Table 4. Water-quality criteria, standards, or recommended limits for selected properties and constituents

[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; 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	Standard	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, 1985).
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.

Table 4. Water-quality criteria, standards, or recommended limits for selected properties and constituents–Continued

[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; 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	Standard	Significance
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.
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).
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 to pregnant women, children, and the elderly.
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 to pregnant women, children, and the elderly.
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.
Phosphorus, orthophosphate	--	Dense algal 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.
Arsenic	[1]10 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 can 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.
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 percent 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.

Table 4. Water-quality criteria, standards, or recommended limits for selected properties and constituents–Continued

[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; 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	Standard	Significance
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).
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.
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.
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.

Table 4. Water-quality criteria, standards, or recommended limits for selected properties and constituents–Continued

[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; 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	Standard	Significance
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 emits 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, 1985).
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). Ingested 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, 1985).
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 (^{3}H) (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 12.4 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	30 µg/L MCL (under review)	Uranium is a chemical and radiological hazard and carcinogen. It emits 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]USEPA currently is implementing a revised MCL for arsenic from 50 to 10 µg/L; public-water systems must meet the revised MCL by January 2006 (U.S. Environmental Protection Agency, 2001).

[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).

General Characteristics for Major Aquifers

A summary of water-quality characteristics from Williamson and Carter (2001) for the major aquifers in the study area (Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers) is presented in this section. Characteristics for the Precambrian aquifer also are included in this section because numerous wells are completed in this aquifer in the crystalline core of the Black Hills.

Most pH values for the major aquifers are within the specified range for the SMCL (6.5 to 8.5 standard units). About 13 percent of the samples from wells completed in Precambrian rocks had pH values less than the lower limit specified for the SMCL, which indicates acidity. In general, pH values are lower in wells completed in Precambrian rocks than in the other major aquifers, which is indicative of a unit containing little carbonate material.

Water temperatures generally increase with well depth. The deepest wells in the study area are completed in the Madison aquifer; thus, measured temperatures in the Madison aquifer generally are the warmest of the major aquifers. The Madison aquifer is the primary source of water to warm artesian springs in the southern Black Hills, where water temperatures may be influenced by factors other than aquifer depth (Whalen, 1994).

Williamson and Carter (2001) quantified relations between dissolved solids and specific conductance concentrations for the major aquifers. The r^2 (coefficient of determination) values are high for all of the major aquifers (fig. 31); thus, the equations provided could be used confidently for estimating dissolved solids concentrations from specific conductance measurements.

Specific conductance generally is low in water from the Precambrian, Deadwood, and Minnekahta aquifers. Dissolved constituents tend to increase with residence time as indicated by the general increase in specific conductance in the Madison aquifer with distance from the outcrop (fig. 32). Generally, water from the Inyan Kara aquifer is high in specific conductance even in some outcrop areas and is higher in specific conductance than the other major aquifers due to greater amounts of shale within the Inyan Kara Group. Water obtained from shales may contain rather high concentrations of dissolved solids (Hem, 1985) and, hence, high specific conductance.

Geologic units that contain little carbonate material, such as the Precambrian rocks, generally contain water with lower carbonate hardness and alkalinity than geologic units that are composed primarily of carbonate rocks. Water in the Madison, Minnelusa, and Minnekahta aquifers generally is hard to very hard because these units consist primarily of carbonate rocks. Water in the Deadwood aquifer also is hard to very hard because this unit consists primarily of sandstone with a calcium carbonate cement. The Inyan Kara aquifer may yield soft water, with hardness generally decreasing with increasing distance from the outcrop (fig. 33). Although concentrations of dissolved solids in the Inyan Kara aquifer actually increase with increasing distance from the outcrop, hardness decreases because calcium and bicarbonate are replaced by sodium and sulfate as water moves downgradient.

In the Black Hills area, water from the major aquifers generally is low in dissolved solids in and near outcrop areas. The Madison, Minnelusa, and Inyan Kara aquifers may yield slightly saline water (dissolved solids concentrations between 1,000 and 3,000 mg/L) at distance from the outcrops, especially in the southern Black Hills. The water in these aquifers generally is highly mineralized outside of the Black Hills area, as previously described and shown in figure 17 for aquifers in the Paleozoic units.

Many of the major aquifers yield a calcium bicarbonate type water in and near outcrop areas, with concentrations of sodium, chloride, and sulfate increasing with distance from outcrops. High concentrations of sodium, chloride, and sulfate occur in the Madison aquifer (fig. 34) in the southwestern part of the study area relative to the rest of the study area. These high concentrations could be due to long residence times, long flowpaths associated with regional flow from the west (Wyoming), or greater amounts of evaporite minerals, such as anhydrite and gypsum, available for dissolution (Naus and others, 2001). In the southern part of the study area, the common-ion chemistry of the water in the Minnelusa aquifer also is characterized by higher concentrations of sodium and chloride (fig. 35). The high chloride concentrations in this area could reflect hydraulic connection between the Madison and Minnelusa aquifers (Naus and others, 2001). The dissolution of evaporite minerals and long residence time also are possible explanations for the occurrence of this water type in the Minnelusa aquifer (Naus and others, 2001).

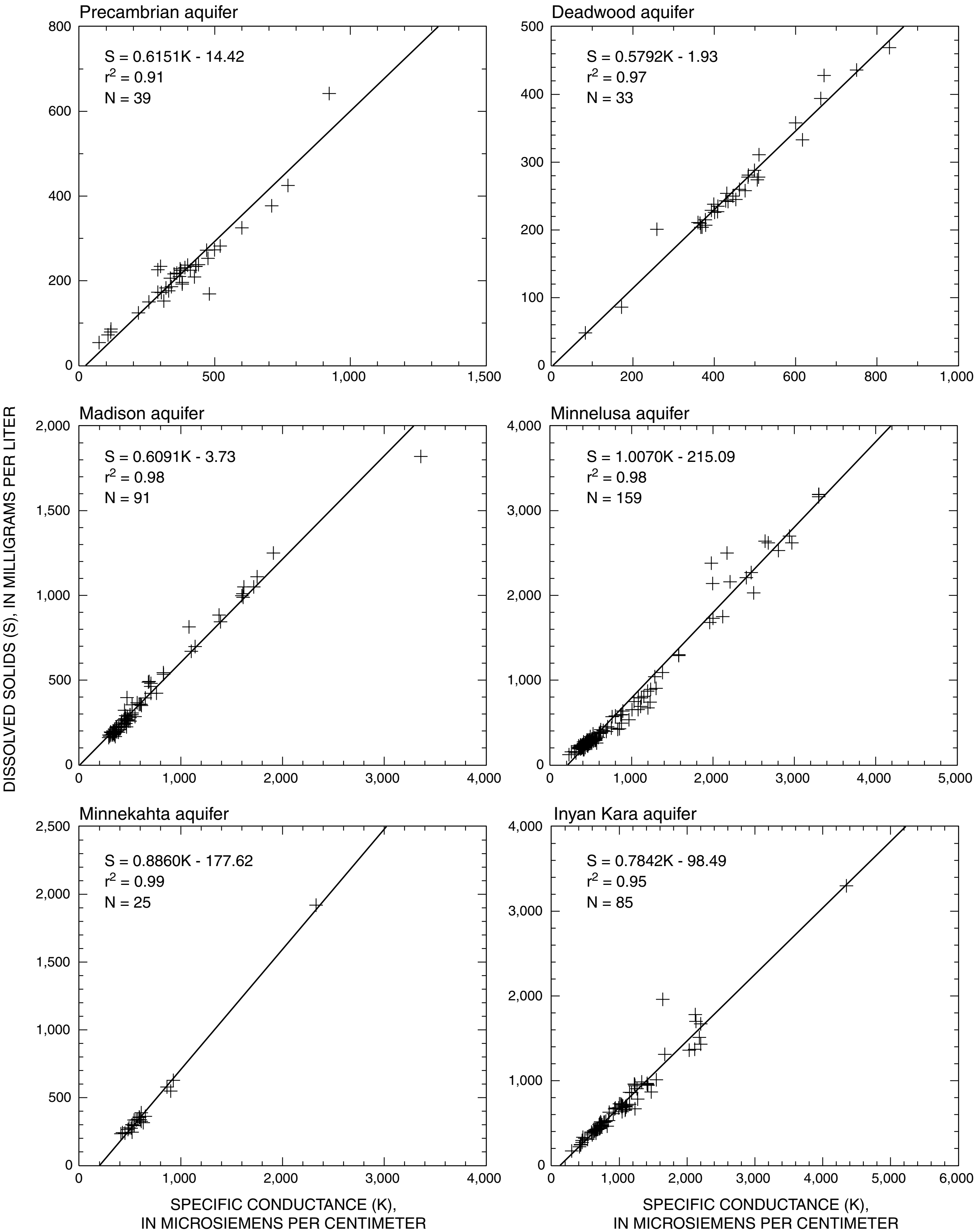

Figure 31. Relations between dissolved solids and specific conductance for the major aquifers.

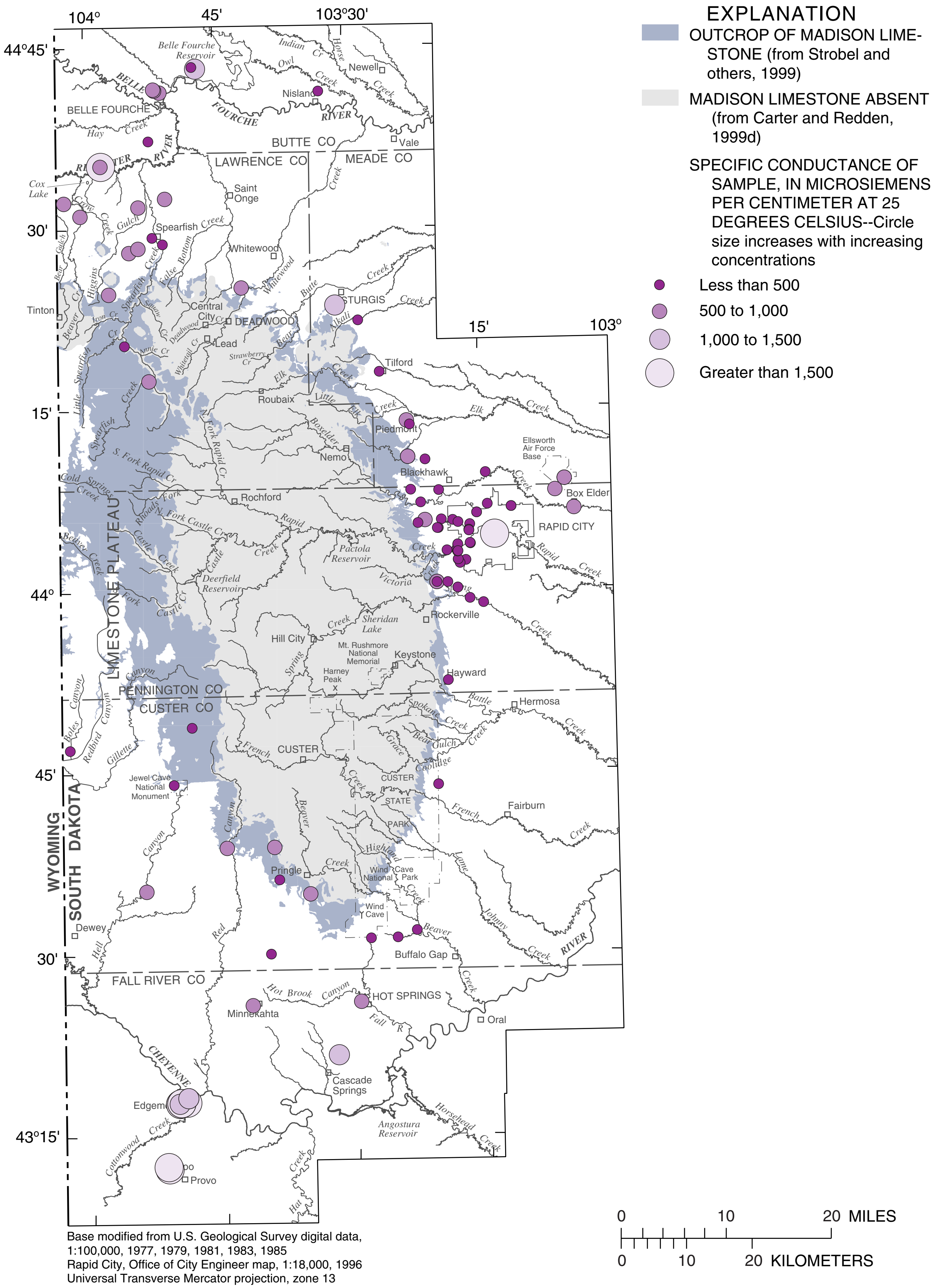

Figure 32. Distribution of specific conductance in the Madison aquifer (modified from Williamson and Carter, 2001).

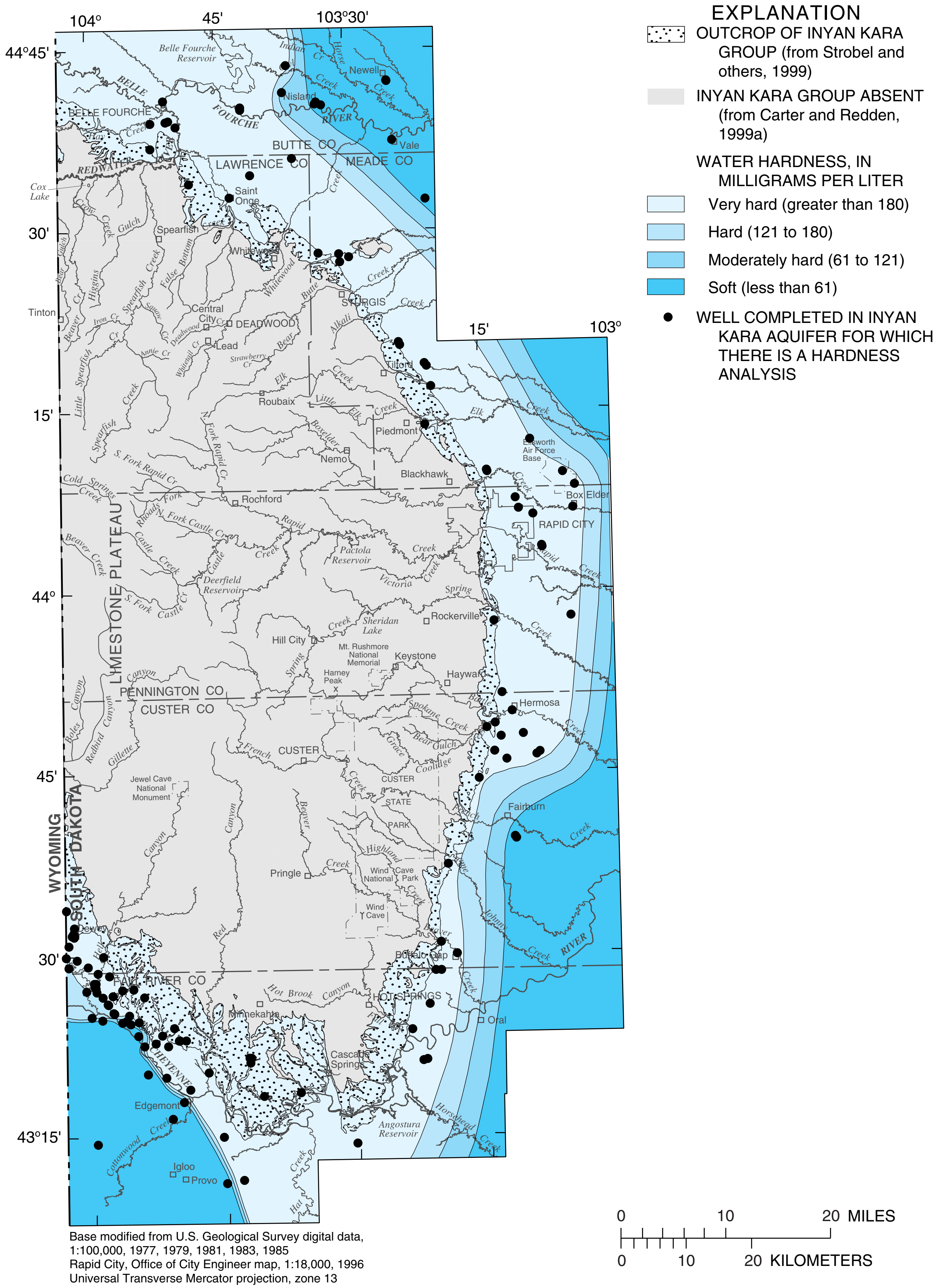

Figure 33. Distribution of hardness in the Inyan Kara aquifer (modified from Williamson and Carter, 2001).

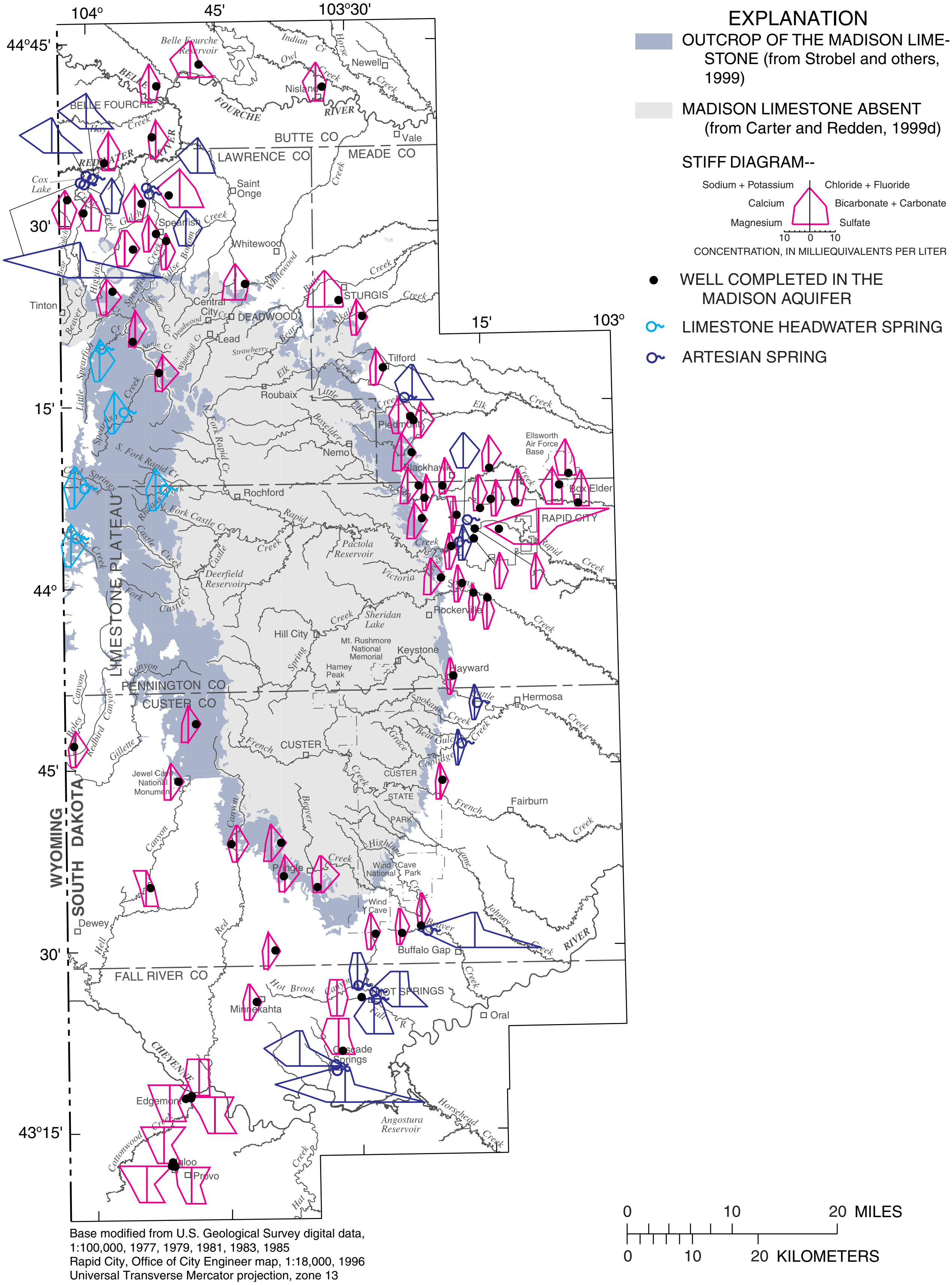

Figure 34. Stiff diagrams (Stiff, 1951) showing the distribution of common-ion chemistry in the Madison aquifer (from Naus and others, 2001).

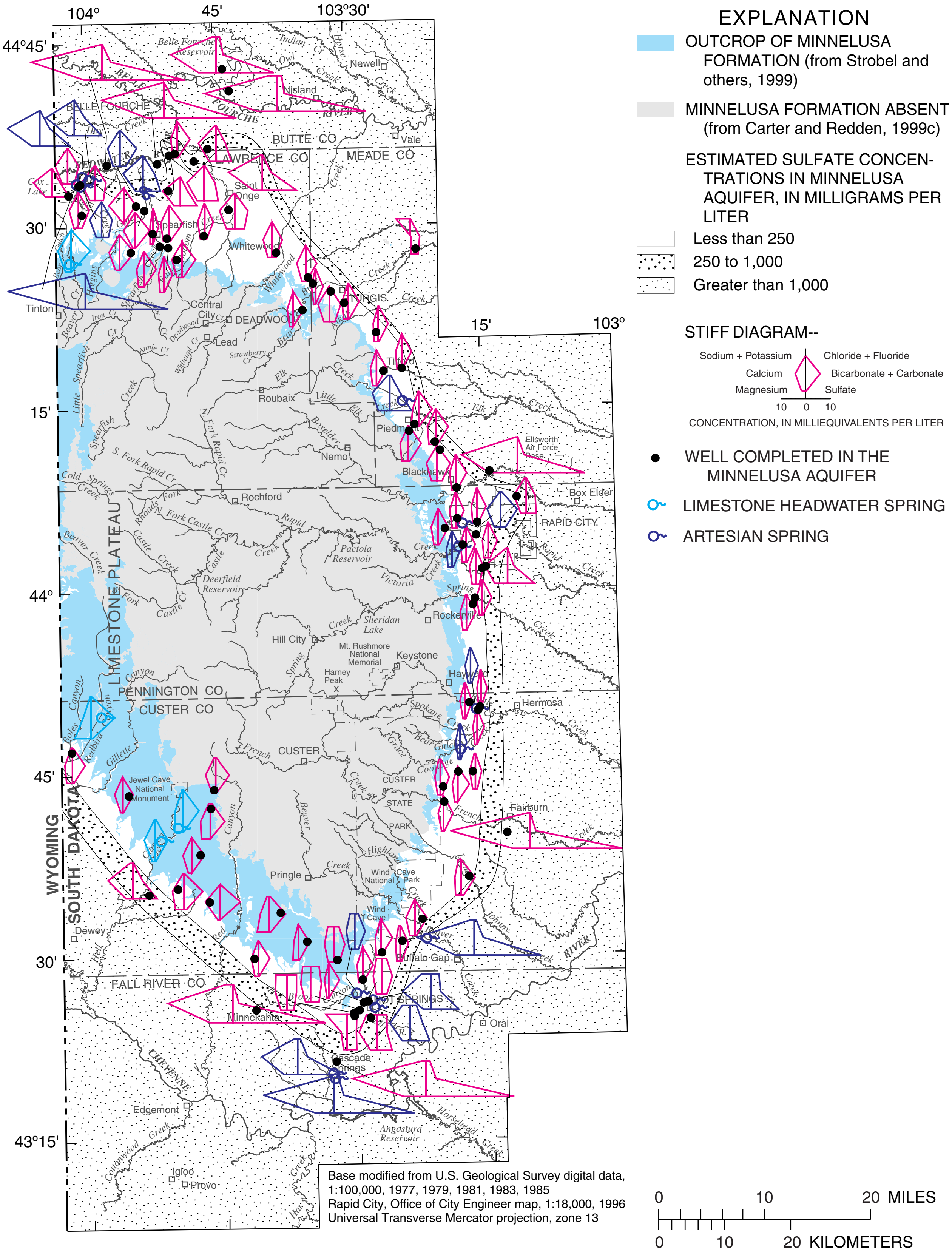

Figure 35. Stiff diagrams (Stiff, 1951) showing the distribution of common-ion chemistry in the Minnelusa aquifer. Approximation location of anhydrite dissolution front showing transition between low and high sulfate concentrations also is shown (from Naus and others, 2001).

Sulfate concentrations in the Minnelusa aquifer are dependent on the amount of anhydrite present in the Minnelusa Formation. Near the outcrop, sulfate concentrations generally are low (less than 250 mg/L) because anhydrite has been removed by dissolution. An abrupt increase in sulfate concentrations occurs downgradient, where a transition zone surrounds the core of the Black Hills. This transition zone is the area within which the sulfate concentrations range from 250 to 1,000 mg/L (fig. 35) and marks an area of active removal of anhydrite by dissolution. Downgradient from the transition zone, sulfate concentrations are greater than 1,000 mg/L, which delineates a zone in which thick anhydrite beds remain in the formation. The transition zone probably is shifting downgradient over geologic time as the anhydrite in the formation is dissolved (Kyllonen and Peter, 1987).

Figures 34 and 35 also show Stiff diagrams (Stiff, 1951) for artesian springs in the Black Hills area, most of which probably originate from the Madison and/or Minnelusa aquifers (Naus and others, 2001). Artesian springs with high sulfate concentrations probably are influenced by anhydrite in the Minnelusa Formation. Artesian springs with low sulfate concentrations occur only upgradient from the transition zone (fig. 35). Additional discussions regarding potential sources of artesian springs are presented in subsequent sections of the report.

Concentrations and variability of many trace elements are small in the major aquifers. Strontium generally has higher concentrations than other trace elements, but is not harmful. Similarly, barium, boron, iron, manganese, lithium, and zinc concentrations also may be high in comparison to other trace elements.

Most naturally occurring radionuclides in water are the result of radioactive decay of uranium-238, thorium-232, and uranium-235, with uranium-238 producing the greatest part of the radioactivity observed (Hem, 1985). In general, gross alpha-particle activity, gross-beta activity, and radium-226 concentrations, are higher in the Deadwood and Inyan Kara aquifers than in the Madison, Minnelusa, and Minnekahta aquifers.

In the Deadwood aquifer, more than 30 percent of the samples analyzed for radium-226 or radium-226 and radium-228 exceeded the MCL of 5 pCi/L for the combined radium-226 and radium-228 standard. Almost 90 percent of the samples from the Deadwood aquifer exceeded the proposed MCL of 300 pCi/L for radon in States without an active indoor air program; several of these samples (fig. 36) also exceeded the proposed MCL of 4,000 pCi/L for radon in States with an active indoor air program. Samples from the Deadwood aquifer have lower uranium concentrations relative to the other major aquifers, which may be due to the reducing conditions of the Deadwood aquifer (Rounds, 1991).

Uranium deposits have been mined in the Inyan Kara Group in the southern Black Hills. Uranium may be introduced into the Inyan Kara Group through upward leakage of water from the Minnelusa aquifer (Gott and others, 1974). As water in the Inyan Kara aquifer migrates downgradient, geochemical conditions favor the precipitation of uranium (Gott and others, 1974). Some water from the Inyan Kara aquifer, especially in the southern Black Hills, contains relatively high concentrations of radionuclides. Almost 20 percent of the samples collected from the Inyan Kara aquifer exceeded the MCL for the combined radium-226 and radium-228 standard; all but one of these samples exceeding the MCL were from wells in the southern Black Hills. About 4 percent of the samples exceeded the MCL for uranium; all these samples exceeding the MCL were from wells located in the southern Black Hills.

General Characteristics for Minor Aquifers

Water-quality characteristics were summarized by Williamson and Carter (2001) for various minor aquifers. The minor aquifers in the study area include the Newcastle aquifer and alluvial aquifers. Local aquifers do exist in the various semiconfining and confining units. Water-quality data also were summarized for several of these local aquifers, which included the Spearfish, Sundance, Morrison, Graneros, and Pierre aquifers.

Relations between dissolved solids and specific conductance concentrations are presented in figure 37 for the minor aquifers with sufficient data, which include the Sundance, Morrison, Newcastle, and alluvial aquifers. The r^2 values are consistently high, indicating strong correlations for these aquifers.

Water in many of the minor aquifers can be very hard and high in dissolved solids concentrations. Most samples from the Sundance aquifer indicate slightly saline water. Sulfate concentrations also can be high in the minor aquifers, such as the Spearfish aquifer where high sulfate concentrations can result from dissolution of gypsum. Both dissolved solids and sulfate concentrations are low in the Newcastle aquifer. A variety of water types can occur within and among the minor

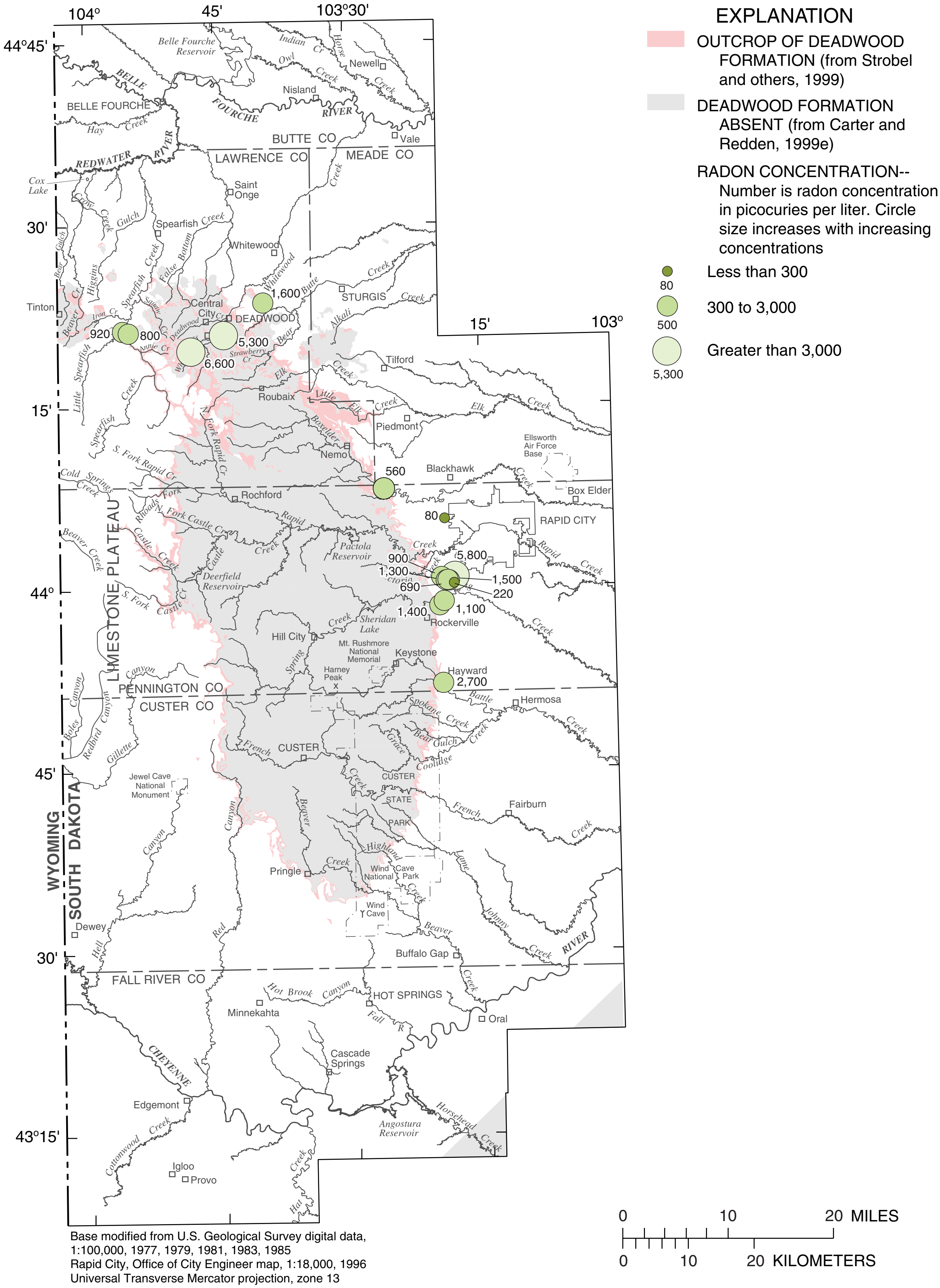

Figure 36. Distribution of radon concentrations in the Deadwood aquifer (from Williamson and Carter, 2001).

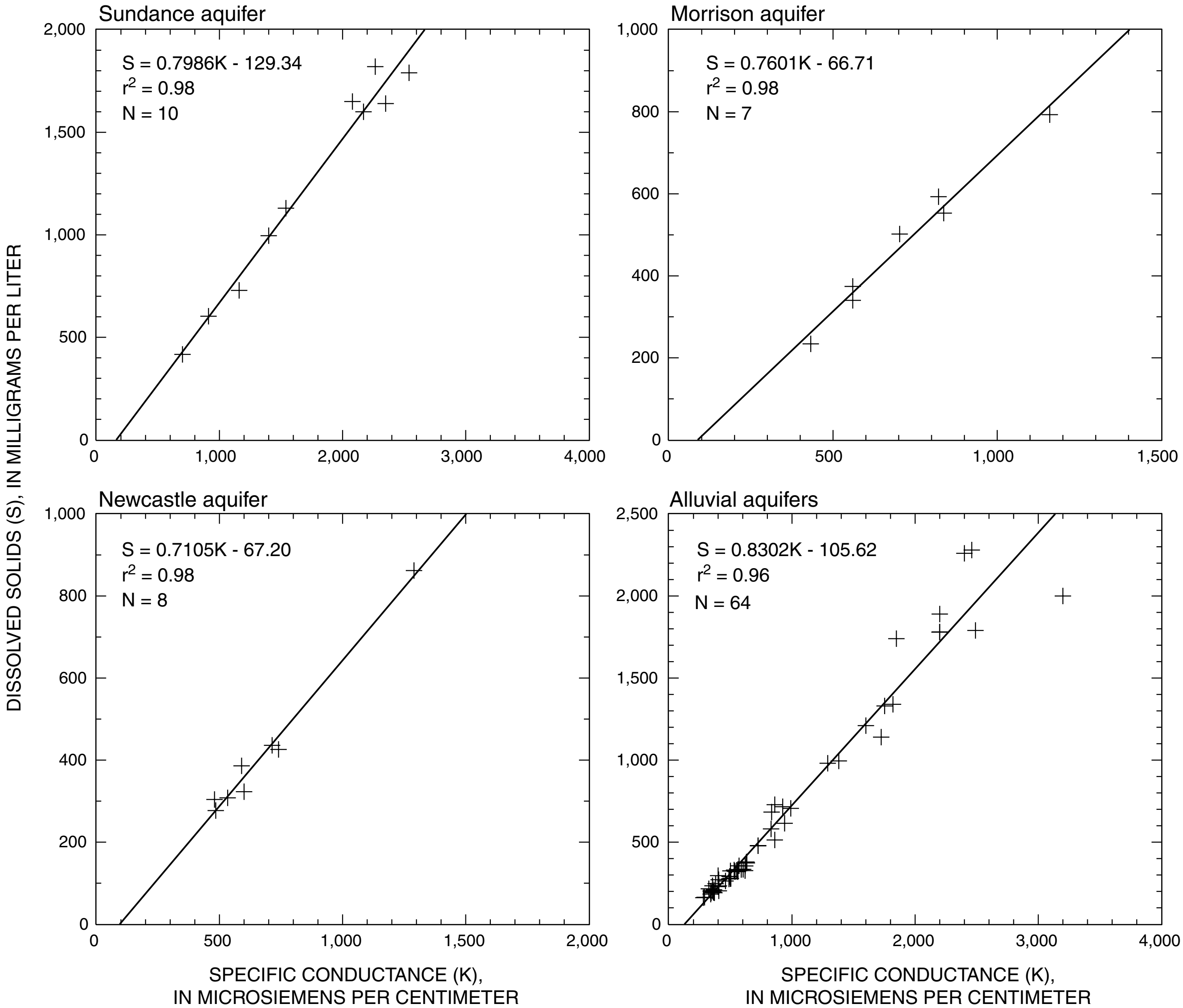

Figure 37. Relations between dissolved solids and specific conductance for the minor aquifers.

aquifers. In general, the dominance of sodium and sulfate increases with increasing amounts of shale present in the formations due to the large cation-exchange capabilities 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 geologic units. The Sundance aquifer has the highest selenium concentrations of all aquifers considered in this report.

Concentrations of common ions in alluvial aquifers generally increase with increasing distance from the core of the Black Hills, which is largely due to contact of the water with underlying geologic units and to the composition of alluvial deposits. Wells completed in alluvial deposits that do not overlie Cretaceous shales generally yield fresh water of a calcium bicarbonate or calcium magnesium bicarbonate type. Wells that are completed in alluvial deposits that overlie the Cretaceous shales generally yield slightly saline water in which sodium and/or sulfate is dominant. Water from alluvial aquifers may be high in uranium concentrations, especially in the southern Black Hills. About 17 percent of the samples exceeded the proposed MCL for uranium, and all samples exceeding this MCL were from wells in the southern Black Hills.

Susceptibility to Contamination

The Black Hills Hydrology Study focused primarily on determination of natural water-quality characteristics, and investigation of contamination potential was not an objective of the study. The susceptibility of the aquifers to contamination in the study area is an important issue, however, and can be addressed to some extent.

Nitrite plus nitrate concentrations for various aquifers (fig. 38) can provide a general indication of possible human influence. Although nitrogen is essential for plant growth, high concentrations of nitrite plus nitrate can cause excessive plant growth and can be harmful to livestock and humans. Excessive concentrations of nitrite plus nitrate in drinking water are a health concern for pregnant women, children, and the elderly (may cause methemoglobinemia (blue-baby syndrome) in small children). Nitrite plus nitrate in ground water can originate from natural processes or as contamination from nitrogen sources, such as fertilizers and sewage, on the land surface or in the soil zone. Nitrite plus nitrate concentrations for most samples in the Black Hills area generally are low (fig. 38); however, samples approaching or exceeding the national nitrate background concentration of 2.0 mg/L (U.S. Geological Survey, 1999) may provide indications of possible human influence in a variety of land-use settings. The extreme values for nitrite plus nitrate in figure 38 are unusually high and may reflect poor well construction and surface contamination as opposed to aquifer conditions.

The potential for contamination of ground water in the Black Hills area can be large because many aquifer outcrops can be subject to various forms of land development. Rapid ground-water velocities also are possible in many aquifers because of high secondary permeability. Contamination of ground water by septic tanks has been documented for wells in the Blackhawk, Piedmont, and Sturgis areas (Bartlett and West Engineers, Inc., 1998).

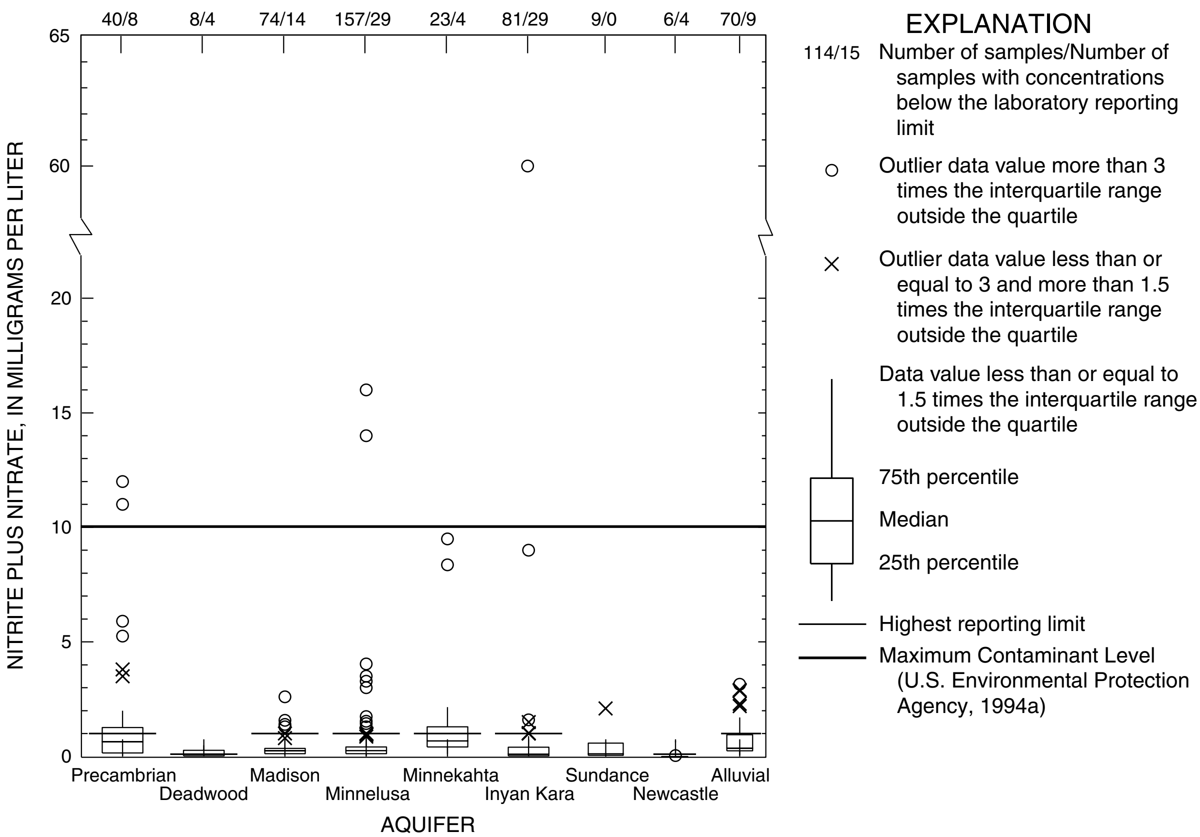

Figure 38. Boxplots of concentrations of nitrite plus nitrate for selected aquifers (modified from Williamson and Carter, 2001).

Maps showing sensitivity of ground water to contamination were produced by Putnam (2000) for Lawrence County and by Davis and others (1994) for the Rapid Creek Basin. The most sensitive hydrogeologic units are limestones, unconsolidated sands and gravels, and sandstones (Putnam, 2000). The least sensitive units include shales or units with interbedded shales. The Madison, Minnelusa, and Minnekahta aquifers are especially sensitive to contamination because of high secondary permeability and potential for streamflow recharge.

Summary Relative to Water Use

Concentrations of various constituents exceeding SMCL's and MCL's 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 affect the water only aesthetically. Radionuclide concentrations can be high in some of the major aquifers, especially in the Deadwood and Inyan Kara aquifers, and may 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 (SAR) and specific conductance, affect irrigation use.

The general suitability of ground water for irrigation in the study area can be determined by using the South Dakota irrigation-water diagram (fig. 39). 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. The adjusted SAR for each aquifer was calculated according to Koch (1983) from the mean concentrations of calcium, magnesium, sodium, and bicarbonate for each aquifer. 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.

High concentrations of iron and manganese occasionally can hamper the use of water from the Precambrian aquifer. None of the reported samples from the Precambrian aquifer exceeded drinking-water standards for radionuclides.

The principal deterrents to use of water from the Deadwood aquifer are 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 ft), concentrations of dissolved solids and sulfate also may deter use from this aquifer. Hot water from deep wells and in the Hot Springs area, may not be desirable for some uses. Radionuclide concentrations in the Madison aquifer generally are acceptable.

The principal properties or constituents that may hamper the use of water from the Minnelusa aquifer include hardness and high concentrations of iron and manganese. Generally, downgradient wells (generally deeper than 1,000 ft) also have high concentrations of dissolved solids and sulfate. Hot water, from deep wells, may not be desirable for some uses. Arsenic concentrations in the Minnelusa aquifer exceed the revised MCL of 10 μg/L in some locations. Only a few samples exceeded the MCL's for various radionuclides.

Samples from the Minnekahta aquifer 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. Water generally is suitable for all water uses; few samples exceeded SMCL's and no samples available for this study from the Minnekahta aquifer exceeded drinking-water standards for any radionuclides.

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.

The use of water from the minor aquifers (Spearfish, Sundance, Morrison, Pierre, Graneros, Newcastle, and alluvial aquifers) may be hampered by hardness and concentrations of dissolved solids and sulfate. Concentrations of radionuclides, with the exception of uranium, generally are at acceptable levels in samples from the minor aquifers. Selenium concentrations in some places are an additional deterrent to the use of water from the Sundance aquifer.

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

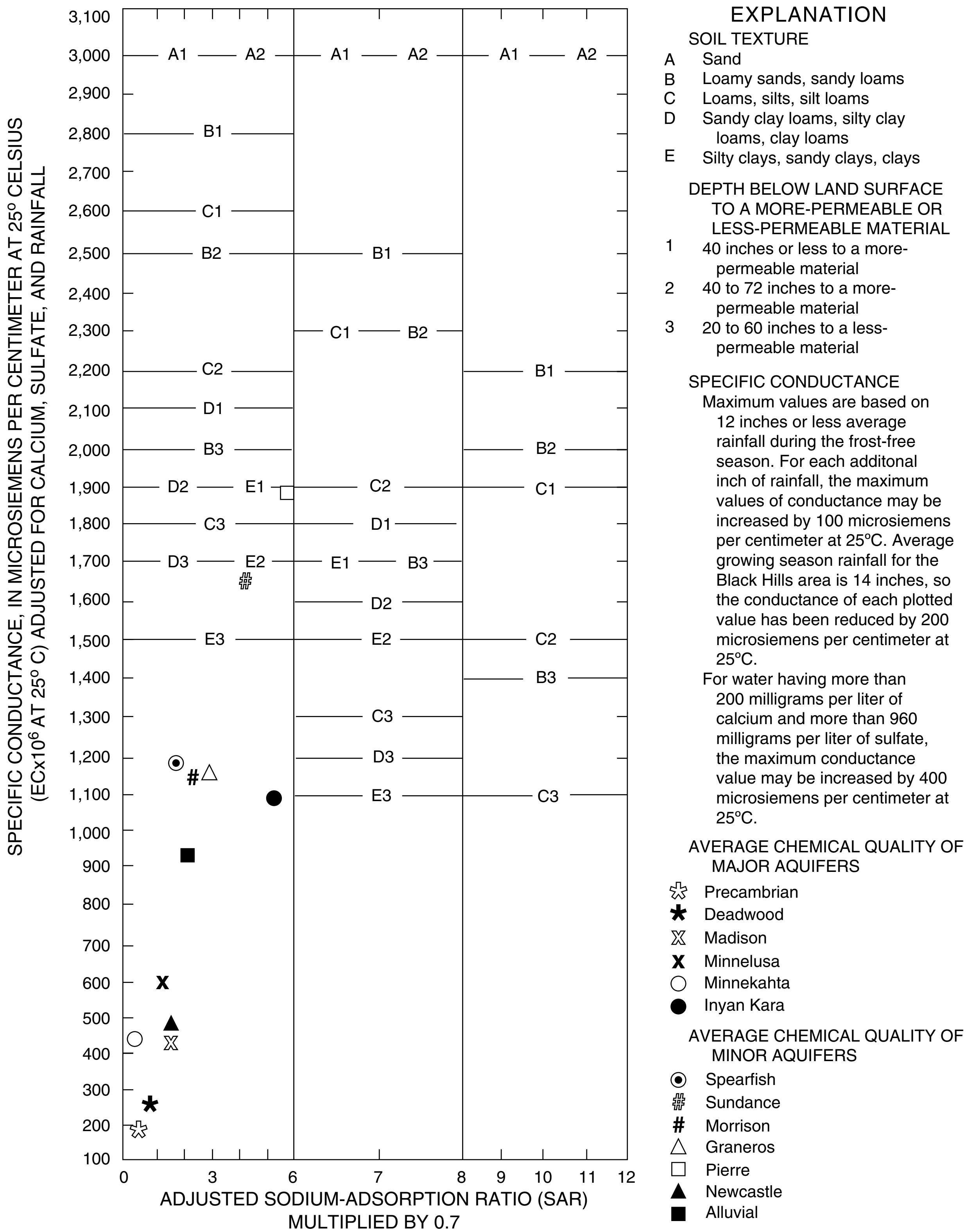

Figure 39. South Dakota irrigation-water classification diagram for selected aquifers (from Williamson and Carter, 2001). This diagram is based on South Dakota standards (revised Jan. 7, 1982) for maximum allowable specific conductance and adjusted sodium-adsorption-ratio values for which an irrigation 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).