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. $\mu S/cm$, microsiemens per centimeter at 25 degrees Celsius; $\mu g/L$, micrograms per liter; mL, milliliters; ^{o}F, degrees Fahrenheit; ^{o}C, degrees Celsius; $\geq$, greater than or equal to; —, no data available]

Property or constituent	Beneficial-use criteria[1]										Aquatic-life criteria for fisheries[1] (acute/ chronic) ($\mu g/L$)
	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)

[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.

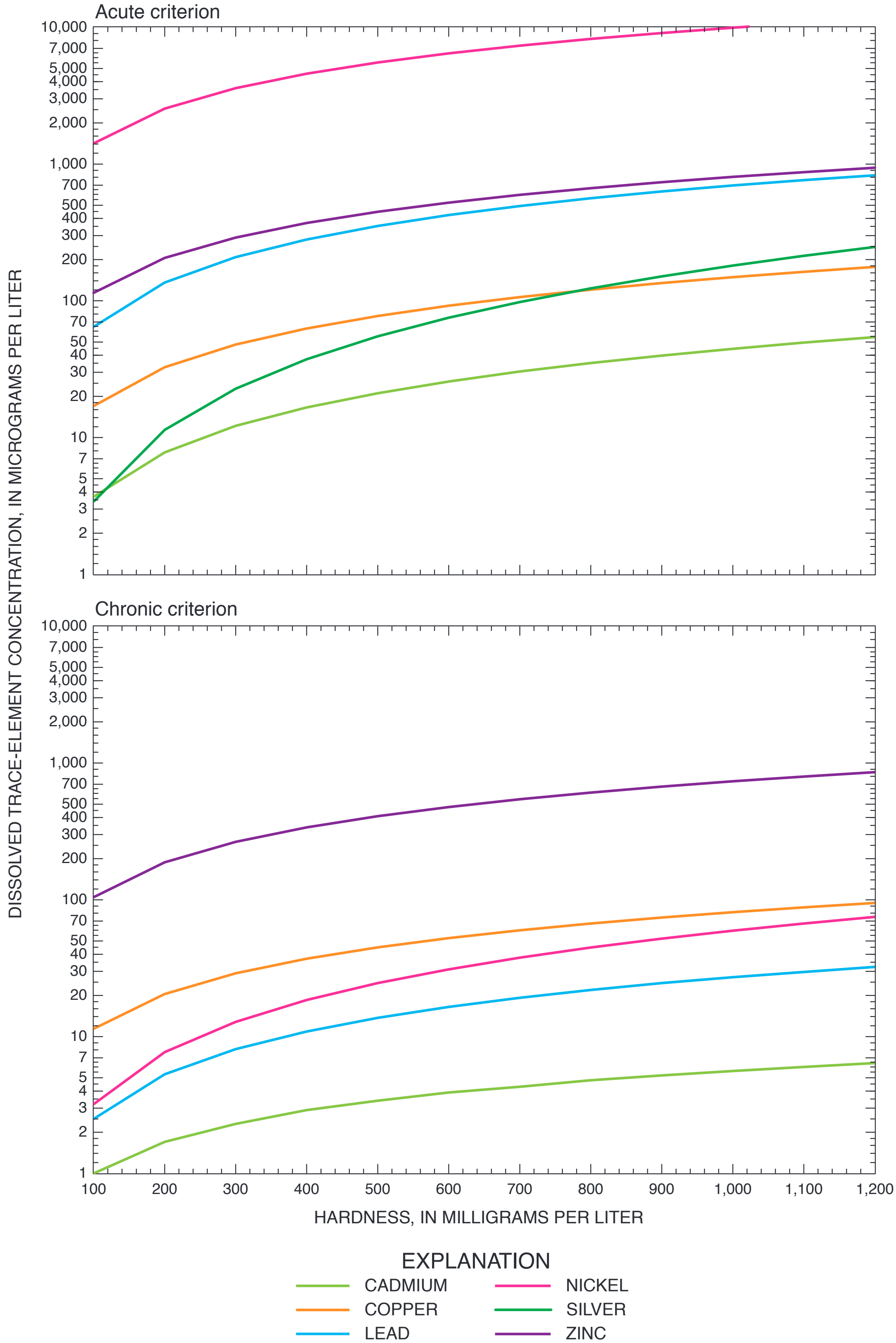


Figure 8. Relations between water hardness and freshwater aquatic-life standards for acute and chronic toxicity of selected trace elements (South Dakota Department of Environment and Natural Resources, 1998a).

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

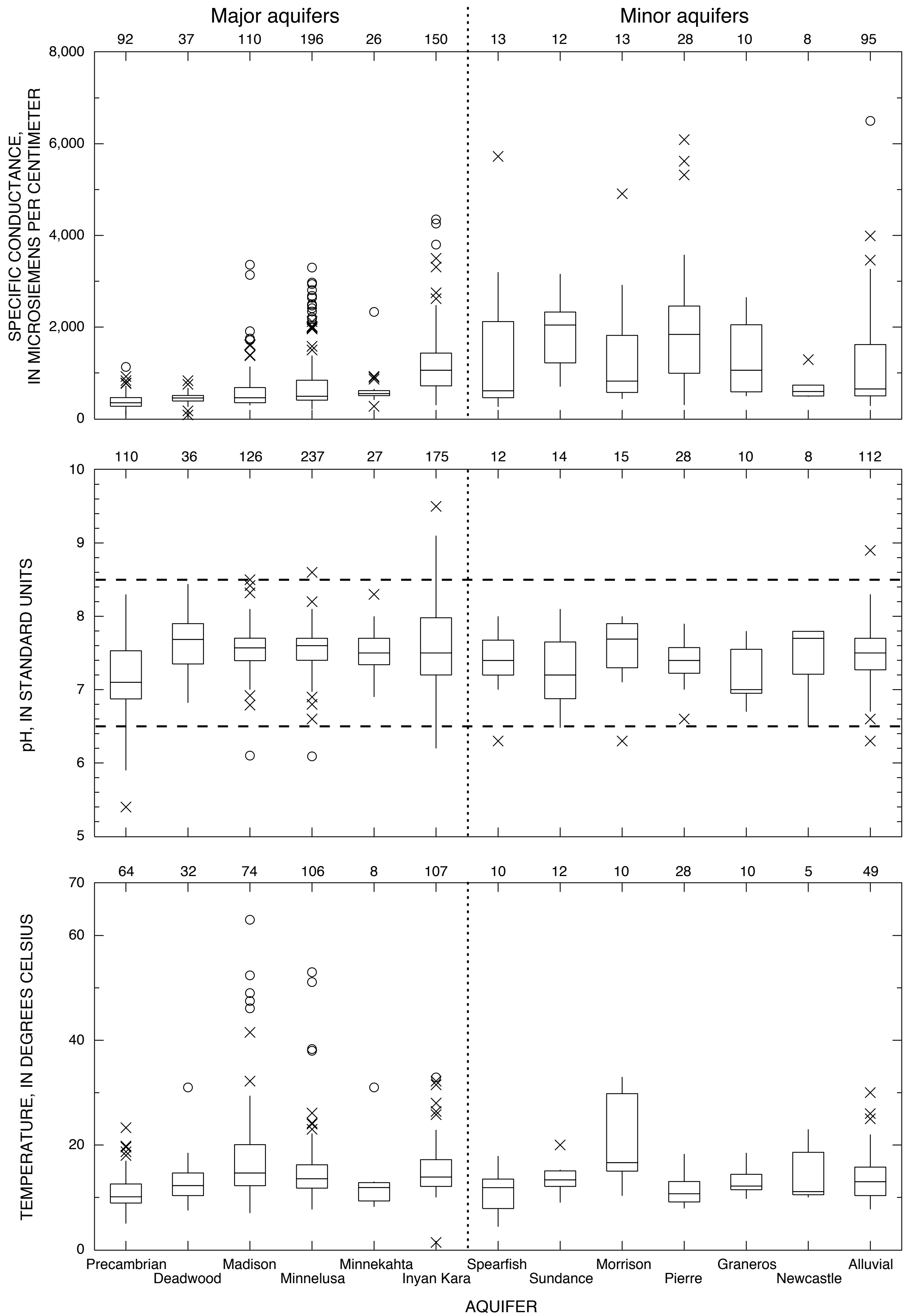


Figure 9. Boxplots of physical properties for selected aquifers.

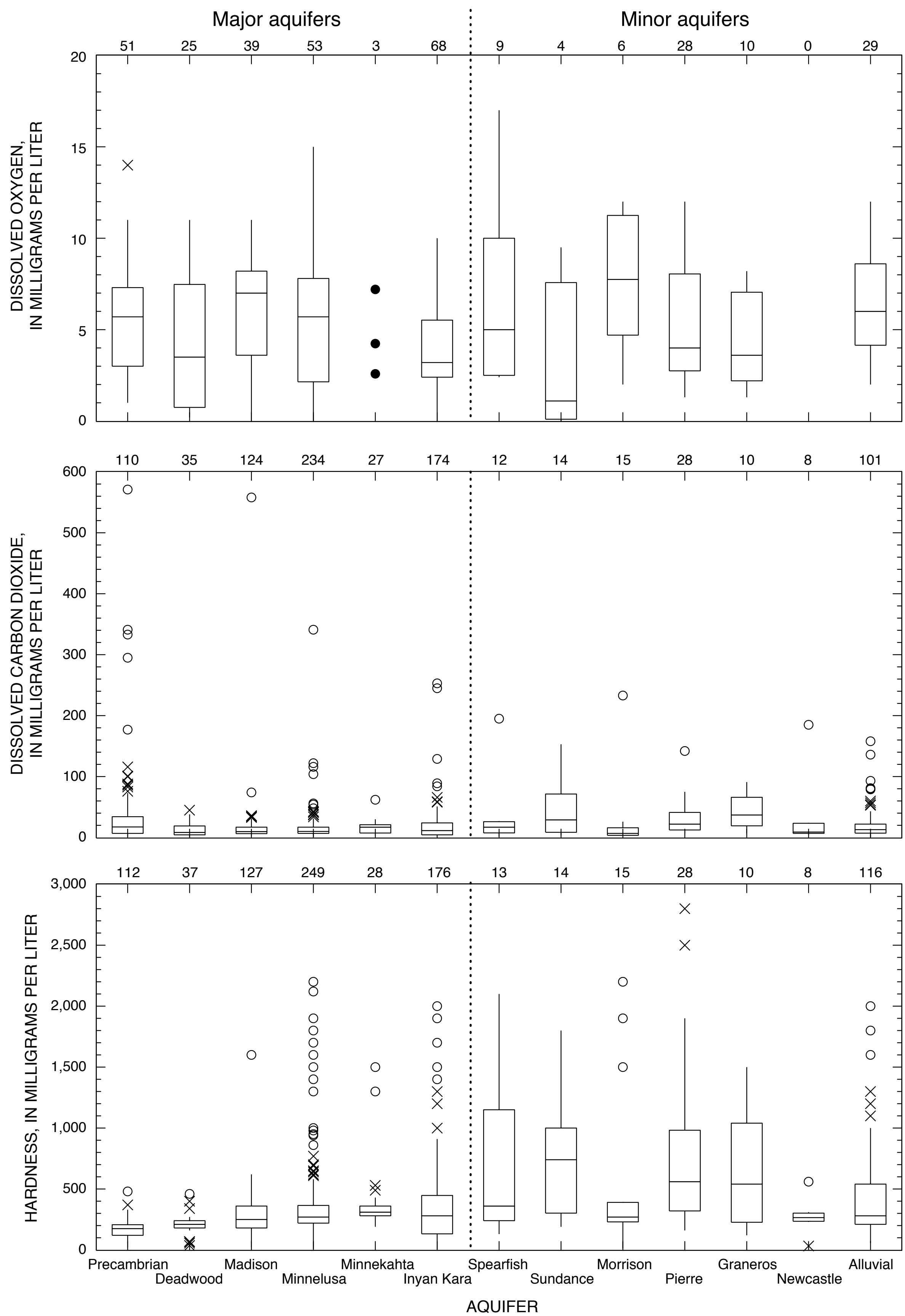
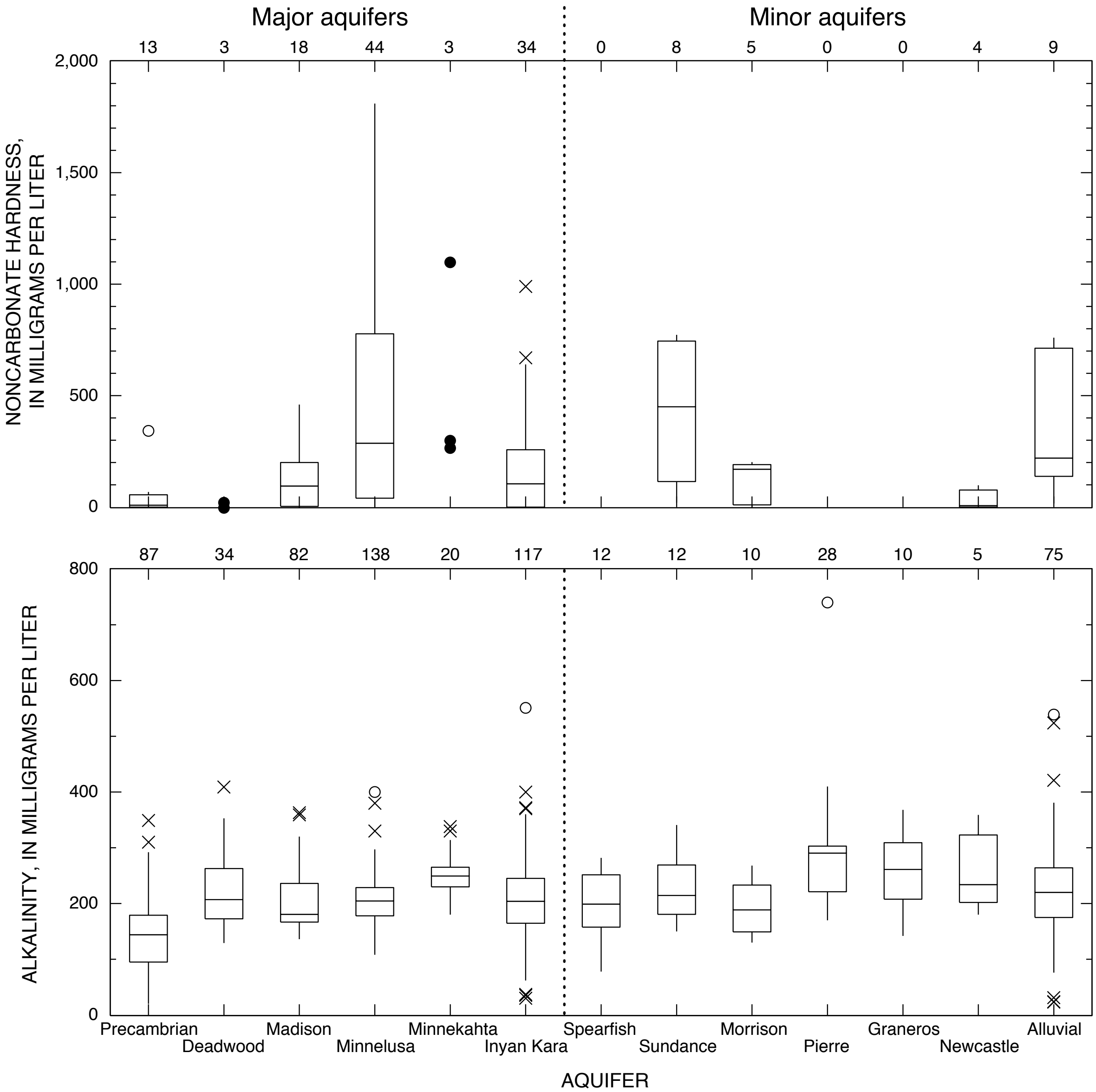


Figure 9. Boxplots of physical properties for selected aquifers.--Continued



EXPLANATION

12 Number of samples

○ 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

Data value less than or equal to 1.5 times the interquartile range outside the quartile

75th percentile

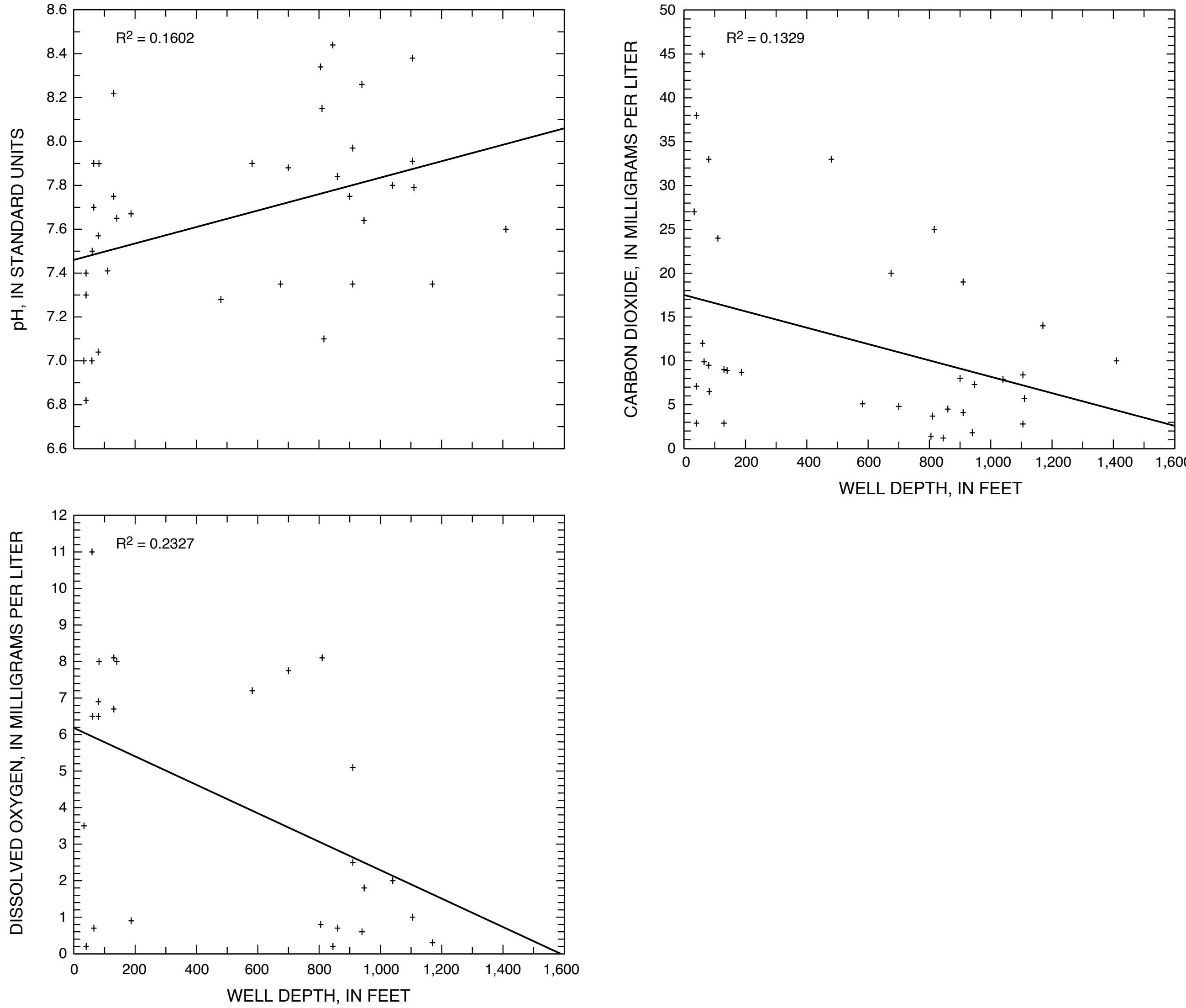
Median

25th percentile

● Single sample

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

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.

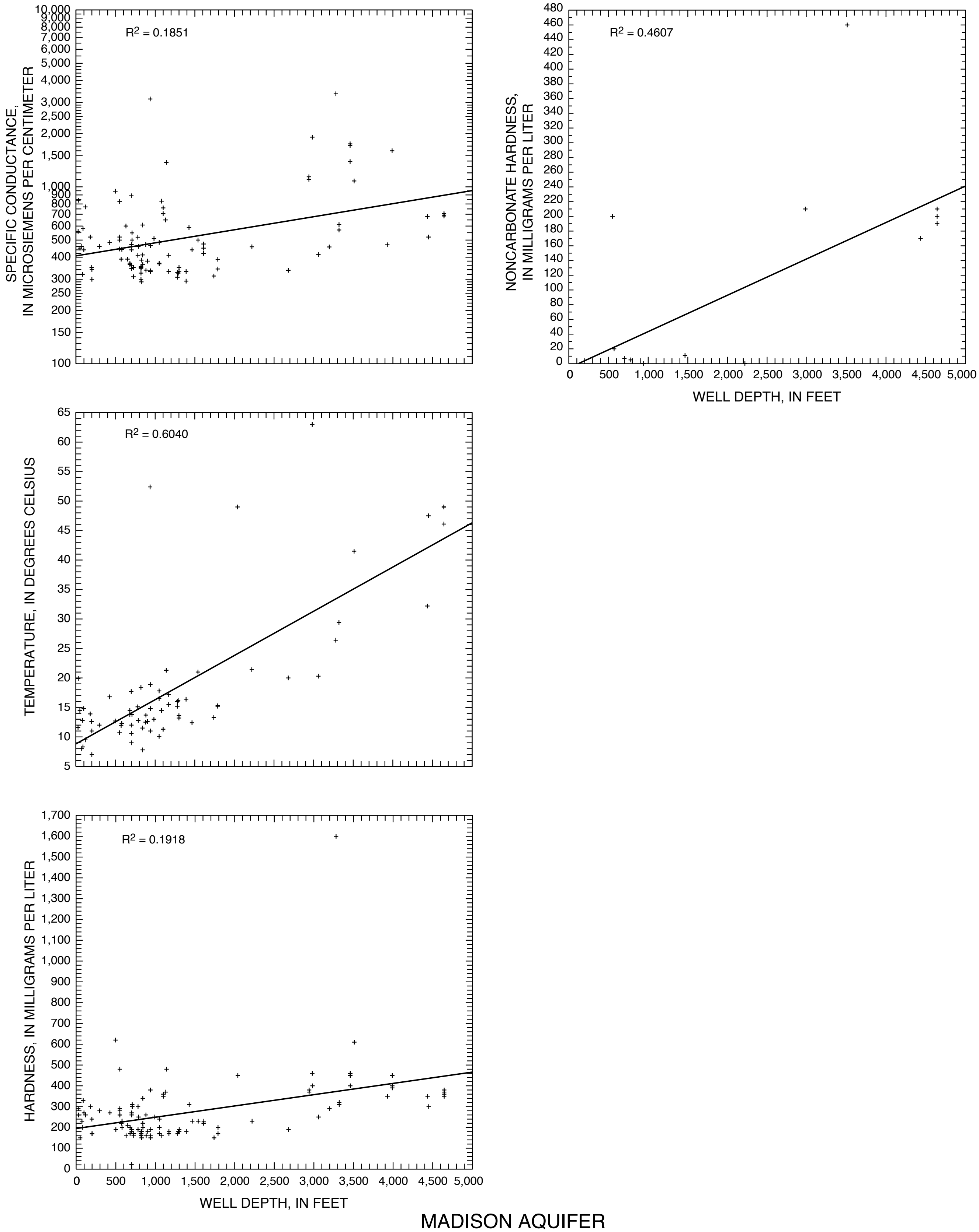
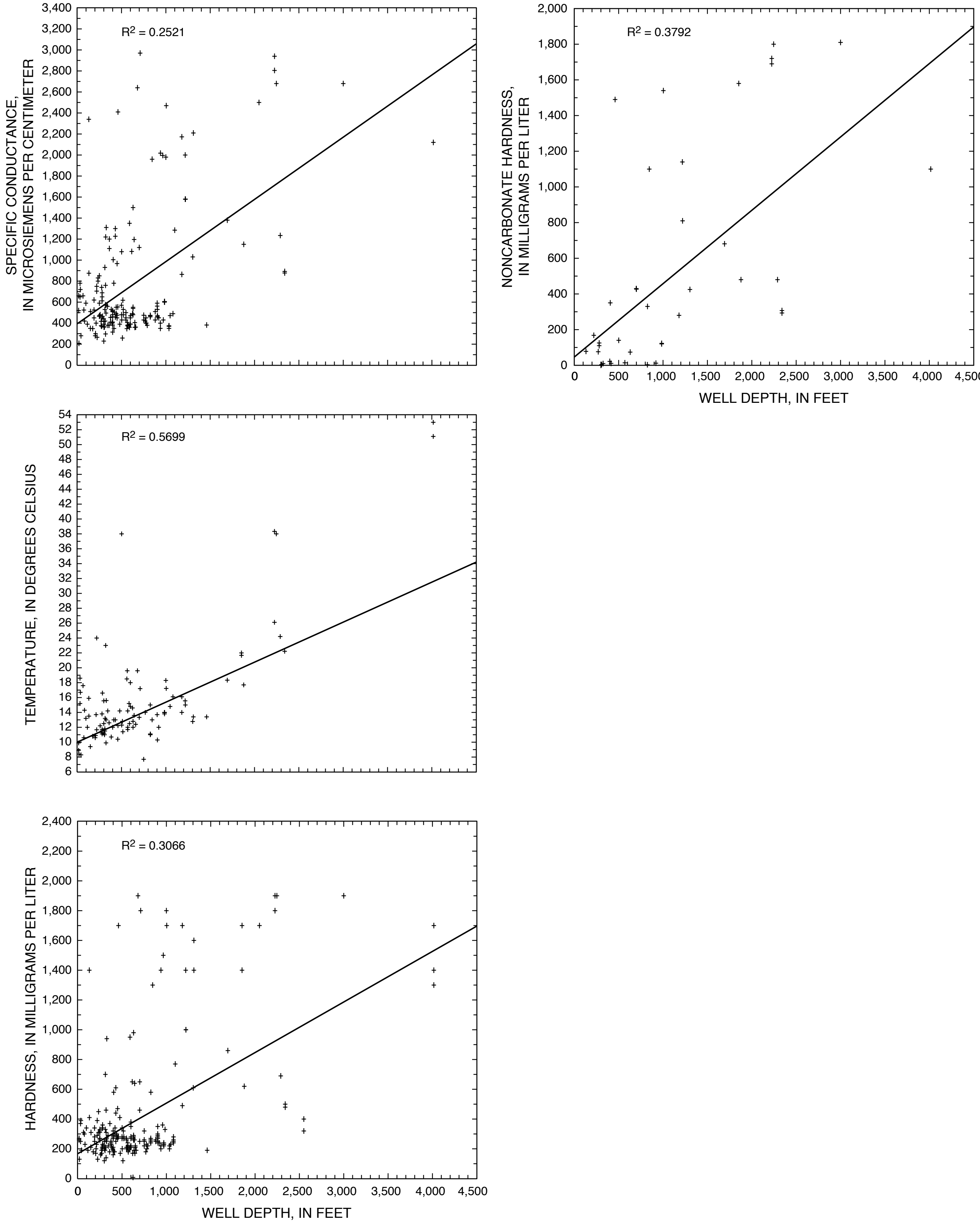


Figure 10. Selected relations between physical properties and well depth for selected aquifers.--Continued



MINNELUSA AQUIFER

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

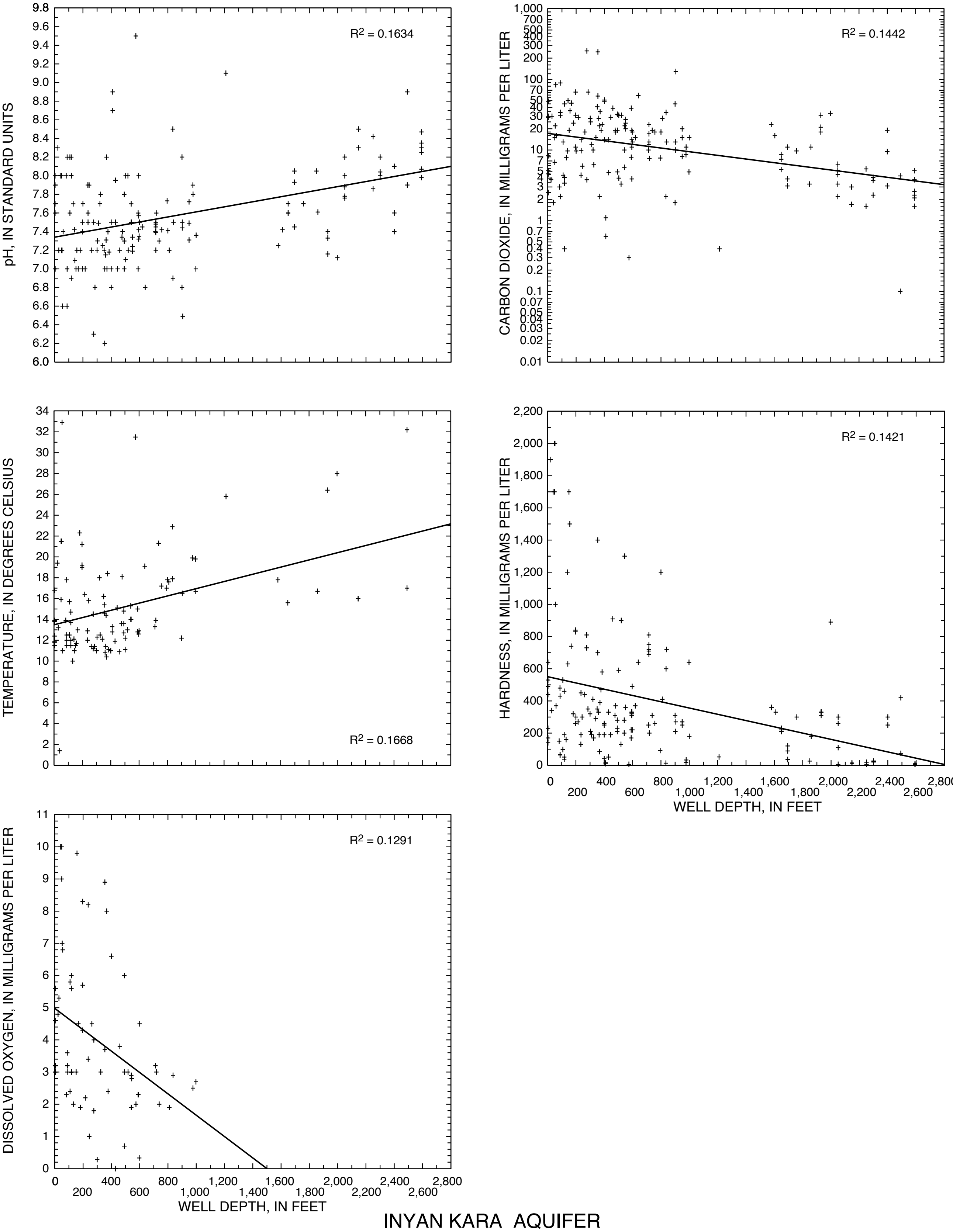


Figure 10. Selected relations between physical properties and well depth for selected aquifers.--Continued

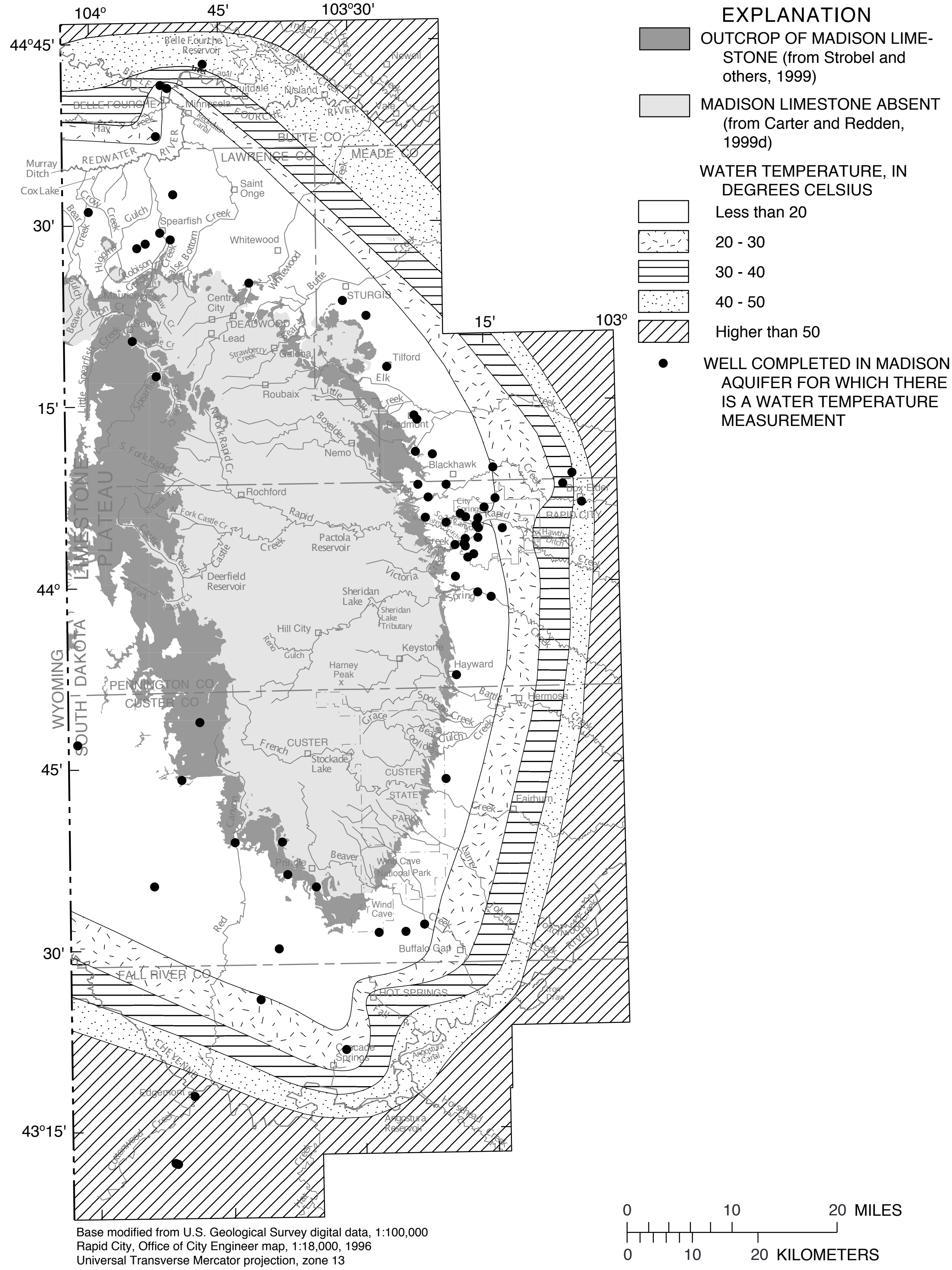


Figure 11. Distribution of water temperature in the Madison aquifer.

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.

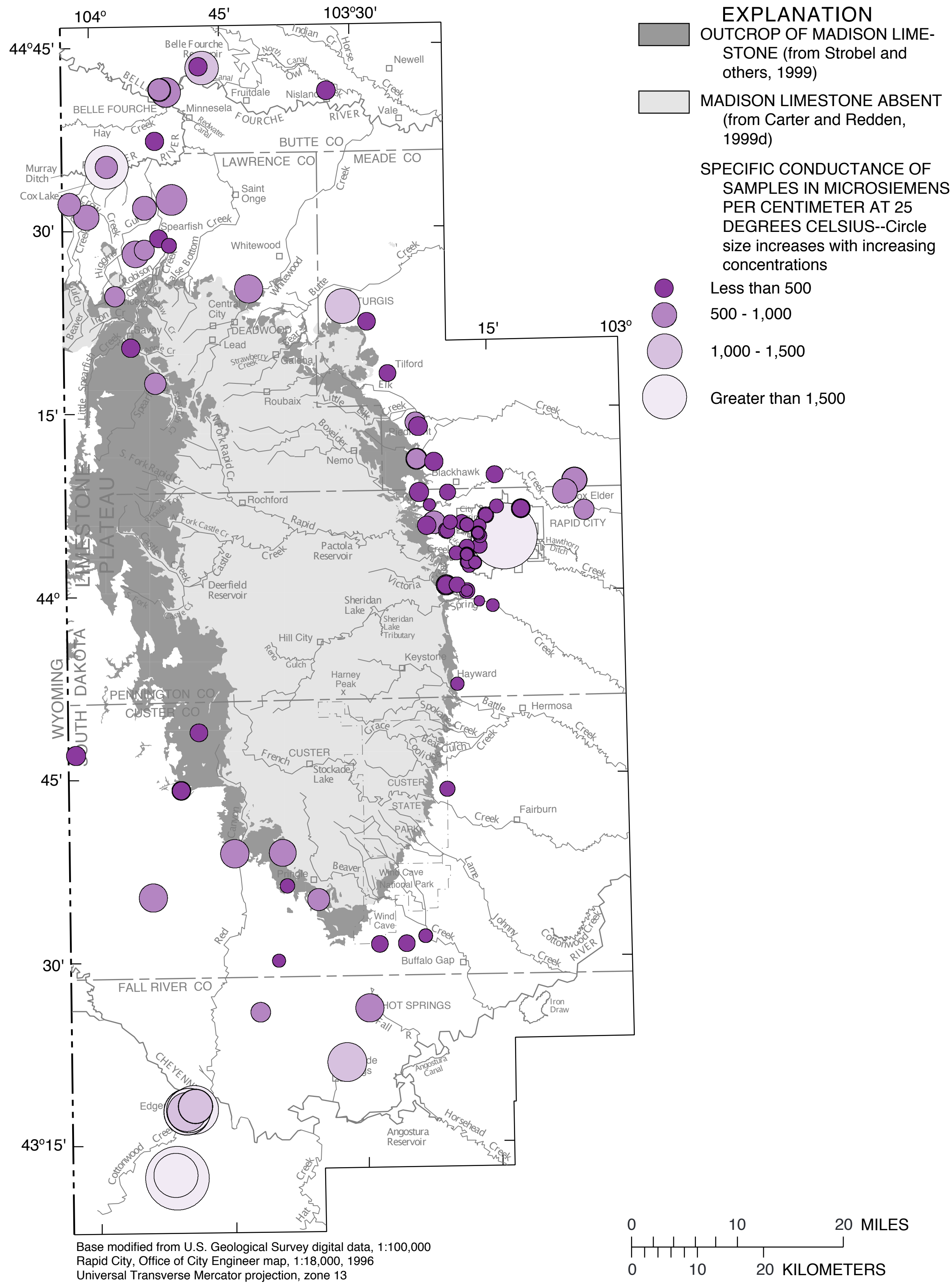


Figure 12. Distribution of specific conductance in the Madison aquifer.

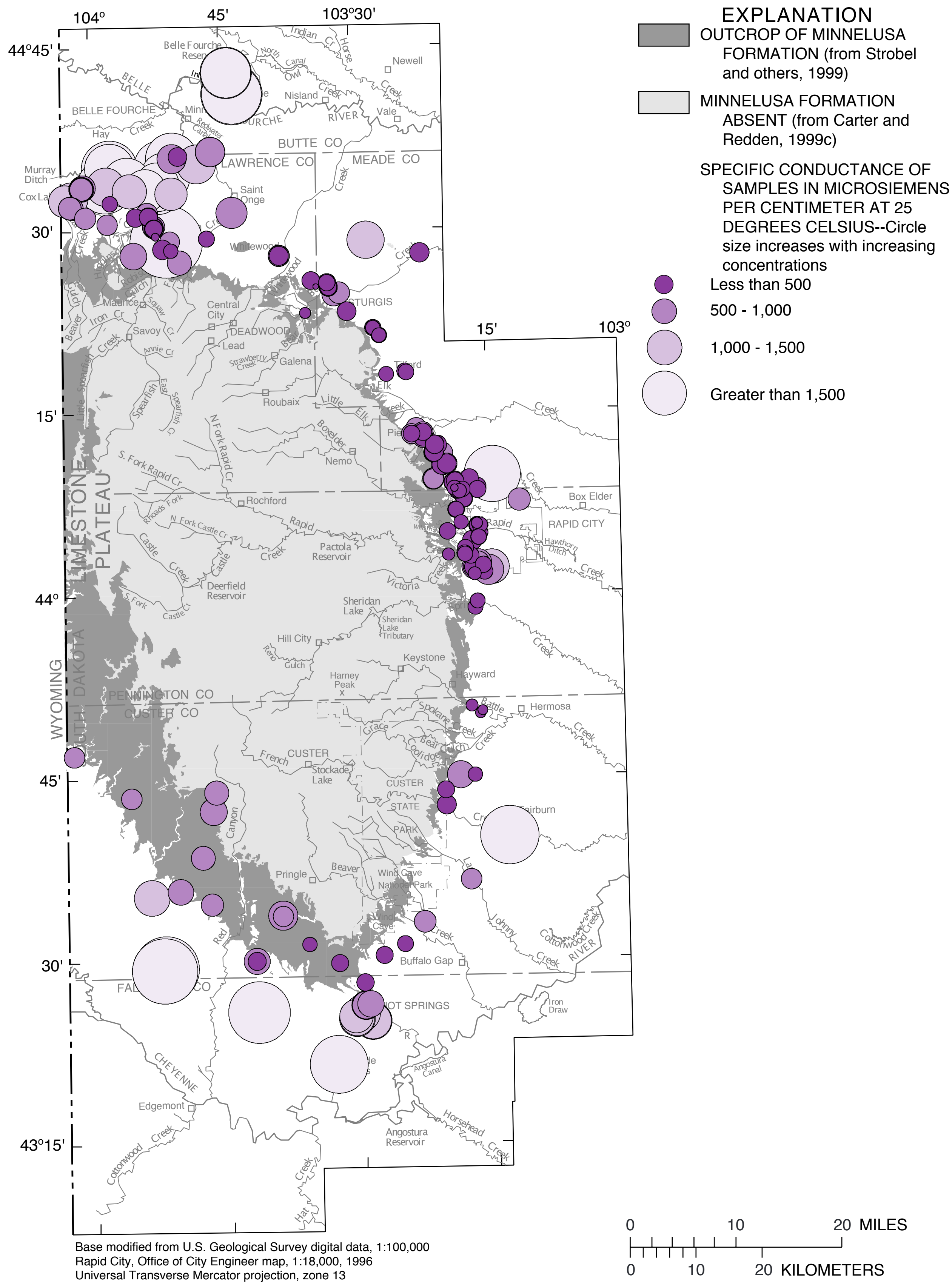


Figure 13. Distribution of specific conductance in the Minnelusa aquifer.

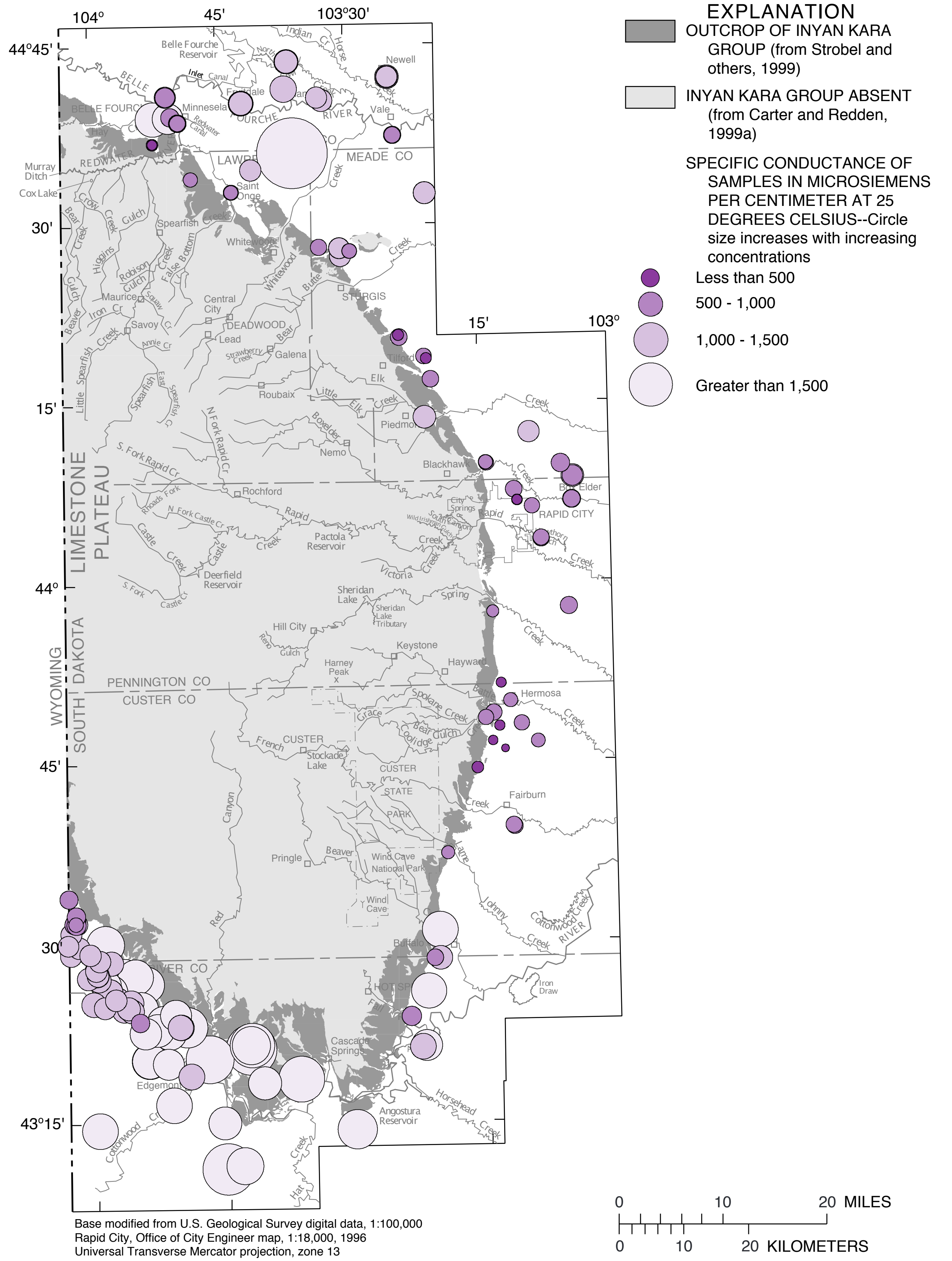


Figure 14. Distribution of specific conductance in the Inyan Kara aquifer.

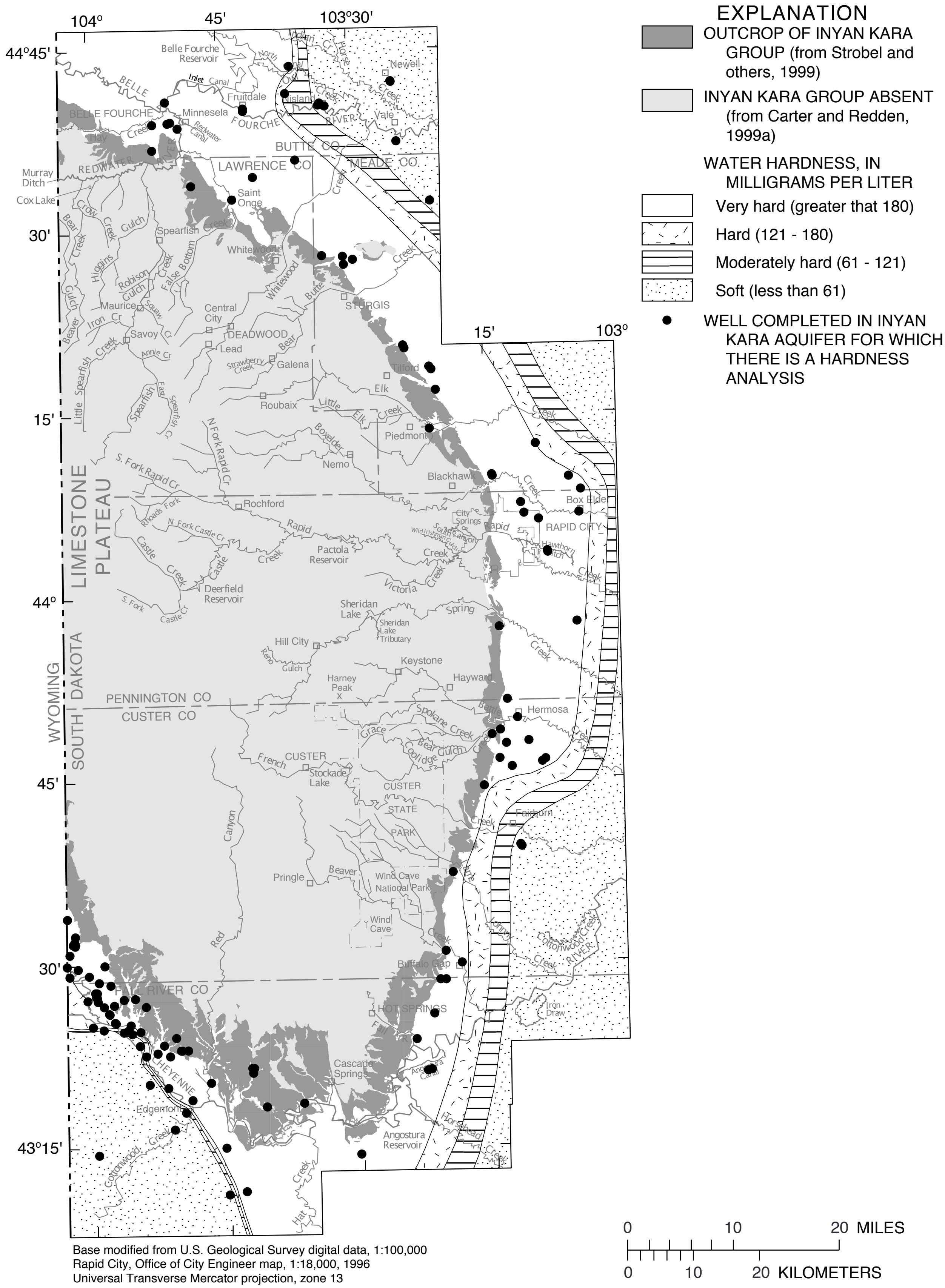


Figure 15. Distribution of hardness in the Inyan Kara aquifer.