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Source, Occurrence, and Extent of Arsenic in the Grass Mountain Area of the Rosebud Indian Reservation, South Dakota

By Janet M. Carter, Steven K. Sando, and Timothy S. Hayes, U.S. Geological Survey, and Richard H. Hammond, South Dakota Geological Survey

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Source, Occurrence, and Extent of Arsenic in the Grass Mountain Area of the Rosebud Indian Reservation, South Dakota

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ABSTRACT

Elevated concentrations of dissolved arsenic in ground water have been reported in the Grass Mountain area of the Rosebud Indian Reservation, South Dakota. The two possible sources of the arsenic are a naturally occurring source and an arsenic pesticide, which may have been used in the Grass Mountain area to eradicate prairie dogs.

The U.S. Geological Survey, in cooperation with the Rosebud Sioux Tribe, conducted an initial study of arsenic concentrations in ground water and surface water in the Grass Mountain area in 1991 and 1992. A more comprehensive study, which included the sampling of ground water, surface water, bed sediments, springs, and drill-hole cuttings, was conducted in 1995 with additional cooperation from the South Dakota Geological Survey.

The only evidence from the results of the study that supports the pesticide source for the elevated arsenic concentrations is the spatial association of high ground-water arsenic concentrations from several wells and one spring with the prairie dog town. However, because other wells and one spring with elevated arsenic concentrations are not downgradient from the prairie dog town, it is unlikely that the elevated arsenic in the Grass Mountain area is due to pesticides used at the prairie dog town.

Dissolved arsenic in ground water was significantly positively correlated with dissolved vanadium and molybdenum, two of the elements commonly associated with naturally occurring arsenic in rocks. Additionally, elevated uranium concentrations were detected in two of the ground-water samples that had high arsenic concentrations. Because the only probable local source of vanadium, molybdenum, and uranium is natural and because of these elements' association with naturally occurring arsenic in rocks, this supports the conclusion that the source of arsenic is natural.

Both dissolved arsenic (As^{+3} plus As^{+5}) and arsenite (As^{+3}) were significantly negatively correlated with calculated oxidation-reduction potentials (Eh) and dissolved oxygen. The decrease in dissolved oxygen concentrations, increase in dissolved iron and manganese concentrations, and relations between concentrations of dissolved solids, soluble ions, and calculated oxidation-reduction potentials in the ground-water samples provide evidence that ground-water conditions become less oxidizing, accompanied by increased dissolution of rock constituents in the more downgradient wells. Arsenic concentrations were found to increase with pH, which indicates greater solubility at high pH and possibly indicates desorption from solid adsorbent surfaces as pH increases. The pH conditions probably control the adsorption of arsenic, which is present in its highest concentration locally in volcanic ash in the Arikaree Formation.

High pH (above 8.0) appears to allow the release of arsenic, uranium, vanadium, selenium, and molybdenum from the volcanic ash and/or aquifer sediments. These trace elements from the

ash then are transported in solution downgradient, and the redox conditions control the valence state of dissolved arsenic. Farther downgradient where the Arikaree Formation is in contact with alluvium, the oxidation of organic carbonaceous materials may react with dissolved oxygen, resulting in a more reduced ground water. Decreases in pH and Eh probably reach a point where trace elements are converted to a more reduced species and ultimately may be precipitated or adsorbed from solution.

Arsenic concentrations may be further controlled by adsorption effects related to the presence of iron and manganese oxides, and clay minerals, although conclusive evidence of adsorption effects by iron and manganese oxides was not found. Analyses of the surface-water and bed-sediment samples support the possibility of iron- and manganese-oxide adsorptive controls. In surface-water samples, arsenic was significantly positively correlated with dissolved iron; in the bed-sediment samples, arsenic was significantly positively correlated with manganese. Additionally, the reddish color of many drill-hole-cuttings samples indicates the presence of iron oxides.

Elevated arsenic concentrations presently do not appear to be a problem in local surface water because arsenic was not elevated in the dissolved phase, suspended phase, or bed-sediment samples collected from the Little White River and its tributaries nearby. The elevated ground-water arsenic concentrations appear to occur in less than a 1- to 2-mile radius around Grass Mountain Community. However, it is possible that elevated arsenic concentrations could be present in the ground water in other parts of Todd County.

INTRODUCTION

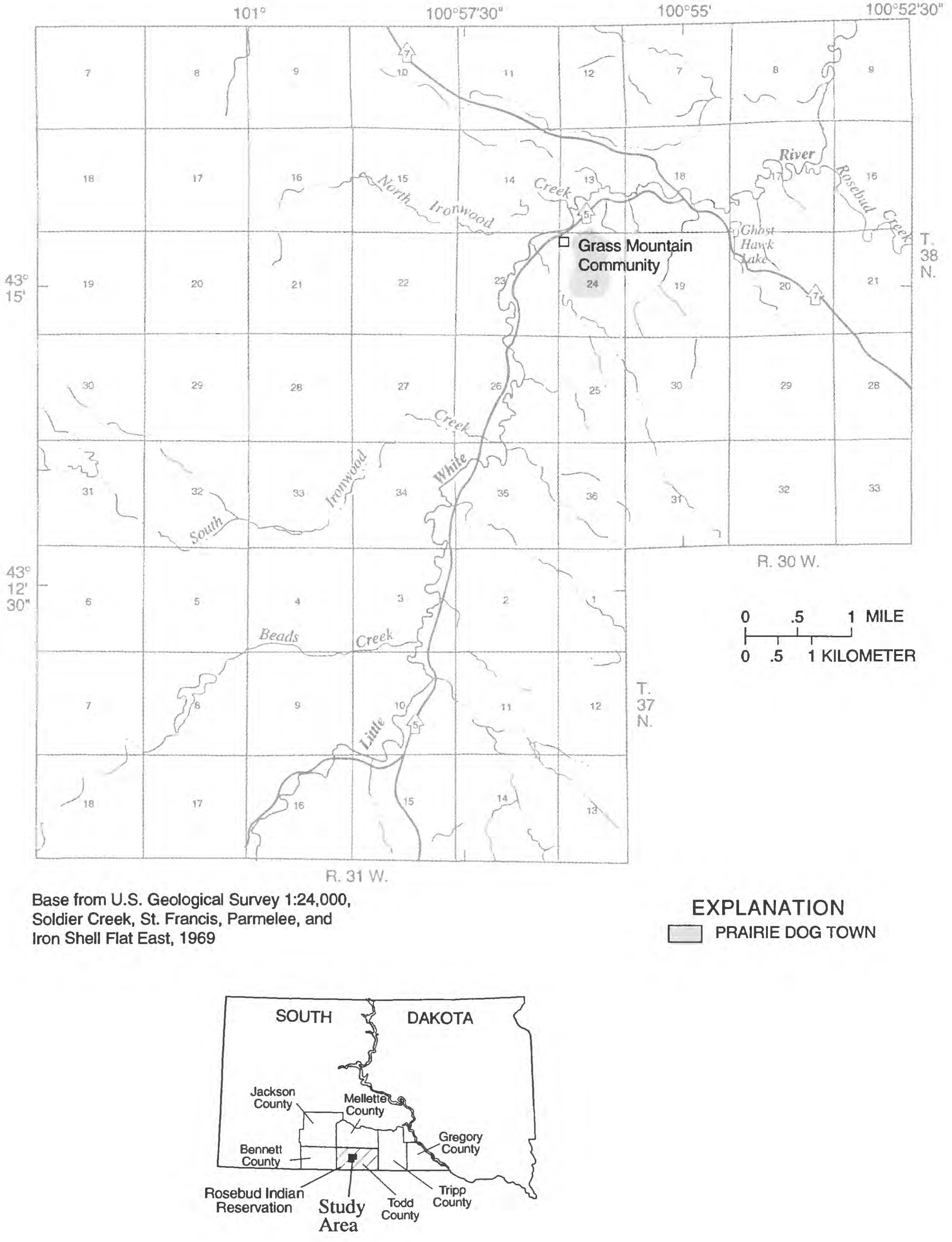
The Grass Mountain area (the study area) is located adjacent to the Little White River about 5 mi (miles) northwest of Rosebud on the Rosebud Indian Reservation, South Dakota (fig. 1). The land in and near the Grass Mountain area is used almost entirely for the grazing of livestock.

Elevated concentrations of arsenic in water from two production wells servicing Grass Mountain Community were detected in 1990 and reported by the Rosebud Sioux Tribe (Huq, 1991). Analyses of the water samples taken from the two production wells indicated arsenic concentrations of 88 and 84 µg/L (micrograms per liter), which exceed the U.S. Environmental Protection Agency's (EPA) drinking water standard of 50 µg/L (U.S. Environmental Protection Agency, 1996). Although the residents of Grass Mountain Community were provided an alternative water source in 1993, the Rosebud Sioux Tribe wanted to determine the extent and source of the arsenic to determine if any private domestic wells were affected, determine whether remediation measures would be necessary, and discern whether arsenic might be a problem in the ground water elsewhere on the reservation.

Arsenic is a known carcinogen to humans (Lucius and others, 1992). The behavior and fate of arsenic in the aquatic environment is highly complex and dependant on many factors including pH, oxidation-reduction (redox) potential (Eh), and the presence of other ions and minerals (Welch and others, 1988). Arsenic in most ground water exists in different oxidation states as As^{+3} (arsenite) or As^{+5} (arsenate), depending on redox conditions. Arsenite is more toxic than arsenate (U.S. Environmental Protection Agency, 1986); however, exposure to elevated concentrations of either species of arsenic is believed to be a very serious health risk (Smith and others, 1992).

Naturally occurring high arsenic concentrations in water in the United States have been attributed to geothermal activity, mining activity, and the reworking of volcanic deposits (Welch and others, 1988). High arsenic concentrations also have been attributed to the use of arsenic compounds, such as Paris-Green (copper acetoarsenite), as pesticides in the early 1900's (Roberts and others, 1985). It is possible that an arsenic pesticide may have been used in the past in the Grass Mountain area to eradicate prairie dogs in the area indicated in figure 1, although there is no formal record of such use. Arsenic is present in all geologic material in all units that form the aquifers beneath the study area. Volcanic ash, which may contain elevated concentrations of arsenic, commonly occurs in some of the geologic units of the Rosebud Indian Reservation and may be a source for the elevated arsenic concentrations in ground water near Grass Mountain Community.

The U.S. Geological Survey (USGS), in cooperation with the Rosebud Sioux Tribe, conducted an initial study of arsenic concentrations in ground water



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

EXPLANATION

▨ PRAIRIE DOG TOWN

Figure 1. Location of study area.

and surface water in the Grass Mountain area in 1991 and 1992. A more comprehensive study, which included the sampling of ground water, surface water, spring water, bed sediments, and drill-hole cuttings, was conducted in 1995 with additional cooperation from the South Dakota Geological Survey (SDGS). The purpose of these studies is to provide better understanding of arsenic occurrence in ground water and to provide the Rosebud Sioux Tribe with the information needed to make sound decisions about future water and land management and possible remedial actions in the Grass Mountain area related to arsenic. The Rosebud Sioux Tribe is especially interested in determining the source of the arsenic, and the extent and magnitude of the elevated arsenic concentrations in ground water and surface water.

Purpose and Scope

This report presents the analytical results, which include arsenic concentrations and common and trace element concentrations, of ground-water, surface-water, spring-water, bed-sediment, and drill-hole-cuttings samples collected in the Grass Mountain area in 1991, 1992, and 1995. This report also presents statistical and geochemical-model results as a basis for evaluating possible sources, occurrence, and extent of arsenic in the study area.

Description of Study Area and General Geology and Hydrology

The study area consists of approximately 58 mi^2 (square miles) near Grass Mountain Community in Todd County (fig. 1). With the exception of Grass Mountain Community, population is sparse in this area and most of the land is accessible only on foot. The Little White River is a perennial stream that flows to the north with an average annual discharge of about 110 ft^3/s (cubic feet per second) in the study area (U.S. Geological Survey, 1996). Quaternary-age alluvium was deposited along the flood plain of the Little White River and its tributaries, and the Miocene-age Arikaree Formation forms the highland away from the river. The creeks that lead from the highland to the river are cut into the Arikaree Formation. The Eocene- and Oligocene-age White River Group underlies the Arikaree Formation. The Arikaree Formation consists generally of tuffaceous (ashy) sandstone and siltstone, and the White River Group consists mostly of tuffaceous mudstone. Volcanic ash is abundant in the Arikaree Formation and White River Group in South Dakota because volcanic activity in Colorado and Wyoming supplied the accumulating Oligocene-age and Miocene-age sediments with airfall ash (U.S. Geological Survey, 1975). The Cretaceous-age Pierre Shale underlies the White River Group. The surficial geology of the Rosebud Indian Reservation is described and shown in Ellis and others (1971).

A potentiometric-surface map of the Arikaree aquifer (hydrogeologic unit corresponding to the Arikaree Formation) in the vicinity of Grass Mountain Community (fig. 2) was constructed from observation-well water levels measured in 1996. The altitudes of the observation wells used in constructing the potentiometric surface were determined using a high-accuracy global positioning system (GPS) and generally have accuracies of about 0.1 ft (feet) (R.C. Thompson, U.S. Geological Survey, written commun., 1997). The general direction of ground-water flow is towards the Little White River and the hydraulic gradient generally is relatively steep near the river. Because only one data point was available from north and west of the Little White River, that area wasn't included in the potentiometric-surface map. Available water-level data (on file with USGS, Rapid City, South Dakota) from outside the study area suggest that ground-water flow on the north and west side of the river also is towards the river.

Several ephemeral springs exist near the Little White River and its tributaries in the Grass Mountain area. The locations of springs also supports that ground-water flow in the Arikaree aquifer is toward the river.

Ground-water discharge from the Arikaree aquifer to the Little White River is observable as streamflow gains in the river within the study area. The Little White River gained about 40 ft^3/s and about 10 ft^3/s between the most upstream and most downstream sites in the study area during the 1991 and 1995 sampling periods, respectively. These gains represented about 30 percent of the total flow at the downstream site in 1991 and about 10 percent in 1995. Although ground-water discharge to the river is supported by the potentiometric surface and the presence of several ephemeral springs near the Little White River, the total gain in the river cannot be entirely attributed to ground water because several small intermittently flowing tributaries also discharge to the river within this reach.

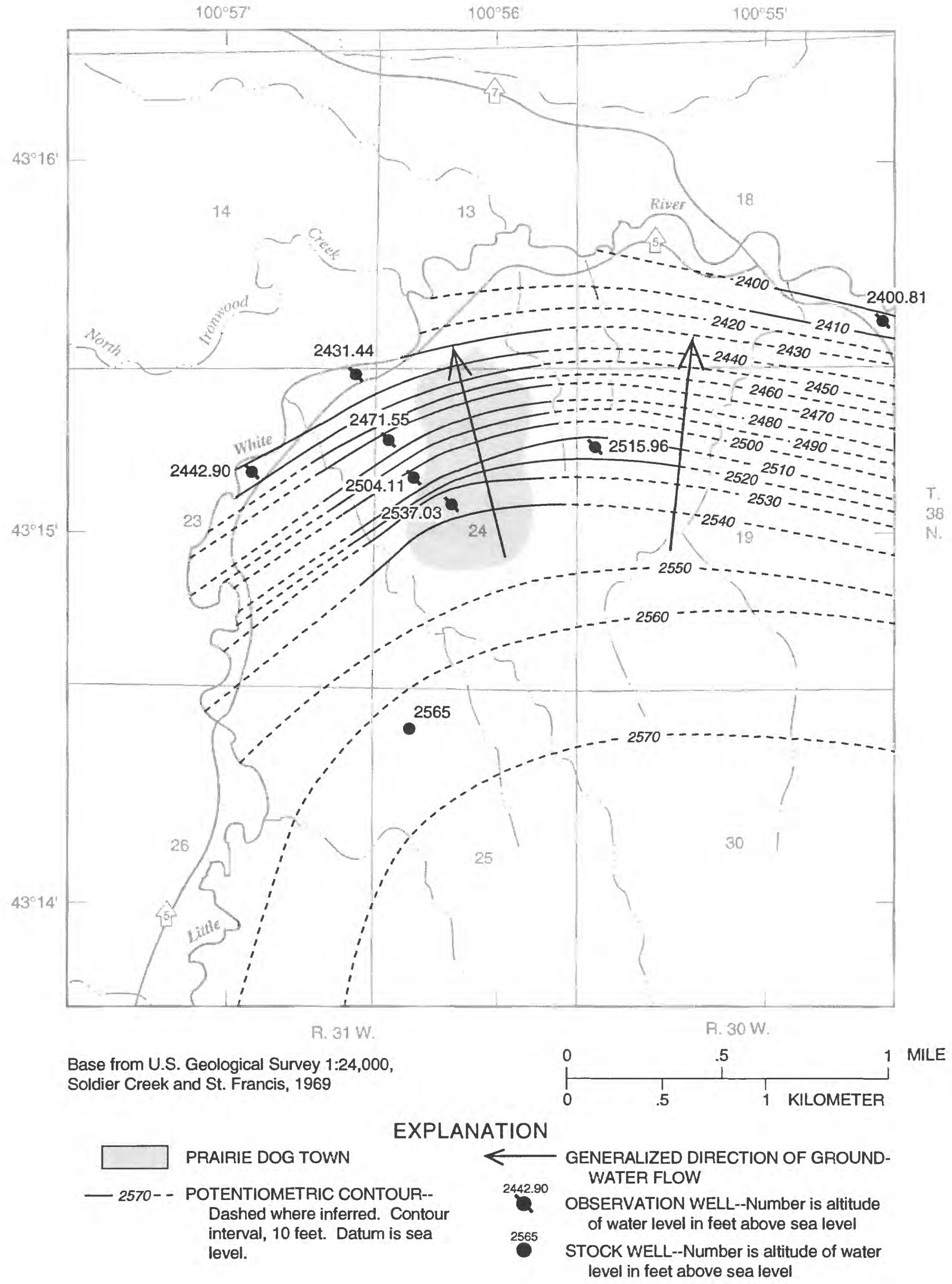


Figure 2. Potentiometric surface of the Arikaree aquifer in the vicinity of Grass Mountain Community, 1996.

Acknowledgments

The authors thank Syed Huq, Charles Mack, John Whiting, and Mark Witt from the Office of Water Resources of the Rosebud Sioux Tribe for providing valuable assistance throughout the studies, including the collection of water-quality samples. The SDGS drilled test holes and installed observation wells for the study in 1995. The cooperation of many residents of the Grass Mountain area who provided access to their property and to wells for these studies is appreciated.

SAMPLING SITES

Water samples were collected from wells, springs, and surface-water sites; bed-sediment samples were collected from surface-water sites; and drill-hole cuttings were collected at observation wells during their construction. During the studies (1991-95), ground-water samples were collected from 21 well sites, which included community, private, and observation wells (table 1). The local number for the wells (table 1) is based on the Federal land-survey system of western South Dakota (fig. 3). Locations of the wells are shown in figure 4. All private domestic and stock wells in the study area that could be located and sampled were used in the studies. Although well logs were unavailable for some of the private wells, it was assumed that all of these wells were completed in the Arikaree aquifer based on known depths of other wells in the area and because the Arikaree aquifer is the shallowest water source in the area (Ellis and others, 1971). The No Heart, Whipple, and Swimmer domestic wells may be partially completed in the alluvial aquifer because of the shallow well depths, but for analysis purposes, these wells were assumed to be completed in the Arikaree aquifer.

Three observation wells were installed for the study in 1991 by the Rosebud Sioux Tribe (table 1: observation wells 1, 2, and 3). Between 1992 and 1995, the Grass Mountain Community well, observation well 2, the Swimmer domestic well, and the Whipple domestic well were destroyed. In 1995, seven additional observation wells were drilled and installed by SDGS for the study. Observation well 4 replaced the destroyed Grass Mountain Community well and observation well 8 replaced observation well 2. All observation wells were drilled using hydraulic rotary methods, were cased with 2-inch diameter polyvinyl chloride (PVC), and were screened with a 10-ft length of 2-inch diameter slotted PVC. All wells were developed with compressed air. A 582-ft test hole was drilled on the north side of the Little White River at 38N31W14DABA. An observation well was not installed at this location because no aquifer was encountered during the drilling; the bottom of the test hole was in the Pierre Shale. Drill-hole-cuttings samples were collected during the drilling of all observation wells and cuttings samples from three of those wells (indicated on fig. 4) were analyzed in 1995.

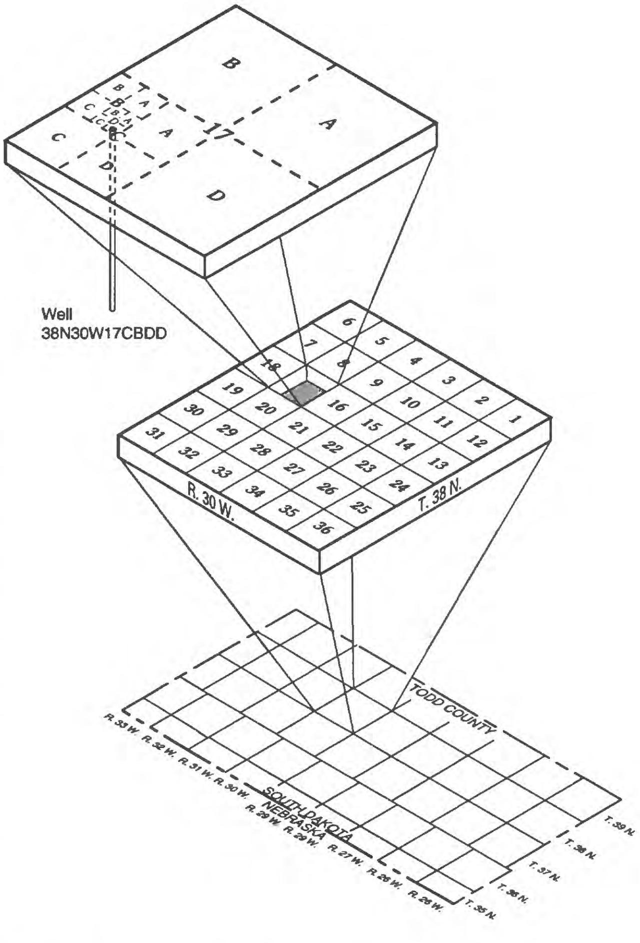


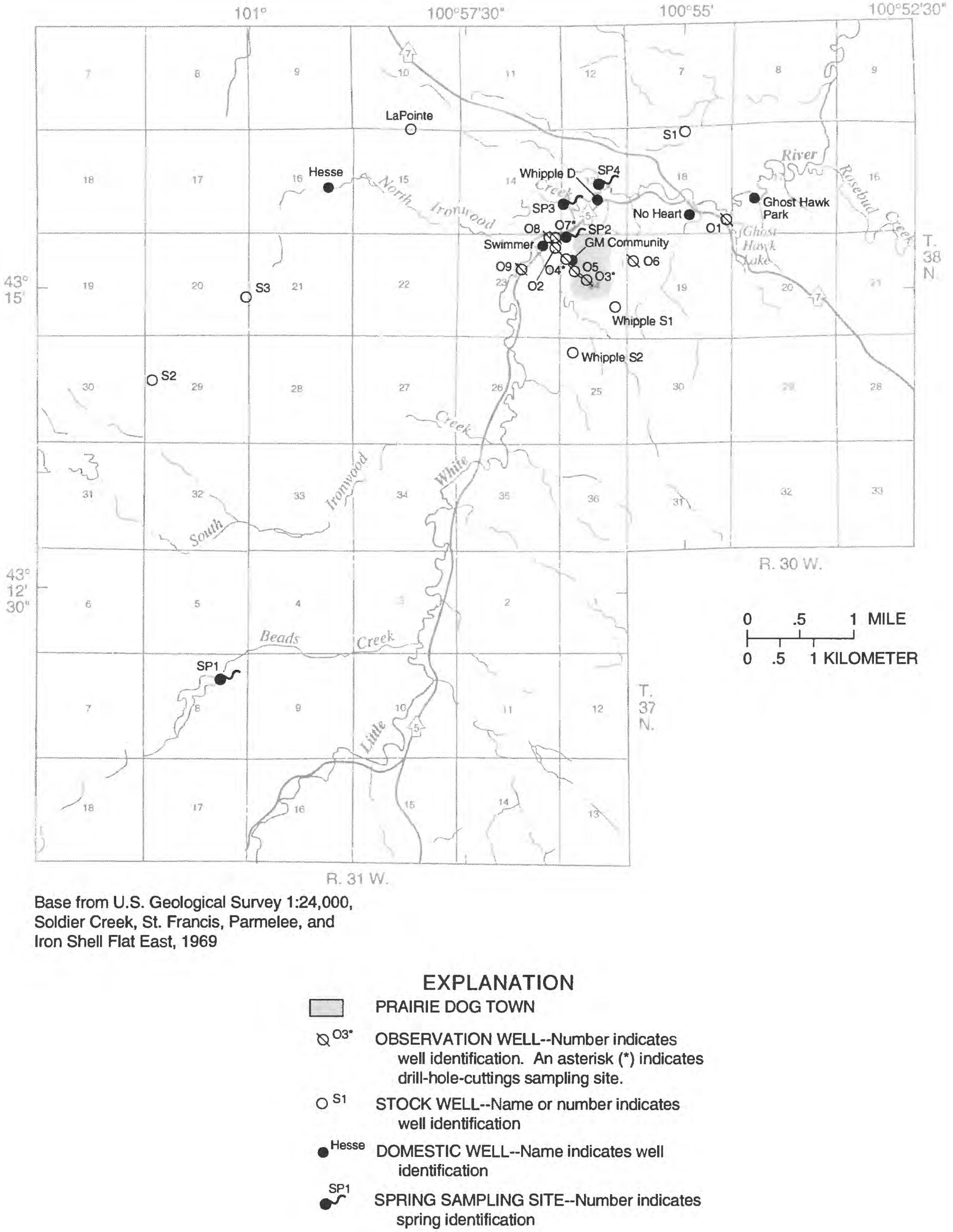
Figure 3. Well-location diagram. The well number consists of the township, followed by "N," the range number followed by "W," and the section number, followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2 1/2-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2 1/2-acre tract.

Table 1. Site information and well-construction data for ground-water sampling locations

[--, data not available]

Well name	Site identification number	Well location	Aquifer	Land-surface altitude[1] (feet above sea level)	Depth of well (feet below land surface)	Open interval (feet below land surface)	Date depth to water level measured	Depth to water level[1] (feet below land surface)	Altitude of water level[1] (feet)
Ghost Hawk Park well	431545100541501	38N30W17CBDD	Alluvium	2,408	--	--	--	--	--
Stock well 1	431620100560601	38N30W18BAAA	Arikaree	2,562	--	--	--	--	--
No Heart domestic well	431540100545801	38N30W18DCBD	Arikaree[2]	2,425	27	14-27	--	--	--
Observation well 1	431536100543101	38N30W18DDAD	Arikaree	2,419.62	62	55-60	09-13-95	18.81	2,400.81
Observation well 6	431515100553901	38N30W19BCBA	Arikaree	2,659.35	274	264-274	10-02-96	143.39	2,515.96
LaPointe stock well	431620100581301	38N31W10DCCC	Arikaree	2,772	--	--	--	--	--
Whipple domestic well[3]	431547100555601	38N31W13DABC	Arikaree[2]	2,425	--	--	--	--	--
Hesse domestic well	431520100593601	38N31W16DBAA	Arikaree	2,710	128	124-128	08-07-75	[4]18.5	2,691.5
Stock well 3	431501101005701	38N31W20DADA	Arikaree	2,939	140	90-140	07-15-65	[4]6	2,933
Observation well 2[3]	431526100563201	38N31W23AAAB	Alluvium	2,445	33	28-33	09-25-91	12.95	2,432
Observation well 7	431526100563202	38N31W23AAAB2	Arikaree	2,442.71	60	50-60	10-02-96	11.27	2,431.44
Observation well 8	431526100563203	38N31W23AAAB3	Alluvium	2,442.55	33	23-33	10-02-96	11.84	2,430.71
Swimmer domestic well[3]	431525100563801	38N31W23ABAD2	Arikaree[2]	2,446	--	--	--	--	--
Observation well 9	431505100565801	38N31W23ACCB	Arikaree	2,459.49	73	63-73	10-02-96	16.59	2,442.90
Observation well 3	431505100560901	38N31W24ACCA	Arikaree	2,671.97	227	217-227	09-12-95	134.94	2,537.03
Grass Mountain Community well[3]	431515100562701	38N31W24BDAC	Arikaree	2,600	--	--	--	--	--
Observation well 4	431517100562301	38N31W24BDAC2	Arikaree	2,573.99	242	222-242	10-02-96	102.44	2,471.55
Observation well 5	431508100562101	38N31W24BDAD	Arikaree	2,604.68	262	252-262	10-02-96	100.57	2,504.11
Whipple stock well 1	431455100554801	38N31W24DADB	Arikaree	2,680	300	--	--	--	--
Whipple stock well 2	431427100561201	38N31W25BBAC	Arikaree	2,722	360	300-360	06-04-81	[4]157	2,565
Stock well 2	431415101010601	38N31W29BCCB	Arikaree	2,920	--	--	--	--	--

[1] Reported to two decimal places if altitudes of wells were determined using global positioning system.
[2] May be partially completed in alluvium.
[3] Well was destroyed between 1992 and 1995.
[4] Data from drillers' logs.



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

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O3* OBSERVATION WELL--Number indicates well identification. An asterisk (*) indicates drill-hole-cuttings sampling site.

○ S1 STOCK WELL--Name or number indicates well identification

● Hesse DOMESTIC WELL--Name indicates well identification

SP1 SPRING SAMPLING SITE--Number indicates spring identification

Figure 4. Locations of ground-water, drill-hole-cuttings, and spring-water sampling sites.

During the initial study in 1991 and 1992, ground-water samples were collected from all observation, domestic, and production wells that existed at that time; surface-water samples also were collected from selected sites on the Little White River. During the comprehensive study in 1995, all ground-water sites (except the wells that had been destroyed) and surface-water sites that were sampled in the initial study were re-sampled. Water samples also were collected from newly constructed observation wells, from additional private domestic and stock wells, from additional surface-water sites on the Little White River and its tributaries, and from selected springs. The four springs, sampled by SDGS, are shown in figure 4. Bed-sediment samples were collected from all of the surface-water sampling sites, and drill-hole cuttings were collected from the construction of all observation wells and analyzed for selected observation wells (fig. 4). Water-quality and bed-sediment samples were collected from 11 stream sites: 8 were collected from the Little White River and 3 were collected from tributaries of the Little White River. Locations of the surface-water and bed-sediment sites are shown in figure 5.

WATER-QUALITY, BED-SEDIMENT, AND DRILL-HOLE-CUTTINGS DATA

A list of the properties and constituents analyzed in samples of ground water, spring water, surface water, bed sediments, and drill-hole cuttings is presented in table 2. Properties and constituents in the ground-water and surface-water samples that were not analyzed in both 1991 and 1995 are indicated in table 2. Methods of sample processing and analysis, as well as laboratories performing the analyses for the various data collected, are presented in table 3. Analytical results are presented in the Supplemental Information section at the end of this report for ground-water samples (table 4), spring-water samples (table 5), surface-water samples (table 6), bed-sediment samples (table 7), and drill-hole-cuttings samples (table 8). In this report, the term "dissolved" refers to any constituent concentration that was determined from water that had been filtered through a 0.45-µm (micrometer) membrane filter.

Quality-assurance samples were collected to evaluate precision and accuracy of the collection, processing, and analysis of samples. These quality-assurance samples included field blanks for the ground-water and surface-water samples, duplicate samples for the ground-water, surface-water, spring-water, bed-sediment, and drill-hole-cuttings samples, and spiked samples for the ground-water and spring-water samples.

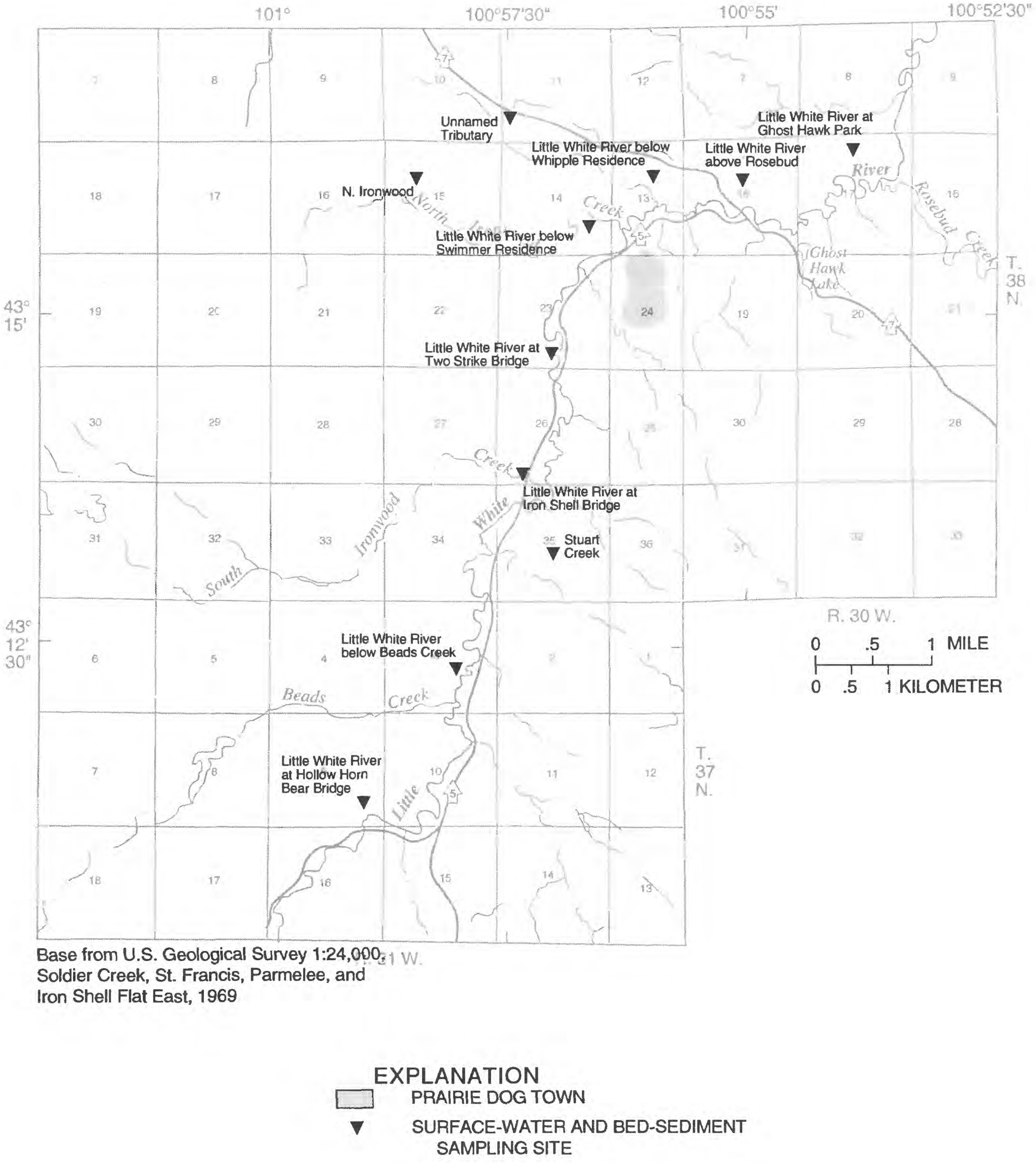
Methods of Collection

Sample collection methods used in this study were designed with the intent that the analytical results were representative of the matrices as they existed in their natural condition, and were based on accepted USGS procedures in effect at the time of collection. The intent to collect representative samples of ground water, surface water, spring water, bed sediment, and drill-hole cuttings required different collecting procedures for the various sample types.

Ground-Water and Spring-Water Samples

The collection of ground-water samples in 1991 and 1992 followed methods presented in Wood (1976). In 1995, many methods described by Horowitz and others (1994) for the collection and processing of surface-water samples were applied to the ground-water sampling program. All ground-water sampling equipment that came in contact with the sample water (submersible pump, tubing, bailer, and churn splitters) was cleaned prior to the sampling trip with a phosphate-free detergent, dilute hydrochloric acid, and deionized water according to procedures described by Horowitz and others (1994). After samples were collected from a well, the sampling device (pump or bailer) and tubing were rinsed with deionized water before sampling the next well.

In order to assure that a representative sample was collected from the aquifer at each well, the ground-water samples were collected after purging a minimum of three casing volumes from the well and after continuous field measurements of specific conductance, pH, and water temperature had stabilized (Wood, 1976). Stability was reached when specific conductance differed less than 5 percent between readings, pH differed less than 0.1 standard units between readings, and water temperature differed less than 0.2°C between readings. Samples were collected from the observation wells using a stainless-steel submersible pump. Water from the observation wells was passed through a flow-through chamber without coming into contact with the atmosphere so that field measurements were measured in a closed system. The samples were collected in appropriate bottles directly from a collection tube.



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

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▼ SURFACE-WATER AND BED-SEDIMENT SAMPLING SITE

Figure 5. Locations of surface-water and bed-sediment sampling sites.

Table 2. Properties and constituents analyzed in samples of ground water, surface water, spring water, bed sediment, and drill-hole cuttings

Ground water		Springs	Surface water		Bed sediment	Drill-hole cuttings
Property	**Constituent**	**Constituent**	**Property**	**Constituent**	**Constituent**	**Constituent**
Specific conductance	Dissolved oxygen[1]	Specific conductance	Discharge	Dissolved oxygen[1]	Calcium	Calcium
	Alkalinity[1]		Specific conductance		Magnesium	Magnesium
pH	Bicarbonate[1]	Temperature		Alkalinity[1]	Sodium	Sodium
Temperature	Carbonate[1]	Arsenic	pH	Bicarbonate[1]	Potassium	Potassium
Oxidation-reduction potential[1]	Calcium		Temperature	Carbonate[1]	Phosphorus	Phosphorus
	Magnesium			Calcium	Aluminum	Aluminum
	Sodium			Magnesium	Arsenic	Arsenic
	Potassium			Sodium	Beryllium	Beryllium
	Sulfate			Potassium	Bismuth	Bismuth
	Chloride			Sulfate	Cadmium	Cadmium
	Fluoride			Chloride	Cerium	Cerium
	Silica			Fluoride	Chromium	Chromium
	Dissolved solids			Silica	Cobalt	Cobalt
	Nitrogen[2]			Dissolved solids	Copper	Copper
	Phosphorus[2]			Nitrogen[2]	Europium	Europium
	Arsenic			Phosphorus[2]	Gallium	Gallium
	Cadmium			Arsenic	Gold	Gold
	Chromium			Cadmium	Holmium	Holmium
	Copper			Chromium	Iron	Iron
	Iron			Copper	Lanthanum	Lanthanum
	Lead			Iron	Lead	Lead
	Manganese			Lead	Lithium	Lithium
	Mercury			Manganese	Manganese	Manganese
	Molybdenum[1]			Mercury	Molybdenum	Molybdenum
	Selenium			Molybdenum[1]	Neodymium	Neodymium
	Uranium[1]			Selenium	Nickel	Nickel
	Vanadium[1]			Uranium[1]	Niobium	Niobium
	Zinc			Vanadium[1]	Scandium	Scandium
	Arsenic speciation[1]			Zinc	Selenium	Selenium
					Silver	Silver
					Strontium	Strontium
					Tantalum	Tantalum
					Thorium	Thorium
					Thorium	Thorium
					Tin	Tin
					Titanium	Titanium
					Uranium	Uranium
					Vanadium	Vanadium
					Ytterbium	Ytterbium
					Yttrium	Yttrium
					Zinc	Zinc

[1] Only analyzed in 1995.

[2] Only analyzed in 1991.

Table 3. Processing and analytical methods for properties and constituents analyzed in samples of ground water, surface water, springs, bed sediment, and drill-hole cuttings

[ASF, automated-segmented flow; CVAA, cold-vapor atomic absorption spectrometry; E, electrometric; FAA, flame atomic absorption spectrometry; GDACSC, USGS Geologic Division Lab; GFAA, graphite-furnace atomic absorption spectrometry; GR, gravimetric; HAA, hydride atomic absorption spectometry; IC, ion chromatography; ICP/AES, inductively coupled plasma-atomic emission spectrometry; ISE, ion-selective electrode; IT, incremental titration; LP, laser phosphorence; MBMG, Montana Bureau of Mines and Geology Laboratory; ME, membrane electrode; NA, not applicable; SDWCL, South Dakota Geological Survey Water Chemistry Laboratory; NWQL, USGS National Water Quality Laboratory; T, thermometric]

Property or constituent	Analysis location	Analytical method	Preservation and processing methods
		Water samples	
Discharge	field	Carter and Davidian, 1968	NA
Specific conductance	field	E	NA
pH	field	E	NA
Temperature	field	T	NA
Dissolved oxygen	field	ME	NA
Oxidation-reduction potential	field	E	NA
Alkalinity	field	IT	NA
Bicarbonate	field	IT	NA
Carbonate	field	IT	NA
Calcium, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Magnesium, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Sodium, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Potassium, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Sulfate, dissolved	NWQL	IC	filter with 0.45-µm cartridge filter
Chloride, dissolved	NWQL	IC	filter with 0.45-µm cartridge filter
Fluoride, dissolved	NWQL	ISE	filter with 0.45-µm cartridge filter
Silica, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Solids, dissolved	NWQL	GR	filter with 0.45-µm cartridge filter
Ammonia, as N, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter; chill to 4°C
Nitrate plus nitrite, as N, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter; chill to 4°C
Nitrite, as N, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter; chill to 4°C
Phosphorus, ortho-, as P, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter; chill to 4°C
Arsenic, dissolved	NWQL; MBMG; SDWCL	HAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Arsenic speciation, dissolved	MBMG		filter with 0.45-µm cartridge filter
Cadmium, dissolved	NWQL	GFAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Chromium, dissolved	NWQL	GFAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Copper, dissolved	NWQL	GFAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Iron, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Lead, dissolved	NWQL	GFAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Manganese, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Mercury, dissolved	NWQL	CVAA	filter with 0.45-µm cartridge filter; acidify with $HNO_3/K_2Cr_2O_7$ to pH<2
Molybdenum, dissolved	NWQL	GFAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Selenium, dissolved	NWQL	HAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Uranium, dissolved	NWQL	LP	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2
Vanadium, dissolved	NWQL	ASF	filter with 0.45-µm cartridge filter
Zinc, dissolved	NWQL	FAA	filter with 0.45-µm cartridge filter; acidify with HNO_3 to pH<2

Table 3. Processing and analytical methods for properties and constituents analyzed in samples of ground water, surface water, springs, bed sediment, and drill-hole cuttings—Continued

Property or constituent	Analysis location	Analytical method	Preservation and processing methods
Bed-sediment and drill-hole-cuttings samples			
Calcium	GDACSG	ICP/AES	
Magnesium	GDACSG	ICP/AES	
Sodium	GDACSG	ICP/AES	
Potassium	GDACSG	ICP/AES	
Phosphorus	GDACSG	ICP/AES	
Aluminum	GDACSG	ICP/AES	
Arsenic	GDACSG	ICP/AES; HAA	
Beryllium	GDACSG	ICP/AES	
Bismuth	GDACSG	ICP/AES	
Cadmium	GDACSG	ICP/AES	
Cerium	GDACSG	ICP/AES	
Chromium	GDACSG	ICP/AES	
Cobalt	GDACSG	ICP/AES	
Copper	GDACSG	ICP/AES	
Europium	GDACSG	ICP/AES	
Gallium	GDACSG	ICP/AES	
Gold	GDACSG	ICP/AES	
Holmium	GDACSG	ICP/AES	
Iron	GDACSG	ICP/AES	
Lanthanum	GDACSG	ICP/AES	
Lead	GDACSG	ICP/AES	
Lithium	GDACSG	ICP/AES	
Manganese	GDACSG	ICP/AES	
Molybdenum	GDACSG	ICP/AES	
Neodymium	GDACSG	ICP/AES	
Nickel	GDACSG	ICP/AES	
Niobium	GDACSG	ICP/AES	
Scandium	GDACSG	ICP/AES	
Selenium[1]	GDACSG	HAA	
Silver	GDACSG	ICP/AES	
Strontium	GDACSG	ICP/AES	
Tantalum	GDACSG	ICP/AES	
Thorium	GDACSG	ICP/AES	
Thorium	GDACSG	ICP/AES	
Tin	GDACSG	ICP/AES	
Titanium	GDACSG	ICP/AES	
Uranium	GDACSG	ICP/AES	
Vanadium	GDACSG	ICP/AES	
Ytterbium	GDACSG	ICP/AES	
Yttrium	GDACSG	ICP/AES	
Zinc	GDACSG	ICP/AES	

[1] Only analyzed in bed-sediment samples.

Samples from the domestic, stock, and community wells were collected by connecting a polyethylene tube to a spigot located so that the samples were not influenced by any pressure, filtration, or chemical treatments. Sample collection at these wells was similar to the observation-well sample collection. The water passed through the instrument chamber without coming into contact with the atmosphere, and the sample water was collected directly from the collection tube.

Samples from observation wells 3 and 6 were obtained using a Teflon bailer because the depth to water in these wells exceeded the lift capacity of the submersible pump. After the water had been purged with the bailer from these wells, the sample water was bailed into a churn splitter. A peristaltic pump was used to collect the samples from the churn splitter. Because the bailed water had come into contact with the atmosphere, measurements of dissolved oxygen were not recorded at these two sites.

Water samples were collected from four springs in January 1995 (fig. 4). None of the springs were flowing at the time the 1995 ground-water and surface-water samples were collected, so the springs were not resampled. All sampling equipment that came in contact with the spring water was cleaned prior to the sampling trip and between sampling sites. The spring samples were collected by excavating the spring to about 1 ft below land surface, and then the spring water was allowed to flow through the sampling chamber for a minimum of one hour. Temperature and specific conductance measurements were made at each spring's discharge point. The samples were collected in the appropriate bottles, preserved with dilute nitric acid, and immediately chilled at each sampling site. The samples were analyzed for inorganic arsenic concentrations by the SDGS Water Chemistry Laboratory.

Surface-Water Samples

Water samples were collected at six sites on the Little White River in 1991, and at eight sites on the Little White River and three tributary sites in 1995 (fig. 5). The collection of surface-water samples in 1991 followed methods presented in Ward and Harr (1990), and Edwards and Glysson (1988). In 1995, methods described by Horowitz and others (1994) for the collection and processing of surface-water samples were employed. All surface-water sampling equipment (samplers, churn splitter, and tubing) was cleaned prior to the sampling trip and between sites using the protocol described by Horowitz and others (1994).

The water samples from the Little White River were collected using the equal-width-increment method described in Edwards and Glysson (1988) to provide depth- and width-integrated samples. The three tributary sites were sampled with a single vertically integrated sample because the discharge was low. The samples were collected with depth-integrating suspended-sediment samplers (DH-48 in 1991 and DH-81 in 1995; Edwards and Glysson, 1988).

Bed-Sediment Samples

In 1995, bed-sediment samples were collected from the 11 surface-water sites (fig. 5) to determine whether arsenic was significantly present in the solid phase in the beds of streams that may be receiving ground-water discharge. Procedures used for collecting and processing the bed-sediment samples are described in Shelton and Capel (1994). All sampling equipment contacting the sediment (spatula, scoop, bowl, sieve cloth, and sieve frame) was cleaned prior to the sampling trip and between sites using the protocol described in Shelton and Capel (1994).

At each surface-water sampling site, 5 to 10 low-flow depositional zones containing fine-grained particulate matter were selected and subsampled. The fine-grained subsamples were composited and pressure-sieved with native water through a 63-µm mesh nylon-sieve cloth held in a plastic frame.

Drill-Hole-Cuttings Samples

During the drilling of the observation wells, cuttings at 10-ft intervals were removed from the collection pit and placed in piles. The cuttings samples were described by USGS and SDGS personnel. From each cuttings pile, samples were collected and placed in mesh sample bags. The samples were stored by SDGS until the samples to be analyzed were selected. Fifty-two cuttings samples from three observation-well sites (fig. 4) were selected for analysis. One of the cuttings samples that was sent for analysis was high graded with volcanic ash (that is, the ash fragments within the sample interval were selectively collected, while non-ash material was excluded from the sample). This was done because it was suspected that the volcanic ash present in the Arikaree Formation may be a source of the elevated arsenic concentrations in ground water in the Grass Mountain area. One sample was high graded with pink siltstone (that is, the pink siltstone fragments were selectively collected, while non-siltstone material was excluded from the sample) to determine the arsenic concentration in the siltstone, and one sample was subsampled. The reason for subsampling was to increase accuracy by converting the samples from an arbitrary sampling interval (10-ft interval) to a lithology-based sampling design.

Quality-Assurance Data

Quality-assurance procedures were performed to evaluate the precision and accuracy of the reported analytical results. The procedures were designed to verify that no significant biases were introduced into the data either during field sampling and processing, or during laboratory analysis of the samples. Quality-assurance procedures for the laboratories involved in this study (USGS National Water Quality Laboratory, NWQL; USGS Geologic Division Analytical Chemistry Services Group, GDACSG; Montana Bureau of Mines and Geology Laboratory, MBMG; and the SDGS Water Chemistry Laboratory, SDWCL) included analyses of reference and calibration materials and internal analyses of blanks, replicates, and spiked samples. Quality-assurance procedures for the NWQL are presented in Friedman and Erdmann (1982) and Pritt and Raese (1992). Quality-assurance procedures for the MBMG are contained in an unpublished internal document (Tim Holland, Montana Bureau of Mines and Geology, written commun., 1997). Quality-assurance procedures for the GDACSG are presented in Arbogast (1990). Quality-assurance procedures for SDWCL are contained in an unpublished internal document (M.C. Coker, South Dakota Geological Survey, written commun., 1984).

Field quality-assurance samples collected during this study included equipment blanks, duplicates, and spiked duplicates. In 1995, the total number of samples collected included a minimum of 10 percent quality-assurance samples; fewer quality-assurance samples were collected during 1991 and 1992.

Laboratory and field equipment blank samples were collected and analyzed to identify the presence and magnitude of contamination that potentially could bias analytical results. Laboratory blanks are samples of ultrapure deionized water that are processed through the sampling equipment in a laboratory; laboratory blanks are used to identify sample contamination introduced from the sampling equipment. Field equipment blanks are samples of ultrapure deionized water that are processed through the sampling equipment at the field collection site; field blanks are used to identify sample contamination introduced from the sampling equipment and contamination introduced during collection and processing of samples in the field.

Three equipment blanks were collected in 1995. A laboratory equipment blank was processed through the ground-water sampling equipment, a field equipment blank was processed through the ground-water sampling equipment, and a field equipment blank was processed through the surface-water sampling equipment. Analytical results for those samples indicated that concentrations of all constituents were below reporting limits or were substantially below environmental concentrations (table 9 in the Supplemental Information section). Equipment blank samples indicated that no significant contamination was added to the samples during collection, processing, or analysis.

Duplicate sample sets are two samples collected as close in time as possible and are assumed to be essentially identical in composition. They are collected to evaluate variability in the data that may be attributed to either field collection and processing procedures or laboratory analytical procedures.

A total of 34 duplicate sample sets were collected during the study. Three duplicate ground-water sample sets were collected between 1991 and 1995 for analyses of selected major ions and trace elements by the NWQL (table 4). Two duplicate ground-water sample sets were collected in 1992 and 1995 for arsenic concentration and speciation analyses by the MBMG (table 4). Twenty-two duplicate ground-water sample sets were collected during 1992 and 1995 for arsenic concentration analyses by the NWQL and the MBMG (table 4); one of the samples from each of these sets was analyzed by the NWQL and the other sample was analyzed by the MBMG. One duplicate sample set was collected from spring 1 in 1995 (table 5) and analyzed by the SDWCL. One duplicate sample set was collected in 1995 from the Little White River at Swimmer Residence (table 6) and analyzed by the NWQL. One duplicate bed-sediment sample set was collected in 1995 (table 7) and analyzed by the GDACSG. Four duplicate drill-hole-cuttings sample sets were collected in 1995 and analyzed by the GDACSG (table 8).

For duplicate water and bed-sediment sample sets that were sent to the same laboratory, adequate numbers of duplicates within each sample type were not collected to allow statistical evaluation of the variability between duplicates. However, those duplicate data indicated that the analytical results for the duplicate pairs generally compared very well. An exception to this was the difference in arsenic concentrations for the duplicate sample set collected from the Grass Mountain Community (GMC) well in 1991 (table 4). The difference in arsenic concentration between the sample and its duplicate was 23 µg/L. Because the subsequent samples of this well and its replacement well yielded arsenic concentrations of 85 µg/L (1992: MBMG), 82 µg/L (1992: NWQL), and 83 µg/L (1995: NWQL), the concentration of 85 µg/L was assumed to be the more accurate of the two 1991 values. The cause of the relatively large difference in the concentrations is not known. Results for the other water duplicate sample sets indicate that this relatively large error was anomalous and not representative of typical variability in arsenic analytical results for the study.

Precision statistics were calculated for the duplicate ground-water sample sets for which one sample of each set was analyzed for arsenic concentration by the NWQL and the other was analyzed by the MBMG. Statistics could be calculated for these duplicates because more than three pairs were collected. The precision of the analytical results for a specific constituent can be estimated by calculating a standard deviation from the differences of pairs of duplicate measurements. The standard deviation is estimated by the following equation (Taylor, 1987):

$$S = \sqrt{\frac{\Sigma d^2}{2k}}$$

where

S = standard deviation of the difference in concentration between duplicate analyses;
d = difference in concentration between each pair of duplicate analyses; and
k = number of pairs of duplicate analyses.

Precision also can be expressed as a relative standard deviation (*RSD*), in percent, for a specific constituent. The *RSD* is calculated from the standard deviation and the mean concentration for all the duplicate analyses as given in the following equation (Taylor, 1987):

$$RSD = \frac{S}{\bar{x}} \times (100)$$

where

RSD = relative standard deviation, in percent;
S = standard deviation; and
$\bar{x}$ = mean concentration for all duplicate analyses.

The standard deviation for the duplicate ground-water samples analyzed for arsenic by the NWQL and the MBMG was 2.6 and the relative standard deviation was 7.2 percent. A typical data-quality objective for precision of duplicate field samples is a maximum relative standard deviation of 20 percent (Taylor, 1987). The precision statistics for these paired samples indicate that the quality of the analytical results for arsenic concentrations in ground water was well within typical data-quality objectives.

Precision statistics also were calculated for the duplicate drill-hole-cuttings samples and the results are presented in table 10 in the Supplemental Information section. The data-quality objective of a maximum relative standard deviation of 20 percent for the precision of field duplicates was met for all analyzed constituents.

Spiked blank and spiked duplicate samples were collected to determine whether any chemical interferences were present in a specific matrix that could bias the analytical measurement of a constituent. One blank and one ground-water sample were spiked at the NWQL with a known amount of arsenic. Acceptable spike recoveries are a maximum deviation of 20 percent from a theoretical 100-percent recovery of the added constituent. Therefore, a spike recovery within the range of 80 to 120 percent indicates no matrix problems. The spike recovery for the blank was 99.6 percent, and the spike recovery for the field sample was 120 percent. These results were within the acceptable range and indicated that significant matrix interferences did not bias the arsenic concentrations reported in this study.

Three of the spring samples were spiked at the SDWCL with a known amount of arsenic. The spike recoveries were 103 percent, 111 percent, and 104 percent. These results were within the acceptable range and again indicated that significant matrix interferences did not bias the arsenic concentrations reported in this study.

SOURCES OF ARSENIC

Arsenic concentrations in samples collected from ground water in a six-county area in south-central South Dakota (Bennett, Gregory, Jackson, Mellette, Todd, and Tripp Counties; fig. 1) were retrieved from the USGS water-quality database. A probability plot of the arsenic concentrations (fig. 6) was used to estimate the background[1] arsenic concentration in the area. The plot shows that arsenic concentrations in south-central South Dakota ground water typically are less than

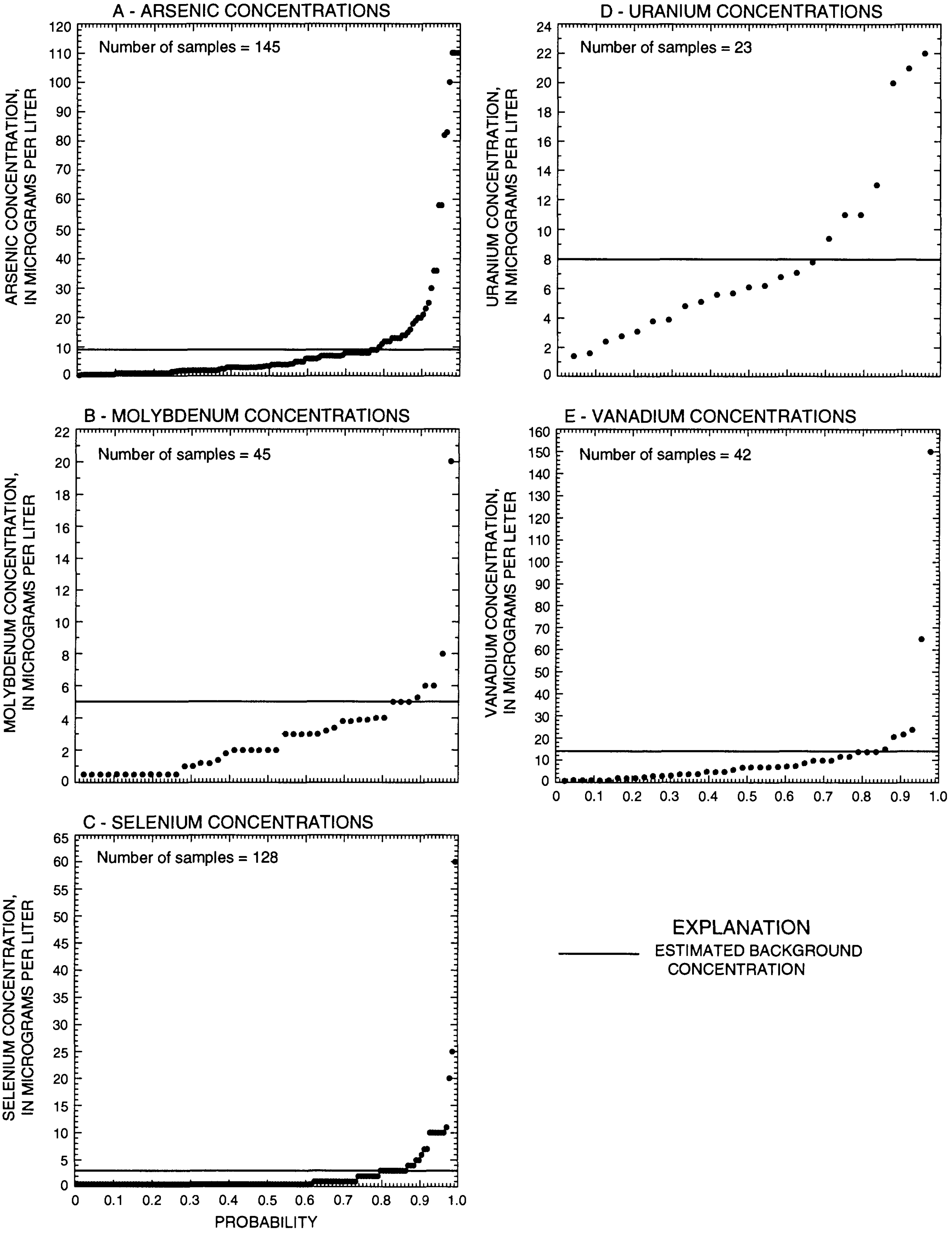

Figure 6. Probability plots for concentrations of arsenic and associated elements in ground water in Todd County and neighboring counties.

9 µg/L; this concentration will be considered as a background level for the purpose of defining elevated concentrations in this report. If a given sampling site had multiple samples, only the most recently collected sample was used in constructing the probability plot. Background levels for other constituents shown in figure 6 will be discussed later.

Arsenic concentrations in ground water in the study area in 1995 are shown in figure 7. The figure shows that the highest concentrations of arsenic generally are located near the prairie dog town. However, several other wells with elevated arsenic concentrations are located both to the east of the prairie dog town and on the north side of the river. Some of the wells with elevated arsenic concentrations are not located downgradient from the prairie dog town (fig. 2 and fig. 7); therefore, it is unlikely that a point source of arsenic at the prairie dog town contributed to the elevated arsenic at these wells.

Naturally occurring arsenic in rocks often is associated with a suite of elements that includes, or may include, molybdenum, selenium, vanadium, and uranium (Rankama and Sahama, 1950; White and Waring, 1963; U.S. Geological Survey, 1964, 1975; Harshman, 1972). Because arsenic and the elements that typically occur in association with arsenic are prevalent in volcanically derived rock (Rankama and Sahama, 1950; U.S. Geological Survey, 1964; Krauskopf, 1979) and volcanic ash is abundant in the rock of the Arikaree Formation, the naturally occurring ash may be a source of the arsenic in the ground water in the Grass Mountain area. If this is the case, it would seem likely that the Arikaree aquifer generally would have higher concentrations of arsenic and associated elements than other units that do not have as abundant ash composition in the rock materials.

Retrievals were made from the USGS water-quality database to determine if arsenic concentrations in the Arikaree aquifer were higher than concentrations in other ground water in south-central South Dakota. Dissolved arsenic concentrations in samples collected from ground water in Todd and neighboring counties (fig. 1) were retrieved from the USGS water-quality database. If a given sampling site had multiple samples, only the most recently collected sample concentration was included. Distributions of those arsenic concentrations by aquifer and location (fig. 8) indicated that the Arikaree aquifer near Grass Mountain Community generally had the highest dissolved arsenic concentrations, with a median concentration of 82 µg/L. Samples collected from the Arikaree aquifer outside of the Grass Mountain area and from the White River aquifer had median dissolved arsenic concentrations of about 11 and 7 µg/L, respectively. Median dissolved arsenic concentrations for aquifers other than the Arikaree and White River aquifers were less than or equal to about 4 µg/L, with the exception of samples from alluvial wells near Grass Mountain Community. These samples had a median dissolved arsenic concentration of 25 µg/L. Because the direction of ground-water flow is towards the river, the elevated dissolved arsenic concentrations at the alluvial wells can be attributed to the flow of water from the Arikaree aquifer to the alluvium. Concentrations at other alluvial wells are more representative of general arsenic concentrations in alluvial aquifers.

Both the Arikaree Formation and White River Group are tuffaceous units. Ash is a significant constituent for deposits of the Arikaree Formation and the White River Group, and the ash was not significantly contributed after late Miocene time (U.S. Geological Survey, 1975). Higher median concentrations of dissolved arsenic in the Arikaree aquifer than in other aquifers in south-central South Dakota support the conclusion that the source of the elevated arsenic in the Grass Mountain area probably is natural. The ash present in the Arikaree Formation may serve as a potential source of arsenic that results in elevated concentrations of arsenic in solution when appropriate geochemical conditions occur. It should be noted that the White River aquifer, although it is not utilized as a water source as extensively as the Arikaree aquifer, also may undergo similar processes. Alluvial aquifers that overlie the Arikaree Formation (and possibly the White River Group) also contain some ground water with elevated arsenic concentrations.

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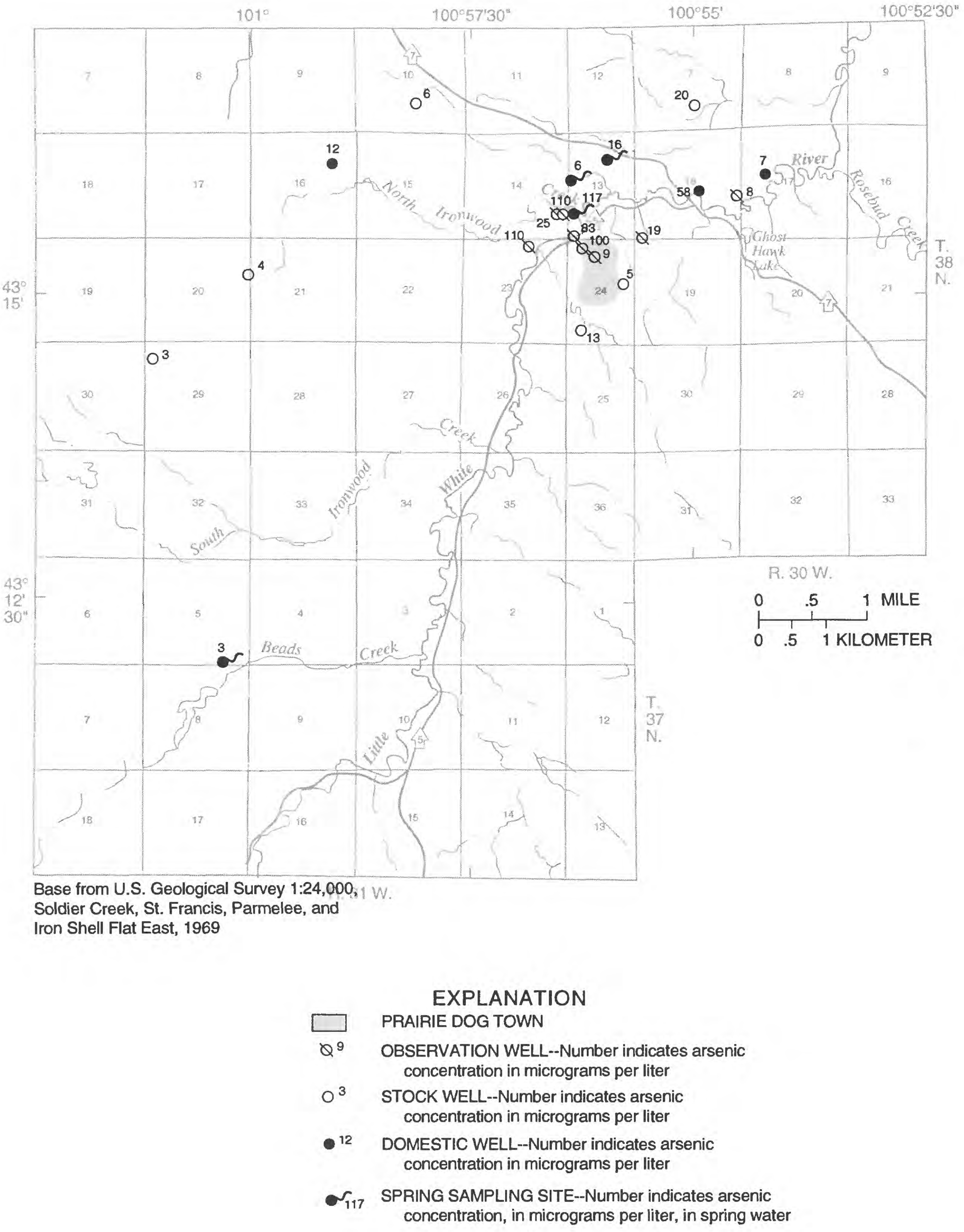
[1] In this report, the term background refers to a level that concentrations in most ground-water samples from the six-county area in south-central South Dakota are less than or equal to and below which the concentrations tend to be fairly uniformly distributed. Background levels in this report are determined simply to identify typical concentration ranges and do not imply that concentrations either below or above the background level are attributable to natural or anthropogenic sources, respectively. The background concentration for each of the various constituents was determined by examining the concentration probability plot and qualitatively identifying the concentration where a marked increase in slope occurs. Above the background level, concentrations tend to be more variable and generally show larger increases with increasing non-exceedance probability. Definition of the background concentration was not based on selection of a given non-exceedance probability. Non-exceedance probabilities of the defined background concentrations for the various constituents range from about 0.88 for molybdenum to about 0.67 for uranium. The non-exceedance probability for the background arsenic concentration of 9 µg/L was about 0.77.



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

Figure 7. Arsenic concentrations in ground water and spring water, 1995.

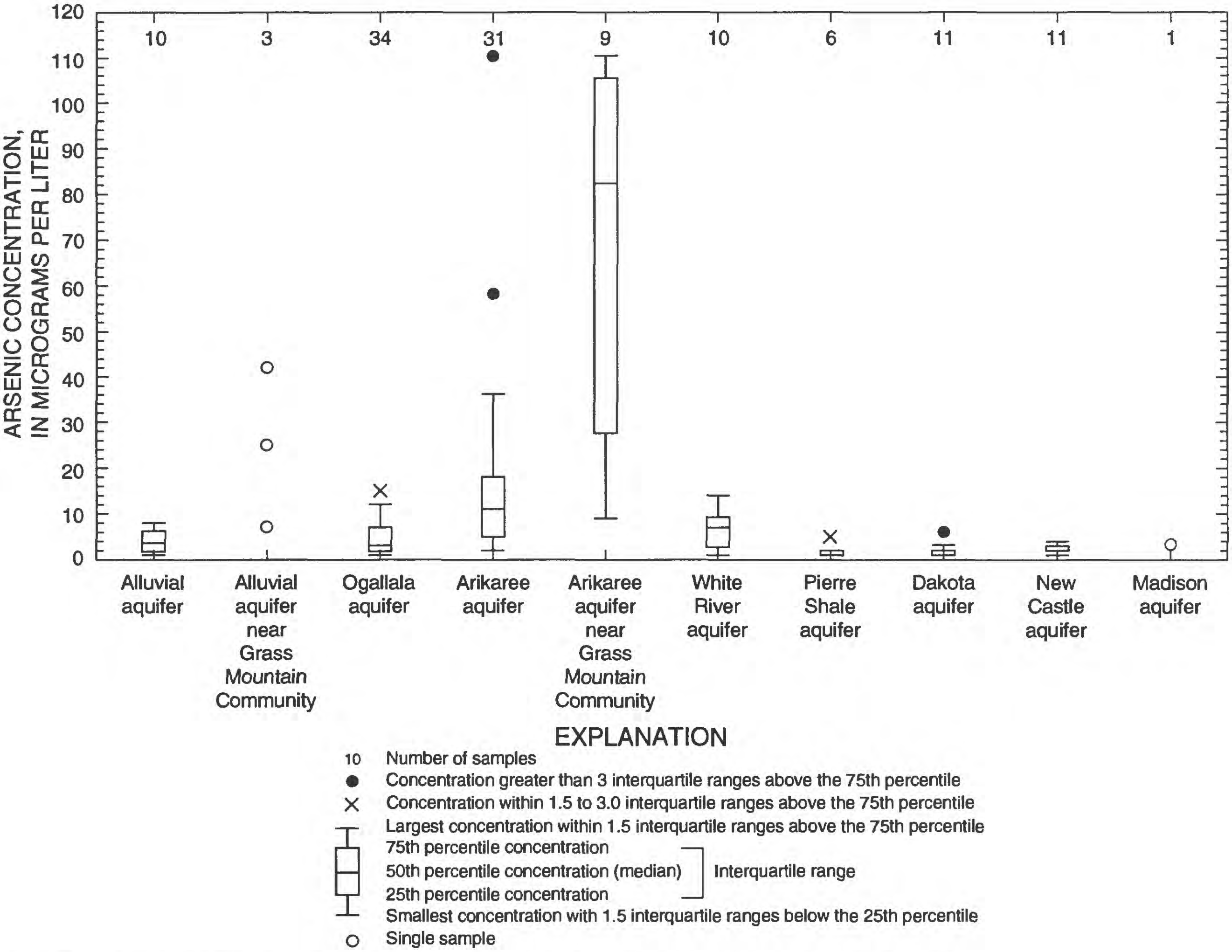


Figure 8. Boxplots of dissolved arsenic concentrations in aquifers in south-central South Dakota.

Adequate numbers of samples with analyses for the associated elements were not present in the USGS water-quality database to allow comparison of concentrations in the Arikaree aquifer with other aquifers in Todd and neighboring counties in south-central South Dakota. However, general comparisons were made between concentrations of these elements in the Arikaree aquifer and typical ground water, as well as all other ground water in the six-county area. According to Hem (1989), vanadium concentrations in most ground water rarely exceed 10 µg/L, and uranium concentrations in natural waters generally range from 0.1 to 10 µg/L. This is supported by the probability plots for vanadium and uranium in south-central South Dakota ground water (fig. 6), which show background concentrations of 14 and 8 µg/L, respectively. Two ground-water sites, No Heart domestic well and observation well 5, in the Grass Mountain area that had elevated dissolved arsenic concentrations also had exceptionally high dissolved vanadium concentrations of 65 and 150 µg/L, respectively (table 3). The No Heart domestic well and observation well 2, both of which had elevated dissolved arsenic concentrations, also had elevated dissolved uranium concentrations of 22 and 21 µg/L, respectively (table 3). Because the only probable local source of vanadium and uranium is natural, and because of their association with naturally occurring arsenic in rocks, this pattern supports the conclusion that the source of the elevated arsenic concentrations in the Grass Mountain area is natural. In addition, the No Heart domestic well is located in an area that is not downgradient from the prairie dog town; therefore, the source of arsenic appears to be natural.

The background selenium concentration in ground water in the six-county area was determined to be 3 µg/L from the probability plot (fig. 6). The background molybdenum concentration was determined to be 5 μg/L from the probability plot (fig. 6). Selenium and molybdenum concentrations in all of the ground-water samples in the vicinity of the Grass Mountain area generally were less than or equal to the background concentration.

The concentrations of dissolved arsenic in the spring samples are presented in table 5 and shown in figure 7. The average dissolved arsenic concentration in South Dakota's springs was calculated to be 6 μg/L based on results of 66 analyses in the USGS water-quality database. Two of the springs sampled in 1995 were substantially higher in dissolved arsenic than this average concentration. The arsenic concentration in water collected from spring 2 was 117 μg/L, which was slightly higher than the largest ground-water arsenic concentration of 110 μg/L, which came from observation well 7, located about 1,000 ft away. Because of the spring's close proximity to the prairie dog town, it is possible that the high arsenic concentration could be attributed to the use of an arsenic pesticide. However, the arsenic concentration from spring 4, located on the north side of the river (fig. 7), also was elevated, which would not have been a result of any activity near the prairie dog town based on ground-water flow directions. Therefore, information obtained solely from the spring samples indicates that at least some of the arsenic cannot be attributed to any known anthropogenic source.

Further evidence supporting the conclusion that the volcanic ash and/or sediments present in the Arikaree Formation is the source of the arsenic in the Grass Mountain area is apparent from the drill-hole-cuttings data in table 8. The high-graded ash sample from drill-hole cuttings at observation well 7 had the highest arsenic concentration (10 μg/g (micrograms per gram), table 8) of all the cuttings samples, as well as the highest concentrations of rare-earth elements including cerium, europium, holmium, lanthanum, ytterbium, and yttrium. These rare-earth elements commonly are present in silicic igneous material (Haskin and others, 1966; Hinkley and others, 1987; Bhandari and others, 1993) in elevated concentrations relative to the concentrations typical in sedimentary rocks. The pyroclastic eruptions that produce airfall ash tapped the upper, more silicic parts of compositionally zoned magma chambers (Smith, 1979; Hildreth, 1981). Observation well 7 also yielded one of the highest dissolved arsenic concentrations of the ground-water samples. These data suggest that a source for the arsenic probably is the ashy sandstones and siltstones of the Arikaree Formation.

A gamma-ray log for observation well 4 was available from the SDGS. The higher arsenic concentrations (greater than 5 μg/g; table 8) for cuttings at observation well 4 roughly coincided with moderately high gamma radiation. High gamma radiation is common in volcanic ash. This again suggests that the ashy sediments near Grass Mountain may account for the increased arsenic concentrations. All of the drill-hole-cuttings samples had higher concentrations of arsenic than the general abundance of arsenic in sandstones of 1 μg/g (Parker, 1967).

Moore and Levish (1955) and Dunham (1961) reported that uranium minerals occur in the Brule Formation of the White River Group in an area about 80 mi west of the study area in South Dakota and Nebraska. Evidence suggests that the uranium in these mineral occurrences may have been leached from volcanic ash in the White River Group and Arikaree Formation (Zielinski, 1980). Thus, association of elevated arsenic in the Grass Mountain study area with elevated uranium in the study area also is considered supporting evidence for the volcanic ash source of arsenic by release of arsenic and uranium from the ash.

Statistical analyses using Spearman's rank correlation (Spearman, 1904) were used to determine associations between arsenic and other constituents in the drill-hole cuttings. Significant correlation between arsenic and other properties or constituents may provide information concerning the source of the arsenic or the processes governing its occurrence. A value of one-half of the detection limit was substituted for all censored (less than) values for this analysis, which do not bias the correlation results because the Spearman's method is a nonparametric procedure performed using ranked data. Significant correlations between arsenic and other constituents and properties in the drill-hole cuttings are presented in table 11. In this study, a correlation was considered to be significant if the probability of incorrectly rejecting the null hypothesis of no correlation (p-value) was less than or equal to 0.10.

Arsenic in drill-hole cuttings positively correlated with many elements including thorium, copper, lithium, vanadium, chromium, cerium, cobalt, europium, and holmium (table 11). A correlation between arsenic and many trace and rare-earth elements was reasonable because the high-graded ash sample had the highest concentrations of both arsenic and these elements. The high-graded ash sample was the only sample that contained detectable concentrations of the rare-earth elements europium and holmium, and it had a greatly elevated cerium concentration. Correlation between arsenic and the associated elements of selenium, molybdenum, and uranium was not possible because selenium was not analyzed and all molybdenum and uranium concentrations were below the detection limits. However, arsenic was significantly correlated with the associated element vanadium. Again, this supports a naturally occurring arsenic source because the only known sources of vanadium are natural.

The following evidence supports the conclusion that volcanic ash probably is the principal source of the arsenic: (1) Samples from several wells and one spring, which were not located downgradient from the prairie dog town, contained elevated dissolved arsenic concentrations; (2) samples from several wells with elevated dissolved arsenic concentrations also had elevated dissolved vanadium and uranium concentrations, which are commonly associated with naturally occurring arsenic in rocks; (3) the high-graded volcanic ash sample contained an elevated arsenic concentration in comparison to typical concentrations in sedimentary rocks; and (4) arsenic concentrations in the drill-hole-cuttings samples correlated with vanadium concentrations, which is commonly associated with naturally occurring arsenic in rocks. Because the ash is present throughout the Arikaree Formation and because water in the Arikaree aquifer does not everywhere attain the arsenic concentrations found in the Grass Mountain area, specific geochemical conditions in the Grass Mountain area must be contributing to the elevated concentrations. The factors that may be controlling arsenic solubility in the Grass Mountain area are discussed and additional evidence from geochemical modeling concerning the source of arsenic is presented in the following section.

OCCURRENCE OF ARSENIC AND GEOCHEMICAL PROCESSES

The behavior and fate of arsenic in the aquatic environment is highly complex and dependant on many factors including pH, redox conditions, the presence of certain ions and minerals, and the presence of organic matter. In aqueous solution, inorganic arsenic can exist in different oxidation states as As^{+3} or As^{+5}, depending on redox conditions. Arsenic commonly is adsorbed by clay minerals and iron- and manganese-oxide minerals (Welch and others, 1988). The distribution of As^{+3} and As^{+5} is affected by redox conditions. Arsenate predominates at higher redox levels, and As^{+3} predominates as the pH increases or the redox decreases (Korte, 1991; McLean and Bledsoe, 1992). In this report, reference to "arsenic" includes both the As^{+3} and As^{+5} species combined; where the discussion focuses on either the As^{+3} or As^{+5} species individually, they are specifically cited.

Geochemical processes were analyzed primarily by examining relations between arsenic concentrations and other constituents, properties, and mineral saturation indices using Spearman's rank correlation. The saturation index (SI) for a particular mineral generally indicates whether the ground water is undersaturated ($SI<0$), at equilibrium ($SI=0$), or oversaturated ($SI>0$) with respect to that particular mineral; however, a saturation index between -0.5 and 0.5 probably is a general indicator of equilibrium because of analytical and thermodynamic uncertainties. If the ground water is undersaturated with respect to a mineral, as indicated by a negative saturation index, the ground water would theoretically dissolve the mineral if it is present. Conversely, if the water is oversaturated with respect to a mineral, as indicated by a positive saturation index, then the mineral theoretically would precipitate from the ground water. Thus, in the following discussion, a negative correlation between an arsenic ionic species and a mineral saturation index indicates possibly that, as the arsenic ion concentration increases, the mineral tends more toward dissolution. Conversely, a positive correlation between an arsenic ionic species and a particular saturation index possibly indicates an increase in dissolved arsenic concentration as that particular mineral tends more toward oversaturation and subsequent precipitation from the ground water.

The geochemical model PHREEQC (Parkhurst, 1995) was used to determine mineral saturation indices and Eh for the ground-water samples. The PHREEQC model calculates Eh, solution speciation, and saturation states of the aqueous phase with respect to various mineral phases, given analytical concentrations of specific elements, pH, and temperature. The PHREEQC model requires either dissolved oxygen concentration or analytical concentrations of both species of a given redox couple to calculate Eh. For ground-water samples collected in 1995, Eh values were calculated using both dissolved oxygen concentration and the arsenic speciation data. For ground-water samples collected in 1991, neither dissolved oxygen nor arsenic speciation data were collected. For the ground-water samples collected in 1992, arsenic speciation data were collected but dissolved-oxygen data were not. Dissolved oxygen-pH-specific conductance-water temperature relations for the 1995 ground-water data were used to estimate approximate dissolved oxygen concentrations for the purpose of performing PHREEQC calculations for the 1991 and 1992 ground-water data. The Eh values calculated using PHREEQC for ground-water samples are presented in table 12. Initially, the SI's were calculated using both oxygen and arsenic speciation for the redox couple. Because more of the samples had been analyzed for arsenic speciation than dissolved oxygen, the arsenic speciation was estimated for the 1991 samples using the 1992 and 1995 speciation data. All SI's reported in table 13 were calculated using arsenic as the redox couple. For all censored values (concentrations below detection limits), a value of one-half the detection limit was used. Spearman's rank correlation then was used to investigate possible relations between measured arsenic concentrations, calculated Eh values, and mineral saturation indices calculated using PHREEQC. Significant correlations between arsenic, other measured concentrations and properties, and mineral saturation indices for the ground-water, surface-water, and bed-sediment samples are presented in table 14.

Some notable relations between concentrations of dissolved arsenic and other constituents or properties are apparent in the correlation results of the ground-water samples. Dissolved arsenic concentrations were significantly positively correlated with pH (fig. 9) indicating greater dissolution at high pH and possibly indicating desorption from or less adsorption to solid surfaces as pH increases. Both dissolved arsenic and As^{+3} were significantly negatively correlated with Eh (fig. 9) and measured dissolved oxygen; these relations are consistent with the findings of McLean and Bledsoe (1992) and Korte (1991). Conditions become less oxidizing downgradient as shown by the decreasing Eh in the more downgradient wells (figs. 2 and 10). Dissolved arsenic concentrations generally increase as the ground water becomes less oxidizing downgradient.

Based on the correlations, dissolved arsenic concentrations appeared to be controlled by pH and Eh. However, pH and Eh are not independent of each other as indicated by their strong correlation (fig. 9). A plot of pH versus dissolved arsenic concentrations in Todd County and neighboring counties (fig. 11) shows that dissolved arsenic concentrations substantially increase above a pH of about 8.0. As previously discussed, dissolved arsenic was significantly positively correlated with dissolved vanadium and uranium, two of the elements commonly associated with naturally occurring arsenic in rocks. It is likely that high pH (above about 8.0) allows for the release of arsenic and associated elements from the volcanic ash or oxides. Arsenic and the associated elements from the volcanic ash then are transported in solution downgradient. In the Grass Mountain area, primary factors that may govern the occurrence of high pH waters include the semi-arid climate and accompanying low organic-acid production by microbial decomposition of organic material in the soil zone.

Increased dissolved arsenic concentrations in the more downgradient wells accompany increased sodium, sulfate (generally conservative ions that may tend to proportionately increase in concentration relative to other ions downgradient in the Arikaree aquifer), and dissolved solids concentrations. Dissolved arsenic was significantly negatively correlated with dissolved magnesium (a less conservative ion that may tend to proportionately decrease in concentration relative to other ions downgradient). The change in water type downgradient is further evidenced in the Piper (trilinear) diagram for the 1995 ground-water samples (fig. 12), which shows that the sites with lower dissolved arsenic concentrations generally are a calcium bicarbonate water type, and the sites with higher dissolved arsenic concentrations generally shifted toward a sodium bicarbonate sulfate water type.

Of additional interest were the positive correlations between As^{+3} and SI's of several uranous (U^{+4}) minerals including $UF_4 \bullet 2.5H_2O$, UF_4, $U(OH)_2SO_4$, U_4O_9, UO_2, coffinite, and uraninite. Additionally, As^{+3} significantly negatively correlated with the SI's of several uranyl (U^{+6}) minerals including UO_3 and schoepite. These correlations again support the potential for the As^{+3} concentrations to increase as conditions become less oxidizing. The uranous minerals would tend strongly toward precipitation with decreasing Eh or dissolved oxygen, as PHREEQC's speciation code caused most of the measured uranium to be speciated at U^{+4} for these relatively insoluble minerals.

The arsenic-uranium relations are important because they provide further evidence that the source of arsenic is natural. A possible local source of uranium appears to be the ashy sedimentary rocks, indicating that any uranium measured in the ground water is almost certainly natural. Because uranium is more soluble in the +6 state (Hem, 1989), it tends to precipitate

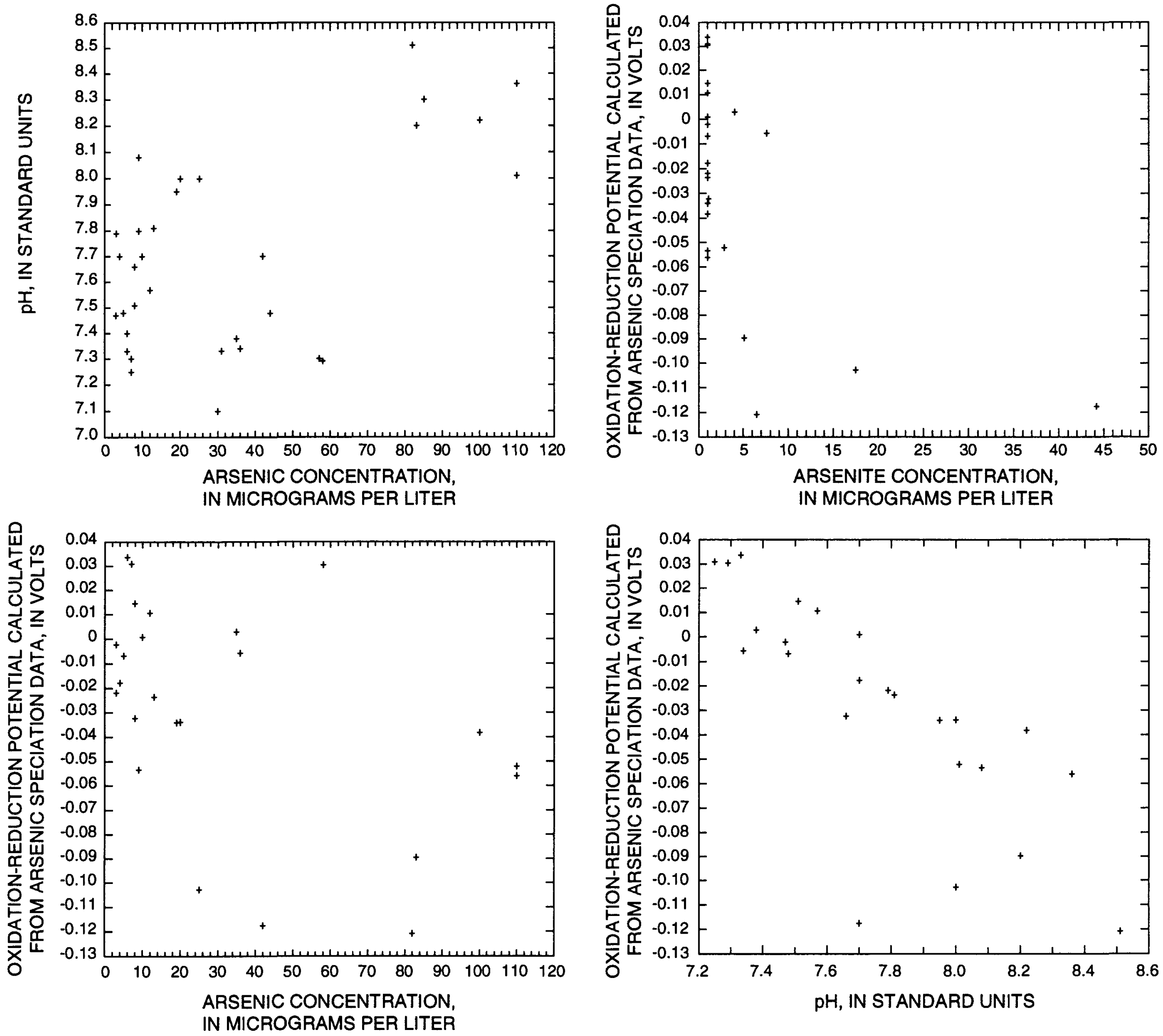
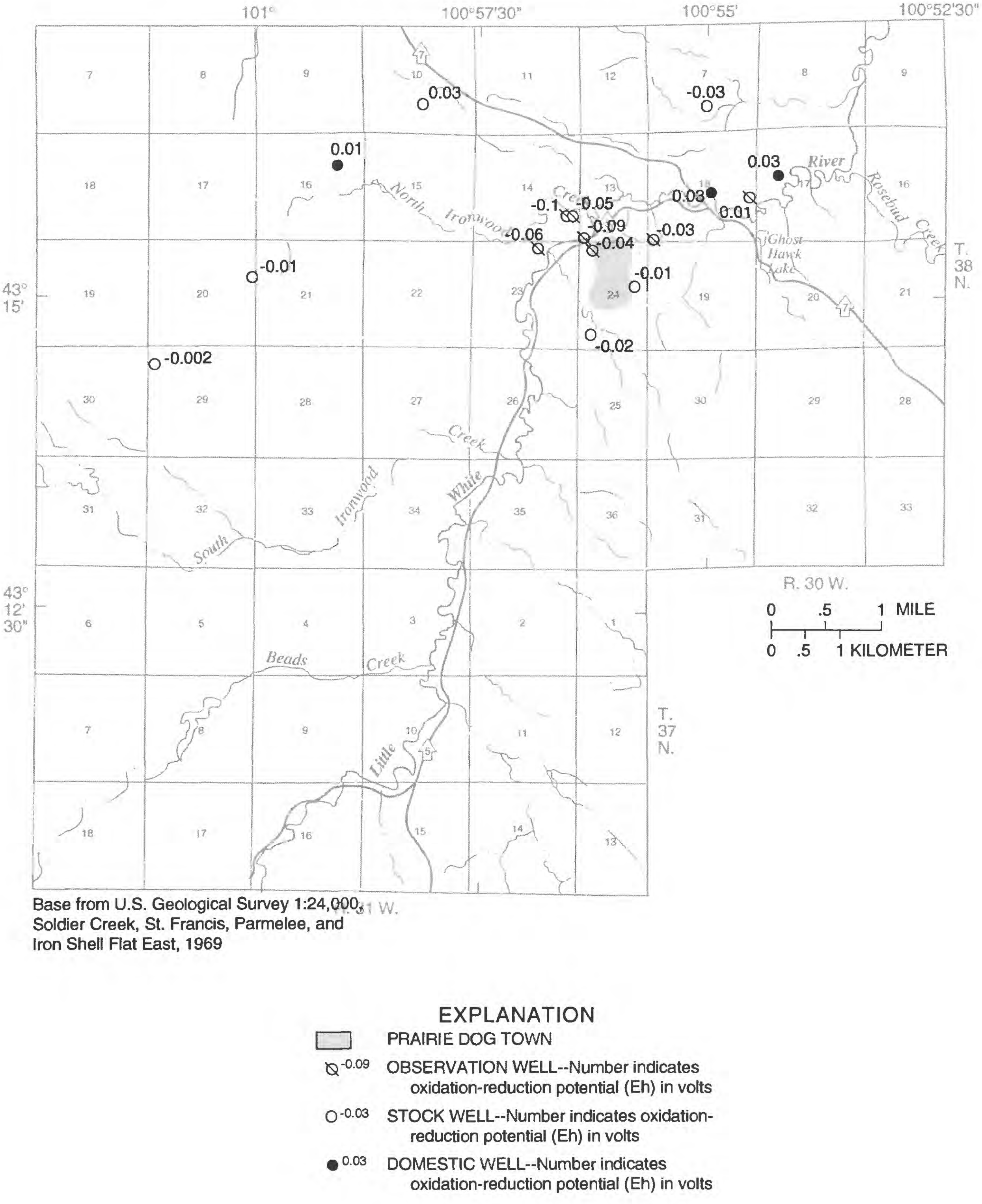
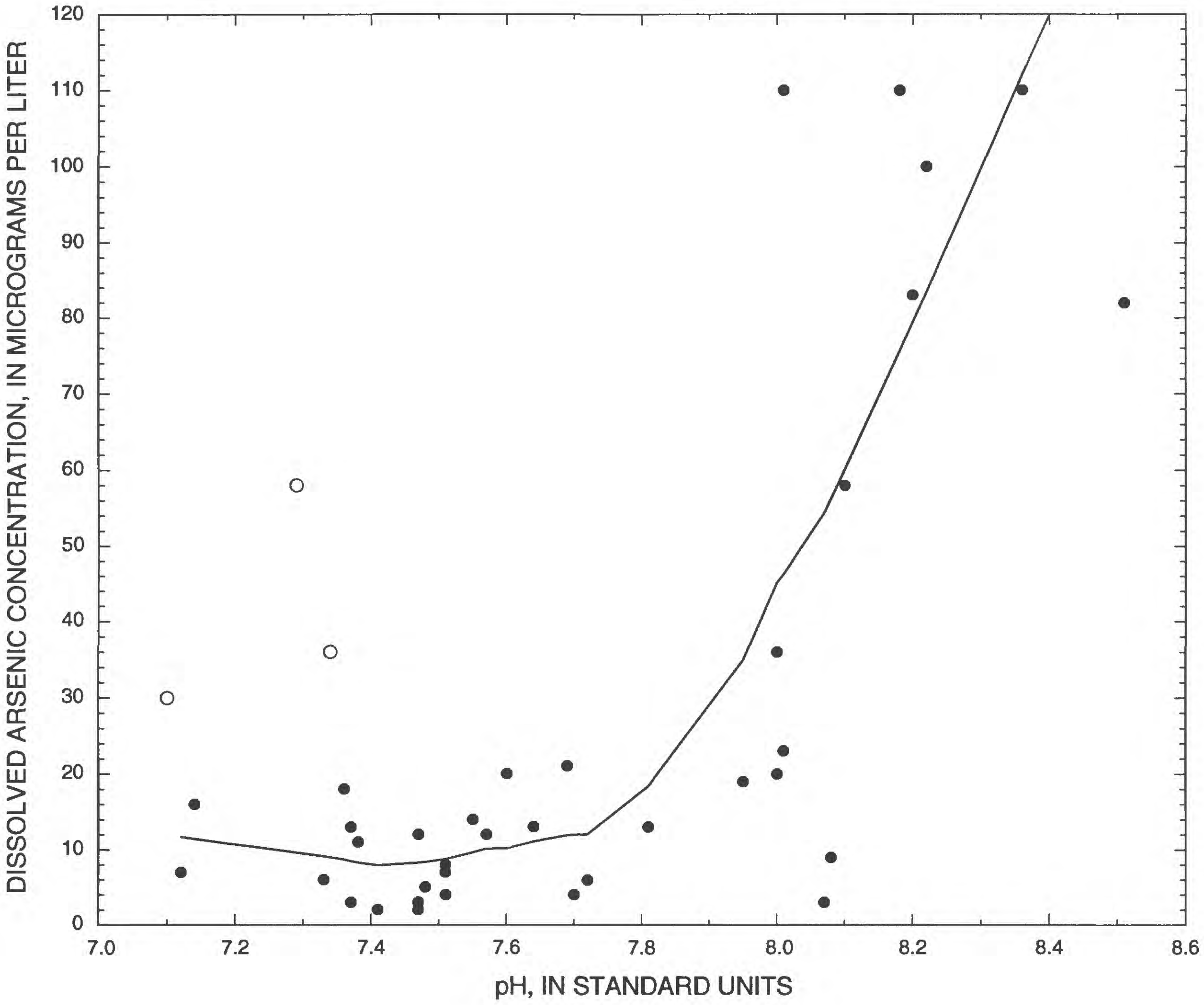


Figure 9. Plots showing selected relations between arsenic, pH, oxidation-reduction potential, and arsenite.



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

Figure 10. Oxidation-reduction potential of 1995 ground-water samples calculated using arsenic speciation data, 1995.



EXPLANATION

——— Lowess smooth (Cleveland, 1979) of pH versus dissolved arsenic concentration

● Dissolved arsenic concentrations in water samples collected from wells in south-central South Dakota completed in the Arikaree aquifer

○ Dissolved arsenic concentrations in water samples collected from wells in south-central South Dakota probably completed in the Arikaree aquifer, but also probably have connection with alluvial aquifers; these values were not included when constructing the Lowess smooth

Figure 11. Arsenic concentrations and pH in water samples collected from wells completed in the Arkaree aquifer in south-central South Dakota.

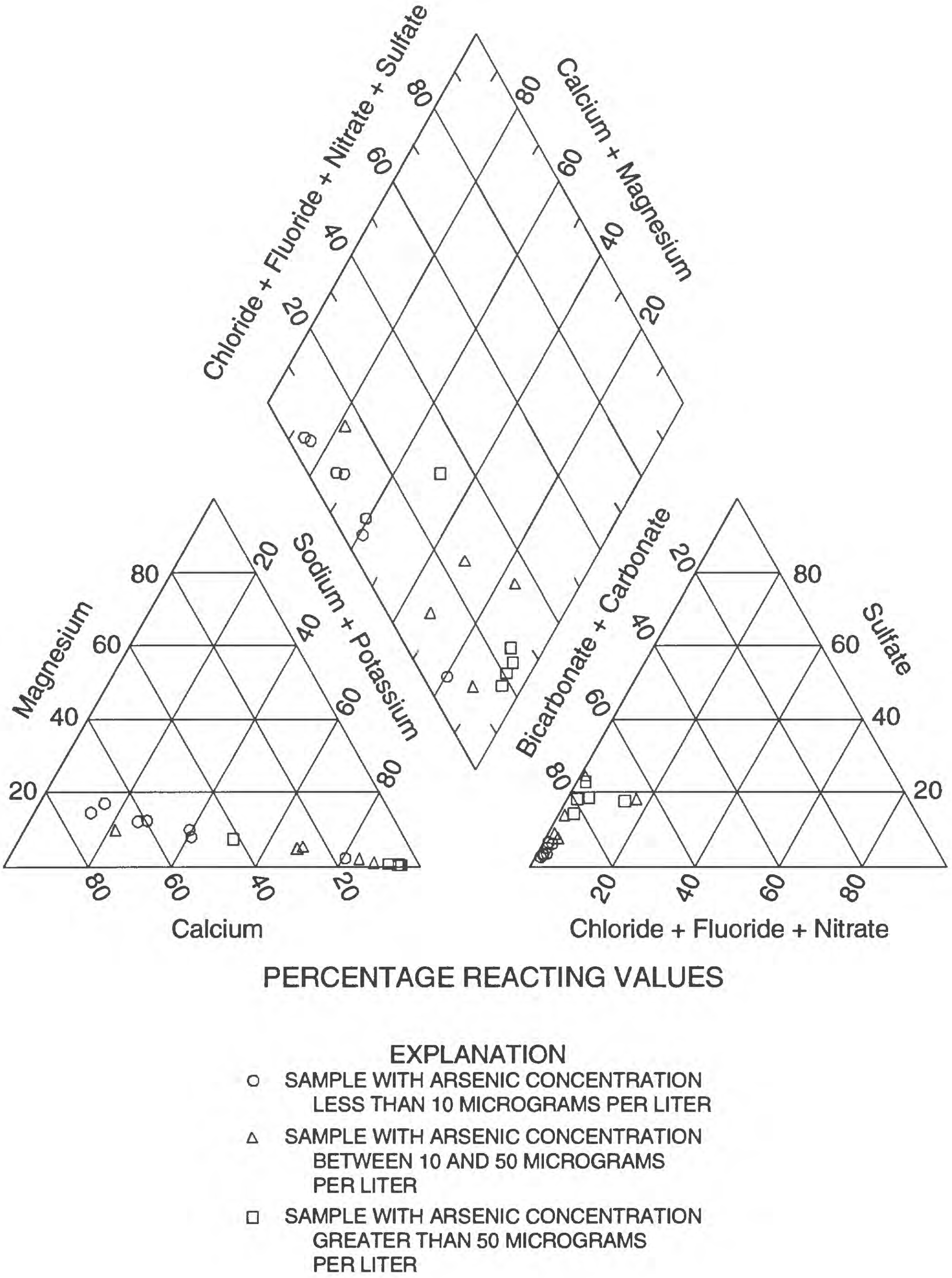


Figure 12. Trilinear diagram (Piper, 1944) showing proportional concentrations of major ions in ground-water samples, 1995.

when it is reduced to the +4 state at a redox boundary. This condition occurred at forming uranium roll-front deposits like those described in Wyoming by Harshman (1972). Arsenite is still stable in the dissolved phase under mildly reducing conditions; therefore, it tends to stay in solution and does not immediately precipitate as U^{+4} probably does. Because redox conditions in the study area generally become less oxidizing downgradient, arsenic is present in solution, but uranium may be precipitated or adsorbed at many sites.

The decrease in dissolved oxygen concentrations, increase in dissolved iron and manganese concentrations, and relations between concentrations of dissolved solids, soluble ions, and calculated Eh values all provide evidence that conditions change from oxidizing to reducing (accompanied by increased dissolution of rock constituents) downgradient in the vicinity of Grass Mountain Community. However, pH conditions probably control the adsorption of arsenic (present, as measured, in the volcanic ash and sediments within the Arikaree Formation), whereas redox conditions control arsenic's valence state. Arsenic concentrations also may be controlled by adsorption effects related to the presence of iron and manganese oxides and clay minerals. Conclusive evidence of adsorption effects by iron and manganese oxides exerting substantial controls on ground-water arsenic concentrations was not obvious in the Grass Mountain area ground-water data. However, Korte (1991) and Welch and Lico (in press) reported that simple and direct relations between arsenic concentrations and iron and/or manganese concentrations may not exist, even when iron and manganese oxides are known to play a substantial role in controlling arsenic solubility. Other factors, such as Eh, local variations in the amount of arsenic available, and coprecipitation/precipitation of iron and manganese in carbonates can mask the interactions between arsenic and iron and manganese oxides. Adsorptive effects of iron and manganese oxides may nonetheless be playing a role in arsenic controls in ground water in the Grass Mountain area because the dissolution of arsenic appears to be related to an increase in pH. The more reduced species of iron and manganese are more soluble. Arsenic that is adsorbed on iron/manganese oxides could be released to solution as conditions become more reducing and solid phase Fe^{+3} is reduced to aqueous Fe^{+2} or solid phase Mn^{+3} is reduced to aqueous Mn^{+2}. Additionally, the reddish color of many of the drill-hole-cuttings samples indicates the presence of iron oxides.

Major ion proportions and selected mineral saturation indices in water samples collected from observation wells 3, 5, 4, and 8 (ordered from most upgradient well to most downgradient well in the ground-water flow system) are presented in figure 13 to show important geochemical changes as water moves downgradient. Changes in the major ion proportions and selected mineral saturation indices in the more downgradient wells show redox geochemical roll-front conditions similar to those that produced sandstone uranium roll-front deposits in Wyoming (Harshman, 1972). Water from the more upgradient wells is a sodium bicarbonate type and is undersaturated with respect to calcium and/or magnesium carbonate minerals, such as calcite, dolomite, and rhodochrosite. Water from the most downgradient well is a calcium bicarbonate type, is above or near saturation with respect to calcium and/or magnesium carbonate minerals, and is anoxic. Oxidation of organic material in the aquifer may account for the changes in redox conditions. Although it is unlikely that substantial amounts of particulate organic material occur in the Arikaree Formation, local recharge water may introduce dissolved organic carbon from alluvium. The Arikaree aquifer first contacts overlying alluvium between observation wells 4 and 8, and it is possible that hydraulic interaction between the Arikaree Formation and the alluvium introduces dissolved organic carbon to the Arikaree aquifer. Oxidation of organic material could result in a decrease in dissolved oxygen, an increase in dissolved carbon dioxide, an increase in dissolved inorganic carbon species, a decrease in pH, and an increase in saturation indices of calcium and/or magnesium carbonate minerals. These hypothesized changes are consistent with observed chemical changes in the more downgradient wells, especially between observation wells 4 and 8. Between observation wells 4 and 8, dissolved oxygen decreases, alkalinity increases, pH decreases, calcium and magnesium substantially increase in proportion, sodium substantially decreases in proportion, and saturation indices of calcium and/or magnesium carbonate minerals increase (table 4, fig. 13).

The observed chemical changes downgradient may have a substantial influence on trace-element (especially arsenic) geochemistry. A distinct change in dominance of arsenic species occurs between observation wells 4 and 8. Arsenate accounts for 93 percent of dissolved arsenic in water collected from observation well 4 and decreases to 32 percent at observation well 8. Arsenite accounts for 7 percent of dissolved

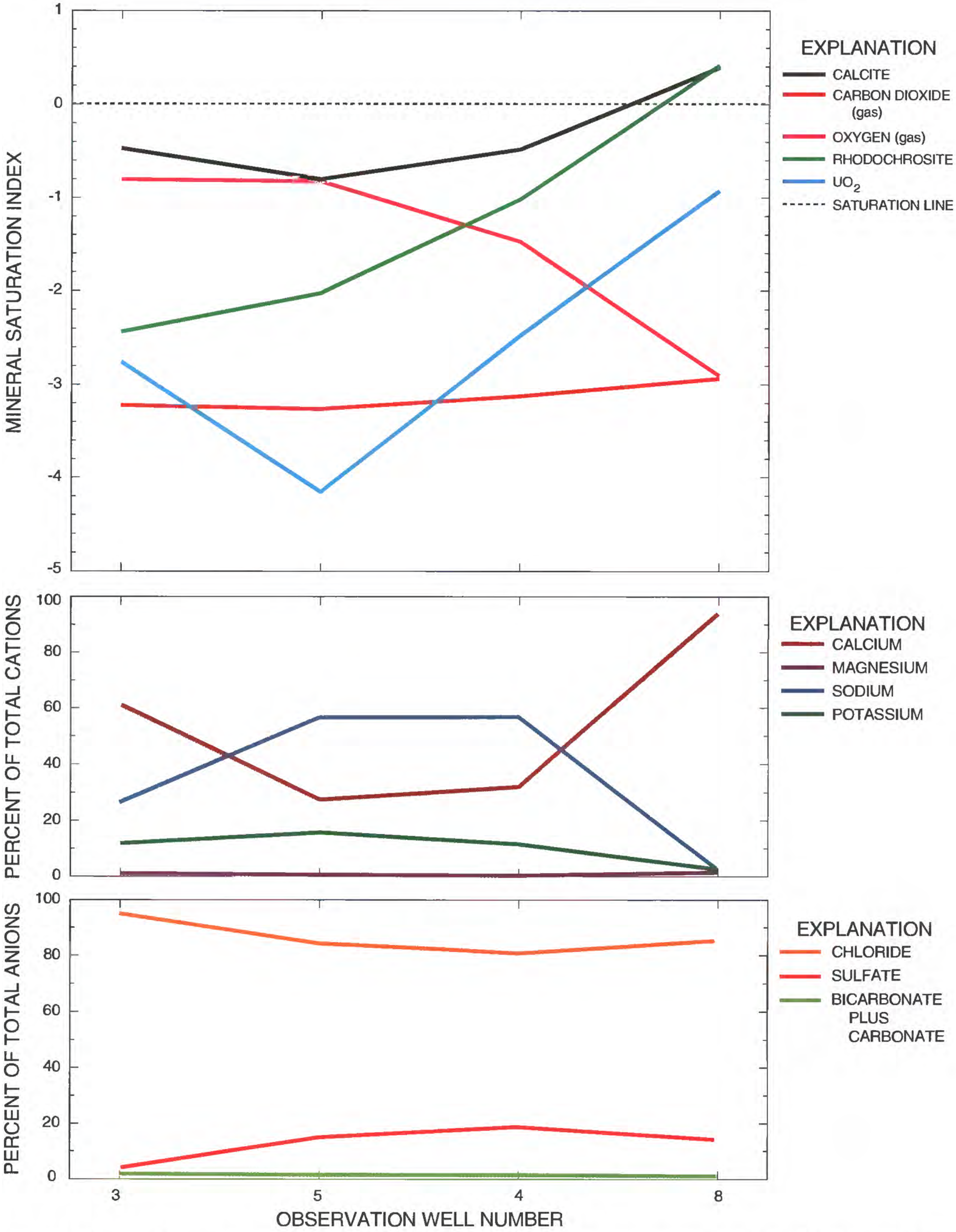


Figure 13. Selected mineral saturation indices and proportions of major ions in water samples collected from observation wells 3, 5, 4, and 8, ordered from most upgradient to most downgradient well.

arsenic at observation well 4 and increases to 68 percent at observation well 8. A decline in dissolved oxygen concentration to anoxia between observation wells 4 and 8 corresponds to the change in dominance of arsenic species. The less oxidizing conditions present at observation well 8 is consistent with the increase of iron and manganese concentrations (an increase in dissolved iron concentration from <3 to 58 µg/L and an increase in dissolved manganese concentration from 9 to 360 µg/L between observation wells 4 and 8, table 4). Dissolution of iron and manganese oxides may release associated arsenic. However, dissolved arsenic concentrations decrease between observation wells 4 and 8. It is possible that pH and redox conditions at observation well 8 result in adsorption of some arsenic from solution. Other trace elements may also be lost from solution; for example, the mineral saturation index for UO_2 increases from much below saturation to near saturation between observation wells 4 and 8. The mineral saturation index of UO_2 at observation well 2 (located very close to observation well 8) indicated above-saturation conditions.

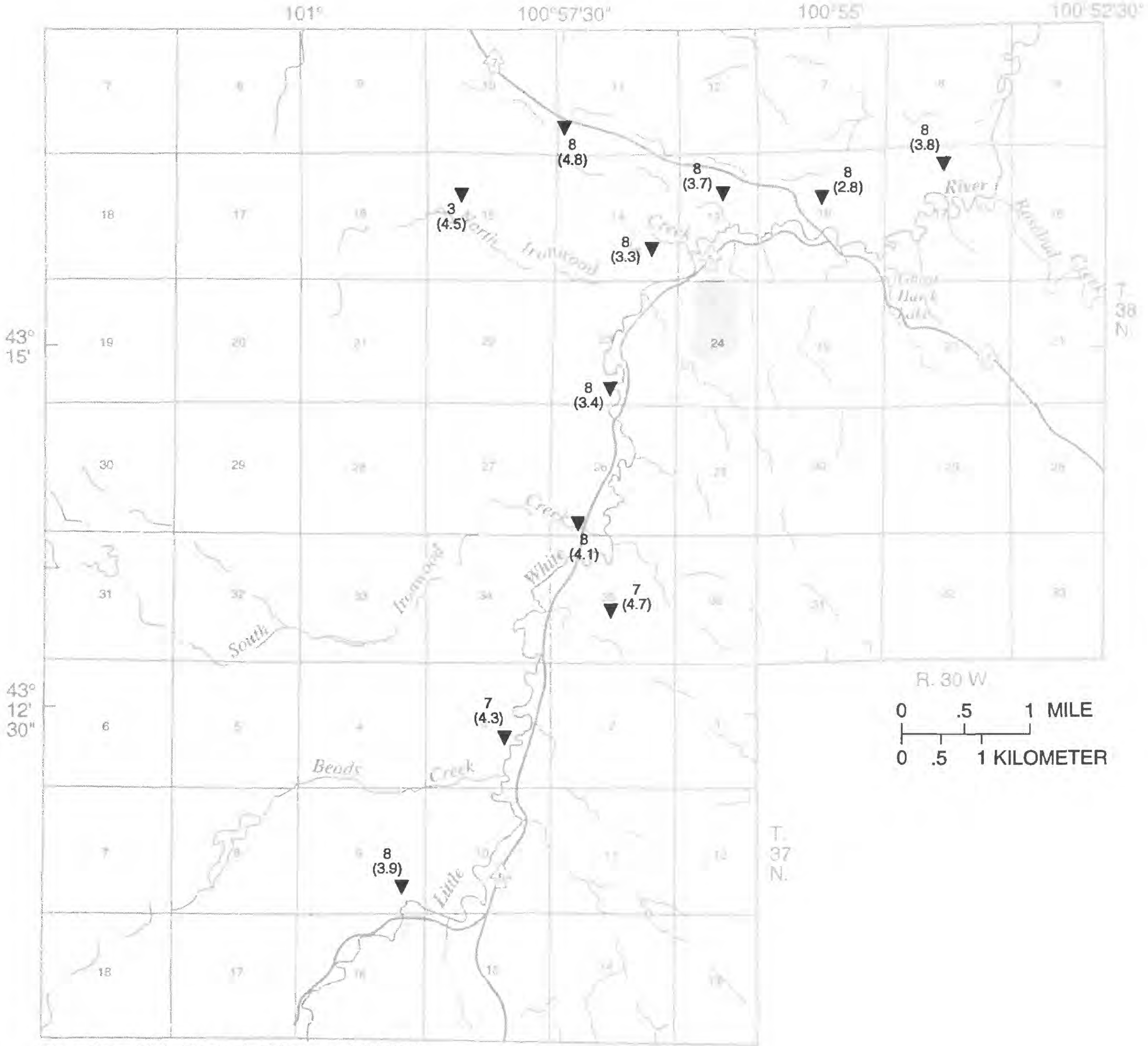
Controls on arsenic concentrations at the springs are not known because only arsenic concentrations were analyzed in the spring samples. However, dissolved arsenic at the springs probably is controlled by the same factors previously described in the groundwater discussion.

Little variability of arsenic concentrations existed among the surface-water sites, with the exception of two samples (table 6 and fig. 14). The mean dissolved arsenic concentration for the surface-water samples was 7.8 µg/L with a standard deviation of 2.0. Surface-water arsenic concentrations ranged from 3 µg/L in the sample from North Ironwood Creek to 14 µg/L in the 1991 sample from the Little White River below Swimmer Residence. At the Swimmer Residence site, elevated arsenic concentrations also were detected in the ground water. The elevated surface-water concentration may indicate that the sample was collected below an area of increased groundwater discharge to the stream. At the next site downstream from the Swimmer Residence (Little White River below Whipple Residence), the dissolved arsenic concentration was 8 µg/L, which is within the range of background concentrations. This is reasonable because arsenic generally decreases to background concentrations in relatively short distances when introduced to oxidizing conditions (Baudo and others, 1990).

Total arsenic concentrations (dissolved plus suspended) were measured in 1995 to determine if arsenic was associated with suspended solids in the surface water. The results show that, because the total arsenic concentrations generally were either equal to or were 1 to 2 µg/L higher than the dissolved concentrations, suspended-phase arsenic is not significantly present in the surface water.

Median dissolved concentrations of arsenic, molybdenum, selenium, uranium, and vanadium in South Dakota's surface water were calculated from all available data stored in the USGS water-quality database. Median concentrations were 4 µg/L for arsenic based on 2,286 samples, 4 µg/L for molybdenum based on 851 samples, 1 µg/L for selenium based on 937 samples, 5 µg/L for uranium based on 156 samples, and 1 µg/L for vanadium based on 840 samples. Concentrations of these elements in the surface-water samples collected for this study generally were comparable to the median South Dakota surface-water values with the exception of vanadium concentrations, which were higher than the South Dakota median at all sites. Vanadium concentrations ranged from 5 to 10 µg/L (table 6). The presence of higher dissolved vanadium concentrations in the surface water in the study area is reasonable because elevated vanadium concentrations were present in ground-water samples and the Arikaree aquifer likely discharges to local surface water in the Grass Mountain area. Based on the association between naturally occurring arsenic and vanadium, the presence of vanadium in the surface water also suggests a naturally occurring source for the dissolved arsenic concentrations because the only probable source for the vanadium is naturally occurring. Because the arsenic concentrations generally are below the median concentration in South Dakota, elevated arsenic concentrations in the dissolved or suspended phase in the surface water does not appear to be a problem in the Grass Mountain area.

In surface-water samples, dissolved arsenic was significantly positively correlated with dissolved iron and magnesium and negatively correlated with pH and fluoride (table 14). A correlation between dissolved arsenic and dissolved manganese could not be run because the differences in detection limits of manganese would mask any relation (table 6). In spite of this, the correlation between dissolved arsenic and dissolved iron suggests that iron (and possibly manganese) oxide minerals may be controlling arsenic concentrations in surface water.



Base from U.S. Geological Survey 1:24,000,
Soldier Creek, St. Francis, Parmelee, and
Iron Shell Flat East, 1969

EXPLANATION

▭ PRAIRIE DOG TOWN

▼ 8 (3.9) SURFACE-WATER AND BED-SEDIMENT SAMPLING SITE--Upper number indicates dissolved arsenic concentration, in micrograms per liter, in surface water. Number in parentheses indicates arsenic concentration in micrograms per gram in bed sediments.

Figure 14. Arsenic concentrations in surface water and bed sediments, 1995.

Little variability of arsenic concentrations existed among the bed-sediment samples collected from surface-water sites (table 7). The mean arsenic concentration for the bed-sediment samples was 3.9 µg/g with a standard deviation of 0.6 µg/g. The arsenic concentrations in the sediments do not appear to be elevated. As previously mentioned, arsenic concentrations were not elevated in either the dissolved or suspended phases in the surface water during the 1995 sampling. Therefore, arsenic concentrations are not elevated in any phase (dissolved, suspended, or bed sediment) in the surface-water in the Grass Mountain area.

Measured constituents in bed-sediment samples that contained censored (less than) values for all sites were not used in the correlation procedure. Arsenic in bed-sediment samples was significantly positively correlated with manganese (table 14), which further supports the conclusion that adsorption of arsenic by manganese oxides and possibly iron oxides may be a factor in dissolved arsenic concentrations in the surface water.

The fate of arsenic in the surface-water system is not certain. Because the relative ground-water contribution to the river may be small, dissolved arsenic in the ground water that is discharged to the stream is diluted in the stream. As suggested in the preceding paragraph, arsenic discharged to the surface water may also be quickly adsorbed onto iron- or manganese-oxide phases.

EXTENT OF ARSENIC

The extent of the elevated arsenic concentrations in ground water is not entirely known. The highest concentrations appear to be near Grass Mountain Community in the Arikaree aquifer within about 1 mi southeast from the Little White River (fig. 7). It appears that the concentrations may not be as great in the alluvial aquifer as in the Arikaree aquifer as evidenced by the substantially lower, yet still elevated, arsenic concentration at observation well 8 (alluvial: 25 µg/L), which is located within 20 ft of observation well 7 (Arikaree: 110 µg/L). Because the concentration of dissolved arsenic appears to be related to higher pH and less oxidizing conditions, it seems unlikely that arsenic concentrations in ground water more than one-half mile to the south of the Grass Mountain Community will exceed the EPA maximum contaminant level of 50 µg/L. Samples from observation well 3 and the Whipple stock wells, all located upgradient and under more oxidizing conditions, support this interpretation.

Elevated arsenic concentrations do not appear to be a problem on the north and west sides of the Little White River; however, it was not possible to install observation wells near the river at these locations because of inaccessibility. However, this area is not likely to be inhabited, and impacts to humans in this area are therefore improbable. All the other private domestic and stock wells on this side of the river in the study area had arsenic concentrations below the EPA maximum contaminant level.

Elevated arsenic concentrations also do not appear to be a problem more than $1^{1}/_{2}$ mi to the east of Grass Mountain Community. Specifically, the eastern boundary of the elevated arsenic concentrations appears to be located between the No Heart domestic well and observation well 1. A possible reason that high arsenic concentrations occur at No Heart and not farther east is that the geochemical conditions needed for high arsenic solubility are not present farther east.

It is likely that other areas in the Rosebud Indian Reservation (Todd County) also may have elevated arsenic concentrations in ground water that exceed the EPA maximum contaminant level. Because volcanic ash is a likely source of arsenic, and is found throughout the Arikaree Formation and White River Group, both of which contain major aquifers in Todd County, that potential source of arsenic may be present throughout much of Todd County. Ground-water samples from two observation wells completed in the Arikaree aquifer in southeastern Todd County that were recently sampled contained dissolved arsenic concentrations in excess of 50 µg/L (Carter, 1997). The arsenic concentrations at these two sites were 58 and 110 µg/L, and there was no evidence at either site that anthropogenic activity may have contributed to the high arsenic concentrations. Therefore, it is likely that arsenic solubility controls in this area locally favor elevated arsenic concentrations. It is not possible to predict where other elevated arsenic concentrations may be present in Todd County without further knowledge of the ground-water redox conditions and pH values throughout the county.

Elevated suspended or dissolved arsenic concentrations were not found in the surface-water samples, and elevated concentrations were not found in the bed-sediment samples. Therefore, it appears that arsenic concentrations are not elevated in any phase (dissolved, suspended, or bed sediment) in the surface water in the Grass Mountain area. The elevated arsenic concentrations in the ground water likely are being diluted after being discharged to the stream and/or arsenic may be being adsorbed by iron and manganese oxides.

SUMMARY AND CONCLUSIONS

Elevated concentrations of dissolved arsenic in ground water have been reported in the Grass Mountain area of the Rosebud Indian Reservation. The two most probable sources of the arsenic are a naturally occurring source and an arsenic pesticide, which may have been used in earlier parts of this century in the Grass Mountain area to eradicate prairie dogs. The Rosebud Sioux Tribe was interested in determining the extent and magnitude of the elevated arsenic concentrations in ground water and possible surface water and also the source of the arsenic in order to make future water-management decisions. The U.S. Geological Survey, in cooperation with the Rosebud Sioux Tribe, conducted an initial study of arsenic concentrations in ground water and surface water in the Grass Mountain area in 1991 and 1992. A more comprehensive study, which included the sampling of ground water, surface water, bed sediments, springs, and drill-hole cuttings, was conducted in 1995 with additional cooperation from the South Dakota Geological Survey. Statistical analyses using the Spearman's rank correlation procedure were used to determine associations between arsenic and other analyzed constituents and physical properties. Geochemical modeling with the PHREEQC program was used to simulate redox conditions and mineral equilibria for the ground-water samples.

The only evidence from the results of the study that supports an arsenic pesticide source for the elevated arsenic concentrations is the high dissolved arsenic concentrations from several wells and one spring located near and downgradient from the prairie dog town. However, because other wells and one spring with elevated arsenic concentrations are not located downgradient from the prairie dog town, it is unlikely that the elevated arsenic in the Grass Mountain area is due to arsenic pesticide use at the prairie dog town.

Dissolved arsenic in ground water was significantly positively correlated with vanadium and molybdenum, two of the elements commonly associated with naturally occurring arsenic in rocks. Additionally, elevated uranium concentrations were detected in two of the ground-water samples that had high arsenic concentrations. Because the only possible local source of uranium is almost certainly natural and because of its association with naturally occurring rock arsenic, the elevated uranium concentrations also support the conclusion that the source of arsenic is natural.

Both arsenic (As^{+3} plus As^{+5}) and arsenite (As^{+3}) were significantly negatively correlated with calculated oxidation-reduction potentials and dissolved oxygen in ground-water samples. The decrease in dissolved oxygen concentrations, increase in iron and manganese concentrations, and relations between concentrations of dissolved solids, soluble ions, and calculated oxidation-reduction potentials in the ground-water samples provide evidence that conditions change from oxidizing to reducing, accompanied by increased dissolution of rock constituents downgradient. Arsenic concentrations were found to increase with pH, which indicates greater solubility at high pH and possibly indicates desorption from solid adsorbent surfaces as pH increases. The pH conditions probably control the extent of arsenic adsorption on the aquifers sediments.

High pH (above about 8.0) appears to allow the release of arsenic, uranium, vanadium, selenium, and molybdenum from the volcanic ash and/or aquifer sediments. These trace elements from the ash then are transported in solution downgradient, and the redox conditions control the valence state of dissolved arsenic. Downgradient, the Arikaree Formation is in contact with the alluvium. Here, oxidation of organic carbonaceous materials may react with dissolved oxygen, resulting in a more reduced ground water. Decreases in pH and Eh probably reach a point where trace elements are converted to more reduced species and ultimately may be precipitated or adsorbed from solution.

Arsenic concentrations may be further controlled by adsorption effects related to the presence of iron and manganese oxide minerals, and clay minerals, although conclusive evidence of adsorption effects by iron- and manganese-oxides was not found. Analyses of the surface-water and bed-material samples further support the possibility of iron- and manganese-oxide controls. In surface-water samples, arsenic was significantly positively correlated with dissolved iron and in the bed-sediment samples, arsenic was significantly positively correlated with manganese. Additionally, the reddish color of many drill-hole-cuttings samples indicates the presence of iron oxides.

Elevated arsenic concentrations do not appear to be a problem in local surface water because arsenic was not significant in the dissolved phase, suspended phase, or bed sediments in samples collected from the Little White River and its tributaries. The elevated ground-water arsenic concentrations appear to be confined to less than a 1- to 2-mile radius around Grass Mountain Community. It is likely that other elevated arsenic concentrations are present in the ground water at places in Todd County; however, it is not possible to better locate these areas without additional study.

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SUPPLEMENTAL INFORMATION

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Table 4. Properties and constituent concentrations for ground-water samples

[Arsenic concentrations given in parentheses and arsenate and arsenite concentrations were determined by the Montana Bureau of Mines and Geology Laboratory; all other concentrations determined by the USGS National Water Quality Laboratory. µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; mV, millivolt; µg/L, micrograms per liter; deg C, degrees Celsius; FET, fixed end point titration; IT, incremental titration; diss, dissolved; GMC, Grass Mountain Community; 2SPE, 2 sigma precision estimate; <, less than; --, no data]

Well name	Date	Specific conductance, field (µS/cm) (00095)	pH, water, whole, field (standard units) (00400)	Temperature, water (deg C) (00010)	Temperature, air (deg C) (00020)	Barometric pressure (mm of Hg) (00025)	Oxygen, dissolved (mg/L) (00300)	Oxygen, dissolved (percent saturation) (00301)
Ghost Hawk Park well	08-07-91	605	7.3	17.0	26.0	--	--	--
	11-30-92	594	7.7	9.5	4.0	--	--	--
	09-20-95	588	7.3	14.5	0.0	785	2.1	20
Stock well 1	09-21-95	428	8.0	14.5	1.0	777	8.3	80
No Heart domestic well	08-07-91	1,730	7.3	13.5	23.0	--	--	--
	11-30-92	1,410	7.4	10.0	--	--	--	--
	09-20-95	1,430	7.3	13.0	0.0	777	3.5	33
Observation well 1	10-02-91	415	7.4	14.5	21.5	--	--	--
	11-30-92	403	7.7	9.5	1.0	--	--	--
	09-20-95	[1]395	7.5	13.0	1.0	785	4.9	45
Observation well 6	09-19-95	617	8.0	14.0	4.0	696	--	--
LaPointe stock well	09-22-95	314	7.3	12.5	-4.0	771	9.4	88
Whipple domestic well	08-07-91	806	7.3	15.0	28.5	--	--	--
	11-30-92	586	7.3	11.0	--	--	--	--
Hesse domestic well	09-21-95	[1]433	7.6	12.5	0.0	777	6.2	57
Stock well 3	09-21-95	249	7.7	12.5	1.0	777	9.2	85
Observation well 2	10-02-91	582	7.5	13.0	19.0	--	--	--
	11-30-92	682	7.7	13.0	5.0	--	--	--
	[2]11-30-92	--	--	--	--	--	--	--
Observation well 7	09-18-95	613	8.0	13.0	--	693	0.1	1
Observation well 8	09-18-95	[1]513	[1]8.0	12.0	--	693	0.0	0
	[2]09-18-95	--	--	--	--	--	--	--
Swimmer domestic well	08-07-91	1,050	7.1	17.0	29.5	--	--	--
Observation well 9	09-18-95	368	8.4	14.0	--	693	7.5	81
Observation well 3	10-03-91	537	7.8	13.0	9.5	--	--	--
	12-01-92	358	7.8	13.5	--	--	--	--
	09-21-95	314	8.1	--	0.0	777	--	--
GMC well	08-07-91	562	8.3	18.5	26.0	--	--	--
	[2]08-07-91	--	--	--	--	--	--	--
	11-30-92	530	8.5	13.5	6.5	--	--	--
Observation well 4	09-20-95	[1]558	8.2	15.0	0.0	777	1.3	13
Observation well 5	09-19-95	391	8.2	16.0	4.0	696	5.7	64
Whipple stock well 1	08-07-91	341	7.8	16.0	25.5	--	--	--
	09-19-95	314	7.5	14.0	4.0	696	8.1	87
Whipple stock well 2	09-21-95	312	7.8	17.0	1.0	777	8.2	84
Stock well 2	09-21-95	293	7.5	13.5	1.0	777	9.3	88

Table 4. Properties and constituent concentrations for ground-water samples—Continued

Well name	Date	Oxidation reduction potential (mV) (00090)	Alkalinity, field, diss, FET (mg/L as $CaCO_3$) (00418)	Alkalinity, field, diss, IT (mg/L as $CaCO_3$) (39086)	Bicarbonate, field, diss, IT, (mg/L as HCO_3) (00453)	Carbonate, field, diss, IT (mg/L as CO_3) (00452)	Calcium, dissolved (mg/L as Ca) (00915)	Magnesium, dissoved (mg/L as Mg) (00925)
Ghost Hawk Park well	08-07-91	--	--	--	--	--	69	6.2
	11-30-92	--	--	--	--	--	--	--
	09-20-95	304	305	305	372	0	66	6.3
Stock well 1	09-21-95	254	188	193	236	0	9.8	0.70
No Heart domestic well	08-07-91	--	--	--	--	--	170	18
	11-30-92	--	--	--	--	--	--	--
	09-20-95	221	472	481	587	0	130	14
Observation well 1	10-02-91	--	--	--	--	--	44	5.3
	11-30-92	--	--	--	--	--	--	--
	09-20-95	262	187	192	235	0	43	5.1
Observation well 6	09-19-95	296	193	193	236	0	16	1.5
LaPointe stock well	09-22-95	209	158	160	195	0	54	8.3
Whipple domestic well	08-07-91	--	--	--	--	--	77	5.2
	11-30-92	--	--	--	--	--	--	--
Hesse domestic well	09-21-95	247	159	162	198	0	23	2.9
Stock well 3	09-21-95	262	97	100	122	0	32	3.8
Observation well 2	10-02-91	--	--	--	--	--	52	4.1
	11-30-92	--	--	--	--	--	--	--
	[2]11-30-92	--	--	--	--	--	--	--
Observation well 7	09-18-95	245	235	238	290	0	9.6	0.53
Observation well 8	09-18-95	52	234	234	286	0	78	6.8
	[2]09-18-95	--	--	--	--	--	77	6.8
Swimmer domestic well	08-07-91	--	--	--	--	--	100	6.5
Observation well 9	09-18-95	225	152	154	171	8	4.1	0.26
Observation well 3	10-03-91	--	--	--	--	--	20	2.7
	12-01-92	--	--	--	--	--	--	--
	09-21-95	196	142	141	173	0	11	0.90
GMC well	08-07-91	--	--	--	--	--	5.3	<0.01
	[2]08-07-91	--	--	--	--	--	5.4	0.03
	11-30-92	--	--	--	--	--	--	--
Observation well 4	09-20-95	203	228	234	286	0	5.9	0.32
Observation well 5	09-19-95	267	161	161	197	0	3.6	0.24
Whipple stock well 1	08-07-91	--	--	--	--	--	31	3.7
	09-19-95	300	143	142	173	0	38	4.8
Whipple stock well 2	09-21-95	241	143	146	178	0	19	2.1
Stock well 2	09-21-95	265	140	143	174	0	45	5.5

Table 4. Properties and constituent concentrations for ground-water samples—Continued

Well name	Date	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 deg C, dissolved (mg/L) (70300)
Ghost Hawk Park well	08-07-91	56	15	12	1.5	0.30	55	388
	11-30-92	--	--	--	--	--	--	--
	09-20-95	54	11	10	3.1	0.30	60	402
Stock well 1	09-21-95	88	7.7	16	3.7	0.60	68	320
No Heart domestic well	08-07-91	170	26	170	90	0.70	55	1200
	11-30-92	--	--	--	--	--	--	--
	09-20-95	170	24	120	70	0.60	66	1020
Observation well 1	10-02-91	37	9.8	20	3.6	0.30	66	297
	11-30-92	--	--	--	--	--	--	--
	09-20-95	33	9.2	13	1.6	0.30	66	281
Observation well 6	09-19-95	100	21	52	34	0.70	65	411
LaPointe stock well	09-22-95	9.6	7.9	5.6	1.5	0.30	65	285
Whipple domestic well	08-07-91	82	14	88	20	0.60	52	553
	11-30-92	--	--	--	--	--	--	--
Hesse domestic well	09-21-95	65	10	52	1.0	0.50	66	313
Stock well 3	09-21-95	12	5.8	5.3	0.80	0.30	57	191
Observation well 2	10-02-91	73	11	42	5.0	0.70	53	393
	11-30-92	--	--	--	--	--	--	--
	[2]11-30-92	--	--	--	--	--	--	--
Observation well 7	09-18-95	130	7.4	70	2.4	1.3	54	414
Observation well 8	09-18-95	22	11	37	2.0	0.60	47	360
	[2]09-18-95	25	11	38	2.1	0.60	48	368
Swimmer domestic well	08-07-91	140	14	48	14	0.60	55	682
Observation well 9	09-18-95	86	6.1	36	1.5	3.1	65	289
Observation well 3	10-03-91	83	16	33	11	0.60	60	377
	12-01-92	--	--	--	--	--	--	--
	09-21-95	55	7.8	5.1	1.9	0.40	71	249
GMC well	08-07-91	120	6.4	54	6.9	1.7	63	399
	[2]08-07-91	120	6.9	55	6.8	1.7	63	401
	11-30-92	--	--	--	--	--	--	--
Observation well 4	09-20-95	120	6.9	52	2.3	1.5	64	396
Observation well 5	09-19-95	85	5.4	27	1.5	1.9	69	291
Whipple stock well 1	08-07-91	35	7.4	11	0.90	0.40	75	260
	09-19-95	16	7.7	9.2	2.4	0.20	71	236
Whipple stock well 2	09-21-95	49	8.7	14	1.0	0.50	71	254
Stock well 2	09-21-95	6.7	5.1	3.7	1.0	0.30	54	207

Table 4. Properties and constituent concentrations for ground-water samples—Continued

Well name	Date	Nitrogen, ammonia dissolved (mg/L as N) (00608)	Nitrogen, nitrite dissolved (mg/L as N) (00613)	Nitrogen, NO_2 +NO_3 dissolved (mg/L as N) (00631)	Phos-phorus, ortho, dissolved (mg/L as P) (00671)	Arsenic, dissolved (µg/L as As) (01000)	Arsenic, dissolved (µg/L as As^{+3}) (Arsenite)	Arsenic, dissolved (µg/L as As^{+5}) (Arsenate)
Ghost Hawk Park well	08-07-91	0.100	<0.010	0.100	0.050	7 (--)	--	--
	11-30-92	--	--	--	--	10 (9)	<1	9
	09-20-95	--	--	--	--	7 (8)	<1	8
Stock well 1	09-21-95	--	--	--	--	20 (18)	<1	18
No Heart domestic well	08-07-91	0.080	0.010	39.0	1.00	57 (--)	--	--
	11-30-92	--	--	--	--	35 (40)	4	36
	09-20-95	--	--	--	--	58 (60)	<1	60
Observation well 1	10-02-91	<0.010	<0.010	0.840	0.030	6 (--)	--	--
	11-30-92	--	--	--	--	8 (7)	1	6
	09-20-95	--	--	--	--	8 (8)	<1	8
Observation well 6	09-19-95	--	--	--	--	19 (17)	<1	17
LaPointe stock well	09-22-95	--	--	--	--	6 (6)	<1	6
Whipple domestic well	08-07-91	0.390	<0.010	1.10	0.070	31 (--)	--	--
	11-30-92	--	--	--	--	36 (38)	8	30
Hesse domestic well	09-21-95	--	--	--	--	12 (13)	<1	13
Stock well 3	09-21-95	--	--	--	--	4 (3)	<1	3
Observation well 2	10-02-91	0.080	<0.010	<0.050	0.070	44 (--)	--	--
	11-30-92	--	--	--	--	42 (44)	44	<1
	[2]11-30-92	--	--	--	--	42 (45)	44	1
Observation well 7	09-18-95	--	--	--	--	110 (102)	3	99
Observation well 8	09-18-95	--	--	--	--	25 (25)	17	8
	[2]09-18-95	--	--	--	--	30 (28)	19	9
Swimmer domestic well	08-07-91	0.110	<0.010	<0.050	0.100	30 (--)	--	--
Observation well 9	09-18-95	--	--	--	--	110 (99)	<1	99
Observation well 3	10-03-91	0.080	0.070	3.30	0.410	9 (--)	--	--
	12-01-92	--	--	--	--	3 (2)	<1	2
	09-21-95	--	--	--		9 (8)	<1	8
GMC well	08-07-91	0.090	<0.010	0.270	0.010	85 (--)	--	--
	[2]08-07-91	--	--	--	--	62 (--)	--	--
	11-30-92	--	--	--	--	82 (85)	7	79
Observation well 4	09-20-95	--	--	--	--	83 (77)	5	72
Observation well 5	09-19-95	--	--	--	--	100 (100)	<1	100
Whipple stock well 1	08-07-91	<0.010	<0.010	1.30	<0.010	9 (--)	--	--
	09-19-95	--	--	--	--	5 (5)	<1	5
Whipple stock well 2	09-21-95	--	--	--	--	13 (11)	<1	11
Stock well 2	09-21-95	--	--	--	--	3 (2)	<1	2

Table 4. Properties and constituent concentrations for ground-water samples—Continued

Well name	Date	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Copper, dissolved (µg/L as Cu) (01040)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Manganese, dissolved (µg/L as Mn) (01056)
Ghost Hawk Park well	08-07-91	<1.0	<1	5	4	<1	2
	11-30-92	--	--	--	--	--	--
	09-20-95	<1.0	<1	4	<3	<1	<1
Stock well 1	09-21-95	<1.0	1	<1	<10	<1	10
No Heart domestic well	08-07-91	<1.0	<1	10	4	<1	34
	11-30-92	--	--	--	--	--	--
	09-20-95	<1.0	<1	15	<3	<1	11
Observation well 1	10-02-91	<1.0	<1	<1	10	<1	10
	11-30-92	--	--	--	--	--	--
	09-20-95	<1.0	<1	<1	<3	<1	1
Observation well 6	09-19-95	<1.0	<1	5	<3	<1	16
LaPointe stock well	09-22-95	<1.0	-<1	2	<10	<1	<10
Whipple domestic well	08-07-91	<1.0	<1	3	<3	<1	<1
	11-30-92	--	--	--	--	--	--
Hesse domestic well	09-21-95	<1.0	2	2	20	<1	<10
Stock well 3	09-21-95	<1.0	<1	<1	<10	<1	20
Observation well 2	10-02-91	<1.0	<1	<1	22	<1	160
	11-30-92	--	--	--	--	--	--
	[2]11-30-92	--	--	--	--	--	--
Observation well 7	09-18-95	<1.0	<1	<1	<3	<1	6
Observation well 8	09-18-95	<1.0	<1	<1	58	<1	360
	[2]09-18-95	<1.0	<1	<1	56	<1	350
Swimmer domestic well	08-07-91	<1.0	<1	3	170	<1	270
Observation well 9	09-18-95	<1.0	<1	<1	<3	<1	1
Observation well 3	10-03-91	<1.0	<1	12	43	<1	6
	12-01-92	--	--	--	--	--	--
	09-21-95	<1.0	<1	<1	<10	<1	<10
GMC well	08-07-91	<1.0	<1	4	<3	<1	<1
	[2]08-07-91	<1.0	<1	4	<3	<1	<1
	11-30-92	--	--	--	--	--	--
Observation well 4	09-20-95	<1.0	<1	3	<3	<1	9
Observation well 5	09-19-95	<1.0	<1	<1	<3	<1	1
Whipple stock well 1	08-07-91	<1.0	1	17	31	<1	1
	09-19-95	<1.0	<1	6	46	2	6
Whipple stock well 2	09-21-95	<1.0	1	<1	<10	<1	<10
Stock well 2	09-21-95	<1.0	<1	<1	<10	<1	<10

Table 4. Properties and constituent concentrations for ground-water samples—Continued

Well name	Date	Mercury, dissolved (µg/L as Hg) (71890)	Molybdenum, dissolved (µg/L as Mo) (01060)	Selenium, dissolved (µg/L as U) (01145)	Uranium, natural, dissolved (µg/L as U) (22703)	Uranium, natural, 2SPE, diss (µg/L) (75990)	Vanadium, dissolved (µg/L as V) (01085)	Zinc, dissolved (µg/L as Zn) (01090)
Ghost Hawk Park well	08-07-91	<0.1	--	<1	--	--	--	89
	11-30-92	--	--	--	--	--	--	--
	09-20-95	<0.1	2	<1	11	0.3	3	31
Stock well 1	09-21-95	<0.1	4	<2	5.6	0.1	22	<10
No Heart domestic well	08-07-91	<0.1	--	3	--	--	--	11
	11-30-92	--	--	--	--	--	--	--
	09-20-95	<0.1	4	2	22	1.4	65	16
Observation well 1	10-02-91	<0.1	--	<1	--	--	--	5
	11-30-92	--	--	--	--	--	--	--
	09-20-95	<0.1	2	<1	6.8	0.2	7	23
Observation well 6	09-19-95	<0.1	4	<1	5.7	0.1	14	28
LaPointe stock well	09-22-95	<0.1	<1	1	3.9	0.1	9	<10
Whipple domestic well	08-07-91	<0.1	--	<1	--	--	--	31
	11-30-92	--	--	--	--	--	--	--
Hesse domestic well	09-21-95	<0.1	4	<2	4.8	0.1	12	70
Stock well 3	09-21-95	<0.1	<1	<1	1.4	0.0	8	<10
Observation well 2	10-02-91	<0.1	--	<1	--	--	--	5
	11-30-92	--	2	<1	21	--	2	--
	[2]11-30-92	--	--	--	--	--	--	--
Observation well 7	09-18-95	<0.1	3	<1	7.8	0.2	12	<3
Observation well 8	09-18-95	<0.1	3	<1	9.4	0.2	1	<3
	[2]09-18-95	<0.1	3	<1	9.4	0.2	1	<3
Swimmer domestic well	08-07-91	<0.1	--	<1	--	--	--	13
Observation well 9	09-18-95	<0.1	1	1	3.8	0.1	24	<3
Observation well 3	10-03-91	<0.1	--	1	--	--	--	6
	12-01-92	--	--	--	--	--	--	--
	09-21-95	<0.1	1	1	5.1	0.1	14	<10
GMC well	08-07-91	0.6	--	3	--	--	--	6
	[2]08-07-91	0.4	--	3	--	--	--	<3
	11-30-92	--	--	--	--	--	--	--
Observation well 4	09-20-95	<0.1	5	<1	5.3	0.1	21	13
Observation well 5	09-19-95	<0.1	1	5	3.1	0.1	150	11
Whipple stock well 1	08-07-91	<0.1	--	2	--	--	--	500
	09-19-95	<0.1	1	2	6.2	0.1	6	960
Whipple stock well 2	09-21-95	<0.1	1	<1	2.4	0.1	10	100
Stock well 2	09-21-95	<0.1	<1	<1	1.6	0.0	8	<10

[1] Laboratory value is presented because field value was determined to be erroneous.

[2] Indicates duplicate sample for quality-assurance purposes.

Table 5. Properties and arsenic concentrations in spring-water samples

[deg C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; --, no data]

Spring identifier	Local number	Latitude	Longitude	Date	Temperature, field (deg C)	Specific conductance, field (µS/cm)	Arsenic, dissolved (µg/L as As)
Spring 1	37N31W 8AACC	43° 11' 46"	101° 00' 22"	01-18-95	5.0	225	3
				[1]01-18-95	5.0	225	3
Spring 2	38N31W24BBBA	43° 15' 26"	100° 56' 16"	01-18-95	3.5	575	117
Spring 3	38N31W13CBCC	43° 15' 42"	100° 56' 22"	01-19-95	5.0	--	6
Spring 4	38N31W13CABA	43° 15' 53"	100° 55' 57"	01-19-95	5.0	--	16

[1] Indicates duplicate sample for quality-assurance purposes.

Table 6. Properties and constituent concentrations for surface-water samples

[LWR, Little White River; inst, instantaneous; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; mm, millimeter; µg/L, micrograms per liter; deg C, degrees Celsius; diss, dissolved; FET, fixed end point titration; IT, incremental titration; 2SPE, 2 sigma precision estimate; <, less than; --, no data]

Site number	Site name	Date	Discharge, inst. (cubic feet per second) (00061)	Specific conductance, field, (µS/cm) (00095)	pH, water whole field (standard units) (00400)	Temperature, water (deg C) (00010)	Temperature, air (deg C) (00020)	Barometric pressure (mm of Hg) (00025)	Oxygen, dissolved (mg/L) (00300)
431555100583400	North Ironwood Creek	09-25-95	0.35	259	8.8	13.0	20.5	680	9.7
431618100573300	Stuart Creek	09-25-95	0.15	462	8.4	13.5	21.5	680	8.7
431618100573300	Unnamed tributary	09-25-95	0.10	373	7.7	9.5	22.5	680	9.6
431602100535300	LWR at Ghost Hawk Park	08-07-91	152	273	8.0	24.5	25.5	--	7.6
		09-26-95	90	336	7.8	10.5	19.0	685	10.0
06449300	LWR above Rosebud	08-07-91	157	267	8.3	23.0	25.0	--	8.0
		09-26-95	89	335	7.9	8.5	7.5	685	10.3
431547100555200	LWR below Whipple Residence	08-06-91	111	301	8.2	28.0	31.5	--	7.4
		09-26-95	83	336	7.9	13.0	27.0	685	9.4
431522100563700	LWR at Swimmer Residence	08-06-91	111	303	8.1	27.0	33.0	--	7.8
		09-26-95	92	335	7.7	16.5	26.5	685	8.8
		[1]09-26-95	--	--	--	--	--	--	--
431428100565800	LWR at Two Strike Bridge	08-06-91	117	302	8.3	26.5	31.5	--	8.2
		09-27-95	84	336	8.1	10.5	19.0	682	10.3
431336100572000	LWR at Iron Shell Bridge	08-06-91	113	300	8.2	23.0	32.5	--	8.2
		09-27-95	84	333	8.1	12.5	25.5	682	10.1
431208100580300	LWR below Beads Creek	09-27-95	84	331	7.9	14.5	31.0	682	9.6
431107100585900	LWR at Hollow Horn Bear Bdg.	09-27-95	81	327	7.8	17.0	34.5	682	9.8

Table 6. Properties and constituent concentrations for surface-water samples—Continued

Site name	Date	Oxygen, dissolved (percent saturation) (00301)	Alkalinity, field, diss, FET (mg/L as $CaCO_3$) (00418)	Alkalinity, field, diss, IT (mg/L as $CaCO_3$) (39086)	Bicar-bonate, field, diss, IT (mg/L as HCO_3) (00453)	Carbonate, field, diss, IT (mg/L as CO_3) (00452)	Calcium, dissolved (mg/L as Ca) (00915)	Mag-nesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)
North Ironwood Creek	09-25-95	103	120	120	122	12	32	4.3	12	9.0
Stuart Creek	09-25-95	94	227	229	278	0	58	5.2	31	10
Unnamed tributary	09-25-95	94	172	174	212	0	40	3.7	29	8.0
LWR at Ghost Hawk Park	08-07-91	--	--	--	--	--	30	4.8	17	10
	09-26-95	100	151	152	185	0	36	6.0	23	9.8
LWR above Rosebud	08-07-91	--	--	--	--	--	30	4.7	16	10
	09-26-95	98	152	155	189	0	37	6.1	23	9.5
LWR below Whipple Residence	08-06-91	--	--	--	--	--	33	5.2	18	13
	09-26-95	99	150	151	184	0	36	6.0	23	9.8
LWR at Swimmer Residence	08-06-91	--	--	--	--	--	33	5.2	18	12
	09-26-95	100	153	155	190	0	36	6.0	23	9.8
	[1]09-26-95	--	--	--	--	--	36	6.0	23	10
LWR at Two Strike Bridge	08-06-91	--	--	--	--	--	33	5.2	18	12
	09-27-95	104	152	153	186	0	35	6.0	22	10
LWR at Iron Shell Bridge	08-06-91	--	--	--	--	--	33	5.3	18	12
	09-27-95	107	150	152	185	0	35	6.0	22	10
LWR below Beads Creek	09-27-95	106	143	144	176	0	34	5.8	21	10
LWR at Hollow Horn Bear Bdg.	09-27-95	113	146	151	185	0	34	5.9	21	11

Table 6. Properties and constituent concentrations for surface-water samples—Continued

Site name	Date	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 deg C, dissolved (mg/L) (70300)	Nitrogen, ammonia dissolved (mg/L as N) (00608)	Nitrogen, nitrite dissolved (mg/L as N) (00613)	Nitrogen, NO_2+ NO_3 dissolved (mg/L as N) (00631)	Phosphorus ortho, dissolved (mg/L as P) (00671)
North Ironwood Creek	09-25-95	6.8	3.8	0.60	32	182	--	--	--	--
Stuart Creek	09-25-95	14	1.7	0.50	58	323	--	--	--	--
Unnamed tributary	09-25-95	8.2	4.6	0.40	69	271	--	--	--	--
LWR at Ghost Hawk Park	08-07-91	12	2.4	0.40	42	186	<0.010	0.010	0.690	0.220
	09-26-95	14	1.8	0.50	47	233	--	--	--	--
LWR above Rosebud	08-07-91	12	1.0	0.40	41	188	<0.010	0.010	0.680	0.220
	09-26-95	14	1.7	0.50	45	235	--	--	--	--
LWR below Whipple Residence	08-06-91	13	1.1	0.40	46	215	<0.010	0.010	0.760	0.240
	09-26-95	14	1.8	0.50	49	240	--	--	--	--
LWR at Swimmer Residence	08-06-91	13	1.0	0.40	47	219	<0.010	0.010	0.740	0.240
	09-26-95	14	1.8	0.50	49	240	--	--	--	--
	[1]09-26-95	14	1.8	0.50	45	239	--	--	--	--
LWR at Two Strike Bridge	08-06-91	12	1.0	0.40	47	225	<0.010	<0.010	0.750	0.220
	09-27-95	14	1.9	0.40	49	238	--	--	--	--
LWR at Iron Shell Bridge	08-06-91	14	1.1	0.40	47	213	<0.010	0.010	0.760	0.250
	09-27-95	14	1.8	0.50	48	242	--	--	--	--
LWR below Beads Creek	09-27-95	14	1.9	0.50	48	237	--	--	--	--
LWR at Hollow Horn Bear Bdg.	09-27-95	14	1.8	0.50	49	263	--	--	--	--

Table 6. Properties and constituent concentrations for surface-water samples—Continued

Site name	Date	Arsenic, total (µg/L as As) (01002)	Arsenic, dissolved (µg/L as As) (01000)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Copper, dissolved (µg/L as Cu) (01040)	Iron, total recov-erable (µg/L as Fe) (01045)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Man-ganese, total recov-erable (µg/L as Mn) (01055)
North Ironwood Creek	09-25-95	3	3	<1.0	<1	<1	40	7	<1	<10
Stuart Creek	09-25-95	7	7	<1.0	<1	<1	1,800	9	<1	150
Unnamed tributary	09-25-95	7	8	<1.0	<1	<1	150	4	<1	<10
LWR at Ghost Hawk Park	08-07-91	--	7	<1.0	<1	1	--	31	<1	--
	09-26-95	8	8	<1.0	<1	<1	3,000	50	<1	160
LWR above Rosebud	08-07-91	--	7	<1.0	<1	1	--	53	<1	--
	09-26-95	8	8	<1.0	<1	<1	3,000	<10	<1	140
LWR below Whipple Residence	08-06-91	--	8	<1.0	<1	5	--	16	<1	--
	09-26-95	8	8	<1.0	<1	<1	3,000	30	<1	150
LWR at Swimmer Residence	08-06-91	--	14	<1.0	<1	5	--	60	<1	--
	09-26-95	8	8	<1.0	<1	<1	3,000	30	<1	150
	[1]09-26-95	9	8	<1.0	<1	1	3,000	50	<1	170
LWR at Two Strike Bridge	08-06-91	--	8	<1.0	<1	2	--	11	<1	--
	09-27-95	9	8	<1.0	<1	<1	3,300	20	<1	200
LWR at Iron Shell Bridge	08-06-91	--	8	<1.0	<1	3	--	10	<1	--
	09-27-95	9	8	<1.0	<1	<1	3,800	70	<1	210
LWR below Beads Creek	09-27-95	9	7	<1.0	<1	<1	3,300	<10	<1	200
LWR at Hollow Horn Bear Bdg.	09-27-95	9	8	<1.0	<1	<1	3,400	150	<1	190

Table 6. Properties and constituent concentrations for surface-water samples—Continued

Site name	Date	Man-ganese, dissolved (µg/L as Mn) (01056)	Mercury, dissolved (µg/L as Hg) (71890)	Molyb-denum, dissolved (µg/L as Mo) (01060)	Selenium, total (µg/L as Se) (01147)	Selenium, dissolved (µg/L as Se) (01145)	Uranium, natural, dissolved (µg/L as U) (22703)	Uranium, natural, 2 sigma water, diss (µg/L (75990)	Vanadium, dissolved (µg/L as V) (01085)	Zinc, dissolved (µg/L as Zn) (01090)
North Ironwood Creek	09-25-95	5	<0.1	<1	<1	<1	0.70	0.0	5	<3
Stuart Creek	09-25-95	5	<0.1	2	<1	<1	2.5	0.1	5	<3
Unnamed tributary	09-25-95	4	<0.1	<1	1	1	6.1	0.1	6	<3
LWR at Ghost Hawk Park	08-07-91	2	<0.1	--	--	<1	--	--	--	<3
	09-26-95	10	<0.1	2	<1	<1	2.1	0.0	9	<10
LWR above Rosebud	08-07-91	3	<0.1	--	--	<1	--	--	--	<3
	09-26-95	20	<0.1	2	<1	<1	2.0	0.0	9	<10
LWR below Whipple Residence	08-06-91	3	<0.1	--	--	<1	--	--	--	5
	09-26-95	<20	<0.1	2	<1	<2	2.1	0.0	9	<10
LWR at Swimmer Residence	08-06-91	19	<0.1	--	--	<1	--	--	--	6
	09-26-95	20	<0.1	2	<1	<2	2.1	0.0	9	<10
	[1]09-26-95	20	<0.1	2	<1	<1	2.1	0.0	9	<10
LWR at Two Strike Bridge	08-06-91	2	<0.1	--	--	<1	--	--	--	<3
	09-27-95	<10	<0.1	1	<1	<1	2.1	0.0	9	<10
LWR at Iron Shell Bridge	08-06-91	3	<0.1	--	--	<1	--	--	--	4
	09-27-95	<10	<0.1	2	<1	<1	2.2	0.0	10	<10
LWR below Beads Creek	09-27-95	<10	<0.1	2	<1	<1	2.1	0.0	9	<10
LWR at Hollow Horn Bear Bdg.	09-27-95	<10	<0.1	2	<1	<1	2.2	0.1	10	<10

[1] Indicates duplicate sample for quality-assurance purposes.

Table 7. Constituent concentrations for bed-sediment samples

[LWR Little White River; mg/g, milligrams per gram; µg/g, micrograms per gram; <, less than]

Station name	Date	Calcium, total in bottom material (mg/g)	Magnesium, total in bottom material (mg/g)	Sodium, total in bottom material (mg/g)	Potassium, total in bottom material (mg/g)	Phosphorus, total in bottom material (mg/g)	Aluminum, total in bottom material (µg/g)	Arsenic, total in bottom material (µg/g)	Barium, total in bottom material (µg/g)	Beryllium, total in bottom material (µg/g)	Bismuth, total in bottom material (µg/g)
North Ironwood Creek	09-25-95	18	8.8	9.8	22	0.9	69,000	4.5	670	2	<10
Unnamed tributary	09-25-95	16	9.8	8.9	20	0.7	69,000	4.8	680	2	<10
Stuart Creek	09-25-95	18	8.2	8.6	20	0.7	60,000	4.7	680	2	<10
LWR above Rosebud	09-26-95	14	4.7	13	24	0.4	58,000	2.8	770	2	<10
LWR at Ghost Hawk Park	09-26-95	19	9.0	9.0	21	0.9	62,000	3.8	650	2	<10
LWR below Whipple Residence	09-26-95	17	8.1	11	22	0.7	63,000	3.7	710	2	<10
LWR below Swimmer Residence	09-26-95	17	8.9	10	21	0.9	65,000	3.3	650	2	<10
	[1]09-26-95	17	8.4	11	20	0.9	64,000	3.6	660	2	<10
LWR at Two Strikes Bridge	09-27-95	17	8.1	10	21	0.8	62,000	3.4	660	2	<10
LWR at Iron Shell Bridge	09-27-95	17	8.0	9.9	20	0.9	60,000	4.1	690	2	<10
LWR below Beads Creek	09-27-95	16	8.3	9.7	20	0.8	60,000	4.3	660	2	<10
LWR at Hollow Horn Bear Bridge	09-27-95	17	8.1	9.7	21	0.9	59,000	3.9	680	2	<10

Table 7. Constituent concentrations for bed-sediment samples—Continued

Station name	Date	Cadmium, total in bottom material (µg/g)	Cerium, total in bottom material (µg/g)	Chromium, total in bottom material (µg/g)	Cobalt, total in bottom material (µg/g)	Copper, total in bottom material (µg/g)	Europium, total in bottom material (µg/g)	Gallium, total in bottom material (µg/g)	Gold, total in bottom material (µg/g)	Holmium, total in bottom material (µg/g)	Iron, total in bottom material (µg/g)
North Ironwood Creek	09-25-95	<2	84	27	10	17	<2	15	<8	<4	27,000
Unnamed tributary	09-25-95	<2	82	26	10	19	<2	17	<8	<4	28,000
Stuart Creek	09-25-95	<2	69	31	8	11	<2	15	<8	<4	28,000
LWR above Rosebud	09-26-95	<2	74	19	5	7	<2	13	<8	<4	15,000
LWR at Ghost Hawk Park	09-26-95	<2	87	36	10	11	<2	14	<8	<4	26,000
LWR below Whipple Residence	09-26-95	<2	82	33	9	13	<2	15	<8	<4	24,000
LWR below Swimmer Residence	09-26-95	<2	160	45	11	12	<2	15	<8	<4	30,000
	[1]09-26-95	<2	200	43	11	11	<2	14	<8	<4	30,000
LWR at Two Strikes Bridge	09-27-95	<2	93	36	9	11	<2	13	<8	<4	25,000
LWR at Iron Shell Bridge	09-27-95	<2	91	36	9	12	<2	14	<8	<4	24,000
LWR below Beads Creek	09-27-95	<2	83	36	8	10	<2	14	<8	<4	25,000
LWR at Hollow Horn Bear Bridge	09-27-95	<2	82	34	9	11	<2	14	<8	<4	24,000

Table 7. Constituent concentrations for bed-sediment samples—Continued

Station name	Date	Lanthanum, total in bottom material (µg/g)	Lead, total in bottom material (µg/g)	Lithium, total in bottom material (µg/g)	Manganese, total in bottom material (µg/g)	Molybdenum, total in bottom material (µg/g)	Neodymium, total in bottom material (µg/g)	Nickel, total in bottom material (µg/g)	Niobium, total in bottom material (µg/g)	Scandium, total in bottom material (µg/g)	Selenium, total in bottom material (µg/g)	Silver, total in bottom material (µg/g)
North Ironwood Creek	09-25-95	43	18	28	720	<2	35	11	18	9	0.4	<2
Unnamed tributary	09-25-95	43	21	31	640	<2	35	11	18	10	0.4	<2
Stuart Creek	09-25-95	40	16	30	1,800	<2	30	12	18	8	0.5	<2
LWR above Rosebud	09-26-95	45	15	19	320	<2	33	6	14	5	0.2	<2
LWR at Ghost Hawk Park	09-26-95	46	16	32	640	<2	37	13	17	8	0.7	<2
LWR below Whipple Residence	09-26-95	47	17	30	510	<2	35	11	18	8	0.4	<2
LWR below Swimmer Residence	09-26-95	88	18	31	590	<2	69	13	22	9	0.4	<2
	[1]09-26-95	100	20	29	590	<2	84	12	23	8	0.4	<2
LWR at Two Strikes Bridge	09-27-95	49	15	30	500	<2	39	12	17	8	0.7	<2
LWR at Iron Shell Bridge	09-27-95	48	16	29	580	<2	37	12	18	7	0.7	<2
LWR below Beads Creek	09-27-95	45	17	30	530	<2	35	12	19	8	0.7	<2
LWR at Hollow Horn Bear Bridge	09-27-95	44	12	30	550	<2	35	11	17	7	0.7	<2

Table 7. Constituent concentrations for bed-sediment samples—Continued

Station name	Date	Strontium, total in bottom material (μg/g)	Tantalum, total in bottom material (μg/g)	Thorium, total in bottom material (μg/g)	Tin, total in bottom material (μg/g)	Titanium, total in bottom material (μg/g)	Uranium, total in bottom material (μg/g)	Vanadium, total in bottom material (μg/g)	Ytterbium, total in bottom material (μg/g)	Yttrium, total in bottom material (μg/g)	Zinc, total in bottom material (μg/g)
North Ironwood Creek	09-25-95	240	<40	18	<5	3,300	<100	56	3	28	72
Unnamed tributary	09-25-95	240	<40	17	<5	3,400	<100	59	3	29	94
Stuart Creek	09-25-95	220	<40	13	<5	2,600	<100	81	2	24	77
LWR above Rosebud	09-26-95	310	<40	13	<5	2,300	<100	39	2	21	44
LWR at Ghost Hawk Park	09-26-95	230	<40	16	<5	3,300	<100	77	3	26	73
LWR below Whipple Residence	09-26-95	270	<40	16	<5	3,300	<100	73	3	25	69
LWR below Swimmer Residence	09-26-95	250	<40	32	<5	5,100	<100	99	4	33	73
	[1]09-26-95	260	<40	40	<5	5,500	<100	94	4	35	70
LWR at Two Strikes Bridge	09-27-95	240	<40	16	<5	3,400	<100	74	3	25	64
LWR at Iron Shell Bridge	09-27-95	230	<40	17	<5	3,400	<100	70	3	26	64
LWR below Beads Creek	09-27-95	230	<40	16	<5	3,400	<100	77	3	25	65
LWR at Hollow Horn Bear Bridge	09-27-95	240	<40	16	<5	3,200	<100	72	3	25	63

[1] Indicates duplicate sample for quality-assurance purposes.

Table 8. Constituent concentrations for drill-hole-cuttings samples

[', feet; mg/g, milligrams per gram; µg/g, micrograms per gram; <, less than]

Depth and description	Calcium, total (mg/g)	Magnsium, total (mg/g)	Sodium, total (mg/g)	Potassium, total (mg/g)	Phosphorus, total (mg/g)	Aluminum, total (µg/g)	Arsenic, total (µg/g)	Barium, total (µg/g)	Beryllium, total (µg/g)	Bismuth, total (µg/g)
Observation well 3										
70-80' Fine sand and cemented siltstone, reddish-brown, hard (subsampled)	11	2.9	10	15	0.2	41,000	1.7	620	<1	<10
70-80' High-graded pink siltstone	14	10	10	19	0.2	71,000	3.3	570	2	<10
80-90' Fine sand and cemented siltstone, reddish-brown, hard	18	7.3	9.8	20	0.5	60,000	3.2	610	2	<10
90-100' Fine sand and cemented siltstone, reddish-brown, hard	22	8.9	9.4	22	1.6	67,000	4.6	610	2	<10
100-110' Fine sand and cemented siltstone, reddish-brown, hard	18	9.3	8.8	22	0.7	68,000	4.4	620	2	<10
[1]100-110'	22	9.9	8.9	23	0.6	70,000	5.2	650	2	<10
110-120' Fine sand and cemented siltstone, reddish-brown, hard	18	9.3	8.9	22	0.6	68,000	4.6	630	2	<10
120-130' Silt and clay, reddish-brown, soft	38	8.9	9.3	21	0.7	65,000	5.2	570	2	<10
130-140' Silt and clay, reddish-brown, soft	21	9.8	9.3	21	0.8	69,000	4.5	590	2	<10
140-150' Silt and clay, reddish-brown, soft	14	10	9.3	22	0.4	73,000	4.3	680	2	<10
150-160' Siltstone, reddish-brown, cemented	13	9.0	10	22	0.3	70,000	4.3	700	2	<10
160-170' Siltstone, reddish-brown, cemented	21	8.5	11	23	0.4	68,000	3.9	1,100	2	<10
170-180' Siltstone, reddish-brown, cemented	23	9.1	9.9	23	0.5	69,000	4.1	1,100	2	<10
180-190' Siltstone, reddish-brown, cemented, with some soft layers	28	9.9	9.9	23	0.5	72,000	4.4	840	2	<10
[1]180-190'	28	9.6	10	23	0.5	71,000	4.5	860	2	<10
190-200' Siltstone, reddish-brown, cemented, with some soft layers	26	10	10	23	0.5	72,000	4.6	980	2	<10
200-210' Siltstone, reddish-brown, cemented, with some soft layers	24	10	11	24	0.5	72,000	4.7	720	2	<10
210-220' Siltstone, reddish-brown, cemented, with some soft layers	23	10	11	24	0.5	73,000	4.5	680	2	<10
220-230' Siltstone, reddish-brown with white silty, pebbly, clay layers	21	9.9	11	23	0.5	72,000	5.0	680	2	<10

Table 8. Constituent concentrations for drill-hole-cuttings samples—Continued

[’, feet; mg/g, milligrams per gram; µg/g, micrograms per gram; <, less than]

Depth and description	Calcium, total (mg/g)	Magnsium, total (mg/g)	Sodium, total (mg/g)	Potassium, total (mg/g)	Phosphorus, total (mg/g)	Aluminum, total (µg/g)	Arsenic, total (µg/g)	Barium, total (µg/g)	Beryllium, total (µg/g)	Bismuth, total (µg/g)
Observation well 3—Continued										
230-240’ Siltstone, reddish-brown with white silty, pebbly, clay layers	16	9.4	11	23	0.5	72,000	5.1	700	2	<10
240-250’ Siltstone, reddish-brown with white silty, pebbly, clay layers	13	10	9.5	21	0.4	73,000	5.2	610	2	<10
[1]240-250’	13	10	9.9	22	0.4	73,000	4.9	620	2	<10
250-260’ Siltstone, reddish-brown with white silty, pebbly, clay layers	13	9.7	9.9	21	0.4	73,000	4.6	640	2	<10
Observation well 4										
0-10’ Siltstone, brown	14	8.9	10	25	0.7	70,000	4.6	580	2	<10
10-20’ Siltstone, brown	13	9.1	9.2	22	0.2	69,000	4.5	610	2	<10
20-30’ Silstone, tan	13	9.4	9.1	23	0.3	71,000	4.7	550	2	<10
30-40’ Siltstone, reddish-brown	14	9.6	9.3	22	0.4	70,000	4.1	630	2	<10
40-50’ Siltstone, reddish-brown	13	9.7	9.1	22	0.7	71,000	4.2	670	2	<10
50-60’ Siltstone, reddish-brown	14	8.2	11	22	0.6	68,000	4.3	630	2	<10
60-70’ Siltstone, reddish-brown	14	9.1	10	22	0.9	71,000	4.4	680	2	<10
70-80’ Siltstone, reddish-brown	36	9.0	10	22	1.2	68,000	5.0	720	2	<10
80-90’ Siltstone, reddish-brown	38	7.3	12	26	0.8	68,000	5.7	860	2	<10
[1]80-90’	38	7.3	12	26	0.8	68,000	5.7	860	2	<10
90-100’ Silt, light-brown	49	8.5	11	24	0.6	67,000	4.7	670	2	<10
100-110’ Siltstone, brown	25	9.2	11	23	0.6	70,000	5.2	640	2	<10
110-120’ Siltstone, brown	23	8.7	12	23	0.5	70,000	5.0	680	2	<10
120-130’ Siltstone, brown	24	8.7	11	23	0.6	69,000	5.6	640	2	<10
130-140’ Siltstone, brown	30	9.2	11	23	1.0	68,000	6.3	650	2	<10
140-150’ Siltstone, brown	14	9.8	9.5	20	0.4	72,000	5.5	550	2	<10
150-160’ Siltstone, brown	16	9.9	9.0	20	0.3	70,000	5.0	1,200	2	<10
160-170’ Siltstone, brown	15	10	8.6	19	0.4	70,000	5.4	1,100	2	<10
170-180’ Siltstone, brown	32	9.8	10	21	0.6	68,000	5.1	1,200	2	<10
180-190’ Siltstone, brown, some green silt	16	11	11	21	0.8	68,000	7.3	940	2	<10

Table 8. Constituent concentrations for drill-hole-cuttings samples—Continued

[', feet; mg/g, milligrams per gram; µg/g, micrograms per gram; <, less than]

Depth and description	Calcium, total (mg/g)	Magnsium, total (mg/g)	Sodium, total (mg/g)	Potassium, total (mg/g)	Phosphorus, total (mg/g)	Aluminum, total (µg/g)	Arsenic, total (µg/g)	Barium, total (µg/g)	Beryllium, total (µg/g)	Bismuth, total (µg/g)
Observation well 4—Continued										
190-200 Silt, light brown to brown, some green silt through 195'	12	11	7.9	20	0.3	71,000	6.2	860	2	<10
200-210' Silt, light brown to brown	13	11	8.5	19	0.3	74,000	4.6	790	2	<10
210-220' Sand, very fine begins at 214'	14	10	9.6	19	0.4	70,000	4.6	760	2	<10
220-230' Sand, very fine	15	9.5	10	20	0.6	69,000	4.8	1,100	2	<10
230-240' Sand, very fine	15	11	11	19	0.5	69,000	4.7	580	2	<10
240-250' Siltstone, brown	21	11	10	19	0.8	67,000	4.9	700	2	<10
250-260' Siltstone, brown	52	10	11	19	0.8	66,000	4.7	580	2	<10
260-270' Siltstone, brown	50	11	11	19	0.7	66,000	4.5	600	2	<10
Observation well 7										
30-40' High-graded ash	66	11	3.0	11	5.7	55,000	10	220	1	<10
30-40' High-graded pink siltstone	17	10	7.6	20	0.3	70,000	5.9	500	2	<10
30-40' Bulk composite. Contact between alluvium and siltstone at 36'	15	7.7	6.6	16	0.8	54,000	4.0	540	2	<10
40-50' Siltstone, pinkish-brown	24	11	9.7	20	0.6	71,000	4.5	810	2	<10
50-62' Siltstone, reddish-brown with some blue siltstone	15	11	7.3	19	0.4	63,000	7.4	1,400	2	<10

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Cadmium, total (µg/g)	Cerium, total (µg/g)	Chromium, total (µg/g)	Cobalt, total (µg/g)	Copper, total (µg/g)	Europium, total (µg/g)	Gallium, total (µg/g)	Gold, total (µg/g)	Holmium, total (µg/g)	Iron, total (µg/g)
Observation well 3										
70-80' Fine sand and cemented siltstone, reddish-brown, hard (subsampled)	<2	34	10	3	4	<2	9	<8	<4	9,000
70-80' High-graded pink siltstone	<2	68	18	9	13	<2	17	<8	<4	22,000
80-90' Fine sand and cemented siltstone, reddish-brown, hard	<2	69	14	7	10	<2	14	<8	<4	18,000
90-100' Fine sand and cemented siltstone, reddish-brown, hard	<2	66	17	9	12	<2	15	<8	<4	22,000
100-110' Fine sand and cemented siltstone, reddish-brown, hard	<2	70	18	9	15	<2	16	<8	<4	23,000
[1]100-110'	<2	70	21	11	15	<2	18	<8	<4	24,000
110-120' Fine sand and cemented siltstone, reddish-brown, hard	<2	73	19	9	14	<2	17	<8	<4	24,000
120-130' Silt and clay, reddish-brown, soft	<2	65	19	9	15	<2	16	<8	<4	22,000
130-140' Silt and clay, reddish-brown, soft	<2	71	24	9	16	<2	18	<8	<4	24,000
140-150' Silt and clay, reddish-brown, soft	<2	63	25	9	15	<2	18	<8	<4	27,000
150-160' Siltstone, reddish-brown, cemented	<2	70	24	7	14	<2	18	<8	<4	24,000
160-170' Siltstone, reddish-brown, cemented	<2	62	23	8	14	<2	18	<8	<4	23,000
170-180' Siltstone, reddish-brown, cemented	<2	64	20	8	14	<2	18	<8	<4	24,000
180-190' Siltstone, reddish-brown, cemented, with some soft layers	<2	66	16	9	16	<2	18	<8	<4	21,000
[1]180-190'	<2	66	16	8	15	<2	17	<8	<4	20,000
190-200' Siltstone, reddish-brown, cemented, with some soft layers	<2	69	15	9	16	<2	19	<8	<4	19,000
200-210' Siltstone, reddish-brown, cemented, with some soft layers	<2	68	16	8	17	<2	19	<8	<4	21,000
210-220' Siltstone, reddish-brown, cemented, with some soft layers	<2	64	17	8	16	<2	17	<8	<4	21,000
220-230' Siltstone, reddish-brown with white silty, pebbly, clay layers	<2	68	20	8	14	<2	18	<8	<4	22,000

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Cadmium, total (µg/g)	Cerium, total (µg/g)	Chromium, total (µg/g)	Cobalt, total (µg/g)	Copper, total (µg/g)	Europium, total (µg/g)	Gallium, total (µg/g)	Gold, total (µg/g)	Holmium, total (µg/g)	Iron, total (µg/g)
Observation well 3—Continued										
230-240’ Siltstone, reddish-brown with white silty, pebbly, clay layers	<2	68	23	8	17	<2	18	<8	<4	23,000
240-250’ Siltstone, reddish-brown with white silty, pebbly, clay layers	<2	64	24	8	17	<2	19	<8	<4	26,000
[1]240-250’	<2	66	24	8	18	<2	17	<8	<4	26,000
250-260’ Siltstone, reddish-brown with white silty, pebbly, clay layers	<2	69	23	8	17	<2	18	<8	<4	24,000
Observation well 4										
0-10’ Siltstone, brown	<2	77	19	7	13	<2	17	<8	<4	23,000
10-20’ Siltstone, brown	<2	73	18	7	14	<2	17	<8	<4	25,000
20-30’ Silstone, tan	<2	80	23	8	13	<2	17	<8	<4	26,000
30-40’ Siltstone, reddish-brown	<2	63	24	9	14	<2	16	<8	<4	28,000
40-50’ Siltstone, reddish-brown	<2	74	25	8	14	<2	17	<8	<4	25,000
50-60’ Siltstone, reddish-brown	<2	59	23	8	15	<2	16	<8	<4	23,000
60-70’ Siltstone, reddish-brown	<2	74	21	9	13	<2	17	<8	<4	24,000
70-80’ Siltstone, reddish-brown	<2	72	18	9	13	<2	16	<8	<4	21,000
80-90’ Siltstone, reddish-brown	<2	77	14	7	12	<2	17	<8	<4	20,000
[1]80-90’	<2	75	13	8	14	<2	16	<8	<4	19,000
90-100’ Silt, light-brown	<2	72	13	8	13	<2	17	<8	<4	18,000
100-110’ Siltstone, brown	<2	77	19	8	17	<2	17	<8	<4	23,000
110-120’ Siltstone, brown	<2	72	24	8	17	<2	17	<8	<4	24,000
120-130’ Siltstone, brown	<2	68	23	9	15	<2	15	<8	<4	24,000
130-140’ Siltstone, brown	<2	68	24	9	18	<2	16	<8	<4	23,000
140-150’ Siltstone, brown	<2	76	27	8	19	<2	17	<8	<4	27,000
150-160’ Siltstone, brown	<2	66	23	9	16	<2	16	<8	<4	25,000
160-170’ Siltstone, brown	<2	93	29	10	26	<2	16	<8	<4	28,000
170-180’ Siltstone, brown	<2	75	25	10	26	<2	17	<8	<4	25,000
180-190’ Siltstone, brown, some green silt	<2	71	31	10	18	<2	16	<8	<4	26,000

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Cadmium, total (µg/g)	Cerium, total (µg/g)	Chromium, total (µg/g)	Cobalt, total (µg/g)	Copper, total (µg/g)	Europium, total (µg/g)	Gallium, total (µg/g)	Gold, total (µg/g)	Holmium, total (µg/g)	Iron, total (µg/g)
Observation well 4—Continued										
190-200 Silt, light brown to brown, some green silt through 195'	<2	58	39	9	20	<2	17	<8	<4	31,000
200-210' Silt, light brown to brown	<2	59	32	10	20	<2	17	<8	<4	30,000
210-220' Sand, very fine begins at 214'	<2	70	30	10	21	<2	16	<8	<4	26,000
220-230' Sand, very fine	<2	67	29	9	19	<2	16	<8	<4	26,000
230-240' Sand, very fine	<2	69	31	10	17	<2	17	<8	<4	26,000
240-250' Siltstone, brown	<2	68	31	10	22	<2	15	<8	<4	25,000
250-260' Siltstone, brown	<2	61	27	10	16	<2	16	<8	<4	23,000
260-270' Siltstone, brown	<2	64	27	10	17	<2	16	<8	<4	23,000
Observation well 7										
30-40' High-graded ash	<2	290	24	8	41	5	15	<2	4	19,000
30-40' High-graded pink siltstone	<2	64	28	9	19	<2	17	<2	<4	28,000
30-40' Bulk composite. Contact between alluvium and siltstone @ 36'	<2	73	22	7	16	<2	12	<2	<4	21,000
40-50' Siltstone, pinkish-brown	<2	73	30	10	21	<2	16	<2	<4	28,000
50-62' Siltstone, reddish-brown with some blue siltstone	<2	74	36	10	15	<2	16	<2	<4	26,000

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Lanthanum, total (µg/g)	Lead, total (µg/g)	Lithium, total (µg/g)	Manganese, total (µg/g)	Molybdenum, total (µg/g)	Neodymium, total (µg/g)	Nickel, total (µg/g)	Niobium, total (µg/g)	Scandium, total (µg/g)	Silver, total (µg/g)
Observation well 3										
70-80' Fine sand and cemented siltstone, reddish-brown, hard (subsampled)	25	11	12	190	<2	20	4	10	3	<2
70-80' High-graded pink siltstone	40	18	27	550	<2	37	9	22	11	<2
80-90' Fine sand and cemented siltstone, reddish-brown, hard	42	19	20	400	<2	36	7	17	7	<2
90-100' Fine sand and cemented siltstone, reddish-brown, hard	40	18	23	540	<2	38	8	19	9	<2
100-110' Fine sand and cemented siltstone, reddish-brown, hard	42	19	25	560	<2	38	10	22	9	<2
[1]100-110'	38	20	27	860	<2	35	11	22	10	<2
110-120' Fine sand and cemented siltstone, reddish-brown, hard	42	18	26	580	<2	39	9	23	10	<2
120-130' Silt and clay, reddish-brown, soft	41	31	25	660	<2	36	9	20	8	<2
130-140' Silt and clay, reddish-brown, soft	44	18	28	580	<2	40	10	19	9	<2
140-150' Silt and clay, reddish-brown, soft	36	22	28	690	<2	30	11	25	9	<2
150-160' Siltstone, reddish-brown, cemented	42	19	25	570	<2	35	11	24	8	<2
160-170' Siltstone, reddish-brown, cemented	35	19	25	530	<2	32	11	21	8	<2
170-180' Siltstone, reddish-brown, cemented	35	18	27	610	<2	32	11	22	8	<2
180-190' Siltstone, reddish-brown, cemented, with some soft layers	36	19	28	760	<2	34	11	19	9	<2
[1]180-190'	37	21	27	730	<2	35	10	21	8	<2
190-200' Siltstone, reddish-brown, cemented, with some soft layers	37	22	28	780	<2	37	9	21	8	<2
200-210' Siltstone, reddish-brown, cemented, with some soft layers	36	21	32	770	<2	34	9	22	8	<2
210-220' Siltstone, reddish-brown, cemented, with some soft layers	36	19	33	730	<2	31	9	22	9	<2
220-230' Siltstone, reddish-brown with white silty, pebbly, clay layers	37	21	32	670	<2	33	9	21	9	<2

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Lanthanum, total (µg/g)	Lead, total (µg/g)	Lithium, total (µg/g)	Manganese, total (µg/g)	Molybdenum, total (µg/g)	Neodymium, total (µg/g)	Nickel, total (µg/g)	Niobium, total (µg/g)	Scandium, total (µg/g)	Silver, total (µg/g)
Observation well 3—Continued										
230-240' Siltstone, reddish-brown with white silty, pebbly, clay layers	37	22	30	580	<2	32	10	23	9	<2
240-250' Siltstone, reddish-brown with white silty, pebbly, clay layers	38	21	32	560	<2	33	11	23	9	<2
[1]240-250'	37	23	31	560	<2	30	11	23	9	<2
250-260' Siltstone, reddish-brown with white silty, pebbly, clay layers	42	21	30	500	<2	36	11	23	8	<2
Observation well 4										
0-10' Siltstone, brown	42	20	27	570	<2	37	9	25	9	<2
10-20' Siltstone, brown	43	17	25	570	<2	37	8	26	10	<2
20-30' Silstone, tan	46	19	27	490	<2	39	10	25	9	<2
30-40' Siltstone, reddish-brown	35	22	27	460	<2	28	12	25	9	<2
40-50' Siltstone, reddish-brown	48	19	26	550	<2	42	11	22	9	<2
50-60' Siltstone, reddish-brown	35	18	24	480	<2	28	10	20	8	<2
60-70' Siltstone, reddish-brown	42	22	28	550	<2	34	10	23	8	<2
70-80' Siltstone, reddish-brown	44	19	27	620	<2	38	9	19	8	<2
80-90' Siltstone, reddish-brown	43	23	22	670	<2	39	7	19	7	<2
[1]80-90'	42	22	23	710	<2	37	7	17	7	<2
90-100' Silt, light-brown	40	22	25	820	<2	37	7	20	7	<2
100-110' Siltstone, brown	43	23	34	790	<2	36	9	23	8	<2
110-120' Siltstone, brown	39	21	31	660	<2	34	10	22	9	<2
120-130' Siltstone, brown	37	22	30	660	<2	34	10	22	8	<2
130-140' Siltstone, brown	39	20	32	730	<2	39	10	19	9	<2
140-150' Siltstone, brown	48	22	30	650	<2	39	11	23	9	<2
150-160' Siltstone, brown	38	23	30	630	<2	31	12	23	8	<2
160-170' Siltstone, brown	54	20	28	550	<2	45	16	24	10	<2
170-180' Siltstone, brown	43	24	31	620	<2	35	13	22	9	<2
180-190' Siltstone, brown, some green silt	39	20	38	480	<2	36	13	21	10	<2

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Lanthanum, total (µg/g)	Lead, total (µg/g)	Lithium, total (µg/g)	Manganese, total (µg/g)	Molybdenum, total (µg/g)	Neodymium, total (µg/g)	Nickel, total (µg/g)	Niobium, total (µg/g)	Scandium, total (µg/g)	Silver, total (µg/g)
Observation well 4—Continued										
190-200 Silt, light brown to brown, some green silt through 195’	33	23	23	830	<2	25	14	25	11	<2
200-210’ Silt, light brown to brown	33	21	27	380	<2	27	14	24	10	<2
210-220’ Sand, very fine begins at 214’	41	20	34	380	<2	38	13	23	9	<2
220-230’ Sand, very fine	39	20	30	460	<2	33	13	22	9	<2
230-240’ Sand, very fine	39	19	38	440	<2	34	13	22	10	<2
240-250’ Siltstone, brown	37	16	39	530	<2	35	13	19	10	<2
250-260’ Siltstone, brown	35	16	38	750	<2	35	13	18	9	<2
260-270’ Siltstone, brown	36	18	39	760	<2	34	13	16	9	<2
Observation well 7										
30-40’ High-graded ash	160	12	32	560	<2	200	14	17	9	<8
30-40’ High-graded pink siltstone	36	18	30	560	<2	30	14	23	10	<8
30-40’ Bulk composite. Contact between alluvium and siltstone @ 36’	42	15	23	690	<2	44	11	15	7	<8
40-50’ Siltstone, pinkish-brown	38	21	34	610	<2	35	15	22	10	<8
50-62’ Siltstone, reddish-brown with some blue siltstone	41	16	41	760	<2	36	13	19	9	<8

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Strontium, total (µg/g)	Tantalum, total (µg/g)	Thorium, total (µg/g)	Tin, total (µg/g)	Titanium, total (µg/g)	Uranium, total (µg/g)	Vanadium, total (µg/g)	Ytterbium, total (µg/g)	Yttrium, total (µg/g)	Zinc, total (µg/g)
Observation well 3										
70-80' Fine sand and cemented siltstone, reddish-brown, hard (subsampled)	250	<40	6	<5	1,100	<100	21	1	13	20
70-80' High-graded pink siltstone	240	<40	12	<5	2,600	<100	42	3	22	54
80-90' Fine sand and cemented siltstone, reddish-brown, hard	220	<40	14	<5	2,100	<100	36	2	21	48
90-100' Fine sand and cemented siltstone, reddish-brown, hard	220	<40	13	<5	2,600	<100	41	3	24	59
100-110' Fine sand and cemented siltstone, reddish-brown, hard	200	<40	13	<5	2,700	<100	40	3	26	64
[1]100-110'	210	<40	13	<5	2,700	<100	47	3	27	64
110-120' Fine sand and cemented siltstone, reddish-brown, hard	210	<40	13	<5	2,900	<100	40	3	26	66
120-130' Silt and clay, reddish-brown, soft	210	<40	15	<5	2,600	<100	39	2	23	59
130-140' Silt and clay, reddish-brown, soft	240	<40	12	<5	2,700	<100	48	3	27	64
140-150' Silt and clay, reddish-brown, soft	230	<40	11	<5	3,000	<100	49	2	21	68
150-160' Siltstone, reddish-brown, cemented	240	<40	13	<5	2,800	<100	46	2	22	65
160-170' Siltstone, reddish-brown, cemented	260	<40	11	<5	2,600	<100	44	2	18	62
170-180' Siltstone, reddish-brown, cemented	240	<40	12	<5	2,700	<100	42	2	20	66
180-190' Siltstone, reddish-brown, cemented, with some soft layers	240	<40	11	<5	2,500	<100	36	2	22	65
[1]180-190'	240	<40	11	<5	2,500	<100	36	2	23	61
190-200' Siltstone, reddish-brown, cemented, with some soft layers	230	<40	13	<5	2,400	<100	34	2	23	61
200-210' Siltstone, reddish-brown, cemented, with some soft layers	220	<40	14	<5	2,500	<100	35	2	22	66
210-220' Siltstone, reddish-brown, cemented, with some soft layers	230	<40	12	<5	2,500	<100	36	2	21	64
220-230' Siltstone, reddish-brown with white silty, pebbly, clay layers	240	<40	13	<5	2,600	<100	40	2	21	63

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Strontium, total (µg/g)	Tantalum, total (µg/g)	Thorium, total (µg/g)	Tin, total (µg/g)	Titanium, total (µg/g)	Uranium, total (µg/g)	Vanadium, total (µg/g)	Ytterbium, total (µg/g)	Yttrium, total (µg/g)	Zinc, total (µg/g)
Observation well 3—Continued										
230-240’ Siltstone, reddish-brown with white silty, pebbly, clay layers	240	<40	13	<5	2,800	<100	45	2	21	68
240-250’ Siltstone, reddish-brown with white silty, pebbly, clay layers	210	<40	14	<5	2,900	<100	49	2	21	71
[1]240-250’	210	<40	14	<5	2,900	<100	48	2	19	71
250-260’ Siltstone, reddish-brown with white silty, pebbly, clay layers	220	<40	14	<5	2,900	<100	47	2	21	69
Observation well 4										
0-10’ Siltstone, brown	200	<40	15	<5	2,800	<100	41	3	25	65
10-20’ Siltstone, brown	210	<40	13	<5	3,200	<100	39	3	26	67
20-30’ Silstone, tan	220	<40	17	<5	3,100	<100	48	3	27	67
30-40’ Siltstone, reddish-brown	230	<40	13	<5	3,000	<100	47	2	20	68
40-50’ Siltstone, reddish-brown	230	<40	13	<5	3,000	<100	44	3	26	70
50-60’ Siltstone, reddish-brown	280	<40	11	<5	2,600	<100	40	2	18	63
60-70’ Siltstone, reddish-brown	250	<40	14	<5	2,900	<100	38	2	22	69
70-80’ Siltstone, reddish-brown	240	<40	12	<5	2,600	<100	34	3	25	63
80-90’ Siltstone, reddish-brown	230	<40	16	<5	2,500	<100	29	3	22	61
[1]80-90’	230	<40	15	<5	2,400	<100	28	2	21	61
90-100’ Silt, light-brown	220	<40	16	<5	2,300	<100	29	2	21	58
100-110’ Siltstone, brown	230	<40	15	<5	2,700	<100	43	3	24	69
110-120’ Siltstone, brown	250	<40	14	<5	2,900	<100	45	2	20	67
120-130’ Siltstone, brown	240	<40	12	<5	2,800	<100	43	2	20	67
130-140’ Siltstone, brown	240	<40	15	<5	2,700	<100	45	3	23	63
140-150’ Siltstone, brown	220	<40	14	<5	3,100	<100	53	3	24	73
150-160’ Siltstone, brown	210	<40	13	<5	2,800	<100	46	2	17	65
160-170’ Siltstone, brown	210	<40	16	<5	3,200	<100	60	3	25	81
170-180’ Siltstone, brown	230	<40	18	<5	2,900	<100	46	2	21	73
180-190’ Siltstone, brown, some green silt	280	<40	13	<5	2,900	<100	76	2	22	63

Table 8. Constituent concentrations for drill-hole cuttings samples—Continued

Depth and description	Strontium, total (µg/g)	Tantalum, total (µg/g)	Thorium, total (µg/g)	Tin, total (µg/g)	Titanium, total (µg/g)	Uranium, total (µg/g)	Vanadium, total (µg/g)	Ytterbium, total (µg/g)	Yttrium, total (µg/g)	Zinc, total (µg/g)
Observation well 4—Continued										
190-200 Silt, light brown to brown, some green silt through 195'	220	<40	13	<5	3,700	<100	64	2	15	78
200-210' Silt, light brown to brown	240	<40	13	<5	3,300	<100	64	2	15	77
210-220' Sand, very fine begins at 214'	240	<40	13	<5	2,900	<100	49	3	26	72
220-230' Sand, very fine	260	<40	13	<5	3,000	<100	52	3	22	67
230-240' Sand, very fine	270	<40	15	<5	2,900	<100	55	2	18	65
240-250' Siltstone, brown	260	<40	12	<5	2,800	<100	53	2	21	65
250-260' Siltstone, brown	260	<40	13	<5	2,500	<100	49	2	20	60
260-270' Siltstone, brown	260	<40	11	<5	2,300	<100	49	2	21	60
Observation well 7										
30-40' High-graded ash	160	<40	18	<5	1,800	<100	48	13	160	63
30-40' High-graded pink siltstone	190	<40	15	<5	3,100	<100	52	2	18	76
30-40' Bulk composite. Contact between alluvium and siltstone @ 36'	180	<40	12	<5	2,100	<100	40	3	31	56
40-50' Siltstone, pinkish-brown	250	<40	14	<5	3,200	<100	51	2	20	82
50-62' Siltstone, reddish-brown with some blue siltstone	240	<40	15	<5	2,800	<100	85	3	22	62

[1] Indicates duplicate sample for quality-assurance purposes.

Table 9. Constituent concentrations for quality-assurance equipment blanks

[mg/L, milligrams per liter; µg/L, micrograms per liter; Deg C, degrees Celsius; diss, dissolved; 2SPE, 2 sigma precision estimate; <, less than; --, no data]

Site type	Date	Calcium, dissolved (mg/L as Ca) (00915)	Mag-nesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 Deg C dissolved (mg/L) (70300)
Laboratory equipment blank	09-15-95	0.06	0.03	0.09	--	--	--	--	0.02	--
Ground-water field equipment blank	09-18-95	0.08	<0.01	<0.20	<0.10	<0.10	<0.10	<0.10	0.20	<1
Surface-water field equipment blank	09-25-95	<0.02	<0.01	<0.20	<0.10	0.10	<0.10	<0.10	<0.10	6

Site type	Date	Arsenic, total (µg/L as As) (01002)	Arsenic, dissolved (µg/L as As) (01000)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Copper, dissolved (µg/L as Cu) (01040)	Iron, total recov-erable (µg/L as Fe) (01045)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Man-ganese, total recov-erable (µg/L as Mn) (01055)
Laboratory equipment blank	09-15-95	--	--	<0.3	0	0	--	<3	<0	--
Ground-water field equipment blank	09-18-95	--	<1	<1.0	<1	<1	--	<3	<1	--
Surface-water field equipment blank	09-25-95	<1	<1	<1.0	<1	<1	<10	<3	<1	<10

Site type	Date	Man-ganese, dissolved (µg/L as Mn) (01056)	Mercury, dissolved (µg/L as Hg) (71890)	Molyb-denum, dissolved (µg/L as Mo) (01060)	Selenium, total (µg/L as Se) (01147)	Selenium, dissolved (µg/L as Se) (01145)	Uranium, natural, dissolved (µg/L as U) (22703)	Uranium, natural, 2SPE, diss (µg/L) (75990)	Vanadium, dissolved (µg/L as V) (01085)	Zinc, dissolved (µg/L as Zn) (01090)
Laboratory equipment blank	09-15-95	0	--	0	--	--	<0.20	--	--	1
Ground-water field equipment blank	09-18-95	<1	<0.1	<1	--	<1	<0.40	0.0	<1	<3
Surface-water field equipment blank	09-25-95	<1	<0.1	<1	<1	<1	<0.40	0.0	<1	<3

Table 10. Precision statistics for duplicate drill-hole-cuttings samples

[Units in micrograms per gram except where indicated. mg/g, milligrams per gram]

Constituent and reporting unit	Number of duplicate pairs	Standard deviation in units (+/-)	Relative standard deviation, in percent (+/-)
Calcium, mg/g	4	2.5	9.8
Magnesium, mg/g	4	0.3	3.7
Sodium, mg/g	4	0.2	1.5
Potassium, mg/g	4	0.2	1.5
Phosphorus, mg/g	4	0.04	6.0
Aluminum	4	800	1.1
Arsenic	4	0.31	6.2
Barium	4	19	2.6
Beryllium	4	0.0	0.0
Bismuth	4	0.0	0.0
Cadmium	4	0.0	0.0
Cerium	4	1.0	1.4
Chromium	4	1.1	6.1
Cobalt	4	0.87	10
Copper	4	0.87	5.7
Europium	4	0.0	0.0
Gallium	4	1.1	6.5
Gold	4	0.0	0.0
Holmium	4	0.0	0.0
Iron	4	600	2.7
Lanthanum	4	1.5	3.9
Lithium	4	0.94	3.5
Manganese	4	108	16
Molybdenum	4	0.0	0.0
Neodymium	4	1.7	4.8
Nickel	4	0.50	5.1
Niobium	4	1.0	4.8
Scanium	4	0.50	5.9
Silver	4	0.0	0.0
Strontium	4	3.5	1.6
Tantalum	4	0.0	0.0
Thorium	4	0.35	2.6
Tin	4	0.0	0.0
Titanium	4	40	0.26
Uranium	4	0.0	0.0
Vanadium	4	2.5	6.4
Ytterbium	4	0.35	15
Yttrium	4	0.94	4.1
Zinc	4	1.4	2.2

Table 11. Significant (α less than or equal 0.10) positive Spearman rank correlations between arsenic and selected constituents for drill-hole-cuttings samples

Constituent	Number of samples	Correlation coefficient	P-value
Thorium	52	0.58	0.00001
Copper	52	0.50	0.00018
Lithium	52	0.46	0.00062
Vanadium	52	0.38	0.0054
Chromium	52	0.35	0.011
Lead	52	0.34	0.014
Manganese	52	0.31	0.028
Cerium	52	0.27	0.054
Cobalt	52	0.26	0.059
Europium	52	0.24	0.089
Holmium	52	0.24	0.089

Table 12. Oxidation-reduction potential (Eh) values calculated using the PHREEQC program for the ground-water samples

[--, no data]

Well name	Date	Eh calculated from arsenic speciation (volts)	Eh calculated from dissolved oxygen concentration (volts)
Ghost Hawk Park well	08-07-91	--	0.77[1]
	11-30-92	0.001	0.77[1]
	09-20-95	0.03	0.78
Stock well 1	09-21-95	-0.03	0.74
No Heart domestic well	08-07-91	--	0.77[1]
	11-30-92	0.003	0.78[1]
	09-20-95	0.03	0.78
Observation well 1	10-02-91	--	0.77[1]
	11-30-92	-0.03	0.77[1]
	09-20-95	0.01	0.77
Observation well 6	09-19-95	-0.03	--
LaPointe stock well	09-22-95	0.03	0.79
Whipple domestic well	08-07-91	--	--
	11-30-92	-0.01	--
Hesse domestic well	09-21-95	0.01	0.77
Stock well 3	09-21-95	-0.02	0.77
Swimmer domestic well	08-07-91	--	--
Observation well 7	09-18-95	-0.05	0.72
Observation well 8	09-18-95	-0.10	0.72
Observation well 2	10-02-91	--	--
	11-30-92	-0.12	--
Observation well 9	09-18-95	-0.06	0.72
Observation well 3	10-03-91	--	--
	12-01-92	-0.02	--
	09-21-95	-0.05	--
Grass Mountain Community well	08-07-91	--	--
	11-30-92	-0.12	--
Observation well 4	09-20-95	-0.09	0.72
Observation well 5	09-19-95	-0.04	0.73
Whipple stock well 1	08-07-91	--	0.75[1]
	09-19-95	-0.01	0.75
Whipple stock well 2	09-21-95	-0.02	0.75
Stock well 2	09-21-95	-0.002	0.78

[1] Indicates that Eh was calculated using an estimated dissolved oxygen concentration.

Table 13. Mineral saturation indices calculated using PHREEQC

[GMC, Grass Mountain Community; (a), amorphous; (c), crystalline; (d), disordered; (ss), solid solution; --, not calculated.]

Well name	Date	Anhydrite	Antlerite	Aragonite	Arsenolite	Artinite	As_2O_5	Atacamite	Azurite	$B\text{-}UO_2(OH)_2$
Ghost Hawk Park well	08-07-91	-2.72	-11.52	-0.29	-32.42	-8.75	-32.58	-9.09	-8.57	--
	11-30-92	-2.75	-11.48	-0.03	-32.15	-8.21	-34.02	-9.14	-9.14	-4.75
	09-20-95	-2.81	-11.59	-0.36	-32.32	-8.95	-32.63	-8.90	-8.80	-4.48
Stock well 1	09-21-95	-3.32	-14.56	-0.66	-32.38	-8.90	-34.40	-10.76	-12.47	-4.49
No Heart domestic well	08-07-91	-1.41	-11.91	0.16	-26.01	-7.87	-30.91	-8.29	-9.64	--
	11-30-92	-1.57	-10.70	0.03	-25.74	-8.38	-31.78	-7.84	-9.00	-4.83
	09-20-95	-1.62	-9.75	-0.01	-28.26	-8.40	-30.91	-7.07	-7.73	-4.78
Observation well 1	10-02-91	-2.63	-14.14	-0.59	-32.33	-8.94	-33.09	-10.72	-12.03	--
	11-30-92	-2.72	-15.58	-0.39	-27.98	-8.50	-34.30	-11.92	-13.82	-4.41
	09-20-95	-2.81	-14.13	-0.55	-32.28	-8.82	-33.23	-10.99	-12.02	-4.23
Observation well 6	09-19-95	-2.66	-11.36	-0.49	-32.36	-8.35	-34.51	-8.02	-9.78	-4.58
LaPointe stock well	09-22-95	-3.09	-12.48	-0.73	-32.25	-9.11	-32.76	-9.76	-10.19	-4.27
Whipple domestic well	08-07-91	-1.86	-12.96	-0.33	-24.82	-9.16	-31.36	-9.61	-11.05	--
	11-30-92	-2.08	-12.99	-0.57	-24.82	-9.58	-31.34	-9.67	-11.23	--
Hesse domestic well	09-21-95	-2.48	-11.52	-0.82	-32.26	-9.16	-33.20	-9.86	-10.22	-4.26
Stock well 3	09-21-95	-3.27	-15.30	-0.74	-32.27	-8.74	-34.81	-11.78	-13.44	-4.47
Observation well 2	10-02-91	-2.28	-19.32	-0.34	-21.70	-8.92	-35.69	-14.28	-17.38	--
	11-30-92	-2.17	-19.66	-0.02	-21.71	-8.14	-36.46	-14.40	-17.64	-4.5
Observation well 7	09-18-95	-2.75	-14.84	-0.65	-26.41	-9.28	-33.00	-11.62	-13.30	-4.71
Observation well 8	09-18-95	-2.18	-17.80	0.24	-23.26	-7.14	-35.22	-13.50	-16.03	-4.66
Swimmer domestic well	08-07-91	-2.06	-10.83	-0.17	-32.41	-9.19	-30.68	-8.12	-8.00	--
Observation well 9	09-18-95	-3.34	-13.94	-0.76	-32.46	-8.73	-34.50	-10.87	-12.45	-4.69
Observation well 3	10-03-91	-2.74	-10.06	-0.53	-32.30	-8.44	-34.28	-7.62	-8.25	--
	12-01-92	-3.24	-15.08	-0.92	-32.29	-9.38	-35.01	-11.14	-13.19	-4.26
	09-21-95	-3.72	-15.61	-0.62	-32.38	-8.51	-35.47	-11.41	-13.31	-4.28
GMC well	08-07-91	-3.10	-14.08	-0.54	-25.37	-11.97	-34.26	-10.22	-12.05	--
	11-30-92	-3.16	-14.22	-0.49	-25.23	--	-35.14	-10.51	-12.63	--
Observation well 4	09-20-95	-3.07	-13.75	-0.63	-25.62	-8.93	-34.01	-10.67	-11.96	-4.92
Observation well 5	09-19-95	-3.51	-13.89	-0.95	-32.49	-9.18	-33.66	-10.72	-12.05	-4.68
Whipple stock well 1	08-07-91	-2.99	-10.36	-0.41	-32.42	-7.99	-34.19	-8.44	-8.11	--
	09-19-95	-2.99	-11.40	-0.69	-32.32	-8.87	-33.62	-8.85	-9.31	-4
Whipple stock well 2	09-21-95	-3.08	-14.84	-0.64	-32.46	-8.43	-34.03	-11.42	-12.72	-4.46
Stock well 2	09-21-95	-3.31	-15.47	-0.63	-32.30	-8.80	-34.33	-11.70	-13.03	-4.57

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Bianchite	Birnessite	Bixbyite	Brochantite	Brucite	$Ca_3(AsO_4)_2\cdot 4H_2O$	Calcite	$CaSeO_3$
Ghost Hawk Park well	08-07-91	-8.60	-21.22	-22.49	-13.40	-6.54	-13.19	-0.14	--
	11-30-92	-8.97	-20.82	-22.96	-13.07	-6.28	-12.28	0.12	-6.45
	09-20-95	-9.11	-21.32	-23.32	-13.47	-6.71	-13.28	-0.21	-6.81
Stock well 1	09-21-95	-10.30	-19.83	-19.46	-17.07	-6.23	-13.25	-0.51	-7.01
No Heart domestic well	08-07-91	-8.63	-20.89	-21.06	-14.27	-6.19	-10.67	0.31	-5.77
	11-30-92	-8.52	-20.97	-22.65	-12.56	-6.58	-11.21	0.18	-5.92
	09-20-95	-8.54	-20.40	-21.74	-11.36	-6.56	-10.96	0.14	-6.03
Observation well 1	10-02-91	-9.52	-20.31	-21.07	-16.92	-6.57	-13.62	-0.44	-6.87
	11-30-92	-9.01	-21.93	-24.01	-18.61	-6.33	-13.06	-0.23	-6.61
	09-20-95	-9.04	-21.05	-22.87	-16.77	-6.48	-13.18	-0.40	-6.78
Observation well 6	09-19-95	-8.56	-19.66	-19.20	-12.96	-5.97	-12.83	-0.34	-6.84
LaPointe stock well	09-22-95	-10.55	-21.44	-24.02	-14.59	-6.70	-13.59	-0.58	-6.56
Whipple domestic well	08-07-91	-8.23	-22.95	-25.20	-15.61	-6.80	-11.95	-0.18	-6.80
	11-30-92	-8.27	-22.89	-25.09	-15.61	-6.95	-12.26	-0.42	-6.90
Hesse domestic well	09-21-95	-7.95	-20.09	-21.11	-13.45	-6.58	-13.41	-0.66	-6.98
Stock well 3	09-21-95	-10.53	-20.03	-20.19	-18.08	-6.22	-13.85	-0.59	-6.70
Observation well 2	10-02-91	-9.30	-22.70	-22.45	-23.86	-6.61	-15.49	-0.19	-6.79
	11-30-92	--	-22.82	-22.15	-24.20	-6.16	-14.90	0.13	-6.91
Observation well 7	09-18-95	-9.75	-20.75	-20.93	-17.64	-6.51	-12.02	-0.50	-7.08
Observation well 8	09-18-95	-10.08	-20.76	-19.33	-21.48	-5.46	-11.48	0.39	-6.16
Swimmer domestic well	08-07-91	-8.96	-18.62	-18.23	-12.81	-6.97	-12.15	-0.02	-6.89
Observation well 9	09-18-95	-10.19	-20.10	-20.12	-16.09	-5.91	-12.12	-0.61	-6.85
Observation well 3	10-03-91	-9.34	-20.25	-20.76	-11.30	-6.18	-13.47	-0.38	-6.58
	12-01-92	-10.17	-21.83	-23.54	-17.94	-6.63	-15.26	-0.77	-6.81
	09-21-95	-10.76	-21.39	-22.18	-18.24	-5.94	-13.51	-0.47	-6.56
GMC well	08-07-91	-9.52	-22.75	-22.56	-16.39	-7.54	-12.22	-0.39	-6.36
	11-30-92	-9.69	-21.15	-20.22	-16.44	--	-12.03	-0.34	-7.07
Observation well 4	09-20-95	-10.08	-21.13	-20.43	-16.02	-6.17	-12.42	-0.48	-7.14
Observation well 5	09-19-95	-9.30	-20.21	-20.22	-16.11	-6.19	-12.62	-0.80	-6.31
Whipple stock well 1	08-07-91	-7.82	-21.20	-21.91	-11.54	-5.80	-12.72	-0.26	-6.05
	09-19-95	-7.51	-20.52	-21.35	-13.09	-6.42	-13.68	-0.54	-6.22
Whipple stock well 2	09-21-95	-8.38	-21.49	-22.31	-17.55	-5.97	-13.18	-0.49	-6.86
Stock well 2	09-21-95	-10.72	-21.90	-23.90	-18.38	-6.40	-14.16	-0.48	-6.74

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Chalcanthite	Chalcedony	Chrysotile	Claudetite	Clinoenstatite	CO_2 (gas)	Coffinite	Cristobalite
Ghost Hawk Park well	08-07-91	-10.89	0.61	-6.76	-32.18	-3.94	-2.08	--	0.66
	11-30-92	-11.40	0.72	-5.32	-31.93	-3.52	-2.53	0.51	0.78
	09-20-95	-10.95	0.68	-6.98	-32.09	-4.02	-2.10	0.06	0.73
Stock well 1	09-21-95	-12.69	0.73	-5.45	-32.15	-3.5	-3.01	-0.98	0.78
No Heart domestic well	08-07-91	-10.34	0.61	-5.70	-25.76	-3.59	-1.90	--	0.66
	11-30-92	-10.10	0.78	-6.12	-25.52	-3.76	-2.08	0.98	0.84
	09-20-95	-9.68	0.74	-6.32	-28.03	-3.80	-1.94	-0.04	0.80
Observation well 1	10-02-91	-11.71	0.72	-6.47	-32.09	-3.84	-2.37	--	0.77
	11-30-92	-12.64	0.78	-5.36	-27.76	-3.51	-2.71	2.10	0.85
	09-20-95	-11.96	0.74	-6.10	-32.04	-3.73	-2.52	0.67	0.80
Observation well 6	09-19-95	-11.30	0.71	-4.67	-32.13	-3.25	-3.00	0.93	0.77
LaPointe stock well	09-22-95	-11.39	0.74	-6.73	-32.02	-3.95	-2.39	0.40	0.80
Whipple domestic well	08-07-91	-10.80	0.60	-7.44	-24.58	-4.19	-2.10	--	0.66
	11-30-92	-10.88	0.61	-7.86	-24.58	-4.33	-2.23	--	0.66
Hesse domestic well	09-21-95	-10.81	0.74	-6.35	-32.03	-3.82	-2.69	0.63	0.80
Stock well 3	09-21-95	-12.85	0.68	-5.39	-32.04	-3.52	-3.00	1.16	0.74
Observation well 2	10-02-91	-13.37	0.64	-6.68	-24.47	-3.95	-2.35	--	0.70
	11-30-92	-13.71	0.64	-5.31	-21.47	-3.50	-2.49	4.57	0.70
Observation well 7	09-18-95	-12.36	0.65	-6.35	-26.18	-3.84	-2.92	1.45	0.71
Observation well 8	09-18-95	-13.57	0.60	-3.25	-23.03	-2.84	-2.94	3.34	0.66
Swimmer domestic well	08-07-91	-10.03	0.61	-8.05	-32.17	-4.37	-1.66	--	0.66
Observation well 9	09-18-95	-12.77	0.71	-4.49	-32.23	-3.19	-3.51	0.78	0.76
Observation well 3	10-03-91	-10.72	0.69	-5.26	-32.07	-3.46	-2.75	--	0.75
	12-01-92	-12.49	0.73	-6.55	-32.06	-3.88	-2.78	1.52	0.79
	09-21-95	-13.49	0.75	-4.49	-32.15	-3.17	-3.23	1.75	0.81
GMC well	08-07-91	-12.60	0.64	-9.76	-25.13	-4.91	-3.22	--	0.69
	11-30-92	-12.90	0.70	--	-25.00	--	-3.48	--	0.76
Observation well 4	09-20-95	-12.35	0.69	-5.37	-25.38	-3.47	-3.13	2.01	0.75
Observation well 5	09-19-95	-12.57	0.71	-5.45	-32.25	-3.48	-3.27	0.40	0.77
Whipple stock well 1	08-07-91	-11.15	0.75	-4.18	-32.18	-3.04	-2.87	--	0.81
	09-19-95	-11.14	0.76	-5.94	-32.08	-3.66	-2.63	1.12	0.81
Whipple stock well 2	09-21-95	-12.56	0.72	-4.82	-32.21	-3.26	-2.91	0.82	0.77
Stock well 2	09-21-95	-12.77	0.64	-6.06	-32.06	-3.74	-2.64	0.79	0.70

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	$Cu(OH)_2$	Cu_2SO_4	$Cu_3(AsO_4)_2 \cdot 6 H_2O$	$CuCO_3$	CuF	CuF_2	$CuF_2 \cdot 2 H_2O$	Cu metal
Ghost Hawk Park well	08-07-91	-3.78	-16.65	-16.48	-5.46	-19.37	-18.78	-14.65	1.47
	11-30-92	-3.80	-17.00	-17.09	-5.67	-19.73	-19.55	-15.23	2.13
	09-20-95	-3.88	-16.97	-16.54	-5.50	-19.56	-18.86	-14.67	1.38
Stock well 1	09-21-95	-4.50	-18.45	-20.18	-7.02	-20.13	-20.25	-16.06	1.63
No Heart domestic well	08-07-91	-4.26	-15.81	-16.23	-5.76	-19.12	-18.58	-14.45	1.76
	11-30-92	-4.04	-15.42	-15.63	-5.48	-19.13	-18.64	-14.33	2.37
	09-20-95	-3.66	-15.44	-13.98	-5.06	-19.05	-18.08	-13.85	1.73
Observation well 1	10-02-91	-4.78	-18.40	-19.69	-6.66	-20.43	-19.95	-15.76	0.71
	11-30-92	-5.23	-18.49	-21.67	-7.29	-20.57	-20.97	-16.65	1.87
	09-20-95	-4.71	-18.60	-19.44	-6.68	-20.48	-20.06	-15.84	0.84
Observation well 6	09-19-95	-3.62	-16.16	-17.57	-6.12	-19.18	-19.24	-15.04	2.56
LaPointe stock well	09-22-95	-4.18	-17.79	-17.35	-6.02	-19.90	-19.14	-14.90	1.13
Whipple domestic well	08-07-91	-4.63	-16.28	-17.57	-6.26	-19.36	-19.02	-14.84	1.88
	11-30-92	-4.60	-16.34	-17.47	-6.36	-19.33	-18.98	-14.80	1.90
Hesse domestic well	09-21-95	-4.00	-16.80	-17.23	-6.13	-19.68	-19.11	-14.87	1.53
Stock well 3	09-21-95	-4.86	-18.91	-21.43	-7.31	-20.46	-20.60	-16.36	1.47
Observation well 2	10-02-91	-6.60	-18.04	-27.58	-8.42	-20.08	-21.23	-17.01	2.82
	11-30-92	-6.60	-17.99	-28.35	-8.55	-20.09	-21.64	-17.41	3.21
Observation well 7	09-18-95	-4.86	-17.81	-19.67	-7.24	-19.83	-19.94	-15.72	2.04
Observation well 8	09-18-95	-5.78	-18.13	-24.52	-8.14	-20.18	-21.54	-17.29	3.00
Swimmer domestic well	08-07-91	-3.87	-16.84	-14.85	-5.13	-19.45	-17.89	-13.76	0.42
Observation well 9	09-18-95	-4.17	-18.21	-19.22	-7.18	-19.49	-19.29	-15.09	1.98
Observation well 3	10-03-91	-3.29	-15.44	-16.25	-5.51	-18.81	-18.65	-14.42	2.78
	12-01-92	-4.92	-18.47	-21.85	-7.16	-20.23	-20.22	-15.99	1.51
	09-21-95	-4.64	-18.90	-21.62	-7.37	-20.29	-20.94	-16.73	2.01
GMC well	08-07-91	-4.15	-16.01	-19.45	-7.03	-18.61	-19.63	-15.54	3.72
	11-30-92	-4.26	-16.35	-20.07	-7.22	-18.90	-20.11	-15.89	4.01
Observation well 4	09-20-95	-4.24	-16.32	-19.07	-6.90	-18.90	-19.61	-15.43	3.39
Observation well 5	09-19-95	-4.16	-18.28	-18.59	-7.00	-19.62	-19.32	-15.17	1.59
Whipple stock well 1	08-07-91	-3.11	-15.52	-15.98	-5.55	-18.71	-18.83	-14.68	2.93
	09-19-95	-3.71	-16.53	-16.96	-5.84	-19.53	-19.42	-15.22	2.04
Whipple stock well 2	09-21-95	-4.61	-18.44	-20.41	-7.12	-20.10	-20.13	-16.00	1.35
Stock well 2	09-21-95	-4.95	-19.08	-21.33	-7.07	-20.44	-20.31	-16.09	1.14

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	CuOCu SO_4	Cupric Ferrite	Cupprite	Cuprous-Ferrite	$CuSO_4$	Diopside	Dioptase	Dolomite	Dolomite (d)
Ghost Hawk Park well	08-07-91	-20.64	1.97	1.89	10.68	-16.94	-4.11	-4.55	-1.09	-1.68
	11-30-92	-21.60	1.41	2.59	10.86	-17.84	-3.13	-4.43	-0.68	-1.30
	09-20-95	-20.95	0.59	1.72	9.99	-17.13	-4.25	-4.57	-1.24	-1.83
Stock well 1	09-21-95	-23.30	2.30	1.35	10.97	-18.86	-3.07	-5.14	-1.97	-2.56
No Heart domestic well	08-07-91	-20.56	0.48	1.71	10.08	-16.38	-3.47	-5.02	-0.11	-0.69
	11-30-92	-20.51	-0.33	2.59	10.10	-16.51	-3.68	-4.61	-0.49	-1.10
	09-20-95	-19.54	0.77	2.31	10.28	-15.93	-3.83	-4.28	-0.51	-1.11
Observation well 1	10-02-91	-22.60	1.94	0.16	10.33	-17.89	-3.98	-5.43	-1.59	-2.19
	11-30-92	-24.27	-0.74	0.90	9.65	-19.07	-3.22	-5.80	-1.27	-1.89
	09-20-95	-22.86	0.68	0.37	9.79	-18.21	-3.72	-5.33	-1.55	-2.15
Observation well 6	09-19-95	-21.05	3.06	3.17	11.82	-17.50	-2.68	-4.27	-1.51	-2.10
LaPointe stock well	09-22-95	-21.81	0.65	1.18	9.93	-17.67	-4.26	-4.81	-1.80	-2.40
Whipple domestic well	08-07-91	-21.51	-1.11	1.47	9.38	-16.95	-4.45	-5.40	-1.31	-1.90
	11-30-92	-21.56	-0.99	1.52	9.45	-17.02	-4.69	-5.36	-1.83	-2.42
Hesse domestic well	09-21-95	-21.03	4.02	1.77	11.81	-17.08	-3.91	-4.62	-2.06	-2.66
Stock well 3	09-21-95	-23.94	0.62	0.84	10.08	-19.13	-3.29	-5.55	-1.93	-2.53
Observation well 2	10-02-91	-26.17	-2.86	0.45	9.01	-19.62	-3.99	-7.32	-1.30	-1.90
	11-30-92	-26.51	-2.51	0.85	9.38	-19.97	-3.08	-7.32	-0.67	-1.27
Observation well 7	09-18-95	-23.42	1.02	1.41	10.56	-18.61	-3.62	-5.58	-2.08	-2.68
Observation well 8	09-18-95	-25.61	1.38	1.47	11.24	-19.88	-1.79	-6.54	-0.11	-0.72
Swimmer domestic well	08-07-91	-19.87	5.12	0.76	11.74	-16.08	-4.83	-4.64	-0.98	-1.56
Observation well 9	09-18-95	-23.08	4.12	2.04	12.06	-18.97	-2.39	-4.83	-2.23	-2.82
Observation well 3	10-03-91	-20.21	5.61	3.72	13.22	-16.97	-3.25	-3.96	-1.46	-2.06
	12-01-92	-23.61	0.41	0.83	9.99	-18.74	-3.99	-5.55	-2.33	-2.93
	09-21-95	-24.27	2.07	1.60	11.06	-19.69	-2.47	-5.26	-1.83	-2.43
GMC well	08-07-91	-22.64	2.04	3.76	11.82	-18.57	-4.10	-4.90	-3.55	-4.12
	11-30-92	-23.33	2.14	3.98	12.10	-19.13	--	-4.93	--	--
Observation well 4	09-20-95	-22.68	1.73	3.36	11.56	-18.50	-2.91	-4.92	-2.02	-2.61
Observation well 5	09-19-95	-22.76	3.83	1.64	11.69	-18.67	-3.04	-4.83	-2.54	-3.13
Whipple stock well 1	08-07-91	-20.29	5.72	4.02	13.30	-17.25	-2.42	-3.74	-1.21	-1.80
	09-19-95	-21.00	4.53	2.55	12.30	-17.34	-3.62	-4.32	-1.78	-2.38
Whipple stock well 2	09-21-95	-23.14	1.72	0.95	10.50	-18.61	-2.83	-5.27	-1.70	-2.28
Stock well 2	09-21-95	-23.89	-0.05	0.42	9.57	-18.99	-3.77	-5.68	-1.69	-2.28

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Epsomite	$Fe(OH)_2 \cdot 7Cl_3$	$Fe(OH)_3$ (a)	$Fe_2(SeO_3)_3$	$Fe_3(OH)_8$	$FeSe_2$	Fluorite	Forsterite	Goethite
Ghost Hawk Park well	08-07-91	-5.69	1.26	-3.16	--	-9.56	--	-1.92	-10.64	2.73
	11-30-92	-5.65	1.15	-3.19	-34.72	-9.44	-15.19	-1.82	-9.98	2.70
	09-20-95	-5.73	0.79	-3.72	-34.44	-11.28	-16.35	-1.90	-10.89	2.17
Stock well 1	09-21-95	-6.36	1.77	-2.56	-34.51	-7.35	-11.99	-2.07	-9.89	3.33
No Heart domestic well	08-07-91	-4.31	1.28	-3.67	-32.08	-10.70	-9.60	-0.97	-9.93	2.22
	11-30-92	-4.42	0.93	-3.96	-33.50	-11.48	-11.22	-1.06	-10.52	1.93
	09-20-95	-4.47	1.21	-3.70	-32.65	-11.16	-15.06	-1.12	-10.53	2.19
Observation well 1	10-02-91	-5.45	1.91	-2.60	-32.50	-7.79	-14.16	-2.05	-10.57	3.29
	11-30-92	-5.50	0.82	-3.55	-35.42	-9.93	-9.05	-1.98	-10.03	2.34
	09-20-95	-5.63	1.15	-3.22	-34.07	-9.65	-15.29	-2.03	-10.38	2.67
Observation well 6	09-19-95	-5.58	2.01	-2.60	-34.63	-7.47	-11.99	-1.77	-9.38	3.29
LaPointe stock well	09-22-95	-5.79	0.94	-3.48	-33.02	-10.55	-16.03	-1.92	-10.82	2.41
Whipple domestic well	08-07-91	-4.94	0.54	-4.21	-35.45	-12.12	-9.76	-1.29	-11.15	1.68
	11-30-92	-5.19	0.55	-4.17	-35.33	-11.98	-9.76	-1.39	-11.44	1.73
Hesse domestic well	09-21-95	-5.26	2.39	-1.88	-31.73	-5.66	-14.51	-1.86	-10.57	4.01
Stock well 3	09-21-95	-6.08	1.07	-3.15	-34.59	-9.06	-11.58	-2.10	-9.91	2.71
Observation well 2	10-02-91	-5.27	0.47	-4.01	-35.87	-10.18	5.06	-1.25	-10.73	1.85
	11-30-92	-5.17	0.61	-3.87	-37.25	-9.47	6.22	-1.20	-9.82	2.02
Observation well 7	09-18-95	-5.90	1.30	-2.97	-35.37	-8.23	-8.83	-1.45	-10.52	2.92
Observation well 8	09-18-95	-5.12	1.94	-2.30	-34.04	-5.29	1.76	-1.20	-8.47	3.59
Swimmer domestic well	08-07-91	-5.17	3.23	-1.54	-29.47	-5.17	-18.01	-1.24	-11.50	4.35
Observation well 9	09-18-95	-6.44	2.29	-1.80	-33.75	-5.07	-11.82	-1.02	-9.26	4.09
Observation well 3	10-03-91	-5.5	3.07	-1.46	-30.69	-4.11	-10.77	-1.77	-9.81	4.43
	12-01-92	-6.09	1.20	-3.25	-33.88	-9.28	-10.31	-2.07	-10.68	2.65
	09-21-95	-6.71	1.63	-2.59	-34.03	-7.17	-8.95	-2.33	-9.28	3.31
GMC well	08-07-91	-8.06	1.34	-2.98	-34.27	-7.69	-0.45	-1.53	-12.60	2.91
	11-30-92	--	1.52	-2.72	-36.98	-6.79	-2.22	-1.50	--	3.17
Observation well 4	09-20-95	-6.24	1.22	-2.98	-36.19	-7.87	-4.49	-1.54	-9.81	2.91
Observation well 5	09-19-95	-6.60	2.14	-2.01	-31.20	-5.86	-11.40	-1.52	-9.83	3.89
Whipple stock well 1	08-07-91	-5.83	2.61	-1.58	-30.02	-4.47	-9.19	-1.94	-9	4.30
	09-19-95	-5.78	2.60	-1.82	-29.45	-5.34	-11.17	-2.43	-10.24	4.07
Whipple stock well 2	09-21-95	-5.96	1.35	-2.87	-34.39	-8.34	-11.68	-1.96	-9.38	3.02
Stock well 2	09-21-95	-6.12	0.83	-3.47	-34.56	-10.13	-12.31	-1.99	-10.30	2.42

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Goslarite	Greenalite	Gummite	Gypsum	H_2 (gas)	Halite	Hausmannite	Hematite	Huntite
Ghost Hawk Park well	08-07-91	-8.33	-5.28	--	-2.47	-12.38	-8.63	-26.91	6.85	-7.37
	11-30-92	-8.63	-4.69	-9.99	-2.50	-12.35	-8.47	-27.59	6.16	-6.66
	09-20-95	-8.83	-6.99	-9.59	-2.56	-12.58	-8.32	-28.25	5.52	-7.67
Stock well 1	09-21-95	-10.01	-2.09	-9.60	-3.07	-11.71	-8.01	-22.03	7.85	-9.26
No Heart domestic well	08-07-91	-8.36	-5.66	--	-1.16	-11.61	-6.41	-24.37	5.83	-5.33
	11-30-92	-8.19	-6.09	-10.05	-1.32	-11.82	-6.53	-26.86	4.68	-6.21
	09-20-95	-8.24	-6.71	-9.93	-1.37	-12.58	-6.50	-25.87	5.44	-6.19
Observation well 1	10-02-91	-9.23	-3.19	--	-2.38	-12.35	-8.41	-24.76	7.77	-8.29
	11-30-92	-8.67	-3.87	-9.65	-2.47	-11.17	-8.56	-28.57	5.44	-7.73
	09-20-95	-8.74	-5.04	-9.38	-2.56	-12.42	-8.80	-27.49	6.40	-8.23
Observation well 6	09-19-95	-8.27	-2.22	-9.70	-2.40	-11.70	-7.01	-21.63	7.72	-8.23
LaPointe stock well	09-22-95	-10.24	-6.20	-9.42	-2.84	-12.70	-9.37	-29.36	5.85	-8.63
Whipple domestic well	08-07-91	-7.94	-6.71	--	-1.61	-11.29	-7.34	-30.42	4.58	-7.96
	11-30-92	-7.99	-6.57	--	-1.83	-11.30	-7.59	-30.27	4.67	-9.04
Hesse domestic well	09-21-95	-7.64	-1.08	-9.42	-2.22	-12.48	-8.71	-24.89	9.03	-9.23
Stock well 3	09-21-95	-10.22	-3.81	-9.62	-3.01	-11.68	-9.53	-23.10	6.50	-9.00
Observation well 2	10-02-91	-9.00	-1.89	--	-2.03	-8.55	-7.98	-24.93	4.76	-7.92
	11-30-92	--	-0.79	-9.64	-1.92	-8.16	-7.83	-24.28	5.10	-6.64
Observation well 7	09-18-95	-9.45	-2.45	-9.85	-2.50	-11.07	-8.04	-23.90	6.90	-9.61
Observation well 8	09-18-95	-9.76	2.22	-9.83	-1.92	-9.28	-8.89	-20.61	8.16	-5.51
Swimmer domestic well	08-07-91	-8.70	-1.85	--	-1.81	-13.33	-7.28	-21.00	10.09	-7.28
Observation well 9	09-18-95	-9.90	0.14	-9.81	-3.09	-11.73	-8.41	-23.02	9.32	-9.84
Observation well 3	10-03-91	-9.04	0.94	--	-2.49	-11.90	-7.57	-24.07	9.92	-7.99
	12-01-92	-9.87	-3.80	--	-2.98	-11.54	-8.08	-28.06	6.35	-9.83
	09-21-95	-10.47	-1.37	-9.40	-3.47	-11.22	-8.50	-25.86	7.75	-8.93
GMC well	08-07-91	-9.27	-0.65	--	-2.86	-9.63	-7.63	-25.64	7.33	-14.22
	11-30-92	-9.39	0.49	--	-2.91	-9.65	-7.67	-22.13	7.43	--
Observation well 4	09-20-95	-9.80	-1.15	-10.02	-2.82	-10.16	-8.10	-22.71	7.04	-9.47
Observation well 5	09-19-95	-9.03	-0.93	-9.75	-3.27	-11.96	-8.42	-23.29	9.07	-10.41
Whipple stock well 1	08-07-91	-7.55	0.83	--	-2.75	-11.67	-9.03	-25.67	9.91	-7.50
	09-19-95	-7.22	-0.43	-9.11	-2.74	-12.13	-8.94	-25.08	9.28	-8.65
Whipple stock well 2	09-21-95	-8.12	-3.13	-9.51	-2.83	-11.66	-8.84	-26.28	7.42	-8.49
Stock well 2	09-21-95	-10.42	-5.12	-9.70	-3.06	-11.83	-9.70	-28.75	5.94	-8.48

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Hydro-magne-site	Jarosite (ss)	Jarosite-K	Jarosite-Na	Jarosit-H	Langite	Maga-diite	Mag-hemite	Hag-nesite
Ghost Hawk Park well	08-07-91	-19.09	-21.16	-19.83	-23.06	-27.98	-15.65	-2.32	-2.92	-1.51
	11-30-92	-18.10	-22.65	-21.88	-25.15	-30.85	-16.11	-1.83	-2.99	-1.32
	09-20-95	-19.53	-23.10	-22.01	-25.15	-30.18	-15.98	-2.07	-4.05	-1.57
Stock well 1	09-21-95	-20.77	-21.37	-20.18	-22.96	-28.91	-19.58	-0.80	-1.72	-2.00
No Heart domestic well	08-07-91	-16.63	-20.45	-19.09	-22.07	-27.46	-16.52	-1.85	-3.94	-0.98
	11-30-92	-17.88	-21.84	-21.06	-24.12	-29.92	-15.54	-1.24	-4.52	-1.19
	09-20-95	-17.84	-20.79	-19.77	-22.77	-28.36	-14.02	-1.29	-4.00	-1.19
Observation well 1	10-02-91	-19.90	-19.41	-18.30	-21.56	-26.53	-19.43	-1.84	-1.80	-1.70
	11-30-92	-19.11	-23.43	-22.69	-26.02	-31.52	-21.66	-1.57	-3.71	-1.56
	09-20-95	-19.77	-21.98	-20.99	-24.28	-29.38	-19.44	-1.79	-3.04	-1.69
Observation well 6	09-19-95	-19.36	-20.21	-18.97	-22.13	-28.15	-15.53	-0.88	-1.81	-1.71
LaPointe stock well	09-22-95	-20.27	-22.94	-22.02	-25.80	-30.18	-17.31	-2.57	-3.56	-1.76
Whipple domestic well	08-07-91	-20.07	-22.65	-21.50	-24.56	-29.74	-18.07	-2.39	-5.03	-1.68
	11-30-92	-21.32	-22.82	-21.70	-24.75	-29.80	-18.07	-2.46	-4.94	-1.96
Hesse domestic well	09-21-95	-20.84	-17.01	-16.04	-19.08	-24.60	-16.17	-1.40	-0.37	-1.93
Stock well 3	09-21-95	-20.28	-23.29	-22.33	-25.87	-30.76	-20.80	-2.48	-2.91	-1.88
Observation well 2	10-02-91	-19.76	-23.42	-22.43	-25.45	-30.88	-26.53	-2.12	-4.69	-1.65
	11-30-92	-18.03	-23.38	-22.33	-25.36	-31.06	-26.87	-1.86	-4.34	-1.34
Observation well 7	09-18-95	-21.51	-21.39	-20.34	-22.94	-29.13	-20.31	-1.33	-2.55	-2.12
Observation well 8	09-18-95	-16.16	-19.96	-18.93	-22.49	-27.95	-24.25	-2.53	-1.21	-1.04
Swimmer domestic well	08-07-91	-19.57	-14.57	-13.31	-16.11	-21.22	-15.06	-2.13	0.32	-1.52
Observation well 9	09-18-95	-21.07	-19.73	-18.53	-21.22	-27.58	-18.65	-0.59	-0.20	-2.16
Observation well 3	10-03-91	-19.16	-16.62	-15.52	-18.65	-24.45	-13.96	-1.39	0.48	-1.62
	12-01-92	-21.56	-22.50	-21.47	-24.54	-30.10	-20.61	-1.39	-3.10	-2.10
	09-21-95	-20.09	-22.73	-21.56	-24.55	-30.42	-20.80	-0.77	-1.77	-1.91
GMC well	08-07-91	-28.92	-22.63	-21.08	-23.59	-29.77	-18.49	-0.64	-2.57	-3.72
	11-30-92	--	-22.57	-21.40	-23.95	-30.56	-19.06	-0.49	-2.05	--
Observation well 4	09-20-95	-21.04	-22.33	-21.08	-23.66	-29.91	-18.47	-0.67	-2.57	-2.09
Observation well 5	09-19-95	-21.92	-19.99	-18.68	-21.29	-27.35	-18.47	-0.59	-0.62	-2.30
Whipple stock well 1	08-07-91	-18.35	-18.22	-16.94	-20.08	-25.36	-13.89	-1.09	0.22	-1.51
	09-19-95	-20.11	-18.12	-17.05	-20.57	-25.31	-15.66	-1.88	-0.25	-1.79
Whipple stock well 2	09-21-95	-19.55	-21.76	-20.39	-23.44	-28.81	-19.8	-1.11	-2.35	-1.76
Stock well 2	09-21-95	-19.92	-24.03	-23.03	-26.76	-31.14	-21.00	-3.09	-3.55	-1.75

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Magnetite	Malachite	Manganite	Melanothallite	Melanterite	Mirabolite	$Mn_2(SO_4)_3$	$Mn_3(AsO_4)\cdot 8H_2O$	$MnCl_2\cdot 4H_2O$
Ghost Hawk Park well	08-07-91	5.91	-5.06	-10.71	-22.24	-9.22	-7.93	-74.06	-17.74	-18.90
	11-30-92	5.02	-5.29	-10.27	-22.70	-9.75	-7.60	-77.49	-17.82	-18.59
	09-20-95	3.86	-5.21	-10.9	-21.68	-9.85	-7.91	-75.26	-18.67	-18.44
Stock well 1	09-21-95	7.78	-7.53	-8.97	-23.53	-9.36	-7.18	-74.73	-13.35	-17.30
No Heart domestic well	08-07-91	4.76	-5.84	-9.99	-19.20	-8.32	-5.98	-69.54	-12.76	-14.28
	11-30-92	3.05	-5.35	-10.16	-19.32	-8.70	-5.80	-72.42	-14.45	-14.62
	09-20-95	3.77	-4.55	-9.98	-18.78	-8.78	-5.89	-70.81	-14.17	-14.77
Observation well 1	10-02-91	7.35	-7.27	-9.78	-22.64	-8.47	-7.89	-72.60	-15.41	-17.26
	11-30-92	4.53	-8.35	-10.80	-23.94	-9.32	-7.77	-77.93	-17.90	-18.33
	09-20-95	5.29	-7.22	-10.54	-23.46	-9.45	-8.10	-75.63	-17.95	-18.89
Observation well 6	09-19-95	7.60	-5.56	-8.80	-20.73	-8.90	-6.57	-73.05	-12.91	-15.19
LaPointe stock well	09-22-95	4.32	-6.03	-11.08	-22.59	-9.80	-9.52	-76.76	-19.49	-19.19
Whipple domestic well	08-07-91	3.08	-6.71	-11.89	-20.83	-8.79	-6.66	-74.33	-18.41	-17.19
	11-30-92	3.22	-6.79	-11.83	-21.04	-8.85	-7.03	-74.54	-18.25	-17.38
Hesse domestic well	09-21-95	9.21	-5.96	-9.62	-23.36	-7.70	-6.86	-72.64	-15.24	-18.58
Stock well 3	09-21-95	5.81	-8.00	-9.16	-24.60	-9.74	-9.29	-75.26	-14.26	-18.10
Observation well 2	10-02-91	4.75	-10.84	-10.33	-24.38	-7.85	-6.94	-73.77	-13.97	-15.77
	11-30-92	5.46	-10.97	-10.18	-24.61	-7.83	-6.76	-74.51	-13.71	-15.66
Observation well 7	09-18-95	6.71	-7.93	-9.57	-24.27	-8.77	-6.16	-74.44	-12.78	-17.90
Observation well 8	09-18-95	9.51	-9.75	-8.68	-25.34	-7.51	-8.00	-73.93	-9.63	-16.23
Swimmer domestic well	08-07-91	10.29	-4.82	-8.58	-20.01	-7.12	-6.61	-66.94	-10.87	-14.92
Observation well 9	09-18-95	10.00	-7.17	-9.26	-24.78	-9.03	-6.81	-76.73	-14.32	-19.16
Observation well 3	10-03-91	10.83	-4.63	-9.49	-20.97	-7.60	-6.88	-74.06	-15.06	-16.50
	12-01-92	5.65	-7.91	-10.88	-23.13	-9.35	-7.50	-77.27	-19.41	-18.24
	09-21-95	7.89	-7.84	-10.29	-24.44	-9.80	-8.04	-79.52	-17.63	-19.12
GMC well	08-07-91	7.97	-7.00	-10.87	-23.29	-8.99	-6.61	-77.83	-15.79	-18.42
	11-30-92	8.21	-7.30	-9.26	-23.82	-8.96	-6.43	-77.06	-11.87	-17.05
Observation well 4	09-20-95	7.33	-6.97	-9.50	-24.10	-8.93	-6.45	-75.37	-12.22	-17.91
Observation well 5	09-19-95	9.47	-6.99	-9.48	-24.39	-9.15	-7.04	-75.88	-14.51	-19.19
Whipple stock well 1	08-07-91	10.87	-4.49	-10.33	-22.98	-8.22	-8.24	-76.44	-17.15	-19.54
	09-19-95	9.73	-5.37	-9.87	-22.11	-8.08	-8.90	-74.46	-15.90	-17.77
Whipple stock well 2	09-21-95	7.13	-7.55	-10.62	-24.39	-9.42	-7.87	-76.41	-17.85	-19.78
Stock well 2	09-21-95	4.88	-7.85	-11.1	-24.11	-9.96	-10.04	-78.25	-19.84	-19.58

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	$MnSO_4$	$Na_4UO_2(CO_3)_3$	Nahcolite	Nantokite	Natron	Nesquehonite	Nsutite	O_2 (gas)	Portlandite
Ghost Hawk Park well	08-07-91	-14.82	--	-4.58	-4.64	-9.33	-3.91	-20.18	-1.58	-11.75
	11-30-92	-15.50	-24.46	-4.52	-4.41	-8.73	-3.72	-19.78	-1.14	-11.58
	09-20-95	-15.29	-24.63	-4.58	-4.37	-9.30	-3.97	-20.28	-1.27	-11.97
Stock well 1	09-21-95	-14.03	-23.67	-4.56	-5.17	-6.36	-4.40	-18.79	-0.67	-11.37
No Heart domestic well	08-07-91	-12.69	--	-3.94	-2.98	-8.23	-3.38	-19.85	-1.10	-11.47
	11-30-92	-13.53	-22.69	-3.95	-2.61	-8.04	-3.59	-19.94	-1.07	-11.93
	09-20-95	-13.43	-22.50	-3.92	-2.71	-8.12	-3.59	-19.37	-1.06	-11.89
Observation well 1	10-02-91	-13.91	--	-4.91	-5.18	-9.69	-4.10	-19.27	-0.99	-11.93
	11-30-92	-15.23	-25.44	-4.89	-5.16	-9.29	-3.95	-20.90	-0.93	-11.75
	09-20-95	-15.15	-25.63	-4.98	-5.49	-9.67	-4.08	-20.01	-0.91	-11.86
Observation well 6	09-19-95	-13.39	-23.54	-4.5	-3.29	-8.24	-4.11	-18.62	-1.12	-11.23
LaPointe stock well	09-22-95	-15.82	-28.23	-5.58	-4.91	-11.00	-4.16	-20.40	-0.63	-12.19
Whipple domestic well	08-07-91	-14.68	--	-4.41	-3.70	-8.96	-4.08	-21.91	-2.89	-11.91
	11-30-92	-14.74	--	-4.67	-3.79	-9.35	-4.36	-21.85	-2.89	-12.02
Hesse domestic well	09-21-95	-13.86	-24.59	-4.75	-5.09	-9.04	-4.33	-19.06	-0.81	-11.99
Stock well 3	09-21-95	-14.17	-28.23	-5.69	-5.75	-10.60	-4.28	-19.00	-0.64	-11.60
Observation well 2	10-02-91	-12.52	--	-4.48	-4.97	-8.83	-4.05	-21.74	-2.90	-11.81
	11-30-92	-12.53	-23.41	-4.35	-4.88	-8.44	-3.73	-21.78	-2.90	-11.35
Observation well 7	09-18-95	-13.75	-22.96	-4.29	-5.30	-7.90	-4.51	-19.71	-2.60	-11.55
Observation well 8	09-18-95	-12.35	-26.04	-5.07	-5.34	-9.42	-3.44	-19.72	-2.91	-10.71
Swimmer domestic well	08-07-91	-12.22	--	-3.97	-4.05	-8.54	-3.92	-17.58	-2.88	-12.05
Observation well 9	09-18-95	-14.78	-23.81	-4.67	-5.60	-8.07	-4.56	-19.06	-0.72	-11.00
Observation well 3	10-03-91	-14.01	--	-4.51	-3.29	-8.51	-4.01	-19.22	-0.83	-11.60
	12-01-92	-15.36	-24.62	-4.79	-4.99	-9.02	-4.50	-20.79	-0.83	-11.96
	09-21-95	-15.80	-24.51	-4.88	-5.42	-8.76	-4.30	-20.35	-0.81	-11.14
GMC well	08-07-91	-14.82	--	-4.41	-4.07	-7.86	-6.12	-21.72	-1.21	-10.75
	11-30-92	-13.84	--	-4.41	-4.10	-7.59	--	-20.11	-1.34	-10.80
Observation well 4	09-20-95	-13.67	-23.15	-4.36	-4.58	-7.84	-4.48	-20.09	-1.48	-11.18
Observation well 5	09-19-95	-14.77	-23.93	-4.66	-5.64	-8.30	-4.70	-19.17	-0.83	-11.29
Whipple stock well 1	08-07-91	-15.10	--	-5.05	-4.27	-9.48	-3.91	-20.16	-0.69	-11.14
	09-19-95	-14.44	-26.98	-5.42	-4.24	-10.44	-4.19	-19.48	-0.69	-11.81
Whipple stock well 2	09-21-95	-15.22	-25.20	-4.96	-5.78	-9.26	-4.16	-20.45	-0.67	-11.27
Stock well 2	09-21-95	-15.93	-29.09	-5.80	-5.68	-11.19	-4.15	-20.87	-0.63	-11.78

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Pyro-chroite	Pyro-lusite	Quartz	Rhodo-chrosite	Rhodo-chrosite (d)	Ruther-fordine	Schoep-ite	Scoro-dite	Se (solid)
Ghost Hawk Park well	08-07-91	-8.31	-20.32	1.06	-2.27	-2.98	--	--	-11.57	--
	11-30-92	-7.85	-21.22	1.20	-2.33	-3.01	-5.02	-4.55	-12.34	4.46
	09-20-95	-8.61	-20.84	1.14	-2.61	-3.31	-4.46	-4.30	-12.16	4.40
Stock well 1	09-21-95	-6.24	-19.35	1.19	-1.14	-1.85	-5.37	-4.31	-11.89	5.34
No Heart domestic well	08-07-91	-7.21	-19.98	1.06	-0.99	-1.70	-11.24	--	-11.24	7.06
	11-30-92	-7.47	-21.28	1.26	-1.50	-2.18	-4.66	-4.63	-11.98	6.44
	09-20-95	-7.67	-20.18	1.21	-1.53	-2.23	-4.55	-4.59	-11.28	5.00
Observation well 1	10-02-91	-7.37	-19.83	1.18	-1.64	-2.34	-11.27	--	-11.27	4.76
	11-30-92	-7.78	-22.33	1.26	-2.45	-3.13	-4.86	-4.21	-12.84	6.82
	09-20-95	-8.16	-20.83	1.20	-2.59	-3.29	-4.58	-4.04	-11.97	4.53
Observation well 6	09-19-95	-6.06	-19.26	1.18	-0.97	-1.67	-5.44	-4.39	-11.98	5.35
LaPointe stock well	09-22-95	-8.83	-21.31	1.21	-3.15	-3.84	-4.48	-4.07	-11.99	4.49
Whipple domestic well	08-07-91	-8.94	-22.38	1.06	-2.93	-3.64	--	--	-12.02	6.97
	11-30-92	-8.89	-22.33	1.07	-3.02	-3.72	--	--	-11.96	6.96
Hesse domestic well	09-21-95	-7.27	-19.96	1.21	-1.88	-2.57	-4.77	-4.07	-10.61	4.29
Stock well 3	09-21-95	-6.41	-19.90	1.15	-1.33	-2.02	-5.28	-4.27	-12.69	5.79
Observation well 2	10-02-91	-6.02	-22.55	1.11	-0.28	-0.98	--	--	-14.02	12.21
	11-30-92	-5.67	-22.60	1.11	-0.08	-0.77	-4.82	-4.31	-14.23	12.41
Observation well 7	09-18-95	-6.52	-20.53	1.11	-1.35	-2.05	-5.46	-4.52	-11.60	6.62
Observation well 8	09-18-95	-4.73	-20.72	1.07	0.41	-0.28	-5.40	-4.46	-12.04	10.22
Swimmer domestic well	08-07-91	-6.66	-17.71	1.06	-0.20	-0.91	--	--	-9.00	3.08
Observation well 9	09-18-95	-6.53	-19.71	1.17	-1.95	-2.65	-6.06	-4.5	-11.18	5.06
Observation well 3	10-03-91	-6.85	-20.03	1.16	-1.51	-2.21	--	--	-10.73	5.52
	12-01-92	-8.06	-21.61	1.20	-2.75	-3.45	-4.87	-4.06	-12.88	6.37
	09-21-95	-7.31	-20.99	1.22	-2.44	-3.14	-5.36	-4.09	-12.45	6.50
GMC well	08-07-91	-7.10	-21.60	1.09	-2.19	-2.90	--	--	-12.23	9.82
	11-30-92	-5.5	-20.84	1.16	-0.89	-1.58	--	--	-12.42	8.75
Observation well 4	09-20-95	-6.00	-20.56	1.15	-1.02	-1.72	-5.93	-4.74	-12.11	8.15
Observation well 5	09-19-95	-6.88	-19.47	1.17	-2.03	-2.74	-5.86	-4.50	-10.96	5.57
Whipple stock well 1	08-07-91	-7.58	-20.56	1.21	-2.34	-3.04	--	--	-10.81	6.25
	09-19-95	-7.35	-20.12	1.22	-1.88	-2.58	-4.48	-3.81	-10.76	5.69
Whipple stock well 2	09-21-95	-7.87	-20.58	1.17	-2.65	-3.36	-5.30	-4.28	-12.01	5.66
Stock well 2	09-21-95	-8.43	-21.60	1.11	-2.97	-3.67	-5.05	-4.38	-12.76	5.71

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	SeO_2	Sepiolite	Sepiolite (d)	Siderite	Siderite (d)	Silicagel	SiO_2(a)	Smithsonite	Talc
Ghost Hawk Park well	08-07-91	--	-3.40	-6.08	-2.21	-2.60	0.07	-0.26	-1.97	-1.95
	11-30-92	-16.14	-1.96	-4.43	-2.57	-2.91	0.17	-0.18	-2.10	-0.41
	09-20-95	-15.69	-3.34	-5.95	-2.87	-3.24	0.14	-0.20	-2.49	-2.07
Stock well 1	09-21-95	-16.49	-2.23	-4.85	-2.17	-2.54	0.19	-0.15	-3.46	-0.45
No Heart domestic well	08-07-91	-14.94	-2.69	-5.38	-2.17	-2.56	0.07	-0.26	-2.86	-0.89
	11-30-92	-15.22	-2.42	-4.90	-2.63	-2.97	0.23	-0.12	-2.76	-1.08
	09-20-95	-15.11	-2.73	-5.30	-2.66	-3.02	0.20	-0.14	-2.77	-1.31
Observation well 1	10-02-91	-15.79	-2.93	-5.54	-1.90	-2.27	0.18	-0.16	-3.30	-1.48
	11-30-92	-16.13	-1.88	-4.35	-2.53	-2.87	0.24	-0.11	-2.52	-0.32
	09-20-95	-15.90	-2.59	-5.16	-2.67	-3.04	0.19	-0.15	-2.61	-1.09
Observation well 6	09-19-95	-16.50	-1.71	-4.31	-2.20	-2.57	0.17	-0.16	-2.22	0.31
LaPointe stock well	09-22-95	-15.38	-2.99	-5.55	-2.94	-3.30	0.19	-0.15	-4.02	-1.73
Whipple domestic well	08-07-91	-15.70	-3.79	-6.41	-2.71	-3.09	0.06	-0.27	-2.51	-2.67
	11-30-92	-15.69	-4.05	-6.68	-2.80	-3.18	0.07	-0.27	-2.58	-3.08
Hesse domestic well	09-21-95	-16.01	-2.73	-5.28	-1.53	-1.89	0.20	-0.14	-2.12	-1.34
Stock well 3	09-21-95	-16.12	-2.20	-4.75	-2.71	-3.07	0.14	-0.21	-3.83	-0.51
Observation well 2	10-02-91	-15.95	-3.13	-5.70	-1.40	-1.76	0.10	-0.24	-3.19	-1.86
	11-30-92	-16.53	-2.22	-4.79	-1.17	-1.53	0.10	-0.24	--	-0.50
Observation well 7	09-18-95	-16.50	-2.91	-5.48	-2.15	-2.52	0.10	-0.24	-3.48	-1.53
Observation well 8	09-18-95	-16.50	-0.88	-3.42	-0.59	-0.95	0.06	-0.29	-3.49	1.46
Swimmer domestic well	08-07-91	-15.49	-4.26	-6.95	-0.65	-1.04	0.07	-0.26	-2.87	-3.24
Observation well 9	09-18-95	-16.74	-1.61	-4.21	-1.92	-2.29	0.17	-0.17	-3.43	0.47
Observation well 3	10-03-91	-15.95	-2.10	-4.67	-0.89	-1.25	0.15	-0.19	-2.96	-0.34
	12-01-92	-15.82	-2.90	-5.48	-2.52	-2.89	0.19	-0.15	-3.68	-1.56
	09-21-95	-16.31	-1.53	-4.13	-2.17	-2.54	0.21	-0.13	-3.47	0.56
GMC well	08-07-91	-16.13	-5.41	-8.14	-1.83	-2.23	0.10	-0.22	-2.75	-4.88
	11-30-92	-17.20	--	--	-1.76	-2.13	0.16	-0.18	-2.83	--
Observation well 4	09-20-95	-16.76	-2.25	-4.88	-1.95	-2.33	0.15	-0.18	-3.46	-0.42
Observation well 5	09-19-95	-15.75	-2.32	-4.97	-2.03	-2.41	0.17	-0.16	-2.54	-0.45
Whipple stock well 1	08-07-91	-15.64	-1.40	-4.06	-1.07	-1.45	0.21	-0.12	-1.05	0.90
	09-19-95	-15.29	-2.49	-5.09	-1.26	-1.63	0.21	-0.12	-1.04	-0.88
Whipple stock well 2	09-21-95	-16.24	-1.93	-4.61	-2.40	-2.79	0.18	-0.15	-1.75	0.20
Stock well 2	09-21-95	-15.9	-2.74	-5.32	-2.76	-3.12	0.1	-0.24	-3.86	-1.24

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Tenorite	Thenar-dite	Thermo-natrite	Tremo-lite	Trona	$U(OH)_2SO_4$	U_3O_8(c)	U_4O_9(c)
Ghost Hawk Park well	08-07-91	-2.76	-9.26	-11.14	-5.27	-15.73	--	--	--
	11-30-92	-2.78	-9.32	-10.91	-1.48	-15.81	-20.02	-5.33	0.09
	09-20-95	-2.86	-9.37	-11.23	-5.57	-15.94	-19.90	-5.15	-0.83
Stock well 1	09-21-95	-3.48	-8.64	-10.29	-1.59	-14.99	-20.14	-4.31	1.76
No Heart domestic well	08-07-91	-3.23	-7.31	-10.04	-2.93	-14.00	--	--	--
	11-30-92	-3.02	-7.49	-10.20	-3.26	-14.51	-18.06	-5.07	1.24
	09-20-95	-2.64	-7.43	-10.13	-3.92	-14.25	-19.01	-5.92	-1.62
Observation well 1	10-02-91	-3.76	-9.35	-11.62	-4.45	-16.66	--	--	--
	11-30-92	-4.21	-9.49	-11.47	-1.58	-16.76	-18.3	-3.13	4.98
	09-20-95	-3.69	-9.63	-11.68	-3.49	-16.86	-19.53	-4.12	1.05
Observation well 6	09-19-95	-2.60	-8.06	-10.20	-0.03	-14.86	-19.67	-4.52	1.56
LaPointe stock well	09-22-95	-3.16	-11.08	-13.03	-5.18	-18.85	-19.76	-4.46	0.20
Whipple domestic well	08-07-91	-3.61	-8.09	-10.87	-6.60	-15.38	--	--	--
	11-30-92	-3.58	-8.46	-11.26	-7.48	-16.04	--	--	--
Hesse domestic well	09-21-95	-2.98	-8.42	-11.07	-4.10	-16.05	-19.13	-4.22	0.88
Stock well 3	09-21-95	-3.84	-10.85	-12.63	-2.03	-18.55	-19.71	-4.04	2.47
Observation well 2	10-02-91	-5.58	-8.47	-10.84	-4.80	-15.52	--	--	--
	11-30-92	-5.58	-8.29	-10.45	-1.61	-15.01	-15.40	-0.66	12.76
Observation well 7	09-18-95	-3.84	-7.70	-9.90	-3.71	-14.41	-18.90	-4.19	3.20
Observation well 8	09-18-95	-4.76	-9.59	-11.48	2.98	-16.81	-17.27	-2.18	9.03
Swimmer domestic well	08-07-91	-2.85	-7.94	-10.35	-8.00	-14.33	--	--	--
Observation well 9	09-18-95	-3.15	-8.30	-10.02	0.69	-14.85	-20.73	-4.88	1.03
Observation well 3	10-03-91	-2.27	-8.41	-10.51	-1.78	-15.24	--	--	--
	12-01-92	-3.90	-9.04	-11.03	-4.49	-16.02	-18.99	-3.30	3.61
	09-21-95	-3.62	-9.52	-10.72	0.62	-15.76	-20.06	-3.13	4.21
GMC well	08-07-91	-3.13	-7.86	-9.59	-8.24	-13.94	--	--	--
	11-30-92	-3.24	-7.94	-9.57	--	-14.16	--	--	--
Observation well 4	09-20-95	-3.22	-7.88	-9.74	-1.28	-14.22	-19.00	-4.10	4.54
Observation well 5	09-19-95	-3.14	-8.43	-10.16	-1.60	-14.88	-20.93	-5.23	-0.11
Whipple stock well 1	08-07-91	-2.09	-9.62	-11.34	1.00	-16.45	--	--	--
	09-19-95	-2.69	-10.39	-12.40	-3.12	-17.97	-19.27	-3.20	2.60
Whipple stock well 2	09-21-95	-3.59	-9.20	-11.07	-0.56	-16.03	-20.05	-4.36	1.39
Stock well 2	09-21-95	-3.93	-11.55	-13.17	-3.74	-19.15	-19.88	-4.58	1.35

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	UF_4(c)	$UF_4 \cdot 2.5H_2O$	UO_2(a)	UO_3 (gamma)	Uraninite(c)	Uranophane	Willemite	Zincite (c)
Ghost Hawk Park well	08-07-91	--	--	--	--	--	--	-2.30	-3.21
	11-30-92	-36.00	-26.30	-3.77	-7.15	0.39	-8.39	-2.04	-3.19
	09-20-95	-34.78	-25.33	-4.4	-6.81	0.01	-8.98	-3.37	-3.80
Stock well 1	09-21-95	-35.46	-26.00	-3.53	-6.82	0.87	-8.29	-3.47	-3.87
No Heart domestic well	08-07-91	--	--	--	--	--	--	-4.42	-4.27
	11-30-92	-33.27	-23.60	-3.38	-7.22	0.80	-8.84	-4.17	-4.28
	09-20-95	-33.84	-24.31	-4.49	-7.13	-0.16	-9.18	-4.29	-4.30
Observation well 1	10-02-91	--	--	--	--	--	--	-4.42	-4.34
	11-30-92	-34.45	-24.75	-2.25	-6.81	1.91	-7.75	-2.45	-3.43
	09-20-95	-35.01	-25.49	-3.78	-6.58	0.54	-8.05	-2.83	-3.57
Observation well 6	09-19-95	-35.25	-25.78	-3.55	-6.91	0.83	-8.29	-1.03	-2.65
LaPointe stock well	09-22-95	-34.50	-24.95	-4.03	-6.62	0.27	-8.39	-5.93	-5.12
Whipple domestic well	08-07-91	--	--	--	--	--	--	-3.47	-3.81
	11-30-92	--	--	--	--	--	--	-3.34	-3.75
Hesse domestic well	09-21-95	-34.57	-25.02	-3.81	-6.61	0.50	-8.15	-1.54	-2.93
Stock well 3	09-21-95	-35.24	-25.68	-3.21	-6.82	1.09	-8.30	-4.40	-4.33
Observation well 2	10-02-91	--	--	--	--	--	--	-4.42	-4.32
	11-30-92	-30.38	-20.86	0.21	-6.85	4.54	-8.26	-3.84	-4.02
Observation well 7	09-18-95	-33.59	-24.06	-2.91	-7.05	1.42	-8.87	-3.84	-4.03
Observation well 8	09-18-95	-33.04	-23.47	-0.93	-7.02	3.34	-7.90	-3.95	-4.07
Swimmer domestic well	08-07-91	--	--	--	--	--	--	-4.93	-4.53
Observation well 9	09-18-95	-34.38	-24.90	-3.68	-7.02	0.69	-8.29	-2.45	-3.36
Observation well 3	10-03-91	--	--	--	--	--	--	-3.11	-3.69
	12-01-92	-34.03	-24.51	-2.92	-6.60	1.4	-8.21	-4.45	-4.38
	09-21-95	-35.80	-26.32	-2.76	-6.61	1.61	-7.52	-3.05	-3.68
GMC well	08-07-91	--	--	--	--	--	--	-1.44	-2.79
	11-30-92	--	--	--	--	--	--	-1.37	-2.81
Observation well 4	09-20-95	-33.61	-24.18	-2.48	-7.24	1.94	-9.11	-3.22	-3.73
Observation well 5	09-19-95	-34.80	-25.42	-4.16	-6.98	0.31	-8.80	-1.02	-2.63
Whipple stock well 1	08-07-91	--	--	--	--	--	--	1.22	-1.53
	09-19-95	-35.26	-25.79	-3.39	-6.33	0.98	-7.62	0.62	-1.85
Whipple stock well 2	09-21-95	-35.10	-25.76	-3.78	-6.75	0.74	-8.47	-0.08	-2.15
Stock well 2	09-21-95	-34.79	-25.29	-3.60	-6.91	0.76	-8.90	-5.15	-4.68

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	Zincosite	$Zn(OH)_2$ (a)	Zn_2 $(OH)_2$ SO4	Zn_2 $(OH)_3Cl$	Zn_3 $(AsO_4)_2\cdot$ $2.5H_2O$	Zn_3O $(SO_4)_2$	$Zn_4(OH)_6$ SO_4	$Zn_5(OH)_8$ Cl_2
Ghost Hawk Park well	08-07-91	-13.75	-4.08	-9.49	-10.17	-14.45	-32.62	-13.64	-20.07
	11-30-92	-14.51	-3.62	-9.40	-9.51	-14.55	-34.14	-12.64	-18.29
	09-20-95	-14.40	-4.52	-10.45	-10.74	-15.84	-34.50	-15.50	-21.66
Stock well 1	09-21-95	-15.58	-4.60	-11.71	-11.51	-17.83	-36.94	-16.90	-23.26
No Heart domestic well	08-07-91	-13.78	-5.14	-10.57	-10.53	-15.95	-33.73	-16.85	-21.85
	11-30-92	-14.03	-4.75	-10.07	-9.94	-15.67	-34.28	-15.56	-20.28
	09-20-95	-13.90	-4.94	-10.29	-10.24	-15.37	-34.02	-16.17	-21.06
Observation well 1	10-02-91	-14.81	-5.07	-11.40	-11.86	-17.94	-35.86	-17.54	-24.44
	11-30-92	-14.55	-3.86	-9.68	-9.89	-15.54	-34.45	-13.40	-19.29
	09-20-95	-14.40	-4.21	-10.06	-10.59	-15.50	-34.28	-14.47	-21.04
Observation well 6	09-19-95	-13.87	-3.35	-8.72	-8.04	-14.18	-32.30	-11.41	-15.09
LaPointe stock well	09-22-95	-15.93	-5.73	-13.09	-13.47	-19.61	-38.91	-20.56	-28.33
Whipple domestic well	08-07-91	-13.49	-4.56	-9.60	-10.01	-14.68	-32.68	-14.72	-20.24
	11-30-92	-13.53	-4.50	-9.58	-10.01	-14.48	-32.71	-14.58	-20.17
Hesse domestic well	09-21-95	-13.34	-3.54	-8.30	-9.56	-13.46	-31.52	-11.37	-18.30
Stock well 3	09-21-95	-15.91	-4.94	-12.27	-12.54	-19.26	-38.07	-18.14	-25.67
Observation well 2	10-02-91	-14.66	-4.95	-11.07	-11.59	-16.30	-35.56	-16.97	-23.79
	11-30-92	-14.72	-4.66	-10.84	-11.13	-20.10	-35.38	-16.16	-22.57
Observation well 7	09-18-95	-15.11	-4.67	-11.23	-11.84	-16.65	-36.17	-16.56	-24.00
Observation well 8	09-18-95	-15.49	-4.65	-11.53	-11.88	-18.81	-36.96	-16.83	-24.06
Swimmer domestic well	08-07-91	-14.12	-5.40	-11.17	-11.64	-16.49	-34.66	-17.96	-24.33
Observation well 9	09-18-95	-15.50	-4.05	-11.05	-11.21	-16.30	-36.26	-15.16	-22.11
Observation well 3	10-03-91	-14.70	-4.33	-10.47	-10.29	-16.91	-35.00	-15.13	-20.56
	12-01-92	-15.53	-5.01	-11.99	-11.93	-19.69	-37.35	-18.02	-24.53
	09-21-95	-16.07	-4.38	-11.95	-11.45	-18.25	-37.73	-16.70	-22.93
GMC well	08-07-91	-14.61	-3.74	-10.07	-9.82	-15.04	-33.89	-13.55	-19.04
	11-30-92	-15.02	-3.48	-9.98	-9.54	-15.23	-34.77	-12.94	-18.21
Observation well 4	09-20-95	-15.34	-4.48	-11.38	-11.69	-17.09	-36.32	-16.35	-23.51
Observation well 5	09-19-95	-14.51	-3.44	-9.55	-9.78	-13.62	-33.55	-12.44	-18.66
Whipple stock well 1	08-07-91	-13.03	-2.34	-6.97	-7.40	-10.84	-29.50	-7.65	-12.79
	09-19-95	-12.82	-2.54	-6.87	-7.09	-10.89	-29.40	-7.96	-12.37
Whipple stock well 2	09-21-95	-13.54	-3.02	-8.22	-8.72	-12.73	-31.13	-10.26	-16.12
Stock well 2	09-21-95	-16.05	-5.35	-12.87	-13.07	-20.00	-38.7	-19.57	-27.13

Table 13. Mineral saturation indices calculated using PHREEQC—Continued

Well name	Date	$ZnCl_2$	$ZnCO_3 \cdot H_2O$	ZnF_2	Zn metal	ZnO (a)	$ZnSiO_3$	$ZnSO_4 \cdot H_2O$
Ghost Hawk Park well	08-07-91	-22.44	-1.63	-14.67	-33.62	-2.94	2.03	-10.00
	11-30-92	-22.83	-1.66	-15.27	-33.84	-2.48	2.14	-10.58
	09-20-95	-22.36	-2.11	-15.20	-34.50	-3.38	1.51	-10.59
Stock well 1	09-21-95	-23.67	-3.09	-16.04	-60.98	-3.46	1.48	-11.77
No Heart domestic well	08-07-91	-19.98	-2.51	-15.05	-60.62	-4.00	0.98	-10.03
	11-30-92	-20.31	-2.34	-15.22	-34.38	-3.60	1.11	-10.12
	09-20-95	-20.18	-2.37	-15.11	-35.05	-3.80	1.06	-10.06
Observation well 1	10-02-91	-22.97	-2.92	-15.93	-61.30	-3.93	1.00	-11.00
	11-30-92	-22.88	-2.09	-15.49	-32.90	-2.72	1.96	-10.62
	09-20-95	-23.08	-2.21	-15.32	-34.16	-3.07	1.79	-10.56
Observation well 6	09-19-95	-20.52	-1.83	-14.68	-32.49	-2.21	2.69	-10.05
LaPointe stock well	09-22-95	-24.28	-3.62	-16.46	-36.01	-4.59	0.23	-12.08
Whipple domestic well	08-07-91	-20.77	-2.14	-14.62	-33.20	-3.42	1.42	-9.69
	11-30-92	-20.95	-2.21	-14.55	-33.15	-3.36	1.49	-9.73
Hesse domestic well	09-21-95	-23.04	-1.72	-14.42	-33.60	-2.40	2.44	-9.48
Stock well 3	09-21-95	-24.82	-3.43	-16.45	-34.20	-3.80	0.97	-12.06
Observation well 2	10-02-91	-22.85	-2.80	-15.34	-60.65	-3.81	0.95	-10.82
	11-30-92	-22.79	-2.64	-15.45	-30.36	-3.52	1.24	-10.88
Observation well 7	09-18-95	-24.19	-3.08	-15.50	-33.27	-3.53	1.24	-11.27
Observation well 8	09-18-95	-24.38	-3.09	-16.21	-31.55	-3.51	1.15	-11.62
Swimmer domestic well	08-07-91	-21.43	-2.52	-15.01	-59.98	-4.26	0.72	-10.37
Observation well 9	09-18-95	-24.73	-3.05	-14.88	-33.22	-2.91	1.98	-11.68
Observation well 3	10-03-91	-22.13	-2.57	-15.43	-61.06	-3.19	1.63	-10.86
	12-01-92	-23.34	-3.29	-16.06	-34.08	-3.87	0.98	-11.68
	09-21-95	-24.24	-3.09	-16.38	-33.04	-3.24	1.70	-12.25
GMC well	08-07-91	-22.69	-2.42	-14.75	-58.75	-2.60	2.49	-10.89
	11-30-92	-23.13	-2.45	-15.06	-30.62	-2.34	2.51	-11.19
Observation well 4	09-20-95	-24.35	-3.09	-15.52	-32.00	-3.34	1.59	-11.55
Observation well 5	09-19-95	-23.62	-2.18	-14.23	-32.65	-2.30	2.71	-10.74
Whipple stock well 1	08-07-91	-22.17	-0.69	-13.69	-58.30	-1.20	3.86	-9.26
	09-19-95	-21.01	-0.66	-13.96	-32.12	-1.40	3.53	-9.00
Whipple stock well 2	09-21-95	-22.71	-1.40	-14.14	-31.85	-1.88	3.20	-9.79
Stock well 2	09-21-95	-24.60	-3.47	-16.43	-34.66	-4.21	0.59	-12.22

Table 14. Significant (α equal 0.10) Spearman rank correlations between arsenic constituents and selected properties, constituents, and mineral saturation indices for ground-water, surface-water, and bed-sediment samples

Constituent	Number of samples	Correlation coefficient	P-value
Significant positive correlations between dissolved arsenic and selected constituents or properties for ground-water samples			
Fluoride	26	0.94	0.0000
Sodium	26	0.82	0.0000
Sulfate	26	0.79	0.0000
Vanadium	17	0.66	0.0038
Dissolved solids	26	0.60	0.0012
Alkalinity	17	0.56	0.0199
Specific conductance	33	0.52	0.0019
Molybdenum	17	0.52	0.0341
Bicarbonate	17	0.43	0.0890
Chloride	26	0.39	0.0469
pH	33	0.37	0.0333
Significant negative correlations between dissolved arsenic and selected constituents or properties for ground-water samples			
Dissolved oxygen	15	-0.61	0.0159
Oxidation-reduction potential calculated from arsenic speciation data	24	-0.53	0.0073
Oxidation-reduction potential calculated from dissolved oxygen data	22	-0.49	0.0214
Magnesium	26	-0.41	0.0364
Significant positive correlations between arsenite (As^{+3}) and selected constituents or properties for ground-water samples			
Specific conductance	24	0.49	0.0157
Alkalinity	17	0.47	0.0591
Bicarbonate	17	0.47	0.0599
Sulfate	17	0.46	0.0657
Manganese	17	0.45	0.0698
Dissolved solids	17	0.42	0.0901
Molybdenum	17	0.41	0.0995
Significant negative correlations between arsenite (As^{+3}) and selected constituents or properties for ground-water samples			
Dissolved oxygen	15	-0.69	0.0041
Silica	17	-0.56	0.0199
Oxidation reduction potential calculated from arsenic speciation data	24	-0.51	0.0110
Oxidation reduction potential (field)	17	-0.50	0.0429
Significant positive correlations between dissolved arsenic and selected constituents for surface-water samples			
Magnesium	17	0.44	0.0784
Significant negative correlations between dissolved arsenic and selected constituents for surface-water samples			
pH	17	-0.42	0.0927
Significant positive correlations between dissolved arsenic and selected constituents for surface-water bed-sediment samples			
Manganese	9	0.70	0.0161
Gallium	9	0.58	0.0624
Zinc	9	0.54	0.0841

Table 14. Significant (α equal 0.10) Spearman rank correlations between arsenic constituents and selected properties, constituents, and mineral saturation indices for ground-water, surface-water, and bed-sediment samples—Continued

Constituent	Number of samples	Correlation coefficient	P-value
Significant negative correlations between dissolved arsenic and selected constituents for surface-water bed-sediment samples			
Sodium	9	-0.82	0.0021
Lanthanum	9	-0.74	0.0099
Potassium	9	-0.65	0.0321
Strontium	9	-0.64	0.0326
Significant positive correlations between dissolved arsenic and mineral saturation indices for ground-water samples			
Thermonatrite [$NaCO_3\cdot H_2O$]	33	0.84	0.0000
Thenardite [Na_2SO_4]	33	0.80	0.0000
Trona [$Na_2CO_3\cdot HNaCO_3\cdot 2H_2O$]	33	0.80	0.0000
Fluorite [CaF_2]	33	0.79	0.0000
Natron [$Na_2CO_3\cdot 10H_2O$]	33	0.79	0.0000
Mirabilite [$Na_2SO4\cdot 10H_2O$]	33	0.79	0.0000
$Na_4UO_2(CO_3)_3$	22	0.79	0.0000
Nahcolite [$NaHCO_3$]	33	0.71	0.0000
$Ca_3(AsO_4)_2\cdot 4H_20$	33	0.66	0.0000
$Mn_3(AsO_4)\cdot 8H_20$	33	0.61	0.0002
Halite [NaCl]	33	0.59	0.0003
$MnSO_4$	33	0.53	0.0016
Copper metal	33	0.52	0.0018
CuF	33	0.51	0.0025
Magadiite [$NaSi_7O_{13}(OH)_3\cdot 3H_2O$]	33	0.50	0.0030
Pyrochroite [$Mn(OH)_2$]	33	0.49	0.0037
Rhodochrosite [$MnCO_3$]	33	0.45	0.0092
Hausmannite [Mn_3O_4]	33	0.43	0.0135
UF_4	22	0.43	0.0470
Portlandite [$Ca(OH)_2$]	33	0.42	0.0149
H_2 (gas)	33	0.41	0.0178
$FeSe_2$	33	0.41	0.0189
$UF_4\cdot 2.5H_2O$	22	0.40	0.0667
Cu_2SO_4	33	0.39	0.0244
Se (solid)	32	0.38	0.0301
Melanterite [$FeSO_4\cdot 7H_20$]	33	0.36	0.0383
Cupprite [Cu_2O]	33	0.35	0.0470
Bixbyite [$(Mn,Fe)_2O_3$]	33	0.34	0.0471
$MnCl_2\cdot 4H_20$	33	0.33	0.0581
Arsenolite [As_2O_3]	33	0.33	0.0636
Manganite [$MnO(OH)$]	33	0.32	0.0680
Claudetite [As_2O_3]	33	0.32	0.0695
Siderite [$FeCO_3$]	33	0.31	0.0768
ZnF_2	33	0.30	0.0874

Table 14. Significant (α equal 0.10) Spearman rank correlations between arsenic constituents and selected properties, constituents, and mineral saturation indices for ground-water, surface-water, and bed-sediment samples—Continued

Constituent	Number of samples	Correlation coefficient	P-value
Significant negative correlations between dissolved arsenic and mineral saturation indices for ground-water samples			
Schoepite [$UO_3 \cdot 2H_2O$]	22	-0.73	0.0001
$BUO_2(OH)_2$	22	-0.71	0.0002
UO_3 gamma	22	-0.67	0.0006
Gummite [$Pb_2U_5O_{17} \cdot 4H_2O$]	21	-0.62	0.0027
O_2 (gas)	33	-0.49	0.0037
Rutherfordine [UO_2CO_3]	24	-0.45	0.0290
Quartz [SiO_2]	33	-0.32	0.0727
Cristobalite [SiO_2]	33	-0.30	0.0846
Chalcedony [SiO_2]	33	-0.30	0.0881
Significant positive correlations between arsenite (As^{+3}) and mineral saturation indices for ground-water samples			
Arsenolite [As_2O_3]	24	0.84	0.0000
Claudetite [As_2O_3]	24	0.84	0.0000
Se (solid)	24	0.82	0.0000
$FeSe_2$	24	0.77	0.0000
$U(OH)_2SO_4$	22	0.76	0.0000
$UF_4 \cdot 2.5H_2O$	22	0.76	0.0001
UF_4	22	0.74	0.0001
H_2 (gas)	24	0.73	0.0000
UO_2	22	0.72	0.0002
Coffinite [$U(SiO_4)_{1-x}(OH)_{4x}$]	22	0.69	0.0004
Copper metal	24	0.67	0.0004
Uraninite [UO_2]	22	0.67	0.0006
U_4O_9	22	0.63	0.0018
Melanterite [$FeSO_4 \cdot 7H_20$]	24	0.57	0.0036
Fluorite [CaF_2]	24	0.56	0.0047
$MnSO_4$	24	0.56	0.0047
$MnCl_2 \cdot 4H_20$	24	0.55	0.0053
Zinc metal	24	0.53	0.0079
Anhydrite [$CaSO_4$]	24	0.50	0.0128
Gypsum [$CaSO4 \cdot 2H_20$]	24	0.50	0.0129
Aragonite [$CaCO_3$]	24	0.50	0.0131
Calcite [$CaCO_3$]	24	0.50	0.0131
Epsomite [$MgSO_4 \cdot 7H_2O$]	23	0.47	0.0254
$Mn_3(AsO_4) \cdot 8H_2O$	24	0.46	0.0248
Rhodochrosite [$MnCO_3$]	24	0.45	0.0274
U_3O_8	22	0.45	0.0342
Mirabilite [$Na_2SO4 \cdot 10H_2O$]	24	0.44	0.0329
Pyrochroite [$Mn(OH)_2$]	24	0.40	0.0535

Table 14. Significant (α equal 0.10) Spearman rank correlations between arsenic constituents and selected properties, constituents, and mineral saturation indices for ground-water, surface-water, and bed-sediment samples—Continued

Constituent	Number of samples	Correlation coefficient	P-value
Significant positive correlations between arsenite (As^{+3}) and mineral saturation indices for ground-water samples—Continued			
$Ca_3(AsO_4)_2 \cdot 4H_2O$]	24	0.39	0.0580
Thenardite [Na_2SO_4]	24	0.38	0.0684
Nahcolite [$NaHCO_3$]	24	0.37	0.0790
Halite [NaCl]	24	0.37	0.0793
Significant negative correlations between arsenite (As^{+3}) and mineral saturation indices for ground-water samples			
O_2 (gas)	24	-0.76	0.0000
$Fe_2(SeO_3)_3$	24	-0.57	0.0040
Gummite [$Pb_2U_5O_{17} \cdot 4H_2O$]	21	-0.49	0.0246
Dioptase [$CuSiO_3 \cdot H_2O$]	24	-0.47	0.0211
UO_3 gamma	22	-0.47	0.0274
Quartz [SiO_2]	24	-0.43	0.0362
Pyrolusite [MnO_2]	24	-0.43	0.0375
Chalcedony [SiO_2]	24	-0.42	0.0399
$Cu(OH)_2$	24	-0.42	0.0399
Tenorite [CuO]	24	-0.42	0.0399
SiO_2	24	-0.42	0.0412
Cristobalite [SiO_2]	24	-0.42	0.0431
$BUO_2(OH)_2$	22	-0.42	0.0493
Schoepite [$UO_3 \cdot 2H_2O$]	22	-0.41	0.0552
Cupric Ferrite	24	-0.39	0.0580
Nsutite [$Mn(OH)_2$]	24	-0.39	0.0624
Birnessite [$(Na,Ca,K)(Mg,Mn)Mn_6O_{14} \cdot 5H_2O$]	24	-0.39	0.0625
SeO_2	24	-0.36	0.0795
$CuCO_3$	24	-0.36	0.0816
Malachite [$Cu_2CO_3(OH)_2$]	24	-0.35	0.0955

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