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.

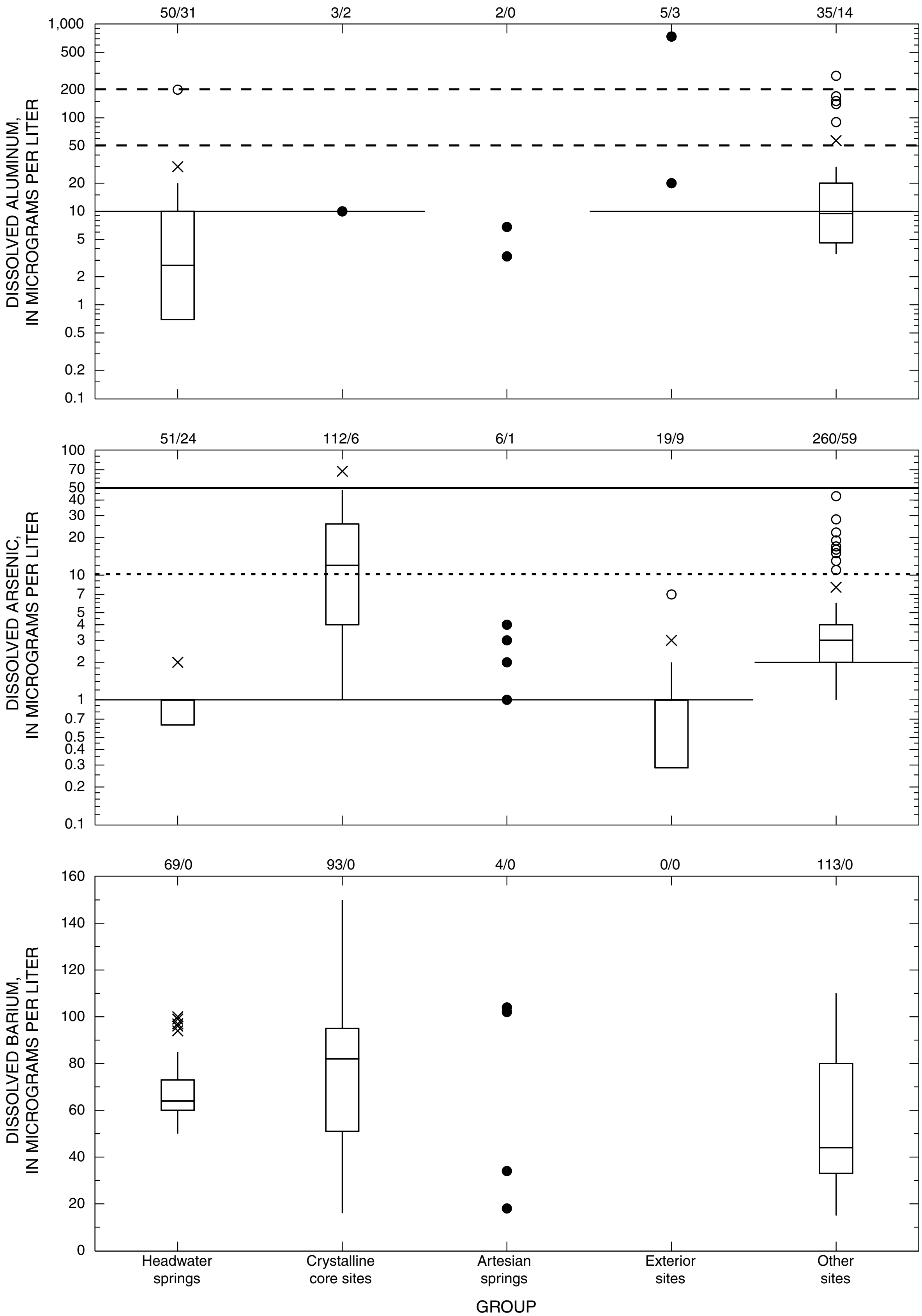


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.

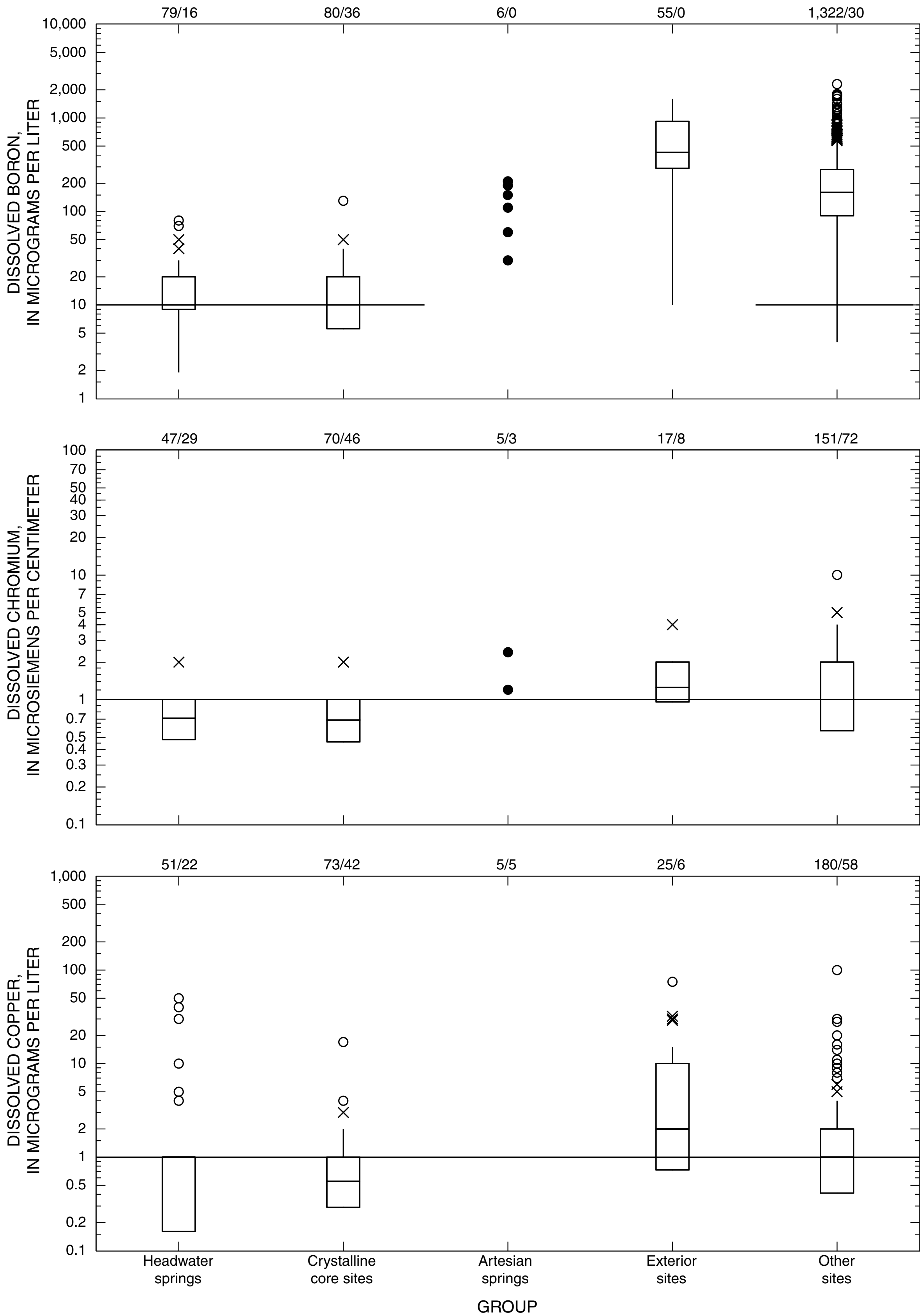


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

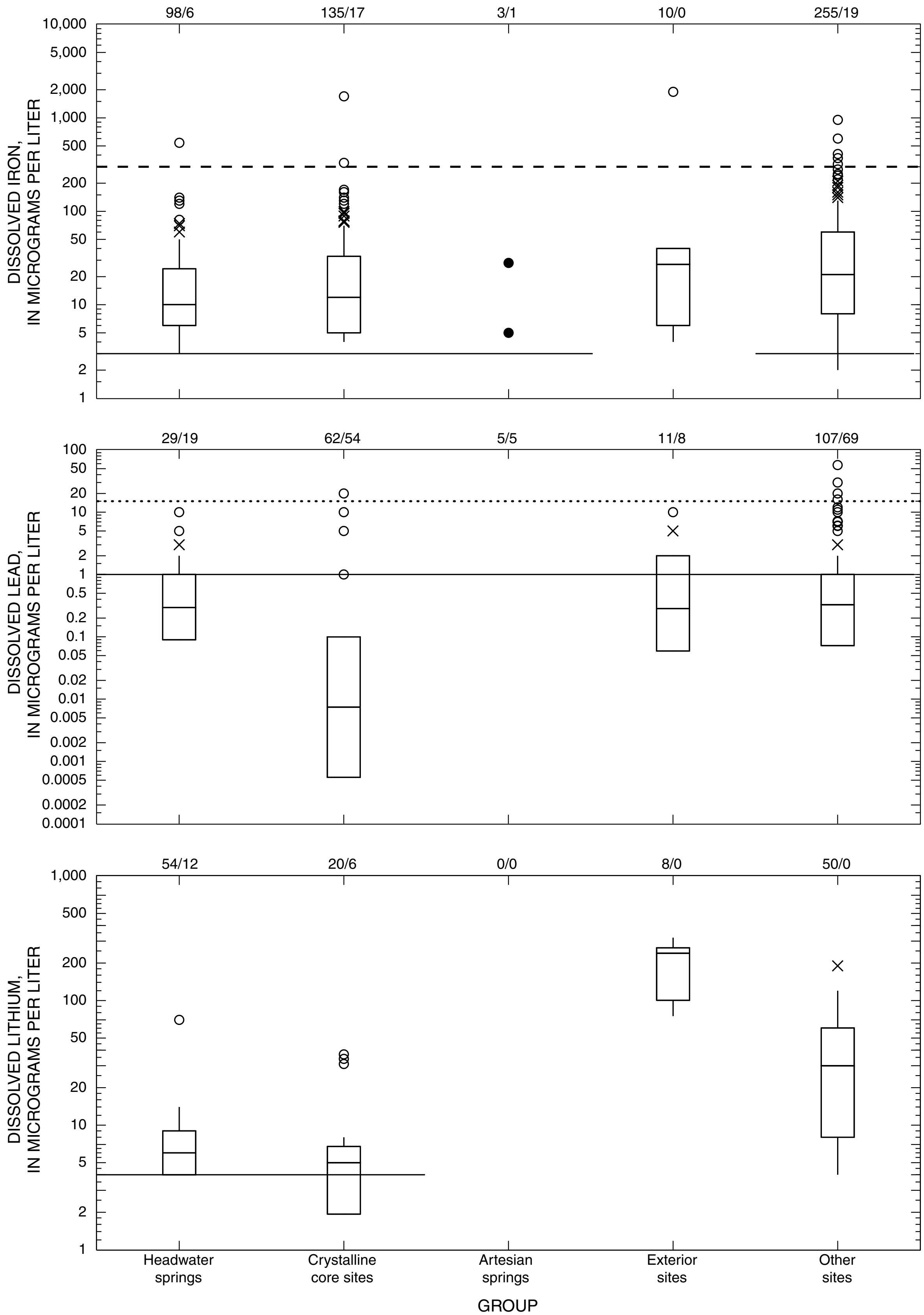


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

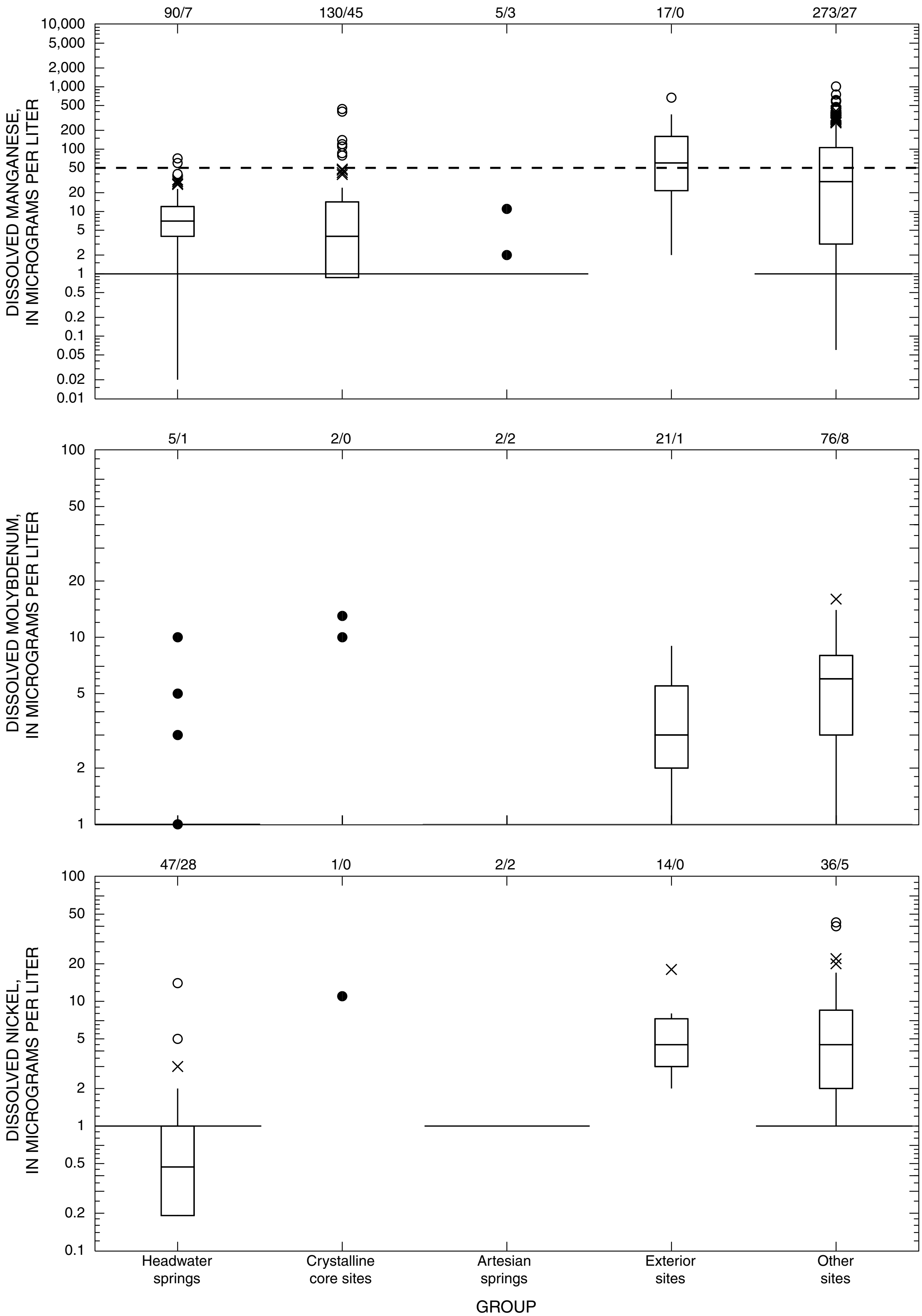


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued

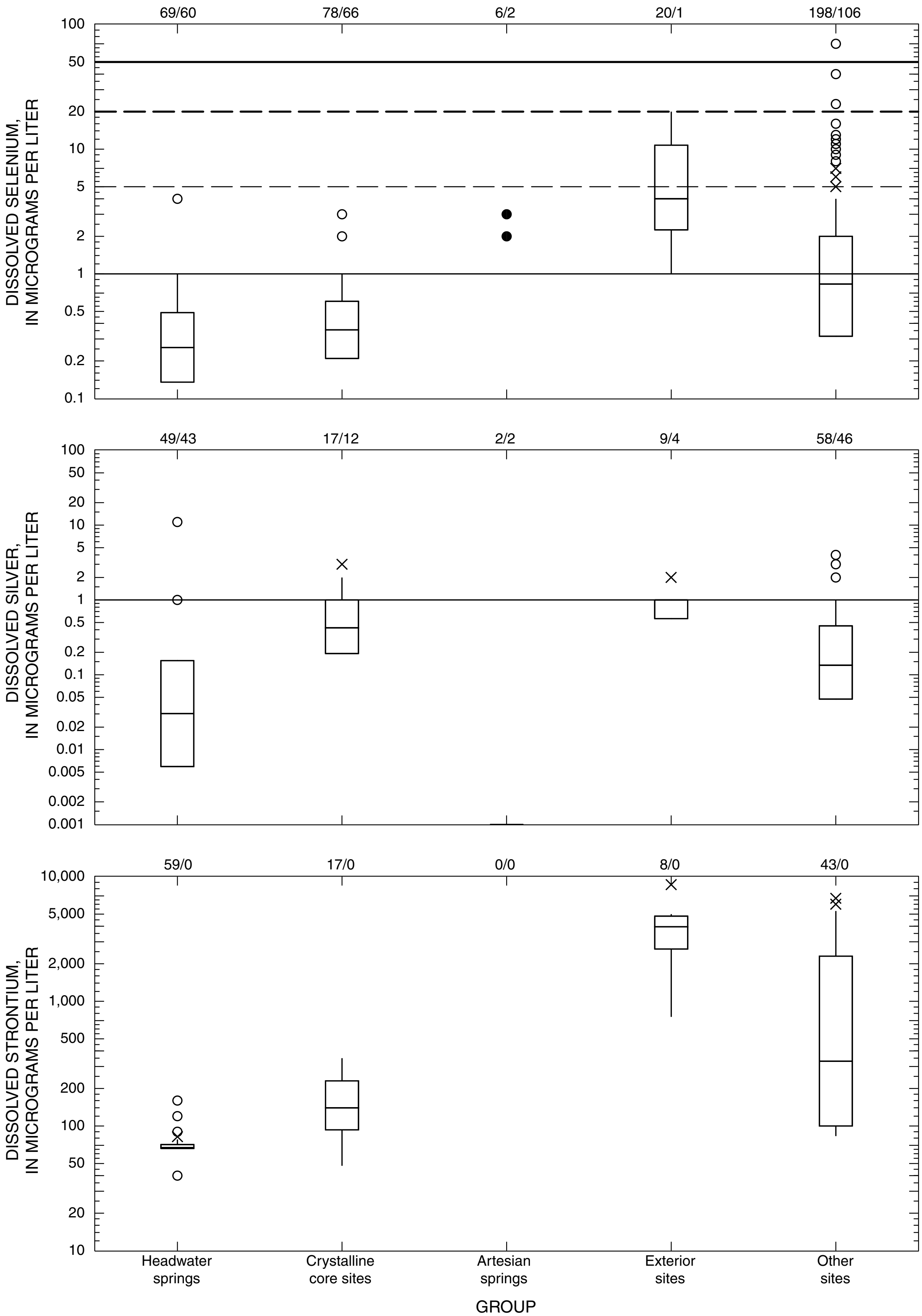
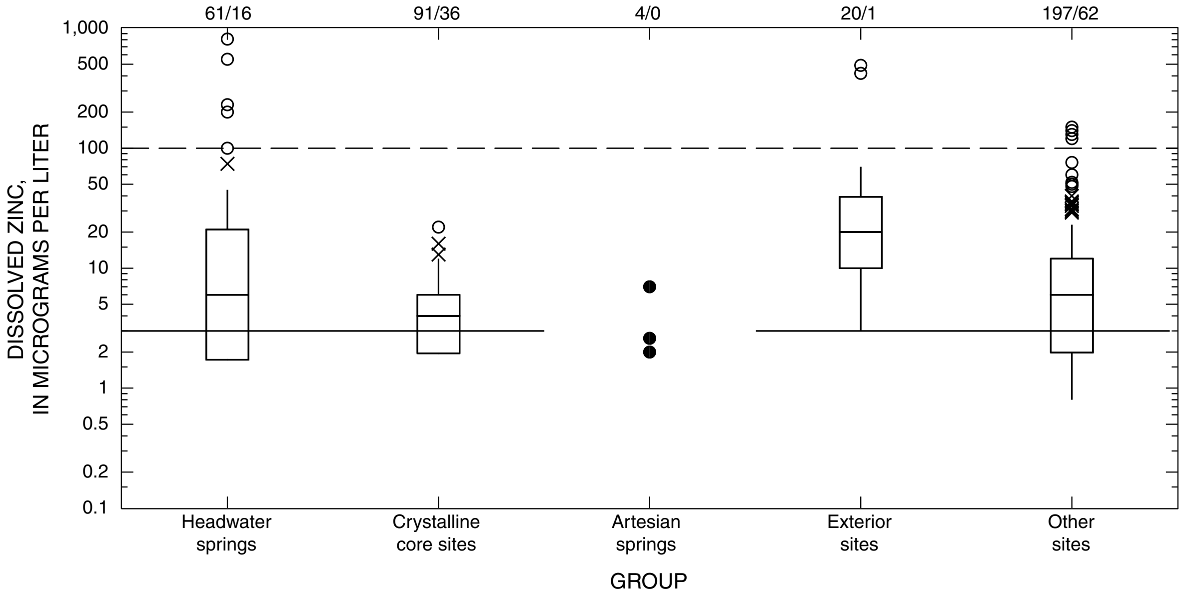


Figure 47. Boxplots of concentrations of selected trace elements by surface-water group.--Continued



EXPLANATION

4/0 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

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

75th percentile

Median

25th percentile

● Single sample

Highest detection limit

Maximum Contaminant Level (mandatory) (U.S. Environmental Protection Agency, 1996)

Proposed Maximum Contaminant Level (U.S. Environmental Protection Agency, 2000)

Secondary Maximum Contaminant Level (recommended) (U.S. Environmental Protection Agency, 1996)

Action level (U.S. Environmental Protection Agency, 1991)

Acute aquatic-life criteria (South Dakota Department of Environment and Natural Resources, 1998)

Chronic aquatic-life criteria (South Dakota Department of Environment and Natural Resources, 1998)

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.

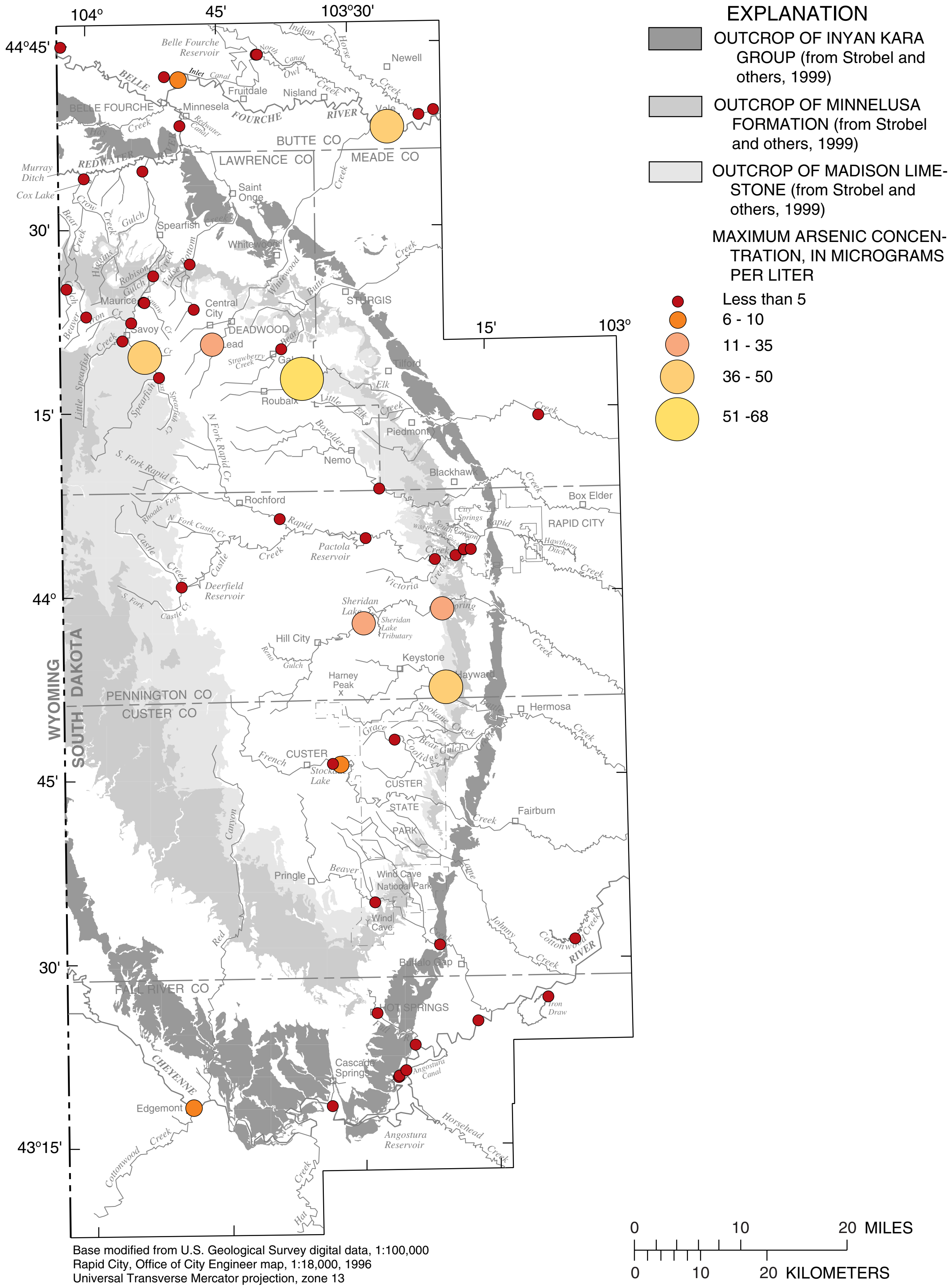


Figure 48. Spatial distribution of maximum arsenic concentrations in surface water.

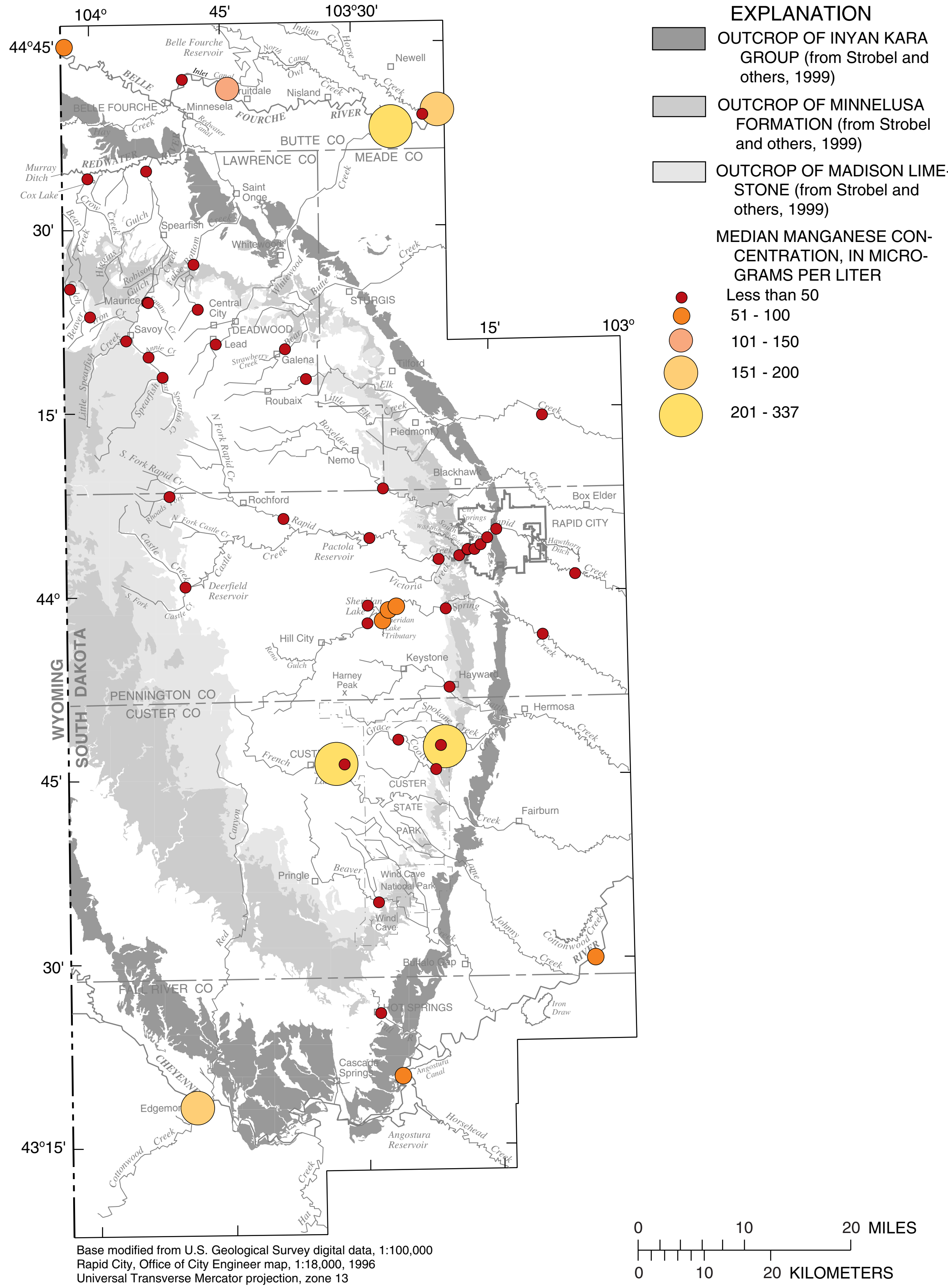


Figure 49. Spatial distribution of median manganese concentrations in surface water.

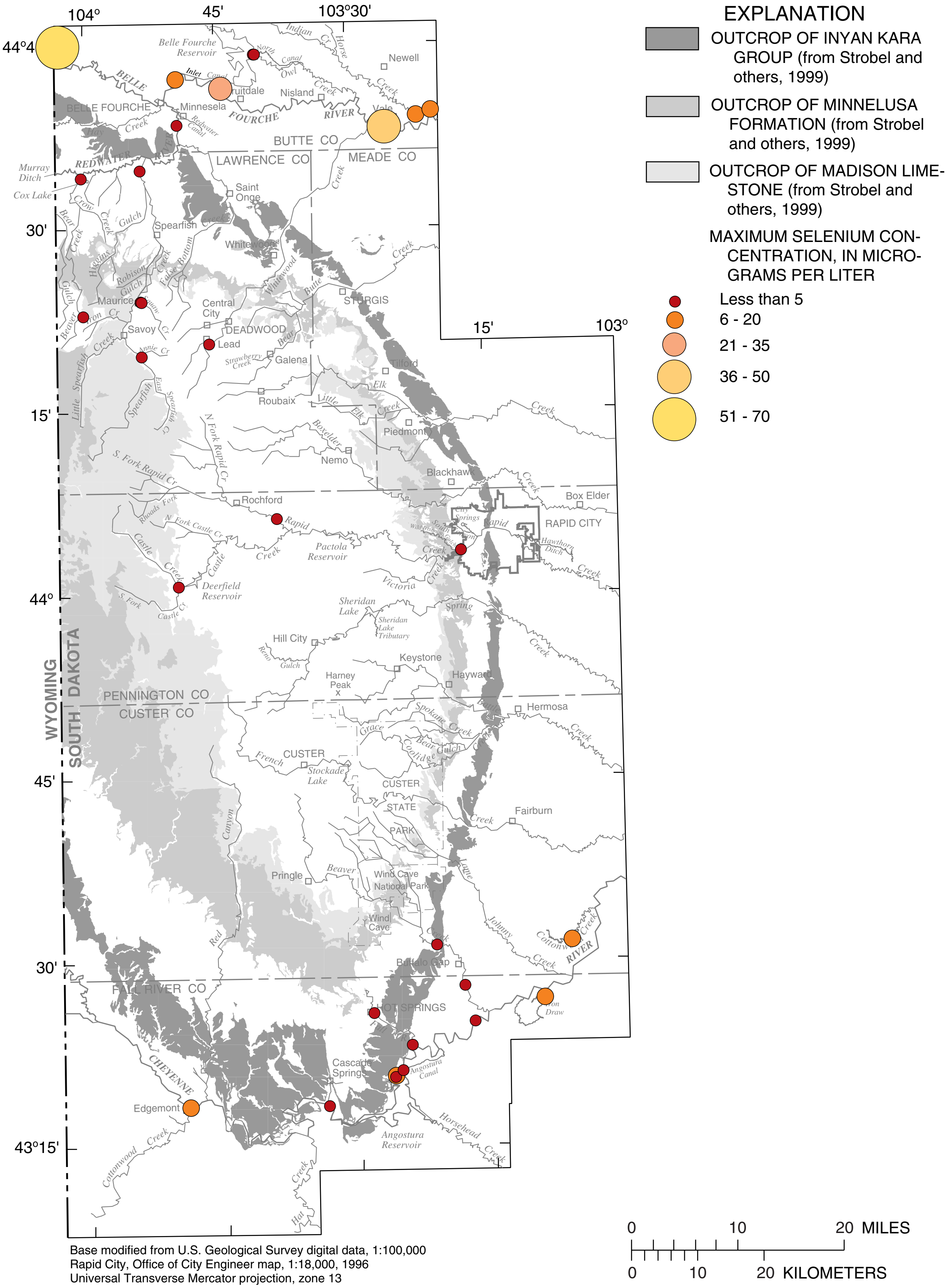


Figure 50. Spatial distribution of maximum selenium concentrations in surface water.

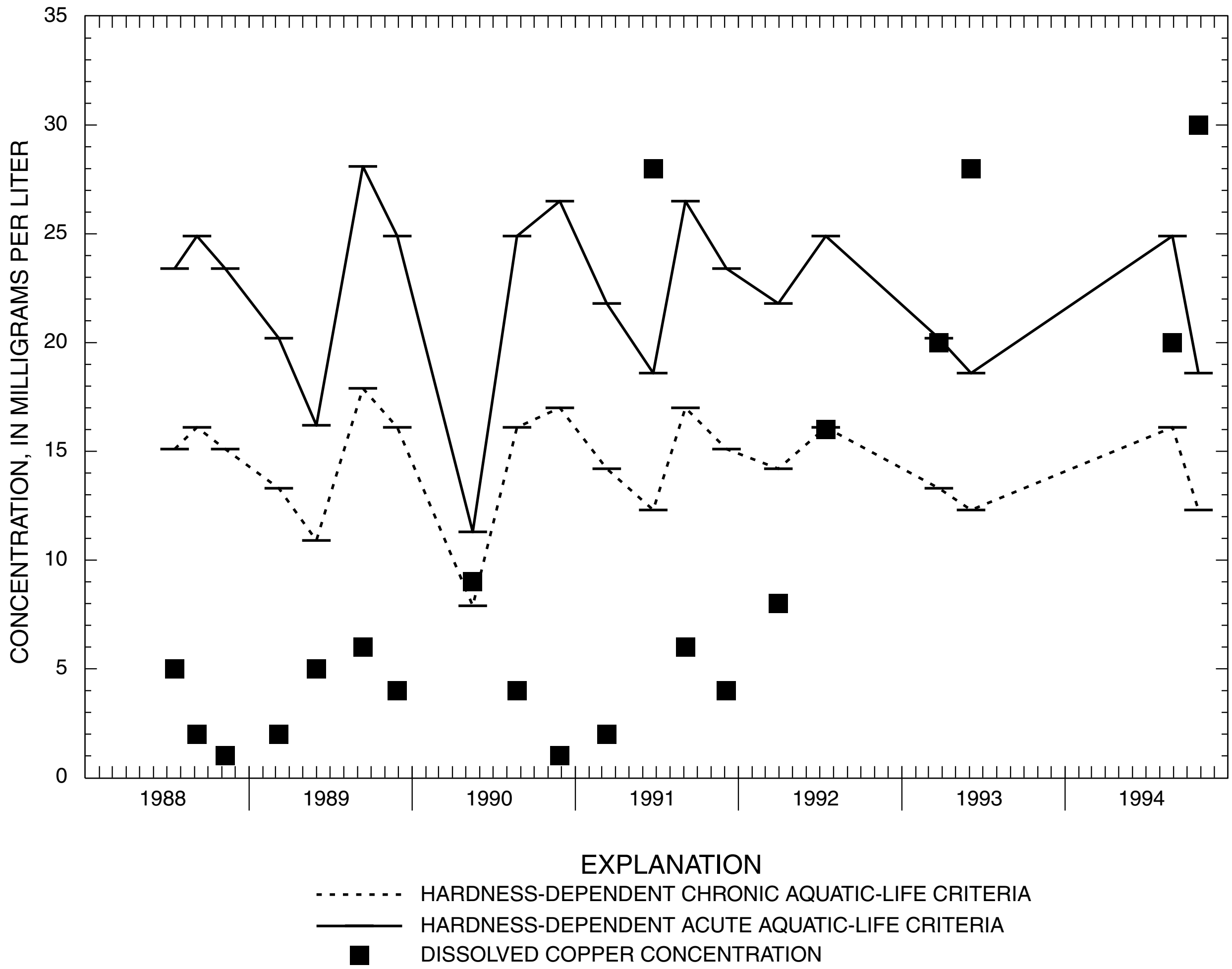


Figure 51. Comparison of dissolved copper concentrations to hardness-dependent chronic and acute aquatic-life criteria for Bear Butte Creek near Deadwood (06437020).

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

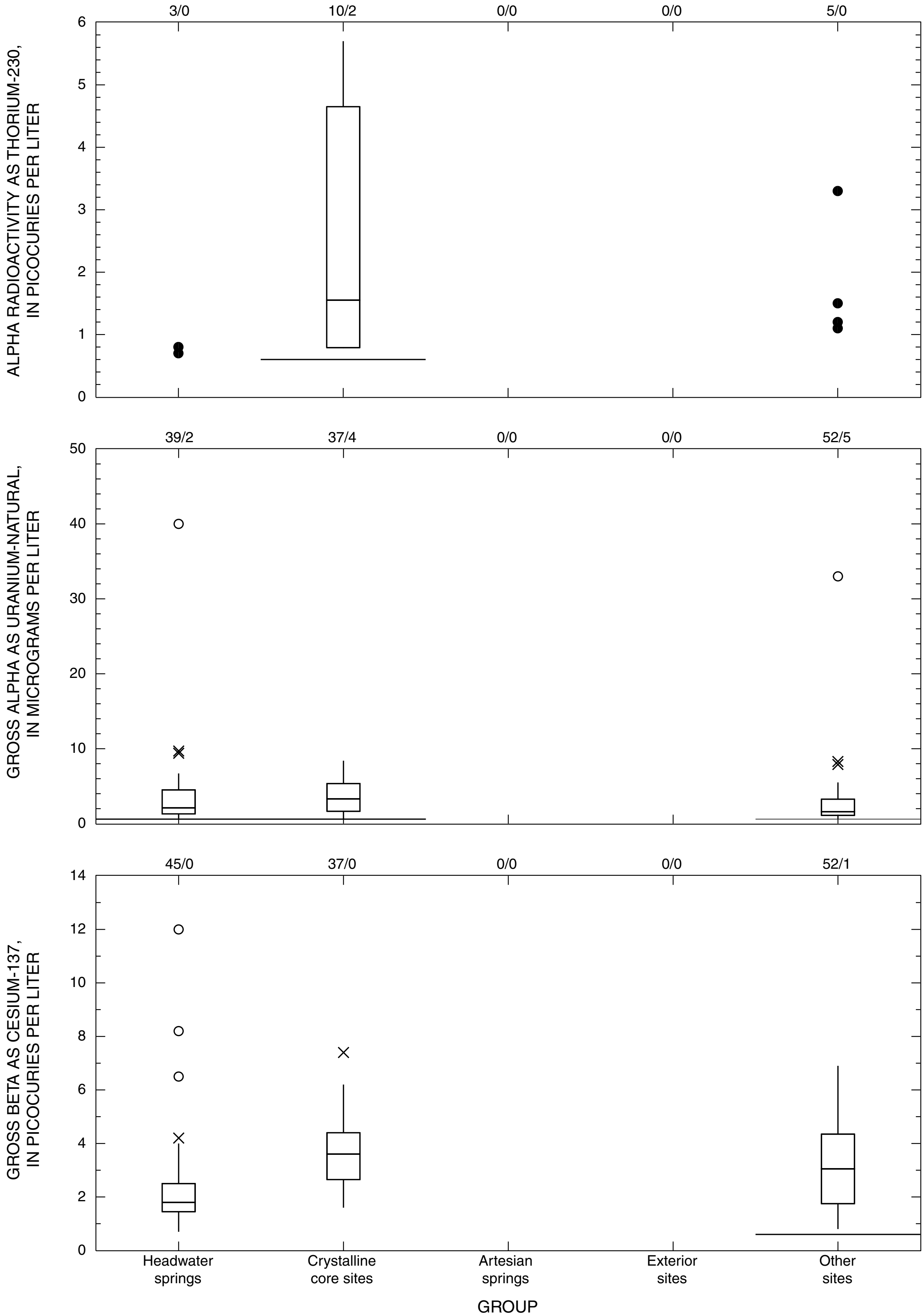


Figure 52. Boxplots of concentrations of selected radionuclides by surface-water group.

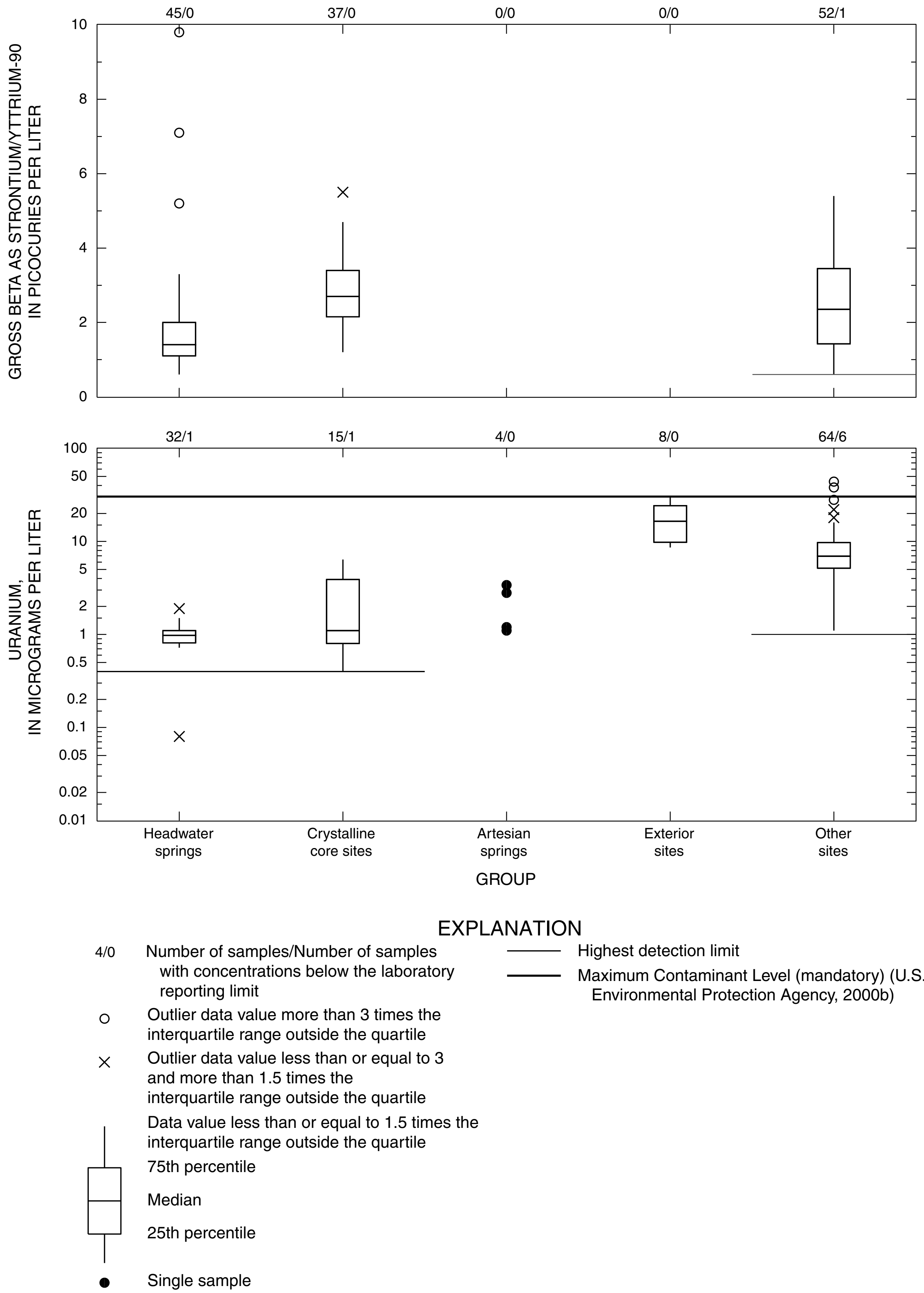


Figure 52. Boxplots of concentrations of selected radionuclides by surface-water group.--Continued

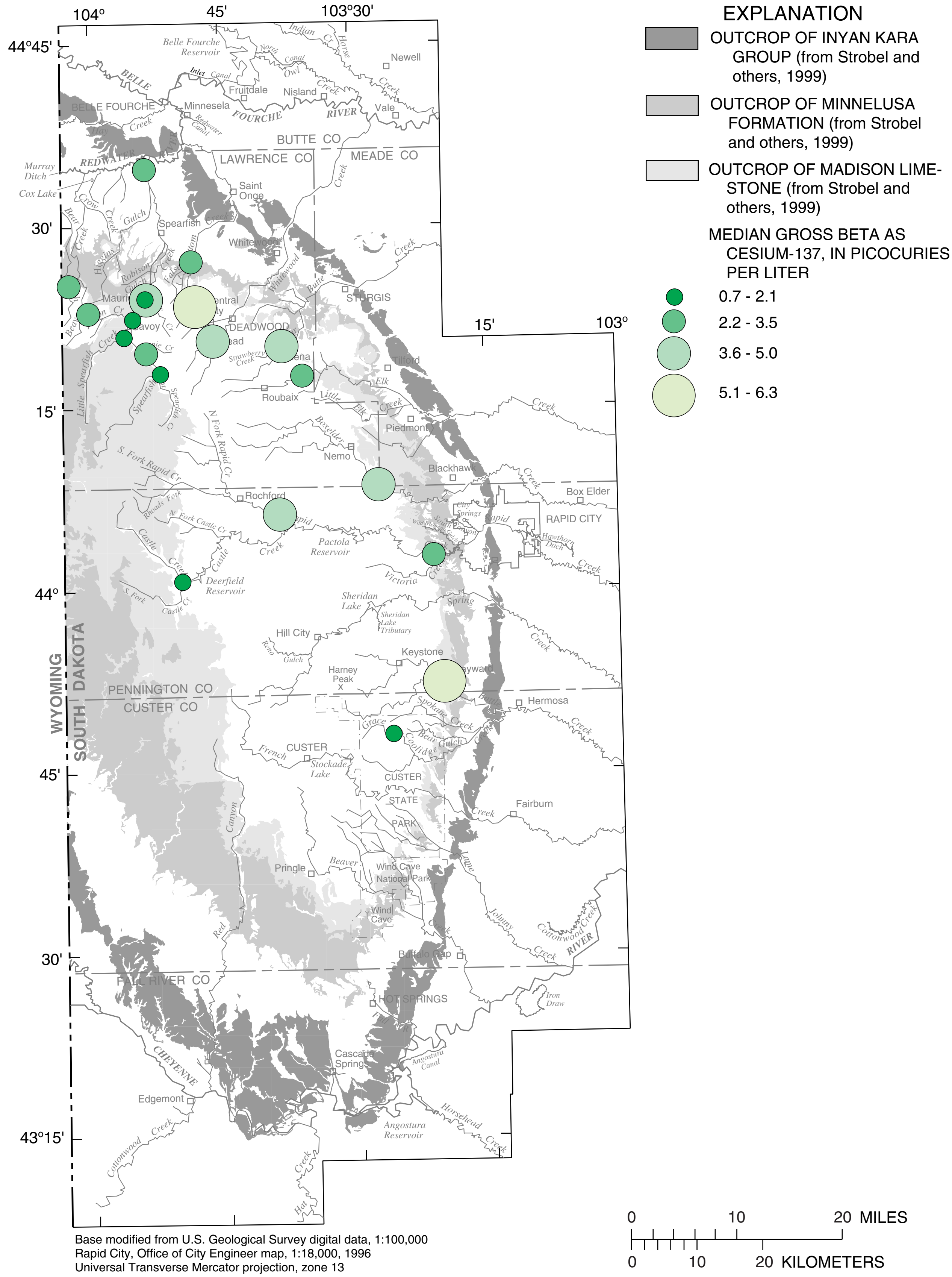


Figure 53. Spatial distribution of median gross beta as cesium-137 concentrations in surface water.

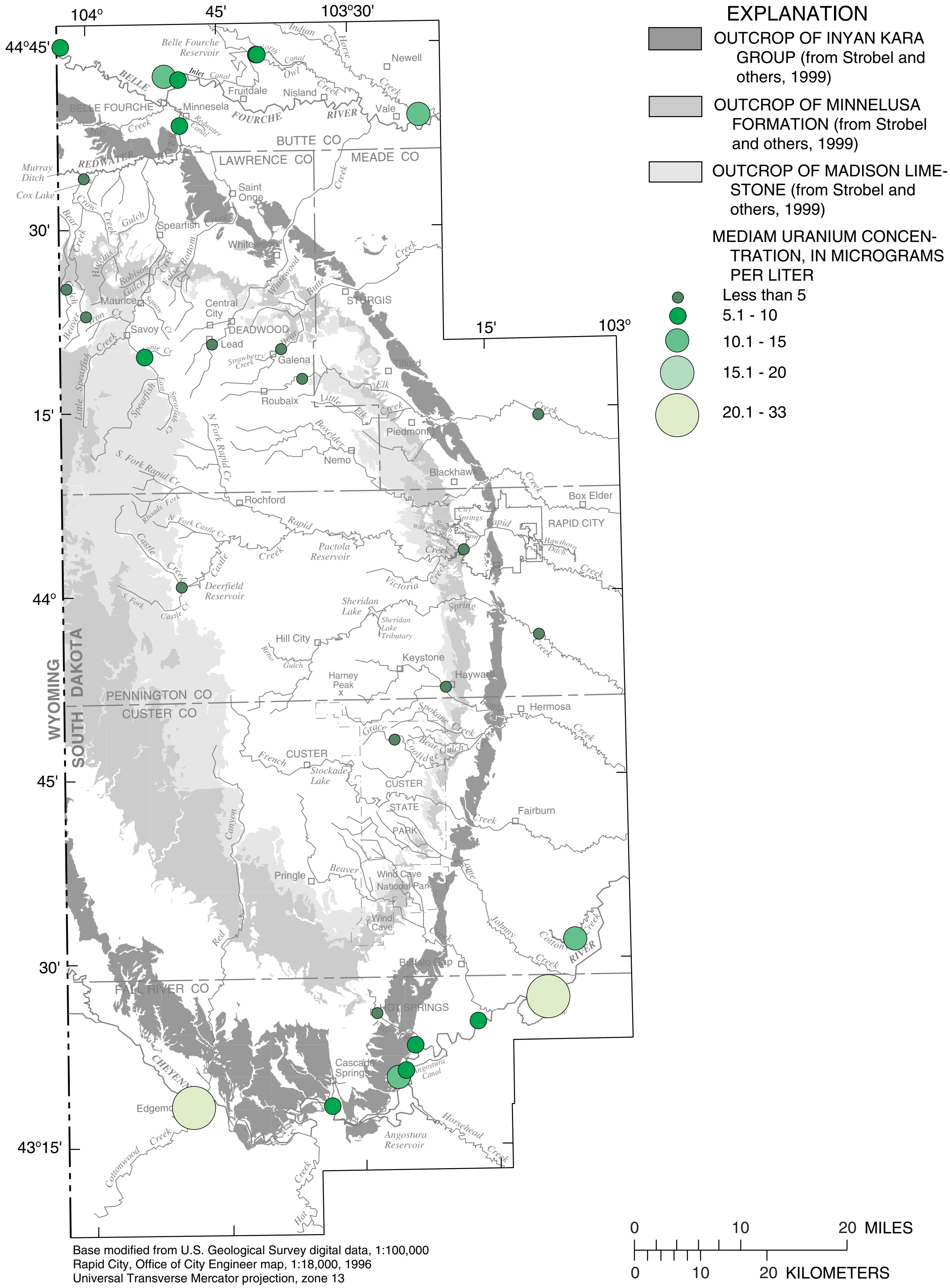


Figure 54. Spatial distribution of median uranium concentrations in surface water.

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.

REFERENCES

Alliance of Engineers and Architects, 1992, Canyon Lake Management Plan—Final report: Rapid City, S. Dak., Alliance of Engineers and Architects and HDR Engineering, Inc., 102 p.

Behal, Rajesh, 1988, Occurrence of selenium in the Inyan Kara aquifer system in Meade, Pennington, and Custer Counties, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 77 p.

Bowles, C.G., and Braddock, W.A., 1963, Solution breccias of the Minnelusa Formation in the Black Hills, South Dakota and Wyoming: U.S. Geological Survey Professional Paper 475-G, p. c-91 to c-95.

Busby, J.F., Lee, R.W., and Hanshaw, B.B., 1983, Major geochemical processes related to the hydrology of the Madison aquifer system and associated rocks in parts of Montana, South Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 83-4093, 171 p.

Busby, J.F., Plummer, L.N., Lee, R.W., and Hanshaw, B.B., 1991, Geochemical evolution of water in the Madison aquifer in parts of Montana, South Dakota, and Wyoming: U.S. Geological Survey Professional Paper 1273-F, 89 p.

Callahan, M.A., Slimak, M.W., Gabel, N.W., May, I.P., Fowler, C.F., Freed, J.R., Jennings, Patricia, Durfee, R.L., Whitmore, F.C., Maestri, Bruno, Mabey, W.R., Holt, B.R., and Gould, Constance, 1979, Water-related environmental fate of 129 priority pollutants, Volume I—Introduction and technical background, metals and inorganice, pesticides and PCBs: U.S. Environmental Protection Agency, Office of Water Planning and Standards, Office of Water and Waste Management, EPA-440/4-79-029a [variously paged].

Carda, D.D., 1975, A study of the radium content of the ground waters of western South Dakota with emphasis on the Madison (Pahasapa) Limestone: Rapid City, South Dakota School of Mines and Technology, unpublished Ph. D. dissertation, 94 p.

Carter, J.M., and Redden, J.A., 1999a, Altitude of the top of the Inyan Kara Group in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-744-A, 2 sheets, scale 1:100,000.

———1999b, Altitude of the top of the Minnekahta Limestone in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-744-B, 2 sheets, scale 1:100,000.

———1999c, Altitude of the top of the Minnelusa Formation in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-744-C, 2 sheets, scale 1:100,000.

———1999d, Altitude of the top of the Madison Limestone in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-744-D, 2 sheets, scale 1:100,000.

———1999e, Altitude of the top of the Deadwood Formation in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-744-E, 2 sheets, scale 1:100,000.

Cherry, J.A., Morel, F.M.M., Rouse, J.V., Schnoor, J.L., and Wolman, M.G., 1986a, Hydrogeochemistry of sulfide and arsenic-rich tailings and alluvium along Whitewood Creek, South Dakota (part 1 of 3 parts): Mineral and Energy Resources, v. 29, no. 4 p. 1-12.

———1986b, Hydrogeochemistry of sulfide and arsenic-rich tailings and alluvium along Whitewood Creek, South Dakota (part 2 of 3 parts): Mineral and Energy Resources, v. 29, no. 5 p. 1-62.

———1986c, Hydrogeochemistry of sulfide and arsenic-rich tailings and alluvium along Whitewood Creek, South Dakota (part 3 of 3 parts): Mineral and Energy Resources, v. 29, no. 6 p. 1-17.

Clark, Ian, and Fritz, Peter, 1997, Environmental isotopes in hydrogeology: Boca Raton, Fla., Lewis Publishers, 328 p.

DeWitt, Ed, Redden, J.A., Buscher, David, and Wilson, A.B., 1989, Geologic map of the Black Hills area, South Dakota and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I -1910, 1 sheet, scale 1:250,000.

DeWitt, Ed, Redden, J.A., Wilson, A.B., and Buscher, David, 1986, Mineral resource potential and geology of the Black Hills Nations Forest, South Dakota and Wyoming: U.S. Geological Survey Bulletin 1580, 135 p.

Driscoll, D.G., 1992, Plan of study for the Black Hills Hydrology Study, South Dakota: U.S. Geological Survey Open-File Report 92-84, 10 p.

Driscoll, D.G., and Bradford, W.L., 1994, Compilation of selected hydrologic data, through water year 1992, Black Hills Hydrology Study, western South Dakota: U.S. Geological Survey Open-File Report 94-319, 158 p.

Driscoll, D.G., Bradford, W.L., and Neitzert, K.M., 1996, Selected hydrologic data through water year 1994, Black Hills Hydrology Study, South Dakota: U.S. Geological Survey Open-File Report 96-399, 162 p.

Driscoll, D.G, Bradford, W.L., and Moran, M.J., 2000, Selected hydrologic data, through water year 1998, Black Hills Hydrology Study, South Dakota: U.S. Geological Survey Open-File Report 00-70, 284 p.

Driscoll, D.G., Hamade, G.R., and Kenner, S.J., 2000, Summary of precipitation data compiled for the Black Hills Hydrology Study, western South Dakota: U.S. Geological Survey Open-File Report 00-329, 151 p.

Driscoll, D.G., and Hayes, T.S., 1995, Arsenic loads in Spearfish Creek, western South Dakota, water years 1989-91: U.S. Geological Survey Water-Resources Investigations Report 95-4080, 28 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Freeman, J.E., and Komor, S.C., 1991, Selected water-quality data for Rapid Creek Basin, southwestern South Dakota, 1946-90: U.S. Geological Survey Open-File Report 91-249, 194 p.

Fuller, C.C., and Davis, J.A., 1989, Influence of coupling of sorption and photosynthetic processes on trace element cycles in natural waters: Nature, v. 340, p. 52-54.

Fuller, C.C., Davis, J.A., and Claypool-Frey, R.G., 1988, Partitioning of arsenic by iron oxides in Whitewood Creek, South Dakota, *in* Mallard, G.E., ed., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Denver, Colo., Feb. 2-4, 1987: U.S. Geological Survey Open-File Report 87-764, p. 19-21.

Fuller, C.C., Davis, J.A., Zellwegger, G.W., and Goddard, K.E., 1989, Coupled chemical, biological, and physical processes in Whitewood Creek, South Dakota—Evaluation of the controls of dissolved arsenic, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Phoenix, Ariz., Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 235-246.

Goddard, K.E., ed., 1988, U.S. Geological Survey applied research studies of the Cheyenne River system, South Dakota—Description and collation of data, water years 1985-86: U.S. Geological Survey Open-File Report 88-484, 158 p.

———1990, U.S. Geological Survey applied research studies of the Cheyenne River System, South Dakota—Description and collation of data, water years 1987-88: U.S. Geological Survey Open-File Report 88-484, 145 p.

Goddard, K.E., 1989a, Composition, distribution, and hydrologic effects of contaminated sediments resulting from the discharge of gold milling wastes to Whitewood Creek at Lead and Deadwood, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 87-4051, 76 p.

———1989b, Overview of research activities on Cheyenne River system, western South Dakota, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Phoenix, Ariz., Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 199-202.

Goddard, K.E., Lockner, T.K., Harms, L.L., and Smith, M.H., 1989, Summary of data pertaining to land use, rainfall, dryfall, stream discharge, and storm runoff collected as part of a study of the effects of urban runoff on Rapid Creek, Rapid City area, South Dakota: U.S. Geological Survey Open-File Report 87-45, 194 p.

Gott, G.B., Wolcott, D.E., and Bowles, C.G., 1974, Stratigraphy of the Inyan Kara Group and localization of uranium deposits, southern Black Hills, South Dakota and Wyoming: U.S. Geological Survey Professional Paper 763, 57 p.

Greene, E.A., 1993, Hydraulic properties of the Madison aquifer system in the western Rapid City area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 93-4008, 56 p.

———1997, Tracing recharge from sinking streams over spatial dimensions of kilometers in a karst aquifer: Ground Water, v. 35, no. 5, p. 898-904.

Greene, E.A., Sowards, C.L., and Hansmann, E.W., 1990, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Angostura Reclamation Unit, southwestern South Dakota, 1988-89: U.S. Geological Survey Water-Resources Investigations Report 90-4152, 75 p.

Gries, J.P., 1975, Mineral and water resources of South Dakota: U.S. Congress, 94th, 1st Session, Interior and Insular Affairs Committee Print, 313 p.

———1996, Roadside geology of South Dakota: Missoula, Mont., Mountain Press Publishing Company, 358 p.

Gries, J.P., and Martin, J.E., 1985, Composite outcrop section of the Paleozoic and Mesozoic strata in the Black Hills and surrounding areas, *in* Rich, F.J., ed., Geology of the Black Hills, South Dakota and Wyoming (2d ed.): Geological Society of America, Field Trip Guidebook, American Geological Institute, p. 261-292.

Gundarlahalli, J.R., 1990, Chemical and biological characteristics of Grace Coolidge and Bear Gulch Creeks after the Galena Forest Fire in Custer State Park, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 207 p.

Hamilton, L.J., and Howells, L.W., 1996, Water resources of Spink County, South Dakota: U.S. Geological Survey Water-Resources Investigation Report 96-4056, 69 p.

Harms, L.L, 1983, Urban runoff control in Rapid City, South Dakota: Executive Summary, Black Hills Council of Local Governments, Rapid City, S. Dak., 21 p.

Harms, L.L., Smith, M.H., and Goddard, K.E., 1983, Urban-runoff control in Rapid City, South Dakota: Rapid City, South Dakota School of Mines and Technology and U.S. Geological Survey, unpublished final report, 153 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Helsel, D.R., and Gilliom, R.J., 1985, Estimation of distributional parameters for censored trace-level water-quality data—II, Verification and applications: U.S. Geological Survey Open-File Report 85-86, 21 p.

Hem, J.D., 1985, Study and interpretation of chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hoof, M.M., 1998, Cheyenne River impact study, Pine Ridge Reservation, Pine Ridge, South Dakota: Pine Ridge, South Dakota, Oglala Lakota Nation Water Resource Department.

Horowitz, A.J., Elrick, K.A., and Cook, R.B, 1989, Source and transport of arsenic in the Whitewood Creek-Belle Fourche-Cheyenne River-Lake Oahe system, South Dakota, 1989, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Phoenix, Arizona, Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 223-234.

Hortness, J.E., and Driscoll, D.G., 1998, Streamflow losses in the Black Hills of western South Dakota: U.S. Geological Survey Water-Resources Investigations Report 98-4116, 99 p.

Johnson, B.N., 1933, A climatological review of the Black Hills: The Black Hills Engineer, Rapid City, South Dakota School of Mines and Technology, 71 p.

Johnson, S.L., 1992, Nutrient, chloride, and indicator bacteria in waters of the Spearfish Creek Basin in Lawrence County, South Dakota—Baseline conditions and comparative analyses for the period 1988-1990: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 130 p.

Klemp, J.A., 1995, Source aquifers for large springs in northwestern Lawrence County, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 175 p.

Koch, N.C., 1983, Irrigation-water classification diagram for South Dakota: South Dakota Academy of Science Proceedings, v. 62, p. 107-114.

Kyllonen, D.P., and Peter, K.D., 1987, Geohydrology and water quality of the Inyan Kara, Minnelusa, and Madison aquifers of the northern Black Hills, South Dakota and Wyoming, and Bear Lodge Mountains, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 86-4158, 61 p.

Langmuir, Donald, 1997, Aqueous environmental geochemistry: Upper Saddle River, N.J., Prentice-Hall, 600 p.

Marron, D.C., 1989, Trends in arsenic concentration and grain-size distribution of metal-contaminated overbank sediments along the Belle Fourche Rive downstream from Whitewood Creek, South Dakota, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Phoenix, Arizona, Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 211-216.

McKallip, T.E., Goddard, K.E., and Horowitz, A.J.,1989, Source and transport of arsenic in the Whitewood Creek-Belle Fourche-Cheyenne River-Lake Oahe system, South Dakota, 1989, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Phoenix, Arizona, Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 203-210.

Meyer, M.R., 1984, Evaluation of the ground-water resources of western South Dakota—Task 5—Water quality suitability by aquifer for drinking, irrigation, livestock watering and industrial use: Pierre, S. Dak., Office of Water Quality, South Dakota Department of Water and Natural Resources, 200 p.

———1986, A summary of ground-water pollution problems in South Dakota: Pierre, S. Dak., Office of Water Quality, South Dakota Department of Water and Natural Resources, 18 p.

Miller, L.D., and Driscoll, D.G., 1998, Streamflow characteristics for the Black Hills of South Dakota, through water year 1993: U.S. Geological Survey Water-Resources Investigations Report 97-4288, 322 p.

Naus, C.A., Driscoll, D.G., and Carter, J.M., in press, Geochemistry of the Madison and Minnelusa aquifers in the Black Hills area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 01-4129.

Orr, H.K., 1959, Precipitation and streamflow in the Black Hills: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Station Paper no. 44, 25 p.

Page, L.R., and Redden, J.A., 1952, The carnotite prospects of the Craven Canyon area, Fall River County, South Dakota: U.S. Geological Survey Circular 175, 18 p.

Peter, K.D., 1985, Availability and quality of water from the bedrock aquifers in the Rapid City area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 85-4022, 34 p.

Rahn, P.H., 1985, Ground water stored in the rocks of western South Dakota, *in* Rich, F.J., ed., Geology of the Black Hills, South Dakota and Wyoming (2d ed.): Geological Society of America, Field Trip Guidebook, American Geological Institute, p. 154-174.

Rahn, P.H., Davis, A.D., Webb, C.J., and Nichols, A.D., 1996, Water quality impacts from mining in the Black Hills, South Dakota, USA: Environmental Geology, v. 27, p. 38-53.

Rahn, P.H., and Gries, J.P., 1973, Large springs in the Black Hills, South Dakota and Wyoming: South Dakota Geological Survey Report of Investigations 107, 46 p.

Robinson, C.S., Mapel, W.J., and Bergendahl, M.H., 1964, Stratigraphy and structure of the northern and western flanks of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geological Survey Professional Paper 404, 134 p.

Roddy, W.R., Greene, E.A., and Sowards, C.L., 1991, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Belle Fourche Reclamation Project, western South Dakota: U.S. Geological Survey Water-Resources Investigations Report 90-4192, 113 p.

Rounds, D.D., 1991, A reconnaissance-level investigation of selected radionuclides and water-quality characteristics of wells penetrating the Deadwood Formation, Black Hills, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 94 p.

South Dakota Department of Environment and Natural Resources, 1975-99, The South Dakota report to Congress—305(b) water-quality assessment: Pierre, South Dakota, South Dakota Department of Environment and Natural Resources (published every 2 years).

———1996, Drinking water standards—1996, Drinking water standards: Administrative Rules of South Dakota, 74:04:05.

———1998a, Surface water quality: Administrative Rules of South Dakota, 74:51, accessed Aug. 14, 1998, at URL http://legis.state.sd.us/rules/ rules/7451.htm

———1998b, Summary of the Mining Industry in South Dakota: Minerals and Mining Program, South Dakota Department of Environment and Natural Resources, accessed Dec. 28, 2000, at URL http://www.state.sd.us/denr/des/mining/ 1998minesum.htm

———2000, Total Maximum Daily Loads (TMDL), Freeman Lake TMDL: South Dakota Department of Environment and Natural Resources, Water Resources Assistance Program, accessed Dec. 29, 2000, at URL http://www.state.sd.us/ denr/DFTA/WatershedProtection/TMDL/TMDLFreeman.htm

———2001, Summary of the mining industry in South Dakota, 2000: Minerals and Mining Program, South Dakota Department of Environment and Natural Resources, retrieved July 10, 2001, from URL http://www.state.sd.us/denr/des/ mining/Goldrpta3.pdf

South Dakota Department of Water and Natural Resources, 1987, Surface water quality standards: Administrative Rules of South Dakota, 74:03:02.

Stiff, H.A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

Strobel, M.L., Jarrell, G.J., Sawyer, J.F., Schleicher, J.R., and Fahrenbach, M.D., 1999, Distribution of hydrogeologic units in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-743, 3 sheets, scale 1:100,000.

Torve, K.C., 1991, Reconnaissance water-quality investigation of bed material, surface water, and ground water of select tributaries draining the mineralized region of Lawrence County, near Lead, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 109 p.

U.S. Department of Commerce, 1997, Climatological data for South Dakota, annual summary: Asheville, N.C. (issued annually).

U.S. Department of Interior, 1967, Black Hills area resources study: Washington, D.C., February 1967, 225 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water (updated May 1986), Update No. 2: Washington, D.C., Office of Water Regulations and Standards, EPA 440/5/-86-001, 398 p.

———1991, Lead and copper role fact sheet: U.S. Environmental Protection Agency, Office of Water, EPA 570/9-91-400, 2 p.

———1994a, Summary of EPA finalized National primary drinking water regulations: U.S. Environmental Protection Agency Region VIII, 7 p.

———1994b, National primary drinking water standards: U.S. Environmental Protection Agency, Office of Water, EPA 810-F-94-001A, 4 p.

———1996, Drinking water regulations and health advisories: Washington, D.C., Office of Water, February 1996, EPA 822-R-96-001.

———1997, National primary drinking water regulations, Code of Federal regulations 40, parts 141 and 143, revised July 1, 1997, p. 288-476.

———1998, National recommended water quality criteria: Federal Register, December 10, 1998, v. 63, no. 237, p. 68353-68364.

———2000a, EPA to reduce arsenic in drinking water: EPA Press release, May 24, 2000, Washington, D.C.

———2000b, National primary drinking water regulations; radionuclides; Final rule: Federal Register, December 7, 2000, v. 65, no. 236, p. 76707-76753.

Union Carbide Corporation, 1979, Hydrogeochemical and stream sediment reconnaissance basic data for Hot Springs NTMS Quadrangle, South Dakota: Oakridge, Tenn., Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K/UR-132, December 1979, 39 p.

———1980, Hydrogeochemical and stream sediment reconnaissance basic data for Rapid City NTMS Quadrangle, South Dakota: Oakridge, Tenn., Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K/UR-139, May 1980, 39 p.

Wanty, R.B., and Nordstrom, D.K., 1993, Natural radionuclides, *in* Alley, W.M., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, p. 423-441.

Ward, J.R., and Harr, C.A., eds., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 71 p.

Wenker, G.A., 1997, Geological setting and water quality of headwater springs in the Black Hills of South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 101 p.

Whalen, P.J., 1994, Source aquifers for Cascade Springs, Hot Springs, and Beaver Creek Springs in the southern Black Hills of South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 299 p.

Williamson, J.E., 1999, Water-quality characteristics during low-flow conditions for selected streams in Lawrence County, South Dakota: Rapid City, South Dakota School of Mines and Technology, unpublished M.S. thesis, 156 p.

Williamson, J.E., and Hayes, T.L., 2000, Water quality characteristics for selected streams in Lawrence County, South Dakota, 1988-92: U.S. Geological Survey Water-Resources Investigations Report 00-4220, 131 p.

Williamson, J.E., Goldstein, R.M., and Porter, S.D., 1996, Selected trace metals in water, sediment, plants, and fish in Rapid Creek, Rapid City, South Dakota, 1993-94: U.S. Geological Survey Water-Resources Investigations Report 96-4276, 30 p.

Zogorski, J.S., Zogorski, E.M., and McKallip, T.E., 1990, Sources and summaries of water-quality information for the Rapid Creek basin, western South Dakota: U.S. Geological Survey Open-File Report 90-115, 35 p.

SUPPLEMENTAL INFORMATION

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

Site identification	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		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	Longitude	Number of valid samples
		(degrees, minutes, seconds)		
		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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
		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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
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 (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Number of valid samples
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 (degree, minutes, seconds)	Longitude (degree, minutes, seconds)	Number of valid samples
	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 (degree, minutes, seconds)	Longitude (degree, minutes, seconds)	Number of valid samples
	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 (degree, minutes, seconds)	Longitude (degree, minutes, seconds)	Number of valid samples
	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 (degree, minutes, seconds)	Longitude (degree, minutes, seconds)	Number of valid samples
	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