EXPLANATION

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

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

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

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, 1994a)

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

Trace Elements

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

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

Precambrian Aquifers

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

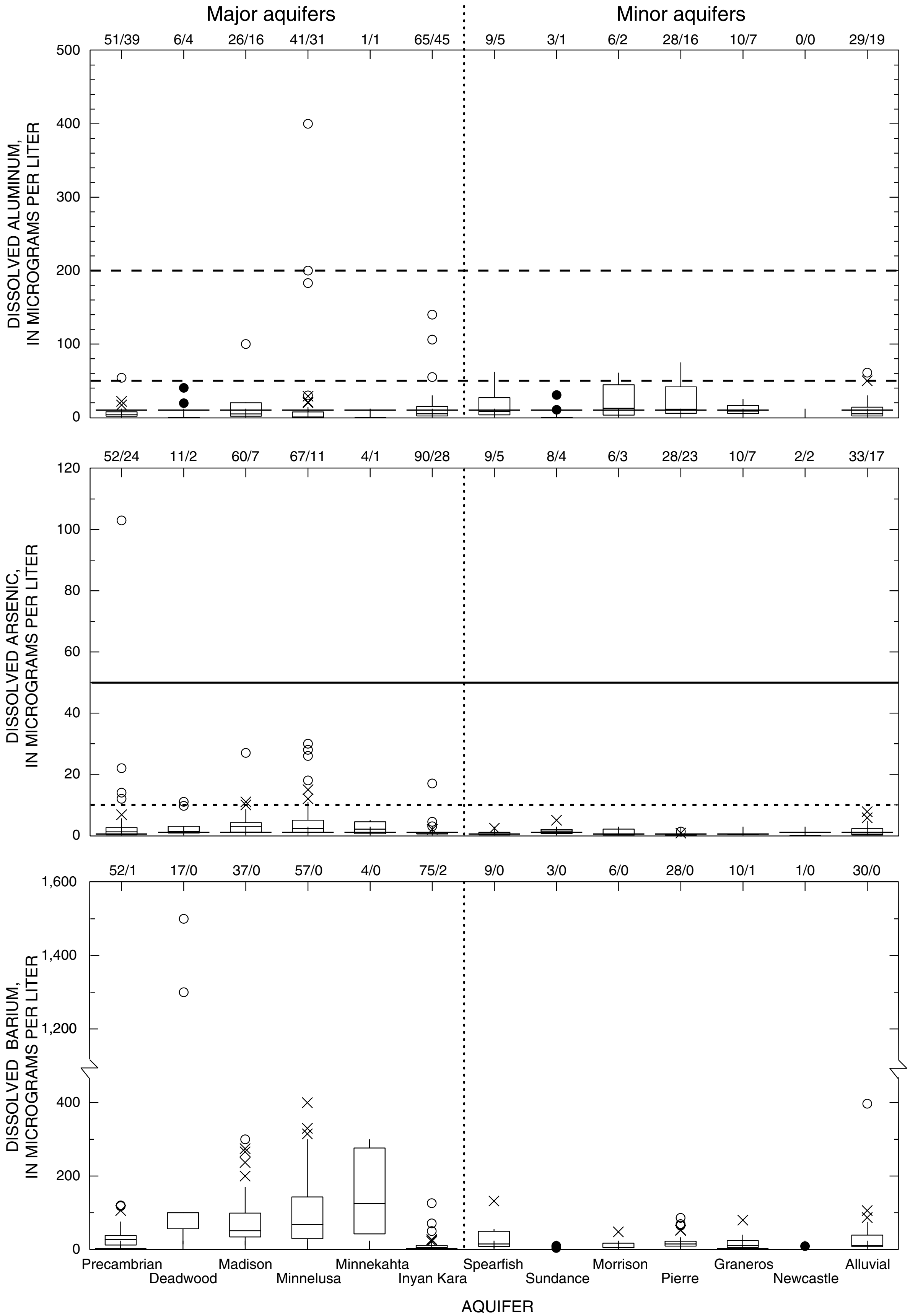


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.

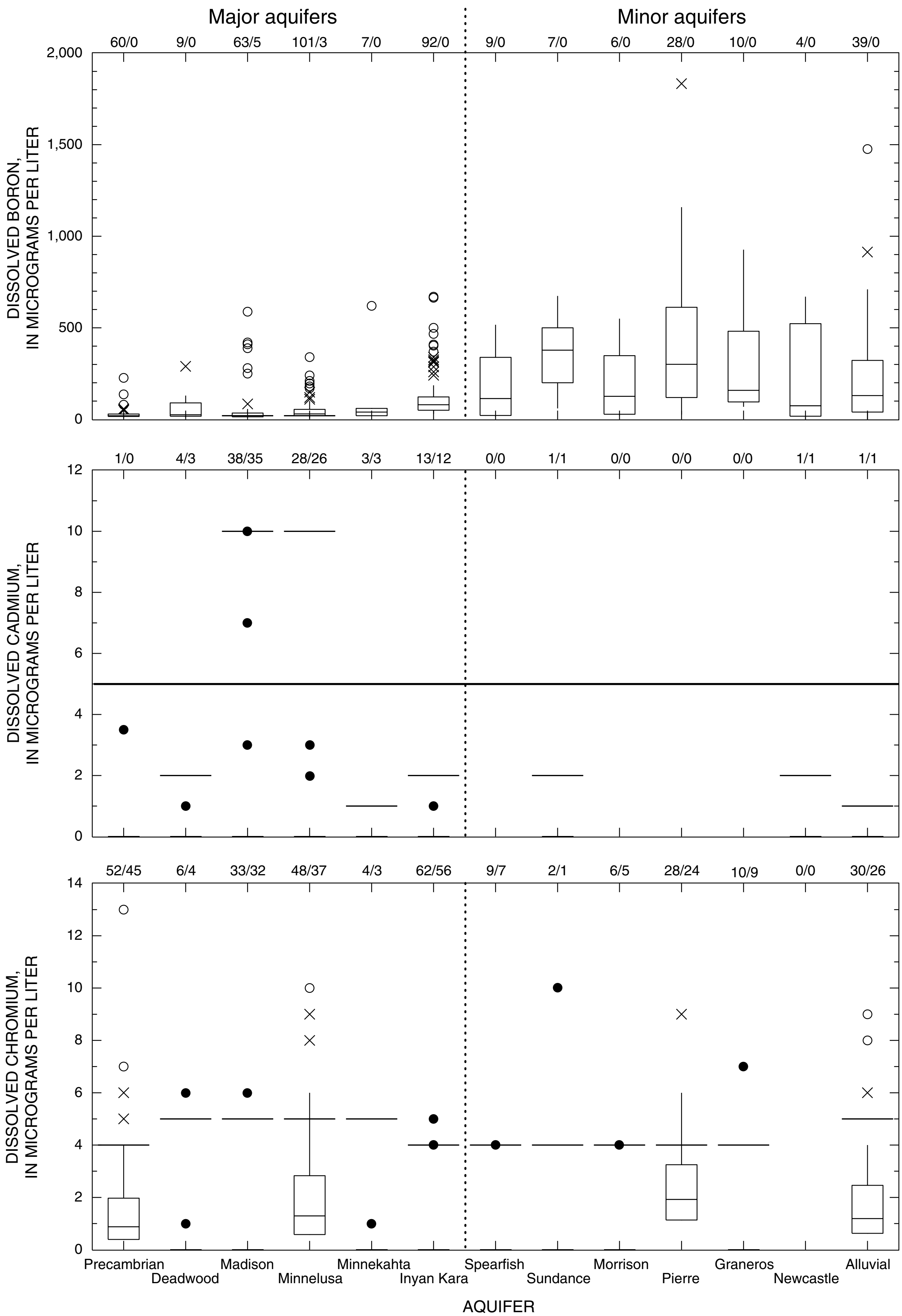


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

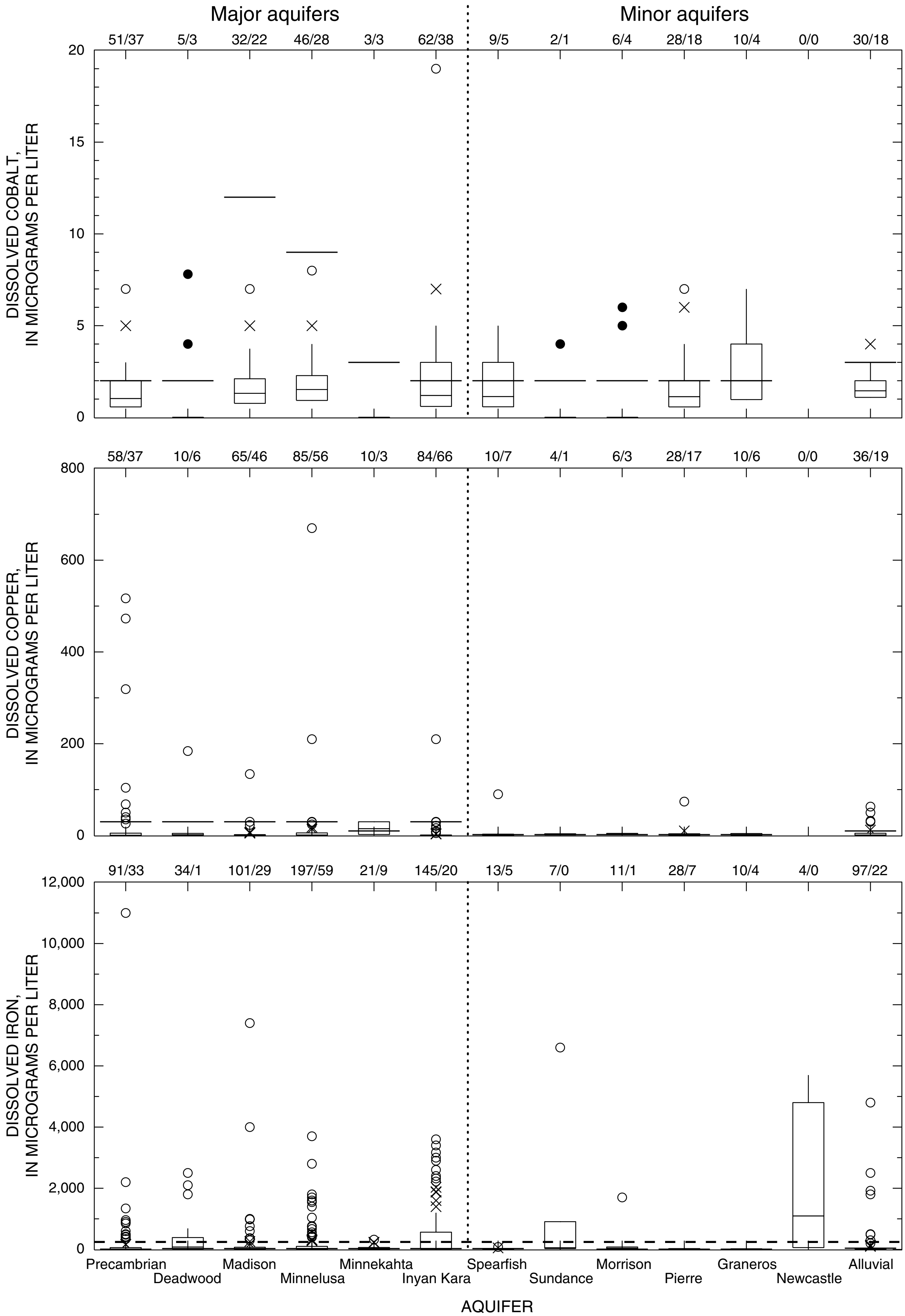


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

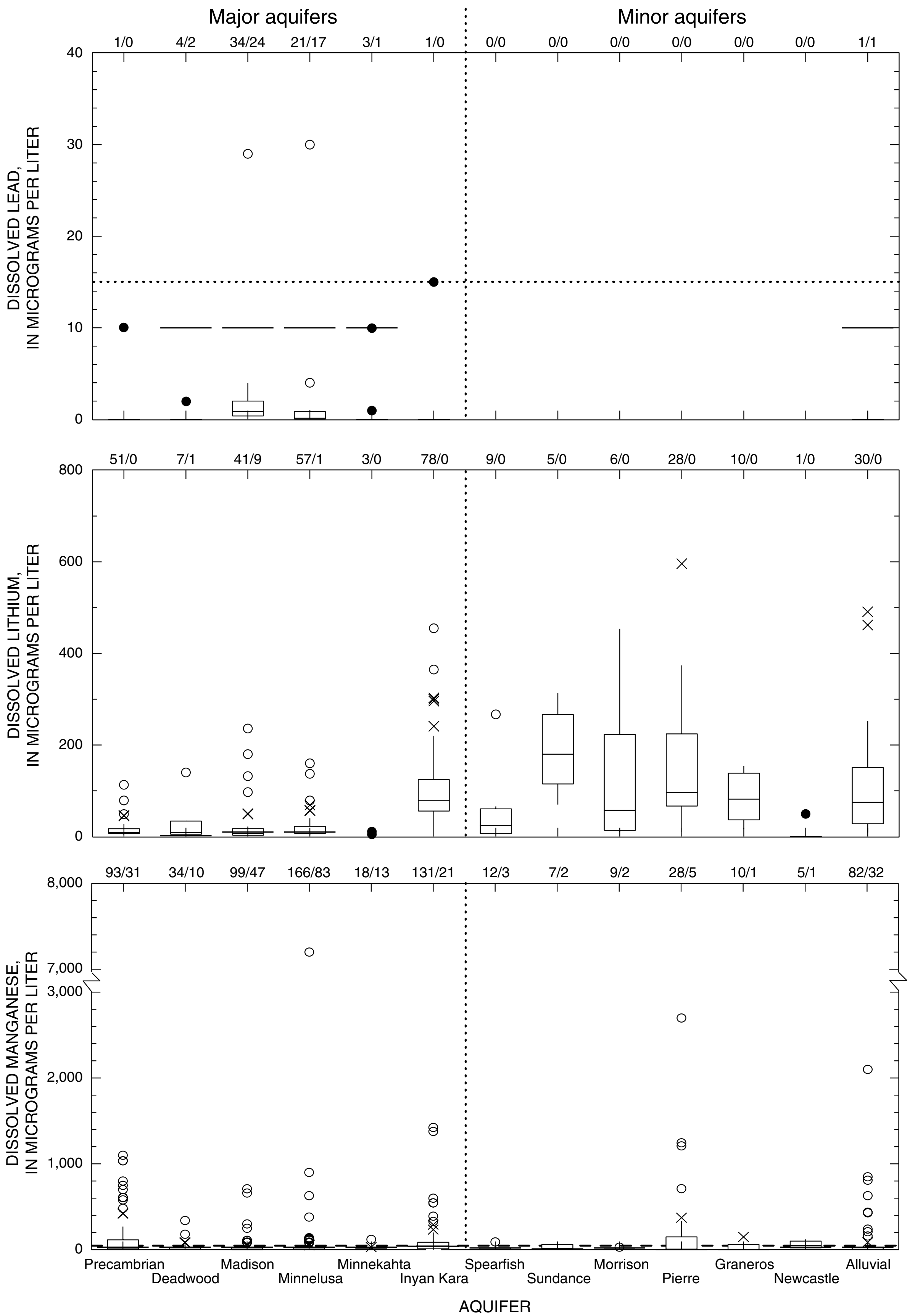


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

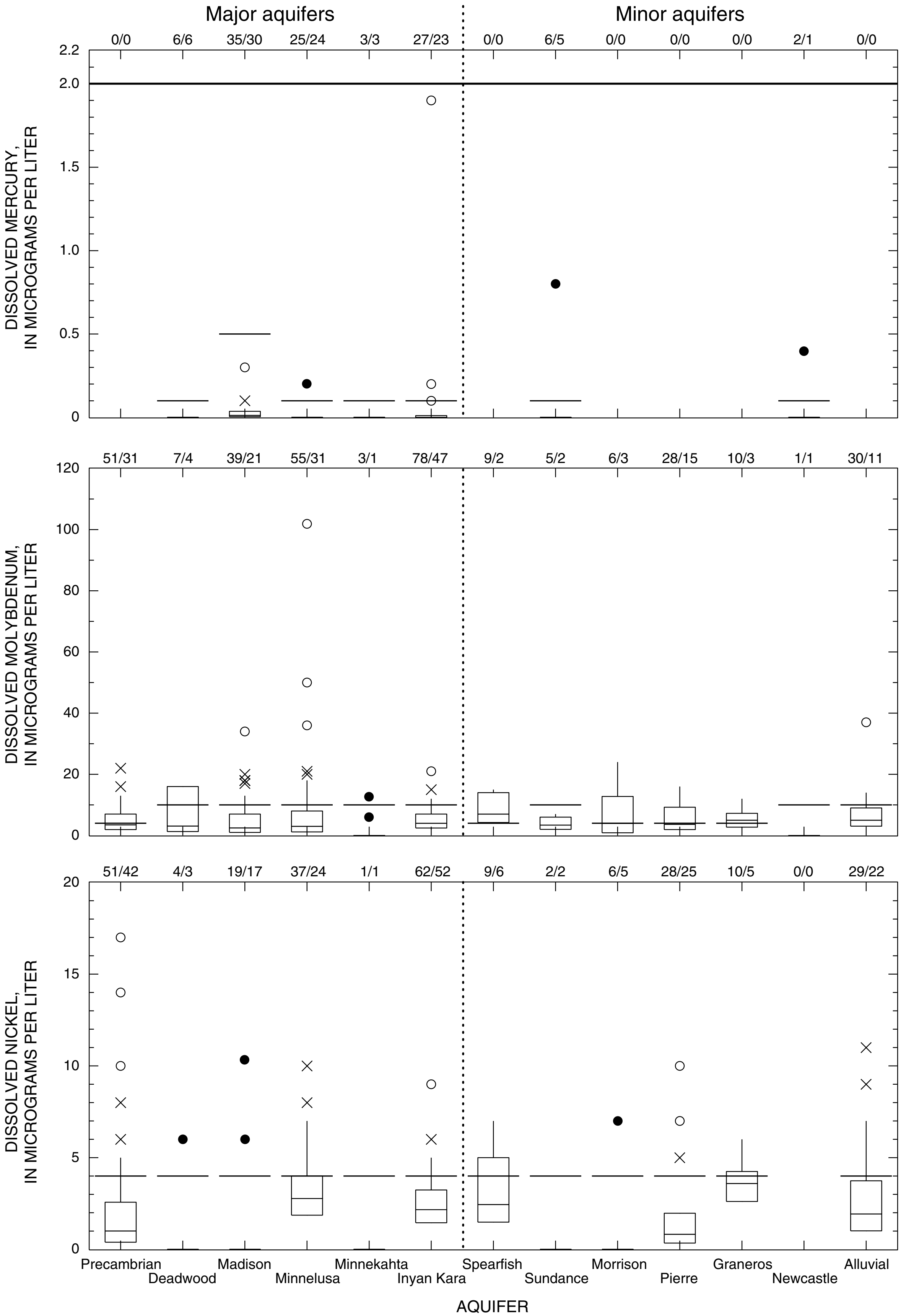


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

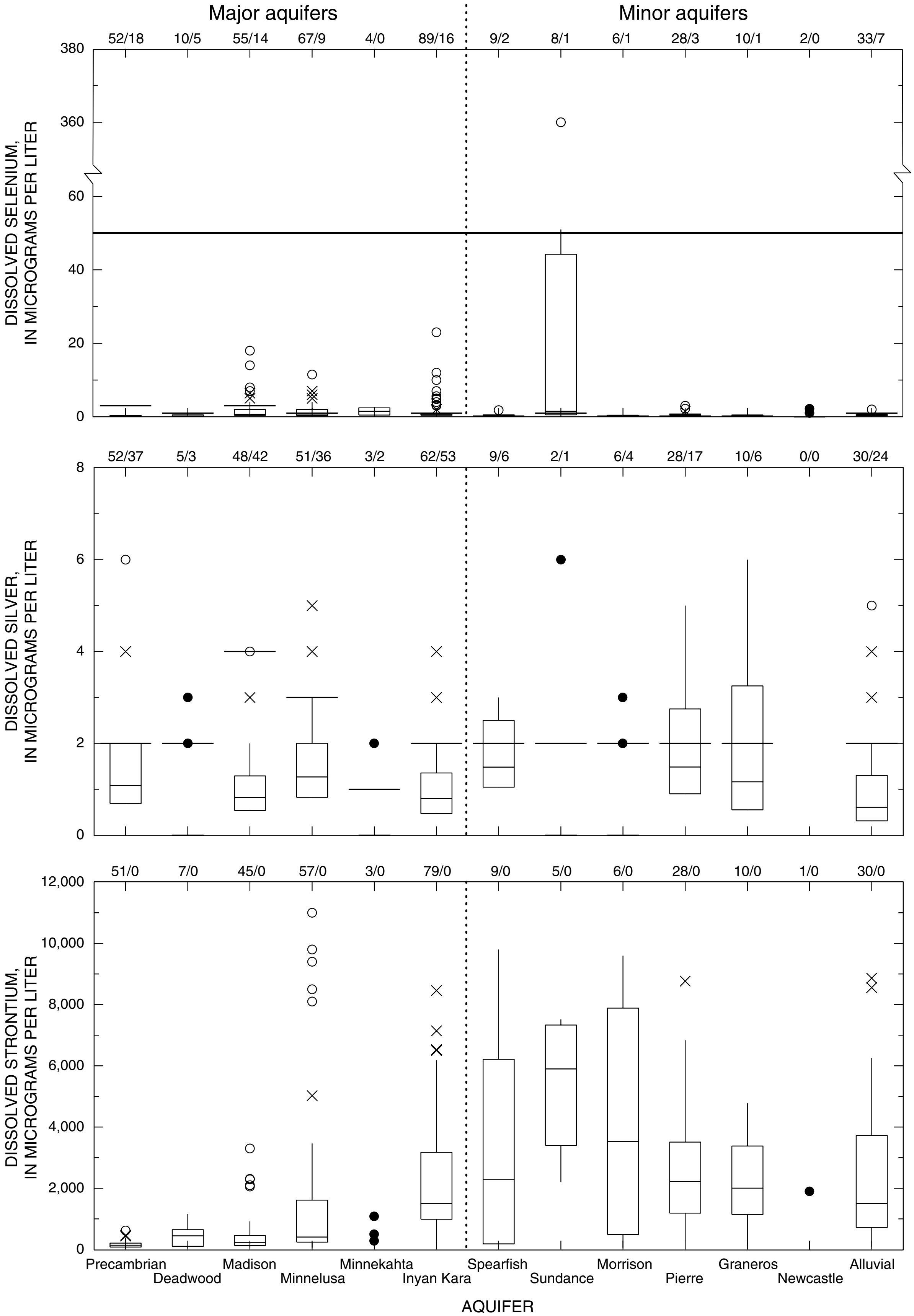


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

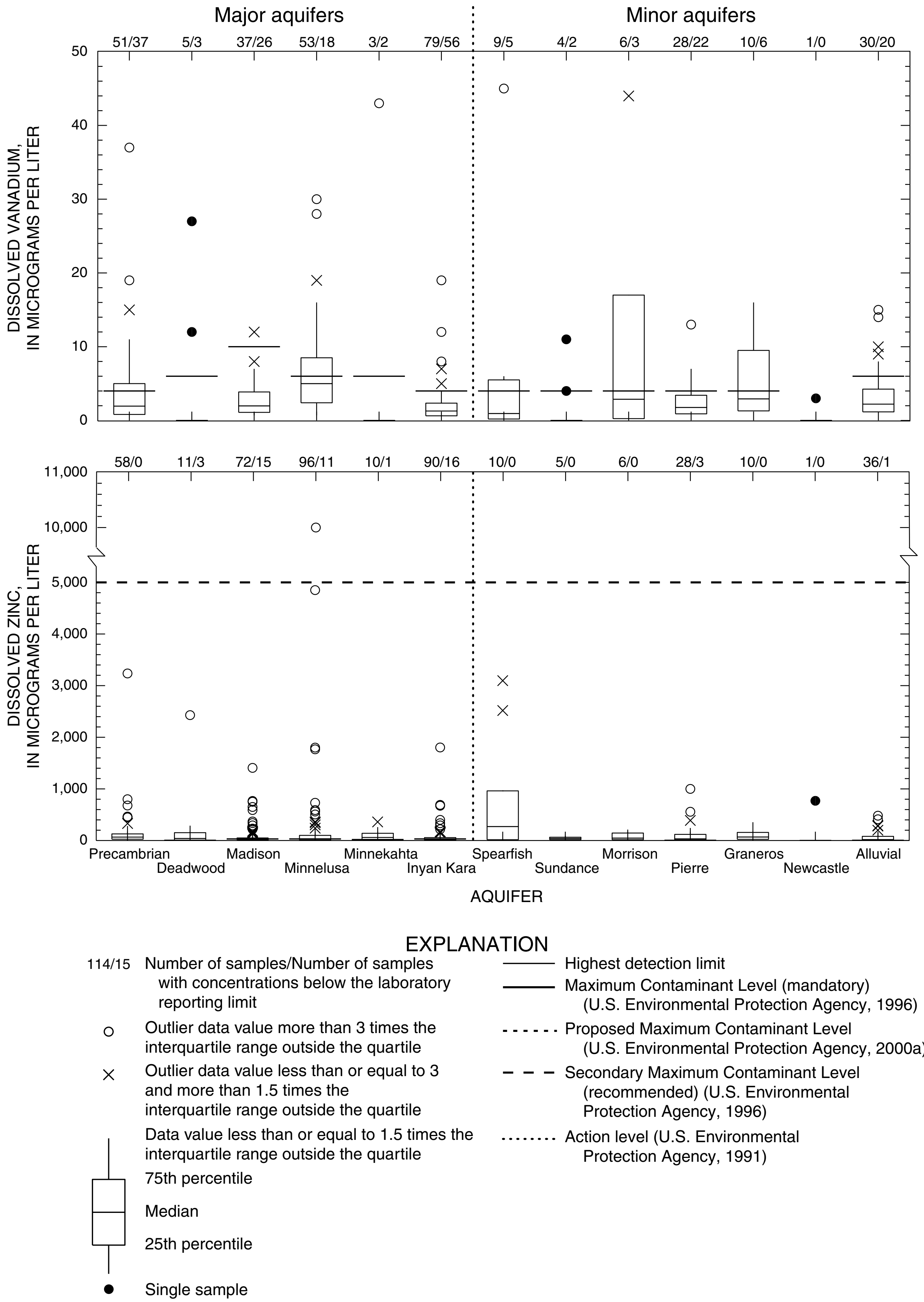


Figure 23. Boxplots of concentrations of selected trace elements for selected aquifers.--Continued

Deadwood Aquifer

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

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

Madison Aquifer

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

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

Minnelusa Aquifer

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

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

Minnekahta Aquifer

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

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

Inyan Kara Aquifer

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

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

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

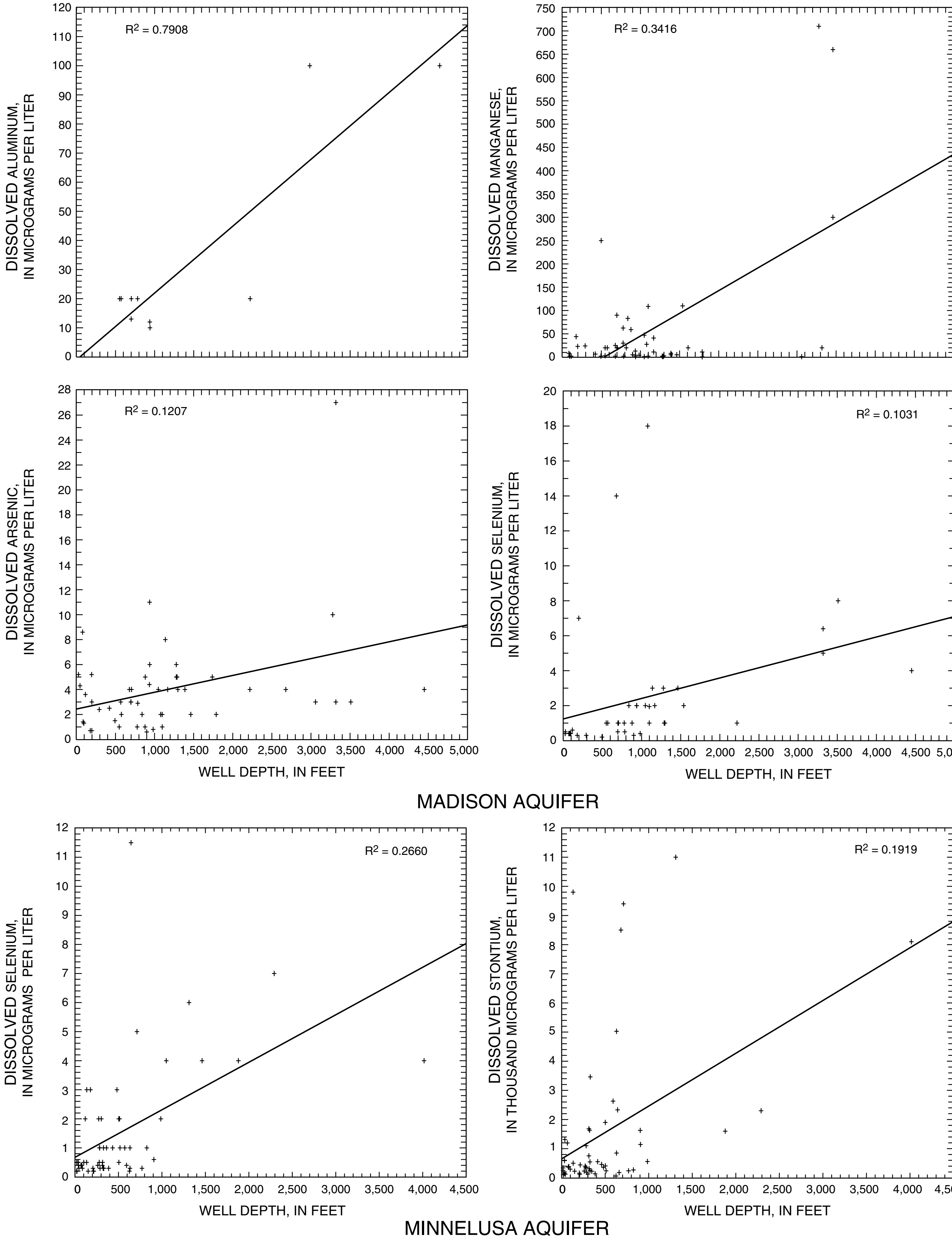


Figure 24. Selected relations between trace elements and well depth for selected aquifers.

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

Minor Aquifers

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

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

Radionuclides

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

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

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

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

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

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

Table 8. Summary of concentrations of radionuclides in ground water

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

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

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

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

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

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

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

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

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

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

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

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

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

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

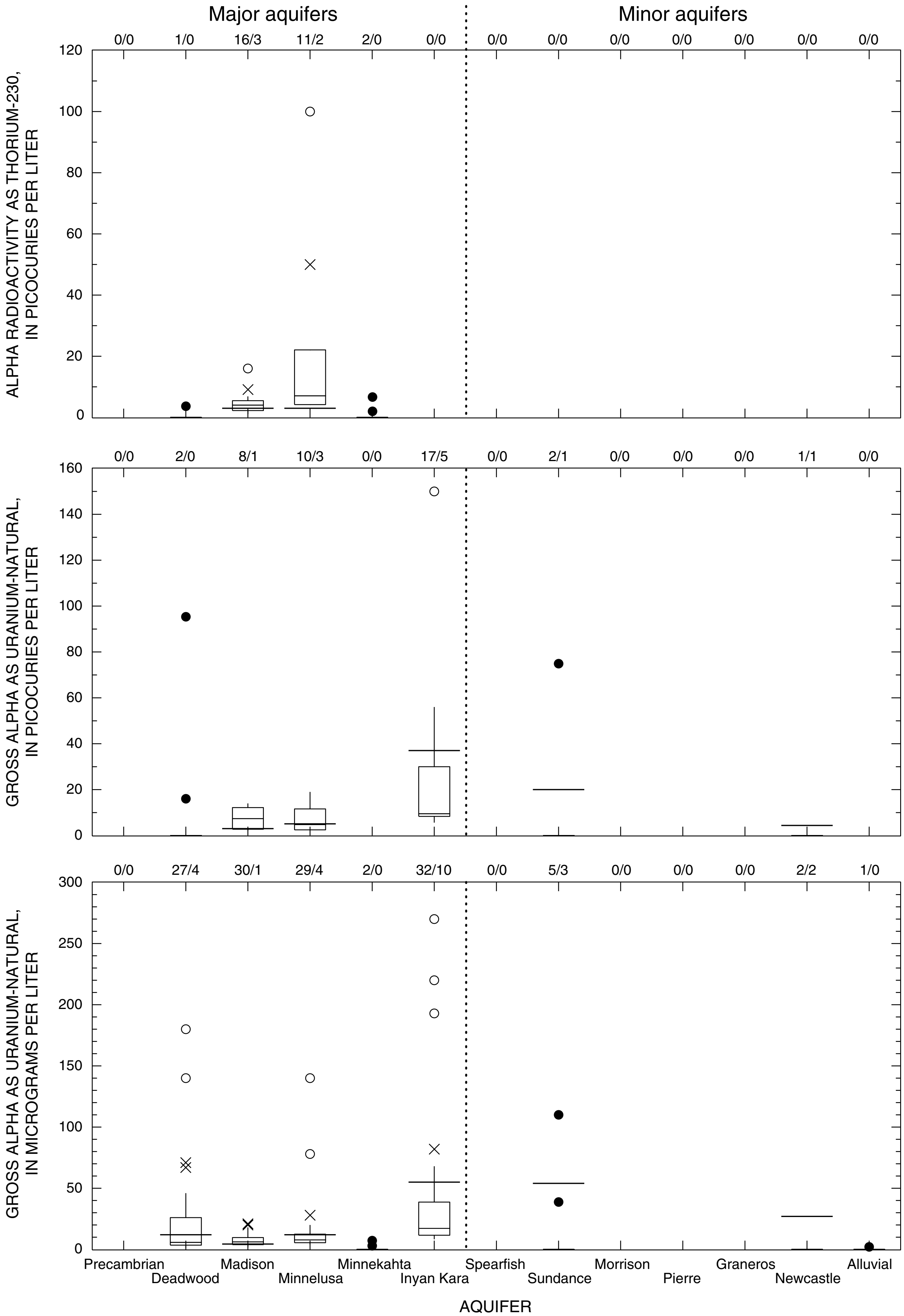


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.

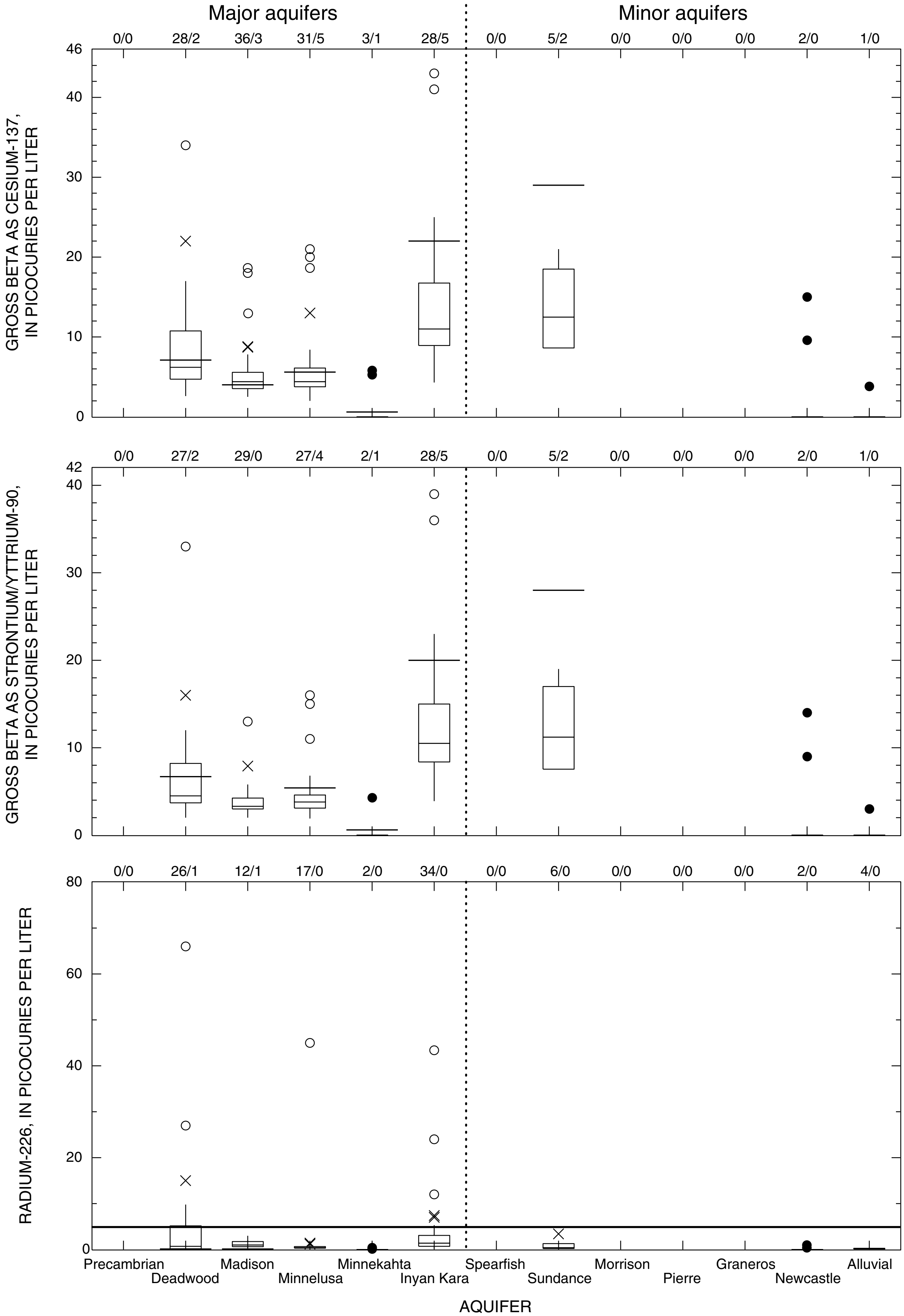


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.--Continued

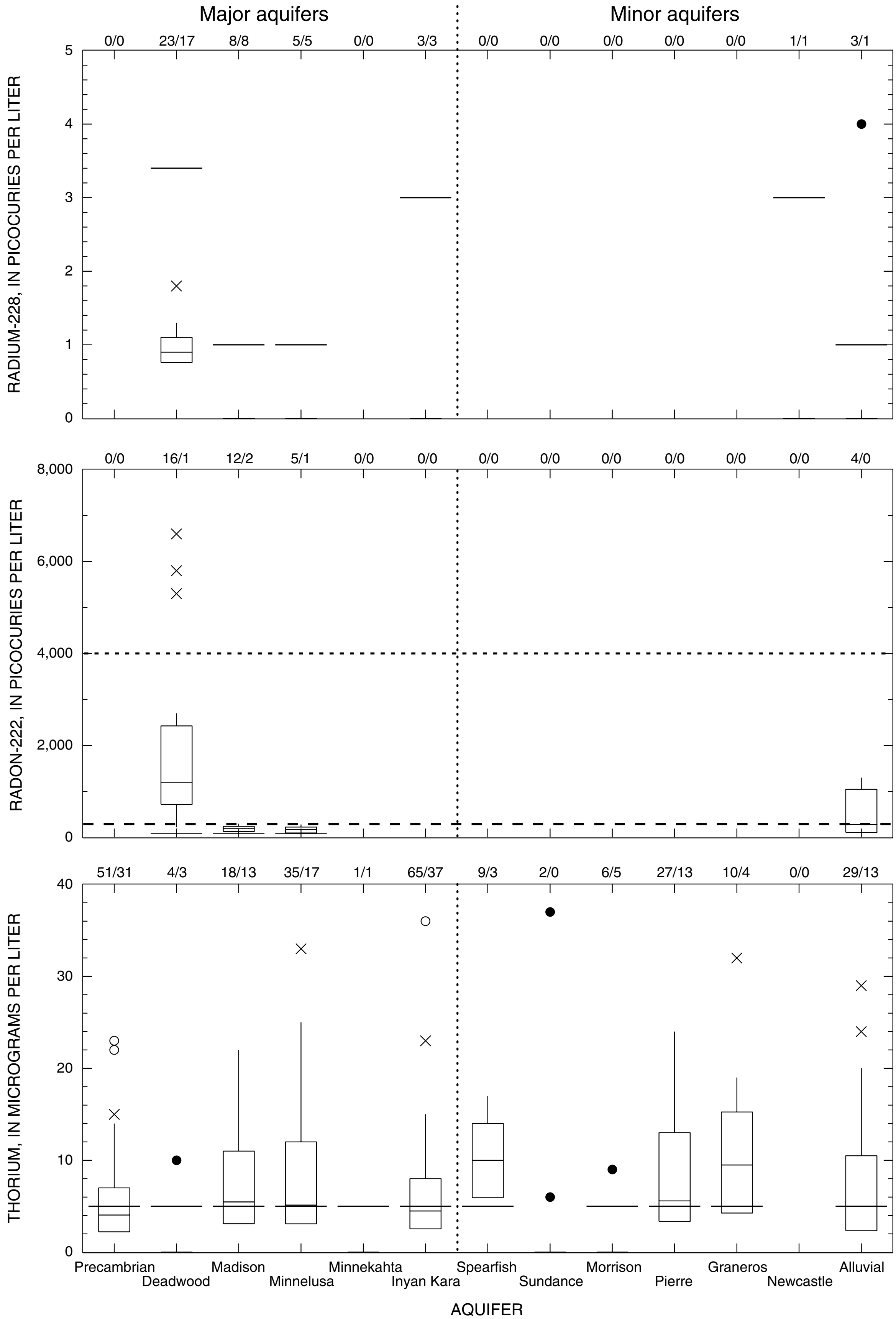
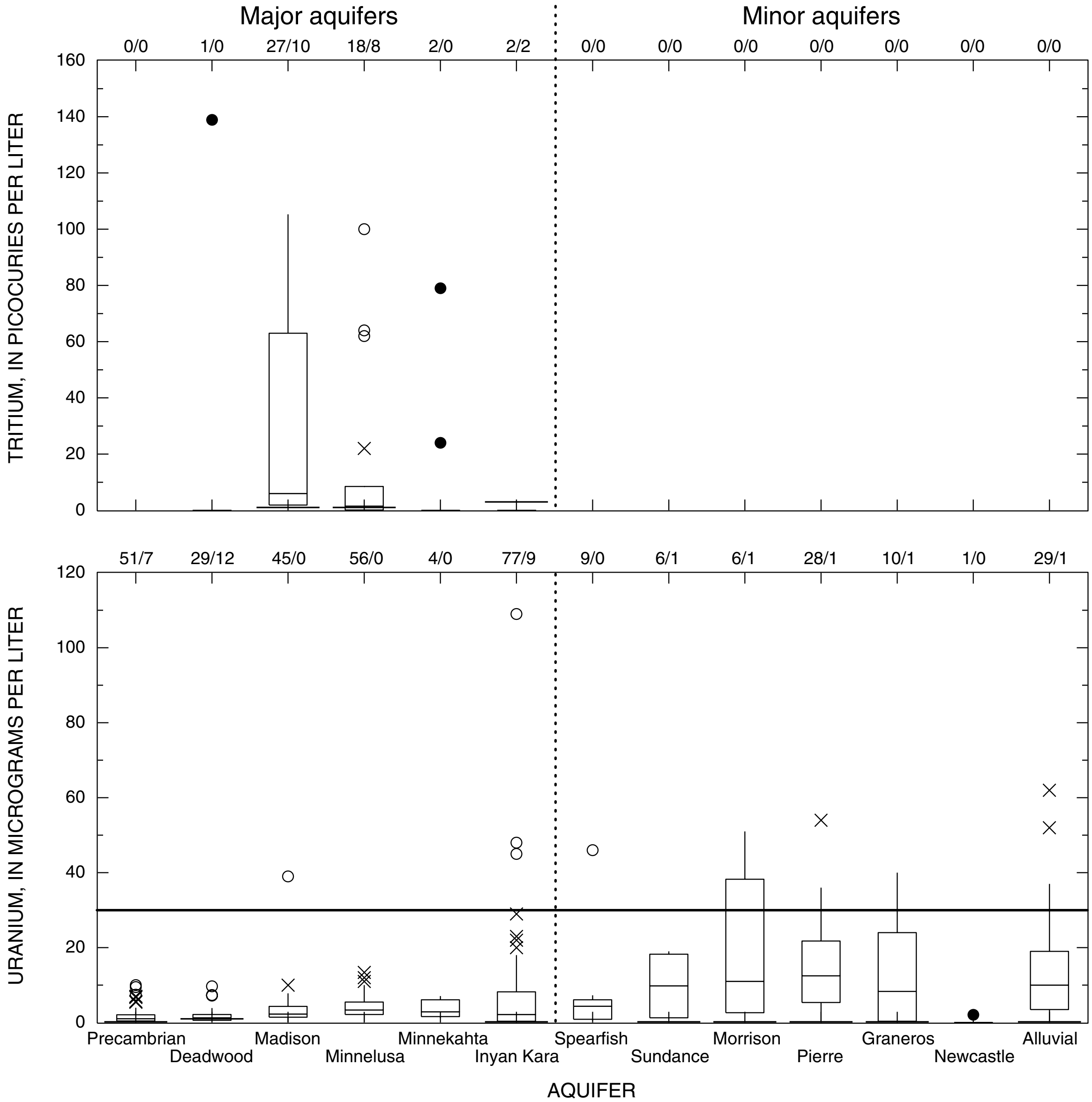


Figure 25. Boxplots of concentrations of selected radionuclides for selected aquifers.--Continued



EXPLANATION

77/9 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) for uranium and for combined radium-226 and radium-228 (U.S. Environmental Protection Agency, 2000b)

Proposed Maximum Contaminant Level for States without an active indoor air program

Proposed Maximum Contaminant Level for States with an active indoor air program

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

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

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

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

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

Deadwood Aquifer

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

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

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

Madison Aquifer

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

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

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

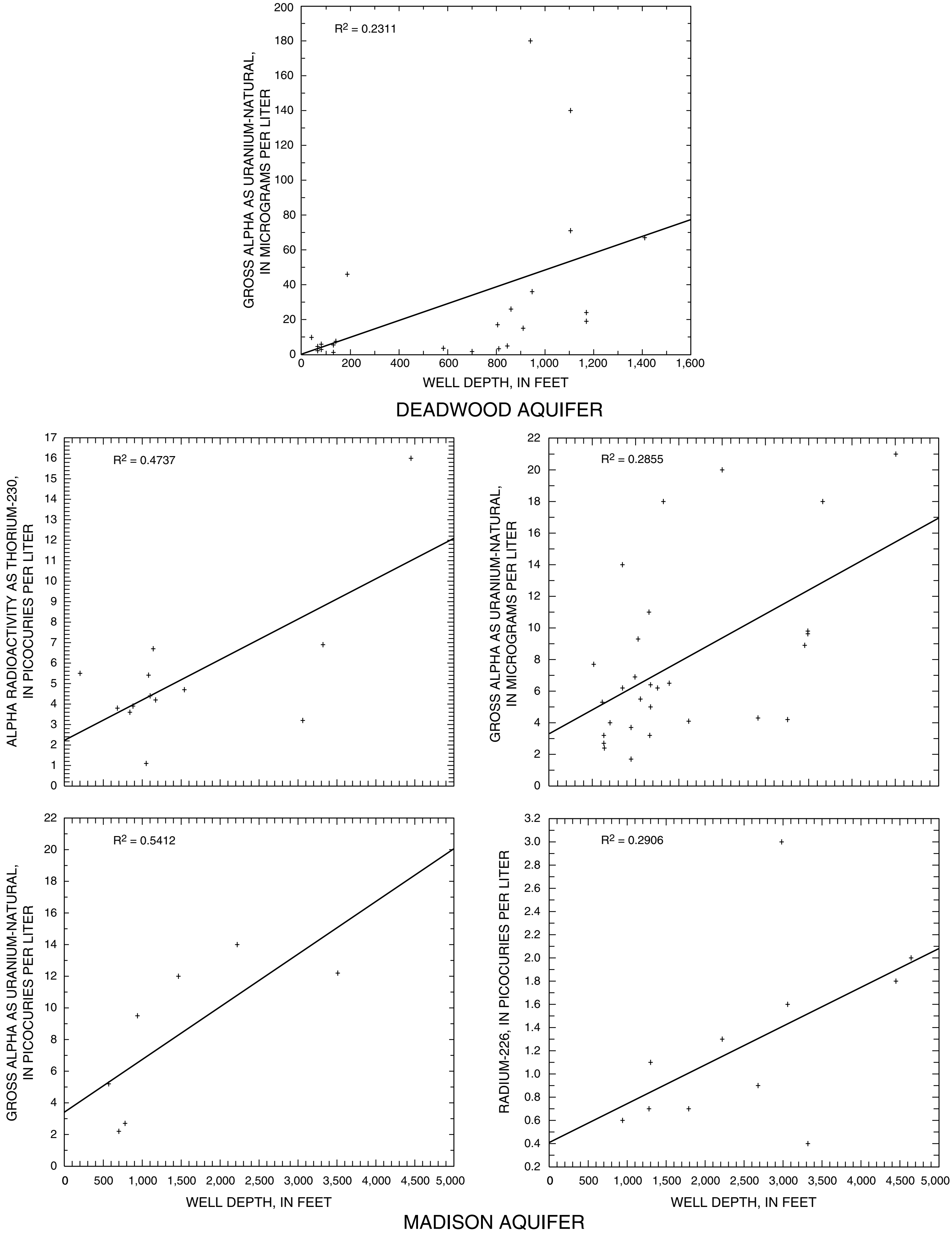


Figure 26. Selected relations between radionuclides and well depth for selected aquifers.

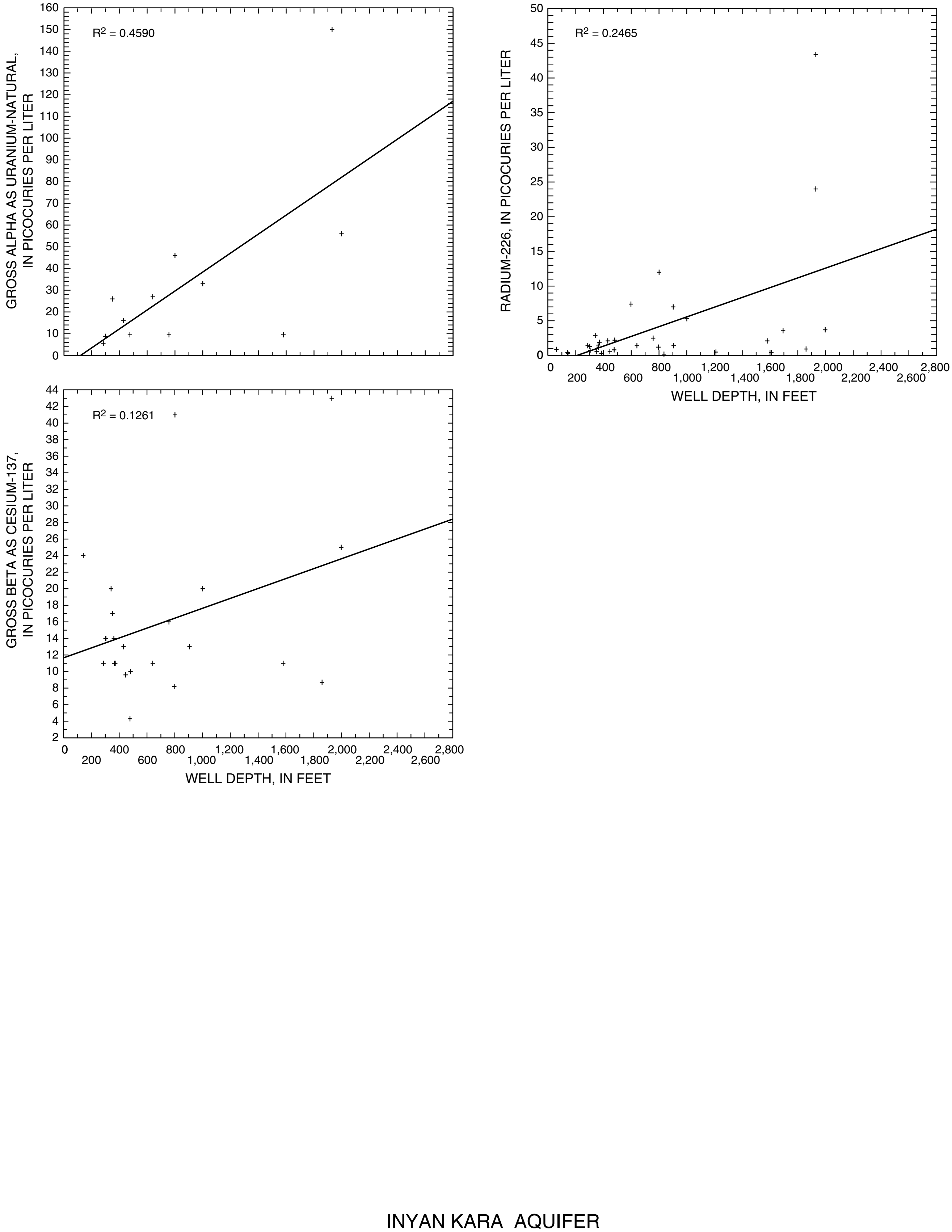


Figure 26. Selected relations between radionuclides and well depth for selected aquifers.--Continued

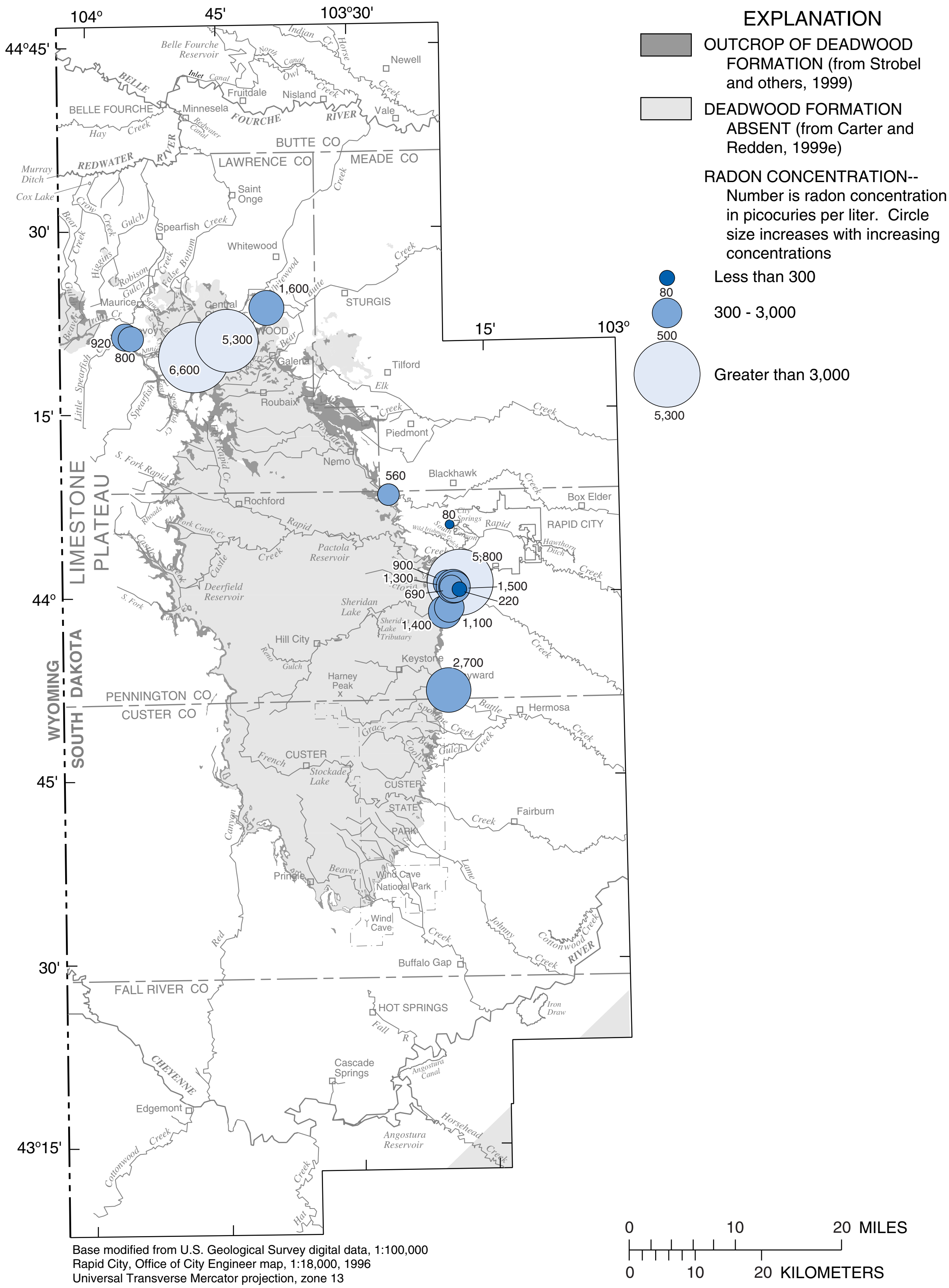


Figure 27. Distribution of radon concentrations in the Deadwood aquifer.