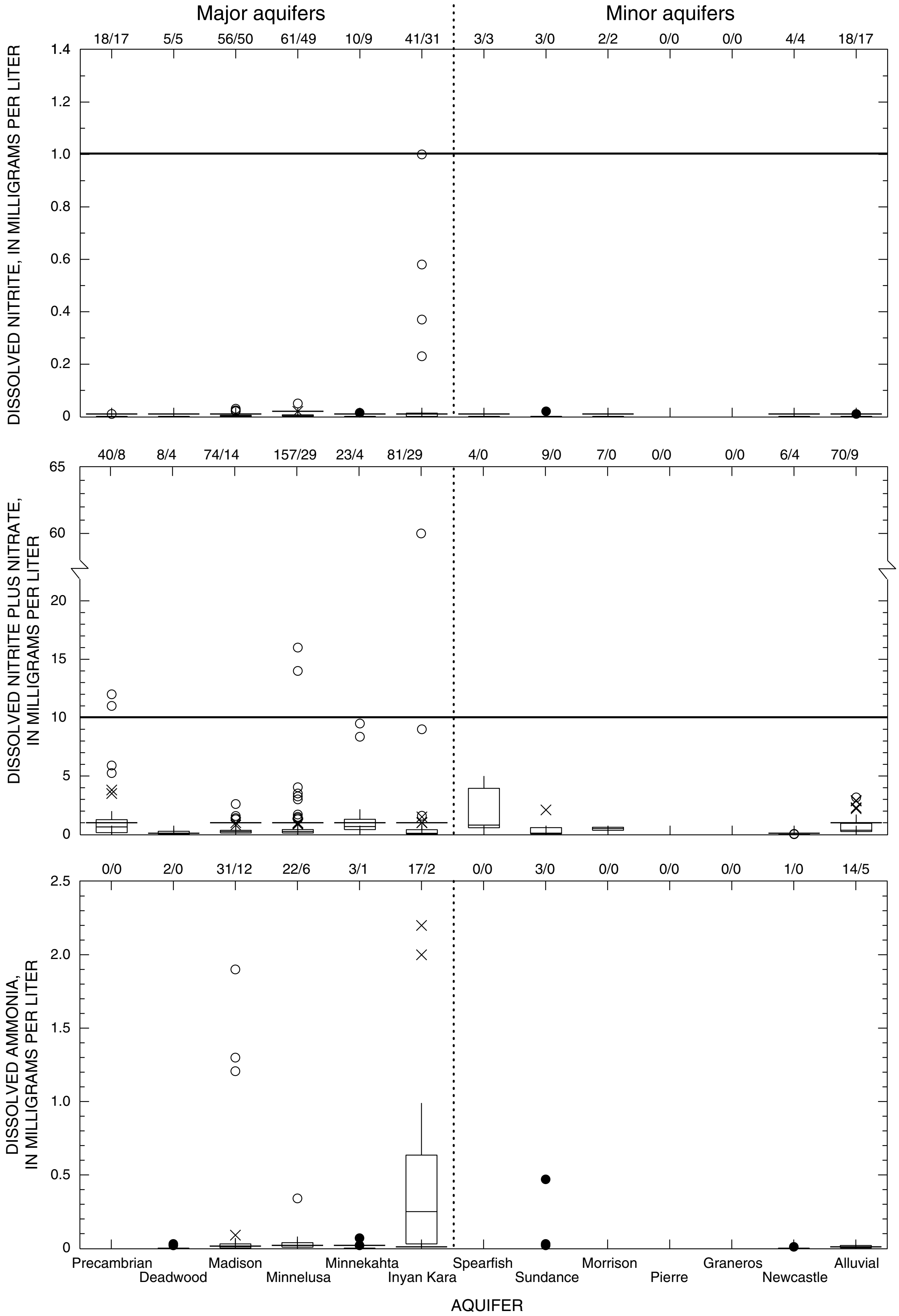


Figure 22. Boxplots of concentrations of selected nutrients for selected aquifers.

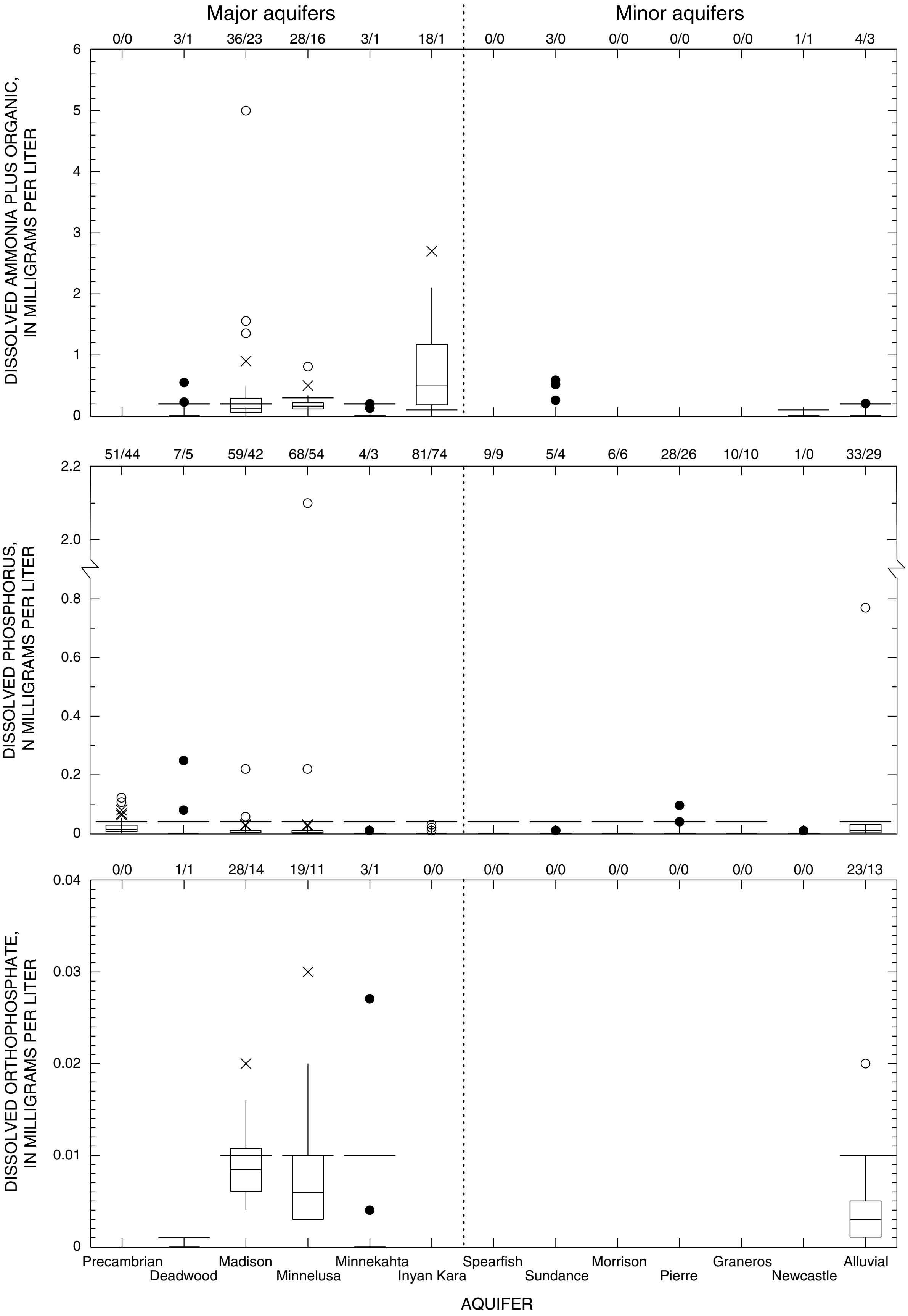


Figure 22. Boxplots of concentrations of selected nutrients for selected aquifers.--Continued

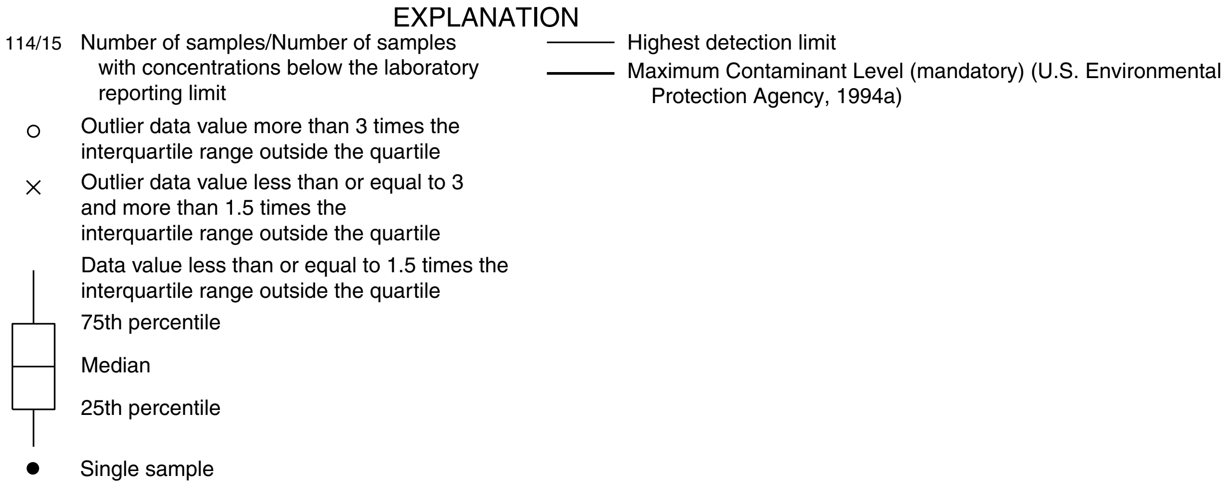


Figure 22. Boxplots of concentrations of selected nutrients for selected aquifers.--Continued

Trace Elements

Summary statistics for selected trace elements, including aluminum, arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, vanadium, and zinc, are presented in table 7. The significance of the various trace elements is described in table 1. Boxplots are presented in figure 23 for each of the trace elements. Some of the trace elements, such as aluminum, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc, are particularly susceptible to sampling/processing contamination. Because ultra-clean techniques were not used in sample collection, some of the results presented may reflect sample contamination.

In all aquifers considered in this report, strontium generally is higher in concentration than the other trace elements. Barium, boron, iron, manganese, lithium, and zinc concentrations also may be high in comparison to other trace elements. Concentrations and variability of many trace elements are small in the aquifers. Boron concentrations generally are much higher and have larger variability in the minor aquifers than in the major aquifers, with generally higher concentrations in the Inyan Kara aquifer than the other major aquifers. The Inyan Kara and Precambrian aquifers generally have lower barium concentrations and generally higher manganese concentrations than the other major aquifers. Lithium concentrations generally are much lower and have smaller variability in the Precambrian, Deadwood, Madison, Minnelusa, and Minnekahta aquifers than in the other aquifers. The Sundance aquifer generally has the highest selenium concentrations of all aquifers considered in this report. In general, strontium concentrations are lower and have smaller variability in the Precambrian, Deadwood, Madison, and Minnekahta aquifers than in the other aquifers.

Precambrian Aquifers

Concentrations of several trace elements in samples collected from the Precambrian aquifers exceed various drinking water standards. One of 51 samples exceeds the lower value of the SMCL range of 50 to 200 µg/L for aluminum. Of the 52 samples analyzed for arsenic concentrations, one sample exceeds the current MCL of 50 µg/L for arsenic, and four samples exceed the proposed MCL of 10 µg/L for arsenic. About 15 percent of the samples (14 of 91 samples) exceed the SMCL of 300 µg/L for iron, and 35 percent of the samples (33 of 93 samples) exceed the SMCL of 50 µg/L for manganese.

Of all samples collected from the major aquifers, samples from the Precambrian aquifers have the highest mean manganese concentration and the highest median zinc concentration. Samples from the Precambrian aquifers also have the lowest mean and median concentrations of boron (equal to the median concentration of the Madison aquifer) and strontium and the lowest median iron concentration.

Table 7. Summary of concentrations of trace elements in ground water

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Precambrian aquifers						
Aluminum	51	39	6.5	3.7	<10	54
Arsenic	52	24	4.2	1.2	<0.5	103
Barium	52	1	33	27	<2.0	120
Boron	60	0	29	20	6.0	227
Cadmium	1	0	--	--	3.5	3.5
Chromium	52	45	[1]--	[1]--	<4.0	13
Cobalt	51	37	1.5	1.0	<2.0	7.0
Copper	58	37	30	0.5	<2.0	517
Iron	91	33	267	11	<10	11,000
Lead	1	0	--	--	10	10
Lithium	51	0	17	9.0	3.0	113
Manganese	93	31	136	10	<2.0	1,100
Mercury	0	--	--	--	--	--
Molybdenum	51	31	5.0	3.5	<4.0	22
Nickel	51	42	[1]--	[1]--	<4.0	17
Selenium	52	18	0.3	0.3	<0.2	0.7
Silver	52	37	1.4	1.1	<2.0	6.0
Strontium	51	0	170	140	11	619
Vanadium	51	37	4.1	2.0	<4.0	37
Zinc	58	0	168	67	4.0	3,236
Deadwood aquifer						
Aluminum	6	4	--	--	<10	40
Arsenic	11	2	2.9	1.3	<1.0	11
Barium	17	0	234	100	14	1,500
Boron	9	0	67	25	11	290
Cadmium	4	3	--	--	<1.0	1.0
Chromium	6	4	--	--	1.0	6.0
Cobalt	5	3	--	--	<2.0	7.8
Copper	10	6	20	1.7	<1.0	184
Iron	34	1	371	80	9.0	2,500
Lead	4	2	--	--	<1.0	2.0
Lithium	7	1	31	9.0	<2.0	140
Manganese	34	10	31	7.0	<1.0	340
Mercury	6	6	--	--	<0.1	<0.1
Molybdenum	7	4	6.1	3.1	<1.0	16.0
Nickel	4	3	--	--	<4.0	6.0
Selenium	10	5	0.4	0.2	<0.2	1.0
Silver	5	3	--	--	<1.0	3.0
Strontium	7	0	442	449	54	1,161
Vanadium	5	3	--	--	<4.0	27
Zinc	11	3	279	40	<3.0	2,430

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Madison aquifer						
Aluminum	26	16	15	4.9	<10	100
Arsenic	60	7	3.6	3.0	<0.5	27
Barium	37	0	85	51	11	300
Boron	63	5	59	20	9.0	588
Cadmium	38	35	--	--	<0.1	10
Chromium	33	32	--	--	<1.0	6.0
Cobalt	32	22	1.8	1.3	<2.0	7.0
Copper	65	46	4.5	0.6	<1.0	134
Iron	101	29	195	20	<3.0	7,400
Lead	34	24	2.2	0.9	<1.0	29
Lithium	41	9	25	7.0	2.0	236
Manganese	99	47	31	2.7	0.6	710
Mercury	35	30	[1]--	[1]--	<0.1	0.3
Molybdenum	39	21	5.7	2.5	<1.0	34
Nickel	19	17	--	--	<4.0	10
Selenium	55	14	1.9	0.7	<0.2	18
Silver	48	42	[1]--	[1]--	<0.2	4.0
Strontium	45	0	501	225	60	3,300
Vanadium	37	26	2.7	2.0	0.7	12
Zinc	72	15	100	13	2.0	1,407
Minnelusa aquifer						
Aluminum	41	31	23	0.7	<10	400
Arsenic	67	11	4.9	2.3	<0.5	30
Barium	57	0	103	68	2.0	400
Boron	101	3	51	30	6.0	340
Cadmium	28	26	--	--	<1.0	3.0
Chromium	48	37	2.5	1.3	<1.0	10
Cobalt	46	28	2.0	1.5	<2.0	8.0
Copper	85	56	15	1.1	<1.0	670
Iron	197	59	199	20	<0.1	3,700
Lead	21	17	[1]--	[1]--	<1.0	30
Lithium	57	1	21	10	4.0	160
Manganese	166	83	70	5.1	<1.0	7,200
Mercury	25	24	--	--	<0.1	0.2
Molybdenum	55	31	8.2	3.0	<1.0	102
Nickel	37	24	3.4	2.8	<2.0	10
Selenium	67	9	1.4	0.5	<0.2	12
Silver	51	36	1.5	1.3	<1.0	5.0
Strontium	57	0	1,547	409	62	11,000
Vanadium	53	18	6.9	5.0	0.7	30
Zinc	96	11	272	33	<3.0	10,000

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Minnekahta aquifer						
Aluminum	1	1	--	--	<10	<10
Arsenic	4	1	2.4	2.1	<1.0	5.0
Barium	4	0	148	125	42	300
Boron	7	0	118	40	19	620
Cadmium	3	3	--	--	<1.0	<1.0
Chromium	4	3	--	--	1.0	<5.0
Cobalt	3	3	--	--	<2.0	<3.0
Copper	10	3	16	15	<2.0	30
Iron	21	9	57	12	0.1	320
Lead	3	1	--	--	1.0	10
Lithium	3	0	8.8	10	5.0	11
Manganese	18	13	13	4.3	<0.02	120
Mercury	3	3	--	--	<0.1	<0.1
Molybdenum	3	1	--	--	6.0	13
Nickel	1	1	--	--	<4.0	<4.0
Selenium	4	0	1.5	1.5	0.3	2.6
Silver	3	2	--	--	<1.0	2.0
Strontium	3	0	626	510	268	1,100
Vanadium	3	2	--	--	<6.0	43
Zinc	10	1	96	61	3.1	360
Inyan Kara aquifer						
Aluminum	65	45	12	5.1	<10	140
Arsenic	90	28	1.1	0.8	<0.5	17
Barium	75	2	12	5.0	<2.0	126
Boron	92	0	125	80	30	670
Cadmium	13	12	--	--	<2.0	<2.0
Chromium	62	56	--	--	<4.0	5.0
Cobalt	62	38	2.0	1.2	<2.0	19
Copper	84	66	4.7	0.2	<2.0	210
Iron	145	20	460	33	1.2	3,600
Lead	1	0	--	--	15	15
Lithium	78	0	103	79	19	455
Manganese	131	21	92	43	<2.0	1,424
Mercury	27	23	[1]--	[1]--	<0.1	1.9
Molybdenum	78	47	5.2	4.0	<1.0	21
Nickel	62	52	[1]--	[1]--	<4.0	9.0
Selenium	89	16	1.6	0.6	<0.2	23
Silver	62	53	[1]--	[1]--	<2.0	4.0
Strontium	79	0	2,133	1,500	31	8,460
Vanadium	79	56	2.2	1.3	<1.0	19
Zinc	90	16	78	20	<3.0	1,803

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Spearfish aquifer						
Aluminum	9	5	17	8.4	<10	62
Arsenic	9	5	0.7	0.4	<0.5	2.4
Barium	9	0	35	15	3.0	132
Boron	9	0	170	114	13	517
Cadmium	0	--	--	--	--	--
Chromium	9	7	--	--	<4.0	4.0
Cobalt	9	5	1.8	1.1	<2.0	5.0
Copper	10	7	9.8	0.02	<2.0	90
Iron	13	5	21	13	<10	80
Lead	0	--	--	--	--	--
Lithium	9	0	55	24	5.0	267
Manganese	12	3	17	7.0	<2.0	91
Mercury	0	--	--	--	--	--
Molybdenum	9	2	8.5	7.0	<4.0	15
Nickel	9	6	3.1	2.4	<4.0	7.0
Selenium	9	2	0.5	0.3	<0.2	1.8
Silver	9	6	1.7	1.5	<2.0	3.0
Strontium	9	0	3,313	2,280	78	9,802
Vanadium	9	5	6.9	0.9	<4.0	45
Zinc	10	0	716	271	6.0	3,096
Sundance aquifer						
Aluminum	3	1	--	--	<10	30
Arsenic	8	4	1.8	1.5	<0.5	5.0
Barium	3	0	7.7	8.0	5.0	10
Boron	7	0	347	378	60	674
Cadmium	1	1	--	--	<2.0	<2.0
Chromium	2	1	--	--	<4.0	10
Cobalt	2	1	--	--	<2.0	4.0
Copper	4	1	2.5	2.5	<2.0	4.0
Iron	7	0	1,101	56	20	6,600
Lead	0	--	--	--	--	--
Lithium	5	0	189	180	70	313
Manganese	7	2	29	18	<1.0	80
Mercury	6	5	--	--	<0.1	0.8
Molybdenum	5	2	3.9	3.4	2.0	7.0
Nickel	2	2	--	--	<4.0	<4.0
Selenium	8	1	55	1.5	0.5	360
Silver	2	1	--	--	<2.0	6.0
Strontium	5	0	5,473	5,900	2,200	7,518
Vanadium	4	2	--	--	<1.0	11
Zinc	5	0	41	40	10	90

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Morrison aquifer						
Aluminum	6	2	22	13	<10	61
Arsenic	6	3	0.9	0.4	<0.5	2.7
Barium	6	0	13	6.0	4.0	48
Boron	6	0	189	126	22	550
Cadmium	0	--	--	--	--	--
Chromium	6	5	--	--	<4.0	4.0
Cobalt	6	4	--	--	<2.0	6.0
Copper	6	3	3.5	3.4	<2.0	6.0
Iron	11	1	191	42	<10	1,700
Lead	0	--	--	--	--	--
Lithium	6	0	123	58	10	454
Manganese	9	2	7.3	5.0	2.0	30
Mercury	0	--	--	--	--	--
Molybdenum	6	3	7.1	4.0	<4.0	24
Nickel	6	5	--	--	<4.0	7.0
Selenium	6	1	0.3	0.4	<0.2	0.5
Silver	6	4	--	--	<2.0	3.0
Strontium	6	0	4,113	3,534	58	9,598
Vanadium	6	3	9.7	2.9	<4.0	44
Zinc	6	0	76	48	4.0	211
Pierre aquifer						
Aluminum	28	16	22	11	<10	75
Arsenic	28	23	[1]--	[1]--	<0.5	1.3
Barium	28	0	22	15	3.0	86
Boron	28	0	425	301	26	1,833
Cadmium	0	--	--	--	--	--
Chromium	28	24	[1]--	[1]--	<4.0	9.0
Cobalt	28	18	1.8	1.1	<2.0	7.0
Copper	28	17	4.5	0.7	<2.0	74
Iron	28	7	21	19	<10	44
Lead	0	--	--	--	--	--
Lithium	28	0	156	97	10	596
Manganese	28	5	250	6.5	<2.0	2,699
Mercury	0	--	--	--	--	--
Molybdenum	28	15	5.5	3.6	<4.0	16
Nickel	28	25	[1]--	[1]--	<4.0	10
Selenium	28	3	0.7	0.6	<0.2	3.0
Silver	28	17	1.9	1.5	<2.0	5.0
Strontium	28	0	2,579	2,227	2,78	8,768
Vanadium	28	22	2.7	1.8	<4.0	13
Zinc	28	3	117	34	<4.0	999

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Graneros aquifer						
Aluminum	10	7	11	8.6	<10	25
Arsenic	10	7	0.4	0.4	<0.5	0.6
Barium	10	1	19	11	<2.0	80
Boron	10	0	304	159	69	927
Cadmium	0	--	--	--	--	--
Chromium	10	9	--	--	<4.0	7.0
Cobalt	10	4	2.6	2.0	<2.0	7.0
Copper	10	6	2.2	1.4	<2.0	6.0
Iron	10	4	15	11	<10	37
Lead	0	--	--	--	--	--
Lithium	10	0	86	82	16	154
Manganese	10	1	32	5.0	<2.0	149
Mercury	0	--	--	--	--	--
Molybdenum	10	3	5.4	5.0	<4.0	12
Nickel	10	5	3.6	3.6	<4.0	6.0
Selenium	10	1	0.4	0.4	<0.2	0.7
Silver	10	6	1.9	1.2	<2.0	6.0
Strontium	10	0	2,250	2,007	167	4,776
Vanadium	10	6	5.4	2.9	<4.0	16
Zinc	10	0	104	70	12	354
Newcastle aquifer						
Aluminum	0	--	--	--	--	--
Arsenic	2	2	--	--	<1.0	<1.0
Barium	1	0	--	--	9.0	9.0
Boron	4	0	205	75	0.1	670
Cadmium	1	1	--	--	<2.0	<2.0
Chromium	0	--	--	--	--	--
Cobalt	0	--	--	--	--	--
Copper	0	--	--	--	--	--
Iron	4	0	1,985	1,095	50	5,700
Lead	0	--	--	--	--	--
Lithium	1	0	--	--	50	50
Manganese	5	1	58	50	<30	120
Mercury	2	1	--	--	<0.1	0.4
Molybdenum	1	1	--	--	<10	<10
Nickel	0	--	--	--	--	--
Selenium	2	0	1.5	1.5	1.0	2.0
Silver	0	--	--	--	--	--
Strontium	1	0	--	--	1,900	1,900
Vanadium	1	0	--	--	3.0	3.0
Zinc	1	0	--	--	770	770

Table 7. Summary of concentrations of trace elements in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
			Alluvial aquifers			
Aluminum	29	19	11	5.0	<10	61
Arsenic	33	17	1.4	0.5	<0.5	7.8
Barium	30	0	36	11	4.0	397
Boron	39	0	243	130	0.3	1,476
Cadmium	1	1	--	--	<1.0	<1.0
Chromium	30	26	[1]--	[1]--	<4.0	9.0
Cobalt	30	18	1.7	1.5	<2.0	4.0
Copper	36	19	7.4	1.1	<2.0	63
Iron	97	22	156	20	<3.0	4,800
Lead	1	1	--	--	<10	<10
Lithium	30	0	112	75	9.0	491
Manganese	82	32	81	5.1	<1.0	2,100
Mercury	0	--	--	--	--	--
Molybdenum	30	11	7.0	5.0	<4.0	37
Nickel	29	22	2.9	1.9	<4.0	11
Selenium	33	7	0.6	0.5	<0.2	2.0
Silver	30	24	[1]--	[1]--	<1.0	5.0
Strontium	30	0	2,390	1,505	91	8,864
Vanadium	30	20	3.8	2.2	<4.0	15
Zinc	36	1	73	19	<4.0	480

[1] Boxplot for constituent is shown in figure 23, although percent of censored values is greater than 80 percent. Mean and median are not reported because they are unreliable.

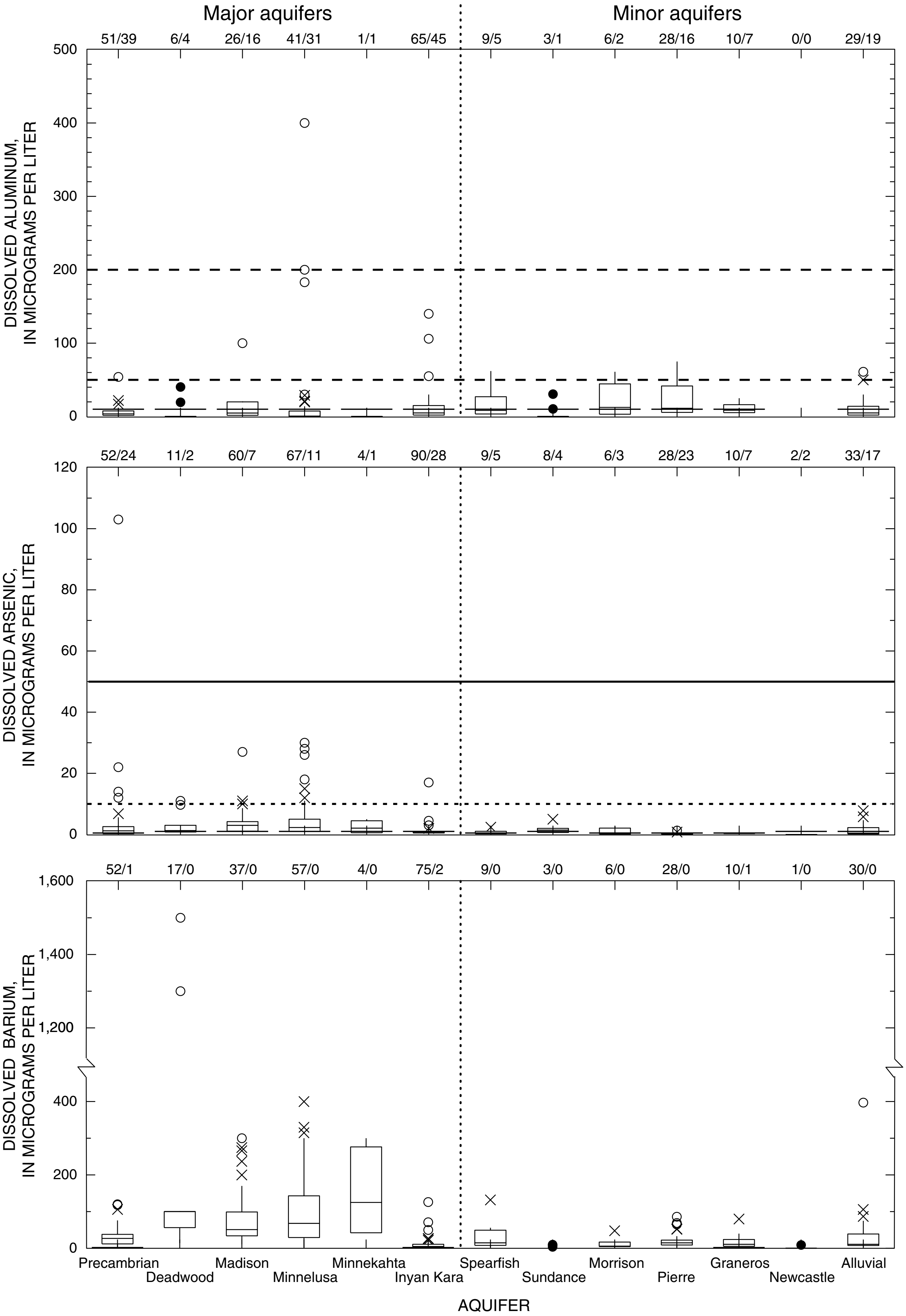


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.

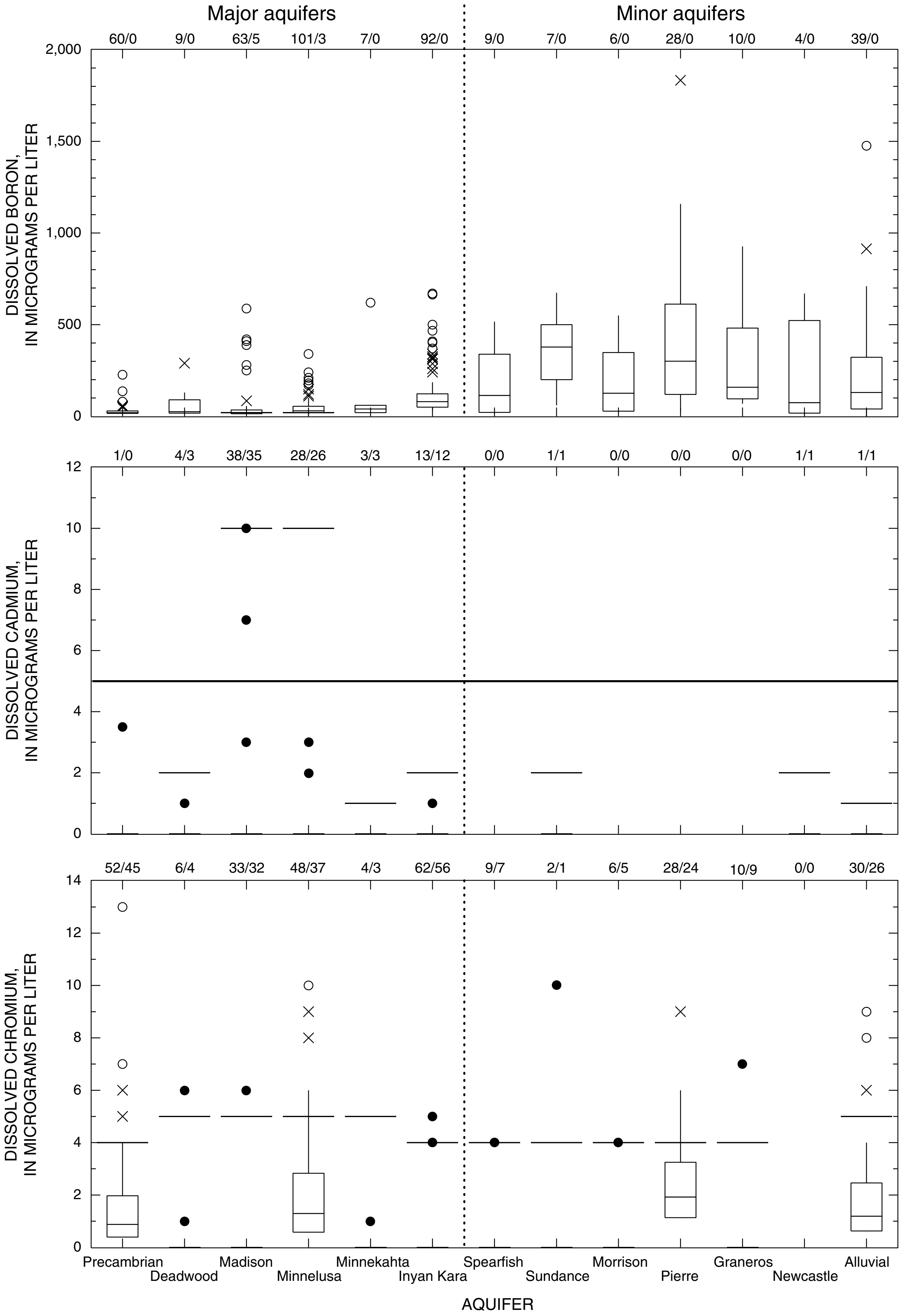


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

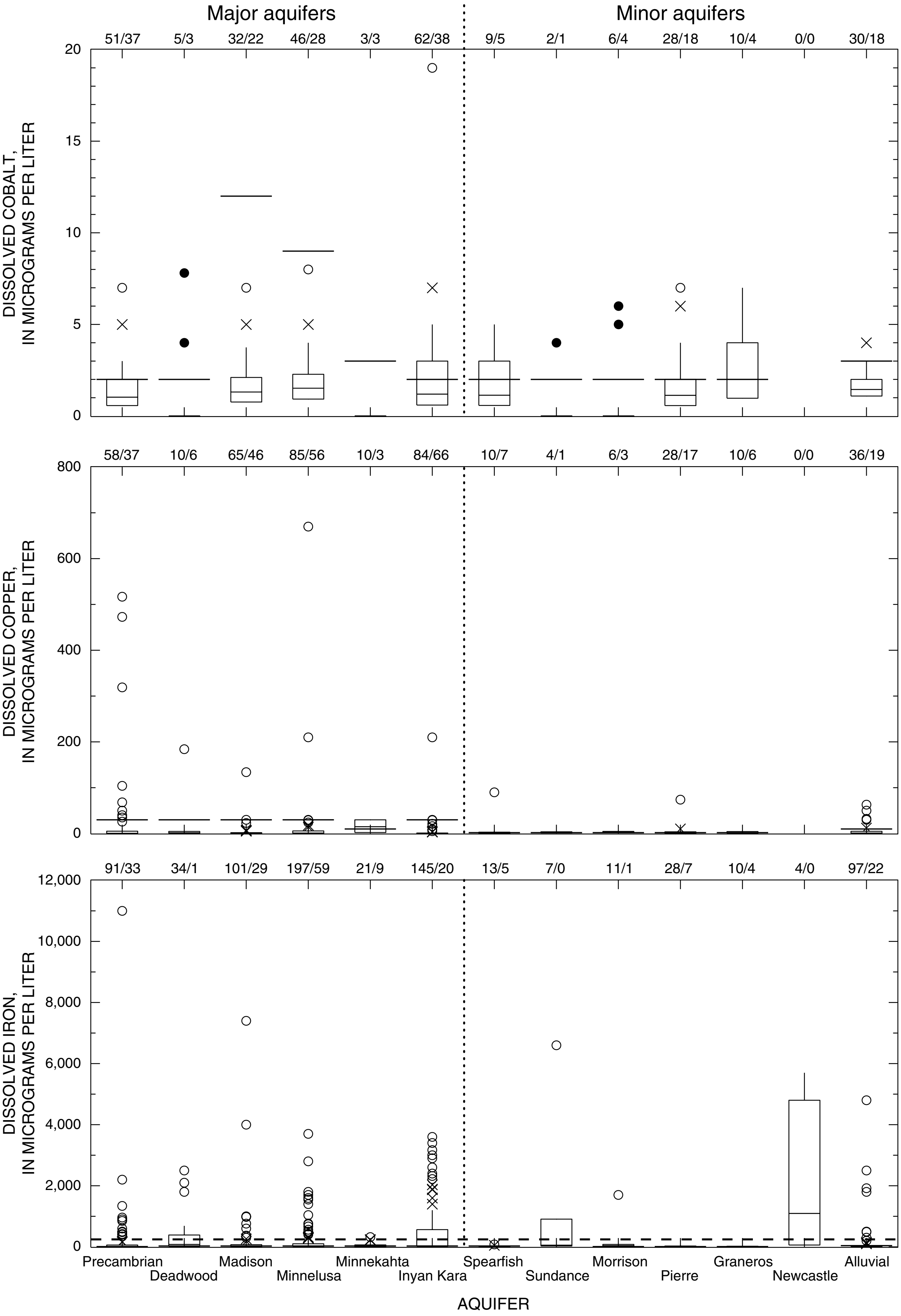


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

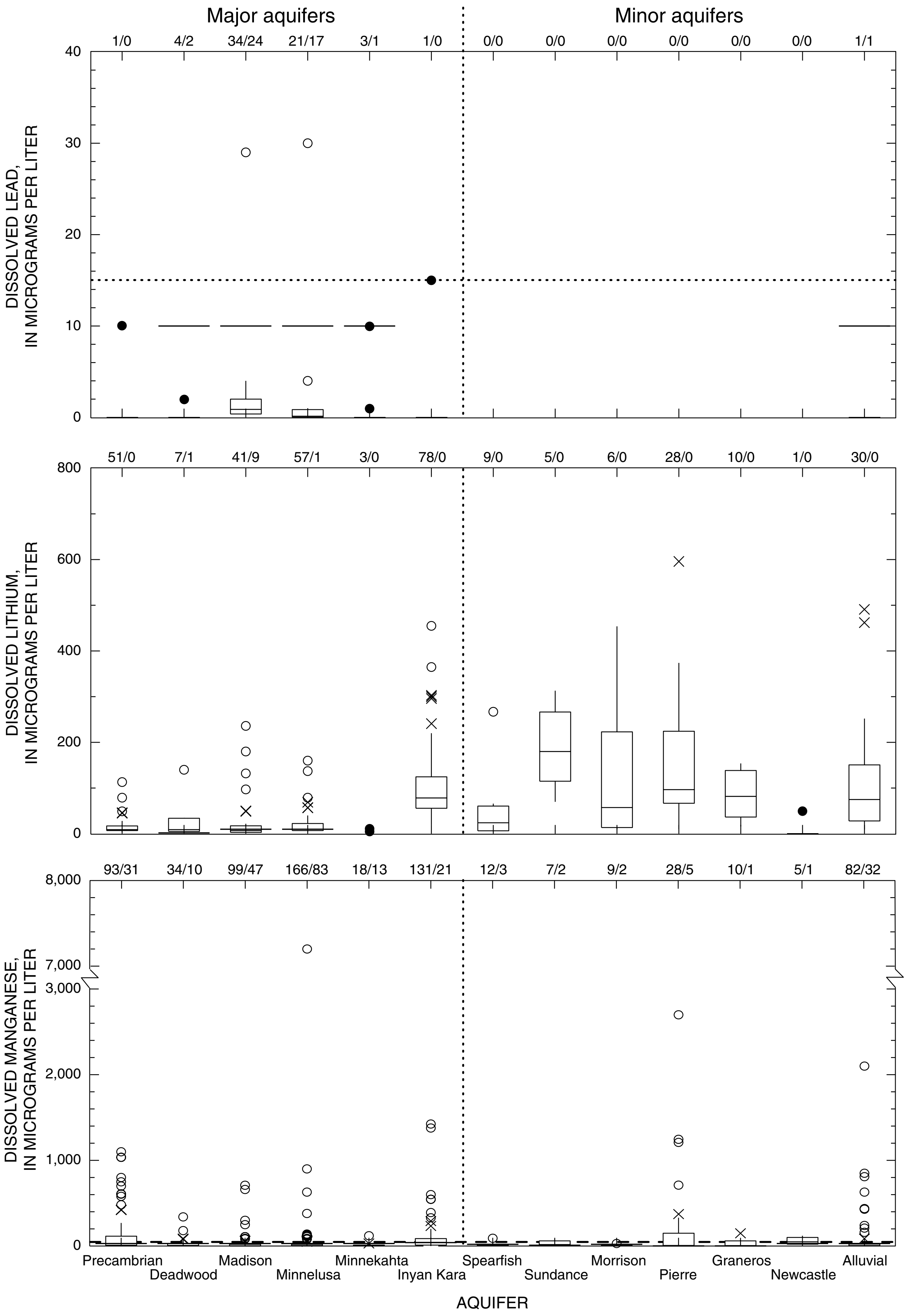


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

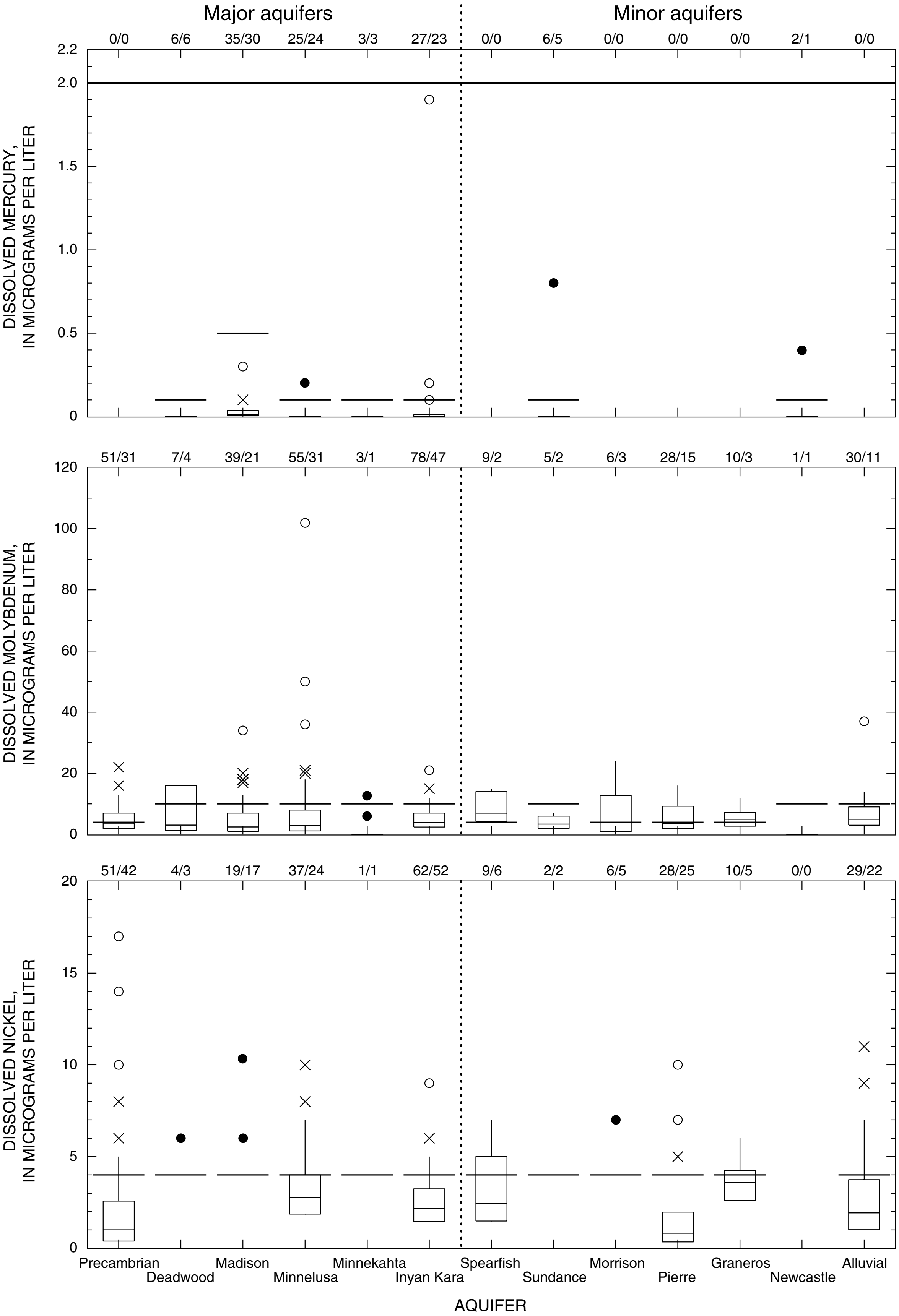


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

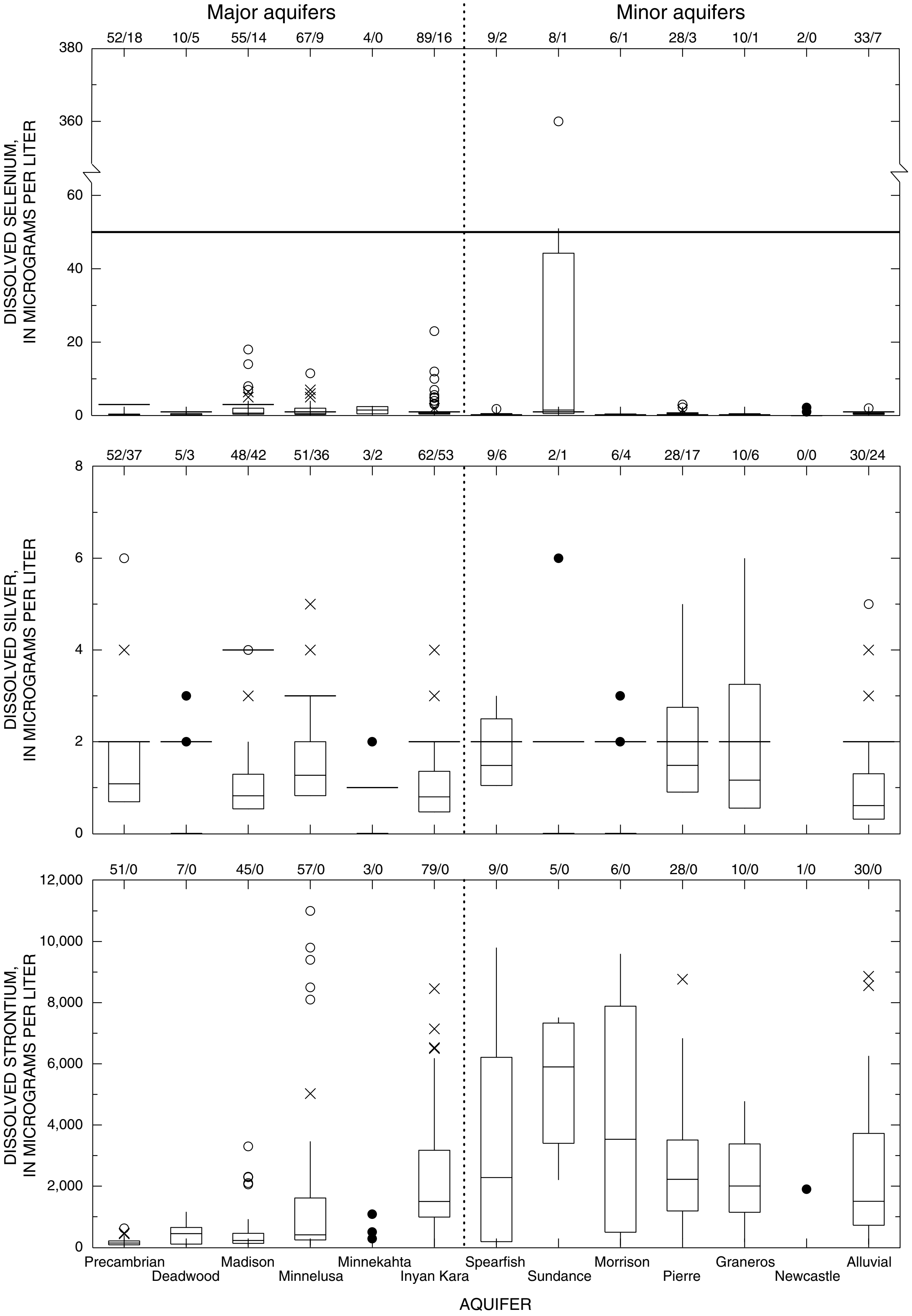


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

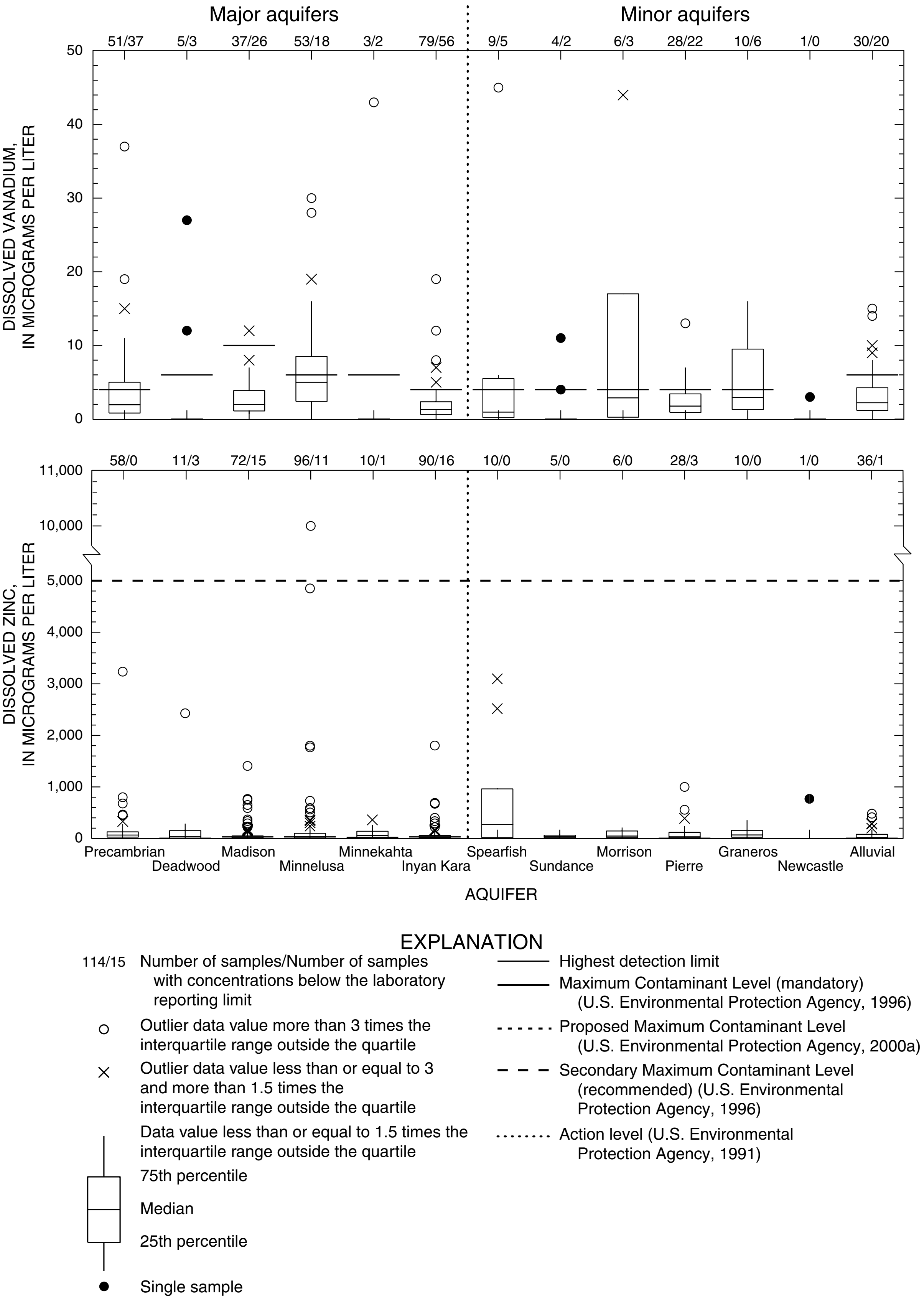


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

Deadwood Aquifer

Samples collected from the Deadwood aquifer have the highest mean barium and zinc concentrations and the highest median iron concentration of samples collected from all the major aquifers. None of the trace element concentrations were found to vary with depth or geographic location.

No samples exceed the current MCL for arsenic; however, 1 of 11 samples exceeds the proposed MCL for arsenic. About 32 percent of the samples (11 of 34 samples) exceed the SMCL for iron and about 18 percent (6 of 34 samples) exceed the SMCL for manganese.

Madison Aquifer

Of all the samples collected from the major aquifers, samples from the Madison aquifer have the lowest median concentrations of boron (equal to samples from the Precambrian aquifers), lithium, manganese, and zinc. Concentrations of aluminum, arsenic, manganese, and selenium generally increase with increasing well depth (fig. 24). The highest lithium concentrations generally occur in the southern Black Hills.

Concentrations of several trace elements in samples collected from the Madison aquifer exceed various drinking-water standards. Two of 26 samples exceed the lower value of the SMCL range for aluminum. No samples exceed the current MCL for arsenic; however, 3 of 60 samples exceed the proposed MCL for arsenic. Two of 38 samples exceed the MCL for cadmium. About 10 percent of the samples exceed the SMCL's for iron (11 of 101 samples) and manganese (10 of 99 samples); almost all of the high iron concentrations are from wells in the southern Black Hills. One of 34 samples exceeds the action level of 15 µg/L for lead.

Minnelusa Aquifer

In the Minnelusa aquifer, concentrations of selenium and strontium generally increase with increasing well depth associated with increasing distance from the outcrop (fig. 24). Concentrations of several other trace elements vary with geographic location. Generally, the highest aluminum concentrations occur in the northern and eastern Black Hills, the highest arsenic concentrations occur in the southern and eastern Black Hills, and the highest lithium concentrations occur in the southern Black Hills.

Concentrations of several trace elements in samples collected from the Minnelusa aquifer exceed various drinking-water standards. About 7 percent of the samples (3 of 41 samples) exceed the lower value of the SMCL range for aluminum; all are from wells located in the northern or eastern Black Hills. No samples exceed the current MCL for arsenic; however, 9 of 67 samples exceed the proposed MCL for arsenic. About 12 percent of the samples (24 of 197 samples) equal or exceed the SMCL for iron. One of 21 samples exceeds the action level for lead. Over 10 percent of the samples (21 of 166 samples) exceed the SMCL for manganese; all are from wells located in the northern or eastern Black Hills. One of 96 samples exceeds the SMCL of 5,000 µg/L for zinc.

Minnekahta Aquifer

Samples collected from the Minnekahta aquifer have the highest median barium concentration of samples collected from the major aquifers. Samples from the Minnekahta aquifer have the lowest mean iron, lithium, and manganese concentrations of the major aquifers.

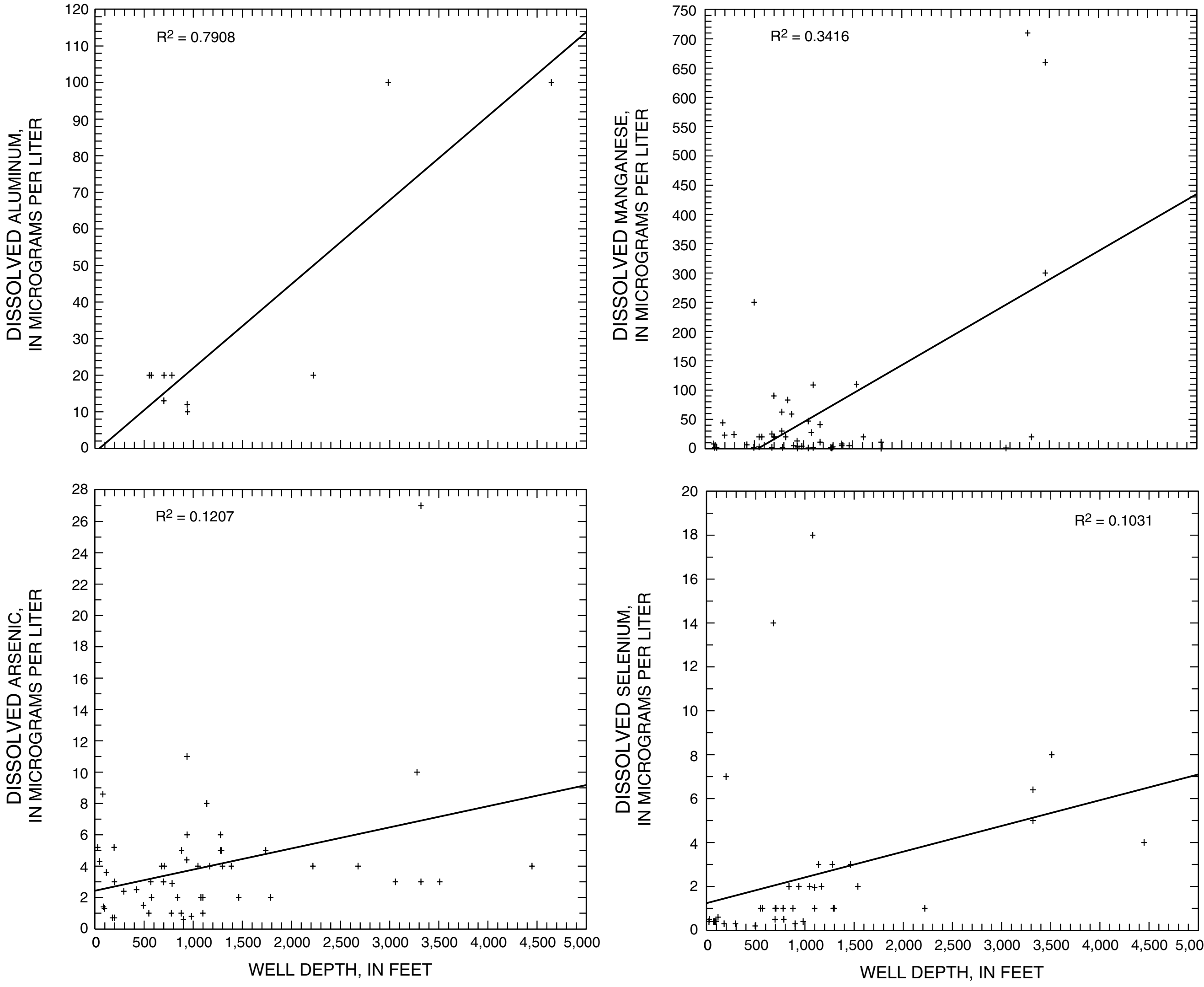
Few samples from the Minnekahta aquifer exceed any of the drinking water standards. One of 21 samples exceeds the SMCL for iron, and 1 of 18 samples exceeds the SMCL for manganese.

Inyan Kara Aquifer

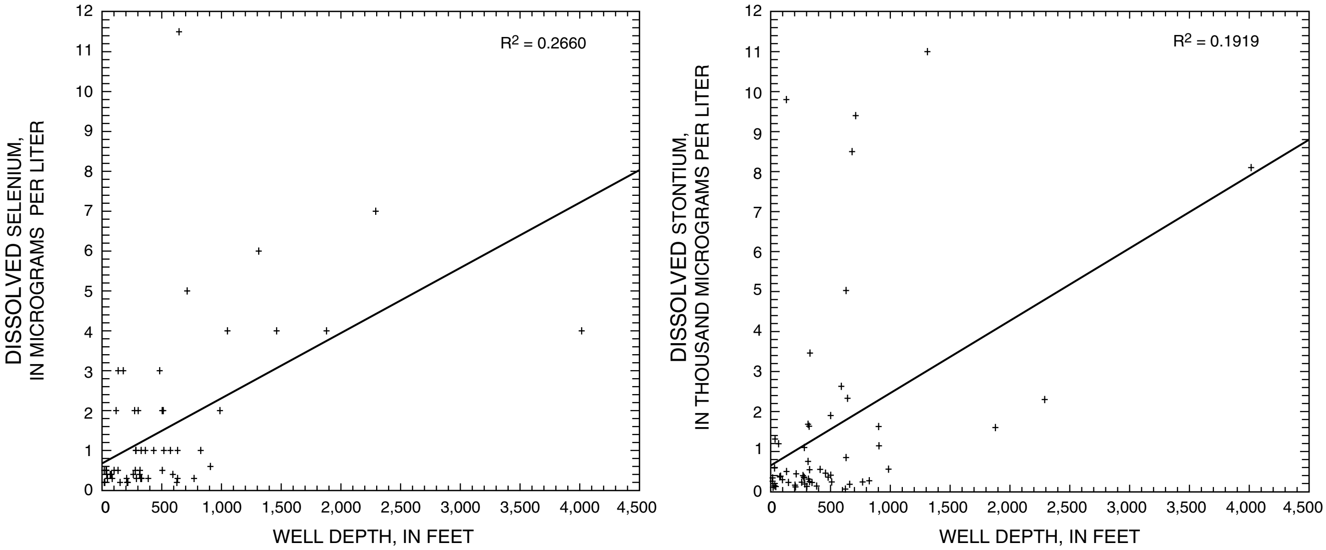
Samples from the Inyan Kara aquifer have the highest mean and median boron, lithium, and strontium concentrations, the highest mean iron concentration, and the highest median manganese concentration of samples from all the major aquifers. Samples from the Inyan Kara aquifer have the lowest mean and median barium concentration and the lowest mean zinc concentration of samples from all the major aquifers.

Relations between various trace element concentrations and well depth in the Inyan Kara aquifer are not apparent; however, a few trace elements vary with geographic location. Generally, the highest lithium, strontium, and zinc concentrations are from wells located in the southern Black Hills, and the highest iron concentrations are from wells in the northern Black Hills.

Of samples collected from the Inyan Kara aquifer, 4 of 65 samples exceed the lower value of the SMCL range for aluminum. About 32 percent of the samples (47 of 145 samples) equal or exceed the SMCL for iron; almost all of these samples are from the northern Black Hills. The source of the undesirable iron concentrations probably is the oxidation and dissolution of iron minerals in the rock (Kyllonen and Peter, 1987). The only sample analyzed for lead has a concentration equal to the action level for lead. About



MADISON AQUIFER



MINNELUSA AQUIFER

Figure 24. Selected relations between trace elements and well depth for selected aquifers.

50 percent of the samples (63 of 131 samples) exceed the SMCL for manganese. No samples exceed the current MCL for arsenic; however, 1 of 90 samples exceeds the proposed MCL for arsenic.

Minor Aquifers

Although few samples from the minor aquifers, with the exception of alluvial aquifers, were analyzed for trace elements, concentrations in samples from each minor aquifer exceed various SMCL's and MCL's. In the Spearfish aquifer, 1 of 9 samples exceeds the lower value of the SMCL range for aluminum, and 1 of 12 samples exceeds the SMCL for manganese. In the Sundance aquifer, 2 of 7 samples exceed the SMCL's for iron and manganese, and 2 of 8 samples exceed the MCL of 50 µg/L for selenium. In the Morrison aquifer, 1 of 6 samples exceeds the lower value of the SMCL range for aluminum, and 1 of 11 samples exceeds the SMCL for iron. In the Pierre aquifer, 4 of 28 samples exceed the lower value of the SMCL range for aluminum, and almost 30 percent of the samples (8 of 28 samples) exceed the SMCL for manganese. Thirty percent of the samples (3 of 10 samples) from the Graneros aquifer exceed the SMCL for manganese. In the Newcastle aquifer, 2 of 4 samples exceed the SMCL for iron, and 3 of 5 samples exceed the SMCL for manganese.

In alluvial aquifers, 2 of 29 samples exceed the lower value of the SMCL range for aluminum. About 10 percent of the samples (8 of 97 samples) exceed the SMCL for iron, and about 15 percent (12 of 82 samples) exceed the SMCL for manganese. Almost all of the samples from alluvial aquifers that exceed drinking-water standards are located downgradient from the central core of the Black Hills.

Radionuclides

Radionuclides are unstable isotopes and have a certain probability of decay (Clark and Fritz, 1997). Radionuclides exist throughout the environment. Most occur naturally like uranium, thorium, radium, and radon, while others are mostly or entirely manufactured like technetium, plutonium, neptunium, and americium (Langmuir, 1997). More than 1,700 radionuclides have been identified (Clark and Fritz, 1997).

Radioactive decay series consist of a succession of radionuclides each with different decay rates. In each decay series, the original elements and each successive "daughter" product disintegrate, forming radionuclides until a stable lead isotope is formed. The decay rate usually is expressed as a half-life, which is the length of time required for one-half the quantity present to disintegrate. Uranium (^{238}U and ^{235}U) and thorium are the original elements in the three natural decay series (Wanty and Nordstrom, 1993) and give rise to most of the naturally occurring radioactivity in water (Hem, 1985).

Uranium concentrations between 0.1 and 10 µg/L are common in most natural waters and concentrations greater than 1,000 µg/L can occur in water associated with uranium-ore deposits (Hem, 1985). Concentrations of radium in natural water generally are less than 1 pCi/L. Thorium probably is more abundant than uranium in most rocks, but is less soluble, so thorium generally has lower concentrations in water.

Radioactivity is the release of energy and energetic particles by changes occurring within atomic or nuclear structures (Hem, 1985). Alpha, beta, and gamma radiation are types of radiation that commonly are measured in ground water. Radionuclide analyses can be expressed in terms of disintegrations per unit time (typically in units of picocuries per liter) or in mass units (typically in units of micrograms per liter).

Summary statistics for selected radionuclides, including alpha radioactivity as thorium-230, gross alpha as uranium, gross beta as cesium-138 and as strontium/yttrium-90, radium-226, radium-228, radon-222, thorium, tritium, and uranium are presented in table 8. The significance of the various radionuclides is described in table 1. Boxplots are presented in figure 25 for each of the radionuclides.

The drinking-water standard for gross alpha-particle activity given in table 1 cannot be compared directly to any of the gross alpha concentrations used in this study. The analyses for alpha radioactivity reported by the USGS excludes radon, but not uranium, as required by the drinking-water standard. Therefore, samples with an alpha radioactivity greater than 15 pCi/L (picocuries per liter) may exceed the drinking-water standard, but this cannot be known without knowing the contribution of uranium to gross alpha. According to Garold Carlson (U.S. Environmental Protection Agency, written commun., 1999), the uranium contribution can be estimated by multiplying the uranium concentration in micrograms per liter by 0.7. This value then can be subtracted from the alpha radioactivity determined by the USGS and the resulting concentration compared to the drinking-water standard. This conversion was not performed for the statistics presented in table 8, but was performed before comparing gross alpha concentrations to the drinking-water standard.

Table 8. Summary of concentrations of radionuclides in ground water

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Precambrian aquifers						
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	0	--	--	--	--	--
Gross beta as cesium-137	0	--	--	--	--	--
Gross beta as strontium/yttrium-90	0	--	--	--	--	--
Radium-226	0	--	--	--	--	--
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	51	31	5.9	4.1	<5.0	23
Tritium	0	--	--	--	--	--
Uranium (µg/L)	51	7	2.3	1.1	<0.2	10
Deadwood aquifer						
Alpha radioactivity as thorium-230	1	0	--	--	3.7	3.7
Gross alpha as uranium-natural	2	0	56	56	16	95
Gross alpha as uranium-natural (µg/L)	27	4	26	5.8	<0.4	180
Gross beta as cesium-137	28	2	8.7	6.2	2.6	34
Gross beta as strontium/yttrium-90	27	2	7.0	4.5	2.0	33
Radium-226	26	1	6.0	0.7	<0.1	66
Radium-228	23	17	0.9	0.9	<1.0	1.8
Radon-222	16	1	1,971	1,200	<80	6,600
Thorium (µg/L)	4	3	--	--	<5	10
Tritium	1	0	--	--	139	139
Uranium (µg/L)	29	12	2.0	1.3	0.7	9.7
Madison aquifer						
Alpha radioactivity as thorium-230	16	3	4.6	4.1	1.1	16
Gross alpha as uranium-natural	8	1	7.6	7.4	2.2	14
Gross alpha as uranium-natural (µg/L)	30	1	7.7	6.2	1.7	21
Gross beta as cesium-137	36	3	5.3	4.4	2.5	19
Gross beta as strontium/yttrium-90	29	0	4.0	3.3	2.0	13
Radium-226	12	1	1.2	1.0	<0.1	3.0
Radium-228	8	8	--	--	<1.0	<1.0
Radon-222	12	2	186	190	<80	300
Thorium (µg/L)	18	13	7.4	5.5	<5.0	22
Tritium	27	10	29	6.0	<1.0	105
Uranium (µg/L)	45	0	3.8	2.3	0.1	39

Table 8. Summary of concentrations of radionuclides in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
		Minnelusa aquifer				
Alpha radioactivity as thorium-230	11	2	19	7.1	<3.0	100
Gross alpha as uranium-natural	10	3	7.0	4.8	<3.3	19
Gross alpha as uranium-natural (µg/L)	29	4	16	7.8	4.2	140
Gross beta as cesium-137	31	5	6.1	4.4	2.0	21
Gross beta as strontium/yttrium-90	27	4	4.9	3.8	1.9	16
Radium-226	17	0	3.1	0.4	0.1	45
Radium-228	5	5	--	--	<1.0	<1.0
Radon-222	5	1	162	170	<80	280
Thorium (µg/L)	35	17	8.8	5.1	<5.0	33
Tritium	18	8	15	1.5	<1.0	100
Uranium (µg/L)	56	0	4.2	3.4	0.2	13
		Minnekahta aquifer				
Alpha radioactivity as thorium-230	2	0	4.4	4.4	2.1	6.7
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	2	0	5.1	5.1	3.0	7.2
Gross beta as cesium-137	3	1	--	--	<0.6	5.8
Gross beta as strontium/yttrium-90	2	1	--	--	<0.6	4.3
Radium-226	2	0	0.3	0.3	0.1	0.4
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	1	1	--	--	<5.0	<5.0
Tritium	2	0	52	52	24	79
Uranium (µg/L)	4	0	3.5	2.9	1.3	7.1
		Inyan Kara aquifer				
Alpha radioactivity as thorium-230	0	0	--	--	--	--
Gross alpha as uranium-natural	17	5	25	9.5	5.6	150
Gross alpha as uranium-natural (µg/L)	32	10	42	17	8.3	270
Gross beta as cesium-137	28	5	14	11	4.3	43
Gross beta as strontium/yttrium-90	28	5	13	11	3.9	39
Radium-226	34	0	4.1	1.4	0.2	43
Radium-228	3	3	--	--	<2.0	<3.0
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	65	37	6.3	4.5	<5.0	36
Tritium	2	2	--	--	<3.0	<3.0
Uranium (µg/L)	77	9	7.7	2.1	0.1	109

Table 8. Summary of concentrations of radionuclides in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Spearfish aquifer						
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	0	--	--	--	--	--
Gross beta as cesium-137	0	--	--	--	--	--
Gross beta as strontium/yttrium-90	0	--	--	--	--	--
Radium-226	0	--	--	--	--	--
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	9	3	9.9	10	<5.0	17
Tritium	0	--	--	--	--	--
Uranium (µg/L)	9	0	8.2	4.4	0.6	46
Sundance aquifer						
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	2	1	--	--	<20	75
Gross alpha as uranium-natural (µg/L)	5	3	--	--	<15	110
Gross beta as cesium-137	5	2	13	12	8.6	21
Gross beta as strontium/yttrium-90	5	2	12	11	7.5	19
Radium-226	6	0	0.9	0.4	0.1	3.4
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	2	0	22	22	6.0	37
Tritium	0	--	--	--	--	--
Uranium (µg/L)	6	1	9.8	9.8	<0.1	19
Morrison aquifer						
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	0	--	--	--	--	--
Gross beta as cesium-137	0	--	--	--	--	--
Gross beta as strontium/yttrium-90	0	--	--	--	--	--
Radium-226	0	--	--	--	--	--
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	6	5	--	--	<5.0	9.0
Tritium	0	--	--	--	--	--
Uranium (µg/L)	6	1	19	11	<0.2	51

Table 8. Summary of concentrations of radionuclides in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
		Pierre aquifer				
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	0	--	--	--	--	--
Gross beta as cesium-137	0	--	--	--	--	--
Gross beta as strontium/yttrium-90	0	--	--	--	--	--
Radium-226	0	--	--	--	--	--
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	27	13	8.6	5.6	<5.0	24
Tritium	0	--	--	--	--	--
Uranium (µg/L)	28	1	15	13	<0.2	54
		Graneros aquifer				
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	0	--	--	--	--	--
Gross beta as cesium-137	0	--	--	--	--	--
Gross beta as strontium/yttrium-90	0	--	--	--	--	--
Radium-226	0	--	--	--	--	--
Radium-228	0	--	--	--	--	--
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	10	4	11	9.5	<5.0	32
Tritium	0	--	--	--	--	--
Uranium (µg/L)	10	1	12	8.3	<0.2	40
		Newcastle aquifer				
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	1	1	--	--	<4.4	<4.4
Gross alpha as uranium-natural (µg/L)	2	2	--	--	<6.5	<27
Gross beta as cesium-137	2	0	12	12	9.6	15
Gross beta as strontium/yttrium-90	2	0	12	12	9.0	14
Radium-226	2	0	0.6	0.6	0.3	1.0
Radium-228	1	1	--	--	<3.0	<3.0
Radon-222	0	--	--	--	--	--
Thorium (µg/L)	0	--	--	--	--	--
Tritium	0	--	--	--	--	--
Uranium (µg/L)	1	0	--	--	2.1	2.1

Table 8. Summary of concentrations of radionuclides in ground water—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; --, not analyzed or not determined; <, less than indicated detection limit]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Alluvial aquifers						
Alpha radioactivity as thorium-230	0	--	--	--	--	--
Gross alpha as uranium-natural	0	--	--	--	--	--
Gross alpha as uranium-natural (µg/L)	1	0	--	--	2.0	2.0
Gross beta as cesium-137	1	0	--	--	3.8	3.8
Gross beta as strontium/yttrium-90	1	0	--	--	3.0	3.0
Radium-226	4	0	0.2	0.2	0.1	0.3
Radium-228	3	1	--	--	<1.0	4.0
Radon-222	4	1	477	280	<80	1,300
Thorium (µg/L)	29	13	7.5	5.0	<5.0	29
Tritium	0	--	--	--	--	--
Uranium (µg/L)	29	1	15	10	<0.2	62

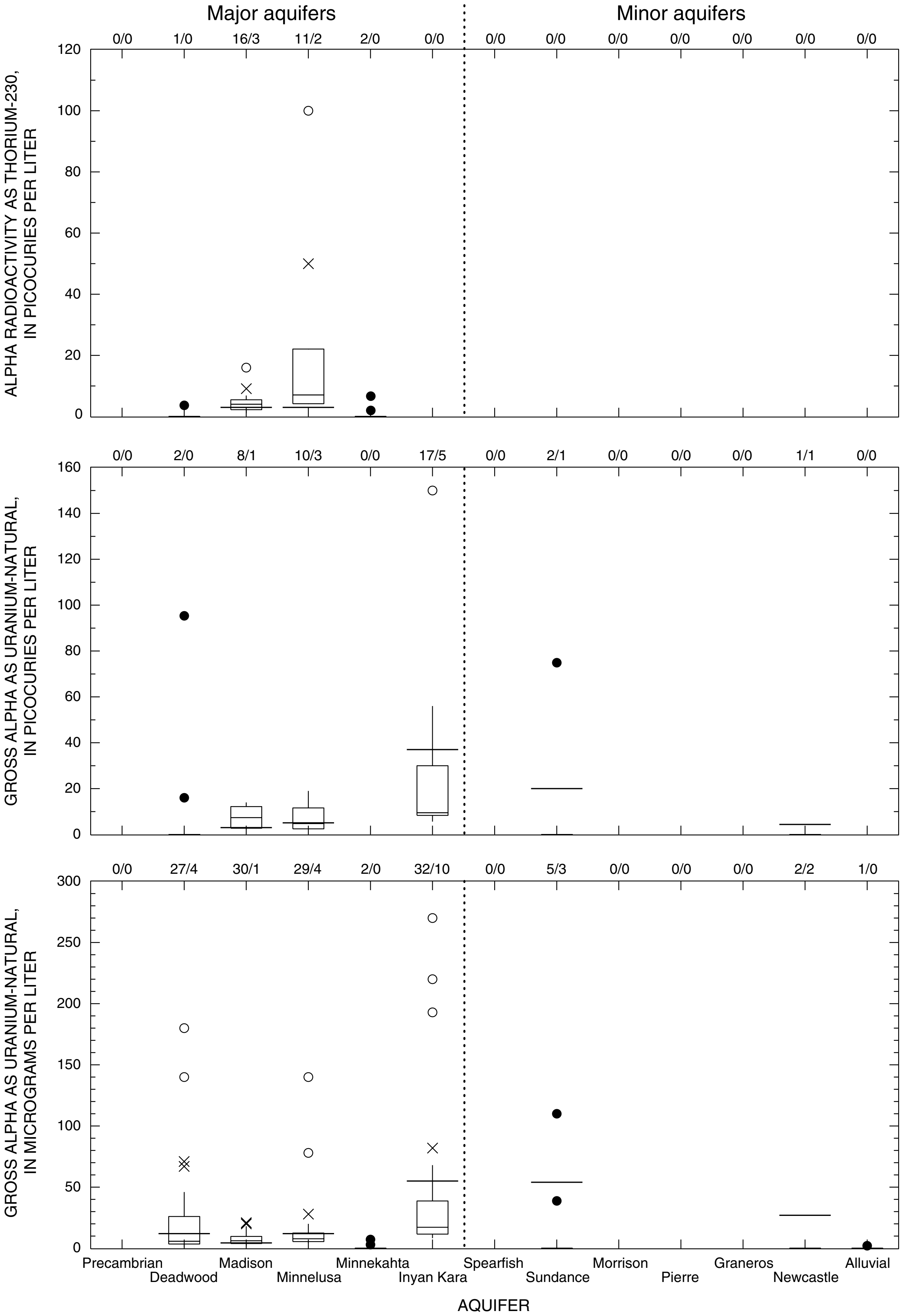


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.

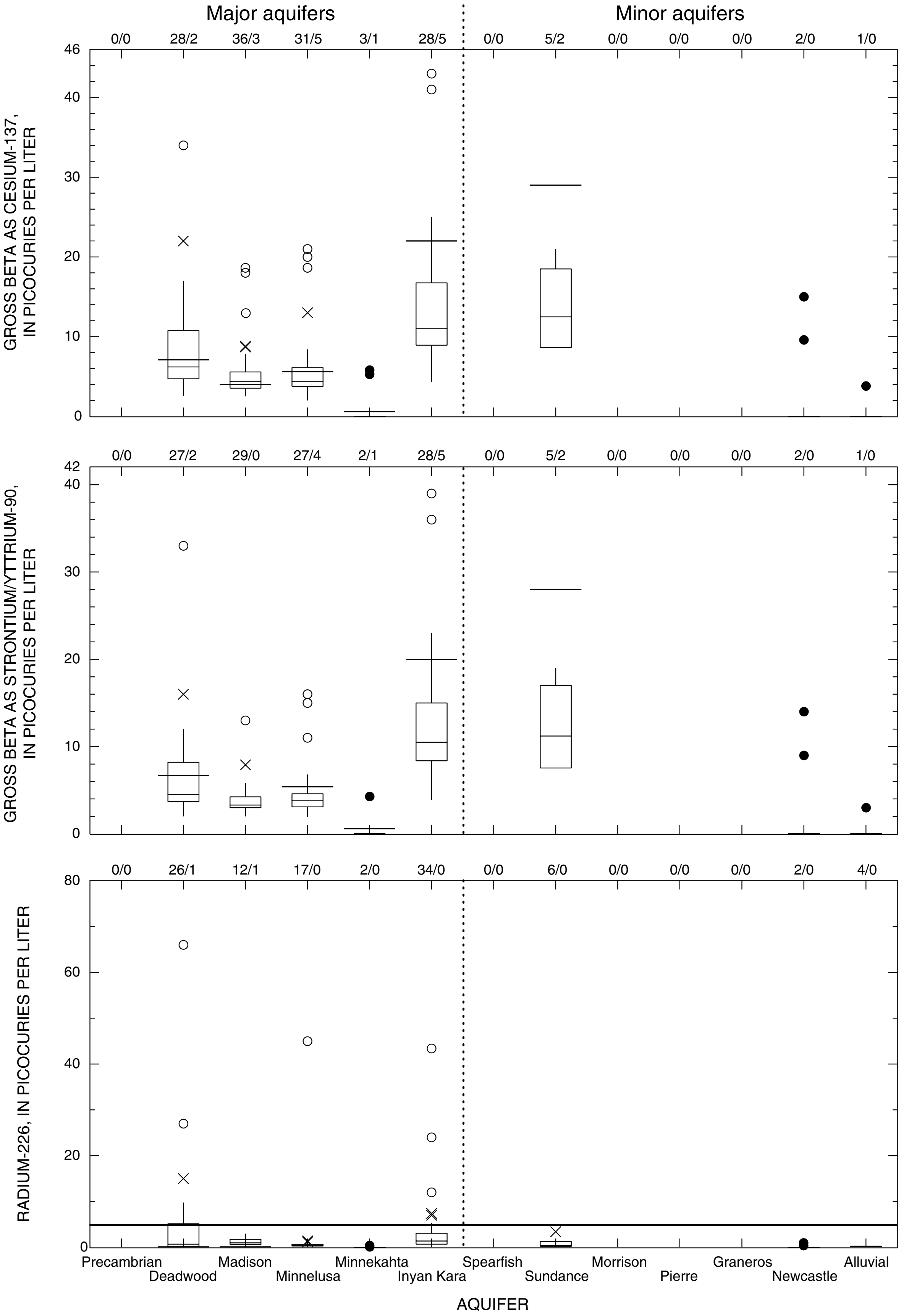


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.--Continued

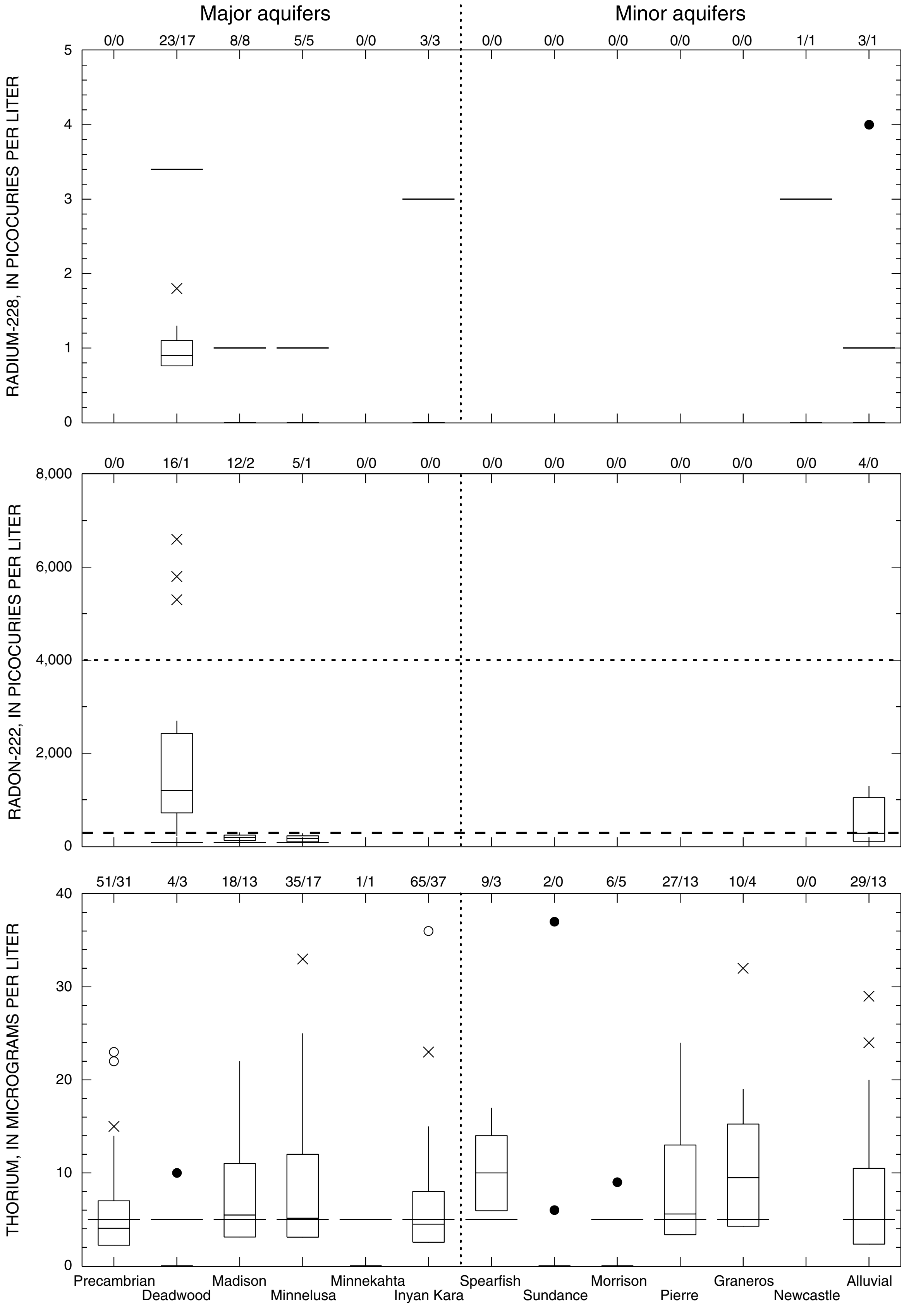


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.--Continued

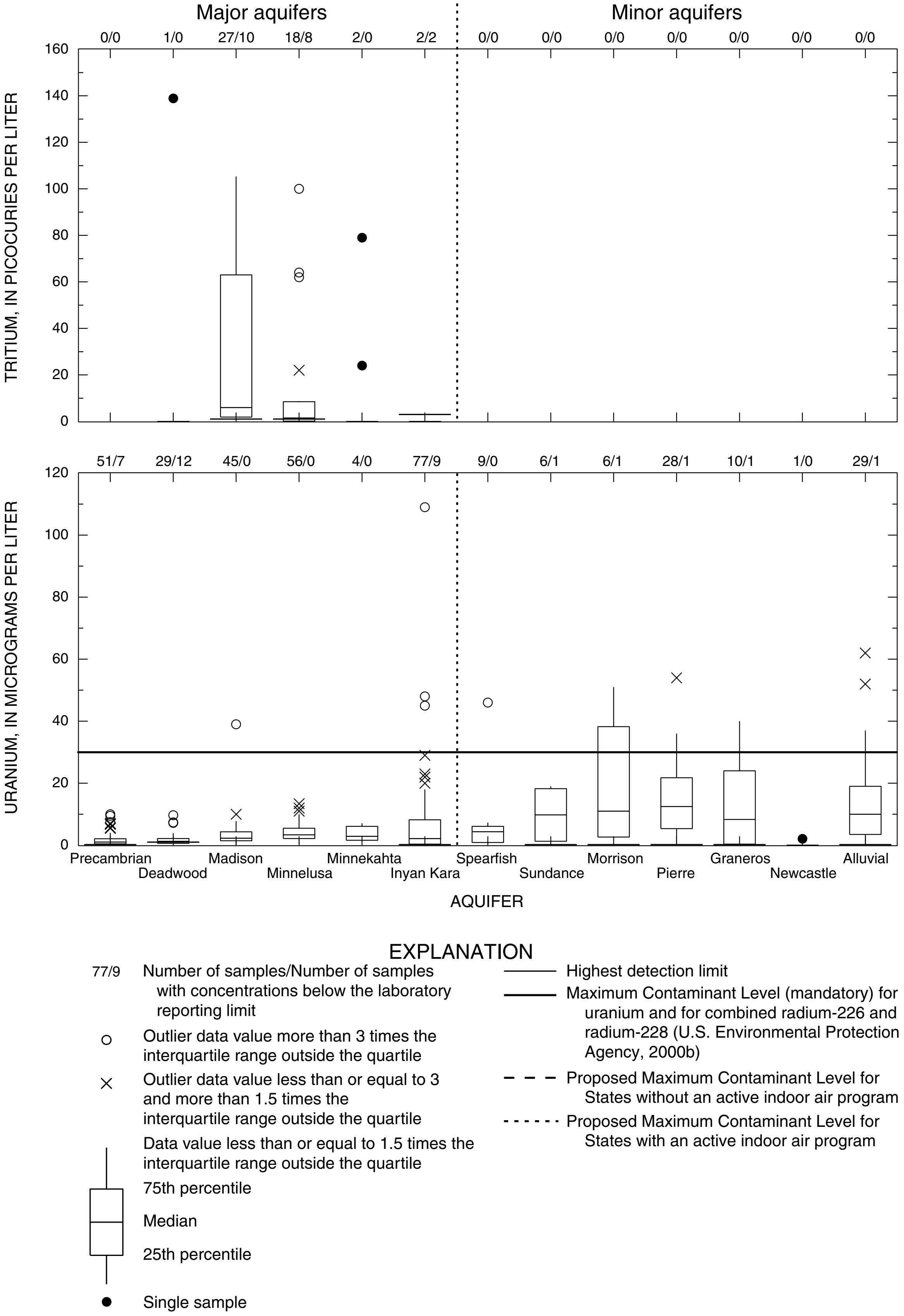


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.--Continued

Also, the drinking-water standard for radium is a combined standard for radium-226 and radium-228. Often, only the radium-226 concentration was determined for most analyses reported by the USGS. Samples with radium-226 concentrations greater than 5 pCi/L exceed the MCL, but samples with concentrations less than 5 pCi/L also may exceed the standard depending on the radium-228 concentrations, which usually are not known for the data used in this study. When possible, concentrations of radium-226 and radium-228 were added. However, in the following sections the number of samples that exceed drinking-water standards for radium should be considered a minimum value because other additional samples also may exceed.

Concentrations that exceed the drinking-water standard for gross beta as strontium/yttrium-90 reported by the USGS cannot be determined by comparison to the standard for strontium-90 because the USGS data include yttrium. It should be noted that any samples that exceed 8 pCi/L for gross beta as strontium/yttrium-90 may exceed the standard for strontium-90.

Because few or no samples were collected from several major aquifers for many radionuclides, comparisons between mean and median concentrations will not be made in this section. General comparisons among the aquifers will be made in this section, and additional discussions on radionuclides for selected aquifers will be presented.

In general, gross alpha, gross beta, and radium-226 is higher in the Inyan Kara and Deadwood aquifers than in the Madison, Minnelusa, and Minnekahta aquifers (fig. 25). Radon-222 concentrations are much higher, and thorium and uranium concentrations are lower in the Deadwood aquifer than in the Madison and Minnelusa aquifers. Radon-222 concentrations also can be high in alluvial aquifers. Uranium concentrations may be high in the Inyan Kara aquifer and have considerable variability in the Sundance, Morrison, Pierre, Graneros, and alluvial aquifers.

Deadwood Aquifer

Concentrations of some radionuclides, especially radon and radium, are known to be high in the Deadwood Formation (Rounds, 1991). Therefore, it is not surprising that water samples from the Deadwood aquifer have elevated concentrations of radon and radium-226. Samples from the Deadwood aquifer have lower uranium concentrations relative to other aquifers, which may be due to the reducing conditions of the Deadwood aquifer (Rounds, 1991).

Concentrations of gross alpha as uranium-natural (micrograms per liter) generally increase with increasing well depth (fig. 26) and are highest in the eastern Black Hills. The highest gross beta concentrations (as both cesium-137 and strontium/yttrium-90) and highest uranium concentrations also occur in the eastern Black Hills.

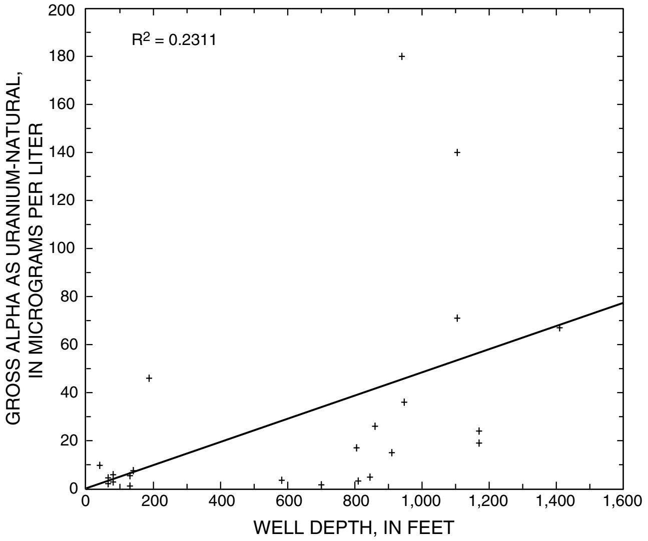
More than 30 percent of the samples (8 of 26) analyzed for radium-226 or radium-226 and radium-228 exceed the MCL of 5 pCi/L for the combined radium-226 and radium-228 standard. Almost 88 percent of the samples (14 of 16) exceed the proposed MCL of 300 pCi/L for radon in States without an active indoor air program; three of these samples also exceed the proposed MCL of 4,000 pCi/L for radon in States with an active indoor air program (fig. 27).

Madison Aquifer

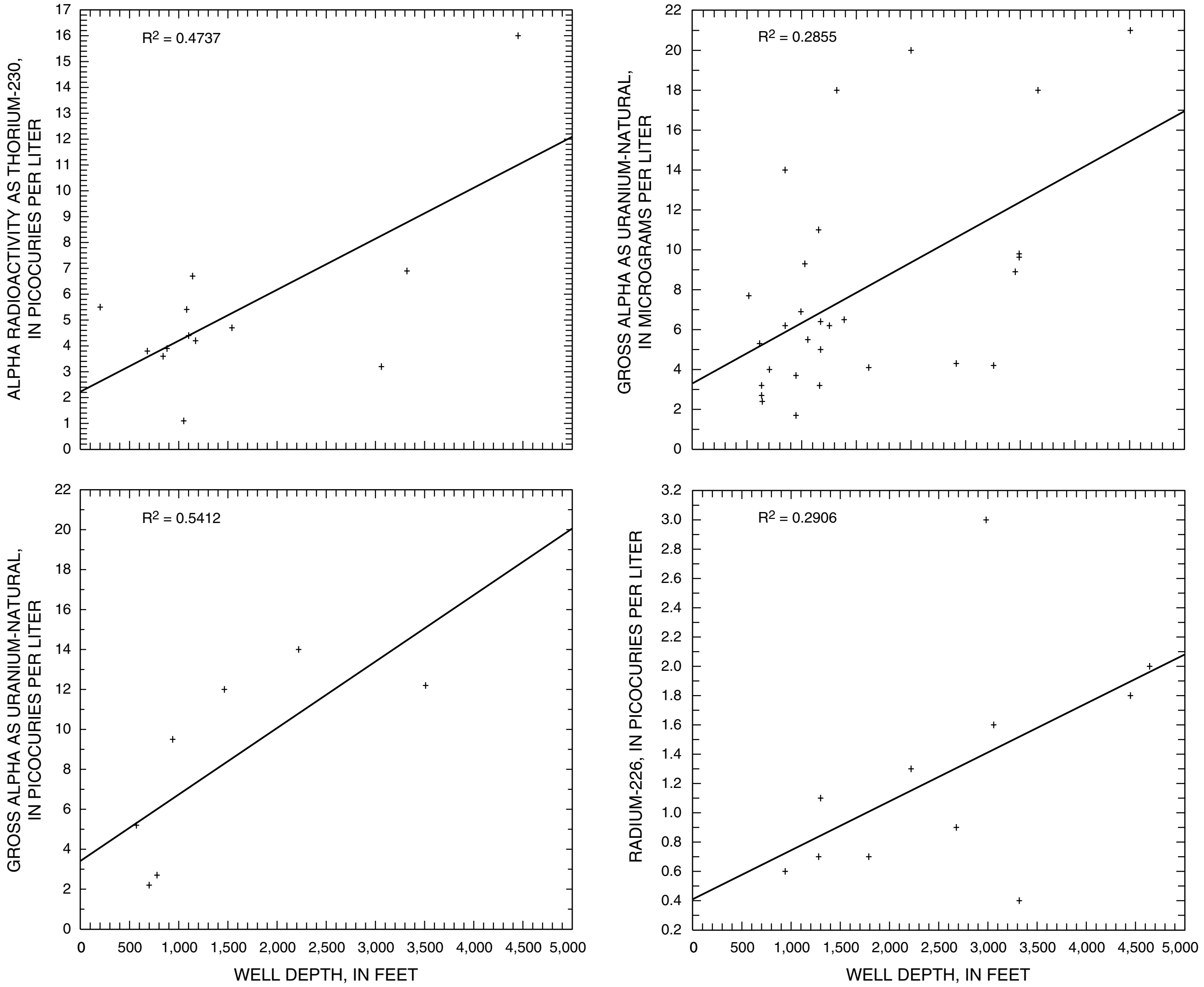
Water from the Madison aquifer generally is low in radionuclide concentrations. Carda (1975) reported that samples collected in the Black Hills area from the Madison aquifer contained no detectable concentrations of radionuclides; however, three Madison wells outside the study area had high concentrations of radium-226 ranging from 190 pCi/L at Midland (about 90 miles east of the study area) to 511 pCi/L at Phillip (about 50 miles east of the study area).

Gross alpha concentrations (measured as alpha radioactivity as thorium-230 and as uranium-natural in both picocuries per liter and micrograms per liter) and radium-226 concentrations generally increase with increasing well depth (fig. 26). Concentrations of other radionuclides vary with geographic location. The highest gross beta concentrations, as both cesium-137 and strontium/yttrium-90, occur in the southern Black Hills. The highest thorium concentrations occur in the eastern and southern Black Hills, and the highest tritium concentrations occur in the eastern and northern Black Hills. Because the only radon concentrations were available from wells in the eastern Black Hills, it is not known if radon concentrations vary with geographic location.

One of 45 samples exceeds the MCL of 30 μg/L for uranium. This sample was collected from a well located in the southern Black Hills. One of 12 samples exceeds the proposed MCL for radon in States without an active indoor air program, but this sample does not exceed the proposed MCL for radon in States with an active indoor air program. This sample was collected from a well in the eastern Black Hills.

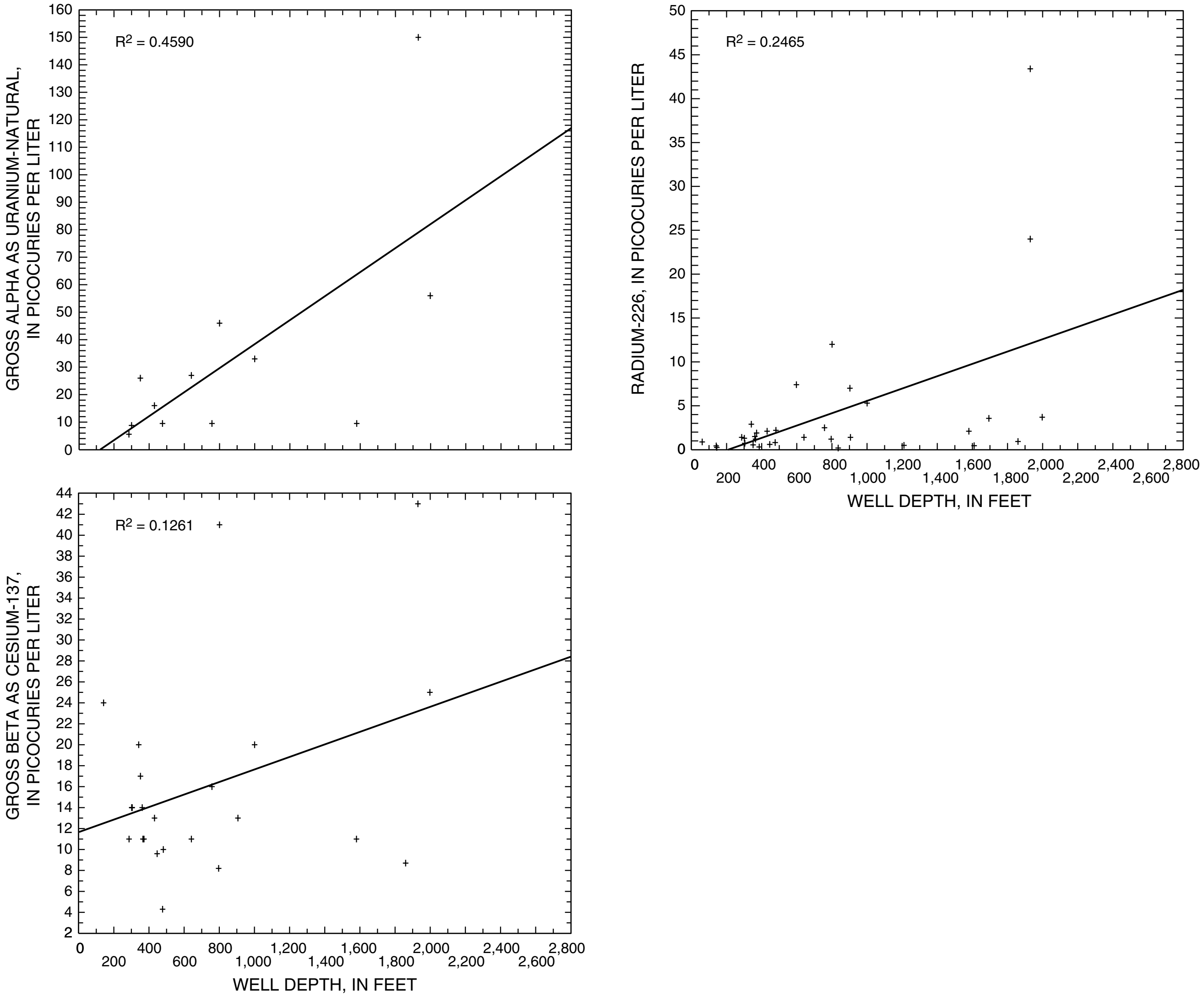


DEADWOOD AQUIFER



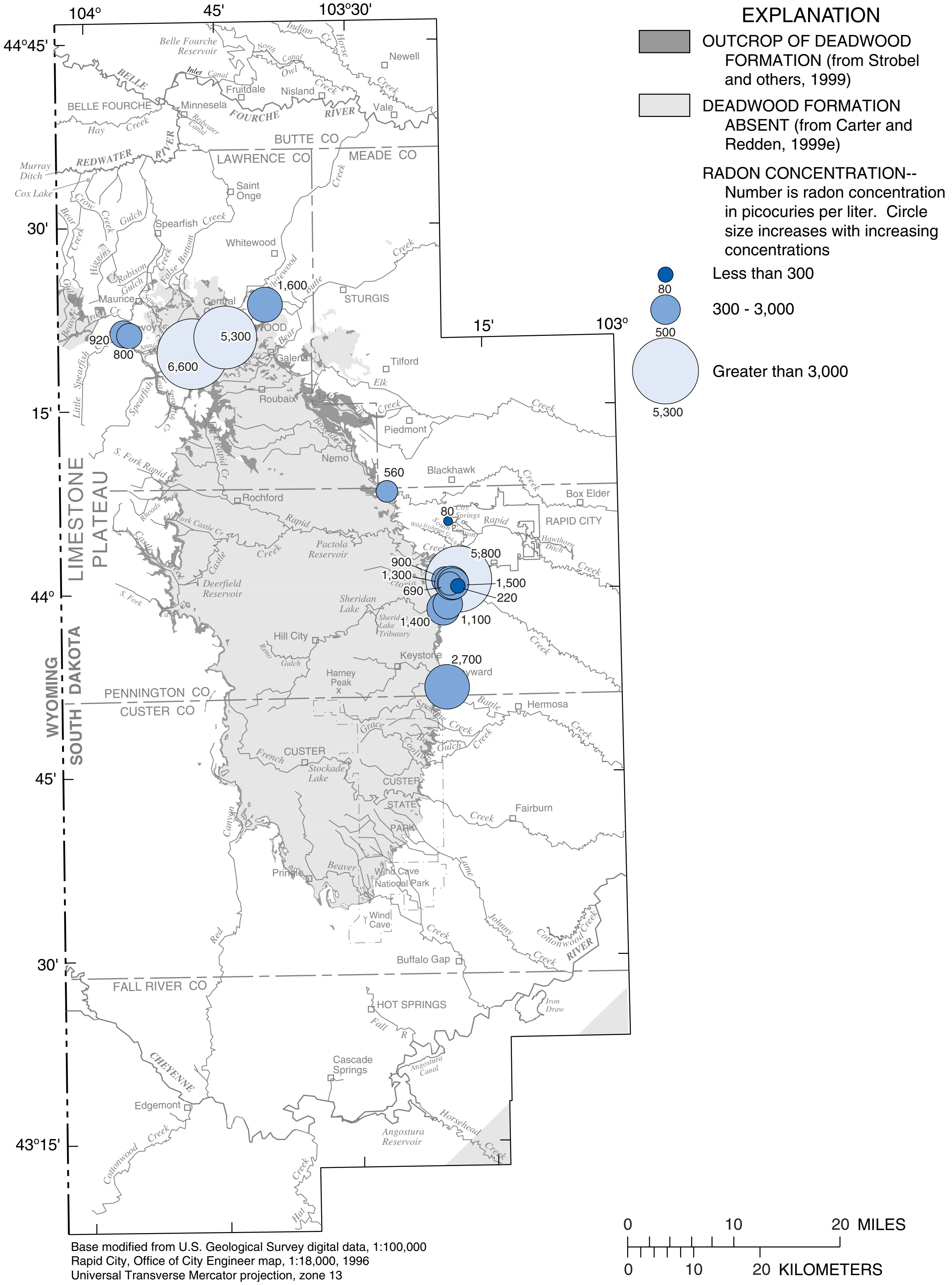
MADISON AQUIFER

Figure 26. Selected relations between radionuclides and well depth for selected aquifers.



INYAN KARA AQUIFER

Figure 26. Selected relations between radionuclides and well depth for selected aquifers.--Continued



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 27. Distribution of radon concentrations in the Deadwood aquifer.

Minnelusa Aquifer

Water from the Minnelusa aquifer generally is low in radionuclide concentrations, but may be high in some areas. In the Minnelusa aquifer, uranium concentrations are highest in the southern and eastern Black Hills. The highest gross beta concentrations (as cesium-137 and strontium/yttrium-90) are in the southern Black Hills. The highest thorium concentrations are in the eastern and southern Black Hills, whereas the highest tritium concentrations are in the eastern and northern Black Hills.

Of the 11 samples analyzed for alpha radioactivity as thorium-230, three samples exceed the MCL of 15 pCi/L for gross alpha; all of the samples that exceed the MCL were from the southern Black Hills. One of 17 samples exceeds the MCL for the combined radium-226 and radium-228; this sample was from a well located in the eastern Black Hills.

Inyan Kara Aquifer

Uranium was discovered in the Black Hills area in Fall River County in 1951 in the basal 100 to 150 feet of the Lakota Formation of the Inyan Kara Group (Page and Redden, 1952). Following the first discovery, numerous other uranium deposits were discovered in the southern Black Hills. Uranium may be introduced into the Inyan Kara Group through the artesian recharge of water from the Minnelusa aquifer (Gott and others, 1974). As water in the Inyan Kara aquifer flows downgradient, geochemical conditions favor the precipitation of uranium (Gott and others, 1974). Therefore, it is not surprising that some water from the Inyan Kara aquifer, especially in the southern Black Hills, contains relatively high concentrations of radionuclides.

Concentrations of several radionuclides vary with well depth (fig. 26). Gross alpha as U-natural in picocuries per liter, gross beta as cesium-137, and radium-226 generally increase with increasing well depth associated with increasing distance from the outcrop. Other concentrations vary with geographic location. The highest uranium and thorium concentrations are from wells located in the southern Black Hills.

Almost 18 percent of the samples (6 of 34 samples) collected from the Inyan Kara aquifer exceed the MCL for combined radium-226 and radium-228; all but one of these samples are from wells in the southern Black Hills. About 4 percent of the samples (3 of 77 samples) exceed the MCL for uranium; all these samples are from wells located in the southern Black Hills.

Minor Aquifers

Excluding analyses from alluvial aquifers, the MCL of 30 μg/L for uranium is the only drinking-water standard that is exceeded by samples from other aquifers in the study area. However, few analyses exist for gross alpha, radium, and radon for the minor aquifers in the study area. In addition to the uranium concentrations in the alluvial aquifers, 1 of 9 samples from the Spearfish aquifer, 2 of 6 samples from the Morrison aquifer, 5 of 28 samples from the Pierre aquifer, and 1 of 10 samples from the Graneros aquifer exceed the MCL for uranium.

Samples from alluvial aquifers may be high in uranium concentrations, especially in the southern Black Hills. About 17 percent of the samples (5 of 29 samples) exceed the MCL for uranium, and all were collected from wells located in the southern Black Hills. In addition to uranium, thorium concentrations were highest in the southern Black Hills. One of four samples from alluvial aquifers exceeds the proposed MCL for radon in States without an active indoor air program, but this sample does not exceed the proposed MCL for radon in States with an active indoor air program.

Summary for Aquifers in Relation to Water Use

Concentrations exceeding the SMCL's or MCL's may affect the use of water in some areas for many aquifers within the study area. Most concentrations exceeding standards are for various SMCL's and generally only affect the aesthetic quality of the water. Radionuclide concentrations may be especially high in some of the major aquifers within the study area and preclude the use of water in some areas. Hard water may require special treatment for certain uses. Other factors, such as the SAR and specific conductance, may affect irrigation use.

High concentrations of iron and manganese occasionally may hamper the use of water from Precambrian aquifers. None of the samples from the Precambrian aquifers exceeded drinking-water standards for radionuclides, although few samples with radionuclide analyses were available.

The principal deterrents to use of water from the Deadwood aquifer are the high concentrations of radionuclides, including radium-226 and radon. In addition, concentrations of iron and manganese can be high.

Water from the Madison aquifer can contain high concentrations of iron and manganese that may deter its use. Water from the Madison aquifer is hard to very hard and may require special treatment for certain uses. In downgradient wells (generally deeper than 2,000 feet), concentrations of dissolved solids and sulfate also may deter use of water from this aquifer. In deep wells and in the Hot Springs area, hot water may not be desirable for some uses. Radionuclide concentrations in the Madison aquifer generally are acceptable.

The principal properties or constituents in the Minnelusa aquifer that may hamper the use of water from this aquifer include hardness and high concentrations of iron and manganese. Generally, downgradient wells (generally deeper than 1,000 feet) also have high concentrations of dissolved solids and sulfate. In deep wells, hot water may be undesirable for some uses. Arsenic may be a problem for some wells if the MCL is lowered to 10 μg/L. Only a few samples exceed the MCL's for various radionuclides.

Water from the Minnekahta aquifer generally is suitable for all water uses because few samples exceed SMCL's or MCL's and no samples available for this study from the Minnekahta aquifer exceed drinking-water standards for any radionuclides; however, samples are available only from shallow wells near the outcrop. Water from the Minnekahta aquifer is harder than that from any of the other major aquifers in the study area, and may require special treatment for certain uses.

The use of water from the Inyan Kara aquifer may be hampered by high concentrations of dissolved solids, iron, sulfate, and manganese. In the southern Black Hills, radium-226 and uranium concentrations also may preclude its use. Hard water from wells located on or near the outcrop of the Inyan Kara Group may require special treatment. Suitability for irrigation may be affected by high specific conductance and the adjusted SAR.

The use of water from minor aquifers may be hampered by hardness and concentrations of dissolved solids and sulfate. Concentrations of radionuclides, with the exception of uranium, generally are acceptable in samples from these minor aquifers. Selenium concentrations may be an additional deterrent to the use of water from the Sundance aquifer. Water from the Pierre and Sundance aquifers generally is not suitable for irrigation. Water from the other minor aquifers generally is suitable, but may not be in specific instances if either the specific conductance or the SAR is high.

Water from alluvial aquifers generally is very hard and may require special treatment for certain uses. In alluvial deposits that overlie the Cretaceous-age shales, the high concentrations of dissolved solids, sulfate, iron, and manganese may limit the use of water from these aquifers. In the southern Black Hills, uranium concentrations can be high in alluvial aquifers in many locations.

Water-Quality Characteristics of Selected Surface-Water Sites

The water-quality characteristics for selected surface-water sites (fig. 7; table 16 in the Supplemental Information section), including streams and springs within the study area, are presented in this section. Surface-water quality depends largely on the geology of the area. Selected sites are used within this section to characterize the geologic influences based on the hydrogeologic settings presented in figure 7. These sites include headwater springs, crystalline core sites, artesian springs, and exterior sites. Headwater springs originate from the Paleozoic units (fig. 2) on the western side of the study area, and each spring tends to have relatively constant water-quality characteristics. Other streams originate in the Precambrian rocks of the crystalline core and tend to have more variability than the headwater springs. Artesian springs occur downgradient from the loss zones and contribute much of the base flow to exterior streams beyond the Black Hills. Additional exterior streams originate around the periphery of the Black Hills and represent sites having greater fluctuations in water-quality characteristics than the representative sites for other settings. The selected representative sites for the hydrogeologic settings generally have longer periods of record and more closely represent sites with characteristics that depend largely on the geologic influences. These sites have been used as representative sites in other reports produced as part of the Black Hills Hydrology Study. Many other surface-water sites from throughout the Black Hills are included in an "other" category to provide indications of the wider ranges that can occur and represent the combination of influences on water-quality characteristics within the study area.

Mineralized areas in the northern Black Hills as well as the generally drier climate of the southern Black Hills influence water-quality characteristics. Changes that occur within a basin as streams flow downslope from headwater areas to the exterior plains also will be examined (fig 7a).

Boxplots and summary statistics are presented for physical properties, common ions, nutrients, trace elements, and radionuclides. Figures illustrating spatial variations as well as trilinear and Stiff diagrams (Stiff, 1951), which indicate water type, also are presented.

Concentrations are compared to drinking-water standards as well as beneficial-use and aquatic-life criteria. Drinking-water standards are directly relevant to a limited number of stream segments with the beneficial use of domestic water supply, but concentrations that exceed these standards may be of interest to local users as a precautionary measure. Many of the aquatic criteria are dependent on hardness. If a concentration exceeds the aquatic criteria that is based upon a hardness of 100 mg/L, the appropriate hardness-calculated criterion is presented. Drinking-water standards are for total concentrations, and results reported by the USGS as dissolved concentrations may be less than those obtained for similar samples analyzed for total concentrations. A summary of how water-quality characteristics may affect the water use for selected sites within the study area is presented at the end of this section.

Physical Properties

The physical properties of the surface-water samples include measurements for discharge, specific conductance, pH, water temperature, dissolved oxygen, carbon dioxide, hardness, and alkalinity. Statistical comparisons identified similarities and differences between the groups of sites—headwater springs, crystalline core sites, artesian springs, exterior sites, and other sites. Summary statistics are presented in table 9, and the significance of the properties is described in table 1. Boxplots are presented in figure 28 for each of the properties by group.

Streamflow and the physical properties of the water can vary with the hydrogeologic settings. Seasonal variability and range in discharge for a representative site from each hydrogeologic setting (fig. 29) illustrate discharge variability by group. Relations commonly exist between discharge and specific conductance (fig. 30) and between temperature and dissolved oxygen (fig. 31).

Group Comparisons

Discharge at headwater springs displays little variability (fig. 28) compared to most other groups, with only artesian springs having similar flow characteristics. Discharge from the artesian springs is relatively constant at each individual site with more variability between sites. Artesian springs generally do not display large seasonal or historic variability in discharge (fig. 29). Discharge for crystalline core sites displays wider ranges in variability and generally varies with season with increasing flows during the spring and summer when snowmelt and precipitation result in greater runoff. The greatest variability in discharge is measured at exterior sites, which have much larger drainage basins than the other groups.

Most of the other physical properties (including specific conductance, hardness, and alkalinity) at headwater springs also display limited variability (fig. 28). The stable nature of both discharge and specific conductance at headwater springs is apparent in figure 30. Specific conductance at crystalline core sites generally decreases as flow increases (fig. 30) due to dilution. Specific conductance varies considerably from one artesian spring to another; however, specific conductance is relatively constant at each site. At exterior sites, specific conductance generally is much higher than that for other hydrogeologic settings with a mean of 3,400 µS/cm and a maximum of 9,250 µS/cm. Compared to sites in the other hydrogeologic settings, much stronger relations exist between discharge and specific conductance at the exterior sites, with more pronounced decreases in specific conductance with increasing discharge (fig. 30).

Twenty-one percent of the samples (56 of 263 samples) from headwater springs exceed the SMCL upper limit of 8.5 for pH, with concentrations exceeding standards for three of the four headwater springs included in this summary. Most values exceeding the SMCL for pH occurred at Castle Creek above Deerfield Reservoir (06409000); samples from this site composed more than 90 percent of the headwater spring samples. There also were 28 samples exceeding the coldwater permanent fisheries criteria (upper limit of 8.6) and 6 samples exceeding the coldwater marginal fisheries criteria (upper limit of 8.8), accounting for 11 and 2 percent of samples, respectively. Fifteen percent of the samples from crystalline core sites exceed the SMCL for pH, and 7 percent and 2 percent exceed the coldwater permanent and marginal criteria, respectively. The pH values for artesian springs are much lower than at headwater springs and crystalline core sites, and generally are less than 8.5. One percent of the pH values at exterior sites exceed the SMCL upper limit of 8.5, and no samples exceed the fisheries beneficial-use pH criteria (table 2).

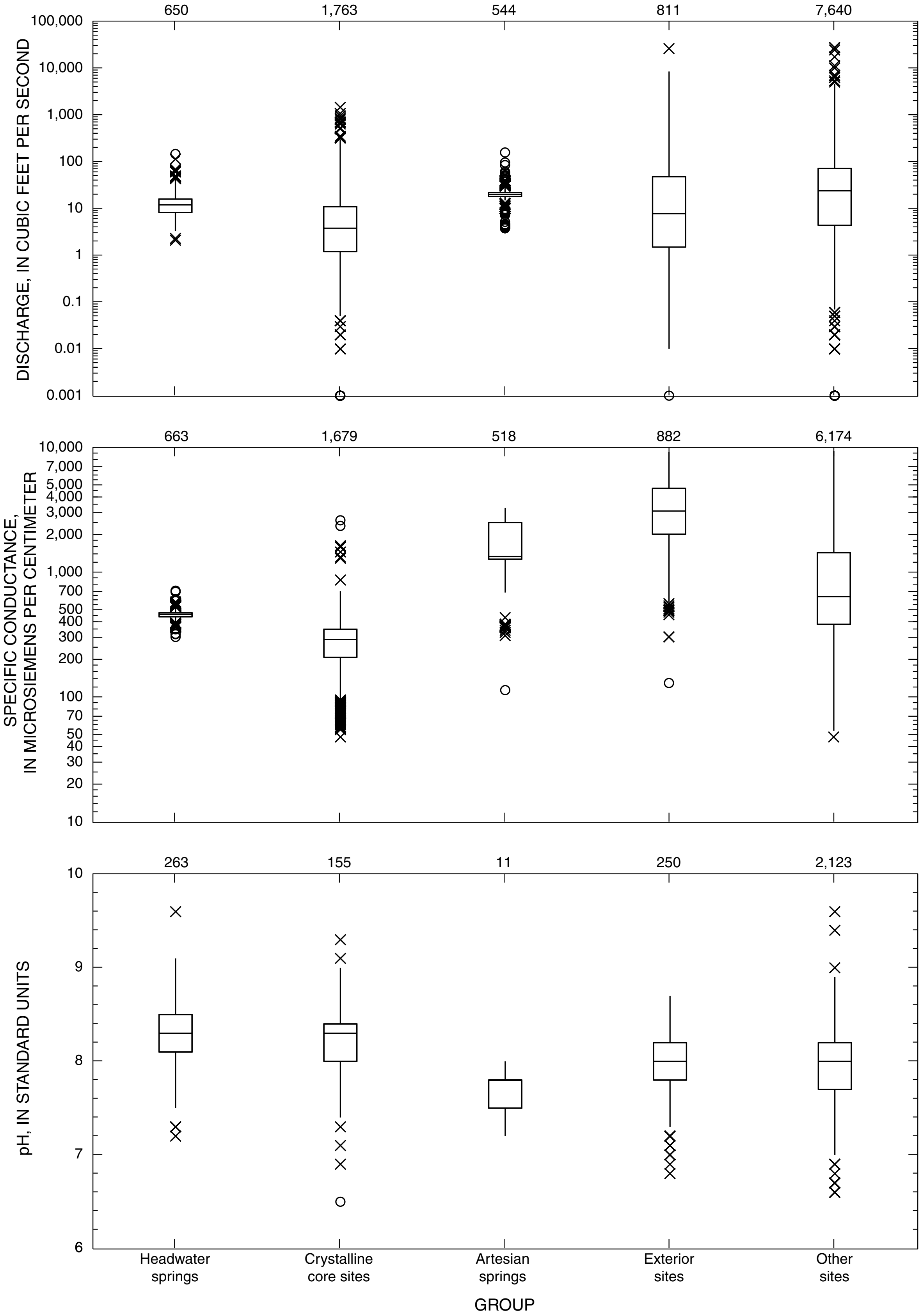


Figure 28. Boxplots of concentrations of selected properties by surface-water group.

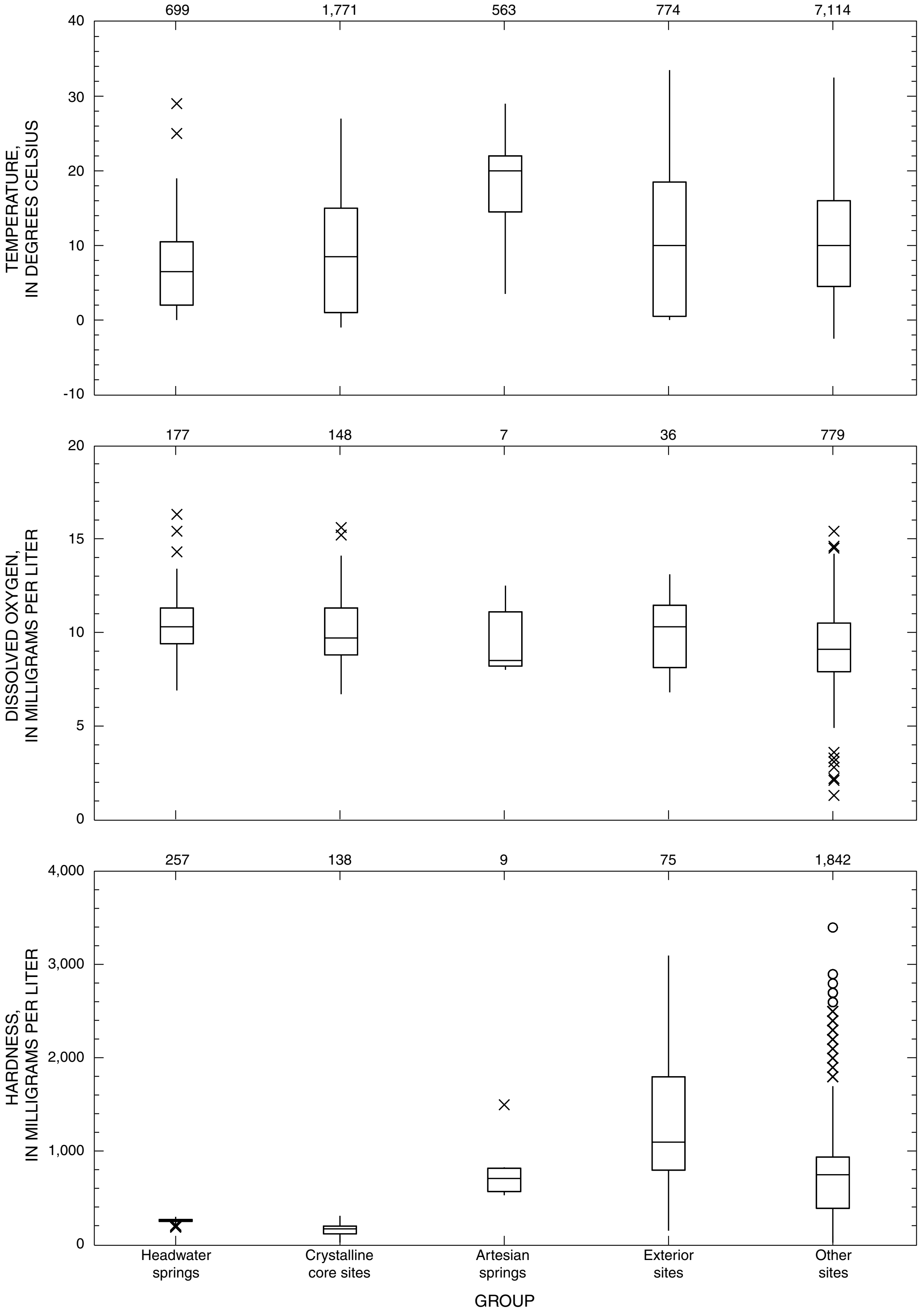


Figure 28. Boxplots of concentrations of selected properties by surface-water group.--Continued

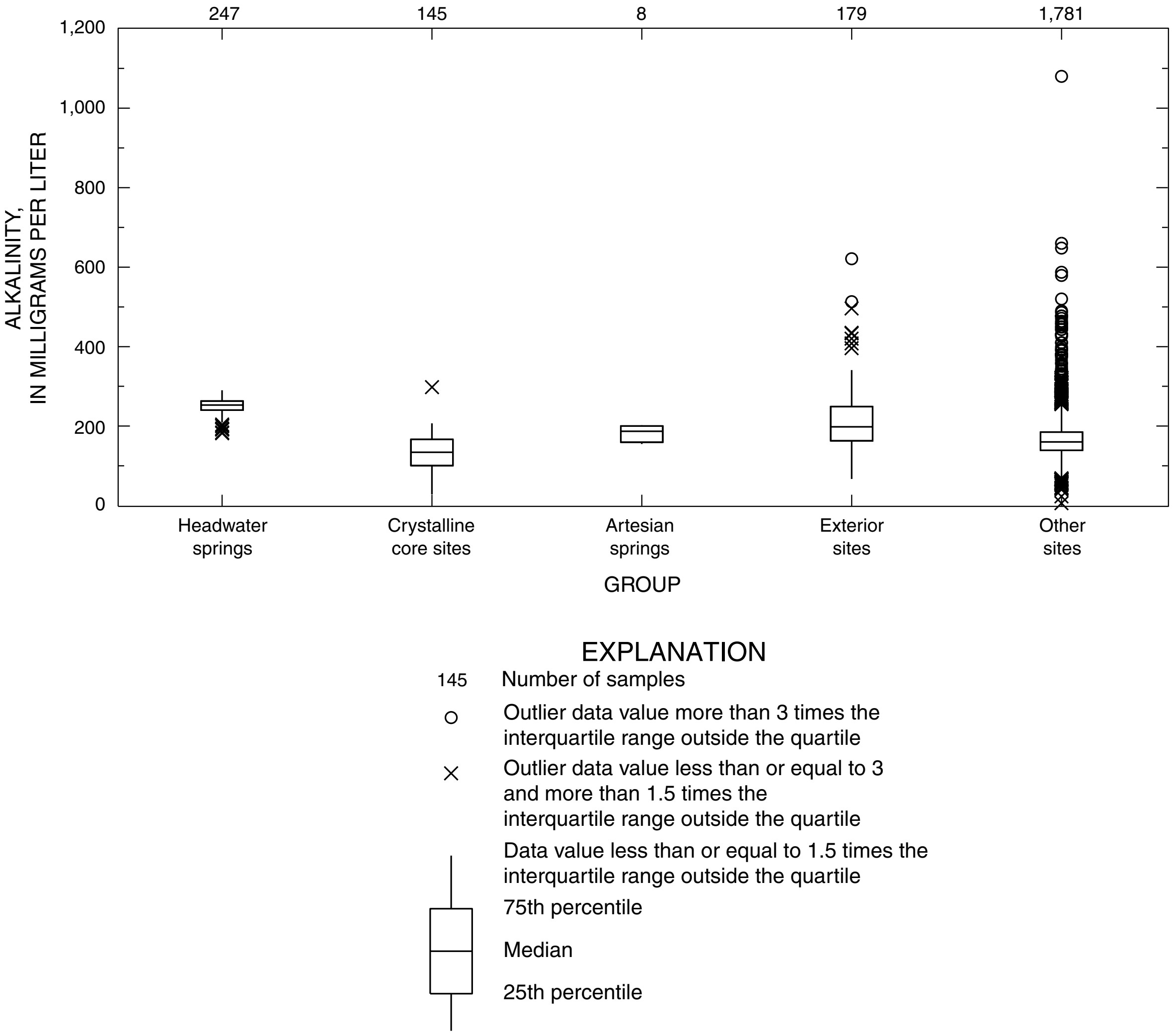


Figure 28. Boxplots of concentrations of selected properties by surface-water group.--Continued

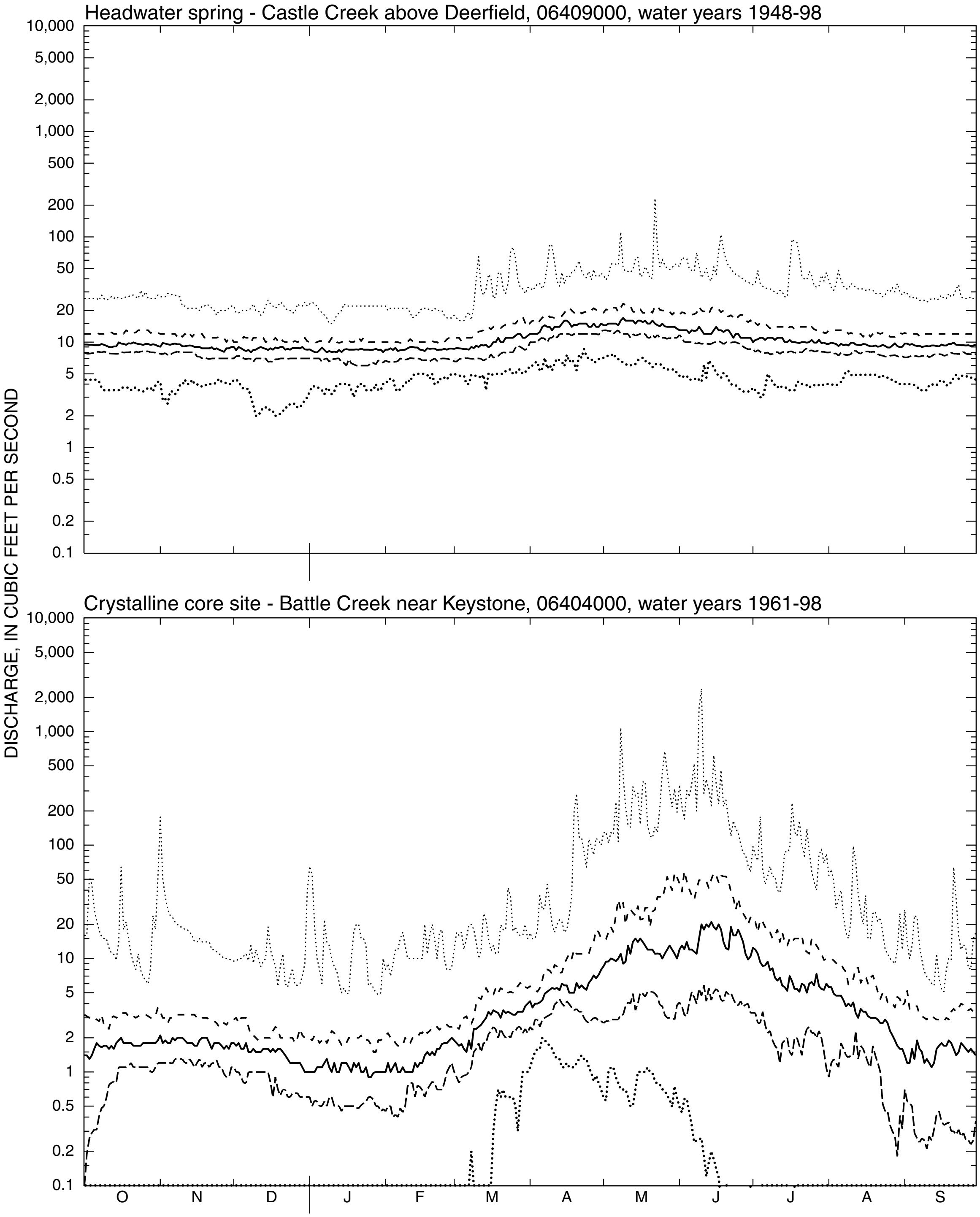


Figure 29. Duration hydrographs of daily mean flow for selected headwater, crystalline, artesian, and exterior surface-water group sites.

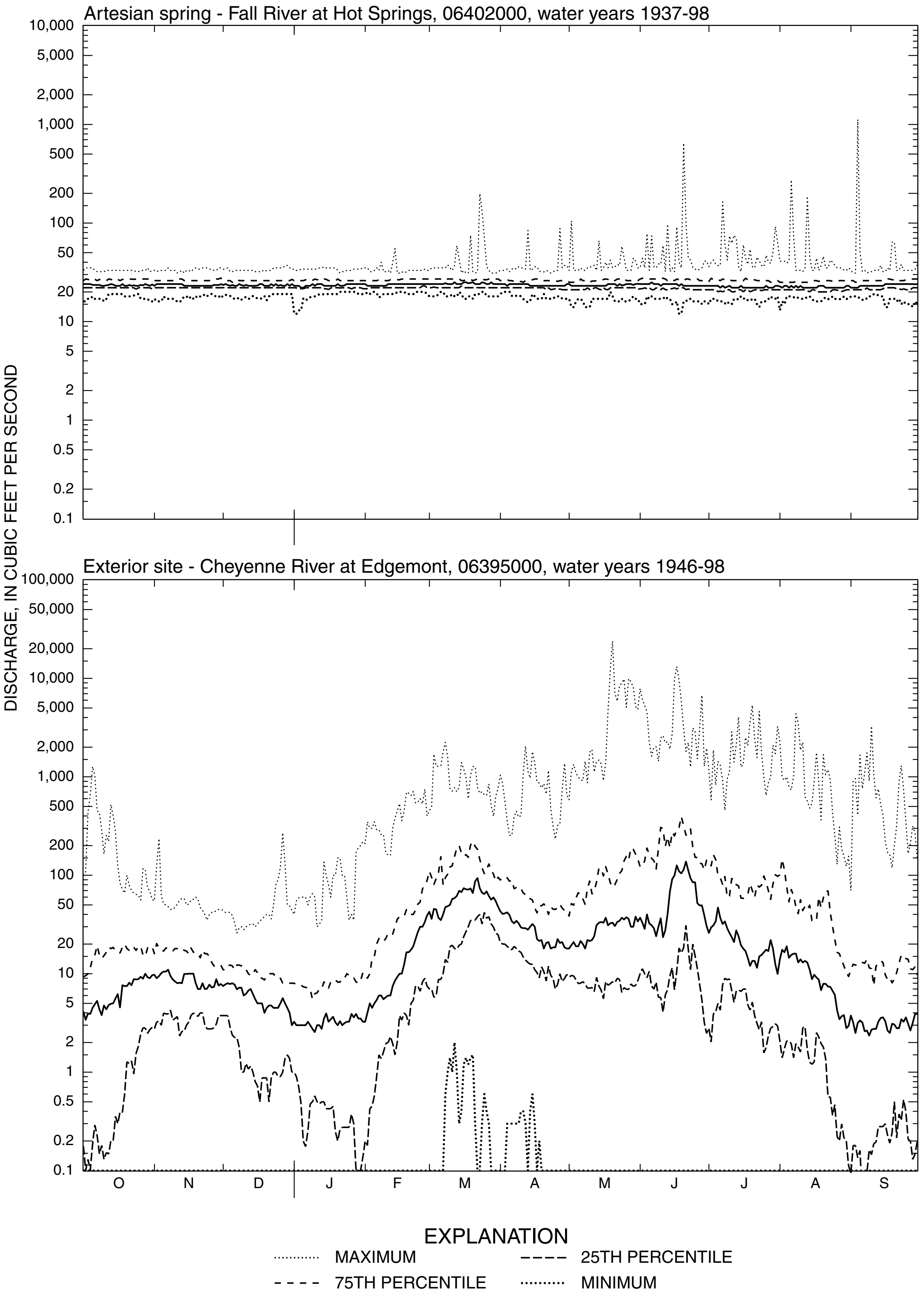


Figure 29. Duration hydrographs of daily mean flow for selected headwater, crystalline, artesian, and exterior surface-water group sites.--Continued

Table 9. Summary of physical properties in surface water by group

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per billion. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Property or dissolved constituent	Number of samples	Mean	Median	Minimum	Maximum
Headwater springs					
Discharge (ft^3/s)	650	14.1	12.0	2.1	147
Specific conductance (µS/cm)	663	460	460	304	715
pH (standard units)	263	8.3	8.3	7.2	9.6
Temperature (°C)	699	6.8	6.5	0.0	29.0
Dissolved oxygen	177	10.4	10.3	6.9	16.3
Hardness	257	258	260	190	300
Alkalinity	247	249	253	182	290
Crystalline core sites					
Discharge (ft^3/s)	1,763	19.4	3.8	0.0	1,460
Specific conductance (µS/cm)	1,679	297	290	48	2,620
pH (standard units)	155	8.2	8.3	6.5	9.3
Temperature (°C)	1,771	8.9	8.5	-1.0	27.0
Dissolved oxygen	148	10.1	9.7	6.7	15.6
Hardness	138	158	170	29	310
Alkalinity	145	130	134	28	298
Artesian springs					
Discharge (ft^3/s)	544	20.5	20.0	3.8	158
Specific conductance (µS/cm)	518	1,692	1,340	114	3,300
pH (standard units)	11	7.7	7.8	7.2	8.0
Temperature (°C)	563	18.9	20.0	3.5	29.0
Dissolved oxygen	7	9.5	8.5	8.0	12.5
Hardness	9	769	710	530	1,500
Alkalinity	8	181	187	155	202
Exterior sites					
Discharge (ft^3/s)	811	177.6	7.8	0.0	26,300
Specific conductance (µS/cm)	882	3,400	3,110	130	9,250
pH (standard units)	250	7.9	8.0	6.8	8.7
Temperature (°C)	774	10.7	10.0	0.0	33.5
Dissolved oxygen	36	9.9	10.3	6.8	13.1
Hardness	75	1,296	1,100	150	3,100
Alkalinity	179	215	198	67	621

Table 9. Summary of physical properties in surface water by group—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per billion. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Property or dissolved constituent	Number of samples	Mean	Median	Minimum	Maximum
		Other sites			
Discharge (ft^3/s)	7,640	110.6	24.0	0.0	27,700
Specific conductance (µS/cm)	6,174	1,035	640	48	9,450
pH (standard units)	2,123	7.9	8.0	6.6	9.6
Temperature (°C)	7,114	10.5	10.0	-2.5	32.5
Dissolved oxygen	779	9.2	9.1	1.3	15.4
Hardness	1,842	769	750	28	3,400
Alkalinity	1,781	170	160	4.0	1,080

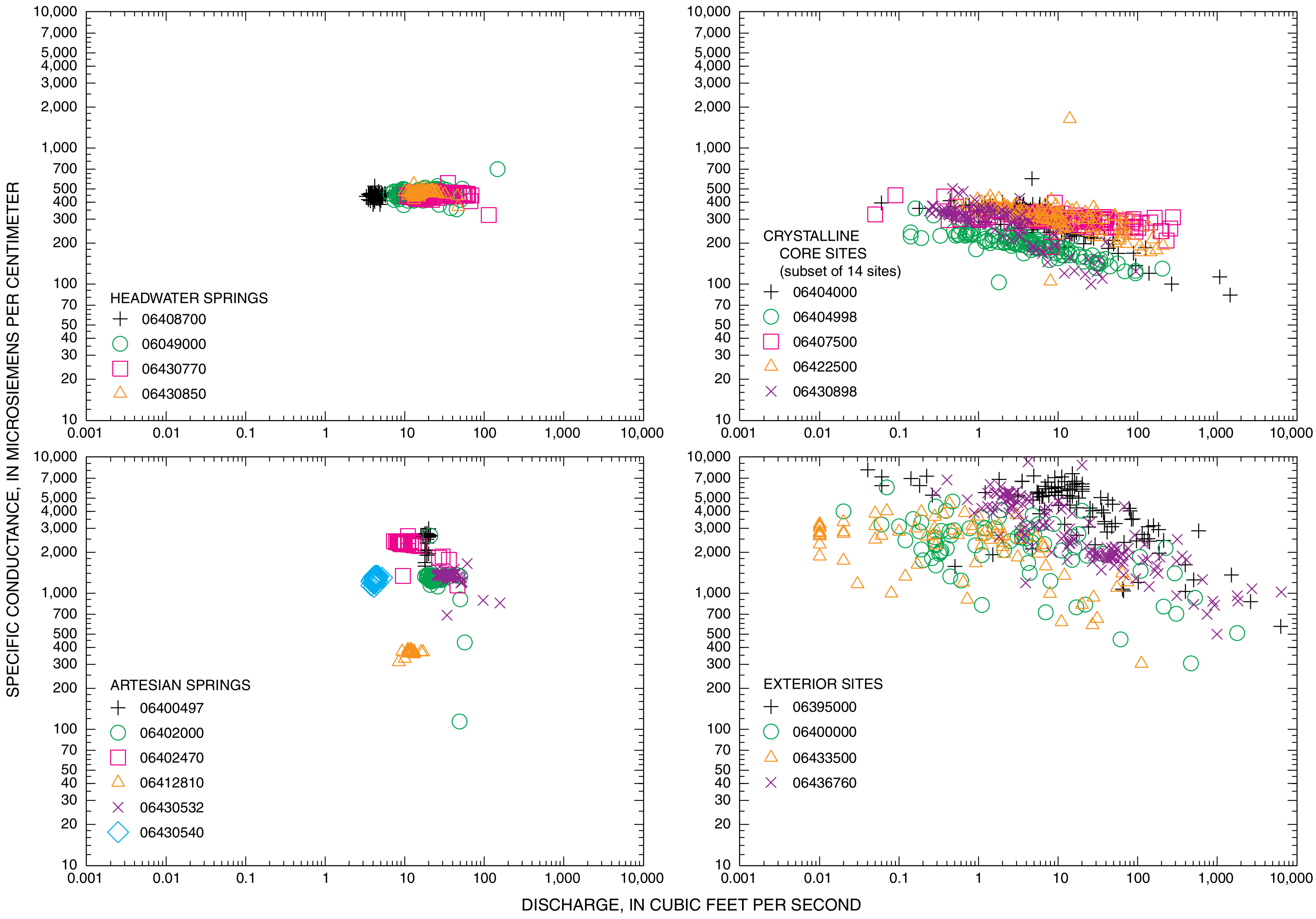


Figure 30. Relations between discharge and specific conductance for selected sampling sites by surface-water group.

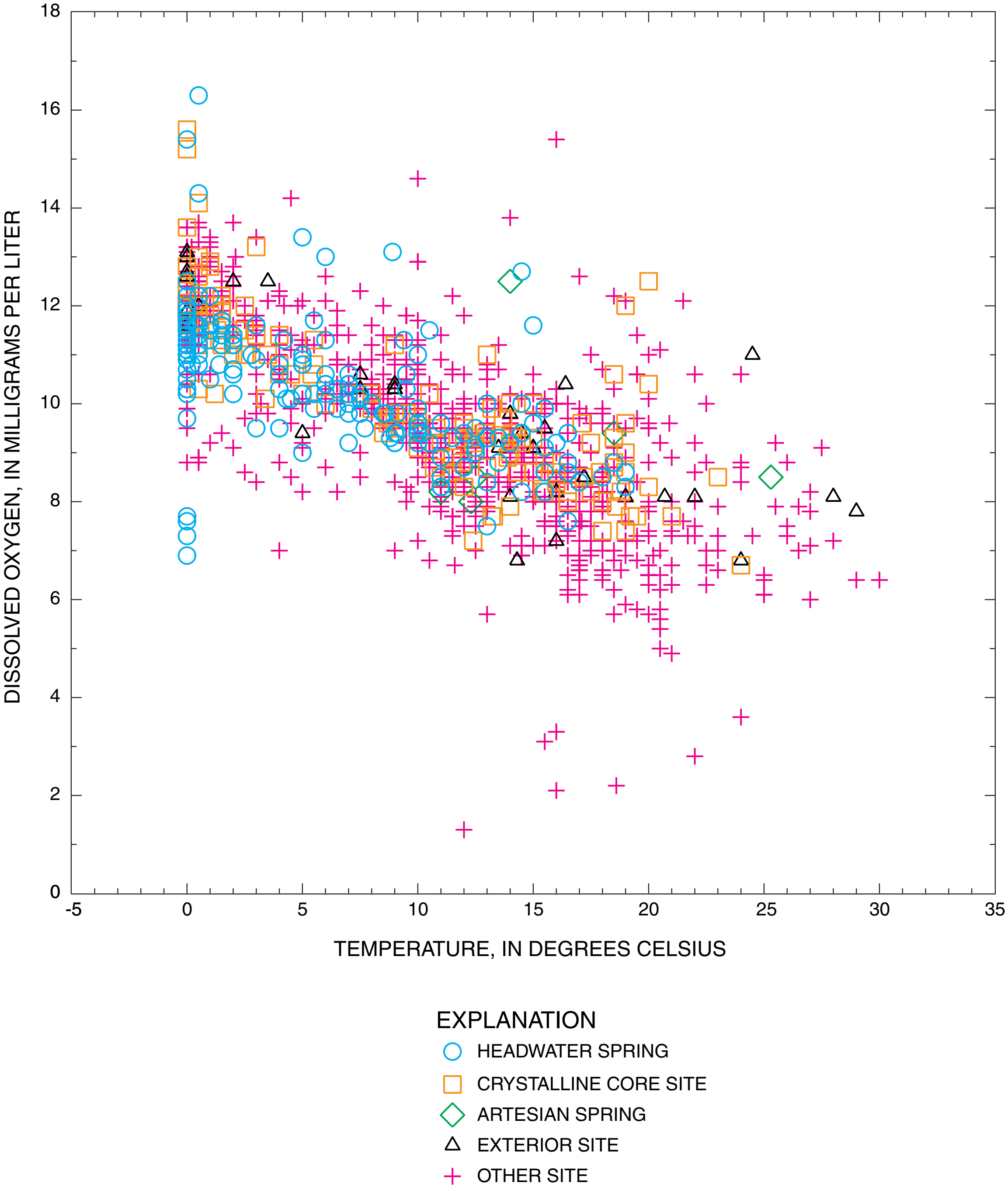


Figure 31. Relations between temperature and dissolved oxygen for selected surface-water groups.

Variations in water temperature occur primarily as seasonal fluctuations. Dissolved oxygen concentrations generally vary with temperature, with lower dissolved oxygen concentrations occurring during periods of higher temperature (fig. 31). For headwater springs, seven samples (1 percent of the samples) exceed the coldwater permanent fisheries criteria for temperature (18.3°C), and two samples exceed the coldwater marginal fisheries temperature criteria (24°C), indicating that temperature may stress fish during unusually warm summer periods with lower flows. Dissolved oxygen concentrations rarely are less than 7 mg/L, the minimum criteria during spawning periods. Almost 12 percent of the water temperature measurements for crystalline core sites exceed the coldwater permanent fisheries criteria of 18.3^{o}C (210 of 1,771 samples), and less than 1 percent exceed the coldwater marginal fisheries criteria of 24^{o}C. The artesian springs generally have higher temperatures (fig. 28) than other groups because of the ground-water contribution to the springs. Water-temperature statistics for the artesian springs are strongly influenced by Fall River at Hot Springs (06402000), which is a warm-water spring in the southern Black Hills. Fall River displays little variability with season, and freezing temperatures have not been recorded at this site. Temperature and dissolved oxygen concentration ranges at exterior sites are similar to the other groups. Dissolved oxygen concentrations in water from the exterior sites generally remain greater than 6 mg/L even at higher temperatures, and ranges of 6 to 12 mg/L are not uncommon for temperature ranges of 10 to 30^{o}C (fig. 31).

Dissolved oxygen concentrations of 2.1, 2.2, and 3.6 mg/L have been measured at an urban runoff site within the Rapid Creek Basin (06416300, Meade Street Drain). Two additional sites with low dissolved oxygen concentrations are Cottonwood Creek near Buffalo Gap and Cheyenne River near Buffalo Gap. In addition, low dissolved oxygen concentrations have been reported at exterior sites (including the Cheyenne River and tributaries) when temperatures are high and flows are very low (Hoof, 1998).

Water from headwater springs generally is very hard with concentrations greater than 190 mg/L (table 9). The median alkalinity for the headwater springs of 253 mg/L (table 9) is the highest of the surface-water groups. Water at the crystalline core sites ranges from soft to very hard, with the soft water occurring primarily because of minimal exposure to limestone and sandstone units, which are a source of calcium and magnesium. Alkalinity at the crystalline core sites ranges from 28 to 298 mg/L. Water from the artesian springs is very hard with alkalinity ranging from 155 to 202 mg/L (table 9). Hardness and alkalinity at exterior sites are higher than or similar to upslope sites with the water being hard to very hard. The maximum alkalinity concentration of 1,080 mg/L occurred at Horse Creek near Vale (06436800, other site group) and approached the wildlife propagation and stock-watering criteria daily maximum of 1,313 mg/L.

Additional Comparisons

Urbanization is one factor that influences natural conditions of streams. Increased runoff during storms, permitted discharges, and factors such as channelization and increased public use, can affect stream quality. Limited urbanization exists in the Black Hills currently, but population in the area continues to grow rapidly. Both Rapid City and Spearfish have experienced recent growth that challenges city and county managers with protection of water and natural conditions while providing for economic growth.

Within a basin, changes in discharge include losses of water as streams cross loss zones and then gains downstream (Hortness and Driscoll, 1998). Additional streamflow losses and gains can occur due to effects from urbanization and agriculture including irrigation. Other physical properties, such as specific conductance and hardness, generally increase downstream with additional exposure to and dissolution of calcium, magnesium, sodium, and sulfate as shown by increasing concentrations in the Rapid Creek Basin from its headwaters to near its confluence with the Cheyenne River (fig. 32, fig. 7a).

Water-quality changes have been identified in streams in the northern Black Hills where sulfide ores have been exposed by mining (Williamson and Hayes, 2000). In areas of acid-mine drainage or naturally occurring iron-bog areas, pH values can be very low, often less than 6. A downstream progression of pH values for two streams (False Bottom and Deadwood Creeks) affected by mining activities is presented in figure 33. Upstream from mining activities, pH levels in the stream are normal for the area. The stream pH then decreases to low levels immediately downstream of mining activities. Farther downstream from mining activities, pH values generally increase to near normal levels again after exposure to the calcium-rich sediments common to the area (Torve, 1991).

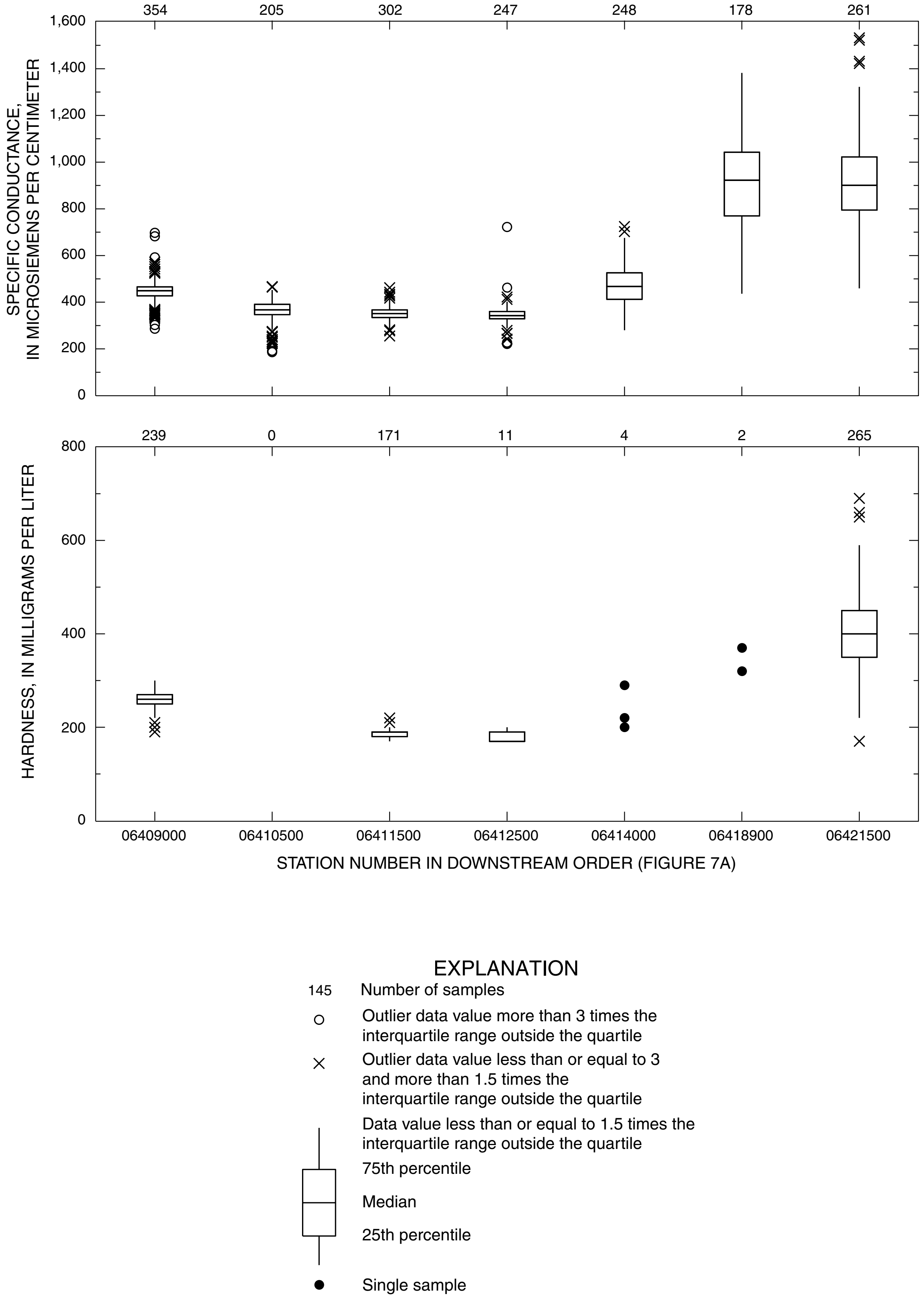


Figure 32. Boxplots of specific conductance and hardness for selected surface-water sites in Rapid Creek Basin.

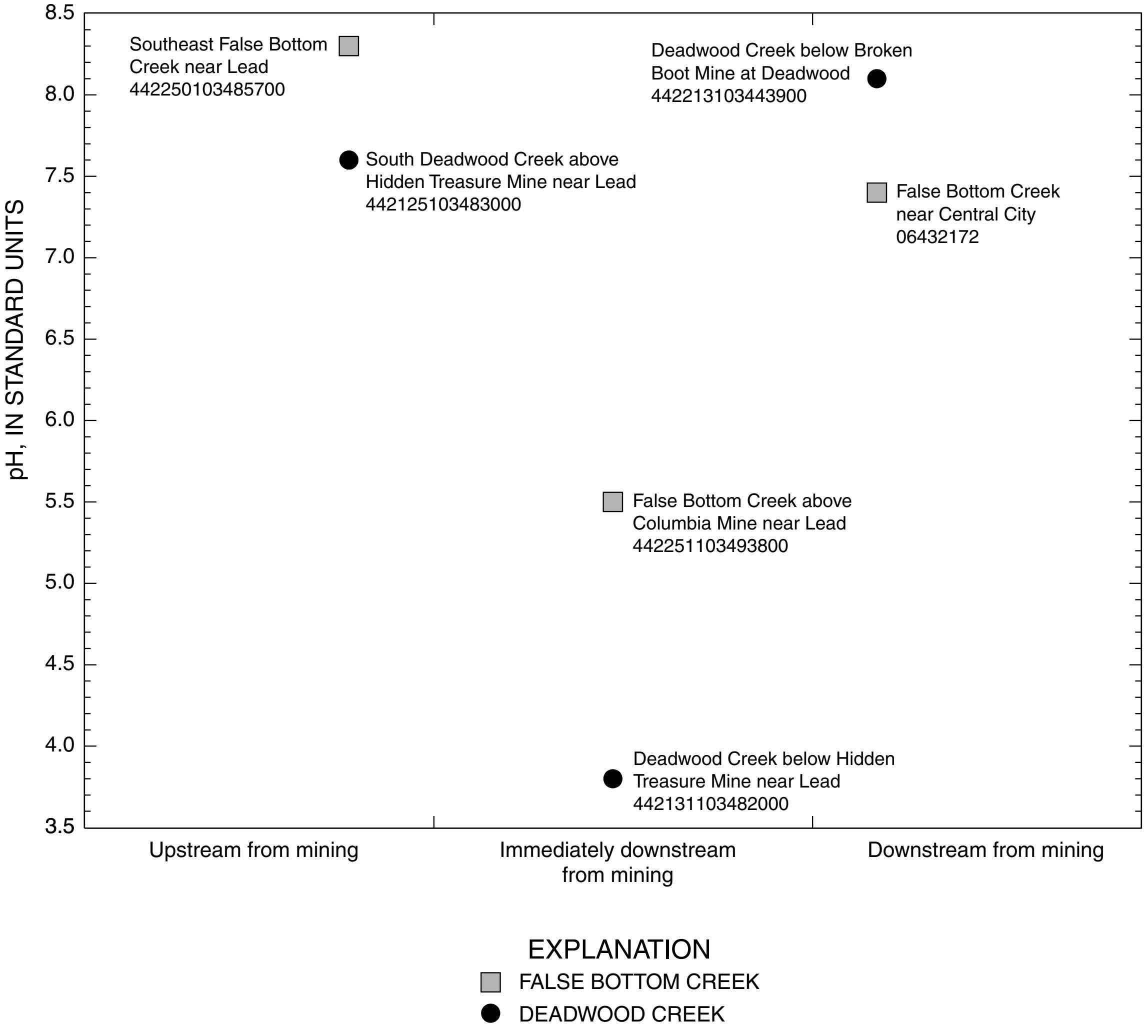


Figure 33. Downstream progression of pH for selected streams influenced by acid mine drainage.

Common Ions

Summary statistics for selected common ions are presented in table 10, and the significance of the various common ions is described in table 1. Boxplots are presented in figure 34 for each of the common ions, except dissolved solids (residue at 180°C), percent sodium, and SAR.

Group Comparisons

Specific conductance can be used to estimate the concentration of dissolved solids. Linear regression was performed using specific conductance (field and laboratory), and concentrations of dissolved solids (sum of constituents or residue) for each group, and results are presented in table 11 and figure 35. The regression of specific conductance and dissolved solids for headwater springs yields a weak relation due to the small variability in both specific conductance and dissolved solids. For headwater springs, specific conductance ranged from 304 to 705 µS/cm, and dissolved solid concentrations (sum of constituents) ranged from 186 to 294 mg/L. The relation between specific conductance and dissolved solids is much stronger for crystalline core sites, artesian springs, and exterior sites where greater variability of specific conductance and dissolved solids occurs. Dissolved solids concentrations (sum of constituents) ranges from 44 to 362 mg/L at crystalline core sites, from 834 to 2,240 mg/L at artesian springs, and from 346 to 6,460 mg/L at exterior sites (table 10).

The variation in water type for the surface-water groups is shown by trilinear diagrams (fig. 36) and Stiff diagrams (fig. 37). Calcium and magnesium are the dominant cations (40 to 60 percent of total cations), and bicarbonate the dominate anion (80 to 99 percent of total anions) for headwater springs (figs. 36 and 37) similar to samples from the Madison aquifer (fig. 17) from wells located on or near the Madison Limestone outcrop. Generally, only crystalline core sites have lower concentrations of common ions than headwater springs (fig. 37). Crystalline core sites generally are a calcium bicarbonate type water or calcium bicarbonate sulfate type water (fig. 36) and are similar to samples from the Precambrian aquifers (fig. 17) with slightly higher sulfate and chloride.

Water from the artesian springs is a calcium sulfate type (fig. 37). Increased sulfate at artesian springs is the most notable difference from headwater springs and crystalline core sites. Sources of sulfate include rock/water interactions in the Minnelusa Formation from upwelling Madison aquifer and/or Minnelusa aquifer water (primary source water for these springs) or exposure to shale units such as the Spearfish Formation at or near land surface. The range of sulfate concentrations, based on the limited data set (eight samples), is similar to ranges found in groundwater samples from the Spearfish aquifer and from the Minnelusa aquifer within the sulfate transition zone (fig. 21). Sulfate concentrations from the artesian springs are all greater than the SMCL of 250 mg/L (table 10).

Exterior sites generally have sodium calcium magnesium sulfate type waters (fig. 36). Increased sodium and sulfate concentrations are the most notable differences for the exterior sites (fig. 37). Sixty-six percent of the samples from the exterior sites have sulfate concentrations greater than 1,000 mg/L. Three of the 73 samples have sulfate concentrations less than the SMCL of 250 mg/L. The SAR does not exceed 10, so the sodium generally does not limit the use of this water for irrigation. Chloride also generally is much higher at these sites than at the headwater springs, crystalline core sites, and artesian springs. Of the 73 samples analyzed for chloride, 26 percent of the samples exceed the SMCL of 250 mg/L, and 10 percent of the samples exceed 500 mg/L. All of the concentrations that exceeded the SMCL are from Cheyenne River at Edgemont.

Concentrations of common ions for the other-sites group are very similar to those of the hydrogeologic settings groups, with maximum concentrations similar to exterior sites and minimum concentrations similar to headwater springs and crystalline core sites (table 10). Two bicarbonate concentrations greater than 800 mg/L and eight chloride concentrations greater than 400 mg/L have been determined for water from Horse Creek near Vale. The minimum bicarbonate concentration of 28 mg/L is for water from False Bottom Creek. All but one sulfate concentrations greater than 1,000 mg/L have occurred in water from exterior sites along the Cheyenne River, Belle Fourche River, or prairie tributaries. The exception is an urban runoff sample within the Rapid Creek Basin with a sulfate concentration of 1,100 mg/L.

Table 10. Summary of concentrations of common ions in surface water by group

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per million; <, less than]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Headwater springs						
Solids, residue at 180°C	224	0	249	252	147	476
Solids, sum of constituents	251	0	255	258	186	294
Calcium	255	0	55	56	25	70
Magnesium	255	0	29	30	20	40
Sodium	255	0	1.7	1.5	0.5	6.7
Sodium, percent	254	0	1.4	1.0	0.0	5.0
Sodium-adsorption ratio	254	0	0.0	0.0	0.0	0.2
Potassium	256	0	1.4	1.2	0.4	6.8
Bicarbonate	245	0	302	306	222	354
Sulfate	250	1	7.2	7.0	<1.0	29
Chloride	257	1	1.6	1.2	<0.1	25
Fluoride	256	8	0.2	0.1	<0.1	2.9
Silica	255	0	8.9	9.0	0.1	21
Crystalline core sites						
Solids, residue at 180°C	100	0	184	192	53	350
Solids, sum of constituents	134	0	191	200	44	362
Calcium	134	0	41	41	8.6	79
Magnesium	134	0	13	14	1.8	28
Sodium	134	0	6.2	4.9	1.7	22
Sodium, percent	132	0	8.6	7.0	3.0	27
Sodium-adsorption ratio	132	0	0.2	0.2	0.1	0.7
Potassium	134	0	2.0	1.8	0.6	6.7
Bicarbonate	136	0	157	162	34	363
Sulfate	136	0	28	22	4.2	110
Chloride	138	0	7.1	3.7	0.2	48
Fluoride	116	4	0.4	0.3	<0.1	1.3
Silica	113	0	13	13	6.8	21
Artesian springs						
Solids, residue at 180°C	6	0	936	990	206	2,130
Solids, sum of constituents	8	0	1,110	966	834	2,240
Calcium	8	0	248	245	150	470
Magnesium	8	0	43	38	33	83
Sodium	8	0	31	18	2.5	72
Sodium, percent	8	0	8.6	2.5	1.0	21

Table 10. Summary of concentrations of common ions in surface water by group—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter except as indicated. One milligram per liter is approximately equal to one part per million; <, less than]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Artesian springs—Continued						
Sodium-adsorption ratio	8	0	0.4	0.2	0.0	1.0
Potassium	8	0	4.4	3.6	1.4	8.1
Bicarbonate	8	0	221	228	190	247
Sulfate	8	0	614	545	350	1,500
Chloride	8	0	39	22	0.7	94
Fluoride	8	0	0.5	0.5	0.3	0.7
Silica	8	0	16	14	11	23
Exterior sites						
Solids, residue at 180°C	126	0	3,274	3,180	363	7,020
Solids, sum of constituents	72	0	2,768	2,605	346	6,460
Calcium	73	0	284	270	44	820
Magnesium	73	0	146	110	4.9	430
Sodium	73	0	371	370	44	890
Sodium, percent	72	0	37	38	19	60
Sodium-adsorption ratio	72	0	4.4	5.0	1.0	9.0
Potassium	72	0	9.6	9.2	1.2	17
Bicarbonate	134	0	273	268	82	757
Sulfate	73	0	1,667	1,400	140	4,200
Chloride	73	0	172	80	1.5	890
Fluoride	68	2	0.5	0.5	<0.1	1.0
Silica	61	0	7.1	6.3	0.9	38
Other sites						
Solids, residue at 180°C	816	0	1,316	1,085	81	9,450
Solids, sum of constituents	1,646	0	1,368	1,150	78	8,380
Calcium	1,701	0	187	200	3.7	590
Magnesium	1,701	0	73	55	3.0	545
Sodium	1,702	0	134	83	1.0	1,420
Sodium, percent	1,641	0	20	20	1.0	63
Sodium-adsorption ratio	1,610	0	1.8	1.0	0.0	11
Potassium	1,663	1	7.6	7.6	<0.1	28
Bicarbonate	1,662	0	207	195	28	1,317
Sulfate	1,714	0	806	700	1.9	5,300
Chloride	1,930	4	39	8.8	<3.0	850
Fluoride	1,441	6	0.5	0.5	<0.1	6.0
Silica	1,418	0	8.9	8.6	0.0	41

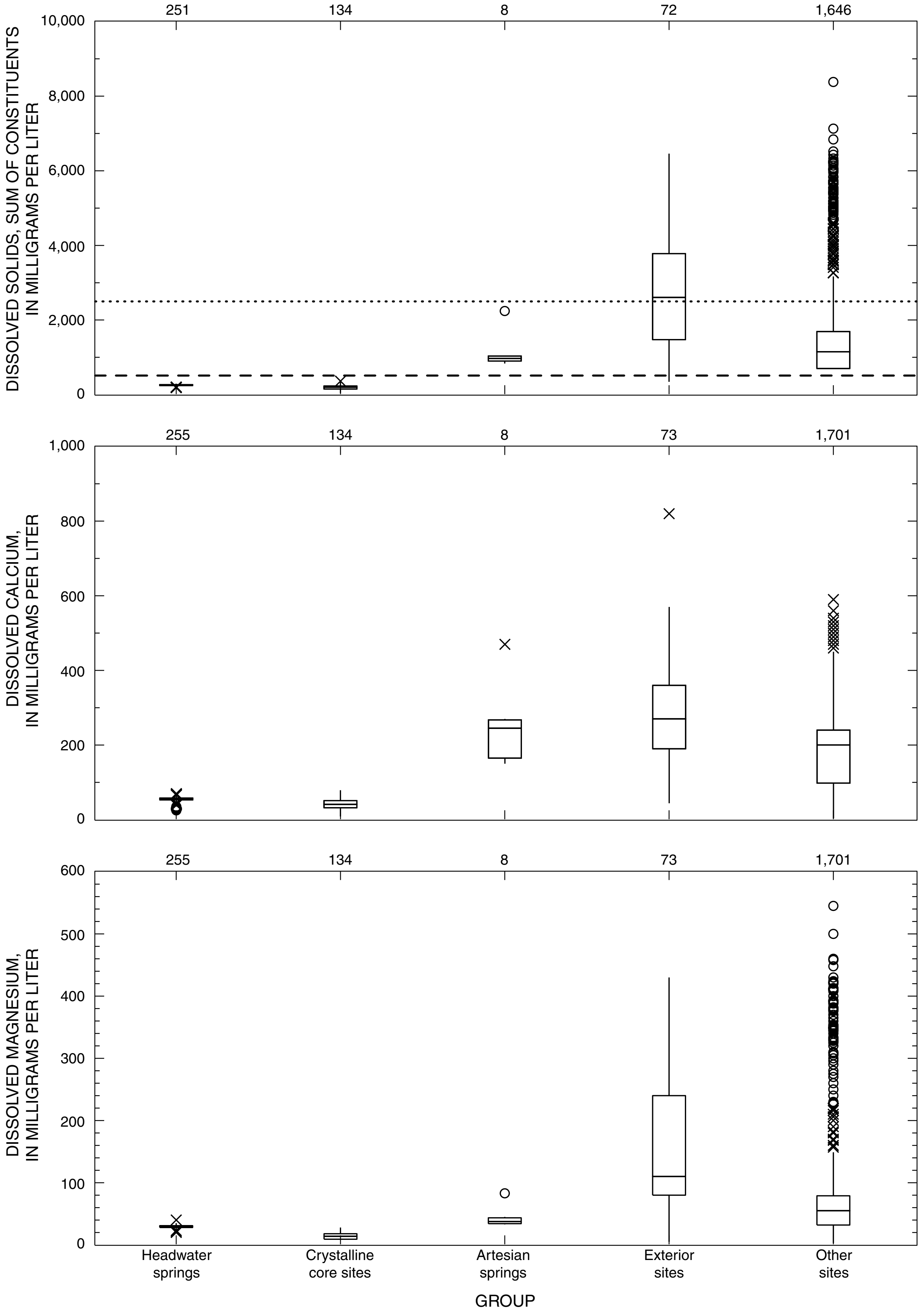


Figure 34. Boxplots of concentrations of selected ions by surface-water group.

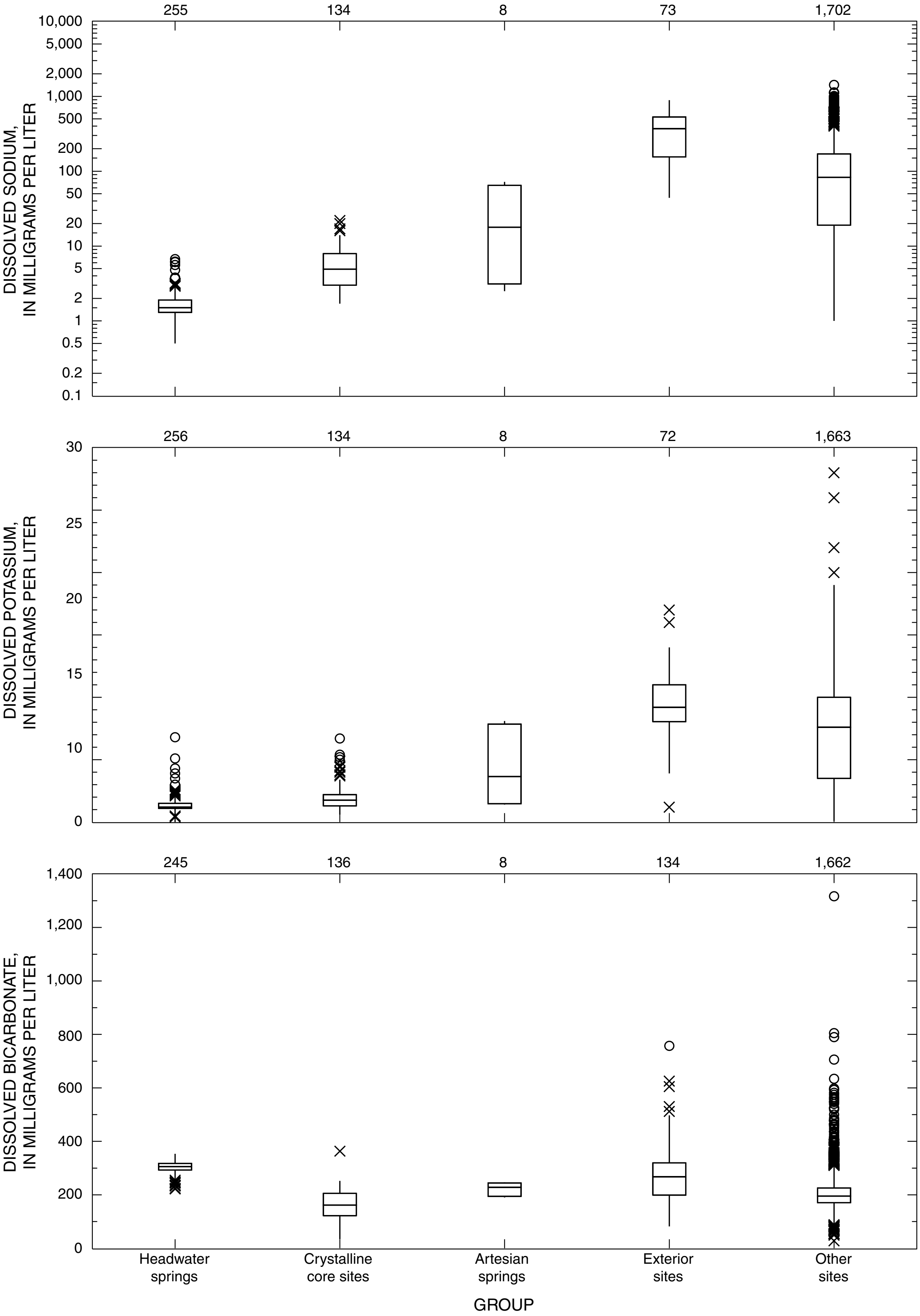


Figure 34. Boxplots of concentrations of selected ions by surface-water group.--Continued

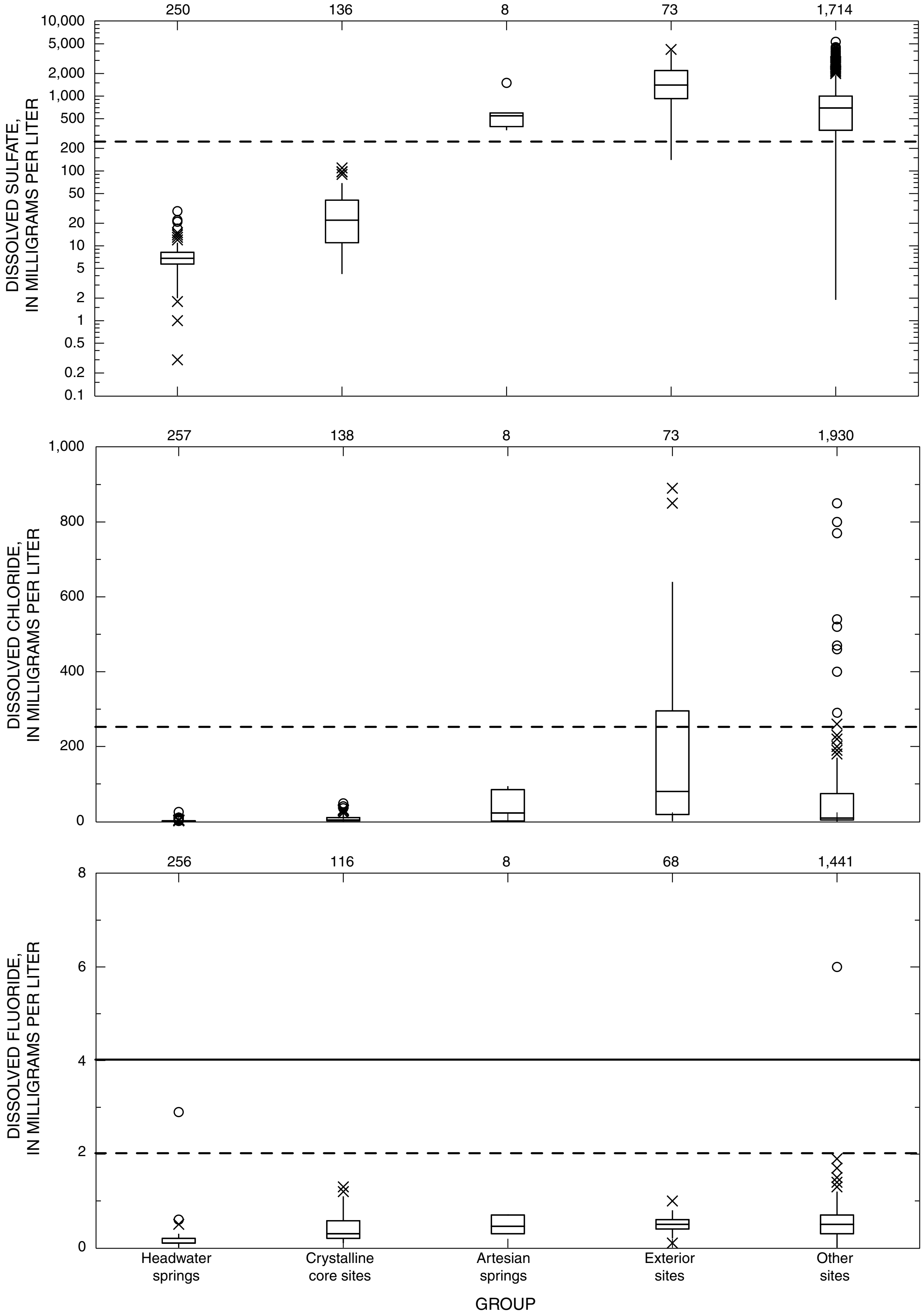


Figure 34. Boxplots of concentrations of selected ions by surface-water group.--Continued

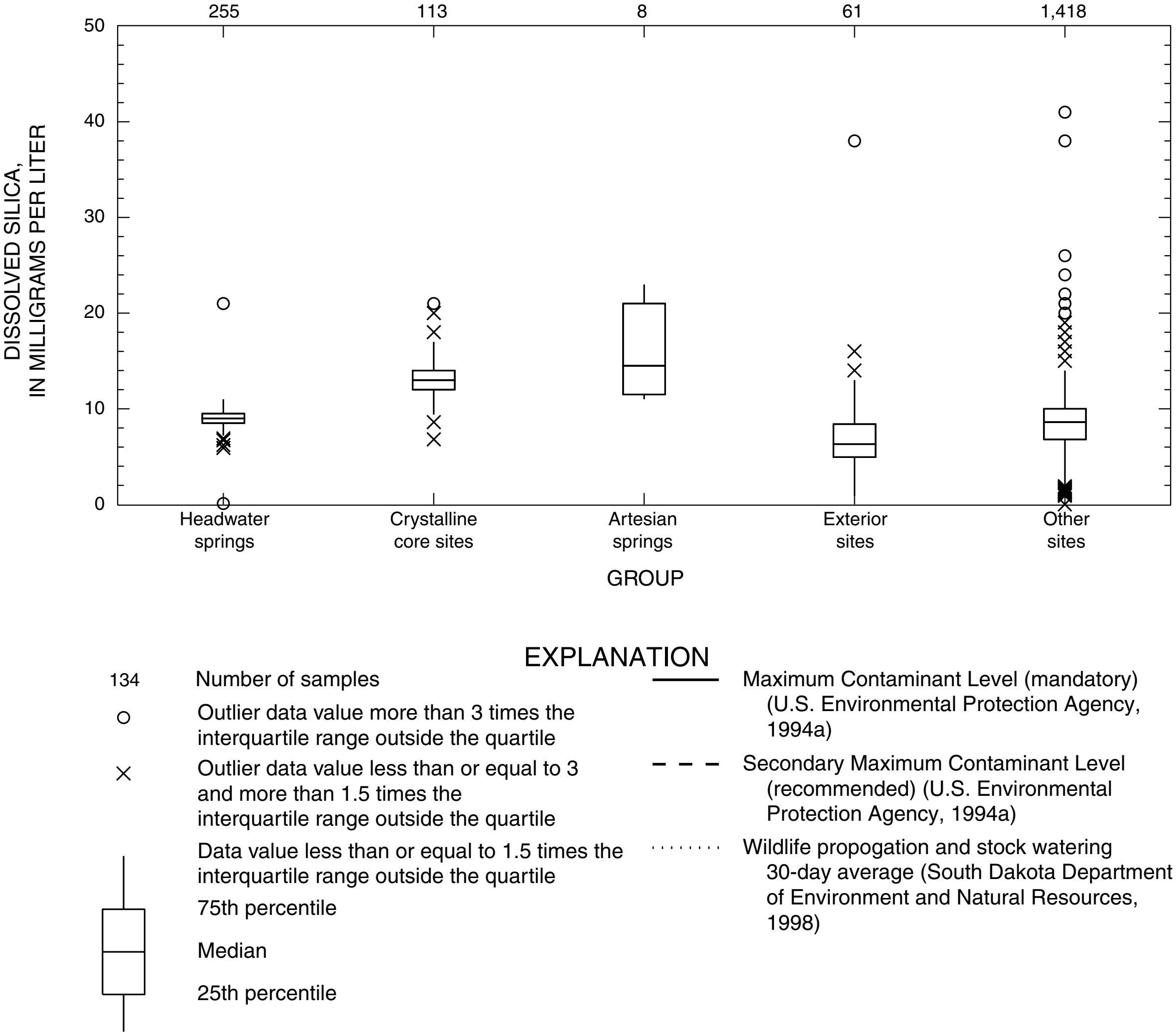


Figure 34. Boxplots of concentrations of selected ions by group.--Continued

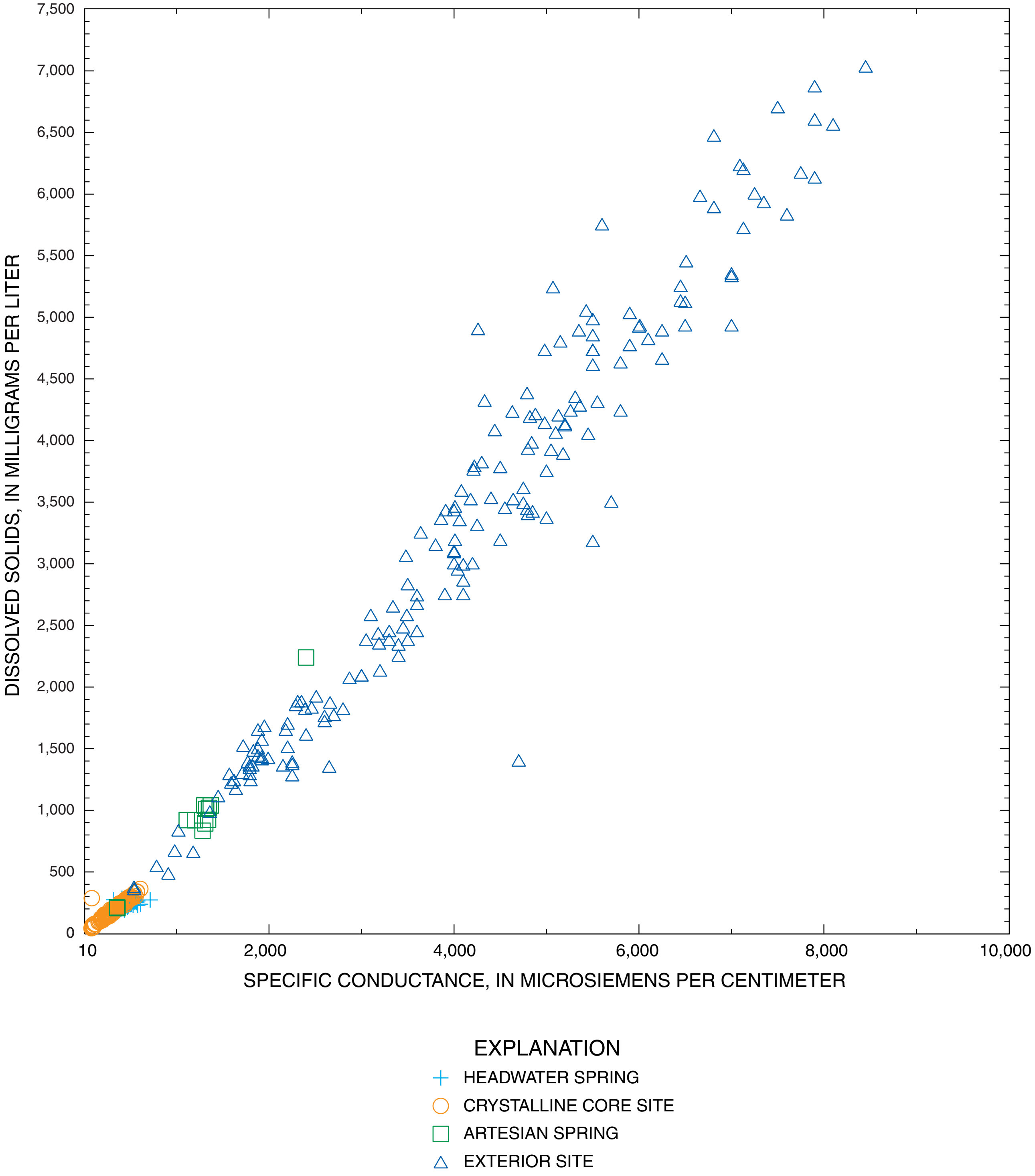
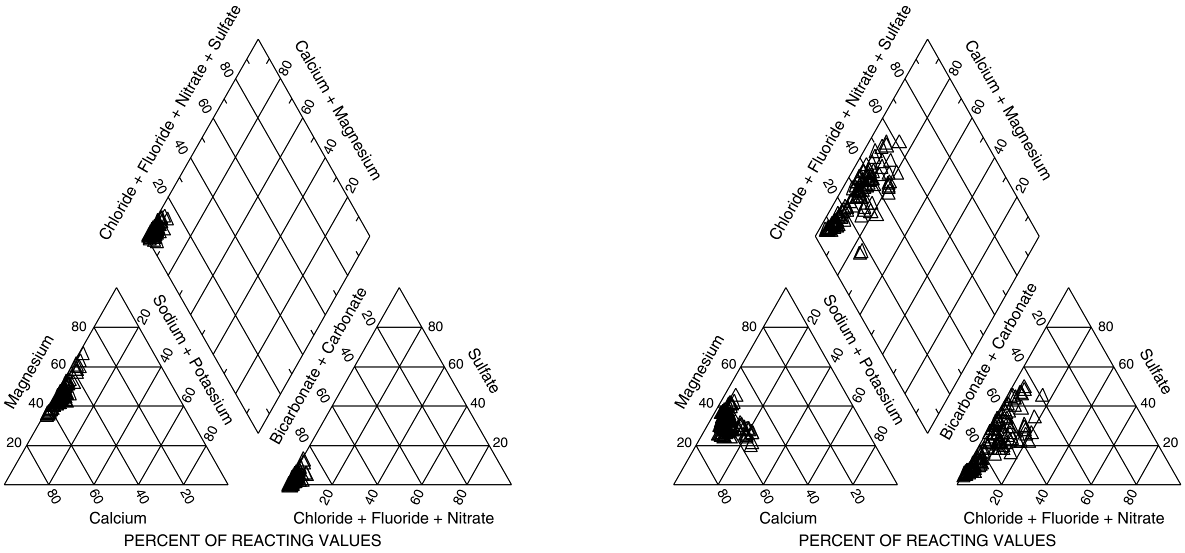
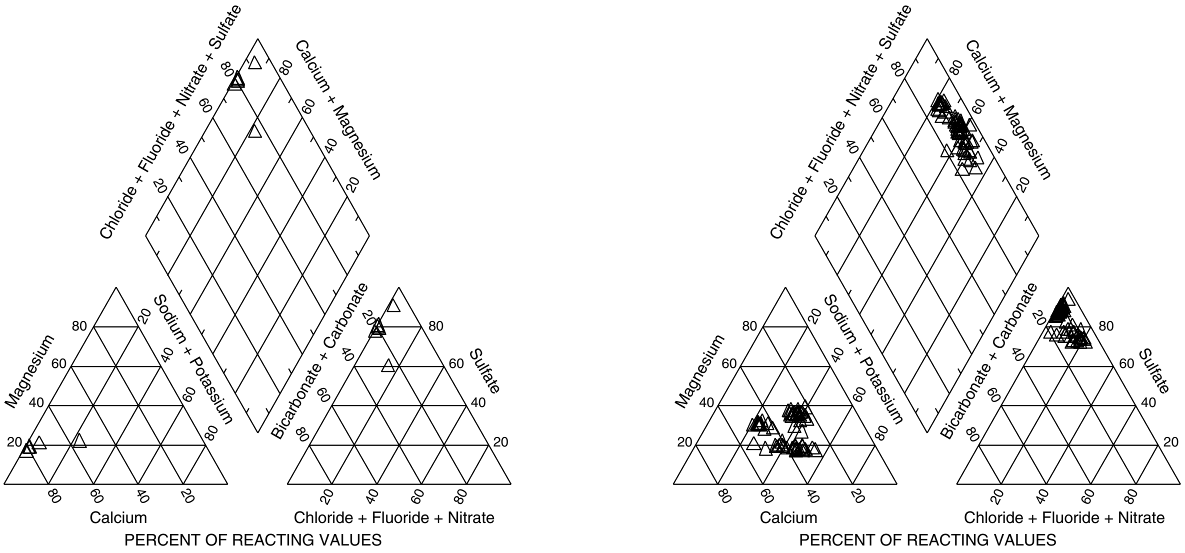


Figure 35. Relation between specific conductance and dissolved solids by surface-water group.

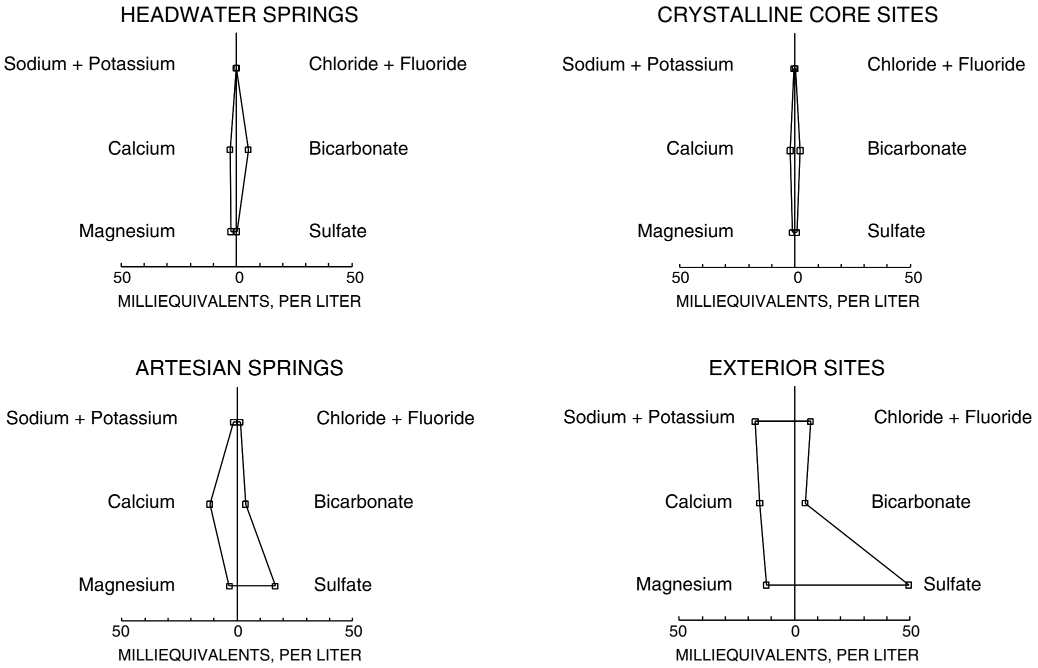


HEADWATER SPRINGS **CRYSTALLINE CORE SITES**

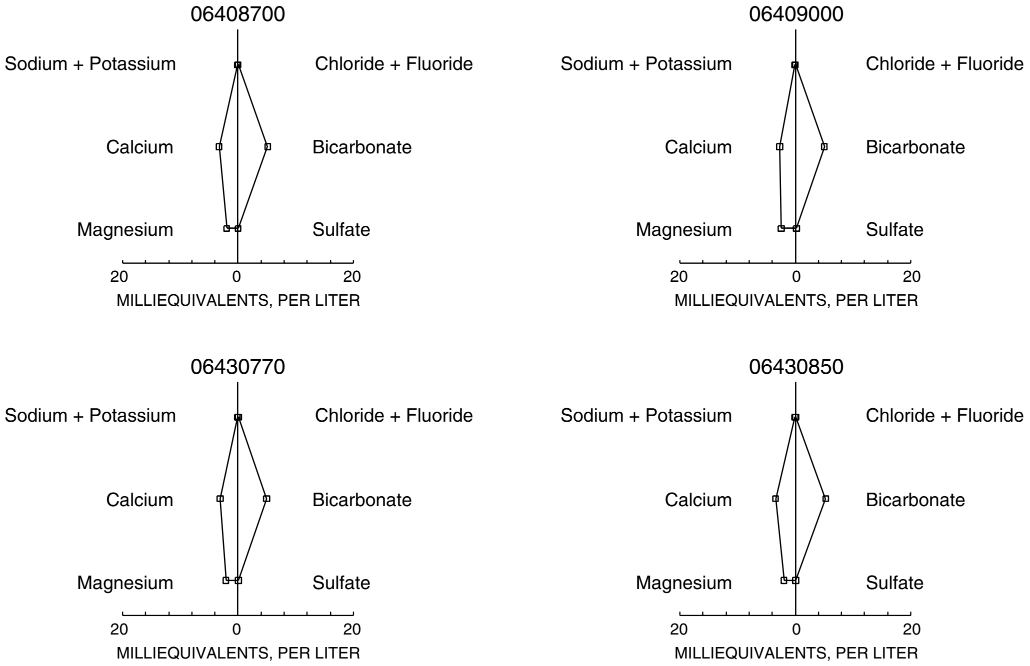


ARTESIAN SPRINGS **EXTERIOR SITES**

Figure 36. Trilinear diagrams showing proportional concentrations of major ions by surface-water group.

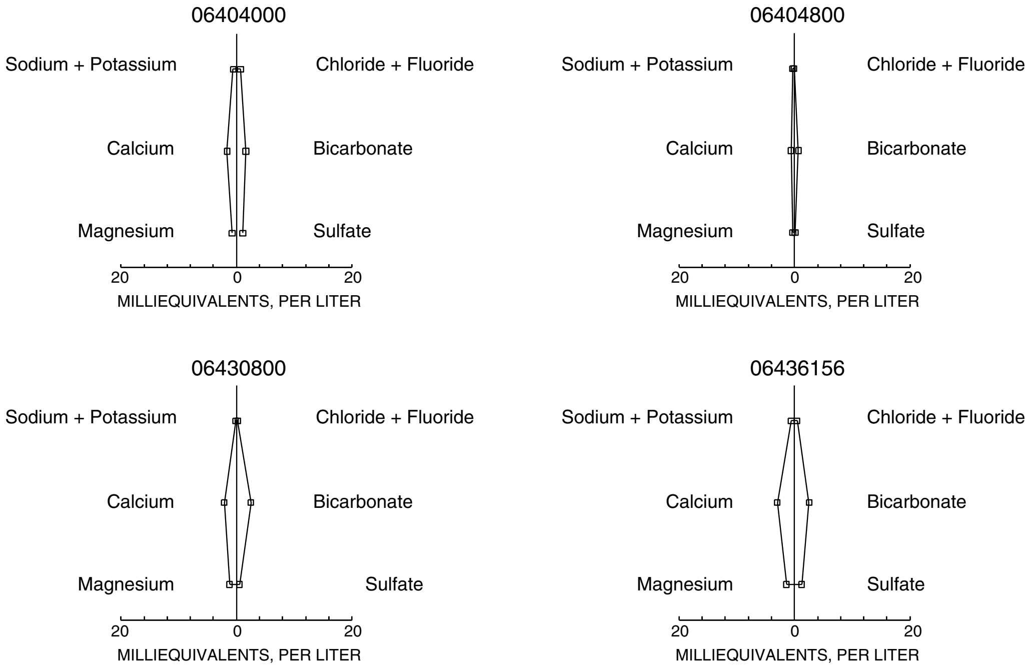


STIFF DIAGRAMS OF MEDIAN CONCENTRATIONS (BY GROUP)

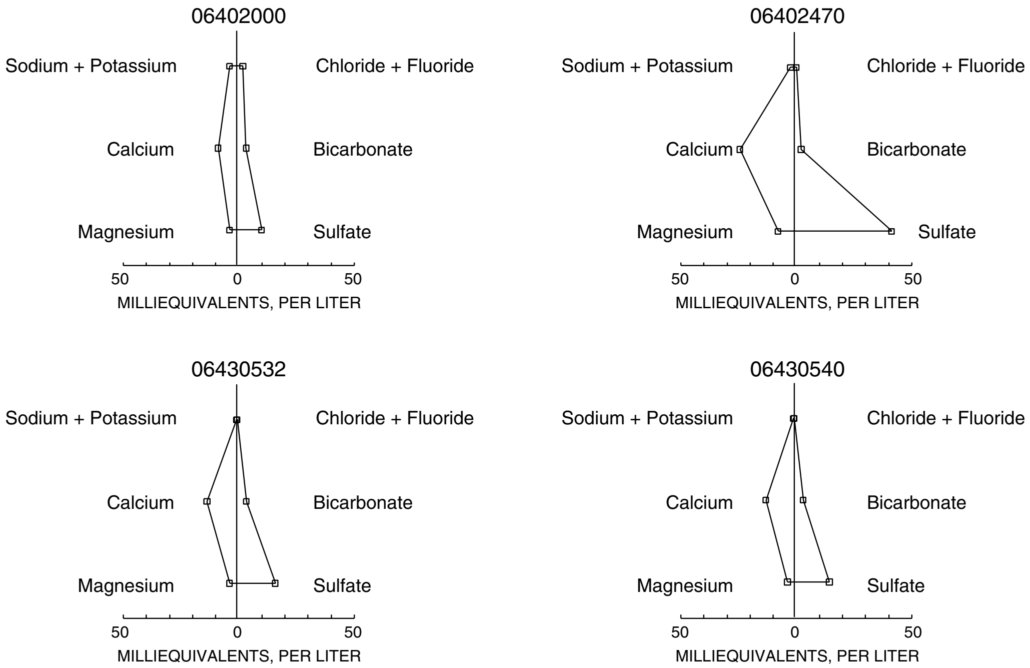


STIFF DIAGRAMS FOR SELECTED HEADWATER SPRINGS

Figure 37. Stiff diagrams for surface-water groups and selected sites.



STIFF DIAGRAMS FOR SELECTED CRYSTALLINE CORE SITES



STIFF DIAGRAMS FOR SELECTED ARTESIAN SPRINGS

Figure 37. Stiff diagrams for surface-water groups and selected sites.--Continued

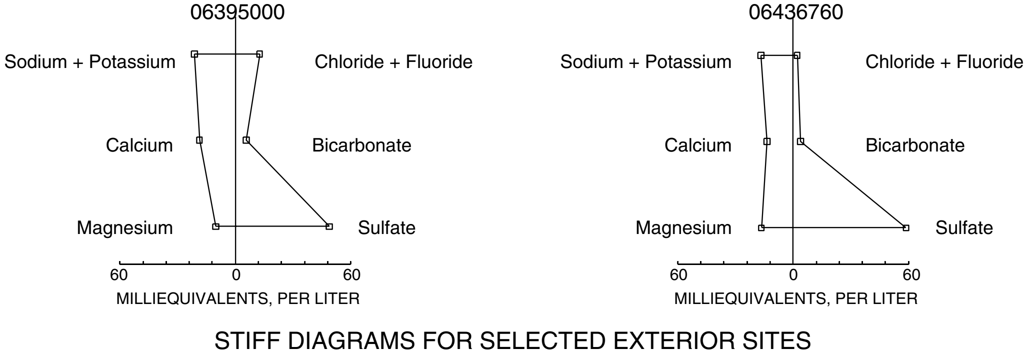


Figure 37. Stiff diagrams for surface-water groups and selected sites.--Continued

Table 11. Relation between specific conductance and dissolved solids for selected surface-water groups

[S = dissolved solids, in milligrams per liter; K = specific conductance, in microsiemens per centimeter

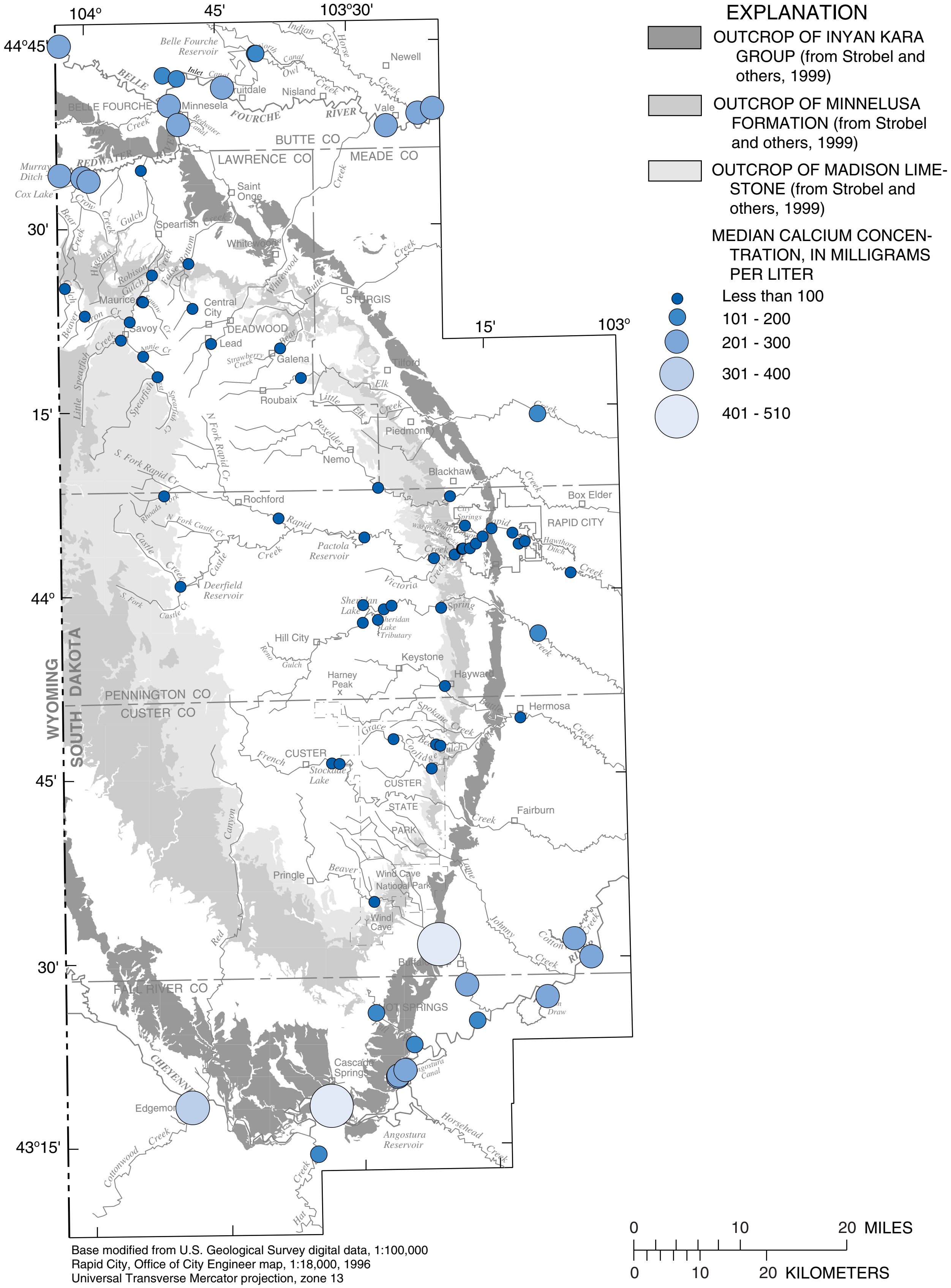
Group	Equation of line	R^2	Number of samples
All	$S = 0.86K - 131.14$	0.9692	2,355
Headwater springs	$S = 0.21K + 158.16$	.2437	261
Crystalline core sites	$S = 0.55K + 15.83$	.8914	136
Artesian springs	$S = 0.93K - 194.22$	.9614	13
Exterior sites	$S = 0.85K - 249.50$	.9676	174

Generally, common ion concentrations tend to increase after the streams come in contact with the Cretaceous-age marine shales surrounding the Black Hills, which results in increased concentrations of sulfate complexed with calcium or sodium. Other ions such as chloride, magnesium, and potassium also tend to increase. figures 38 and 39 present spatial distributions of mean calcium and sulfate concentrations, respectively, for the study area. Specific conductance follows this same general pattern and linear relations commonly exist between specific conductance and selected common ion concentrations (fig. 40).

Additional Comparisons

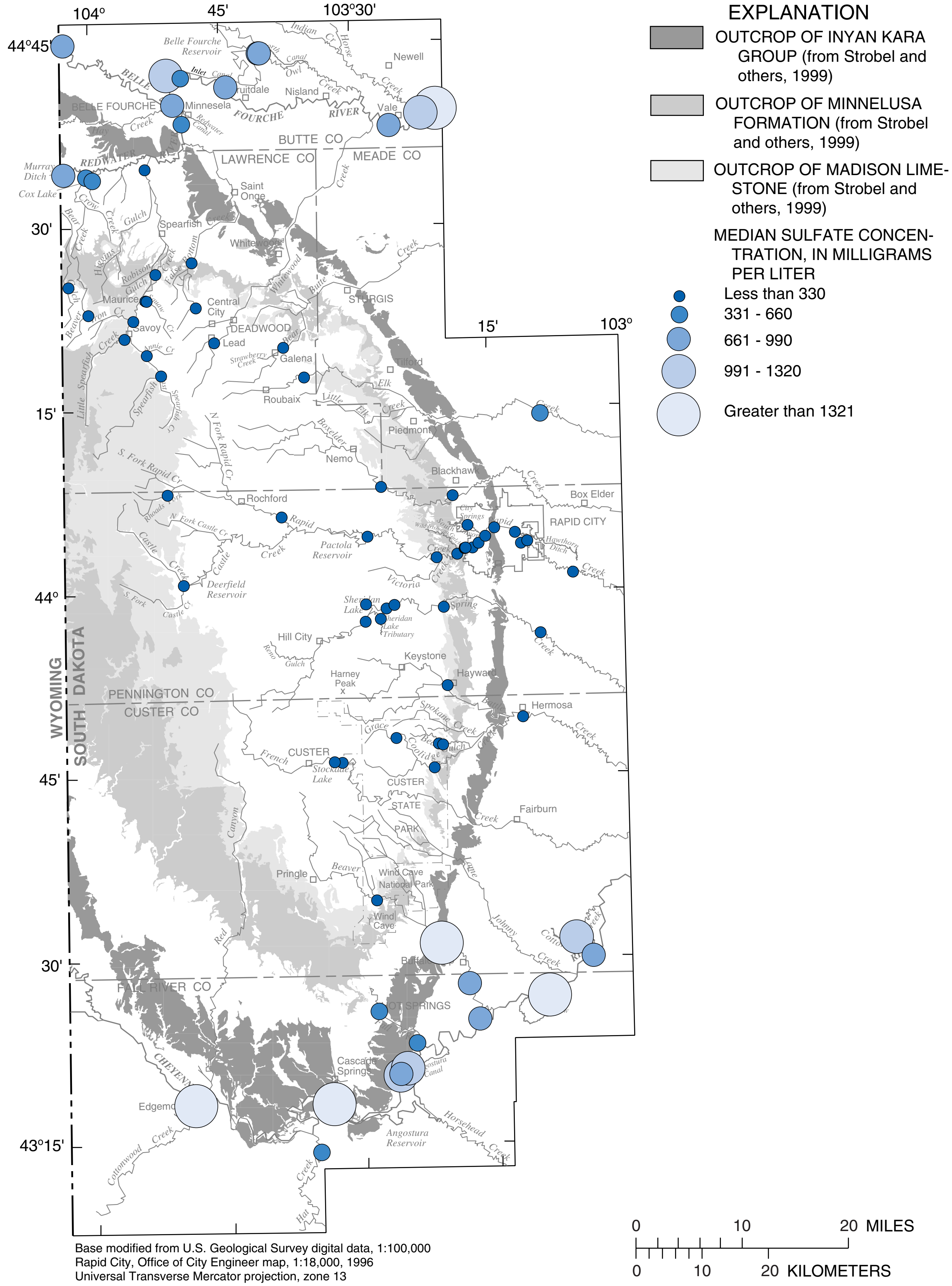
A downstream progression of calcium and sulfate concentrations for Rapid Creek is shown in figure 41. Downstream from Rapid Creek above Canyon Lake, 06412500, concentrations of calcium and sulfate increase notably, which is consistent with the increased exposure to limestone and then Cretaceous-age marine shales.

Changes in ion concentrations over time often can provide indications of land-use changes near a site. Dissolved solids, sodium, and sulfate concentrations in the water from Bear Butte Creek near Deadwood, 06437020, display increases during 1996 and 1997 (fig. 42). In January 1996, the DENR issued a permit for mining in the Strawberry Creek Basin (South Dakota Department of Environment and Natural Resources, 1998), a tributary immediately upstream of the Bear Butte Creek site. Increases in sodium and sulfate may indicate that mining and reclamation activities were affecting the stream. A mining area in the Strawberry Creek Basin recently has been listed on the Superfund National Priorities List (South Dakota Department of Environment and Natural Resources, 2001).



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 38. Spatial distribution of median calcium concentrations in surface water.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 39. Spatial distribution of median sulfate concentrations in surface water.

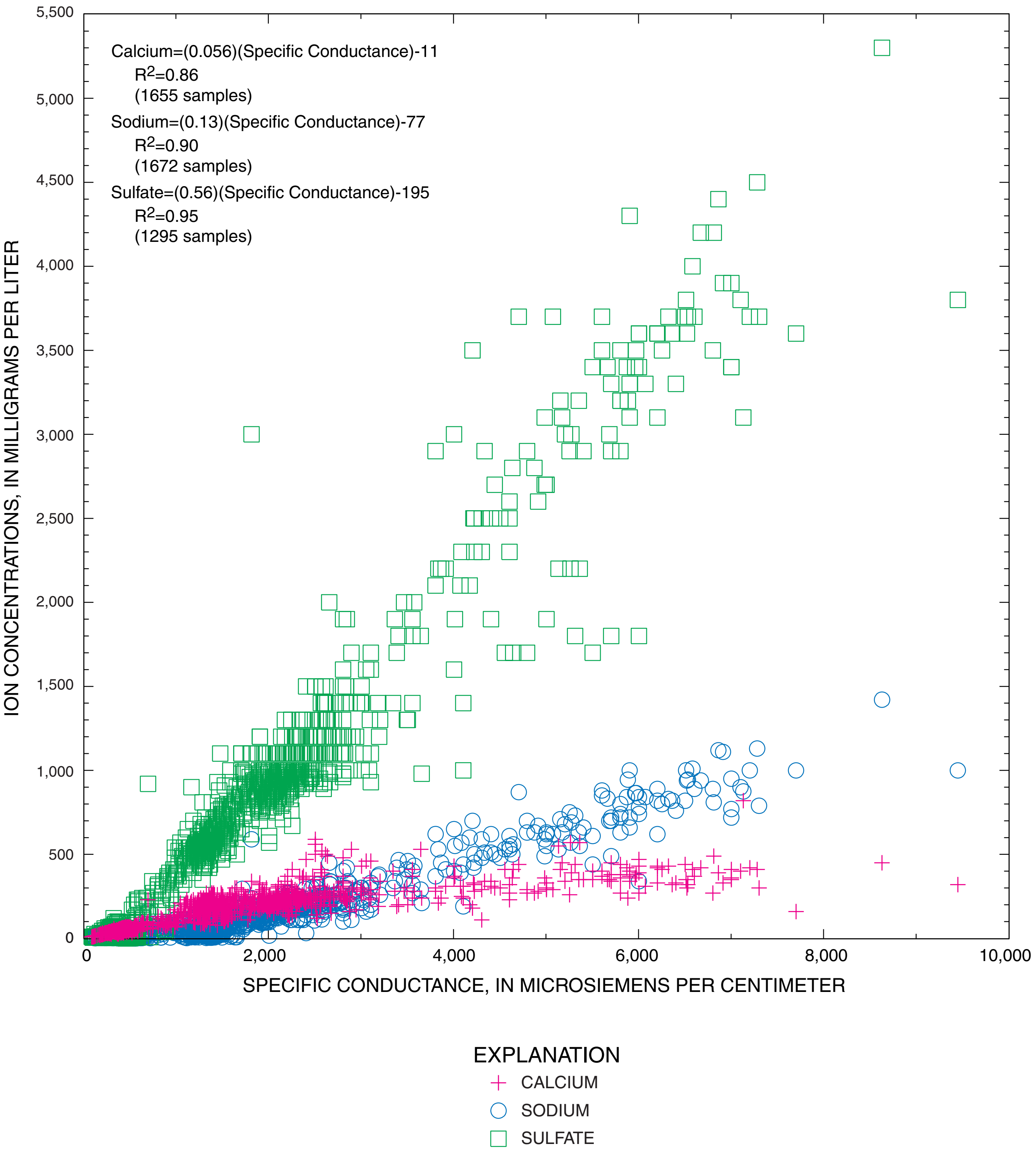


Figure 40. Relation between specific conductance and calcium, sodium, and sulfate concentrations in surface water.

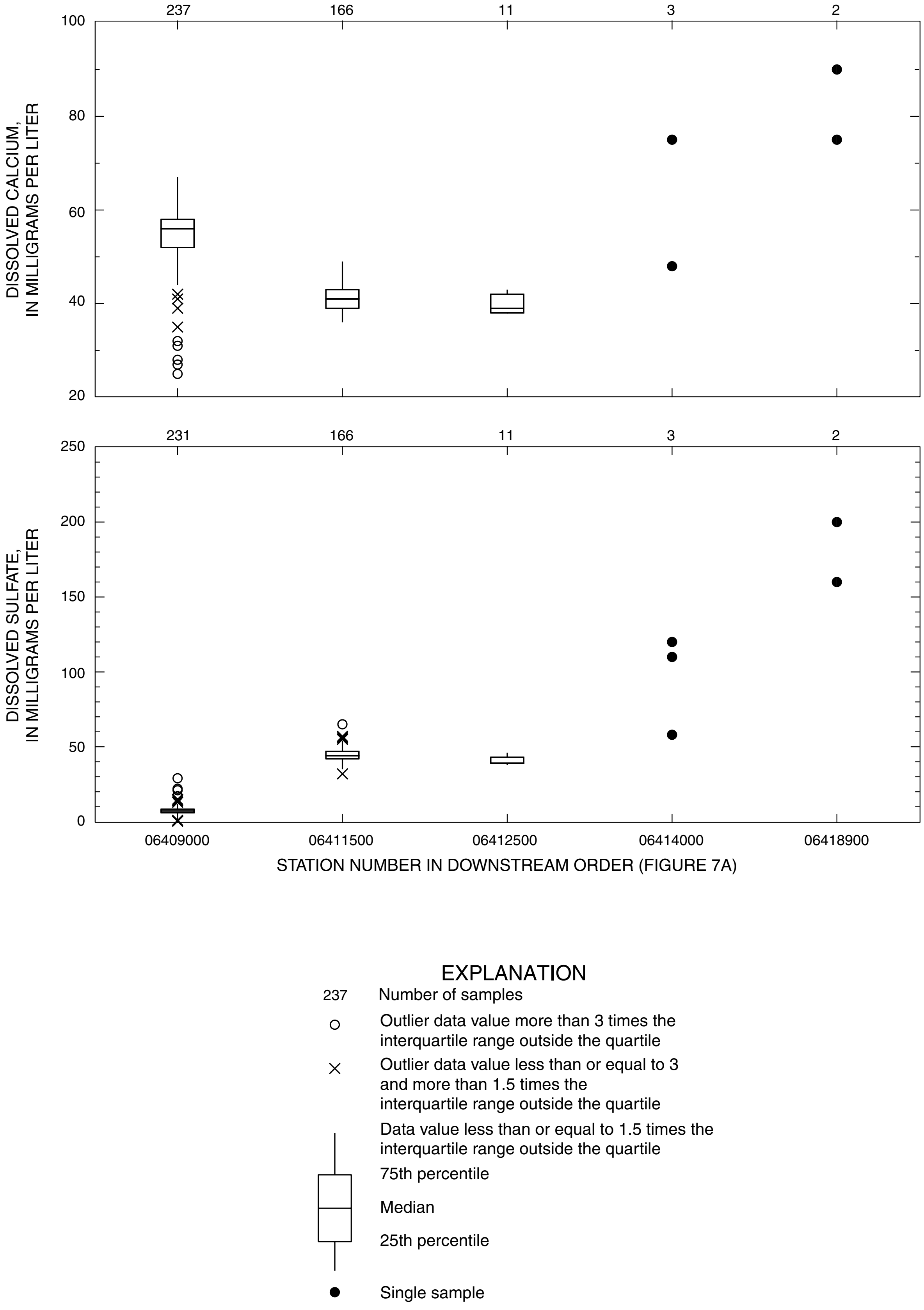


Figure 41. Boxplots of selected ions for selected surface-water sites in Rapid Creek Basin.

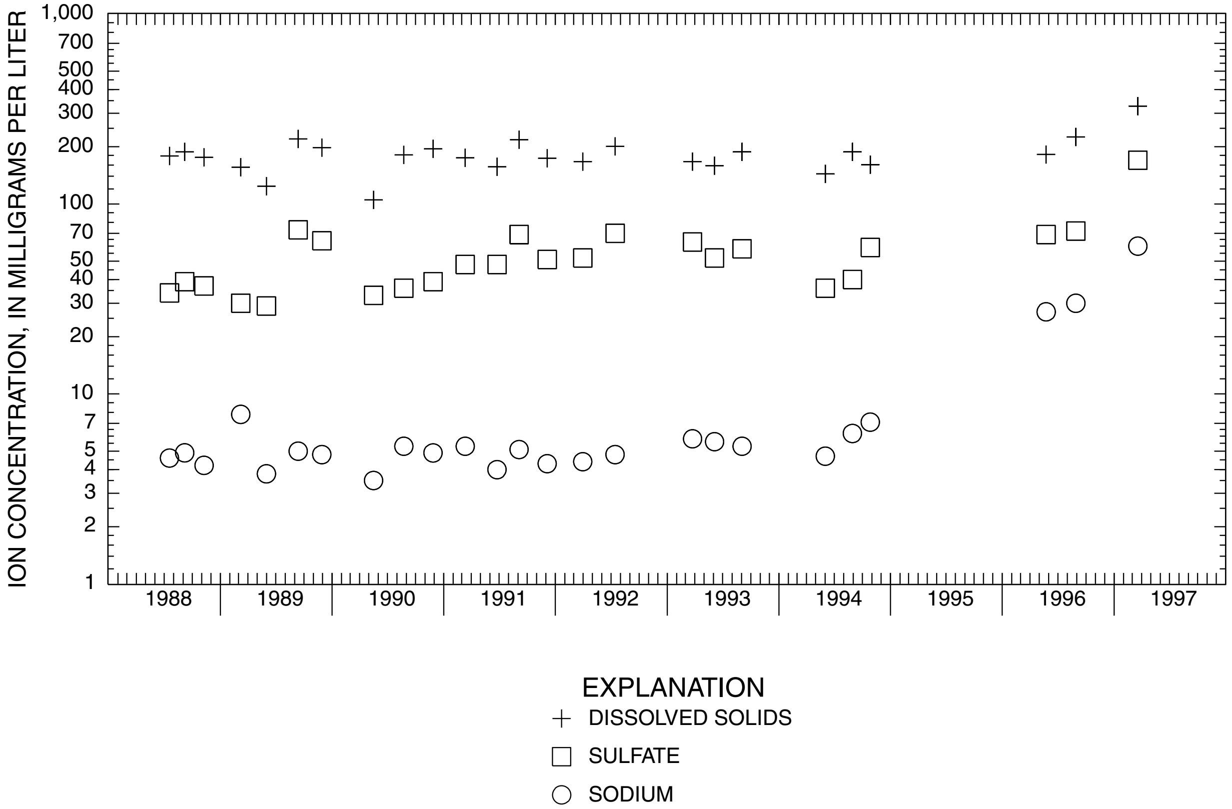


Figure 42. Changes in selected ions at Bear Butte Creek near Deadwood (06437020), 1988-97.

Nutrients

Nitrogen occurs in surface water as nitrite (NO_2^-), nitrate (NO_3^-), and as ammonium (NH_4^+), as well as other oxidation states. Nitrate is the form most commonly found in oxygenated surface waters. Nitrate concentrations in drinking water above 10 mg/L (U.S. Environmental Protection Agency, 1994a) can cause methemoglobinemia (blue-baby syndrome) in small children. Some sources of nitrate in water include septic systems, barnyards where animals are confined to small areas, fertilizers, impacts from mining including explosives and the breakdown of cyanide, as well as nitrification associated with in-stream riparian systems.

Summary statistics for selected nutrients are presented in table 12, and the significance of the various nutrients is described in table 1. Boxplots are presented in figure 43 for selected nutrients.

Group Comparisons

Nutrient concentrations for headwater springs are relatively low with most concentrations of nitrite below the laboratory reporting limit, and nitrate and nitrite plus nitrate concentrations much less than the MCL of 10 mg/L. For all sites, ammonia concentrations generally are low (less than 1 mg/L), with a few concentrations greater than 1 mg/L at exterior sites. Phosphate and orthophosphate concentrations generally also are less than 1 mg/L. Nutrient concentrations for crystalline core sites generally are higher than headwater springs but similar in magnitude to the other groups. The crystalline core sites do, however, have several nitrate and nitrite plus nitrate concentrations that exceed the MCL. The high concentrations are from Annie Creek near Lead (06430800). Nitrite plus nitrate concentrations at Annie Creek increased during the 1990's (fig. 44), with the highest concentrations in 1995 and 1996. Johnson (1992) concluded that mining effects were the cause of the higher nitrate levels in Annie Creek. Denitrification facilities were put in place within the Annie Creek Basin in 1997. Various levels of nitrate reduction by these facilities have been achieved (South Dakota Department of Environment and Natural Resources, 1998b).

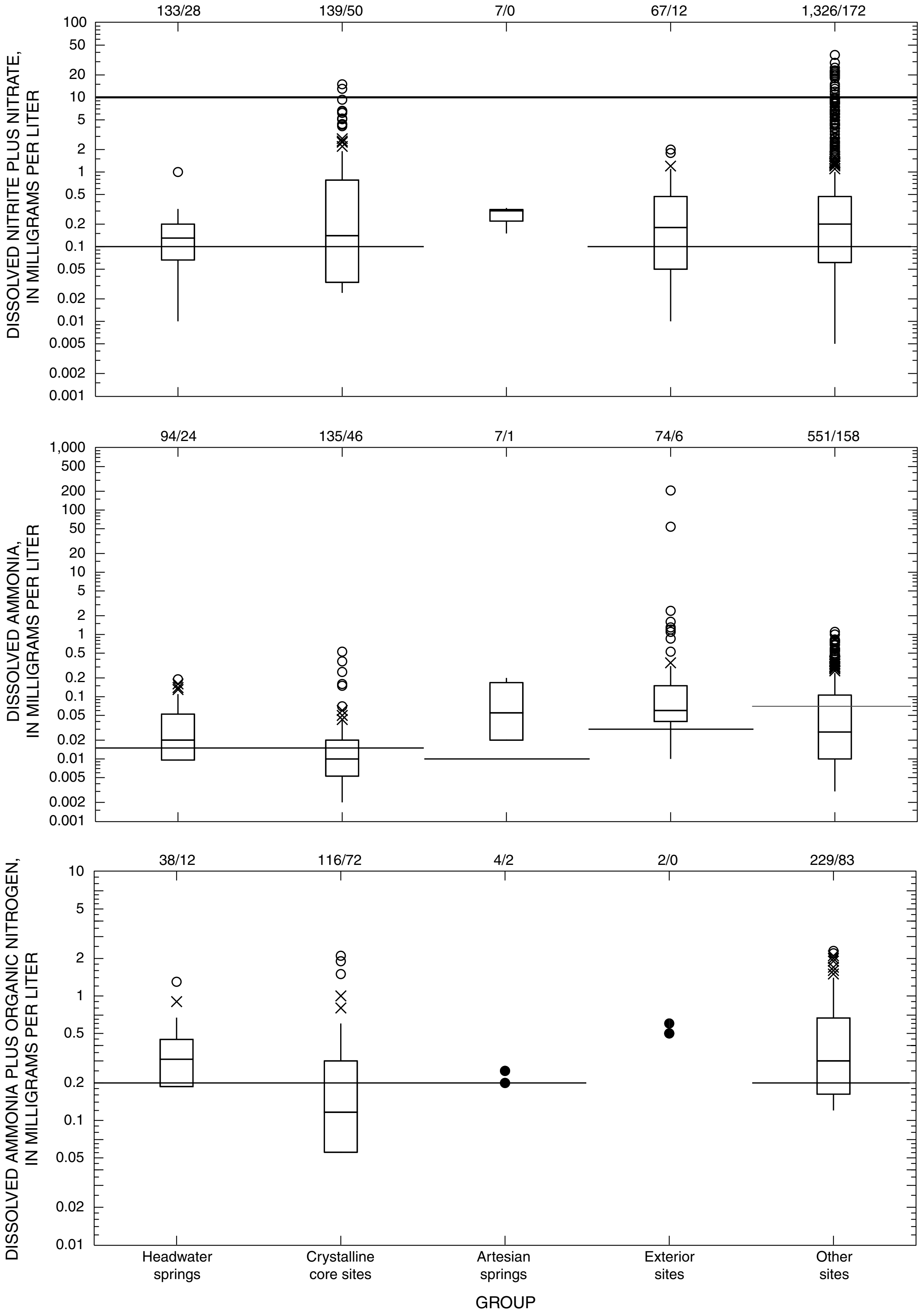


Figure 43. Boxplots of concentrations of selected nutrients by surface-water group.

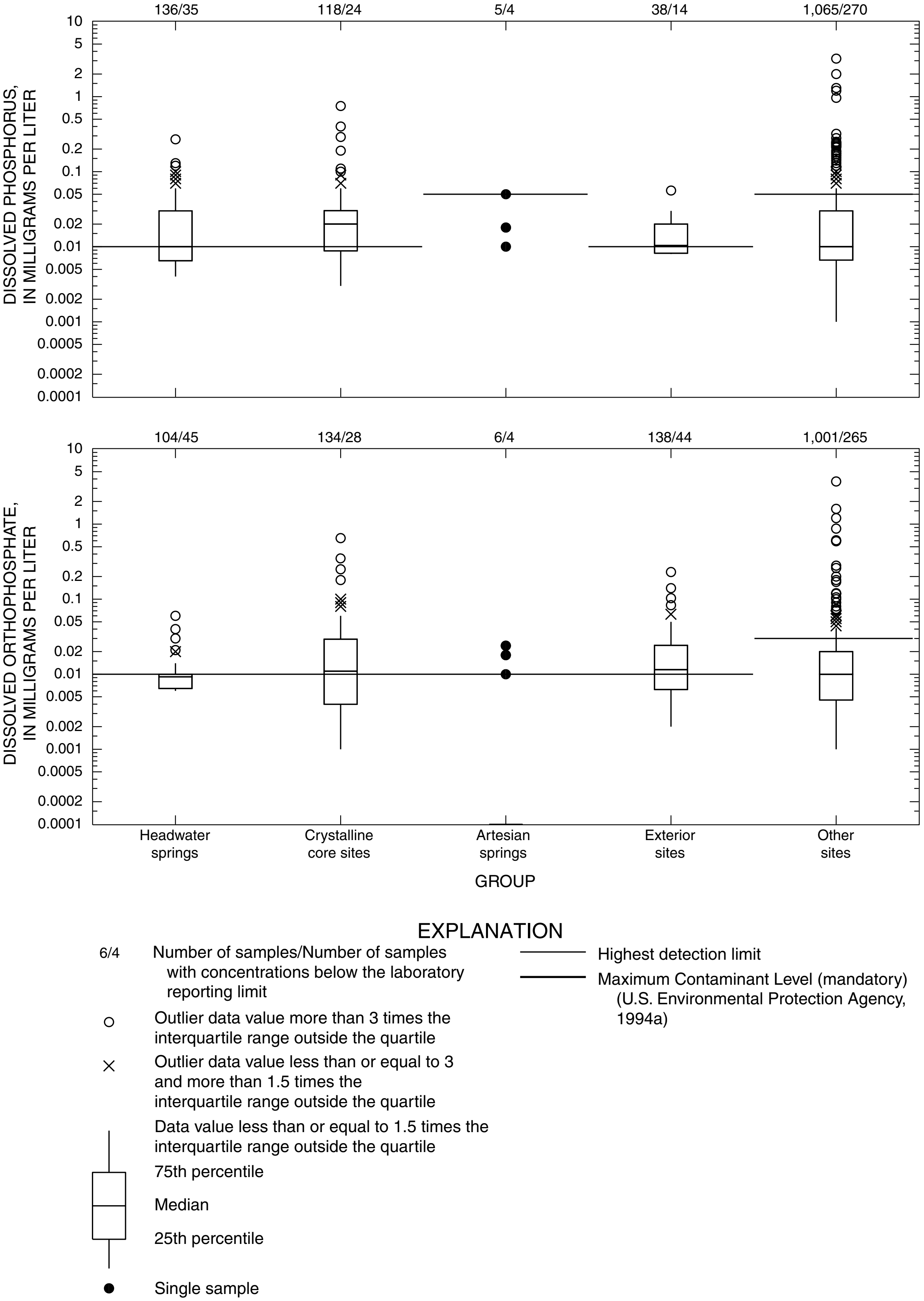


Figure 43. Boxplots of concentrations of selected nutrients by surface-water group.--Continued

Table 12. Summary of concentrations of nutrients in surface water by group

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in milligrams per liter. One milligram per liter is approximately equal to one part per million; --, not analyzed or determined; <, less than]

Dissolved constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Headwater springs						
Nitrate, as N	30	0	0.174	0.18	0.01	0.41
Nitrite, as N	62	54	[1]--	[1]--	<0.01	<0.05
Nitrite plus nitrate, as N	133	28	0.141	0.13	0.01	1
Ammonia, as N	94	24	0.034	0.02	<0.01	0.19
Ammonia plus organic nitrogen, as N	38	12	0.355	0.31	<0.2	1.3
Phosphorus, as P	136	35	0.023	0.01	0.004	0.27
Orthophosphate, as P	104	45	0.012	0.009	0.006	0.06
Crystalline core sites						
Nitrate, as N	20	0	1.588	0.139	0.019	14.1
Nitrite, as N	114	92	[1]--	[1]--	0.001	0.93
Nitrite plus nitrate, as N	139	50	0.950	0.14	<0.005	15
Ammonia, as N	135	46	0.026	0.01	<0.002	0.53
Ammonia plus organic nitrogen, as N	116	72	0.213	0.116	<0.2	2.1
Phosphorus, as P	118	24	0.036	0.02	0.003	0.75
Orthophosphate, as P	134	28	0.027	0.011	<0.001	0.65
Artesian springs						
Nitrate, as N	0	0	--	--	--	--
Nitrite, as N	6	6	[1]--	[1]--	<0.01	<0.01
Nitrite plus nitrate, as N	7	0	0.265	0.302	0.15	0.33
Ammonia, as N	7	1	0.081	0.055	<0.01	0.2
Ammonia plus organic nitrogen, as N	4	2	[1]--	[1]--	<0.2	0.25
Phosphorus, as P	5	4	[1]--	[1]--	<0.01	0.05
Orthophosphate, as P	6	4	[1]--	[1]--	<0.01	0.024
Exterior sites						
Nitrate, as N	36	0	0.365	0.205	0.01	2
Nitrite, as N	25	16	0.007	0.006	<0.01	0.03
Nitrite plus nitrate, as N	67	12	0.359	0.18	0.01	2
Ammonia, as N	74	6	3.708	0.06	<0.01	206
Ammonia plus organic nitrogen, as N	2	0	0.55	0.55	0.5	0.6
Phosphorus, as P	38	14	0.016	0.010	0.008	0.056
Orthophosphate, as P	138	44	0.020	0.012	0.002	0.23
Other sites						
Nitrate, as N	171	0	0.716	0.233	0.003	29
Nitrite, as N	312	182	0.008	0.004	<0.001	0.16
Nitrite plus nitrate, as N	1326	172	0.821	0.2	<0.005	37
Ammonia, as N	551	158	0.083	0.027	<0.002	1.1
Ammonia plus organic nitrogen, as N	229	83	0.464	0.3	0.12	2.3
Phosphorus, as P	1065	270	0.033	0.01	<0.001	3.2
Orthophosphate, as P	1001	265	0.027	0.01	<0.001	3.7

[1] Percent of censored values is greater than 80 percent. Mean and median are not reported because they are unreliable.

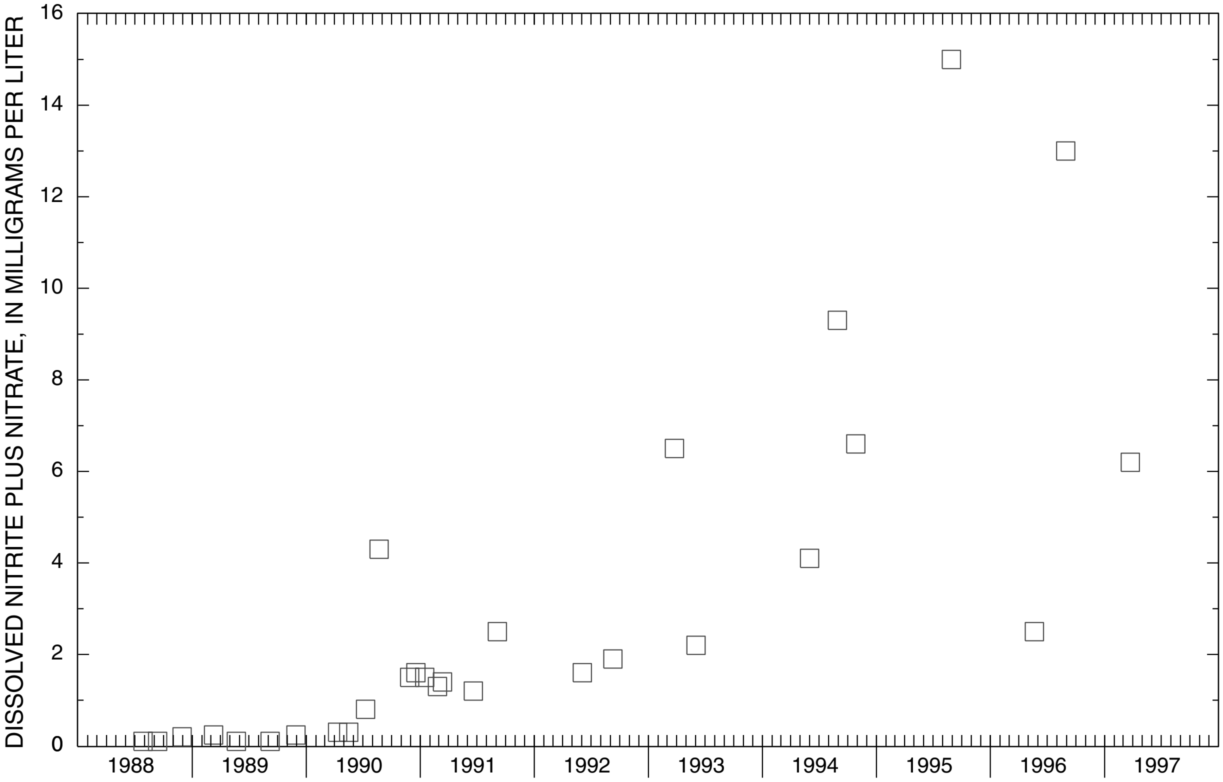


Figure 44. Nitrite plus nitrate concentrations in Annie Creek near Lead (06430800), 1988-97.

Based on a relatively limited data set, nutrient concentrations from the artesian springs are similar to other hydrogeologic settings. With ground water (primarily from the Madison and/or Minnelusa aquifers) as the source for these springs, the low nutrient concentrations provide an indication that at least for these limited sites, impacts from septic systems, mining, or other nutrient contamination sources are not currently taking place to the ground-water system. Because major sources of recharge to these regional aquifers are the outcrop areas upstream from these springs, contamination is a concern, including continued urban development and the placement of rural septic systems. Delineation of source-water protection areas and education are ongoing efforts by State and local governmental agencies.

Exterior sites have low nutrient concentrations with the exception of a few high ammonia concentrations. The two ammonia concentrations above 5 mg/L were from the Cheyenne River at Edgemont (06395000) during January and February of 1975. Both concentrations (54 mg/L and 206 mg/L) are more than two orders of magnitude higher than monthly samples collected prior to and after these samples. Possible causes of high ammonia concentrations could be related to stagnant/semi-stagnant conditions under ice, which causes reducing conditions. With reducing conditions, ammonia would be the end-product of the breakdown of organic material in the sediments. The corresponding pH values were the lowest of record for this site, which would be consistent with consumption of oxygen and dissolution of carbon dioxide.

The majority of nutrient concentrations from the other-sites group are similar to concentrations from the hydrogeologic setting groups. Some high nitrate and nitrite plus nitrate concentrations occurred at Horse Creek near Vale (06436800) during the 1970's, but concentrations decreased by the early 1980's (fig. 45). It is unknown if these levels were due to irrigation or farming practices during that time period. Horse Creek drains a portion of the irrigated lands that are part of the Belle Fourche Irrigation Project. Further sampling during the late 1980's and early 1990's at Horse Creek above Vale (06436760), which is located about 1.5 miles upstream, indicated concentrations similar to those from the early 1980's at Horse Creek near Vale. Slight seasonal trends are apparent at the Horse Creek above Vale site with higher concentrations during late fall and winter when ground-water discharge from alluvial aquifers likely would constitute most of the streamflow. Additionally, relatively high nitrate levels are not uncommon to the shales in western South Dakota (South Dakota Department of Environment and Natural Resources, 2000).

Additional Comparisons

Nutrient concentrations in Rapid Creek generally are low but do show a slight increase with distance downstream and a notable increase in nitrite plus nitrate and orthophosphate from samples at Rapid Creek near Farmingdale (06421500) (fig. 46). Limited data exist between just above Rapid City to Farmingdale for orthophosphates, so increases may be more gradual than indicated by the data. Trends indicate that urbanization and/or agricultural practices may be affecting Rapid Creek, although concentrations are relatively low.

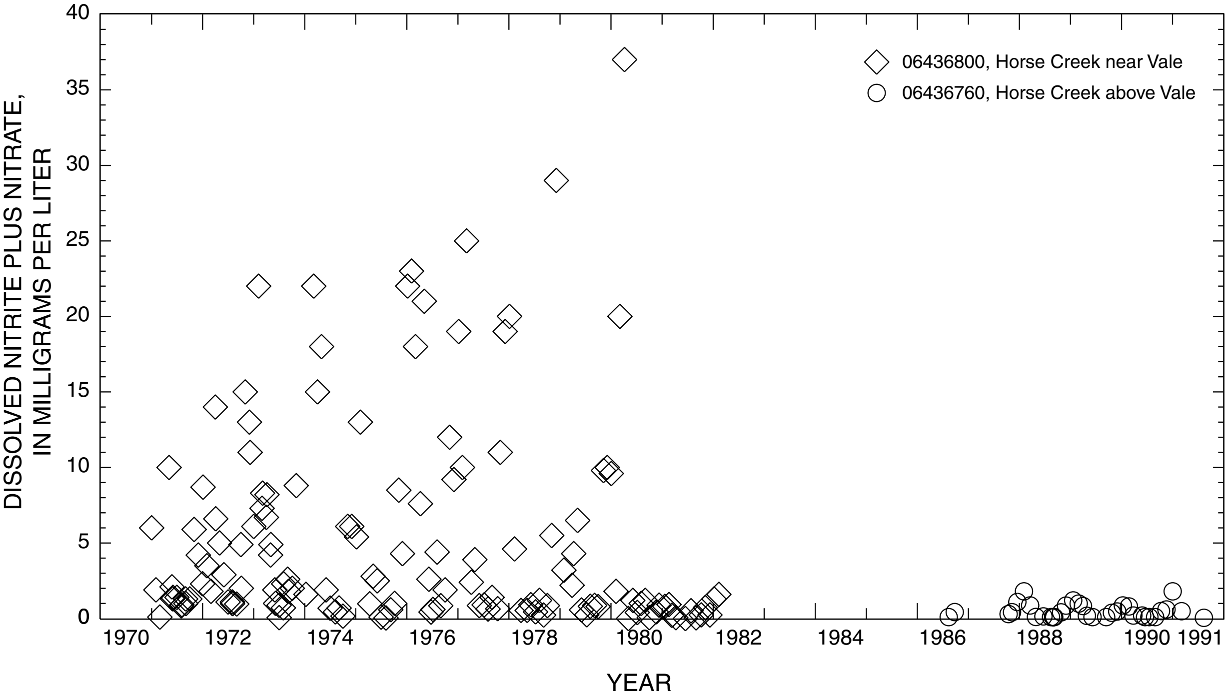


Figure 45. Nitrite plus nitrate concentrations at Horse Creek near Vale (06436800) and Horse Creek above Vale (06436760).

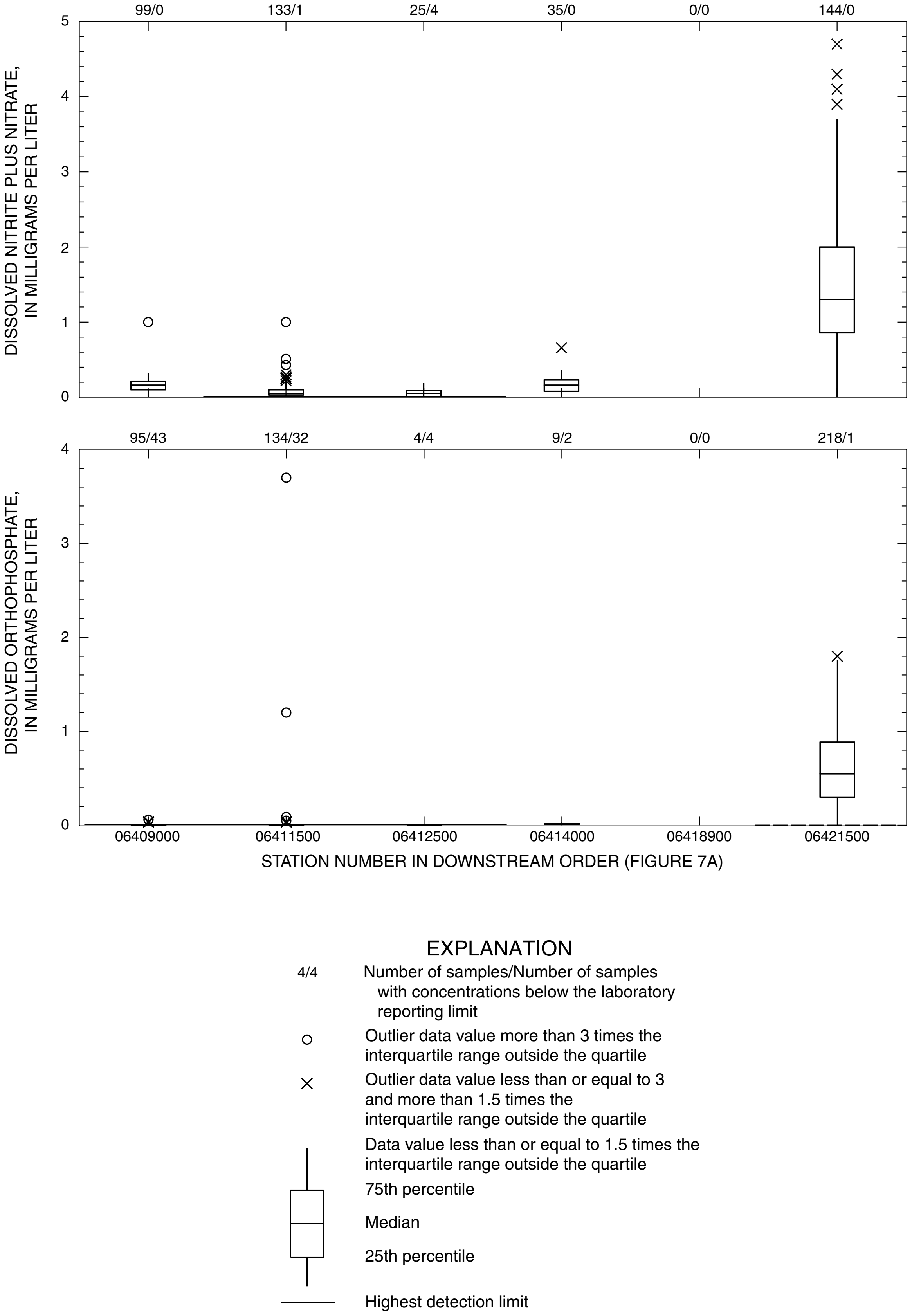


Figure 46. Boxplots of selected nutrients for selected surface-water sites in Rapid Creek Basin.

Trace Elements

Statistical summaries are presented in this section for selected trace elements (table 13). Boxplots are presented for those constituents where sufficient data were available above laboratory reporting limits (fig. 47).

Group Comparisons

Headwater springs generally have low concentrations of trace elements; most have similar concentrations as other groups or slightly higher than the crystalline core sites and artesian springs but less than exterior sites. For headwater springs, some concentrations exceed SMCL's and aquatic standards for aluminum, copper, iron, lead, silver, and zinc. All of the concentrations exceeding standards were from Castle Creek above Deerfield Reservoir (06409000; samples from this site compose more than 90 percent of the headwater springs samples). Dissolved concentrations for aluminum (three at 200 μg/L), iron (one at 540 μg/L), and manganese (71 μg/L and 60 μg/L) are greater than their respective SMCL's. The maximum concentration for silver does not exceed the hardness-dependent aquatic standard. The concentrations of lead that are greater than aquatic standards were from samples collected during the 1960's and 1970's when lead contamination in samples was not uncommon. Lead contamination often was introduced during the collection and analyses of a sample because lead was so prevalent in the environment during that timeframe. One major source of lead in the environment was leaded gasoline. More recent analyses (1990's) for lead along Castle Creek have all yielded concentrations less than the laboratory reporting limit of 1 μg/L. Three dissolved copper concentrations exceed the hardness-dependent aquatic chronic criteria and two exceed the hardness-adjusted acute criteria. These samples also were from the 1960's and have higher concentrations than samples from the early 1990's, which are at or near the laboratory reporting limit of 1 μg/L. The four zinc concentrations above 100 μg/L are similar in that they occasionally exceeded hardness-dependent aquatic criteria, but more recent sampling indicates that concentrations are within a range of 1 to 20 μg/L.

Samples from crystalline core sites generally have very low concentrations of trace elements but have the highest mean and maximum concentration for dissolved barium. One dissolved arsenic concentration from Elk Creek near Roubaix (06424000) exceeded the current MCL of 50 μg/L, and numerous dissolved arsenic concentrations (64 percent) are greater than the proposed MCL of 10 μg/L. The highest dissolved copper concentration (greater than 11 μg/L) does not exceed the hardness-dependent aquatic criterion for copper. A dissolved iron concentration of 1,700 μg/L at Bear Gulch near Hayward (06405800) and a concentration of 330 μg/L at Elk Creek near Roubaix (06424000) both are greater than the SMCL for iron. Dissolved lead concentrations of 20 μg/L from two northern Black Hills sites, Annie Creek near Lead (06430800) and Squaw Creek near Spearfish (06430898), exceed the action level. Dissolved manganese concentrations greater than the SMCL include two samples from Grace Coolidge Creek near the Game Lodge (06404998), two samples from Bear Gulch near Hayward (06405800), two samples from Spring Creek above Sheridan Lake (06406920), and one sample from Whitetail Creek at Lead (06436156).

Trace element concentrations at artesian springs generally are very low but limited data are available from which comparisons could be made. No standards or criteria for trace elements have been exceeded in the available samples from artesian springs.

Concentrations of trace elements at exterior sites generally are either similar to or higher than concentrations from other hydrogeologic settings. Exterior sites have the highest median concentrations for boron, chromium, copper, iron, lithium, manganese, selenium, silver, strontium, and zinc. Samples from the 1960's and 1970's from Cheyenne River at Edgemont (06395000) had concentrations that exceed the SMCL's for aluminum, iron, and manganese. Copper and zinc concentrations do not exceed hardness-dependent aquatic criteria. Two manganese concentrations greater than the SMCL are from Horse Creek above Vale. Seven of the nine selenium concentrations exceeding the chronic aquatic criteria are from Horse Creek above Vale, and two are from Cheyenne River at Edgemont. Selenium is present in the Cretaceous-age marine shales common to the plains surrounding the Black Hills.

Table 13. Summary of concentrations of trace elements in surface water by group

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or determined; <, less than]

Dissolved Constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
		Headwater springs				
Aluminum	50	31	17	2.6	<10	200
Arsenic	51	24	0.95	1.0	<1.0	2.0
Barium	69	0	68	64	50	100
Boron	79	16	15	10	1.9	80
Cadmium	47	40	[1]--	[1]--	<1.0	4.0
Chromium	47	29	0.84	0.71	<1.0	2.0
Cobalt	53	51	[1]--	[1]--	2.0	3.0
Copper	51	22	3.5	1.0	<1.0	50
Iron	98	6	27	10	<3.0	540
Lead	29	19	1.1	0.29	<1.0	10
Lithium	54	12	7.5	6.0	<4.0	70
Manganese	90	7	10	7.0	0.02	71
Mercury	51	44	[1]--	[1]--	<0.10	0.20
Molybdenum	5	1	[1]--	5.0	<1.0	10
Nickel	47	28	1.1	0.47	<1.0	14
Selenium	69	60	[1]--	[1]--	<1.0	4.0
Silver	49	43	[1]--	[1]--	<1.0	11
Strontium	59	0	72	67	40	160
Vanadium	4	0	3.2	2.5	2.0	6.0
Zinc	61	16	41	6.0	<3.0	810
		Crystalline core sites				
Aluminum	3	2	[1]--	[1]--	<10	10
Arsenic	112	6	15	12	<1.0	68
Barium	93	0	77	82	16	150
Boron	80	36	15	10	<10	130
Cadmium	49	45	[1]--	[1]--	<1.0	3.0
Chromium	70	46	0.82	0.69	<1.0	2.0
Cobalt	17	15	[1]--	[1]--	<3.0	12
Copper	73	42	0.98	0.55	<1.0	17
Iron	135	17	40	12	<3.0	1,700
Lead	62	54	[1]--	[1]--	<1.0	20
Lithium	20	6	8.6	5.0	<4.0	37
Manganese	130	45	18	4.0	<1.0	440
Mercury	76	70	[1]--	[1]--	<0.10	0.3
Molybdenum	2	0	12	11.5	10	13
Nickel	1	0	[1]--	[1]--	11	11
Selenium	78	66	[1]--	[1]--	<1.0	3.0
Silver	17	12	0.75	0.42	<1.0	3.0
Strontium	17	0	170	140	48	350
Vanadium	0	0	--	--	--	--
Zinc	91	36	4.9	4.0	<3.0	22

Table 13. Summary of concentrations of trace elements in surface water by group—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or determined; <, less than]

Dissolved Constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Artesian springs						
Aluminum	2	0	5.0	5.0	3.3	6.8
Arsenic	6	1	[1]--	2.5	<1.0	4.0
Barium	4	0	64	68	18	104
Boron	6	0	120	130	30	210
Cadmium	2	2	[1]--	[1]--	<1.0	<1.0
Chromium	5	3	[1]--	[1]--	<1.0	2.4
Cobalt	2	2	[1]--	[1]--	<1.0	<1.0
Copper	5	5	[1]--	[1]--	<1.0	<1.0
Iron	3	1	[1]--	5	<3.0	28
Lead	5	5	[1]--	[1]--	<1.0	<1.0
Lithium	0	0	--	--	--	--
Manganese	5	3	[1]--	[1]--	<1.0	11
Mercury	3	3	[1]--	[1]--	<0.10	<0.10
Molybdenum	2	2	[1]--	[1]--	<1.0	<1.0
Nickel	2	2	[1]--	[1]--	<1.0	<1.0
Selenium	6	2	[1]--	[1]--	<1.0	3.0
Silver	2	2	[1]--	[1]--	<1.0	<1.0
Strontium	0	0	--	--	--	--
Vanadium	0	0	--	--	--	--
Zinc	4	0	4.6	4.8	2.0	7.0
Exterior sites						
Aluminum	5	3	[1]--	[1]--	<10	740
Arsenic	19	9	1.1	1.0	<1.0	7.0
Barium	0	0	--	--	--	--
Boron	55	0	592	430	10	1,600
Cadmium	20	14	0.94	0.17	<1.0	9.0
Chromium	17	8	1.6	1.3	<1.0	4.0
Cobalt	7	6	00	<1.0	<1.0	3.0
Copper	25	6	9.1	2.0	<1.0	75
Iron	10	0	209	27	4.0	1,900
Lead	11	8	[1]--	[1]--	<1.0	10
Lithium	8	0	201	240	75	320
Manganese	17	0	122	60	2.0	670
Mercury	12	11	[1]--	[1]--	<0.10	0.10
Molybdenum	21	1	3.8	3.0	<1.0	9.0
Nickel	14	0	5.7	4.5	2.0	18
Selenium	20	1	6.7	4.0	<1.0	20
Silver	9	4	0.91	1.0	<1.0	2.0
Strontium	8	0	3,984	3,950	750	8,620
Vanadium	21	2	3.0	2.0	<1.0	15
Zinc	20	1	65	20	<3.0	490

Table 13. Summary of concentrations of trace elements in surface water by group—Continued

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in micrograms per liter. One microgram per liter is approximately equal to one part per billion; --, not analyzed or determined; <, less than]

Dissolved Constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
		Other sites				
Aluminum	35	14	33	9.4	3.5	281
Arsenic	260	59	2.6	2.0	<1.0	43
Barium	113	0	55	44	15	110
Boron	1322	30	235	160	4.0	2,300
Cadmium	175	151	[1]--	[1]--	<0.10	5.0
Chromium	151	72	1.3	1.0	<1.0	10
Cobalt	44	39	[1]--	[1]--	<1.0	3.0
Copper	180	58	3.1	1.0	<1.0	100
Iron	255	19	53	21	<2.0	950
Lead	107	69	2.8	0.33	<0.01	57
Lithium	50	0	37	30	4.0	190
Manganese	273	27	90	30	0.06	1,010
Mercury	199	179	[1]--	[1]--	<0.10	5.3
Molybdenum	76	8	5.6	6.0	<1.0	16
Nickel	36	5	7.5	4.5	<1.0	43
Selenium	198	106	2.4	0.83	<1.0	70
Silver	58	46	[1]--	[1]--	<0.20	4.0
Strontium	43	0	1295	330	83	6,700
Vanadium	64	17	1.8	2.0	<1.0	6.0
Zinc	197	62	13	6.0	<0.50	150

[1] Percent of censored values is greater than 80 percent or number of samples is less than 7. Mean and/or median are not reported because they are unreliable.

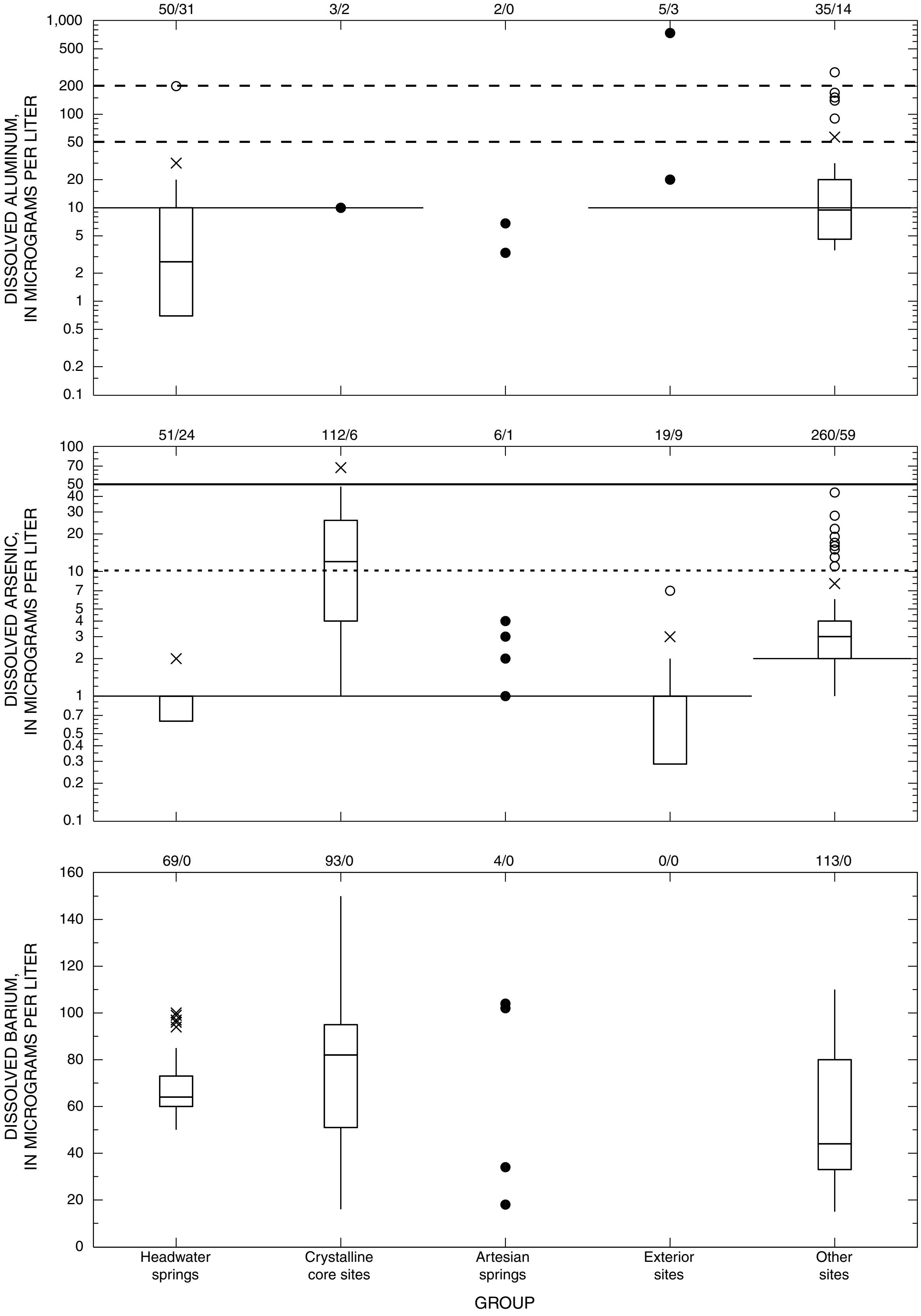


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.

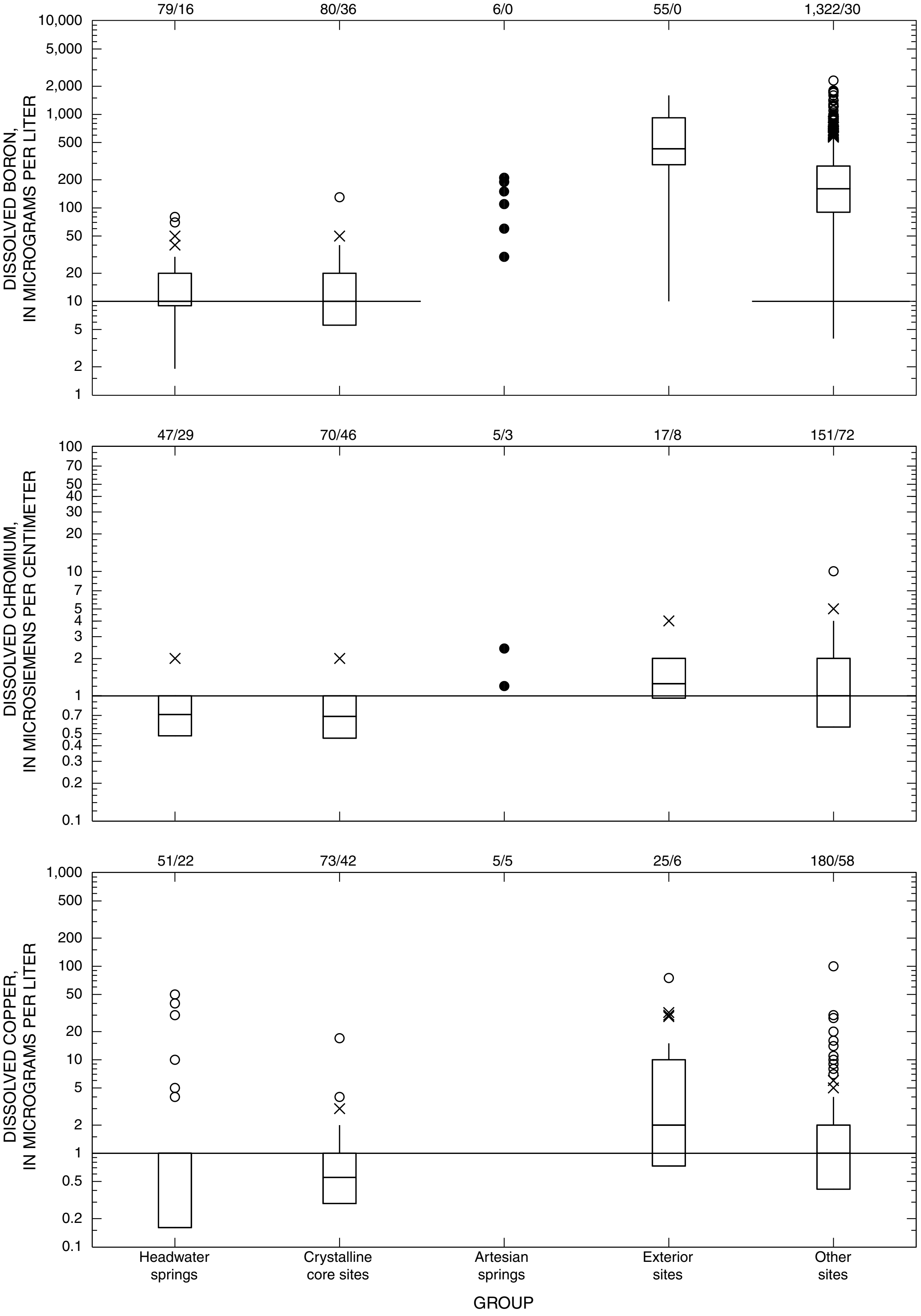


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

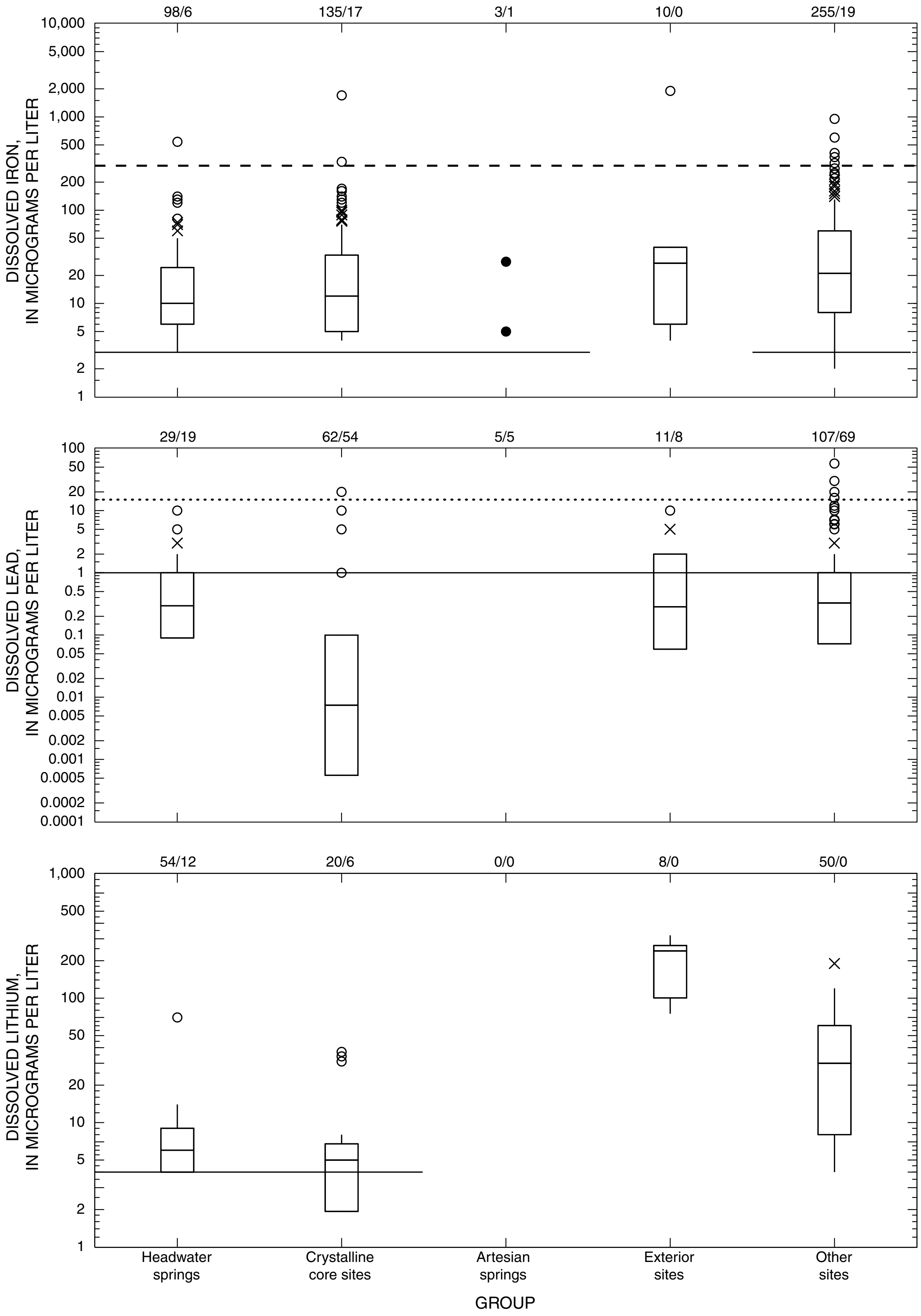


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

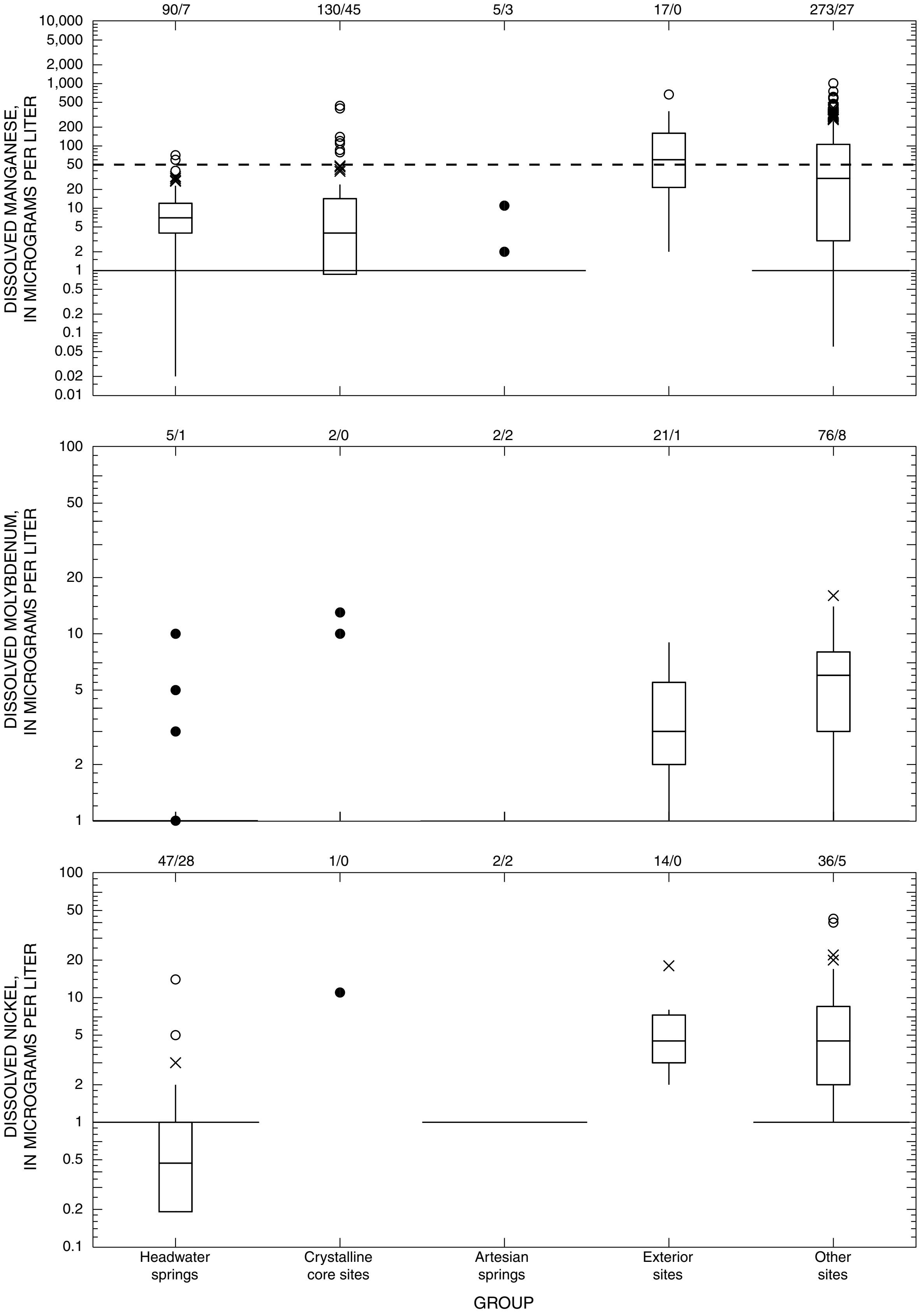


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

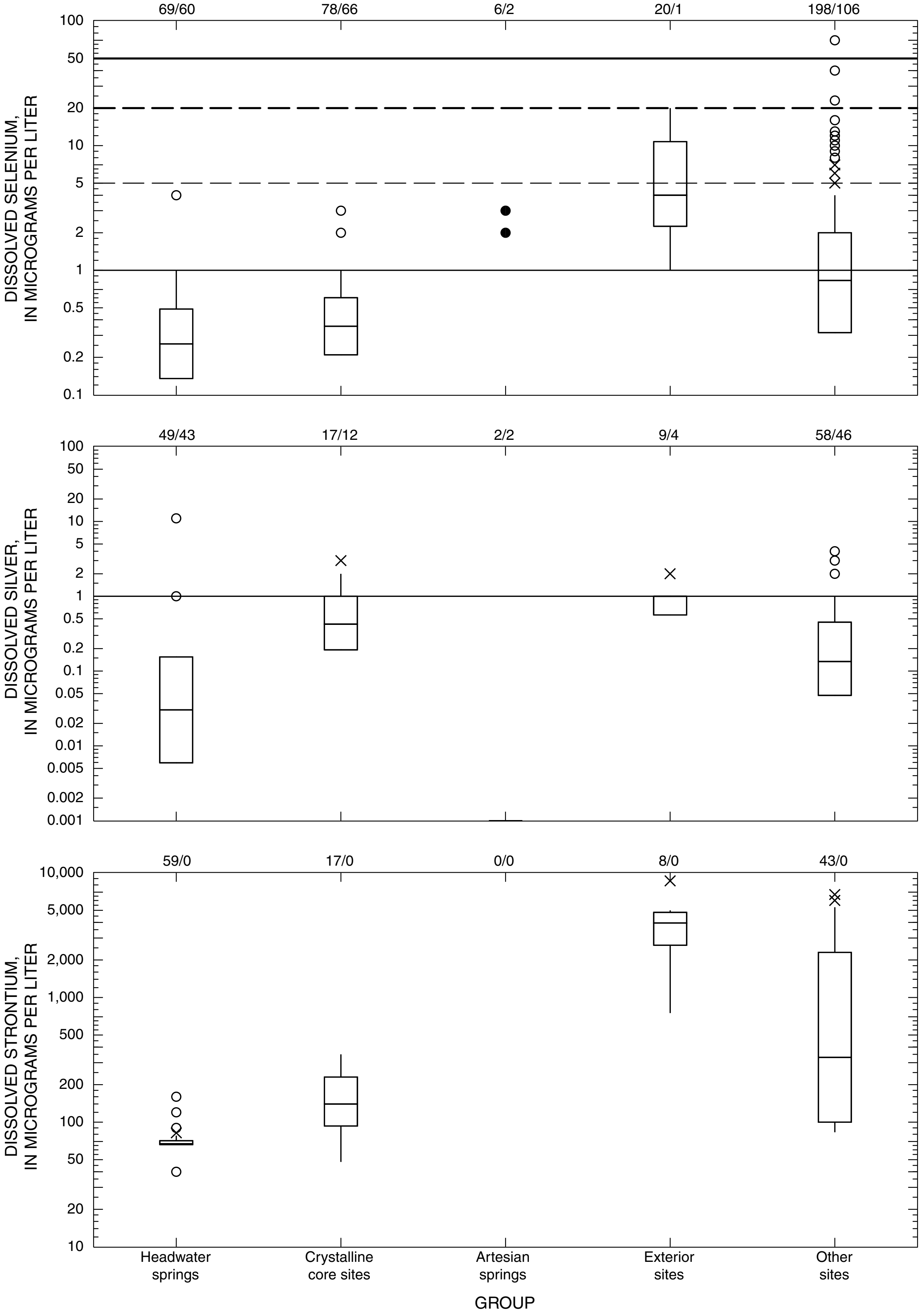


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

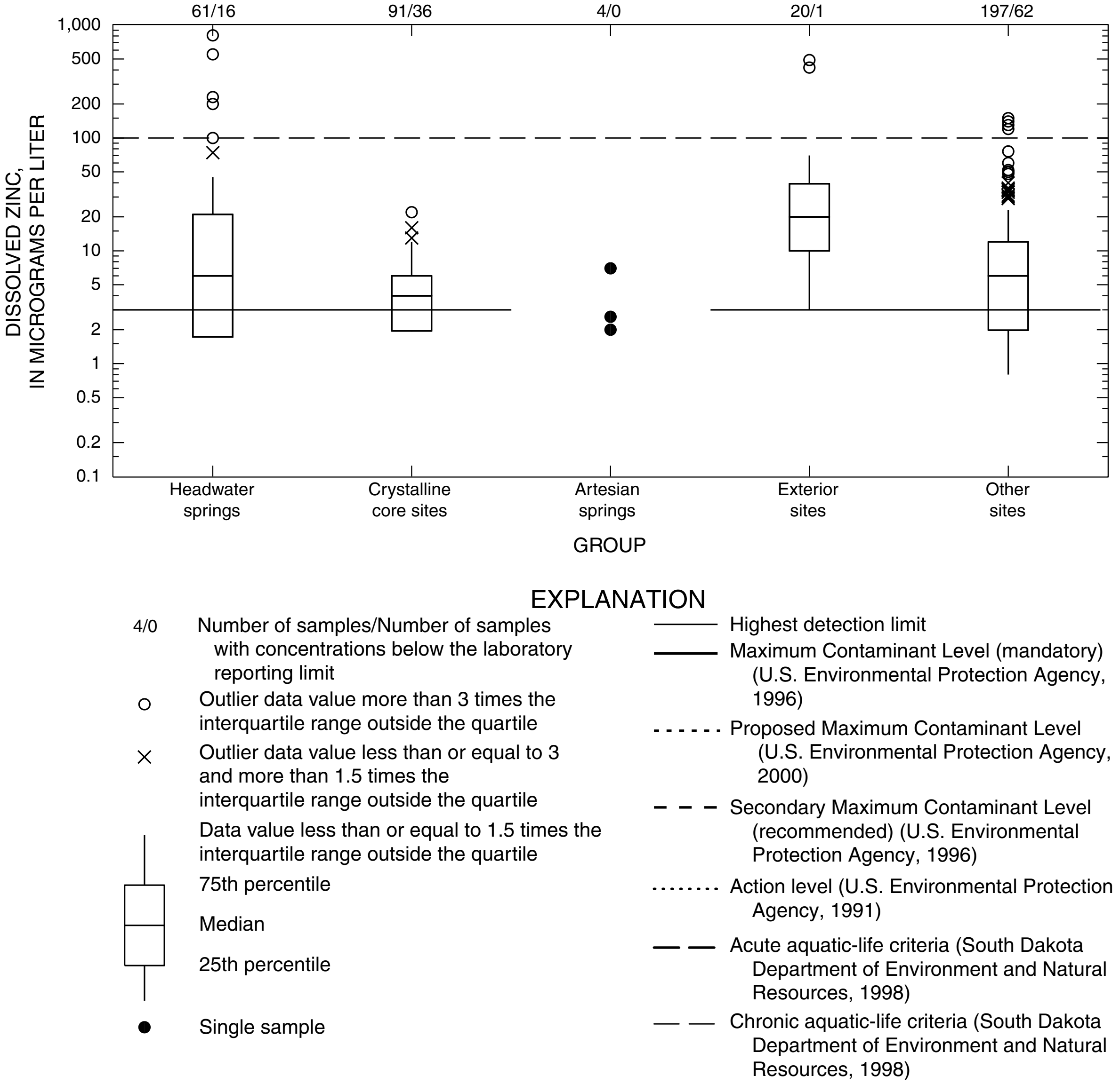


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

Concentrations for the other sites are similar to the exterior sites, with many of the higher concentrations from older samples including aluminum and lead concentrations. Concentrations for the other sites exceed various standards, including SMCL's for aluminum, iron, and manganese; the action level for lead; and the MCL and aquatic-life criterion for selenium.

Arsenic concentrations exceeding the proposed MCL occur in surface waters in the Black Hills (fig. 47). Arsenic is associated with the mineralogy common to the northern Black Hills and with Precambrian metamorphic and igneous rocks (fig. 2) of the central core. Sulfide-bearing ore bodies common in the northern Black Hills and gold-mining activities have resulted in historic loading into the streams of mine tailings containing arsenopyrite, which has contributed to high arsenic (total and dissolved) concentrations at some sites (fig. 48). Arsenic concentrations above 5 mg/L also occur at exterior sites with exposure to Cretaceous-age marine shales (Greene and others, 1990). Streams with arsenic concentrations greater than 10 µg/L include Annie Creek, Battle Creek, Belle Fourche River, Cheyenne River, Elk Creek, French Creek, Spring Creek, and Whitetail Creek.

Manganese is another trace element that commonly is found at concentrations greater than its SMCL throughout the Black Hills (fig. 49). Median concentrations for manganese range up to 337 µg/L with maximum concentrations as high as 1,010 µg/L (table 13). Selenium concentrations generally are higher at sites where the streams have exposure to Cretaceous-age marine shales (fig. 50) with concentrations greater than 5 µg/L (aquatic chronic criterion) occurring in 7 percent of all samples and 11 percent of the exterior sites and other-sites group (table 13).

Several samples at Bear Butte Creek near Deadwood (06437020) have exceeded the hardness-dependent chronic and/or acute aquatic-life copper criteria, generally for samples collected between 1992-94 (fig. 51). These samples were collected prior to additional mining upstream of this site within the Strawberry Creek Basin. Insufficient data are available to determine if abandoned mines have contributed to these high copper concentrations. Concentrations for zinc at this site have not exceeded the hardness-dependent aquatic criteria.

Additional Comparisons

Limited data are available for trace elements within the Rapid Creek Basin. A study to examine selected trace elements in water, sediment, plants, and fish in Rapid Creek from just above the City of Rapid City to just below the Rapid City Wastewater Treatment Plant (Williamson and others, 1996) found that there generally were slight increases in silver, copper, and zinc from upstream to downstream, but little variability in cadmium. Increases in concentrations from immediately above to below the Rapid City Wastewater Treatment Plant were consistent with concentrations being added by the Wastewater Treatment Plant.

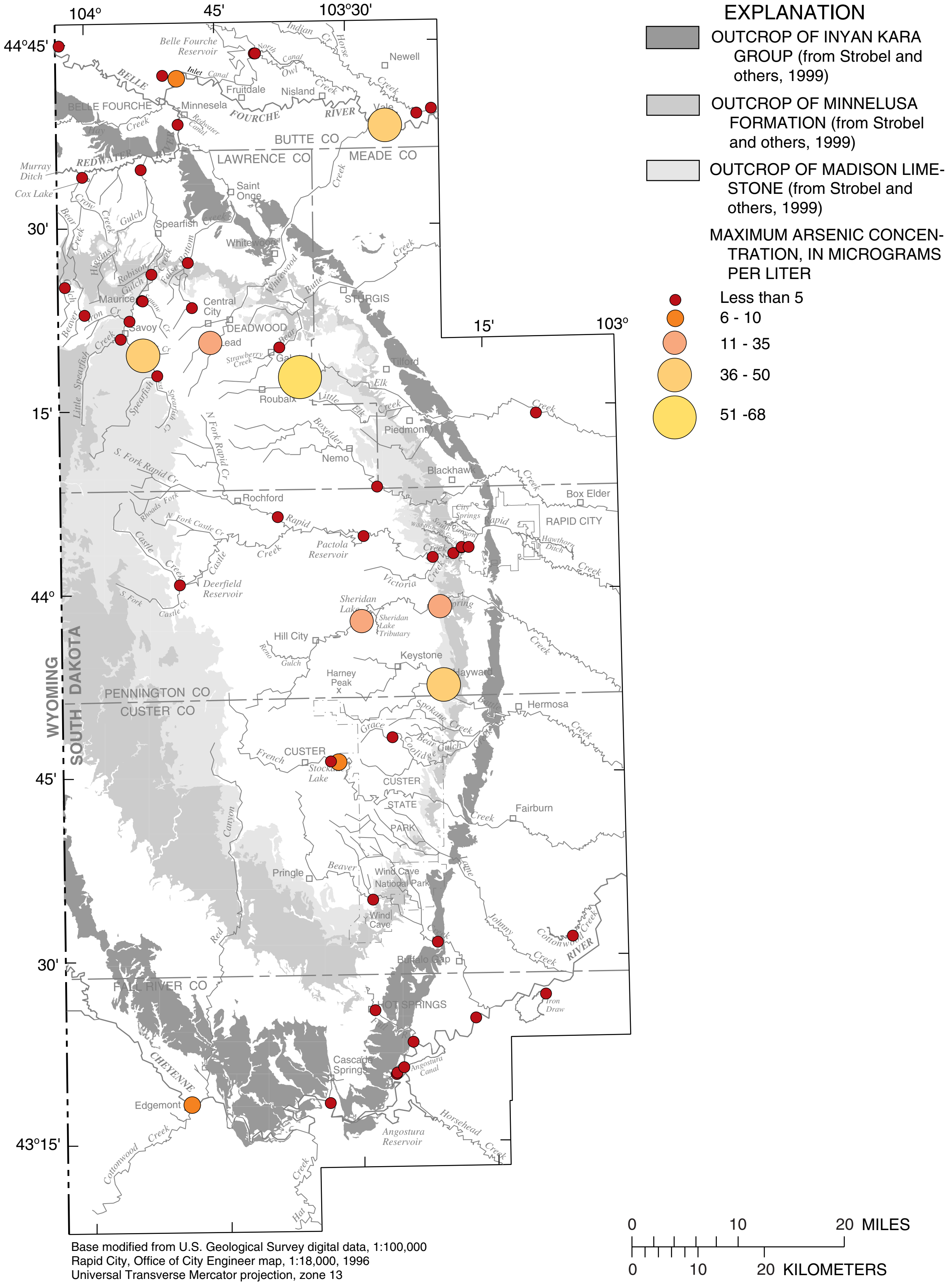
Radionuclides

Radionuclides are unstable isotopes and have a certain probability of decay (Clark and Fritz, 1997). Radionuclides exist throughout the environment. Most occur naturally like uranium, thorium, radium, and radon, while others are mostly or entirely manufactured like technetium, plutonium, neptunium, and americium (Langmuir, 1997). More than 1,700 radionuclides have been identified (Clark and Fritz, 1997).

Radioactive decay series consist of a succession of radionuclides each with different decay rates. In each decay series, the original elements and each successive "daughter" product disintegrate, forming radionuclides until a stable lead isotope is formed. The decay rate usually is expressed as a half-life, which is the length of time required for one-half the quantity present to disintegrate. Uranium (^{238}U and ^{235}U) and thorium are the original elements in the three natural decay series (Wanty and Nordstrom, 1993) and give rise to most of the naturally occurring radioactivity in water (Hem, 1985).

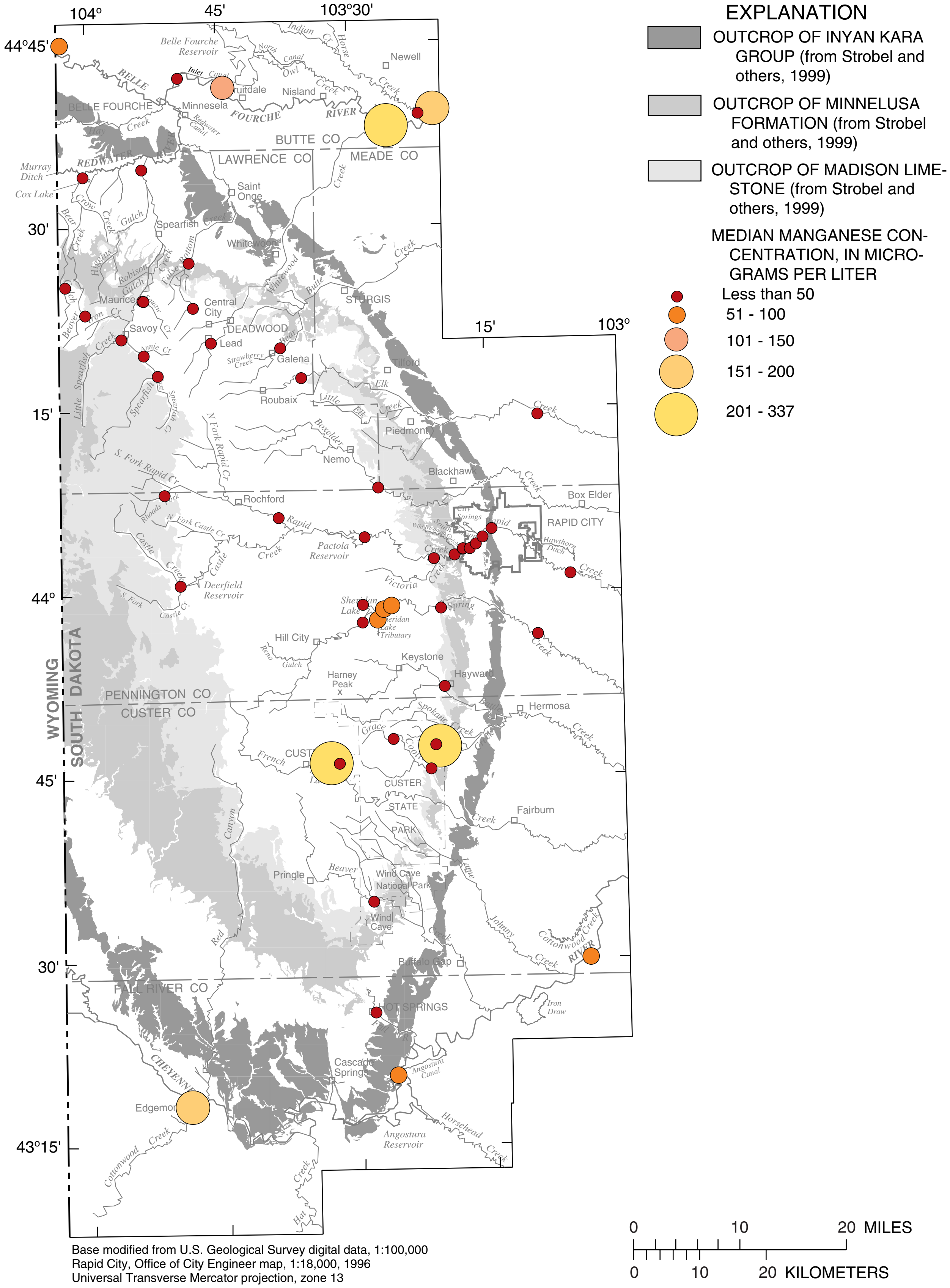
Radioactivity is the release of energy and energetic particles by changes occurring within atomic or nuclear structures (Hem, 1985). Radionuclide analyses can be expressed in terms of disintegrations per unit time (typically in units of picocuries per liter) or in mass units (typically in units of micrograms per liter).

Uranium concentrations between 0.1 and 10 µg/L are common in most natural waters and concentrations greater than 1,000 µg/L can occur in water associated with uranium-ore deposits (Hem, 1985). Concentrations of radium in natural water generally are less than 1 pCi/L. Thorium probably is more abundant than uranium in most rocks, but is less soluble, so thorium generally has lower concentrations in water.



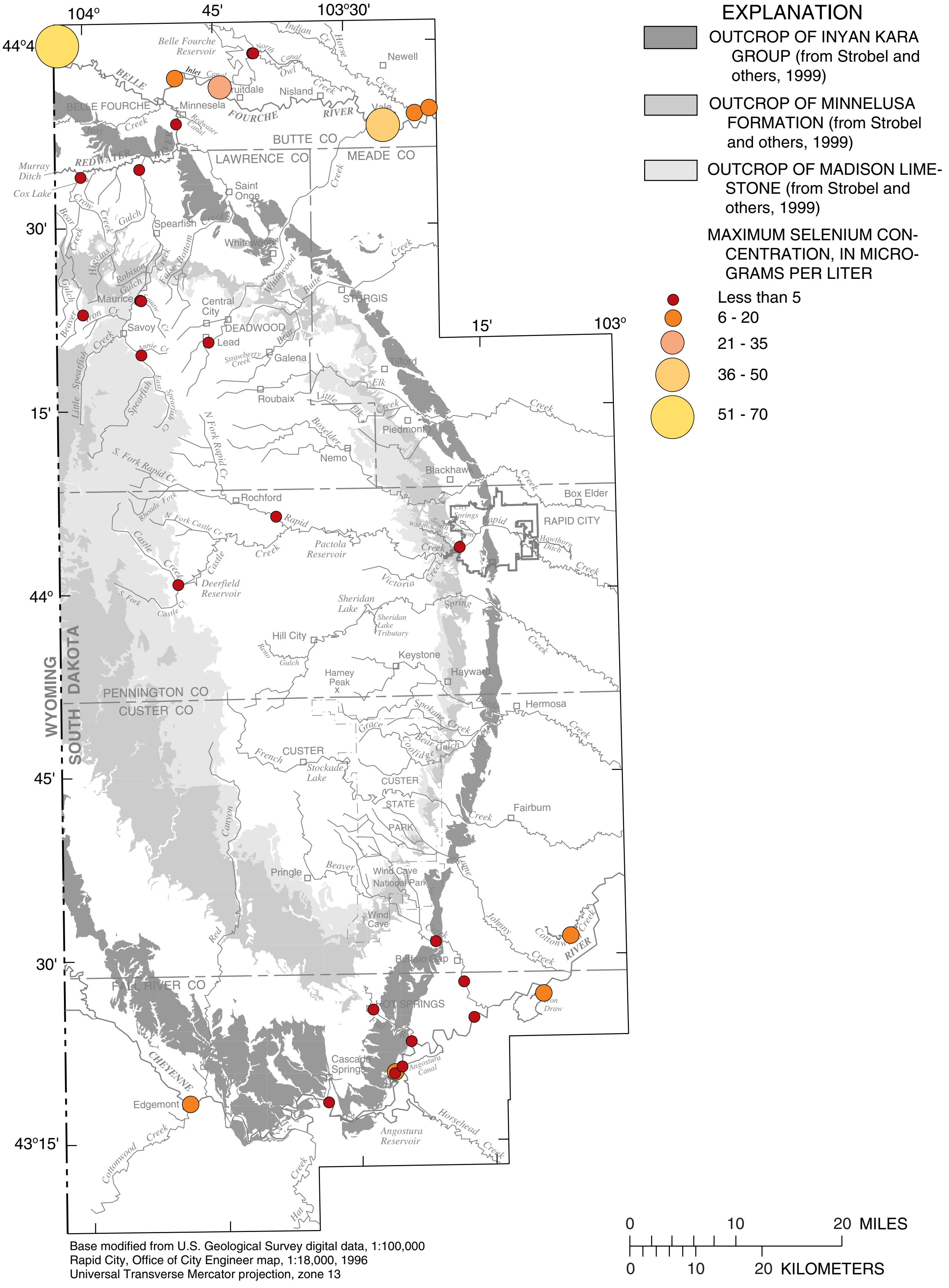
Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 48. Spatial distribution of maximum arsenic concentrations in surface water.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 49. Spatial distribution of median manganese concentrations in surface water.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 50. Spatial distribution of maximum selenium concentrations in surface water.

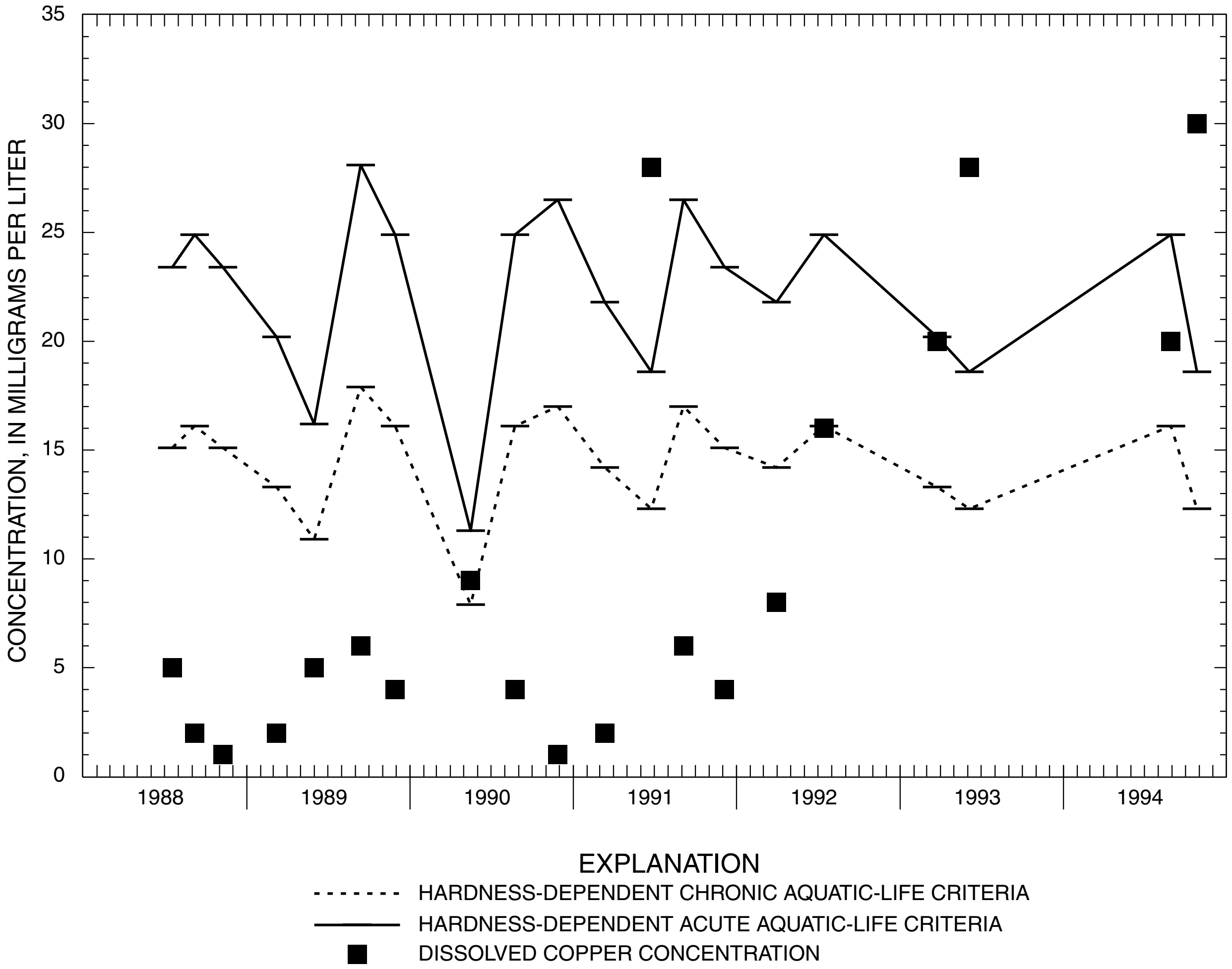


Figure 51. Comparison of dissolved copper concentrations to hardness-dependent chronic and acute aquatic-life criteria for Bear Butte Creek near Deadwood (06437020).

Summary statistics for selected radionuclides including alpha radioactivity as thorium-230, gross alpha as uranium, gross beta as cesium-137 and as strontium/yttrium-90, radium-226, radium-228, radon-222, tritium, and uranium are presented in table 14. Boxplots are presented in figure 52 for constituents with sufficient data.

Limited radionuclide data are available for analysis, especially for the artesian springs and exterior sites. Data for most of the radionuclide concentrations primarily are from the northern and north-central Black Hills and do not show any systematic spatial patterns (figs. 53); however, igneous rocks often are a source of radionuclides.

Uranium concentrations for crystalline core sites are greater than headwater springs, similar to artesian springs, and generally lower than the exterior sites and the other-sites group. Uranium concentrations for crystalline core sites are very similar to those summarized for the Precambrian aquifers. The highest uranium concentrations in the study area generally are beyond the Inyan Kara outcrop (fig. 54), and probably are due to influences from naturally occurring uranium in the Cretaceous-age marine shales. Historic uranium mining did occur near the Cheyenne River near the town of Edgemont. Uranium concentrations have exceeded the uranium MCL (table 2) at Iron Draw near Buffalo Gap and Horse Creek above Vale.

Table 14. Summary of concentrations for radionuclides in surface water by group

[Results based on data stored in U.S. Geological Survey National Water Information System water-quality database. Results in picocuries per liter except as indicated. One microgram per liter (µg/L) is approximately equal to one part per billion; ND, not determined; <, less than]

Constituent	Number of samples	Number of censored samples	Mean	Median	Minimum	Maximum
Headwater springs						
Alpha radioactivity as thorium-230	3	0	0.7	0.8	0.7	0.8
Gross alpha as uranium-natural	11	3	2.1	1.7	<0.8	6.4
Gross alpha as uranium-natural (µg/L)	39	2	3.8	2.1	<0.6	40
Gross beta as cesium-137	45	0	2.4	1.8	0.7	12
Gross beta as strontium/yttrium-90	45	0	1.9	1.4	0.6	9.8
Radium-226	39	1	0.09	0.08	0.04	0.22
Uranium (µg/L)	32	1	0.97	0.98	0.08	1.9
Crystalline core sites						
Alpha radioactivity as thorium-230	10	2	2.3	1.6	<0.6	5.7
Gross alpha as uranium-natural (µg/L)	37	4	3.7	3.3	<0.6	8.4
Gross beta as cesium-137	37	0	3.7	3.6	1.6	7.4
Gross beta as strontium/yttrium-90	37	0	2.9	2.7	1.2	5.5
Tritium	12	0	79	69	51	190
Uranium (µg/L)	15	1	2.4	1.1	<0.4	6.4
Artesian springs						
Tritium	3	0	45	61	8	67
Uranium (µg/L)	4	0	2.1	2	1.1	3.4
Exterior sites						
Uranium (µg/L)	8	0	17	16	8.6	30
Other sites						
Alpha radioactivity as thorium-230	5	0	1.6	1.2	1.1	3.3
Gross alpha as uranium-natural (µg/L)	52	5	2.9	1.6	<0.6	33
Gross beta as cesium-137	52	1	3.2	3.0	<0.6	6.9
Gross beta as strontium/yttrium-90	52	1	2.5	2.4	<0.6	5.4
Radium-228	3	0	4	4	4	4
Radon-222	3	1	ND	100	<80	220
Tritium	11	0	84	82	42	130
Uranium (µg/L)	64	6	8.5	7.0	<1	44

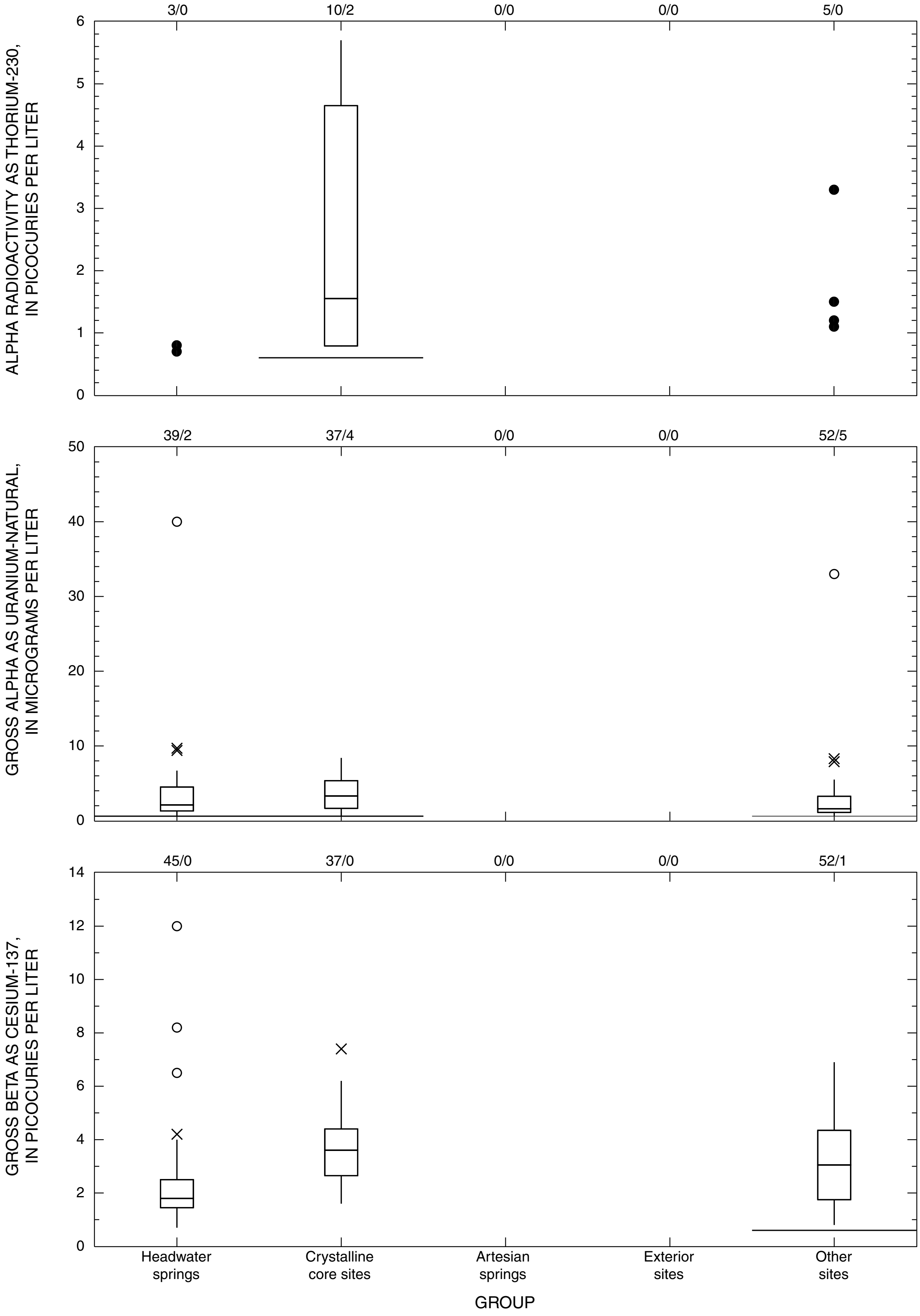


Figure 52. Boxplots of concentrations of selected radionuclides by surface-water group.

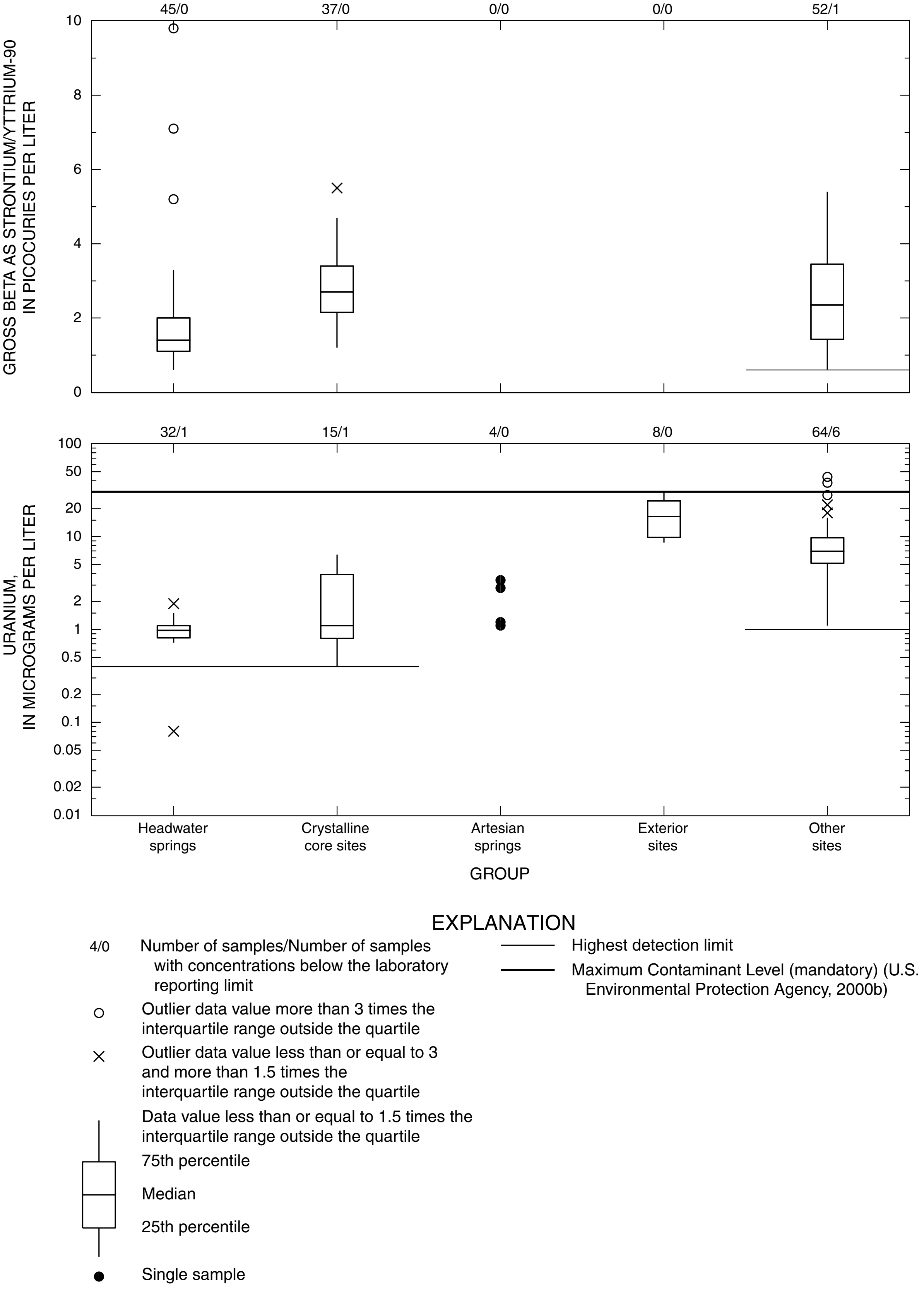
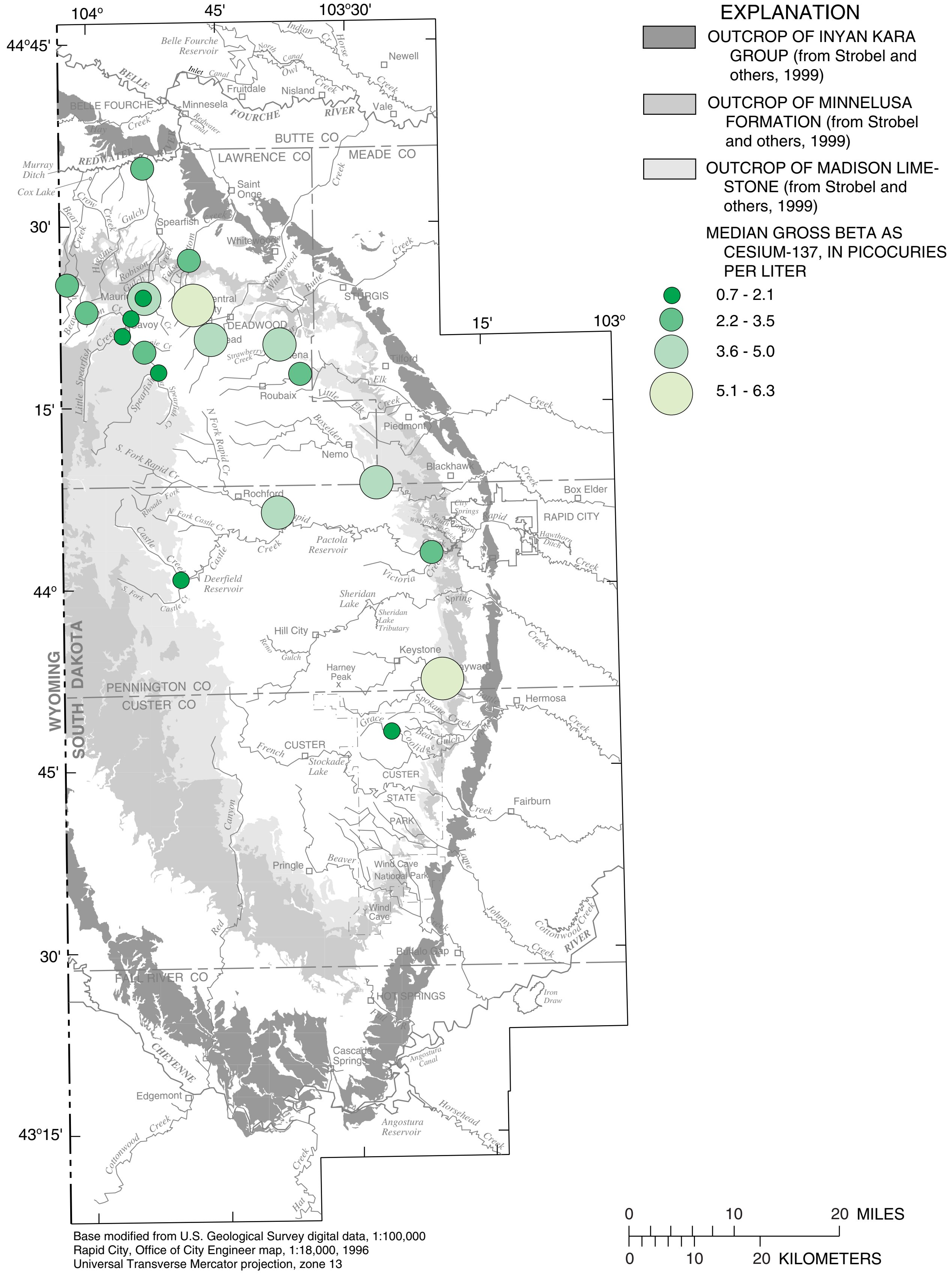
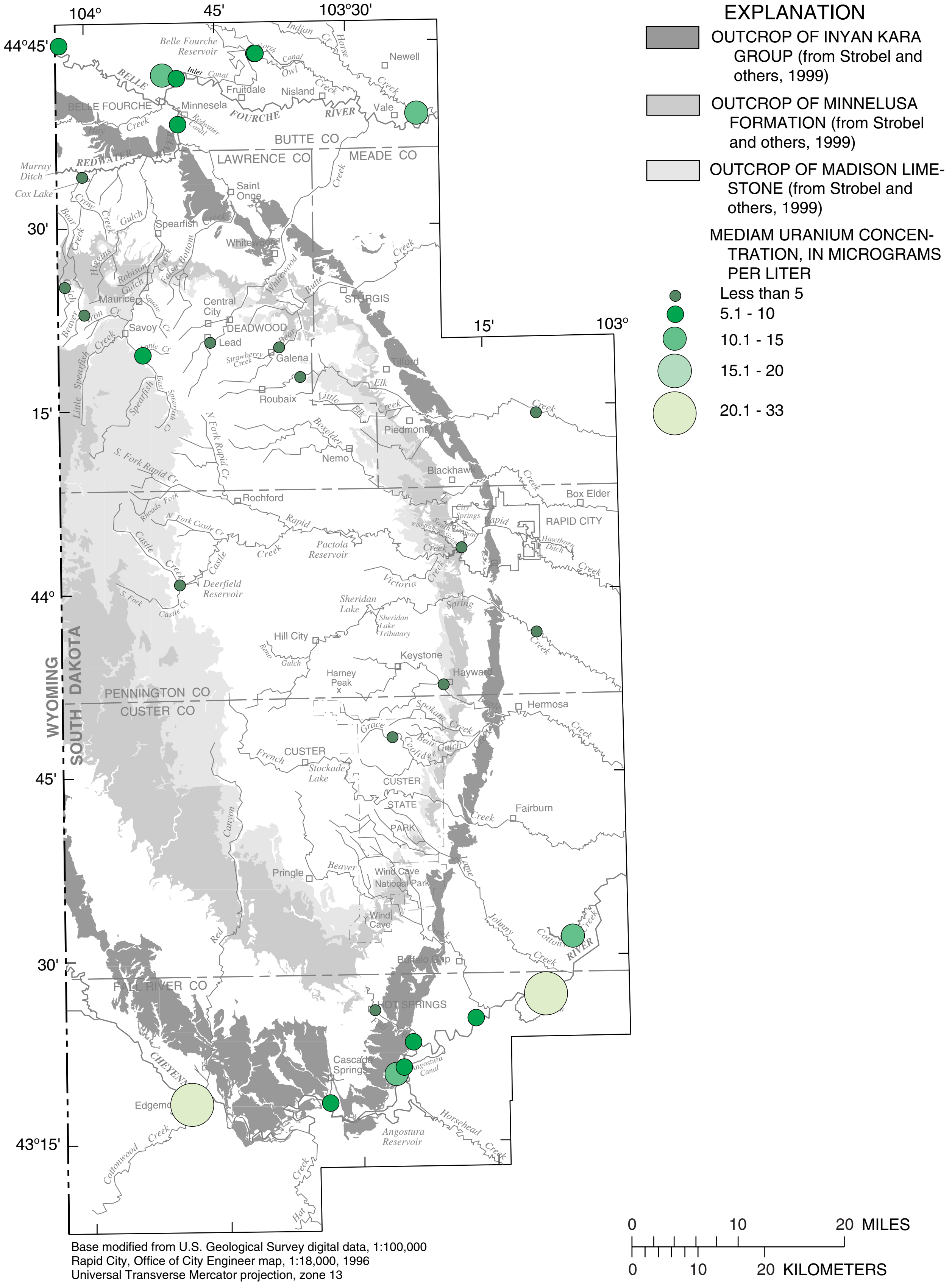


Figure 52. Boxplots of concentrations of selected radionuclides by surface-water group.--Continued



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 53. Spatial distribution of median gross beta as cesium-137 concentrations in surface water.



Base modified from U.S. Geological Survey digital data, 1:100,000
Rapid City, Office of City Engineer map, 1:18,000, 1996
Universal Transverse Mercator projection, zone 13

Figure 54. Spatial distribution of median uranium concentrations in surface water.

Summary for Surface-Water Groups in Relation to Water Use

Surface-water quality within the Black Hills and surrounding area generally is very good but the water is hard to very hard. The pH levels of some streams occasionally exceed beneficial-use pH ranges. Most surface water is calcium bicarbonate or calcium magnesium bicarbonate type water, with increased sodium and sulfate at sites exterior to the outcrop of the Minnelusa Formation. Dissolved solids, sodium, sulfate, selenium, and uranium concentrations tend to be higher exterior to the Black Hills, primarily due to influences from the Cretaceous-age marine shales. Arsenic concentrations greater than the proposed MCL of 10 µg/L can be found in several streams within the Black Hills and surrounding plains.

Headwater springs have relatively constant discharge, specific conductance, dissolved solids, and concentrations of most other constituents. These springs rarely show variability and generally do not approach drinking-water or beneficial-use criteria with the exception of occasional pH levels and temperature. Headwater springs have low common ion concentrations, with calcium and magnesium being the dominant cations and bicarbonate being the dominate anion. Both nutrient and trace element concentrations generally are low at headwater springs.

Crystalline core sites generally show more variability in all physical properties and constituents. Temperature and pH occasionally may exceed various beneficial-use criteria. Crystalline core sites generally have low common ion concentrations, have calcium bicarbonate or calcium bicarbonate sulfate type waters, and have concentrations that are very similar to samples from the Precambrian aquifers. Some high nitrate concentrations greater than the MCL of 10 mg/L occur at Annie Creek near Lead and have been attributed to mining impacts (Johnson, 1992). Trace element concentrations generally are low with the exception of arsenic where 64 percent of samples exceed 10 µg/L; however, the samples exceeding are from only 10 percent of the sites sampled. Samples with high arsenic concentrations predominately are from Annie Creek, Battle Creek, Elk Creek, French Creek, and Whitetail Creek. Iron and manganese concentrations that exceed the SMCL's also occur at some crystalline core sites.

Artesian springs have relatively constant discharge and specific conductance at each site but show variability between sites. Dissolved solids concentrations greater than the SMCL of 500 mg/L are common for these sites, and sulfate concentrations greater than the SMCL of 250 mg/L are not uncommon. Artesian springs generally have calcium sulfate type waters with rock/water interactions in the Minnelusa Formation or contact with Spearfish Formation probably being the source of sulfate. The artesian springs generally have low nutrient and trace element concentrations.

Exterior sites show high variability in discharge, specific conductance, and dissolved solids. Low dissolved oxygen concentrations occur only at sites exterior to the Black Hills where high temperature and low flow are occasionally problematic. Exterior sites have a mixed water type of calcium magnesium sodium sulfate with 66 percent of the samples exceeding 1,000 mg/L sulfate. Chloride also is much higher at these sites. Generally, nutrient concentrations are low with the exception of two high ammonia concentrations in the 1970's. The high ammonia concentrations could possibly be due to stagnant/semi-stagnant conditions under ice. Exterior sites also have higher trace element concentrations than headwater springs, crystalline core sites, and artesian springs. Some concentrations exceeding the selenium aquatic-life criteria and the iron and manganese SMCL's occur at these sites. Radionuclide data are limited, but higher uranium concentrations occur at sites exterior to the Inyan Kara outcrop.

Other site specific issues occur within the Black Hills. Occasionally very low pH levels are recorded immediately below abandoned mine sites (Torve, 1991), but pH levels generally increase to within acceptable ranges after mixing with additional stream water. Water-quality changes in Bear Butte Creek also have been noted for specific conductance, sodium, and sulfate after additional mining activities in a tributary basin. Bear Butte Creek also had some samples that exceeded the acute and chronic copper aquatic-life criteria during 1992-94. Arsenic, manganese, and selenium are trace elements with geologic sources in the Black Hills area, and concentrations greater than or near the MCL, SMCL's, and aquatic-life standards may occur.

Historic mining in the northern Black Hills has been shown to affect water quality, especially on Whitewood Creek (Cherry and others, 1986; Fuller and Davis, 1989; Fuller and others, 1988, 1989; Goddard, 1989a, 1989b; Horowitz and others, 1989; Marron, 1989; McKallip and others, 1989). High arsenic concentrations in Whitewood Creek have been attributed to more than 100 years of mine tailings being dumped into the stream. The Belle Fourche and Cheyenne Rivers downstream from Whitewood Creek also have been affected to lesser extents but were not included in the summaries of this report.

Within-basin changes for Rapid Creek followed the general trend of increasing concentrations from upstream to downstream. Nutrient levels are low but show an increase downstream, indicating that land-use practices, urban and/or agricultural, may be affecting the stream. A report summarizing and examining nutrient loading to Canyon Lake (Alliance of Engineers and Architects, 1992) noted a phosphorus source upstream of Canyon Lake and indicated that this may be the result of septic systems in the area. Effects to streams in the Black Hills area may include urban sprawl, urban stormwater runoff and point-source discharges, agricultural and farming land-use practices, and active and abandoned mining activities.

SUMMARY

This report summarizes the water-quality characteristics of ground water and surface water in the Black Hills area. Water-quality data for the Black Hills Hydrology Study and other studies from October 1, 1930, to September 30, 1998, were used to identify similarities and differences between the major and minor aquifers as well as between groups of surface-water sites. The major aquifers include the Precambrian, Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. The minor aquifers include the Spearfish, Sundance, Morrison, Pierre, Graneros, Newcastle, and alluvial aquifers. Surface-water sites are grouped by hydrogeologic settings, including headwater springs, crystalline core sites, artesian springs, and exterior sites. Constituents summarized and discussed include physical properties, common ions, nutrients, trace elements, and radionuclides. Comparisons of concentration levels are made to drinking-water standards for both ground and surface water and to beneficial-use and aquatic-life criteria for surface water.

Specific conductance generally is low for the Precambrian, Deadwood, and Minnekahta aquifers. Dissolved constituents tend to increase with residence time as indicated by the increase in specific conductance with well depth in the Madison and Minnelusa aquifers. Generally, water from the Inyan Kara aquifer and the minor aquifers, with the exception of the Newcastle aquifer, is higher in specific conductance due to shales within the units relative to the other major aquifers. Generally, the specific conductance of alluvial aquifers increases with increasing distance from the core of the Black Hills due to streams flowing across units with increasing amounts of shale.

Units that contain few carbonate rocks, such as the Precambrian rocks, generally contain water with lower carbonate hardness and alkalinity than units that are composed primarily of carbonate rocks. Water from the Deadwood, Madison, Minnelusa, and Minnekahta aquifers generally is hard to very hard. The hardness of water from the Inyan Kara aquifer ranges from soft to very hard. Hardness in the Inyan Kara aquifer decreases with increasing well depth, or distance from the outcrop. Water from the minor aquifers generally is very hard.

Generally, water from the major aquifers is fresh in and near the outcrop areas. The Madison, Minnelusa, and Inyan Kara aquifers may yield slightly saline water at distance from the outcrops especially in the southern Black Hills. Water from all aquifers, with the exceptions of the Pierre and Sundance aquifers, generally is suitable for irrigation, but may not be in specific instances if either the specific conductance or sodium-adsorption ratio (SAR) is high.

Many of the major aquifers yield a calcium bicarbonate type water in and near outcrop areas, with increasing concentrations of sulfate, chloride, and sodium with distance from the outcrop. The concentration of sulfate in the Minnelusa aquifer is dependent on the amount of anhydrite present in the Minnelusa Formation. Sulfate and dissolved solids concentrations generally are high in the minor aquifers, with the exception of the Newcastle aquifer.

Generally, concentrations of nitrogen and phosphorus are low in water from the aquifers considered. The extreme concentrations noted in this study are unusually high and may reflect poor well construction and surface contamination as opposed to aquifer conditions.

In all aquifers considered in this report, strontium generally is higher in concentration than the other trace elements. Barium, boron, iron, manganese, lithium, and zinc concentrations also may be high in comparison to other trace elements. Concentrations and variability of many trace elements are low in the aquifers. Boron concentrations generally are much higher and have larger variability in the minor aquifers than in the major aquifers, with generally higher concentrations in the Inyan Kara aquifer than the other major aquifers. The Inyan Kara and Precambrian aquifers generally have lower barium concentrations and higher manganese concentrations than the other major aquifers. Lithium concentrations generally are much lower and have smaller variability in the Precambrian, Deadwood, Madison, Minnelusa, and Minnekahta aquifers than in the other aquifers. The Sundance aquifer has the highest selenium concentrations of all aquifers considered in this report. In general, strontium concentrations generally are lower and have smaller variability in the Precambrian, Deadwood, Madison, and Minnekahta aquifers than in the other aquifers.

In general, gross alpha-particle activity, gross-beta activity, and radium-226, are higher in the Inyan Kara and Deadwood aquifers than in the Madison, Minnelusa, and Minnekahta aquifers. Radon-222 concentrations are much higher, and thorium and uranium concentrations are lower in the Deadwood aquifer than in the Madison and Minnelusa aquifers. Radon-222 concentrations also can be high in alluvial aquifers. Uranium concentrations may be high in the Inyan Kara aquifer and have considerable variability in the Sundance, Morrison, Pierre, Graneros, and alluvial aquifers.

Concentrations that exceed the Secondary and Maximum Contaminant Levels may affect the use of water in some areas for many aquifers within the study area. Concentrations that exceed various Secondary Maximum Contaminant Levels (SMCL's) generally affect the water only aesthetically. Radionuclide concentrations may be especially high in some of the major aquifers used within the study area and preclude the use of water in some areas. Hard water may require special treatment for certain uses. Other factors, such as the sodium-adsorption ratio and specific conductance, affect irrigation use.

High concentrations of iron and manganese are the only concentrations that may hamper the use of water from Precambrian aquifers. No samples reported by this study from the Precambrian aquifers exceed any of the drinking-water standards for radionuclides.

The principal deterrents to use of water from the Deadwood aquifer are the high concentrations of radionuclides, including radium-226 and radon-222. In addition, concentrations of iron and manganese may be high.

Water from the Madison aquifer may contain high concentrations of iron and manganese. Water from the Madison aquifer is hard to very hard and may require special treatment for certain uses. In downgradient wells (generally deeper than 2,000 feet), higher concentrations of dissolved solids and sulfate occur. In the southern Black Hills, hot water may not be desirable for some uses. Radionuclide concentrations in the Madison aquifer generally do not exceed drinking-water standards.

The principal properties or constituents in the Minnelusa aquifer that may hamper the use of water include hardness and high concentrations of iron and manganese. Generally, downgradient wells (generally deeper than 1,000 feet) also have high concentrations of dissolved solids and sulfate. Arsenic may be a problem for some wells if the Maximum Contaminant Level (MCL) is lowered to 10 µg/L (micrograms per liter). A few samples from the Minnelusa aquifer exceed the MCL's for various radionuclides.

Water from the Minnekahta aquifer generally is suitable for all water uses because few samples exceed SMCL's or MCL's. No samples available for this study from the Minnekahta aquifer exceed any standards for radionuclides. However, water from the Minnekahta aquifer is harder than that from any of the other major aquifers in the study area.

The principal properties or constituents in the Inyan Kara aquifer that may hamper the use of water include high concentrations of dissolved solids, iron, sulfate, and manganese. In the southern Black Hills, radium-226 and uranium concentrations may preclude its use. Suitability for irrigation may be affected by high specific conductance and the adjusted SAR.

The principal properties or constituents in the minor aquifers included in this study that may hamper the use of water include hardness, dissolved solids, and sulfate concentrations. Concentrations of radionuclides, with the exception of uranium, generally are less than MCL's in samples from the minor aquifers. Selenium concentrations from the Sundance aquifer exceeded the MCL of 50 µg/L in 2 of 8 samples.

Water from alluvial aquifers generally is very hard and may require special treatment for certain uses. In wells that overlie the Cretaceous-age shales, the high concentrations of dissolved solids, sulfate, iron, and manganese may limit the use of water. In the southern Black Hills, uranium concentrations are high.

Surface-water quality is influenced to a large extent by the geology of the area. Headwater springs tend to have very constant water-quality characteristics. Crystalline core sites tend to have more variability than the headwater springs. Artesian springs comprise much of the base flow for exterior streams beyond the Black Hills. Exterior sites have greater fluctuations in stream characteristics and water quality.

Discharge at headwater springs displays little variability when compared to other groups with only artesian sites having similar flow characteristics. Artesian springs generally have more variability between sites, but individual sites do not have large seasonal fluctuations. Discharge for crystalline core sites displays wider ranges in variability than headwater springs and generally vary with season with increasing flows during the spring and summer when snowmelt and precipitation result in greater runoff. The greatest variability in discharge for the hydrogeologic settings occurs at exterior sites, which have much larger drainage basins and numerous sources for flow.

Headwater springs have very stable characteristics of both discharge and specific conductance, while at crystalline core sites, specific conductance generally decreases as flow increases due to dilution. Specific conductance varies considerably from one artesian spring to another, however, specific conductance is relatively constant at each site. For exterior sites, specific conductance generally is much higher than at sites in the other hydrogeologic settings with a mean of 3,400 µS/cm (microsiemens per centimeter) and a maximum of 9,250 µS/cm. Strong relations exist between discharge and specific conductance at the exterior sites.

In some samples, pH levels exceed the SMCL and fisheries criteria (coldwater permanent and coldwater marginal) at headwater springs and crystalline core sites. Dissolved oxygen generally varies with temperature, with lower dissolved oxygen occurring during higher temperature periods. For headwater springs, 1 percent of the samples exceed the coldwater permanent fisheries criterion for temperature. Almost 12 percent of the temperature measurements for crystalline core sites exceed the coldwater permanent fisheries criterion, and just less than 1 percent exceed the coldwater marginal fisheries criterion. Dissolved oxygen generally remains above beneficial-use criteria although a few dissolved oxygen concentrations below 4 mg/L (milligrams per liter) have been recorded at three sites. Dissolved oxygen measurements of 2.1, 2.2, and 3.6 mg/L have been measured at an urban runoff site within the Rapid Creek Basin, indicating that urban runoff situations probably stress aquatic life. Two additional sites with low dissolved oxygen concentrations are Cottonwood Creek near Buffalo Gap and Cheyenne River near Buffalo Gap.

Specific conductance can be closely related to dissolved solids concentrations. Headwater springs have little variability in both specific conductance and dissolved solids with dissolved solids concentrations ranging from 147 to 476 mg/L, and specific conductance with a similar minimal range 304 to 705 µS/cm. The relation between dissolved solids and specific conductance is much stronger for crystalline core sites, artesian springs, and exterior sites where wider ranges of specific conductance and dissolved solids exist.

Generally, most surface waters are a calcium bicarbonate type water with increased magnesium at headwater springs and increased sulfate at crystalline core sites. Artesian springs have a calcium sulfate type water. Exterior sites generally have sodium calcium magnesium sulfate type waters after the streams come in contact with the Cretaceous-age marine shales surrounding the Black Hills, which results in increased concentrations of sulfate complexed with calcium or sodium. In downstream progressions of common ion concentrations for Rapid Creek, calcium and sulfate increase notably, which is consistent with increased exposure to limestone and then Cretaceous-age marine shales.

Nutrient concentrations generally are low with most concentrations less than or near the laboratory reporting limit. Annie Creek near Lead (0640800) had increasing nitrite plus nitrate concentrations since the 1990's, with the highest concentrations in 1995 and 1996. Mining impacts were the cause of the higher nitrate levels in Annie Creek and denitrification facilities were put in place within Annie Creek Basin in 1997.

Two high ammonia concentrations were measured at Cheyenne River at Edgemont (06395000) during January and February of 1975 (54 mg/L and 206 mg/L). The high ammonia concentrations could be related to stagnant/semi-stagnant conditions under ice, which causes reducing conditions. With reducing conditions, ammonia would be the end-product of the breakdown of organic material in the sediments. The corresponding pH values were the lowest of record for this site, which would be consistent with consumption of oxygen and dissolution of carbon dioxide.

Headwater springs generally have low concentrations of trace elements, although some concentrations exceed SMCL's and aquatic standards for aluminum, copper, iron, lead, and zinc. All concentrations exceeding standards were from Castle Creek above Deerfield Reservoir (06409000; samples from this site comprised over 90 percent of the headwater springs samples). Concentrations of copper, lead, and zinc exceeding aquatic standards were from samples collected during the 1960's and 1970's when trace element contamination in samples was not uncommon. Concentrations in more recent samples from Castle Creek have all been less than the aquatic standards.

For crystalline core sites, there are numerous arsenic concentrations (60 percent) greater than 10 µg/L (proposed MCL), and one sample from Elk Creek near Roubaix (06424000) exceeds the current MCL of 50 µg/L. Two iron concentrations greater than the SMCL and two lead concentrations greater than the SMCL have been reported from northern Black Hills sites. Several manganese concentrations greater than the SMCL also have been reported.

Trace element concentrations at artesian springs generally are very low, however, limited data are available from which comparisons can be made. No standards or criteria for trace elements have been exceeded in the available samples. Concentrations of trace elements at exterior sites generally are either similar to or higher than concentrations than other groups. Samples from the 1960's and 1970's exceeded SMCL's for aluminum, iron, and manganese (possibly the result of sample contamination). Seven of the nine selenium concentrations exceeding the chronic aquatic criterion of 5 µg/L are from Horse Creek above Vale, and two are from Cheyenne River at Edgemont. Selenium is present in the Cretaceous-age marine shales common to the plains surrounding the Black Hills.

Several samples at Bear Butte Creek near Deadwood have exceeded the hardness-adjusted chronic and acute copper criteria, generally for samples collected between 1992-94. These samples were collected prior to additional mining upstream of this site within the Strawberry Creek Basin. Insufficient data are available to determine if abandoned mines have contributed to these high copper concentrations.

Limited radionuclide data are available for analysis, especially for artesian springs and exterior sites. Data for most of the radionuclides are from the northern and north-central Black Hills; however, igneous rocks are often a source of radionuclides. Concentrations of gross alpha as uranium are high in two samples from Spearfish Creek near Lead (40 pCi/L (picocuries per liter)) and Rapid Creek near Rochford (33 pCi/L). Uranium concentrations for crystalline core sites are very similar to those summarized for samples from Precambrian aquifers. Uranium is the only radionuclide with data distribution throughout the Black Hills with higher concentrations exterior to the outcrop of the Inyan Kara Group. Historic uranium mining did occur near the Cheyenne River near the town of Edgemont.

Other site specific issues occur within the Black Hills. Occasionally very low pH levels are recorded immediately below abandoned mine sites but pH levels generally increase to within acceptable ranges after mixing with additional stream water. Water-quality changes in Bear Butte Creek also have been noted for dissolved solids, sodium, and sulfate after additional mining activities in a tributary basin. Bear Butte Creek also had some samples that exceeded the acute and chronic copper aquatic-life criteria during 1992-94. Arsenic, manganese, and selenium are trace elements with geologic sources in the Black Hills area, and concentrations exceeding or near the MCL, SMCL's, and aquatic-life standards may occur. Historic mining in the northern Black Hills has been shown to affect water quality, especially on Whitewood Creek.

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SUPPLEMENTAL INFORMATION

Table 15. Ground-water sampling sites summarized in this report

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
	Precambrian wells			
442143103472601	5N 3E30DDAA	442143	1034726	5
442016103473401	4N 3E 5BCBC	442016	1034734	1
441612103342201	4N 4E25DDDD	441612	1033422	1
441644103380601	4N 4E28ADDB	441644	1033806	1
441639103410501	4N 4E30CAAA	441639	1034105	1
441344103401201	3N 4E 8CCAD	441344	1034012	1
441048103361401	3N 4E35BADB	441048	1033614	1
441142103301801	3N 5E27BAC	441142	1033018	1
440852103420501	2N 3E12ACDD	440853	1034201	1
440722103430401	2N 3E23AABC	440722	1034304	1
440607103440901	2N 3E27DABD	440607	1034409	1
440827103342601	2N 4E12DDDA	440827	1033426	1
440834103271401	2N 5E12DDBB	440834	1032714	1
440509103334601	2N 5E31DBCB	440509	1033346	1
440755103451801	2N 6E16DAAB	440755	1034518	1
440458103261601	2N 6E31DC3	440458	1032616	1
440456103255701	2N 6E31DDDD	440456	1032557	2
440456103255702	2N 6E31DDDD2	440456	1032557	2
440115103465101	1N 3E29ABDB	440115	1034651	1
440010103422801	1N 3E36BDCB	440010	1034228	1
440451103383801	1N 4E 4ABBB	440451	1033836	1
440339103391401	1N 4E 8ADD	440339	1033914	1
440007103383401	1N 4E33ACCC	440007	1033834	1
440248103321601	1N 5E17ADC	440248	1033216	1
440223103321701	1N 5E17DDC	440223	1033217	4
440003103301001	1N 5E34DBBB	440003	1033010	1
440550103255801	1N 6E 6AAAA	440550	1032558	3
435927103494801	1S 2E 1CBAA	435920	1034955	1
435916103463301	1S 3E 5DADD	435916	1034633	1
435642103433701	1S 3E23CADB	435642	1034337	1
435916103414201	1S 4E 6CBCC	435916	1034142	1
435709103370801	1S 4E24ABCC	435709	1033708	2
435616103344801	1S 4E25AACA	435616	1033448	1
435446103381601	1S 4E33DDAC	435446	1033816	1
435916103342201	1S 5E 6CBDC	435916	1033422	1
435549103342001	1S 5E30DABD	435602	1033346	1
435515103313001	1S 5E33ACBA	435515	1033130	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		Precambrian wells—Continued		
435645103211801	1S 6E 4CBAB	435922	1032504	1
435837103244601	1S 6E 9BDCB	435837	1032446	1
435837103204201	1S 6E12ACDC	435837	1032042	1
435657103221801	1S 6E22ADDD	435657	1032218	1
435642103233401	1S 6E22CACB	435642	1032334	1
435930103184401	1S 7E 5BACD	435930	1031844	2
435927103185201	1S 7E 5BCAA	435927	1031852	1
435327103351601	2S 4E12BDAD	435327	1033516	1
434948103413801	2S 4E31CBBD	434948	1034138	1
435356103320601	2S 5E 4CCAB	435356	1033206	1
435338103285801	2S 5E11ABDA	435338	1032858	1
435206103273701	2S 5E13DDD	435206	1032737	1
435428103224101	2S 6E 2BC	435428	1032241	4
435404103245501	2S 6E 4CC	435404	1032455	2
435300103265601	2S 6E 7CD	435300	1032656	1
435300103265001	2S 6E 7CDD	435300	1032650	1
435230103254502	2S 6E 8CAD2	435230	1032545	2
435230103254501	2S 6E 8CADA	435230	1032545	1
435334103233401	2S 6E10BACC	435339	1032329	1
435242103261801	2S 6E18ADDDB	435234	1032624	1
434752103380201	3S 4E10CCAC	434752	1033802	1
434742103351301	3S 4E12CDDD	434742	1033513	1
434616103354301	3S 4E24CBCD	434616	1033543	3
434604103362301	3S 4E24CDDC	434604	1033623	1
434555103363601	3S 4E26BA	434550	1033640	2
434549103363701	3S 4E26BACD	434549	1033637	6
434527103374101	3S 4E27CADA	434527	1033741	2
434521103380601	3S 4E27CBCD	434521	1033806	1
433531103371501	3S 4E27DABD	433531	1033715	2
434536103384702	3S 4E28	434534	1033843	2
434420103391401	3S 4E33CCDB	434420	1033914	1
434445103344801	3S 4E36ADCA	434445	1033448	1
434752103311901	3S 5E 9DDBC	434752	1033119	1
434438103311501	3S 5E33DABA	434438	1033115	1
434644103240001	3S 6E21AAAC	434644	1032400	1
434210103394601	4S 4E17ACDA	434210	1033946	1
434200103410201	4S 4E18DBBD	434200	1034102	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Precambrian wells—Continued		
434113103363201	4S 4E23BDDC	434113	1033632	1
434018103373101	4S 4E27DBB	434018	1033731	1
434007103371901	4S 4E27DDBB	434007	1033719	1
433923103380501	4S 4E34CB	433923	1033805	1
434236103303201	4S 5E10CDBB	434236	1033032	1
434257103282601	4S 5E12BCDC	434257	1032826	1
433834103320601	5S 5E 4BCDD	433834	1033206	1
433657103322701	5S 5E17ADAC	433657	1033227	1
433444103300001	5S 5E27DDDD	433444	1033000	1
		Deadwood wells		
442102103552201	5N 2E31ACC	442111	1035508	1
442118103553401	5N 2E31BCBB	442120	1035546	1
442053103503901	5N 2E35CC	442053	1035039	2
442356103482501	5N 3E18BBCB	442356	1034825	1
442058103441201	5N 3E34DBC	442058	1034412	1
442340103393201	5N 4E17CAAD	442335	1033937	1
442200103370001	5N 4E27ACDC	442200	1033700	1
441938103475701	4N 3E 7AACB	441938	1034757	1
441920103420801	4N 3E12CAAD	441913	1034217	1
441758103465801	4N 3E17DBCB	441819	1034701	1
441803103465501	4N 3E17DCCA	441805	1034658	1
441648103481401	4N 3E30BDAD	441648	1034814	1
441431103315801	3N 5E 9BAB	441428	1033139	1
440811103222202	2N 6E15ADAA2	440811	1032222	1
440816103261801	2N 6E18ADAA	440809	1032601	1
440824103260201	2N 6E18ADBA	440810	1032607	1
440606103212701	2N 6E26DBDA	440606	1032127	1
440530103190101	2N 7E31ACAD	440539	1031916	1
440052103181201	1N 7E29CADD	440053	1031810	1
440049103194401	1N 7E30CBDD	440049	1031944	1
440003103185001	1N 7E31AAAB	440033	1031850	1
440034103190001	1N 7E31ABAA	440034	1031900	1
440025103190701	1N 7E31ABDC	440025	1031907	1
440032103191201	1N 7E31BAAB	440032	1031912	1
440019103181801	1N 7E32BDBB	440019	1031818	1
440002103181401	1N 7E32CA	440002	1031814	1
435959103181301	1N 7E32CADB	435959	1031813	1
435850103193001	1S 7E 7ACA	435850	1031930	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Deadwood wells—Continued		
435830103200001	1S 7E 7CB	435830	1032000	1
435835103175001	1S 7E 9CBBD	435835	1031750	1
435641103195801	1S 7E19CCAA	435641	1031958	1
435206103194501	2S 7E18CA	435206	1031945	1
435212103200201	2S 7E18CCAD	435212	1032007	1
434406103503301	4S 2E 2ABD	434406	1035033	1
434407103461401	4S 3E 4BBDB	434408	1034626	1
		Madison wells		
444128103514701	9N 2E34CDD	444128	1035147	1
444129103514801	9N 2E34CDDCA	444129	1035148	1
444320103471801	9N 3E20CC	444320	1034718	1
444312103465901	9N 3E20CDDD	444313	1034653	1
444116103510301	8N 2E 3AAC	444116	1035103	1
443716103522501	8N 2E28DDCB	443716	1035225	1
444114103323901	8N 5E 5BCAB	444114	1033239	1
443511103575801	7N 1E11BCAD	443511	1035758	1
443210104021601	7N 1E30DDAB	443210	1040216	1
443100104002001	7N 1E33CCDD	443104	1040025	1
443227103503401	7N 2E26BDB	443227	1035034	1
443148103534001	7N 2E32AACC	443148	1035340	1
442842103505501	6N 2E14CBCC	442842	1035055	1
442919103511601	6N 2E15BBBB	442917	1035206	4
442802103544601	6N 2E19DABA	442759	1035449	1
442822103534501	6N 2E20ABAB2	442822	1035345	1
442435103571101	5N 1E11DABA	442435	1035711	1
442504103415301	5N 3E 1DCCB	442504	1034153	1
442335103311001	5N 5E16CAAD	442336	1033111	1
442217103272201	5N 5E26ABDA	442215	1032829	1
442024103545701	4N 2E 6AACD	442024	1035457	1
441749103515701	4N 2E22BACB	441749	1035157	1
441759103261202	4N 6E19AABA2	441759	1032612	1
441355103230901	3N 6E10CDBB	441355	1032309	1
441337103225002	3N 6E15ABB2	441335	1032250	1
441055103230501	3N 6E34BA	441055	1032305	3
441033103210301	3N 6E35ADDA	441040	1032107	1
440811103222201	2N 6E15ADAA	440811	1032221	1
440708103214301	2N 6E23BDD	440708	1032143	1
440541103211401	2N 6E35AADA	440541	1032114	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Madison wells—Continued		
440527103220401	2N 6E35BCAB	440527	1032204	1
440931103141401	2N 7E 2DBDD	440931	1031414	1
440808103193701	2N 7E18BCA	440808	1031937	1
440655103140501	2N 7E23DACD	440655	1031407	1
440612103152001	2N 7E27DABB	440612	1031522	1
440541103192301	2N 7E31BADA	440541	1031923	1
440500103193601	2N 7E31CCCA	440458	1031950	1
440500103195001	2N 7E31CCCA2	440500	1031950	1
440544103180002	2N 7E32ABBD2	440543	1031805	1
440526103173001	2N 7E32ADDD	440526	1031730	2
440519103160701	2N 7E34CBAA	440519	1031607	1
440850103045001	2N 8E13BDC	440801	1030616	2
440650103110001	2N 8E20CCCD	440641	1031120	3
440851103044801	2N 9E 7CDCC	440855	1030510	4
440629103040901	2N 9E29BBCC	440629	1030409	1
440032103195901	1N 6E36AAAB	440032	1031959	3
440427103131701	1N 7E 1DBBB	440427	1031317	1
440446103161701	1N 7E 3BBCC	440445	1031616	2
440443103161301	1N 7E 3BBCD	440443	1031613	1
440430103160202	1N 7E 3CBAA2	440430	1031602	1
440338103173302	1N 7E 8ADDD2	440338	1031733	1
440310103173802	1N 7E 8DDCD2	440312	1031740	1
440342103160701	1N 7E10BCDB	440342	1031609	1
440220103164001	1N 7E16DCDC	440220	1031640	2
440300103173501	1N 7E17AAAC2	440305	1031739	4
440223103173201	1N 7E17DDDA	440225	1031734	2
440308103184601	1N 7E18AAAD	440308	1031847	1
440205103172001	1N 7E21BCAB	440205	1031720	1
440032103184601	1N 7E30DDDC	440032	1031846	1
440026103194001	1N 7E31BBDA	440026	1031940	1
440002103173901	1N 7E32DA2	440002	1031739	2
435916103161801	1S 7E 3CDBD	435915	1031620	1
435851103143501	1S 7E11ACAB	435848	1031445	1
435227103185301	2S 7E17CCAA	435227	1031852	1
434700104021401	3S 1E18DDDB	434701	1040215	1
434846103481801	3S 3E 6DCBB	434846	1034818	1
434402103502301	4S 2E 2ADB	434402	1035023	2

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		Madison wells—Continued		
434350103201901	4S 6E 1DAAA	434350	1032020	1
433517103534201	5S 2E28BCCB	433517	1035342	1
433849103442701	5S 3E 3ADBB	433849	1034427	1
433852103384901	5S 4E 4ABCB	433852	1033849	1
433607103383401	5S 4E21ACAD	433607	1033834	1
433506103344001	5S 4E25DAAA	433510	1033445	1
433000103393901	6S 4E29ADCA	433000	1033939	1
433114103281601	6S 5E24BAAA	433114	1032816	1
433150103230501	6S 6E15ABDD	433150	1032305	3
433115103251401	6S 6E21BBBB	433115	1032516	1
432548103414801	7S 4E19BCCB	432545	1034151	1
432616103294702	7S 5E14CBDD2	432616	1032947	1
432603103295901	7S 5E 14CCCC	432603	1032959	1
432136103321001	8S 5E16BBAD	432136	1033210	1
431810103491701	9S 2E 1AABC	431810	1034917	3
431804103492101	9S 2E 1ABDD	431804	1034921	1
431753103492601	9S 2E 1ACDB	431753	1034926	2
431750103500301	9S 2E 1BCDC	431750	1035003	6
431743103501501	9S 2E 2DAAA	431743	1035015	5
431232103513501	10S 2E 3DAA	431232	1035135	3
431218103512501	10S 2E 3DADD	431218	1035125	1
431220103514001	10S 2E 3DDAA	431220	1035140	1
		Minnelusa wells		
444253103440001	9N 3E27ADBD	444253	1034359	3
444108103432201	8N 3E 2BDBC	444108	1034322	2
443655103482001	8N 3E31ACA	443650	1034744	2
443627103460301	8N 3E33CCB	443625	1034555	2
443515103572501	7N 1E11ACAC	443508	1035730	2
443339103575701	7N 1E14CCD	443339	1035757	1
443355103574501	7N 1E14CCDD	443343	1035802	1
443320104004501	7N 1E20AAD	443328	1040045	3
443320104003501	7N 1E21BBC	443334	1040035	1
443215103573001	7N 1E26ACD	443215	1035730	1
443240104024001	7N 1E30AAAD	443240	1040155	1
443330104024501	7N 1E30CADD	443230	1040241	1
443150104020001	7N 1E30DDDC	443156	1040205	2
443153104015101	7N 1E32BBBB	443153	1040151	1
443100104002002	7N 1E33CCDD2	443104	1040025	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Minnelusa wells—Continued		
443603103494001	7N 2E 1BBC	443603	1034940	1
443553103502101	7N 2E 2CACA	443553	1035021	2
443108103530601	7N 2E 4BD	443108	1035306	2
443010103523001	7N 2E 9ABAB	443010	1035230	4
443515103513901	7N 2E10BADC	443513	1035143	2
443423103510801	7N 2E15AADC	443423	1035108	1
443330103520301	7N 2E15CC	443348	1035203	1
443355103553001	7N 2E18CA	443359	1035532	1
443420103551001	7N 2E19CAAA	443315	1035514	1
443318103532701	7N 2E20ADD	443318	1035327	1
443323103515501	7N 2E22BCA	443324	1035158	2
443255103502501	7N 2E23CDAB	443300	1035028	1
443230103504101	7N 2E26BCDA	443230	1035041	2
443240103531002	7N 2E29AA2	443240	1035310	1
443215103533001	7N 2E29D	443215	1035330	1
443117103541301	7N 2E32BAC	443147	1035413	1
443124103531601	7N 2E33CBCD2	443124	1035316	1
443515103473001	7N 3E 7AABA	443525	1034732	1
443124103433401	7N 3E35CB	443124	1034334	1
443032103575001	6N 1E 2CABC	443032	1035750	1
443019103523101	6N 2E 4DCAD	443019	1035231	4
443100103543001	6N 2E 5BBBB	443104	1035437	1
442930103522001	6N 2E 9D	442930	1035220	1
442937103511201	6N 2E10DACB	442937	1035112	1
442906103504201	6N 2E14BBCC	442906	1035042	1
442906103510501	6N 2E15AADC	442906	1035105	1
442802103544601	6N2E19DABA	442759	1035449	1
442857103513401	6N 2E22ABBB	442827	1035132	1
442820103503501	6N 2E23BBBA	442820	1035035	1
442721103493701	6N 2E25BBCB	442721	1034937	1
442917103462901	6N 3E17ABAA	442917	1034629	2
442749103381401	6N 4E21DBCD	442749	1033814	4
442901103281601	6N 5E14ADBD	442901	1032816	1
442754103220801	6N 6E22DABD	442754	1032208	1
442545103343701	5N 4E 1ABBD	442544	1033437	1
442515103340401	5N 4E 1DAAD	442515	1033404	1
442306103352001	5N 4E23AAAD	442306	1033520	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Minnelusa wells—Continued		
442533103324801	5N 5E 5BBCB	442533	1033248	2
442502103325401	5N 5E 5CC	442511	1033238	4
442435103320301	5N 5E 8ACDD	442435	1033203	1
442443103312701	5N 5E 9BCAA	442443	1033127	4
442431103314101	5N 5E 9CBCC	442431	1033141	2
442337103303501	5N 5E16DAA	442337	1033035	5
442311103303501	5N 5E21AAA	442311	1033035	2
442148103273801	5N 5E25CADB2	442148	1032738	2
442111103265701	5N 5E36ADDA	442111	1032657	3
441807103235601	4N 6E16DCAC	441807	1032356	1
441812103230501	4N 6E16DCB	441812	1032405	1
441759103261201	4N 6E19AABA	441759	1032612	1
441303103232601	3N 6E10CBBA	441303	1032326	2
441311103220801	3N 6E14CBAB	441311	1032208	3
441247103220701	3N 6E14CCDD	441247	1032207	2
441337103225001	3N 6E15ABB	441335	1032250	1
441208103205001	3N 6E24C	441208	1032050	3
441318103221301	3N 6E24CADD	441207	1032033	1
441127103195801	3N 6E25ADDC	441127	1031958	1
441130103205601	3N 6E25BCDC	441130	1032056	3
441028103200401	3N 6E36DA	441028	1032004	4
441033103193001	3N 7E31CAA	441033	1031930	2
441023103194401	3N 7E31CBDD	441023	1031944	1
440920103210401	2N 6E 1CCCD	440920	1032104	2
440919103210201	2N 6E 1CCCD2	440919	1032102	1
440939103142001	2N 7E 2DBDD	440939	1031420	1
440919103170501	2N 7E 4CDCD	440920	1031658	1
440901103184801	2N 7E 7ADAB	440901	1031848	4
440907103183501	2N 7E 8BBCD	440907	1031835	3
440833103184101	2N 7E 8CCBC	440833	1031841	2
440826103174701	2N 7E 8DDCC2	440826	1031747	1
440824103160401	2N 7E10CCDC	440824	1031604	1
440832103160901	2N 7E10CDCA	440837	1031609	1
440818103180801	2N 7E17BAAD	440819	1031809	1
440817103181701	2N 7E17BACA2	440817	1031817	2
440738103173601	2N 7E17DDDB	440738	1031736	2
440647103183201	2N 7E20CCDB	440647	1031832	2

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Minnelusa wells—Continued		
440516103194001	2N 7E31CDCB	440501	1031933	1
440544103180001	2N 7E32ABBD	440544	1031800	1
440538103161201	2N 7E34BBBC	440538	1031612	1
440528103161001	2N 7E34BCCA	440528	1031610	3
440528103155201	2N 7E34BDAD	440528	1031552	1
440504103161501	2N 7E34CCBC	440504	1031615	3
440730103112001	2N 8E17CCCD	440730	1031120	1
440452103155301	1N 7E 3BABD	440452	1031553	1
440436103161201	1N 7E 3BCBC	440436	1031612	1
440430103160201	1N 7E 3CBAA	440430	1031602	4
440414103164601	1N 7E 4DCB2	440414	1031646	4
440338103173301	1N 7E 8ADDD	440338	1031733	1
440310103173801	1N 7E 8DDCD	440312	1031740	1
440351103171301	1N 7E 9BBCA	440351	1031713	3
440338103171601	1N 7E 9BCDC	440338	1031716	3
440331103171601	1N 7E 9CBAC	440331	1031716	1
440225103160801	1N 7E15CC	440225	1031608	2
440300103165801	1N 7E16BADB	440300	1031658	1
440237103173401	1N 7E17DADA	440237	1031734	1
440307103193001	1N 7E18BABB	440307	1031930	1
440202103164101	1N 7E21ACA	440202	1031641	3
440142103164301	1N 7E21DBDB	440142	1031643	2
440130103163401	1N 7E21DDC	440130	1031634	1
440213103153401	1N 7E22AB	440213	1031534	1
440140103152601	1N 7E22D	440140	1031526	1
440203103143601	1N 7E23BDAB	440203	1031436	1
440148103150001	1N 7E23CBBA	440148	1031500	1
435916103161802	1S 7E 3CDBD2	435915	1031620	1
435845103163401	1S 7E10BCAC	435845	1031634	1
435042103171101	2S 7E28DB	435042	1031711	1
435018103155801	2S 7E34ABBA	435018	1031558	1
435004103161301	2S 7E34BD	435004	1031613	1
434700104021402	3S 1E18DDDB2	434701	1040215	1
434503103183601	3S 7E32BABA	434503	1031836	1
434502103165801	3S 7E33AACB	434502	1031658	1
434326103555101	4S 2E 6CCDC	434326	1035551	1
434351103461501	4S 3E 4BCDA	434351	1034615	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
Minnelusa wells—Continued				
434218103463701	4S 3E17ADAB	434218	1034637	1
434350103201902	4S 6E 1DAAA2	434350	1032020	1
434236103201601	4S 6E12DDAD	434236	1032016	1
434001103131301	4S 7E25DDDB	434001	1031313	1
433545103502701	5S 2E23DCAB	433545	1035027	1
433517103534202	5S 2E28BCCB2	433517	1035342	1
433831103475201	5S 3E 6DAAC	433831	1034752	1
433440103465501	5S 3E32ABAB	433440	1034655	1
433628103173801	5S 7E16CDCA	433628	1031738	1
432927103520401	6S 2E34BA	432927	1035204	1
432927103521001	6S 2E34BABC	432927	1035210	1
432917103522101	6S 2E34BC	432917	1035221	2
433003103420701	6S 3E25ADDC	433000	1034158	2
433347103385101	6S 4E 4BADA	433343	1033857	1
433339103385601	6S 4E 4BADD	433339	1033856	1
433119103360001	6S 4E14DDAC	433119	1033600	1
433021103273601	6S 5E24DDDD	433021	1032736	1
432945103323801	6S 5E29DBDA	432945	1033238	1
433303103225801	6S 6E 3DDCA	433303	1032258	1
433115103251402	6S 6E21BBBB2	433115	1032516	1
432548103414802	7S 4E19BCCB2	432545	1034151	1
432808103294901	7S 5E 2CBAB	432808	1032949	1
432616103294701	7S 5E14CBDD	432616	1032947	2
432616103294702	7S 5E14CBDD2	432616	1032947	2
432622103291501	7S 5E14DBC	432622	1032915	1
432537103301401	7S 5E22ADBC	432537	1033014	1
432523103305401	7S 5E22CDCB	432523	1033054	1
432510103304801	7S 5E22CDCD	432510	1033048	2
432459103290101	7S 5E26AACA	432459	1032901	2
432127103325601	8S 5E17ACBB	432127	1033256	1
Minnekahta wells				
443310104024501	7N 1E30BDA2	443230	1040242	2
443100104002003	7N 1E33CCDD3	443104	1040025	1
443253103515401	7N 2E22CCDB	443253	1035154	1
443213103530001	7N 2E28C	443213	1035300	1
443230103541501	7N 2E30AD	443230	1035415	1
443151103543601	7N 2E31AA	443151	1035436	3
443043103521801	6N 2E 4ADDB	443043	1035218	4

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Minnekahta wells—Continued		
443101103530601	6N 2E 4BBAA	443101	1035306	2
443023103521301	6N 2E 4DDAA	443023	1035213	2
443024103522601	6N 2E 4DDBB	443024	1035226	2
443100103543002	6N 2E 5BBBB2	443104	1035437	1
442950103535801	6N 2E 8ACCC	442950	1035358	3
442634103425701	6N 3E35ABAB	442634	1034257	1
440740103174601	2N 7E17DDBC	440740	1031746	2
433115103251403	6S 6E21BBBB3	433115	1032514	1
432619103283501	7S 5E13CBDA	432619	1032835	1
		Inyan Kara wells		
444337103363001	9N 4E22DAAA	444337	1033630	5
444213103244601	9N 6E32ABBA	444217	1032449	4
444213103244602	9N 6E32ABBA2	444213	1032446	6
444046103504501	8N 2E 2CCAA	444046	1035045	3
443859103502801	8N 2E14CDD	443859	1035028	1
443905103501201	8N 2E14DC	443905	1035012	1
443855103521501	8N 2E16DDD	443855	1035215	1
443835103492001	8N 2E24BCAD	443835	1034920	3
443649103522001	8N 2E33ADCA	443649	1035220	2
444006103415201	8N 3E12	444006	1034152	1
444011103415302	8N 3E12 (2)	444011	1034153	5
444120103365301	8N 4E 3ABDB	444120	1033653	3
444035103330301	8N 5E 7AABA	444035	1033303	2
444024103330801	8N 5E 7AACC	444024	1033308	1
444020103323001	8N 5E 8BCB2	444020	1033230	1
443723103240701	8N 6E28CCAB	443721	1032414	4
443347103474701	7N 3E18DBCD	443352	1034754	1
443244103431501	7N 3E26BA	443244	1034315	1
443245103434001	7N 3E26BAAA	443245	1034312	4
443557103360401	7N 4E 2BDAC	443558	1033559	1
443451103403801	7N 4E 7CDCA	443435	1034053	1
443228103203701	7N 6E25BC	443228	1032037	2
442804103330401	6N 5E19AAAC	442804	1033304	1
442755103302501	6N 5E21DABA	442758	1033041	2
442545103291501	6N 5E22DDBC	442743	1032930	2
442708103311401	6N 5E28ADA2	442719	1033035	1
442038103240001	5N 6E33CDCD	442038	1032400	1
442027103235501	4N 6E 4ABD	442027	1032355	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Inyan Kara wells—Continued		
441820103205801	4N 6E13BBBC	441850	1032105	1
441839103204901	4N 6E14BACC	441839	1032049	1
441834103232501	4N 6E25ACAB	441655	1032020	1
441345103210701	3N 6E12CCCB	441345	1032107	1
441219103090801	3N 8E21DAAD	441222	1030904	1
440949103140401	2N 7E 2ACAD	440949	1031404	1
440953103140801	2N 7E 2ADBC	440953	1031408	2
440941103052701	2N 8E 1DABB	440941	1030527	2
440735103105601	2N 8E17CDD	440735	1031056	1
440641103103501	2N 8E20DCDD	440641	1031035	3
440610103085201	2N 8E27CBBA	440610	1030852	1
440831103040801	2N 9E 8CDBA	440837	1030406	3
440640103041501	2N 9E19DDDD	440640	1030415	3
440330103094901	1N 8E10DAAA	440330	1030753	1
440330103080001	1N 8E10DADD	440326	1030753	3
435725103134001	1S 7E13DCBC	435725	1031340	1
435746103045101	1S 9E18ADCA	435746	1030451	1
435127103125201	2S 8E19CCCC	435127	1031252	1
434958103114901	2S 8E32BCBC	434958	1031149	1
434830103134301	3S 7E 1CAAD	434858	1031347	1
434832103150501	3S 7E11ABAD	434834	1031442	1
434752103130801	3S 7E12DDAD	434752	1031308	1
434638103135601	3S 7E24BDB	434638	1031356	1
434424103154601	3S 7E34DCAA	434424	1031546	1
434803103103501	3S 8E 9CBC	434803	1031035	1
434633103084401	3S 8E22ACDB	434633	1030844	1
434620103090601	3S 8E22CA	434620	1030906	1
434557103123201	3S 8E30BAAB	434557	1031232	1
433931103114401	4S 8E32BCDC	433933	1031144	1
433928103113801	4S 8E32BCDC3	433928	1031138	1
433350104030301	5S 1E31CCCD	433350	1040303	1
433720103192301	5S 7E18AAAB	433720	1031923	1
433224104021301	6S 1E 7DACA	433224	1040213	1
433158104021601	6S 1E18AACB	433158	1040216	1
433144104022701	6S 1E18ACDB	433144	1040227	1
433151104021601	6S 1E18ADBB	433151	1040216	1
433144104021601	6S 1E18ADCB2	433144	1040216	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Inyan Kara wells—Continued		
433144104020901	6S 1E18ADDB	433144	1040209	1
433140104021301	6S 1E18DABA	433140	1040213	1
433054104024901	6S 1E19BDCA	433054	1040249	1
433000103585501	6S 1E27DBBA	433000	1035855	1
432945104015501	6S 1E29CBCD	432945	1040155	1
432956104031001	6S 1E30CBCA	432956	1040310	1
432906104025201	6S 1E31BDCC	432906	1040252	1
432909104003901	6S 1E33BCAC	432909	1040039	1
433055103202801	6S 7E19BCC	433055	1032028	1
432956103184001	6S 7E29 (2)	432956	1031840	1
432826103581501	7S 1E 2BBDD	432826	1035815	1
432837103593401	7S 1E 3BBBB	432837	1035934	1
432750104000001	7S 1E 4DDBC	432750	1040000	1
432710104005401	7S 1E 8DADA	432710	1040054	1
432735104000101	7S 1E 9AAAB	432749	1035949	1
432728103595301	7S 1E 9ADCA2	432728	1035953	1
432725103594901	7S 1E 9ADDD	432725	1035949	1
432703103594201	7S 1E 9DDAA	432703	1035942	1
432714103564901	7S 1E12CACA	432714	1035649	1
432645103575401	7S 1E14ABDD	432645	1035754	1
432638103585201	7S 1E15ACDA	432638	1035852	1
432602103582601	7S 1E23BBB	432602	1035826	2
432603103582801	7S 1E23BBB2	432603	1035828	2
432522103574601	7S 1E23DBCD	432522	1035746	1
432522103574301	7S 1E23DCBA	432522	1035743	1
432432103564901	7S 1E25CDAB	432432	1035649	1
432439103562001	7S 1E25DABC	432439	1035620	1
432443103590201	7S 1E27CAAA	432443	1035902	1
432501104001801	7S 1E28ABAC	432501	1040018	1
432710103553001	7S 2E 7CADA	432717	1035530	1
432638103541801	7S 2E17BDAD	432638	1035418	1
432508103560201	7S 2E30BBBB	432508	1035602	1
432425103555501	7S 2E30CCAC	432425	1035555	1
432436103545401	7S 2E30DADA	432436	1035454	1
432327103550101	7S 2E31DDCD	432327	1035501	1
432327103521901	7S 2E34CCDB	432327	1035219	1
432403103505601	7S 2E35BDBB	432403	1035056	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
Inyan Kara wells—Continued				
432813103210601	7S 6E 1BAAB	432835	1032106	1
432549103215701	7S 6E23AACC	432549	1032153	1
432214103234301	7S 6E34CBDB	432343	1032355	1
432834103203301	7S 7E 6BBBC	432834	1032028	1
432302103493701	8S 2E 1BDDB	432302	1034937	1
432302103502401	8S 2E 2ACDA	432302	1035024	1
432302103502001	8S 2E 2ADCB	432302	1035020	1
432233103513901	8S 2E 3DCDC	432233	1035139	1
432248103530201	8S 2E 4DBCC	432248	1035302	1
432233103542501	8S 2E 8BABA	432233	1035425	1
432015103535801	8S 2E20DACC	432015	1035358	2
431958103515001	8S 2E22DCCC	431958	1035150	1
431855103491301	8S 2E36ADBB	431855	1034913	1
432128103421401	8S 3E13ACAB	432128	1034214	1
432128103422101	8S 3E13ACBB	432128	1034221	1
432107103422101	8S 3E13DBCB	432107	1034221	1
432020103470601	8S 3E20CAAA	432020	1034706	1
431818103405101	8S 4E31DDCB	431818	1034051	1
431836103363901	8S 4E35BDCD	431836	1033639	1
432113103224801	8S 6E14ADCD	432116	1032214	1
432110103224001	8S 6E14BCDC	432110	1032240	1
431427103594501	9S 1E28ADAB	431427	1035945	1
431752103495701	9S 2E 1BCDA	431752	1034957	1
431632103511501	9S 2E11CCDC	431632	1035115	1
431500103452801	9S 3E22CCCC	431500	1034528	1
431420103302101	9S 5E27ADCA	431420	1033021	1
431124103431501	10S 3E11DDAC	431124	1034315	1
431242103451001	10S 3E15BA	431109	1034510	1
Spearfish wells				
444330103502701	9N 2E23CAA	444330	1035027	1
442757103431201	6N 3E21CAAB	442757	1034312	1
442754103384901	6N 4E21CBBB	442754	1033849	1
442458103330901	5N 5E 7A	442458	1033309	3
441142103173101	3N 7E29AADB	441142	1031731	1
440003103151001	1N 7E34DABA	440003	1031510	1
434243103581901	4S 1E11CBCD	434243	1035819	1
434055104002501	4S 1E21CD	434055	1040025	1
433556103564501	5S 1E24CAAB	433556	1035645	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Spearfish wells—Continued		
433245103532701	6S 2E 9BCAB	433245	1035327	1
433234103494401	6S 2E12BDCB	433234	1034944	1
		Sundance wells		
443421103515501	7N 2E15BDAD	443414	1035134	2
442734103384501	6N 4E21CCDC	442734	1033845	1
442720103380601	6N 4E28ABCC	442723	1033818	1
434908103145201	3S 7E 2ACC	434908	1031452	1
434111103183801	4S 7E20CAA	434111	1031838	1
433858103202001	5S 7E 6ACAA	433850	1031930	1
432653103580501	7S 1E14BAAC	432653	1035805	1
432816103513801	7S 2E 3ACDD	432816	1035138	1
432804103553001	7S 2E 6CADA	432804	1035530	1
432723103493201	7S 2E12DDAA	432723	1034932	1
431825103414201	8S 4E31CCBA	431825	1034142	1
431943103294701	8S 5E26BCAA	431943	1032947	2
		Morrison wells		
444333103590201	9N 1E22CAA	444333	1035902	1
442754103343301	6N 4E24DBB	442754	1033433	1
440659103064701	2N 8E23DA	440659	1030650	4
440844103050601	2N 9E 7CABC	440844	1030506	2
440759103045501	2N 9E18BDDC	440759	1030500	2
435338103160801	2S 7E10BADB	435338	1031608	1
433252103583001	6S 1E10AAAD	433252	1035830	1
432233103423201	8S 3E 1CDCA	432233	1034232	1
432034103392801	8S 4E20AADD	432034	1033928	1
		Pierre wells		
443834103241801	8N 6E 1BCBB	443834	1032418	1
443751103264201	8N 6E30BBBC	443751	1032642	1
443610103232701	7N 6E 4ABAA	443610	1032327	1
443300103242501	7N 6E20DAD	443300	1032425	1
441933103062801	4N 8E12BBC	441933	1030628	1
441301103035401	3N 9E17CBDA	441301	1030354	1
440834103013301	2N 9E10CBDC	440834	1030133	1
440646103035401	2N 9E20CCDA	440646	1030354	1
440628103014401	2N 9E28ADAA	440628	1030144	1
440148103040101	1N 9E20CBBA	440148	1030401	1
440018103025201	1N 9E33ACBA	440018	1030252	1
435631103053801	1S 9E19CCDA	435631	1030538	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		Pierre wells—Continued		
435031103005701	2S 9E26CCBA	435031	1030057	1
434800103022401	3S 9E 9DADB	434800	1030224	1
433932103084201	4S 8E34ACDB	433932	1030842	1
433701103075501	5S 8E14ABCC	433701	1030755	1
433440103022701	5S 9E27CCDC	433440	1030227	1
433202103091401	6S 8E10CDDD	433202	1030914	1
433137103013001	6S 9E15DAAA	433137	1030130	1
433108103055601	6S 9E19BBAA	433108	1030556	1
432952103004601	6S 9E26ACCD	432952	1030046	1
432754103125001	7S 8E 6CDAB	432754	1031250	1
432508103122801	7S 8E 9DCDD	432508	1031228	1
432244103140201	8S 7E 1CADC	432244	1031402	1
432244103164801	8S 7E 3CBCD	432244	1031648	1
432233103194001	8S 7E 6DCDC	432233	1031940	1
432009103192601	8S 7E19DADC	432009	1031926	1
431948103154601	8S 7E27AAAC	431948	1031546	1
		Graneros wells		
443842103463301	8N 3E20ABB	443842	1034633	1
443101103311501	7N 5E33CDCC	443101	1033115	1
443014103275401	6N 5E 1CCBC	443014	1032754	1
442757103303901	6N 5E21DABB	442757	1033039	1
442515103220101	5N 6E 3DAAD	442515	1032201	1
441745103164001	4N 7E21ABDC	441745	1031640	1
441402103161201	3N 7E10CBBB	441402	1031612	1
435251103114901	2S 8E17BBBC	435251	1031149	1
434810103103001	3S 8E 9BCDC	434810	1031030	1
431355103441601	9S 3E26CCCB	431355	1034416	1
		Newcastle wells		
440800103131301	2N 7E13BDAA	440800	1031313	1
435005103114901	2S 8E32BCBD	435005	1031149	3
435309103124501	2S 8E 7CDB	435309	1031245	1
433932103114401	4S 8E32BCDC2	433932	1031144	1
434348103131701	4S 7E 1DAAB	434348	1031317	2
		Alluvial wells		
444152103464001	9N 3E32ACC2	444152	1034640	1
443954103512401	8N 2E10DC	443954	1035124	1
443623103260301	8N 6E31DC	443623	1032603	1
443054103524201	6N 2E 4AB	443054	1035242	2

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
Alluvial wells—Continued				
443018103521901	6N 2E 4AD	443018	1035219	1
443024103522001	6N 2E 4D	443024	1035220	2
440506103142801	2N 7E35CDAA	440506	1031431	1
440506103142803	2N 7E35CDAA3	440506	1031431	1
440709103064001	2N 8E23ADAD	440709	1030640	2
440700103080000	2N 8E23C	440700	1030800	1
440651103065001	2N 8E23D	440651	1030650	1
440745103054001	2N 8E23DACD	440745	1030540	1
440713103061601	2N 8E24B	440713	1030616	1
440718103062201	2N 8E24B2	440718	1030622	2
440444103262601	1N 6E 6ABCD	440444	1032626	3
440350103243401	1N 6E 9BBDC	440350	1032434	4
440447103121220	1N 7E 1ABCB20	440447	1031220	1
440320103161501	1N 7E 3CCA	440412	1031603	1
440409103160501	1N 7E 3CCAD	440409	1031605	4
440320103161509	1N 7E 3CDCC	440405	1031559	1
440304103161505	1N 7E 3DBA5	440430	1031530	1
440315103182002	1N 7E 8CDAC2	440315	1031820	2
440328103190501	1N 7E 8DBC	440333	1031805	1
440327103180501	1N 7E 8DBC(2)	440327	1031805	3
440344103163006	1N 7E 9ADA6	440344	1031630	5
440344103163007	1N 7E 9ADA7	440344	1031630	4
440346103163201	1N 7E 9ADBB	440346	1031632	3
440343103163001	1N 7E 9ADCA	440343	1031630	2
440400103100000	1N 8E 4C	440400	1031000	1
440410103112601	1N 8E 5CCCB	440410	1031126	1
440222103033801	1N 9E19DCCB	440222	1030338	1
435602103340201	1S 5E30	435602	1033402	3
435630103340601	1S 5E30BDDD	435630	1033406	1
435537103342501	1S 5E30CCDD	435537	1033425	5
435808103100401	1S 8E20ABBC	435808	1031004	1
440200103110000	1S 8E20B	440200	1031100	1
435558103082701	1S 8E27DABA	435558	1030827	1
435408103243201	2S 6E 4CADA	435408	1032432	3
435038103202001	2S 6E25DAAC	435038	1032020	1
435045103160801	2S 7E27CAAA	435045	1031608	1
435410103075101	2S 8E 2CABD	435410	1030751	1

Table 15. Ground-water sampling sites summarized in this report—Continued

Site identification	Local number	Latitude	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
	Alluvial wells—Continued			
435000103110000	2S 8E32BA	435000	1031100	1
435002103115001	2S 8E32BCCA	435002	1031150	5
435309103033601	2S 9E 8DADC	435309	1030336	1
435139103050901	2S 9E 9ACCD	435139	1030509	1
435237103013301	2S 9E15ACBD	435237	1030133	1
434803103162601	3S 7E10CBAC	434803	1031626	1
434601103074401	3S 8E23CDDC	434601	1030744	1
434818103053101	3S 9E 7BDDB	434818	1030531	1
434528103002801	3S 9E26CAAD	434528	1030028	1
434351103200901	4S 7E 6BCCB	434351	1032009	1
434104103192801	4S 7E18DCDA	434104	1031928	1
434238103065901	4S 8E12CC	434238	1030659	1
434100103120000	4S 8E19D	434100	1031200	1
433955103100802	4S 8E33BAAA2	433955	1031008	1
433913103033701	4S 9E32DDA	433913	1030337	1
433932103011901	4S 9E34ADBD	433932	1030119	1
433101103582601	6S 1E23BCBB	433101	1035826	1
433332103362801	6S 4E 2ACBC	433332	1033628	1
433231103152501	6S 7E11BCDC	433231	1031525	1
433245103134401	6S 7E12ABDB	433245	1031344	1
433043103103301	6S 8E21CABA	433043	1031033	1
432833103071501	6S 8E36CCCD	432833	1030715	1
433206103035401	6S 9E 8DDDD	433206	1030354	1
432613103283201	7S 5E13C	432613	1032832	2
432508103272501	7S 5E19CCDC	432508	1032725	1
432407103242501	7S 6E33ABAC	432407	1032425	1
432504103163001	7S 7E27BAB3	432504	1031630	1
432306103464401	8S 3E 5ADBD	432306	1034644	1
431532103392501	9S 4E21BBAA	431532	1033925	1
431445103352401	9S 4E24DCCA	431445	1033524	1
431724103224401	9S 6E 2CDBD	431724	1032244	1
431355103161501	9S 7E27DDCB	431355	1031615	1

Table 16. Surface-water sampling sites summarized in this report

Station identification	Site Name	Latitude	Longitude	Number of valid samples
		(degree, minutes, seconds)		
	Headwater springs			
06408700	Rhoads Fork near Rochford, SD	440812	1035129	142
06409000	Castle Creek above Deerfield Reservoir, near Hill City, SD	440049	1034948	478
06430770	Spearfish Creek near Lead, SD	441756	1035202	91
06430850	Little Spearfish Creek near Lead, SD	442058	1035608	93
	Crystalline core sites			
06402430	Beaver Creek near Pringle, SD	433453	1032834	67
06402995	French Creek above Stockade Lake, near Custer, SD	434610	1033210	76
06403300	French Creek above Fairburn, SD	434302	1032203	164
06404000	Battle Creek near Keystone, SD	435221	1032010	243
06404800	Grace Coolidge Creek near Hayward, SD	434807	1032603	101
06404998	Grace Coolidge Creek near Game Lodge, near Custer, SD	434540	1032149	240
06405800	Bear Gulch near Hayward, SD	434731	1032049	79
06406920	Spring Creek above Sheridan Lake, near Keystone, SD	435739	1032918	97
06407500	Spring Creek near Keystone, SD	435845	1032025	155
06422500	Boxelder Creek near Nemo, SD	440838	1032716	280
06424000	Elk Creek near Roubaix, SD	441741	1033547	70
06430800	Annie Creek near Lead, SD	441937	1035338	97
06430898	Squaw Creek near Spearfish, SD	442404	1035335	103
06436156	Whitetail Creek at Lead, SD	442036	1034557	104
	Artesian springs			
06400497	Cascade Springs near Hot Springs, SD	432010	1033307	157
06402000	Fall River at Hot Springs, SD	432550	1032833	218
06402470	Beaver Creek above Buffalo Gap, SD	433120	1032123	58
06412810	Cleghorn Springs at Rapid City, SD	440332	1031749	49
06430532	Crow Creek near Beulah, WY	443414	1040019	63
06430540	Cox Lake Outlet near Beulah, WY	443356	1035937	48
	Exterior sites			
06395000	Cheyenne River at Edgemont, SD	431820	1034914	520
06400000	Hat Creek near Edgemont, SD	431424	1033516	198
06433500	Hay Creek at Belle Fourche, SD	444001	1035046	144
06436760	Horse Creek above Vale, SD	443908	1032159	210
	Other sites			
06396300	Cottonwood Creek tributary near Edgemont, SD	431748	1035202	1
06400500	Cheyenne River near Hot Springs, SD	431819	1033343	221
06401500	Cheyenne River below Angostura Dam, SD	432042	1032612	305
06402150	Fall River at mouth near Hot Springs, SD	432312	1032420	5
06402400	Cheyenne River above Buffalo Gap, SD	432505	1031716	5

Table 16. Surface-water sampling sites summarized in this report—Continued

Station identification	Site Name	Latitude	Longitude	Number of valid samples
		(degree, minutes, seconds)		
	Other sites—Continued			
06402500	Beaver Creek near Buffalo Gap, SD	432800	1031820	236
06402520	Iron Draw near Buffalo Gap, SD	432655	1030923	5
06402600	Cheyenne River near Buffalo Gap, SD	433005	1030423	186
06402800	Cottonwood Creek near Buffalo Gap, SD	433136	1030614	5
06402990	French Creek below Custer, SD	434614	1033304	20
06403500	French Creek near Fairburn, SD	434050	1031610	5
06403810	Battle Creek above Keystone, SD	435417	1032748	4
06403850	Grizzly Bear Creek near Keystone, SD	435241	1032614	4
06405000	Grace Coolidge Creek near Custer, SD	434540	1032142	18
06405400	Grace Coolidge Creek near Fairburn, SD	434613	1032028	38
06405500	Grace Coolidge Creek near Hermosa, SD	434629	1031942	9
06405797	Bear Gulch above Hayward, SD	434737	1032117	8
06406000	Battle Creek at Hermosa, SD	434941	1031144	252
06406700	Spring Creek at Oreville, near Hill City, SD	435158	1033724	5
06406740	Sunday Gulch below Johnson Canyon, near Hill City, SD	435210	1033455	6
06406760	Reno Gulch near Hill City, SD	435435	1033643	6
06406950	Horse Creek at Highway 385, near Hill City, SD	435905	1032913	12
06406960	Sheridan Lake tributary near Calumet Ridge, near Keystone, SD	435751	1032735	9
06406994	Spring Creek below Sheridan Lake, near Keystone, SD	435843	1032654	9
06407000	Spring Creek near Hill City, SD	435900	1032600	11
06408000	Spring Creek near Rapid City, SD	435920	1031555	37
06408500	Spring Creek near Hermosa, SD	435631	1030932	202
06408860	Rapid Creek near Rochford, SD	440617	1033835	67
06410000	Castle Creek below Deerfield Dam, SD	440145	1034653	221
06410500	Rapid Creek above Pactola Reservoir, at Silver City, SD	440505	1033448	246
06411500	Rapid Creek below Pactola Dam, SD	440436	1032854	384
06411900	Rapid Creek above Johnson Siding, below Pactola Dam, SD	440455	1032732	3
06412000	Rapid Creek at Big Bend, near Rapid City, SD	440343	1032505	3
06412200	Rapid Creek above Victoria Creek, near Rapid City, SD	440248	1032106	142
06412220	Victoria Creek above Victoria Dam, near Rapid City, SD	440147	1032606	4
06412250	Victoria Creek below Victoria Dam, near Rapid City, SD	440105	1032307	5
06412300	Tittle Springs at Rapid City, SD	440242	1031937	87
06412500	Rapid Creek above Canyon Lake, near Rapid City, SD	440304	1031847	362
06412510	Rapid Creek above Rapid City, SD	440310	1031841	8
06412580	Wild Irishman Gulch near Rapid City, SD	440452	1032154	4
06412600	Cleghorn Springs main channel at Fish Hatchery, at Rapid City, SD	440332	1031754	84
06412700	Cleghorn Springs south channel at Fish Hatchery, at Rapid City, SD	440331	1031756	26

Table 16. Surface-water sampling sites summarized in this report—Continued

Station identification	Site Name	Latitude	Longitude	Number of valid samples
		(degree, minutes, seconds)		
	Other sites—Continued			
06412800	Cleghorn Springs north channel at Fish Hatchery, at Rapid City, SD	440332	1031754	24
06412900	Rapid Creek below Cleghorn Springs, at Rapid City, SD	440333	1031749	128
06413200	Rapid Creek below Park Drive, at Rapid City, SD	440333	1031702	78
06413300	Leedy Ditch at headgate below Canyon Lake Dam, at Rapid City, SD	440327	1031712	12
06413550	Leedy Ditch at mouth, at Rapid City, SD	440349	1031622	11
06413570	Rapid Creek above Jackson Boulevard, at Rapid City, SD	440355	1031621	30
06413600	City Springs at Rapid City, SD	440524	1031732	84
06413620	South Canyon near Rapid City, SD	440534	1031937	4
06413650	Lime Creek at mouth, at Rapid City, SD	440430	1031600	96
06413660	Storybook Ditch at headgate, at Rapid City, SD	440404	1031615	24
06413670	Storybook Ditch at mouth, at Rapid City, SD	440429	1031544	18
06413700	Rapid Creek above Water Treatment Plant, at Rapid City, SD	440429	1031534	170
06413800	Deadwood Avenue Drain at mouth, at Rapid City, SD	440458	1031522	42
06414000	Rapid Creek at Rapid City, SD	440509	1031431	392
06414700	Rapid Creek at East Main Street, at Rapid City, SD	440445	1031212	151
06415500	Hawthorn Ditch at Rapid City, SD	440430	1031110	1
06416000	Rapid Creek below Hawthorn Ditch, at Rapid City, SD	440402	1031049	203
06416300	Meade Street Drain at Rapid City, SD	440351	1031132	231
06418900	Rapid Creek below Sewage Treatment Plant, near Rapid City, SD	440124	1030543	193
06422650	Boxelder Creek at Doty School, near Blackhawk, SD	440703	1032154	27
06423000	Boxelder Creek at Blackhawk, SD	440750	1031910	1
06423010	Boxelder Creek near Rapid City, SD	440754	1031754	79
06425100	Elk Creek near Rapid City, SD	441425	1030903	152
06428500	Belle Fourche River at Wyoming-South Dakota State line	444459	1040249	582
06429000	Belle Fourche River at Belle Fourche, SD	444030	1035120	1
06429920	Bear Gulch near Maurice, SD	442514	1040226	27
06429997	Murray Ditch above headgate at Wyoming-South Dakota State line	443435	1040320	42
06430000	Murray Ditch at Wyoming-South Dakota State Line	443435	1040258	53
06430500	Redwater Creek at Wyoming-South Dakota State Line	443426	1040254	345
06430520	Beaver Creek near Maurice, SD	442257	1040013	27
06430525	McNenny State Fish Hatchery rearing pond outlet near Beulah, WY	443330	1040034	173
06430528	McNenny State Fish Hatchery viewing pond outlet near Beulah, WY	443331	1040036	167
06430765	East Spearfish Creek near Lead, SD	441744	1035210	73
06430865	Iron Creek near Lead, SD	442225	1035507	12
06430900	Spearfish Creek above Spearfish, SD	442406	1035340	102
06430910	Aqueduct Inlet below Maurice, SD	442432	1035352	1
06430950	Spearfish Creek below Robison Gulch, near Spearfish	442614	1035232	50

Table 16. Surface-water sampling sites summarized in this report—Continued

Station identification	Site Name	Latitude	Longitude	Number of valid samples
		(degree, minutes, seconds)		
	Other sites—Continued			
06431500	Spearfish Creek at Spearfish, SD	442857	1035140	235
06432020	Spearfish Creek below Spearfish, SD	443448	1035337	93
06432172	False Bottom Creek near Central City, SD	442328	1034758	10
06432180	False Bottom Creek near Spearfish, SD	442709	1034822	9
06432500	Redwater Canal at Minnesela, SD	443900	1034800	1
06432900	Redwater River above Willow Creek, at Belle Fourche, SD	443828	1034919	6
06433000	Redwater River above Belle Fourche, SD	444002	1035020	245
06434496	Crow Creek near Belle Fourche, SD	444229	1035101	3
06434500	Inlet Canal near Belle Fourche, SD	444214	1034923	563
06436000	Belle Fourche River near Fruitdale, SD	444127	1034414	297
06436100	Belle Fourche River Below Nisland, SD	444012	1032930	3
06436250	Belle Fourche River at Vale, SD	443810	1032537	50
06436800	Horse Creek near Vale, SD	443930	1032017	263
06436850	North Canal near Fruitdale, SD	444412	1034019	4
06437020	Bear Butte Creek near Deadwood, SD	442008	1033806	100
06437200	Bear Butte Creek near Galena, SD	442348	1033436	5
06437400	Bear Butte Creek at Sturgis, SD	442444	1032910	10
	Additional sites used for basin or mining-related comparisons			
06421500	Rapid Creek near Farmingdale, SD	435631	1025112	265
442125103483000	South Deadwood Creek above Hidden Treasure Mine, near Lead, SD	442125	1034830	1
442131103482000	Deadwood Creek below Hidden Treasure Mine, near Lead, SD	442131	1034820	1
442213103443900	Deadwood Creek below Broken Boot Mine, at Deadwood, SD	442213	1034439	1
442250103485700	Southeast False Bottom Creek near Lead, SD	442250	1034857	1
442251103493800	False Bottom Creek above Columbia Mine, near Lead, SD	442251	10349381	1