Water-Chemistry Data for Selected Springs, Geysers, and Streams in Yellowstone National Park, Wyoming, 2006–2008

Open-File Report 2010–1192

U.S. Department of the Interior
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Front Cover Photography: View taken in 2006 of an unnamed hot spring in the Rabbit Creek area, Yellowstone National Park.

Back Cover Photography: View taken in 2006 of an unnamed hot spring near Perpetual Spouter, Norris Geyser Basin, Yellowstone National Park

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By James W. Ball, R. Blaine McCleskey, and D. Kirk Nordstrom

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
nanometer (nm)	0.00000003937	inch (in.)
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Volume	
microliter (µL)	0.0000338	ounce, fluid (fl. oz)
milliliter (mL)	0.0338	ounce, fluid (fl. oz)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Mass	
nanogram (ng)	0.00000000003527	ounce, avoirdupois (oz)
microgram (µg)	0.00000003527	ounce, avoirdupois (oz)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Density	
kilogram per cubic meter (kg/m^3)	0.06242	pound per cubic foot (lb/ft^3)
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8
Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27)

Water-Chemistry Data for Selected Springs, Geysers, and Streams in Yellowstone National Park, Wyoming, 2006–2008

By James W. Ball, R. Blaine McCleskey, and D. Kirk Nordstrom

Abstract

Water analyses are reported for 104 samples collected from numerous thermal and non-thermal features in Yellowstone National Park (YNP) during 2006–2008. Water samples were collected and analyzed for major and trace constituents from 10 areas of YNP including Apollinaris Spring and Nymphy Creek along the Norris-Mammoth corridor, Beryl Spring in Gibbon Canyon, Norris Geyser Basin, Lower Geyser Basin, Crater Hills, the Geyser Springs Group, Nez Perce Creek, Rabbit Creek, the Mud Volcano area, and Washburn Hot Springs. These water samples were collected and analyzed as part of research investigations in YNP on arsenic, antimony, iron, nitrogen, and sulfur redox species in hot springs and overflow drainages, and the occurrence and distribution of dissolved mercury. Most samples were analyzed for major cations and anions, trace metals, redox species of antimony, arsenic, iron, nitrogen, and sulfur, and isotopes of hydrogen and oxygen. Analyses were performed at the sampling site, in an on-site mobile laboratory vehicle, or later in a U.S. Geological Survey laboratory, depending on stability of the constituent and whether it could be preserved effectively.

Water samples were filtered and preserved on-site. Water temperature, specific conductance, pH, emf (electromotive force or electrical potential), and dissolved hydrogen sulfide were measured on-site at the time of sampling. Dissolved hydrogen sulfide was measured a few to several hours after sample collection by ion-specific electrode on samples preserved on-site. Acidity was determined by titration, usually within a few days of sample collection. Alkalinity was determined by titration within 1 to 2 weeks of sample collection. Concentrations of thiosulfate and polythionate were determined as soon as possible (generally a few to several hours after sample collection) by ion chromatography in an on-site mobile laboratory vehicle. Total dissolved iron and ferrous iron concentrations often were measured on-site in the mobile laboratory vehicle.

Concentrations of dissolved aluminum, arsenic, boron, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, potassium, lithium, magnesium, manganese, molybdenum, sodium, nickel, lead, selenium, silica, strontium, vanadium, and zinc were determined by inductively coupled plasma–optical emission spectrometry. Trace concentrations of dissolved antimony, cadmium, cobalt, chromium, copper, lead, and selenium were determined by Zeeman-corrected graphite-furnace atomic-absorption spectrometry. Dissolved concentrations of total arsenic, arsenite, total antimony, and antimonite were determined by hydride generation atomic-absorption spectrometry using a flow-injection analysis system. Dissolved concentrations of total mercury and methylmercury were determined by cold-vapor atomic fluorescence spectrometry. Concentrations of dissolved chloride, fluoride, nitrate, bromide, and sulfate were determined by ion chromatography. For many samples, concentrations of dissolved fluoride also

were determined by ion-specific electrode. Concentrations of dissolved ferrous and total iron were determined by the FerroZine colorimetric method. Concentrations of dissolved ammonium were determined by ion chromatography, with reanalysis by colorimetry when separation of sodium and ammonia peaks was poor. Dissolved organic carbon concentrations were determined by the wet persulfate oxidation method. Hydrogen and oxygen isotope ratios were determined using the hydrogen and CO_2 equilibration techniques, respectively.

Introduction

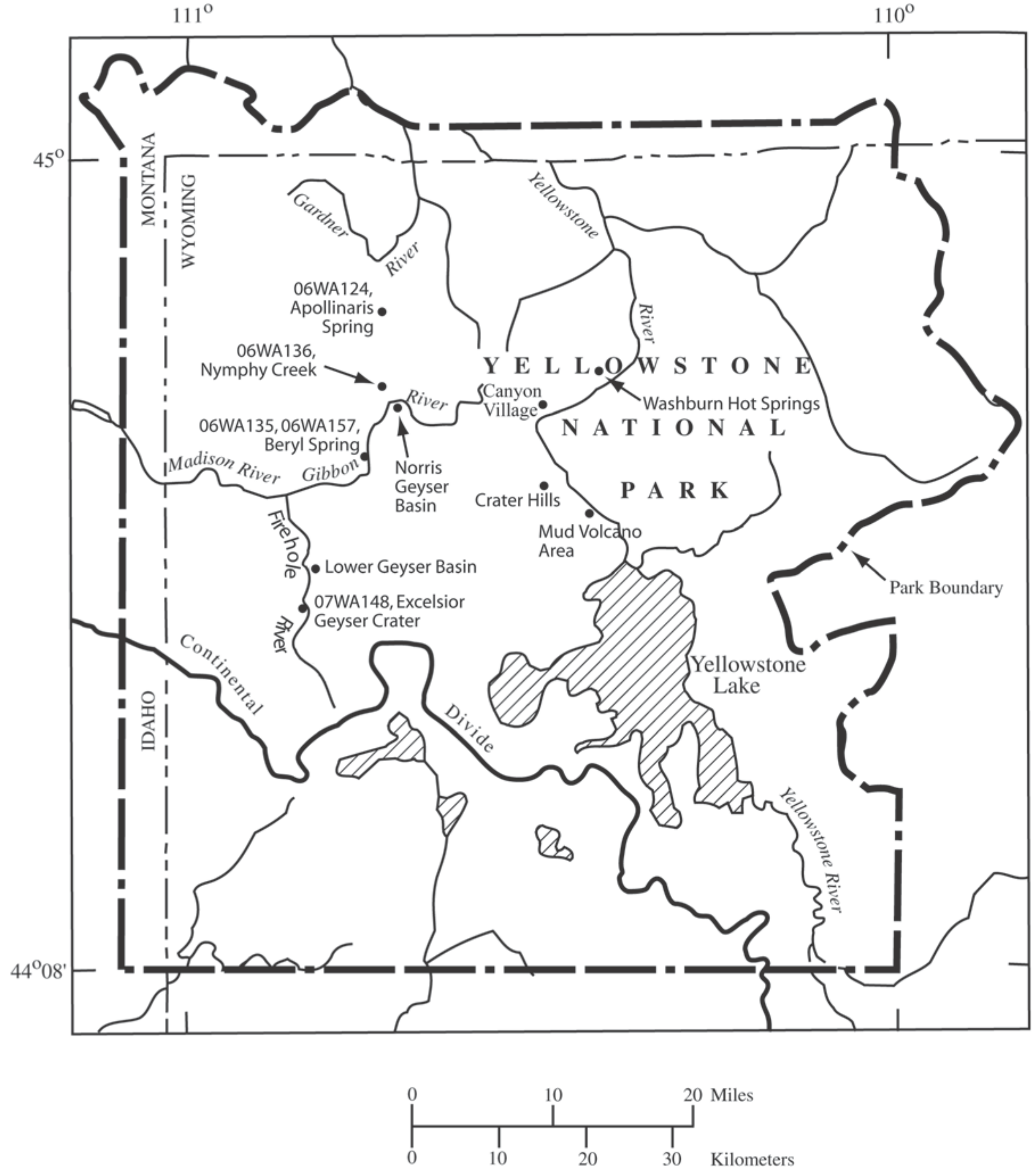
Investigations into the water chemistry of hot springs, geysers, streams, and rivers in Yellowstone National Park (YNP) have been conducted by the U.S. Geological Survey (USGS) and other earth-science organizations and academic institutions dating back to 1888. A list of publications that report results of these investigations is presented in table 1 of Ball and others (2006). Waters at YNP have pH values ranging from about 1 to 10, temperatures from ambient to about 95 degrees Celsius (°C; 93°C is boiling at YNP's altitude; some pools are superheated), and high concentrations of silica, arsenic, boron, fluoride, hydrogen sulfide, lithium, sulfate, and alkalinity relative to most natural waters. Numerous redox reactions and mineral-precipitation reactions occur. In addition to being valuable natural resources and tourist attractions, active geothermal areas such as those in YNP provide insight into formation of mineral deposits, microbiological processes in extreme environments, and water-rock interactions.

Purpose and Scope

The purpose of this report is to: (1) provide water-chemistry data from numerous sample sites in YNP for 2006–2008; (2) describe methods used to collect and analyze the samples; (3) describe quality-assurance and quality-control procedures; and (4) supplement interpretive reports. The samples were collected during four field trips to YNP: May and September 2006, September 2007, and September 2008. The primary purpose of the field trips was to study and interpret the geochemical processes (including mineral precipitation) affecting redox species of antimony, arsenic, iron, nitrogen, and sulfur in mineral springs and geothermal waters and their drainages. The evolution and chemical composition of several newly developed hydrothermal features of the Ragged Hills area of Norris Geyser Basin and the occurrence and distribution of total dissolved mercury and methylmercury in geothermal waters also was studied during these field trips. Several papers have been published on earlier phases of this project and of other collaborative research efforts (Xu and Schoonen, 1995; Xu and others, 1996; 1998; 2000; McCleskey and others, 2004; Ball and others, 1998a, b; 2001; 2002; 2006; Nordstrom and others, 2005; King and others, 2006; Planer-Friedrich and others, 2007; Boyd and others, 2009; Nordstrom and others, 2009; Sherman and others, 2009).

During 2006–2008, 104 water samples were collected from YNP (fig. 1). Five individual samples were collected from Apollinaris Spring and Nymphy Creek along the Norris-Mammoth corridor, Beryl Spring near Gibbon Canyon, and Excelsior Geyser Crater at Midway Geyser Basin. The remaining 99 samples were collected from eight areas of YNP: Norris Geyser Basin, Crater Hills, the Geyser Springs Group, Lower Geyser Basin, Porcupine Hills, Rabbit Creek, Mud Volcano, and Washburn Hot Springs. Thirty-five analyses are reported for samples collected for May–June 2006, 20 analyses are reported for September 2006, 21 analyses are reported for September 2007, and 28 analyses are reported for September 2008. Constituents determined include dissolved concentrations of calcium (Ca), magnesium (Mg), strontium (Sr), barium (Ba), sodium (Na), potassium (K), lithium (Li), sulfate (SO_4), thiosulfate (S_2O_3), polythionate (S_nO_6), hydrogen sulfide (H_2S), alkalinity (as HCO_3), acidity, fluoride (F), chloride

(Cl), bromide (Br), nitrate (NO_3), ammonium (NH_4), silica (SiO_2), boron (B), aluminum (Al), total iron (Fe(T)), ferrous iron (Fe(II)), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), cobalt (Co), total mercury (Hg(T)), methylmercury (CH_3Hg), nickel (Ni), lead (Pb), beryllium (Be), vanadium (V), molybdenum (Mo), total antimony (Sb(T)), antimonite (Sb(III)), selenium (Se), total arsenic (As(T)), arsenite (As(III)), dissolved organic carbon (DOC), and isotopes of hydrogen (δD) and oxygen ($\delta^{18}O$).



Base from Stauffer and others (1980)

Figure 1. Location of sampling areas in Yellowstone National Park, Wyoming.

Methods of Sample Collection, Preservation, and Analysis

Sample Locations

Because many geothermal features can be within meters of each other, it is critical that sample sites be accurately located and described. To this end, we have made every effort to include detailed maps (figs. 2–12), written descriptions and accurate latitude and longitude measurements (table 1), and photographs (Appendix) of all the sample sites for which analytical results are reported.

The locations of sampling areas in YNP, and for Apollinaris and Beryl Springs, Excelsior Geyser Crater, and Nymphy Creek, are shown on figure 1. Sample locations for the remaining eight areas sampled are shown on the following maps: Norris Geyser Basin (figs. 2–5), West Nymph Creek Thermal Area (fig. 6), Crater Hills (fig. 7), the Geyser Springs Group (fig. 8), Lower Geyser Basin (fig. 9), the Porcupine Hills area (fig. 10), the Rabbit Creek thermal area (fig. 11), the Mud Volcano area (fig. 12) and Washburn Hot Springs (fig. 13). Official names are taken from either the Geographic Names Information System (GNIS; http://geonames.usgs.gov/) or Whittlesey (1988). Several features that did not have official names were assigned names by the authors for project purposes. Features named by the authors are in quotations in tables 1 and 5–14.

For terminology in this report, “source” samples were collected at the origin of the spring, and overflow “drainage channel” samples were collected at various distances downstream from the source. Series of transect samples were collected in the overflow drainage channels from Ojo Caliente Spring, “Succession Spring” in the Ragged Hills area of Norris Geyser Basin, and drainage channels from two unnamed hot springs in the Rabbit Creek area. Latitudes and longitudes were acquired using a portable global positioning system (GPS; Garmin III+ or Garmin Rino 530) with latitudes and longitudes referenced to the NAD27 datum (North American Datum of 1927), compatible with USGS topographic maps.

Sample Collection and Preservation

Samples were collected from streams, tributaries, and overflow drainage channels as close to the center of flow as possible and in areas that appeared to be well mixed. For springs and geysers, samples were collected as close to the discharge source as possible. Extreme care was taken to safely collect water samples from the geothermal sites, to protect fragile hot-spring mineral formations, and to minimize changes in temperature, pH, and water chemistry during sampling. Samples were collected from the middle of large pools and geysers by positioning the sample tubing intake using an insulated stainless-steel container as a flotation device attached to the end of an extendable aluminum pole. At more easily accessible sites, the tubing intake was positioned in the source or channel by hand. A Teflon block attached to the end of the sampling tubing was used as a weight to keep the sample tubing in place (McCleskey and others, 2004).

Samples were collected and filtered on-site by either or both of two techniques. The first technique consisted of pumping the water directly from the source with a battery-operated peristaltic pump fitted with medical-grade silicone tubing through a pre-cleaned 142-millimeter (mm) diameter all-plastic filter holder (Kennedy and others, 1976) containing a 0.1-micrometer (µm) pore size mixed-cellulose-ester filter membrane. The second technique consisted of filling a 60-milliliter (mL) syringe by suctioning from the source, rinsing three times, and immediately forcing the water through a 25-mm disposable filter having a mixed-cellulose-ester membrane with a pore size of 0.2 or 0.45 µm.

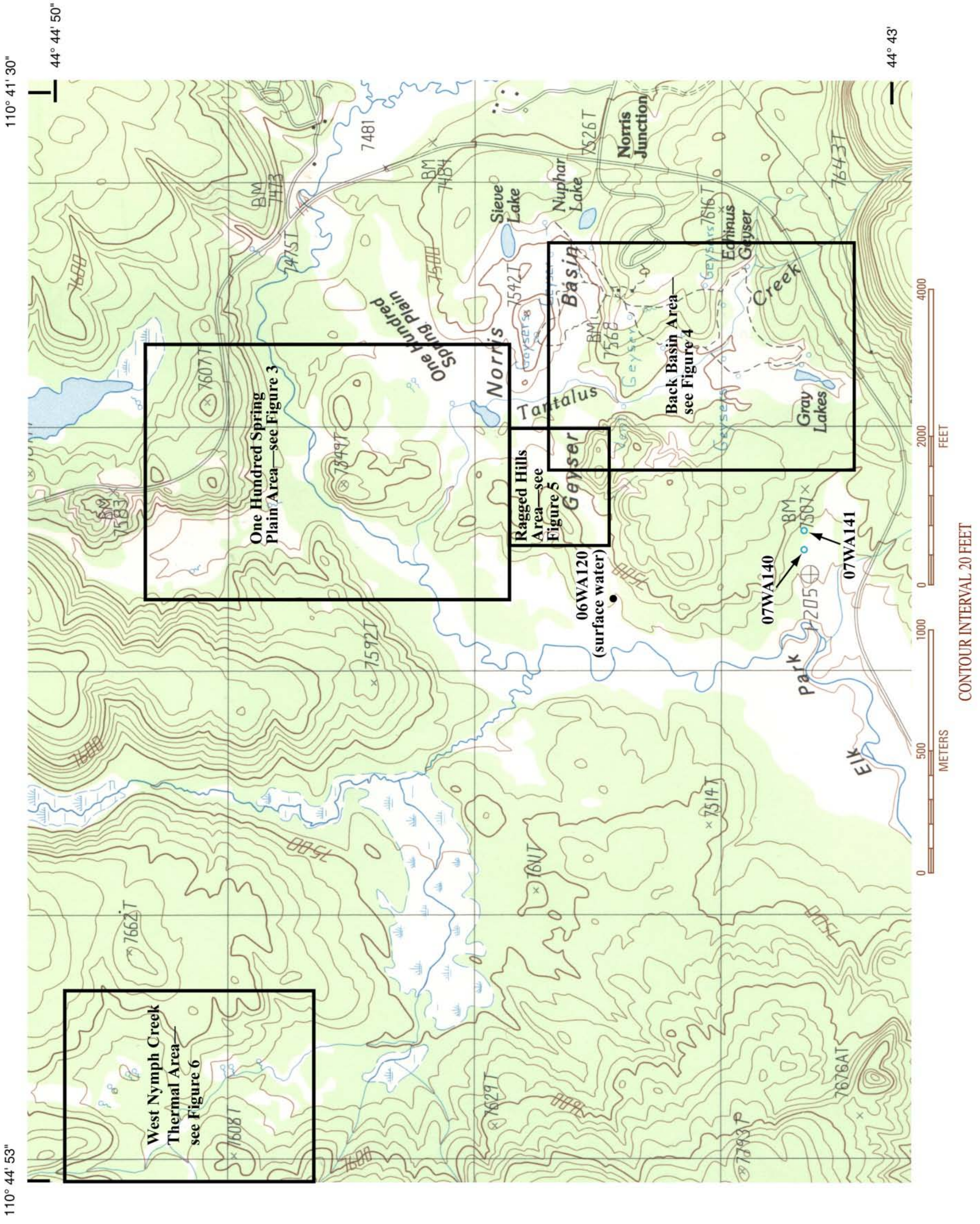
Table 1. Detailed sample site descriptions, locations, map, photograph, and chemical data table reference.

[--, not measured or not photographed; cm, centimeters; m, meters]

Name and Site Description	Sample code number	North Latitude	West Longitude	Chemical data (table)	Map (figure)	Photograph (appendix)
Norris-Mammoth Corridor						
Apollinaris Spring	06WA124	44° 50' 34.0"	110° 43' 57.8"	5	1	24
Nymphy Creek	06WA136	44° 45' 12.5"	110° 43' 33.5"	5	1	35
West Nymph Creek Thermal Area						
Uppermost pool, West Nymph Creek Thermal Area	08WA118	44° 44' 44.4"	110° 44' 40.4"	5	6	80
Sunken circular pool, West Nymph Creek Thermal Area	08WA119	44° 44' 34.6"	110° 44' 40.5"	5	6	81
Norris Geyser Basin (One Hundred Spring Plain area)						
Cinder Pool	07WA113	44° 43' 57.2"	110° 42' 35.6"	6	3	61
Realgar Creek at mouth	06WA106	44° 44' 16.8"	110° 42' 32.7"	6	3	1
Realgar Creek at mouth	06WA139	44° 44' 16.8"	110° 42' 32.7"	6	3	36
Tantalus Creek at weir	06WA107	44° 44' 2.7"	110° 42' 54.6"	6	3	2
Tantalus Creek at weir	06WA158	44° 44' 2.7"	110° 42' 54.6"	6	3	39
Tantalus Creek at weir	08WA105	44° 44' 2.7"	110° 42' 54.6"	6	3	73
Unnamed hot spring northeast of Cinder Pool	06WA109	44° 43' 59.1"	110° 42' 29.3"	6	3	4
Norris Geyser Basin (Back Basin area)						
Cistern Spring	06WA123	44° 43' 23.4"	110° 42' 14.8"	6	4	23
Cistern Spring	06WA159	44° 43' 23.4"	110° 42' 14.8"	6	4	40
Cistern Spring	07WA116	44° 43' 23.4"	110° 42' 14.8"	6	4	64
Cistern Spring	08WA127	44° 43' 23.4"	110° 42' 14.8"	6	4	89
Echinus Geyser	08WA126	44° 43' 20.0"	110° 42' 4.8"	6	4	88
Perpetual Spouter	06WA132	44° 43' 35.7"	110° 42' 32.7"	6	4	31
Perpetual Spouter	07WA144	44° 43' 35.7"	110° 42' 32.7"	6	4	69
Perpetual Spouter	08WA130	44° 43' 35.7"	110° 42' 32.7"	6	4	92
Porkchop Geyser	07WA143	44° 43' 20.0"	110° 42' 26.6"	6	4	68
Porkchop Geyser	08WA129	44° 43' 20.0"	110° 42' 26.6"	6	4	91
Second Erupter	06WA122	44° 43' 20.2"	110° 42' 24.5"	6	4	22
Second Erupter	07WA142	44° 43' 20.2"	110° 42' 24.5"	6	4	67
Second Erupter	08WA128	44° 43' 20.3"	110° 42' 24.2"	6	4	90
Tantalus Creek - Back Basin Drainage	06WA134	44° 43' 35.4"	110° 42' 29.9"	6	4	33
Unnamed acid spring next To Perpetual Spouter	06WA133	44° 43' 35.5"	110° 42' 33.1"	6	4	32
Unnamed acid spring next To Perpetual Spouter	07WA145	44° 43' 35.5"	110° 42' 33.1"	6	4	70
Unnamed hot spring, north end of Elk Park	07WA140	44° 43' 11.7"	110° 42' 56.7"	6	2	65
Unnamed hot spring, north end of Elk Park near 07WA140	07WA141	44° 43' 11.7"	110° 42' 53.4"	6	2	66
Norris Geyser Basin (Ragged Hills area)						
Appendage side spring to "Lifeboat Spring"	08WA124	44° 43' 39.8"	110° 42' 49.8"	6	5	86
Circular clay hot spring 2 meters from 08WA121	08WA123	44° 43' 44.3"	110° 42' 41.5"	6	5	85
Crystal Spring - eastern side	06WA112	44° 43' 43.6"	110° 42' 40.1"	6	5	6
Crystal Spring - eastern side	07WA147	44° 43' 43.6"	110° 42' 40.1"	6	5	71
Crystal Spring - western side	06WA111	44° 43' 43.7"	110° 42' 40.2"	6	5	6
Crystal Spring - western side	07WA146	44° 43' 43.7"	110° 42' 40.2"	6	5	71
Crystal Spring - western side	08WA120	44° 43' 43.7"	110° 42' 40.2"	6	5	82
The Gap northeast outflow	06WA121	44° 43' 45.2"	110° 42' 40.5"	6	5	21
The Gap southwest outflow	06WA120	44° 43' 37.0"	110° 43' 6.0"	6	2	20
Hot Spring next to "Orpiment Puddle 2"	07WA107	44° 43' 44.3"	110°42'41.6"	6	5	55
"Kaolin Spring"	07WA106	44° 43' 41.8"	110° 42' 44.7"	6	5	54
"Kaolin Spring"	08WA131	44° 43' 41.8"	110° 42' 44.7"	6	5	93
"Lifeboat Spring"	06WA118	44° 43' 39.5"	110° 42' 48.2"	6	5	18
"Lifeboat Spring"	07WA115	44° 43' 39.5"	110° 42' 48.2"	6	5	63
"Lifeboat Spring"	08WA125	44° 43' 39.5"	110° 42' 48.2"	6	5	87
"Orpiment Puddle 3"	06WA110	44° 43' 44.4"	110° 42' 41.6"	6	5	5
"Persnickety Geyser"	06WA119	44° 43' 40.1"	110° 42' 49.9"	6	5	19
"Persnickety Geyser"	07WA105	44° 43' 40.1"	110° 42' 49.9"	6	5	53
"Succession Spring"	06WA126	44° 43' 45.8"	110° 42' 41.9"	6	5	26
"Succession Spring" drainage channel	06WA127	44° 43' 45.8"	110° 42' 41.8"	6	5	27
"Succession Spring" drainage channel	06WA128	44° 43' 46.0"	110° 42' 41.6"	6	5	28
"Succession Spring" drainage channel	06WA129	44° 43' 46.0"	110° 42' 41.5"	6	5	29
"Succession Spring" drainage channel	06WA130	44° 43' 46.1"	110° 42' 41.4"	6	5	29
"Succession Spring" mat	06WA131	44° 43' 46.2"	110° 42' 41.2"	6	5	30
"Titanic Spring"	06WA117	44° 43' 39.4"	110° 42' 50.9"	6	5	17
"Titanic Spring"	07WA114	44° 43' 39.4"	110° 42' 50.9"	6	5	62
Unnamed pool near The Gap	08WA121	44° 43' 44.3"	110° 42' 41.5"	6	5	83
Unnamed pool near "Succession Spring"	06WA125	44° 43' 44.3"	110° 42' 44.5"	6	5	25

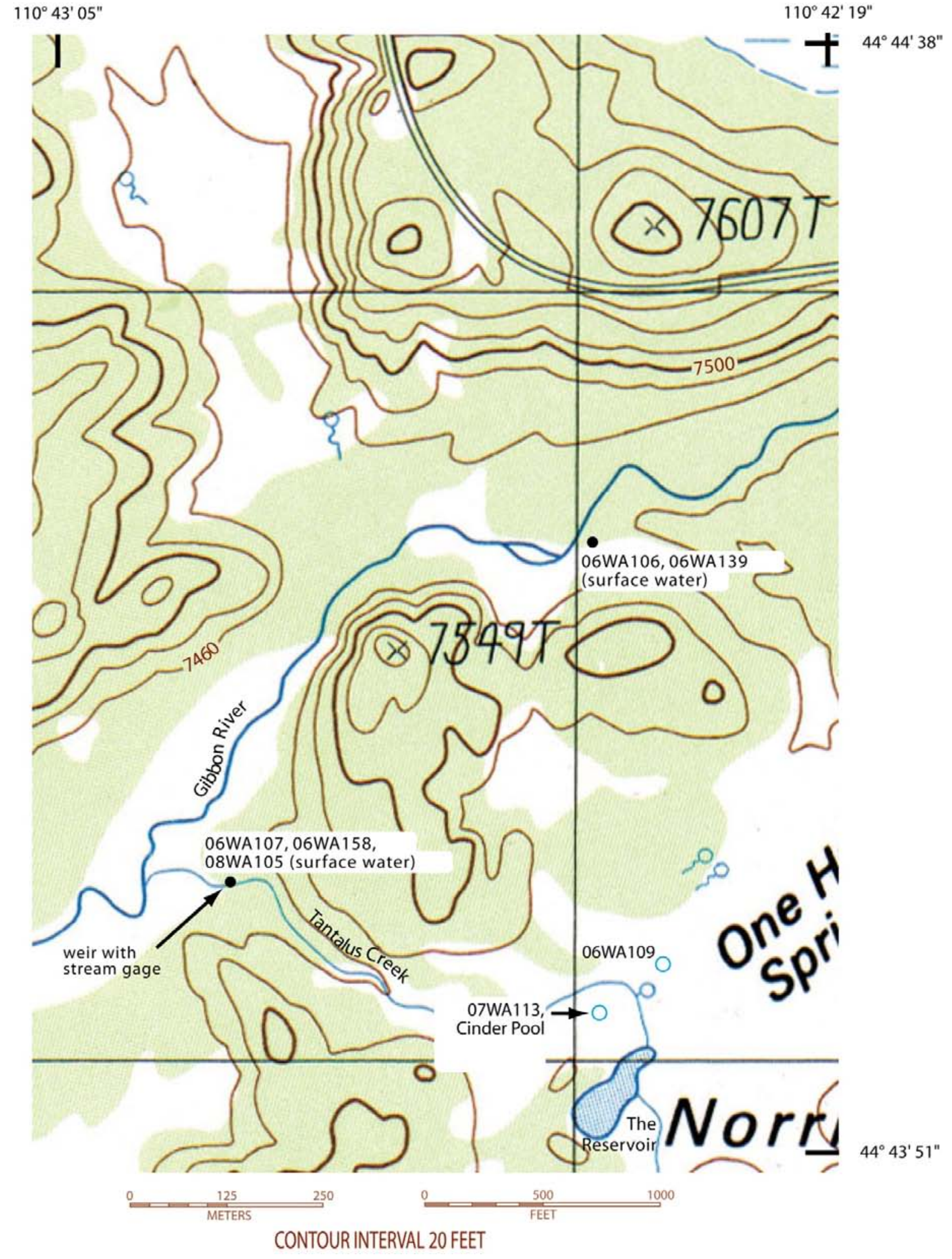
Table 1. Detailed sample site descriptions, locations, map, photograph, and chemical data table reference—Continued.

Name and Site Description	Sample code number	North Latitude	West Longitude	Chemical data (table)	Map (figure)	Photograph (appendix)
Gibbon Canyon and Geyser Springs Group						
Beryl Spring	06WA135	44° 40' 43.5"	110° 44' 44.7"	7	1	38
Beryl Spring	06WA157	44° 40' 43.5"	110° 44' 44.7"	7	1	38
Unnamed pool, Geyser Springs Group	07WA108	44° 41' 25.8"	110° 43' 43.6"	7	8	56
Unnamed pool, Geyser Springs Group	08WA122	44° 41' 25.8"	110° 43' 43.6"	7	8	84
Unnamed acid pool, Geyser Springs Group	08WA117	44° 41' 25.3"	110° 43' 42.2"	7	8	--
Crater Hills area						
Sulphur Spring	07WA111	44° 39' 16.7"	110° 28' 54.8"	8	7	59
Sulphur Spring	08WA115	44° 39' 16.7"	110° 28' 54.8"	8	7	78
Unnamed hot spring	07WA112	44° 39' 12.1"	110°28'36.7"	8	7	60
Unnamed acid pool near Sulphur Spring	08WA116	44° 39' 15.3"	110° 28' 59.0"	8	7	79
Lower Geyser Basin						
Ojo Caliente Spring at discharge	06WA160	44° 33' 46.1"	110°50'16.9"	9	9	--
Ojo Caliente Spring at pool exit	06WA161	44° 33' 46.5"	110° 50' 17.1"	9	9	--
Ojo Caliente Spring 7.5 m from pool outflow	06WA162	44° 33' 46.4"	110° 50' 17.2"	9	9	--
Ojo Caliente Spring 20.6 m from pool outflow	06WA163	44° 33' 46.1"	110° 50' 17.2"	9	9	--
Ojo Caliente Spring source, 50 feet below surface	08WA112	44° 33' 46.1"	110° 50' 16.9"	9	9	76
Ojo Caliente Spring midpoint of main pool	08WA113	44° 33' 46.3"	110° 50' 17.0"	9	9	--
Ojo Caliente Spring, at pool exit	08WA111	44° 33' 46.5"	110° 50' 17.1"	9	9	--
Ojo Caliente Spring 13.8 m downstream from pool exit	08WA110	44° 33' 46.3"	110° 50' 17.2"	9	9	--
Ojo Caliente Spring 20.4 m downstream from pool exit	08WA109	44° 33' 46.1"	110° 50' 17.2"	9	9	--
Ojo Caliente Spring 25.9 m downstream from pool exit	08WA108	44° 33' 46.0"	110° 50' 17.2"	9	9	--
Porcupine Hills area						
Snort Geyser	06WA173	44° 34' 4.0"	110° 48' 18.4"	10	10	49, 50
Unnamed hot spring, Morning Mist Group	06WA170	44° 34' 26.0"	110° 48' 26.0"	10	10	46
Unnamed hot spring, Quagmire Group	06WA171	44° 34' 3.7"	110° 48' 26.0"	10	10	47
Unnamed hot spring, Quagmire Group	06WA172	44° 34' 2.7"	110° 48' 25.0"	10	10	48
Unnamed hot spring, Quagmire Group	06WA174	44° 34' 1.7"	110° 48' 17.0"	10	10	51
Unnamed hot spring, Quagmire Group	08WA132	44° 34' 3.7"	110° 48' 26.0"	10	10	94
Unnamed hot spring, Quagmire Group	08WA133	44° 34' 2.7"	110° 48' 25.0"	10	10	95
Unnamed hot spring, Quagmire Group	08WA134	44° 34' 1.7"	110° 48' 17.0"	10	10	96
Midway Geyser Basin and Rabbit Creek area						
Excelsior Geyser Crater	07WA148	44° 31' 34.2"	110° 50' 8.9"	11	1	72
Unnamed hot spring	06WA113	44° 31' 9.8"	110° 48' 35.3"	11	11	7
Unnamed hot spring drainage channel	06WA114	44° 31' 9.0"	110° 48' 30.2"	11	11	8
Unnamed hot spring drainage channel	06WA114B	44° 31' 9.0"	110° 48' 30.7"	11	11	9
Unnamed hot spring drainage channel	06WA114C	44° 31' 9.0"	110° 48' 31.8"	11	11	10
Unnamed hot spring drainage channel	06WA114D	44° 31' 9.1"	110° 48' 33.5"	11	11	11
Unnamed hot spring	06WA115	44° 31' 1.5"	110° 48' 57.2"	11	11	12
Unnamed hot spring	06WA116	44° 31' 2.1"	110° 49' 19.1"	11	11	13
Unnamed hot spring drainage channel	06WA116B	44° 31' 2.1"	110° 49' 20.3"	11	11	14
Unnamed hot spring drainage channel	06WA116C	44° 31' 2.1"	110° 49' 21.3"	11	11	15
Unnamed hot spring drainage channel	06WA116D	44° 31' 1.8"	110° 49' 22.9"	11	11	16
Mud Volcano area						
Sulphur Caldron	06WA164	44° 37' 41.5"	110° 25' 55.9"	12	12	41
Sulphur Caldron	07WA110	44° 37' 41.5"	110° 25' 55.9"	12	12	58
Sulphur Caldron	08WA114	44° 37' 41.5"	110° 25' 55.9"	12	12	77
Turbulent Pool	06WA165	44° 37' 42.4"	110° 25' 57.3"	12	12	42
Turbulent Pool	07WA109	44° 37' 42.4"	110° 25' 57.3"	12	12	57
Washburn Hot Springs						
Inkpot Spring #1	06WA166	44° 45' 52.8"	110° 25' 48.9"	13	13	43
Inkpot Spring #3	06WA167	44° 45' 53.2"	110° 25' 48.1"	13	13	43
Unnamed thermal feature 160 feet elevation above inkpots	06WA169	44° 46' 0.5"	110° 45' 45.1"	13	13	44
Upper large hot pool, Inkpot Spring area	06WA168	44° 45' 53.9"	110° 25' 46.2"	13	13	45



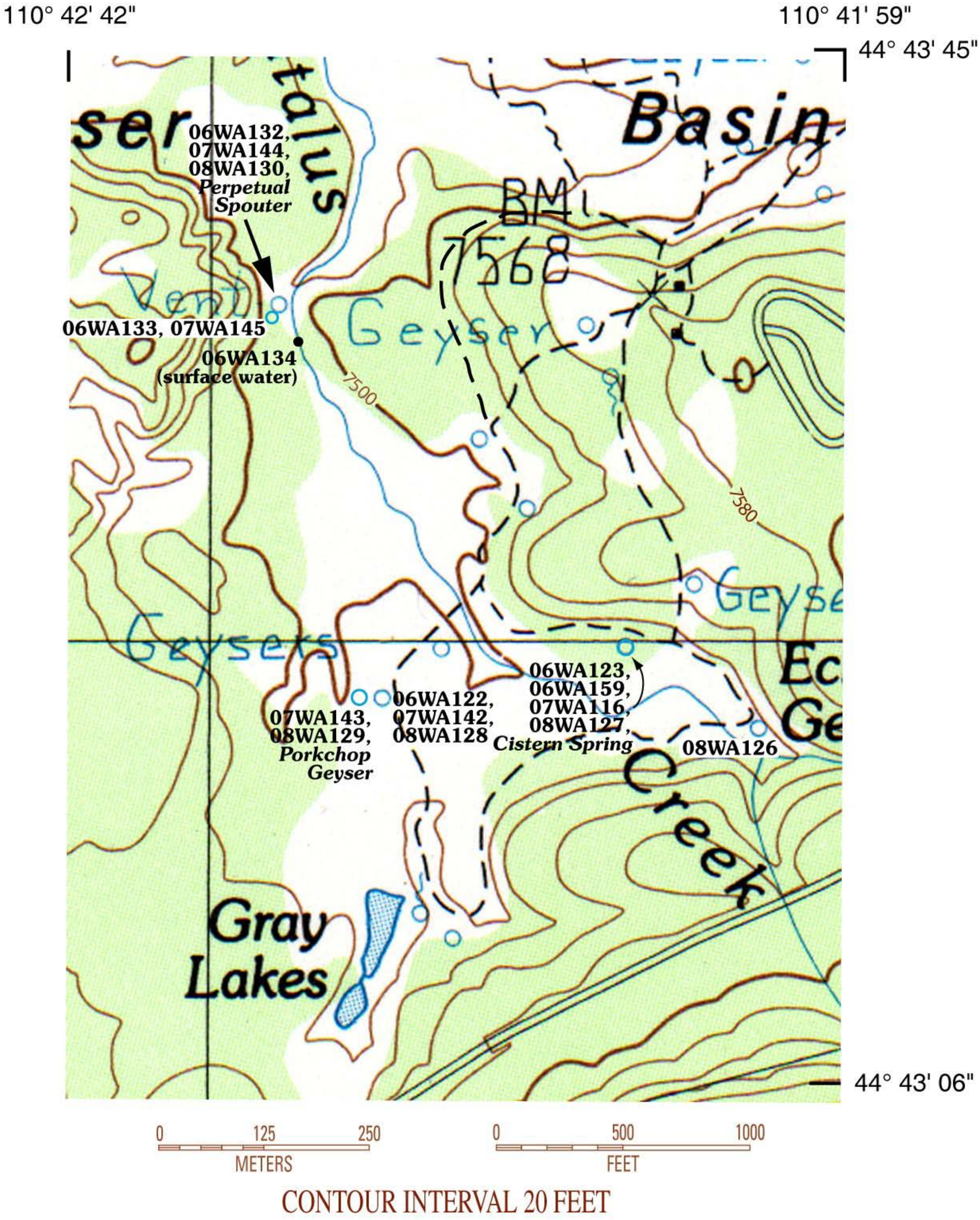
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 2. Sampling locations for hot springs, geysers, and surface waters at Norris Geyser Basin and West Nymph Creek thermal area, Yellowstone National Park, Wyoming.



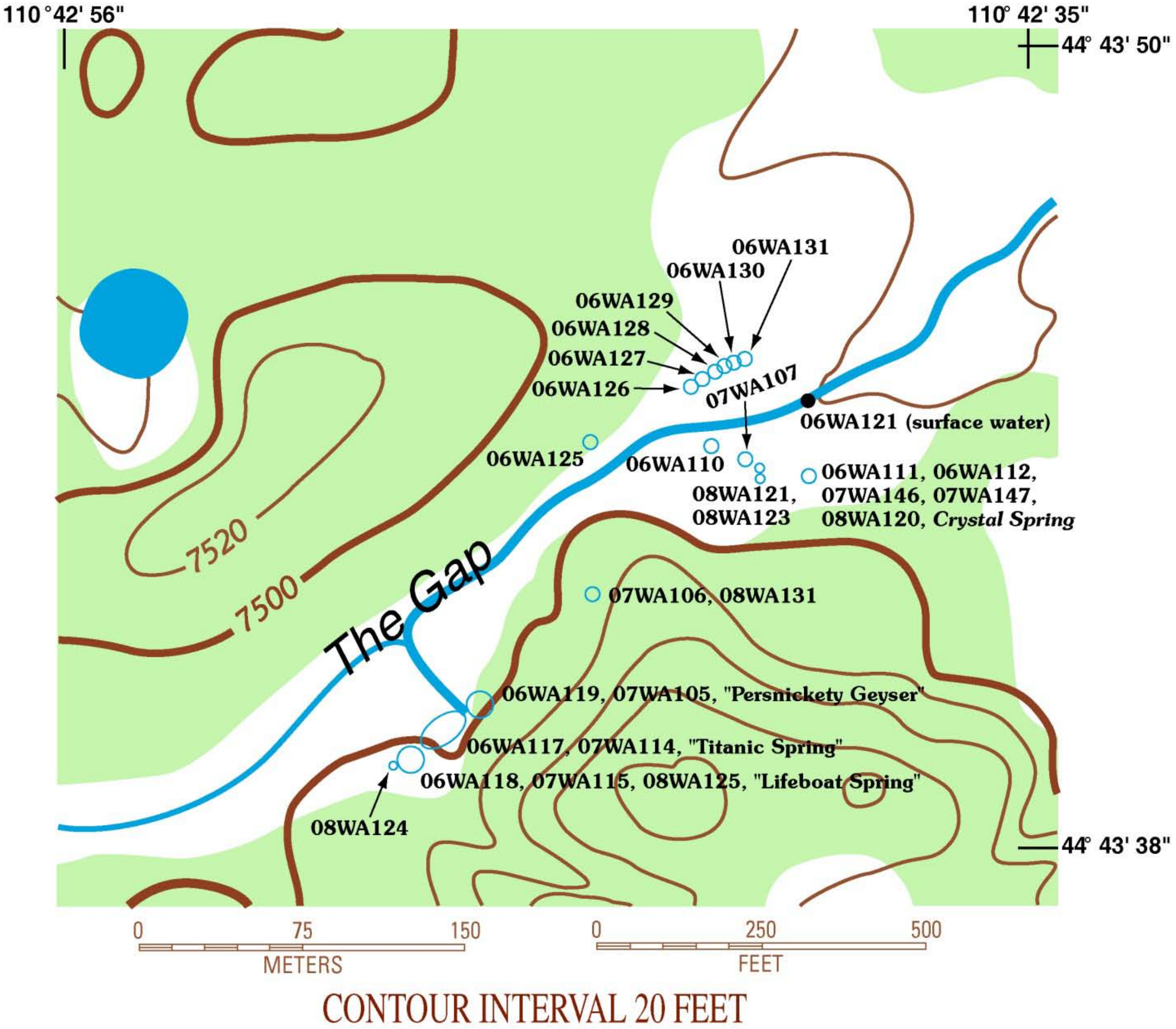
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 3. Sampling locations with sample code numbers for hot springs and two surface-water samples in the One Hundred Spring Plain area of Norris Geyser Basin, Yellowstone National Park, Wyoming (see figure 2).



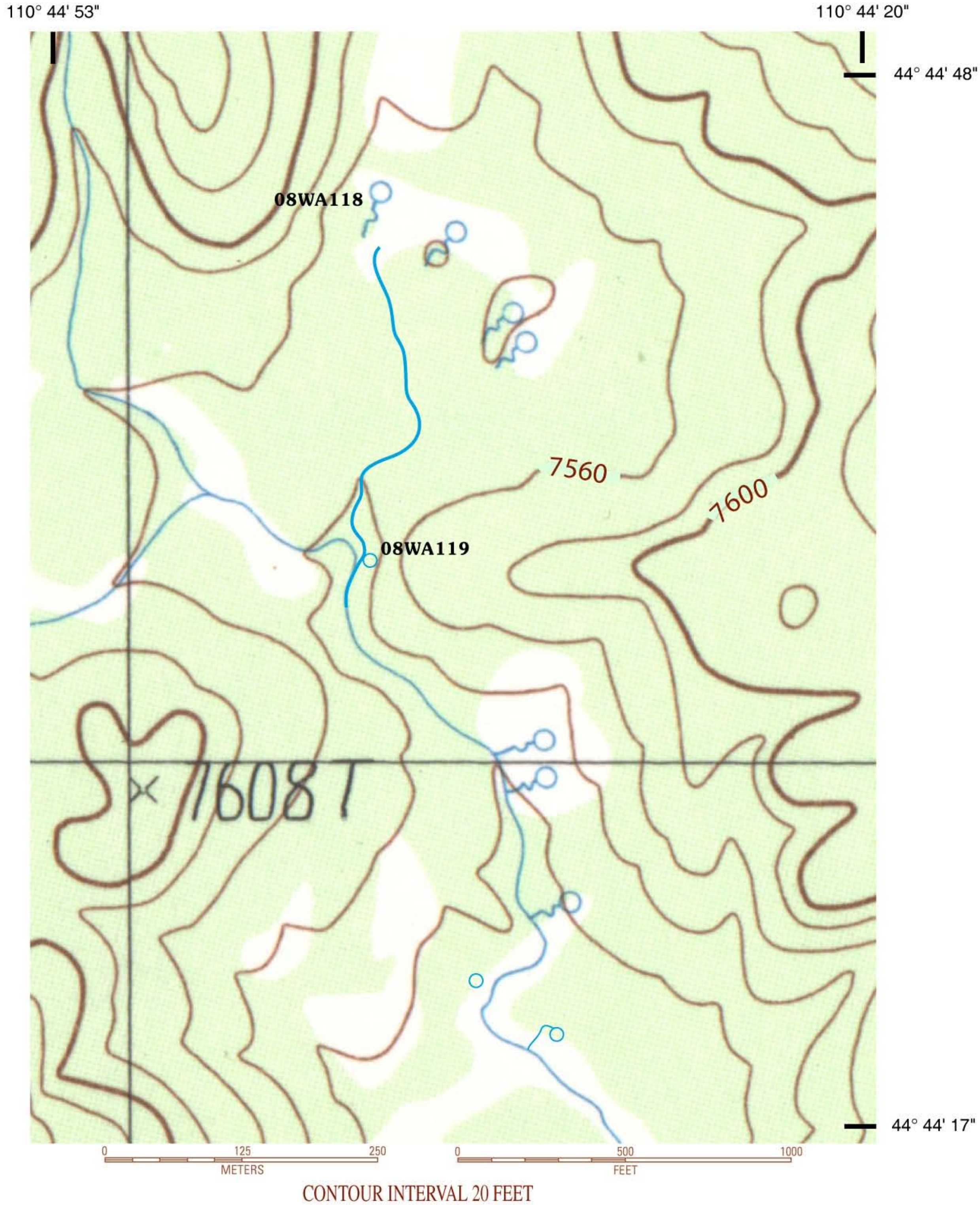
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 4. Sampling locations with sample code numbers for thermal features and one surface-water sample in the Back Basin area of Norris Geyser Basin, Yellowstone National Park, Wyoming (see figure 2).



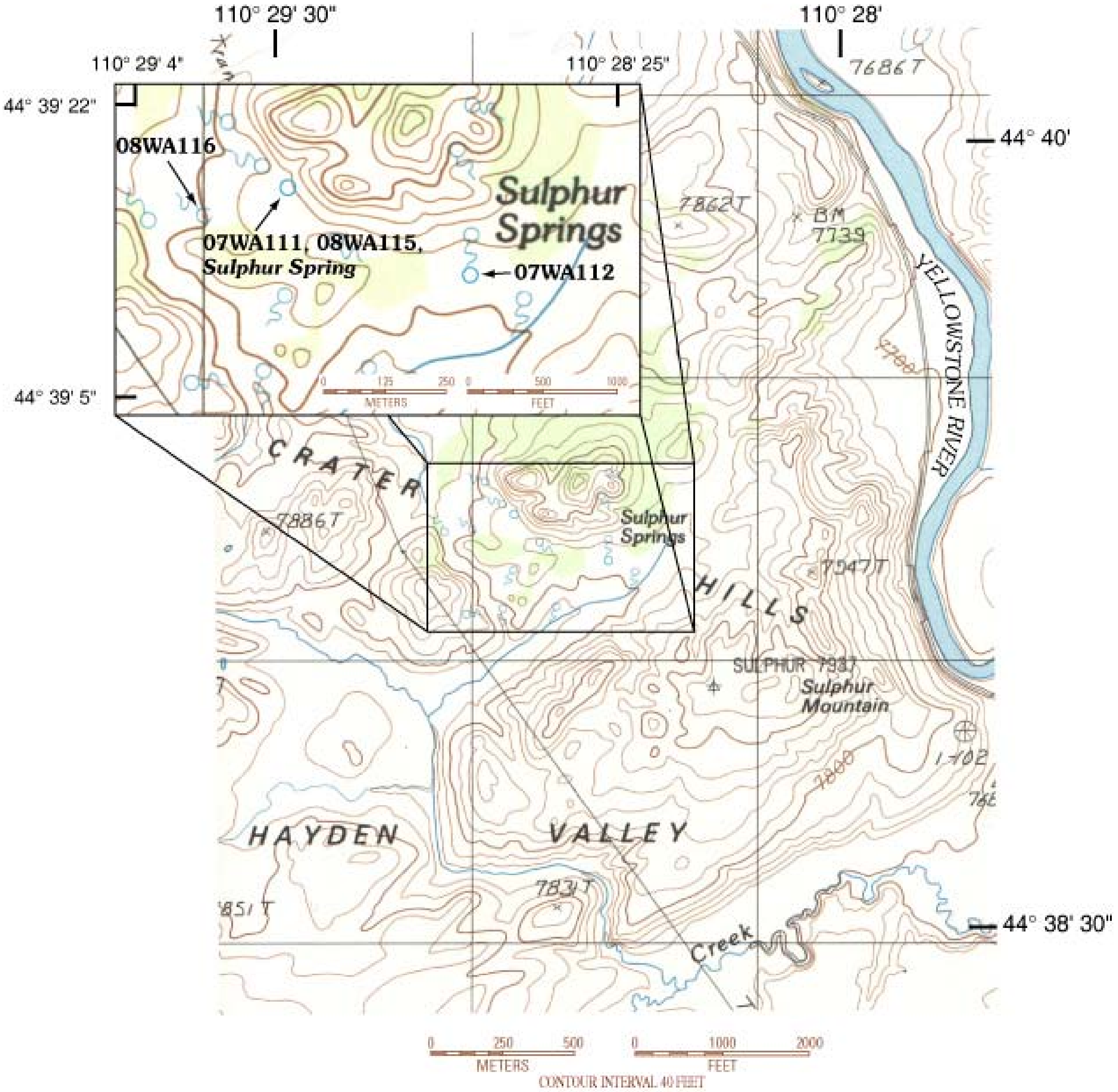
Sketch based on U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 5. Sampling locations with sample code numbers for thermal features and one surface-water sample in the Ragged Hills area of Norris Geyser Basin, Yellowstone National Park, Wyoming (see figure 2).



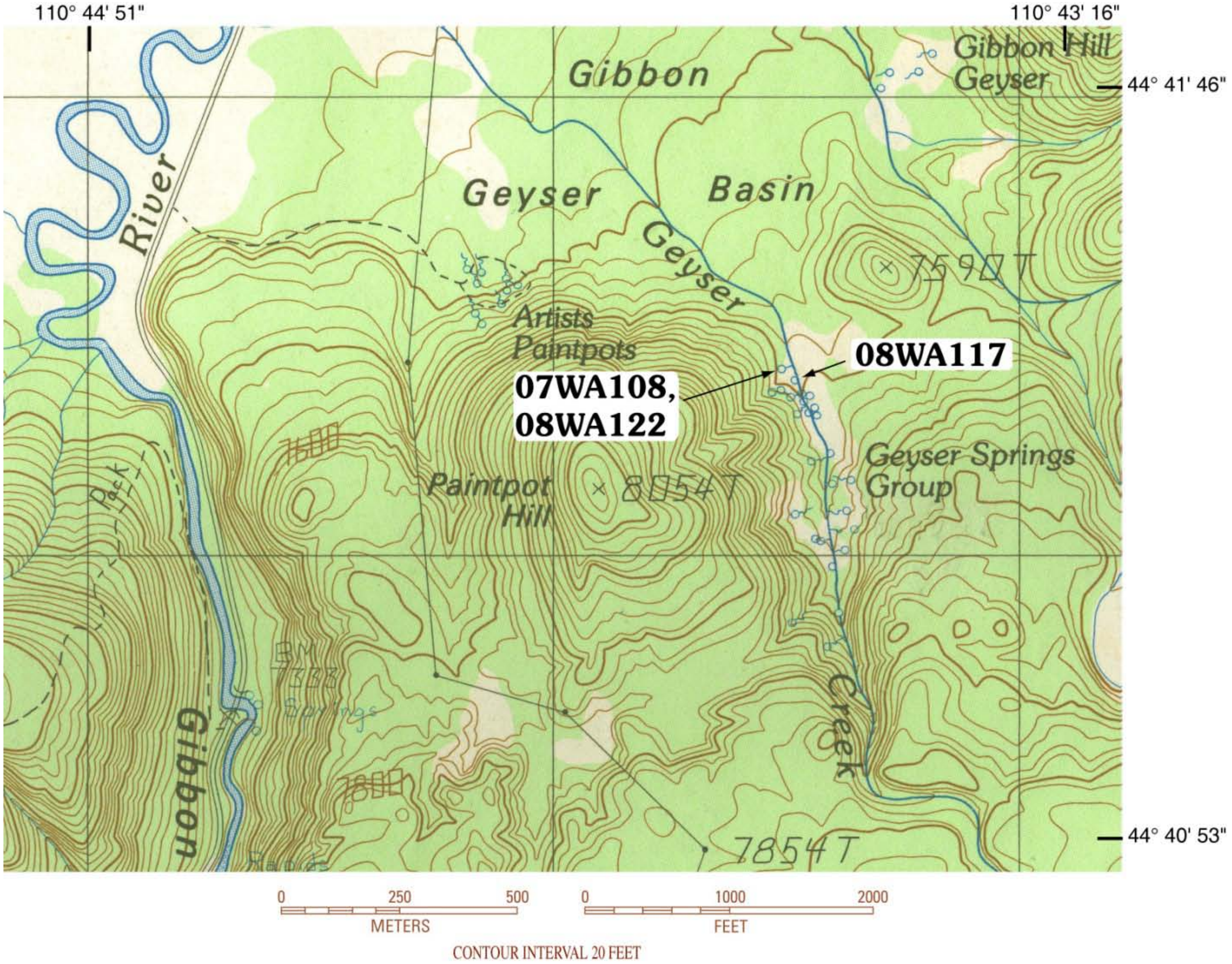
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 6. Sampling locations with sample code numbers for thermal features in the West Nymph Creek Thermal Area near Norris Geyser Basin, Yellowstone National Park, Wyoming (see figure 2).



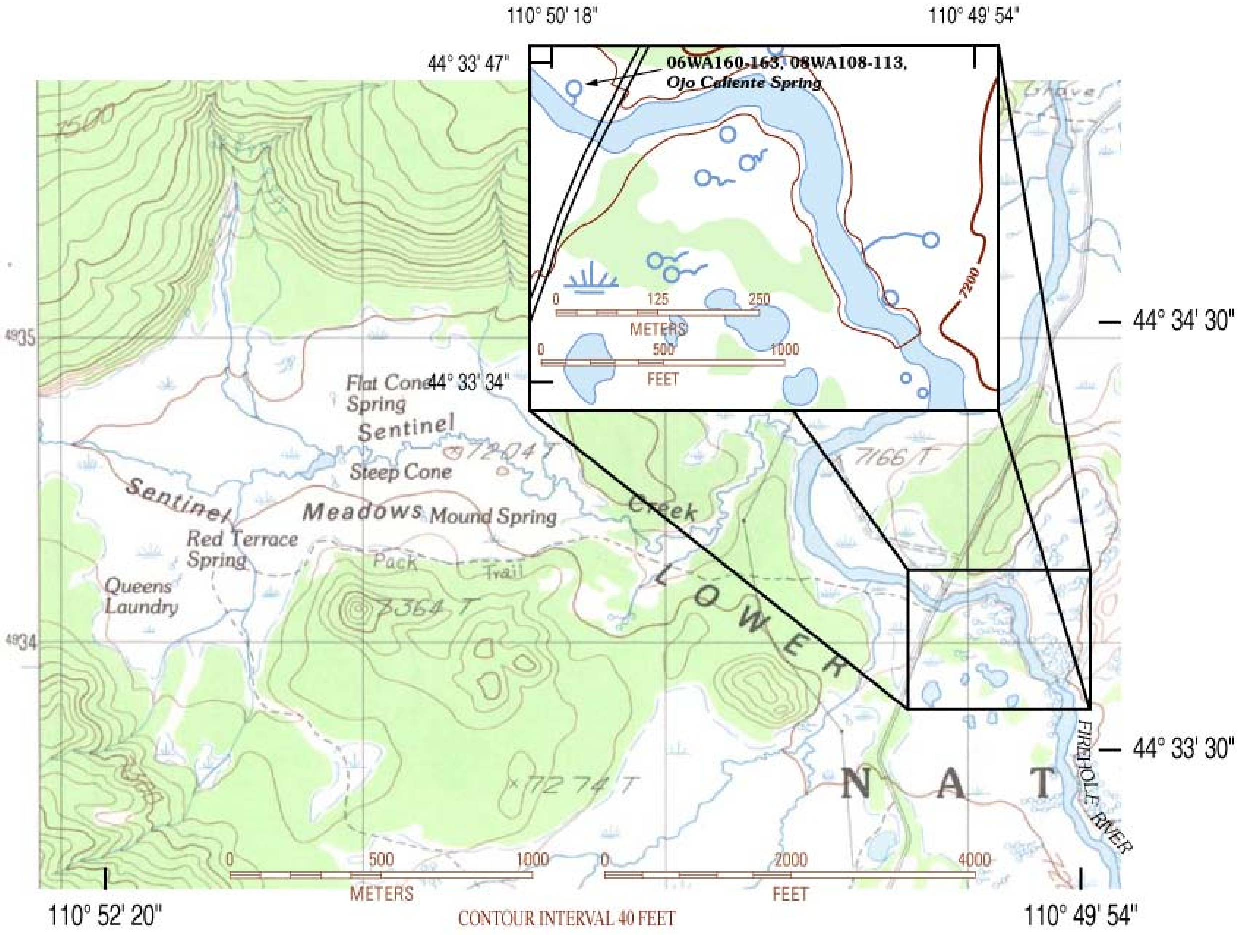
Base from U.S. Geological Survey Canyon Village quadrangle, 1:24,000 (1986)

Figure 7. Sampling locations with sample code numbers for thermal features at the Crater Hills area, Yellowstone National Park, Wyoming.



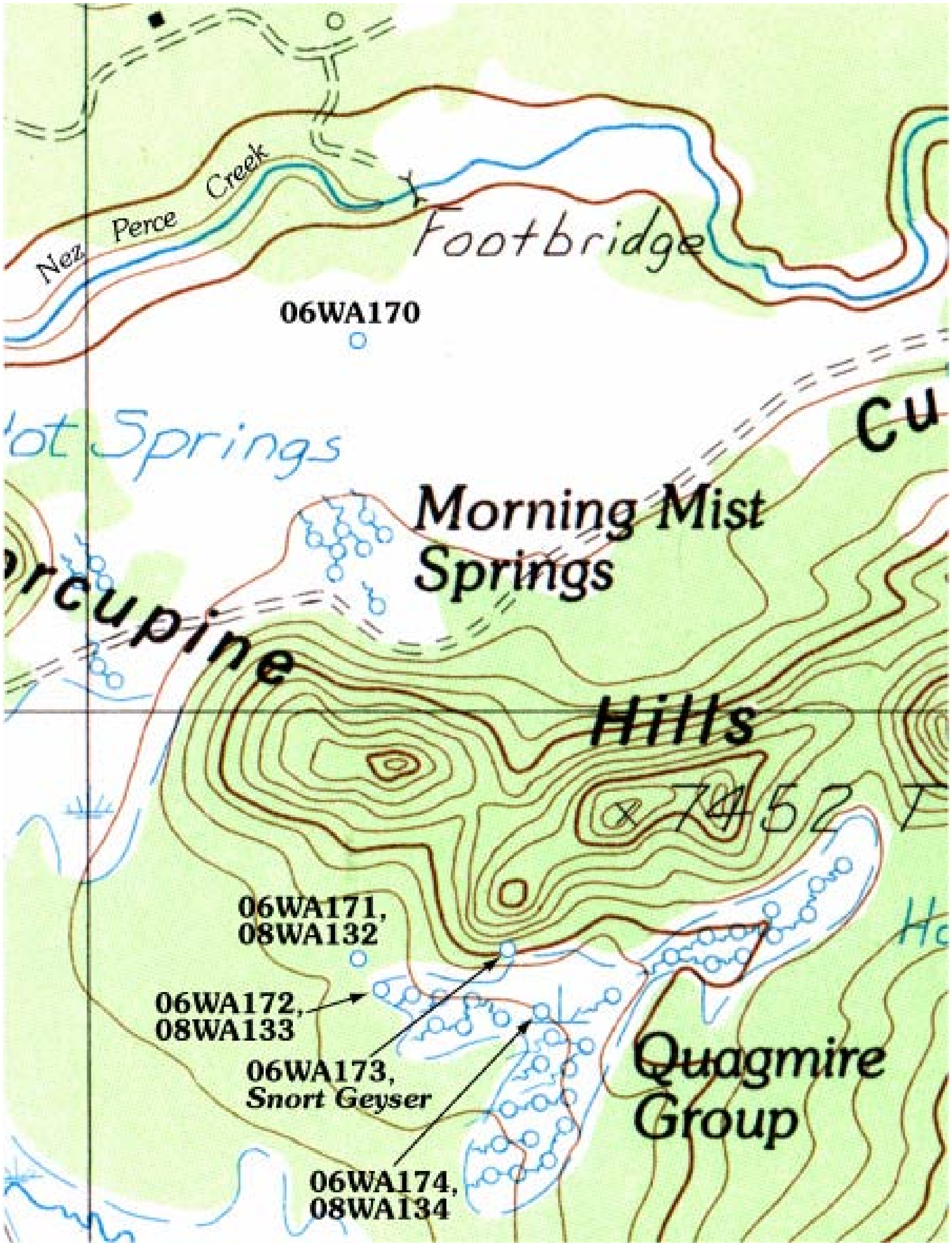
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 8. Sampling location with sample code number for thermal features in the Geyser Springs Group, Yellowstone National Park, Wyoming.



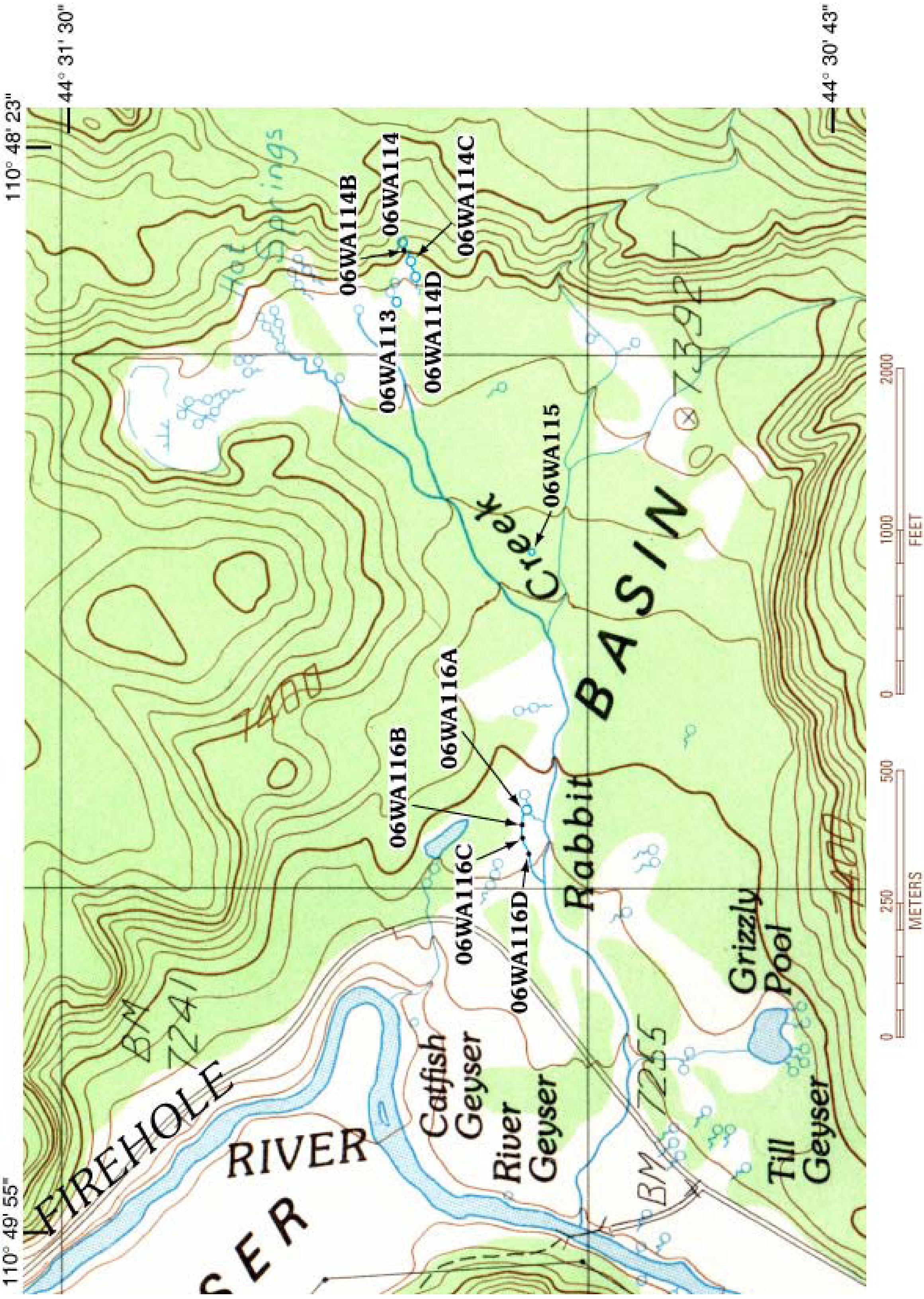
Base from U.S. Geological Survey Lower Geyser Basin quadrangle, 1:24,000 (1986)

Figure 9. Sampling location with sample code numbers for Ojo Caliente Spring in Lower Geyser Basin, Yellowstone National Park, Wyoming.



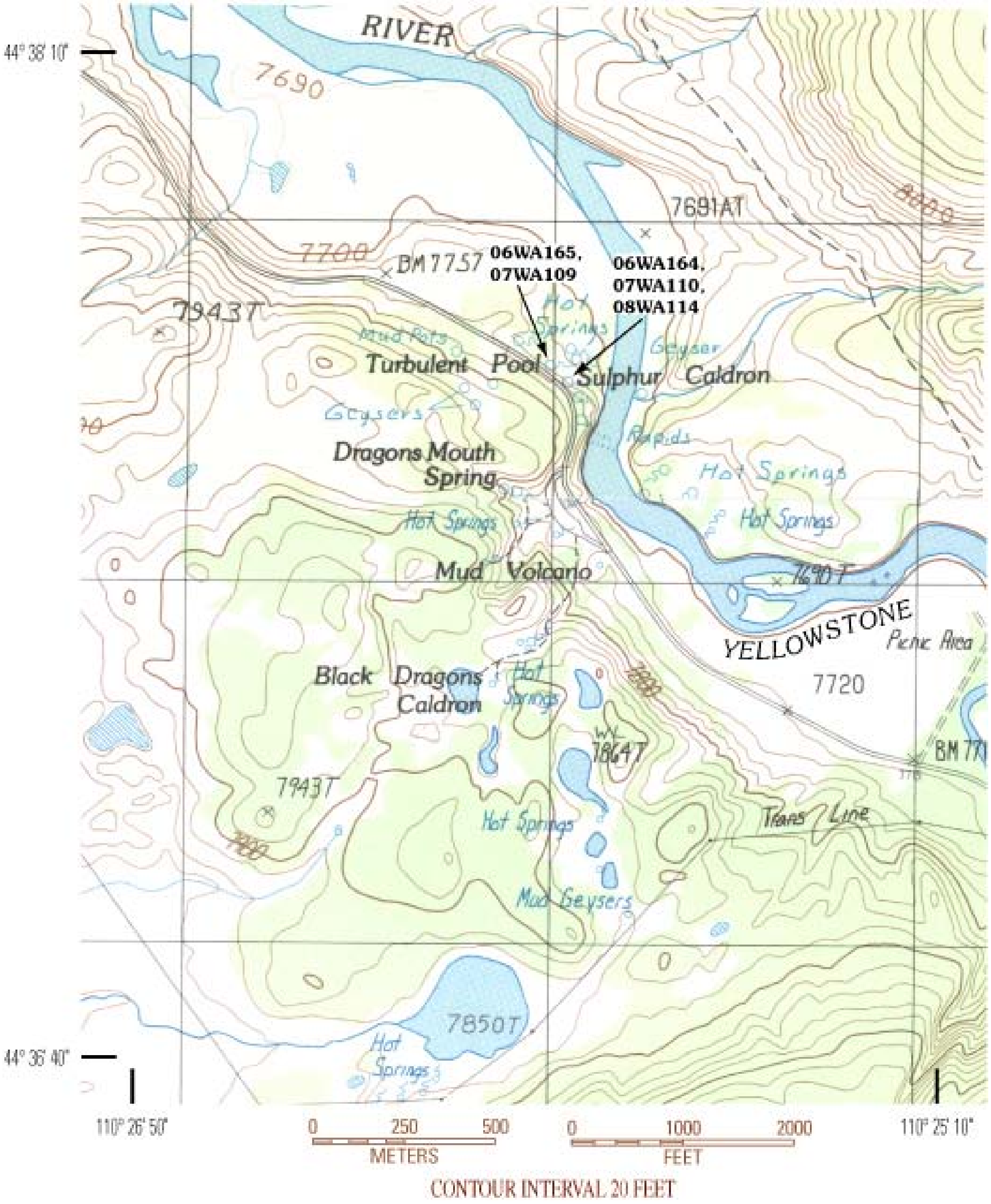
Base from U.S. Geological Survey Lower Geyser Basin quadrangle, 1:24,000 (1986)

Figure 10. Sampling locations with sample code numbers for thermal features in the Porcupine Hills area, Yellowstone National Park, Wyoming.



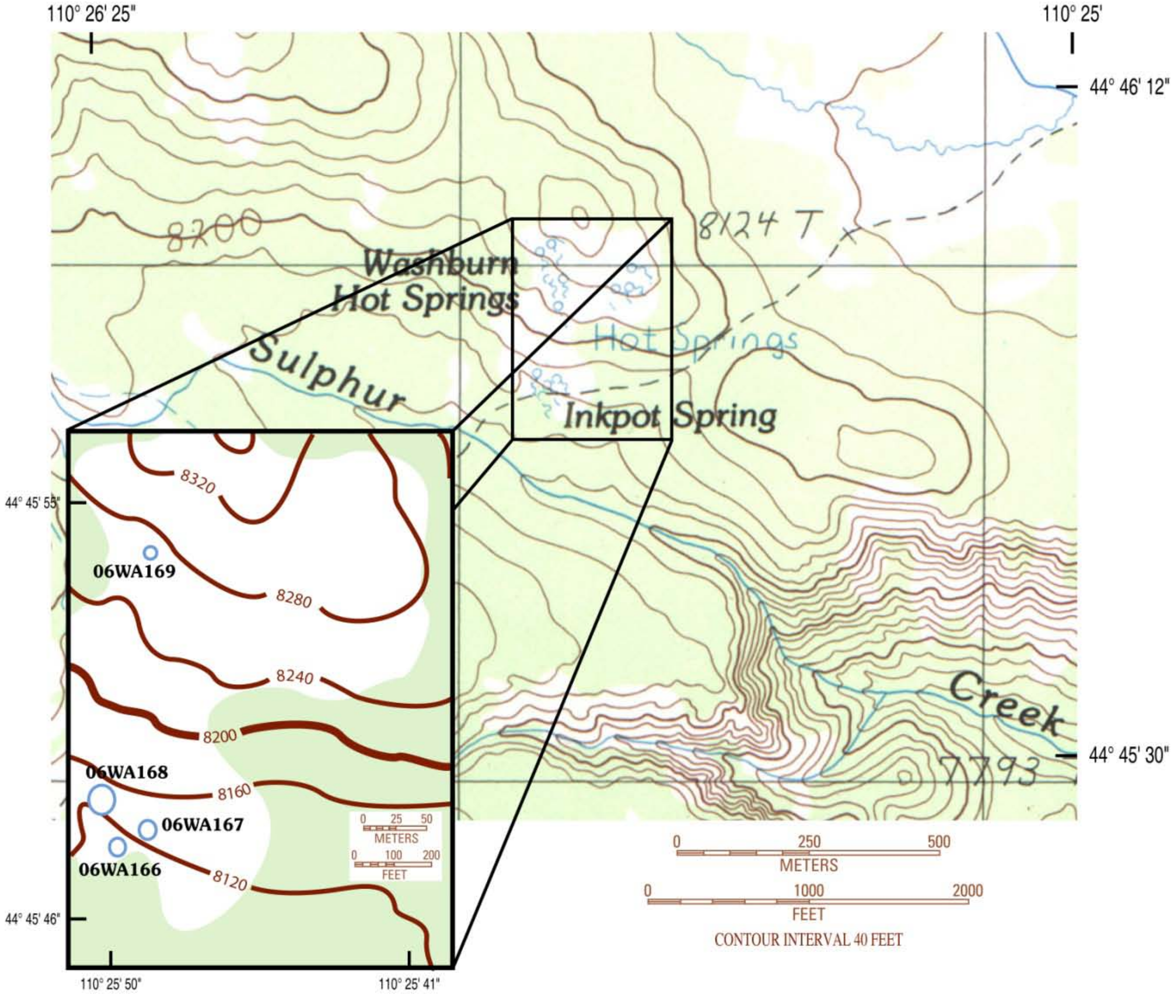
Base from U.S. Geological Survey Lower Geyser Basin quadrangle, 1:24,000 (1986)

Figure 11. Sampling locations with sample code numbers for the Rabbit Creek area, Yellowstone National Park, Wyoming.



Base from U.S. Geological Survey Lake and Canyon Village quadrangles, 1:24,000 (1986)

Figure 12. Sampling locations with sample code numbers for thermal features in the Mud Volcano area, Yellowstone National Park, Wyoming.



Base from U.S. Geological Survey Mount Washburn quadrangle, 1:24,000 (1986)

Figure 13. Sampling locations with sample code numbers for thermal features at Washburn Hot Springs, Yellowstone National Park, Wyoming.

As many as 11 sample bottles were filled at each site. Sequential aliquots were filtered into separate containers for the determination of inorganic constituents, redox species, stable hydrogen and oxygen isotopes of water, and dissolved organic carbon (DOC). Container preparation, storage, and stabilization methods for filtered samples are summarized in table 2. Samples for the determination of major cations and trace metals (Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, SiO_2, Sr, V, and Zn), major anions (Br, Cl, F, NO_3, and SO_4), alkalinity, acidity, density, NH_4, DOC, and water isotopes (δD and $\delta^{18}O$) were filtered and then stabilizing reagents, if needed, were added. Stabilizing reagents for intermediate sulfur species were put into the sample bottles before the samples were collected; therefore, these bottles were not pre-rinsed. The remaining sample bottles were pre-rinsed with filtered water prior to sample collection. With the exception of the cation, water isotope, and silica dilution samples, all sample aliquots were chilled as soon as practical after sample collection.

To prevent over-estimation of S_2O_3 and polythionate concentrations, S(-II) oxidation was minimized by precipitating S(-II) with zinc chloride. This technique caused zinc sulfide (ZnS) species to precipitate. The ZnS in the samples was further stabilized by adding NaOH. Polythionate was converted to thiocyanate (SCN) by adding potassium cyanide (KCN) to that sample split (Moses and others, 1984). For the analysis of dissolved SiO_2 in thermal waters, 1 mL of sample was diluted on-site to 25 mL with deionized water to minimize precipitation of SiO_2 as the sample cooled. Samples for the determination of DOC were filtered through a 142-mm diameter all-plastic plate filter containing a 0.1-µm mixed-cellulose-ester filter membrane and collected in a glass bottle that had been baked at 600°C. At least 1 liter (L) of sample water was passed through the all-plastic plate-filter assembly before a DOC sample was collected. Samples for δD and $\delta^{18}O$ (water isotopes) determinations were filtered when the water filtered easily; otherwise water-isotope samples were not filtered.

Field and Laboratory Measurements

Analytical methods, typical precision, detection limits, equipment used, pertinent references, and comments are described briefly in table 3. Detection limits were equal to 3 times the standard deviation (s) of several dozen measurements of the constituent in a blank solution analyzed as a sample. Relative standard deviation for each analytical method is determined from the measurement of an analyte concentration at least 10 times the detection limit. Techniques, general conditions, and variants from standard procedures are discussed in the following sections.

All reagents were equal to the reagent-grade standards of the American Chemical Society or more pure. Double-distilled or de-ionized water and re-distilled or trace-metal-grade acids were used in all preparations. Samples were diluted as necessary to bring the analyte concentration within the optimal range of the method. Each sample was analyzed at least twice for each dilution and for all constituents.

Table 2. Container preparation and stabilization methods for filtered samples.

[°C, degrees Celsius; HCO_3, bicarbonate; HCl, hydrochloric acid; HNO_3, nitric acid; 1:9 H_2SO_4, one part sulfuric acid plus nine parts water; KCN, potassium cyanide; $K_2Cr_2O_7$, potassium dichromate; M, molar; mL, milliliter; N, normal; NaOH, sodium hydroxide; (S-II), sulfide; v/v, volume per volume; w/v, weight per volume; $ZnCl_2$, zinc chloride; %, percent]

Constituent(s) to be determined	Storage container and preparation	Stabilization treatment in addition to refrigeration
Major cations and trace metals (Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb(T), Sb(III), Se, SiO_2, Sr, V, and Zn)	Polyethylene bottles, soaked in 5% HCl and rinsed 3 times with deionized water	1% (v/v) concentrated redistilled HNO_3 added; samples were not chilled
Total mercury (Hg(T))	Borosilicate glass bottles, soaked with 5% HNO_3 and rinsed 3 times with deionized water	1 % (v/v) concentrated redistilled HNO_3 / 1 % (w/v) $K_2Cr_2O_7$ added
Methylmercury (CH_3Hg)	Amber borosilicate glass bottles, soaked with 5% HNO_3 and rinsed 3 times with deionized water	5 mL 6 M redistilled HCl added
Iron, arsenic, and antimony redox species (Fe(T), Fe(II), As(T), As(III), Sb(T), and Sb(III))	Opaque polyethylene bottles, soaked in 5% HCl and rinsed 3 times with deionized water	1% (v/v) redistilled 6 M HCl added
Major anions (Br, Cl, F, and SO_4), alkalinity as HCO_3, acidity, density, and nitrate (NO_3)	Polyethylene bottles filled with distilled water and allowed to stand for 24 hours, then rinsed 3 times with deionized water	None
Ammonium (NH_4)	Same as major cations and trace metals	1% (v/v) 1:9 H_2SO_4 added
Silica (SiO_2)	Same as major anions, alkalinity, and density	1 mL diluted to 25 mL with distilled water on-site; samples were not chilled
Thiosulfate (S_2O_3) and polythionate (S_nO_6)	30-mL polyethylene bottle	1.7% (v/v) 0.6 M $ZnCl_2$ plus 1% (v/v) 1 M NaOH added; 1.7% (v/v) 1 M KCN also added to S_nO_6 bottle
Dissolved organic carbon (DOC)	Amber glass bottle baked at 600°C	None
Water Isotopes (δD and $\delta^{18}O$)	60-mL glass bottle	None (unfiltered sample collected when filtration was not possible); samples were not chilled
Sulfide	30-mL polyethylene bottle	15–mL sulfide anti-oxidant buffer followed by 15–mL sample

Field Measurements

Measurements of temperature, pH, Eh, specific conductance, dissolved oxygen (DO), and H_2S were performed on-site . Measurements of Eh and pH were made on unfiltered sample water pumped from the source through an acrylic plastic flow-through cell, which minimized sample contact with air. The flow-through cell contained a combination redox electrode, a combination pH electrode, a thermistor, and test tubes containing buffer solutions for calibration of the pH electrode. All components were thermally equilibrated with the sample water before obtaining measurements. Where possible, specific conductance and sampling tube intake temperature were measured by immersing the combined specific conductance/temperature probe directly into the source as close to the sampling point as possible. Otherwise, the probe was immersed in the flow-through cell. Because sample temperatures usually were greater than the upper limit (45°C) of the DO probe, DO was determined using the azide modification of the Winkler titration (American Public Health Association (APHA), 1971).

A mobile laboratory truck containing an ion chromatograph, ultraviolet-visible spectrophotometer, autotitrator, and reagent-grade water system was set up at the overnight lodging site so that unstable intermediate sulfur oxyanion species could be determined as soon as possible after sample collection. Iron redox species also were determined in the mobile laboratory from time to time to guide sampling strategies. The autotitrator was used each evening to perform alkalinity and acidity titrations before oxidation and hydrolysis reactions occurred, and to determine H_2S concentrations in samples preserved on-site.

pH Measurements

Because field measurement of pH in geothermal waters is challenging and accurate pH measurements are critical for interpreting analytical results (Ball and others, 2006), special care was taken when measuring this parameter. At each site, the flow-through cell, temperature probe, electrode, and calibration buffers were equilibrated to sample temperature prior to calibration and measurement. The system was calibrated using at least two bracketing standard buffers (chosen from among 1.68, 4.01, 7.00, or 10.00) corrected to their values at the sample temperature. After calibration, the pH electrode was placed in the sample water in the flow-through cell and monitored until no change in temperature (± 0.1°C) or pH (± 0.01 standard unit) was detected for at least 30 seconds. Following sample measurement, the electrode was immersed in the standard buffer of pH closest to that of the sample and allowed to equilibrate. The entire calibration and measurement process was repeated as many times as necessary until the measured value for the buffer differed by no more than 0.05 standard units from its certified pH at the measured temperature.

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references.

[cm, centimeter; Cs, cesium; CVAFS, cold vapor atomic fluorescence spectrometry; °C, degrees Celsius; GFAAS, graphite furnace atomic absorption spectrometry; HCl, hydrochloric acid; HGAAS, hydride generation atomic absorption spectrometry; IC, ion chromatography; ICP-OES, inductively coupled plasma-optical emission spectrometry; ISE, ion-selective electrode; KCl, potassium chloride; KI, potassium iodide; M, molar; $Mg(NO_3)_2$, magnesium nitrate; µg/L, micrograms per liter; mg/L, milligrams per liter; mM, millimolar; mN, millinormal; MS, mass spectrometry; N, normal; $NaHCO_3$, sodium bicarbonate; Na_2CO_3, sodium carbonate; ng/L, nanograms per liter; nm, nanometer; Pd, palladium; RSD, relative standard deviation; SLAP, standard light antarctic precipitation; TISAB, total ionic strength adjustment buffer; TOC, total organic carbon; VSMOW, Vienna standard mean ocean water; ≤, less than or equal to; %, percent]

Constituent	Analytical Technique	Typical RSD[1], detection limit (mg/L)	Equipment Used	Comments or Reference(s)
Field Measurements				
Temperature	Electronic sensor	Not applicable	Beckman 265 pH meter with Beckman temperature probe or Orion Research model 1230 multi-parameter meter with temperature sensor built into conductivity electrode	Temperatures were reported to the nearest 0.1 °C
pH	Potentiometry	0.02 pH units[2]	Beckman 265 pH meter with Orion Ross combination electrode	Two- or three-buffer calibration at sample temperature using 1.68, 4.01, 7.00, and 10.00 pH buffers
Specific Conductance (SC)	Conductometry	0.5%	Orion Research model 1230 multi-parameter meter with conductivity electrode	Automatic temperature correction to 25°C, cell constant determined with 0.0100 N KCl
Eh	Potentiometry	10%	Orion Research model 96-78-00 combination redox electrode	Electrode checked using ZoBell's solution (ZoBell, 1946; Nordstrom, 1977)
Dissolved oxygen (DO)	Titration	1%	Burette and Erlenmeyer flask	Winkler Titration using manganous sulfate, alkaline iodide-azide, sulfamic acid, starch indicator, phenyl arsine oxide (APHA, 1971)
Hydrogen sulfide (H_2S)	Colorimetry /	≤20%, *0.002*	Hach model DR-2000 or DR-2800 ultraviolet - visible spectrometer and Hach method # 8131 reagents /	Methylene Blue Method based on APHA (1985)
Laboratory Measurements				
Calcium (Ca)	ICP-OES	2%, *0.04*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 315.887 nm, view: radial
Magnesium (Mg)	ICP-OES	2%, *0.001*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 280.270 nm, view: axial
Sodium (Na)	ICP-OES	2%, *0.1*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 589.592 nm, view: radial

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references—Continued.

Constituent	Analytical Technique	Typical RSD[1], detection limit (mg/L)	Equipment Used	Comments or Reference(s)
Potassium (K)	ICP-OES	3%, *0.04*	Leeman Labs Direct Reading Echelle[3]	1,000 mg/L Cs ionization buffer, Wavelength: 766.490 nm, view: axial
Strontium (Sr)	ICP-OES	2%, *0.0007*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 421.611 nm, view: axial
Barium (Ba)	ICP-OES	2%, *0.0008*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 455.403 nm, view: axial
Lithium (Li)	ICP-OES	2%, *0.003*	Leeman Labs Direct Reading Echelle[3]	1,000 mg/L Cs ionization buffer, Wavelength: 670.784 nm, view: axial
Sulfate (SO_4)	IC	3%, *1.0*	Dionex model 100 or 600 ion chromatograph with AG22A guard and AS22A separator columns and Anion Self-Regenerating Suppressor-II	3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995)
Thiosulfate (S_2O_3)	IC	3%, *0.1*	Dionex model 100 ion chromatograph with two AG4A guard and an Anion Self-Regenerating Suppressor-II	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent (Moses and others, 1984)
Polythionate (S_nO_6)	IC	3%, *0.3*	Dionex model 100 ion chromatograph with two AG4A guard and an Anion Self-Regenerating Suppressor-II	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent (Moses and others, 1984)
Alkalinity (as HCO_3)	Titration	2%, *1.0*	Orion Research model 960/940 autotitrator, potentiometric detection, end-point determined by the first derivative technique	(Barringer and Johnsson, 1996; Fishman and Friedman, 1989)
Acidity (total/free H^+)	Titration	2%, *0.4 mM*	Orion Research model 960/940 autotitrator, potentiometric detection	(Barringer and Johnsson, 1996; Fishman and Friedman, 1989)
Hydrogen sulfide (H_2S)	ISE	5%, *0.002*	Orion Research model 960/940 autotitrator, Accumet model 13-620-551 Silver/Sulfide combination electrode	Sample mixed 1:1 on-site with Orion Research 941609 Sulfide Anti-Oxidant Buffer and analyzed within 24 hours of collection (APHA, 1998)
Fluoride (F)	ISE; IC	3%, *0.05*; 3%, *0.15*	Orion Research model 96-09 combination F electrode; Dionex model 100 or 600 ion chromatograph with AG22A guard and AS22A separator columns and Anion Self-Regenerating Suppressor-II	Sample mixed 1:1 with Orion Research 940911 TISAB III (Barnard and Nordstrom, 1980); 3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995)
Chloride (Cl)	IC	3%, *0.05*	Dionex model 100 or 600 ion chromatograph with AG14A guard and AS14A separator columns and an Anion Self-Regenerating Suppressor-II	3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995)

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references—Continued.

Constituent	Analytical Technique	Typical RSD[1], detection limit (mg/L)	Equipment Used	Comments or Reference(s)
Bromide (Br)	IC	3%, *0.03*	Dionex model 100 or 600 ion chromatograph with AG14A guard and AS14A separator columns and an Anion Self-Regenerating Suppressor-II	3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995)
Nitrate (NO_3)	IC	3%, *0.1*	Dionex model 100 or 600 ion chromatograph with AG22A guard and AS22A separator columns and Anion Self-Regenerating Suppressor-II	3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995)
Ammonium (NH_4)	Colorimetry	3%, *0.05*	Dionex model DX-300 ion chromatograph with CS12A IonPac column	22 mN H_2SO_4 eluent (Smith and others, 2006)
Silica (SiO_2)	ICP-OES	2%, *0.05*	Leeman Labs Direct Reading Echelle[3]	Sample diluted 25X in field, Wavelength: 251.611 nm, view: axial
Boron (B)	ICP-OES	2%, *0.01*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 249.678 nm, view: axial
Aluminum (Al)	ICP-OES; GFAAS	2%, *0.06*; 5%, *0.001*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 308.215 nm, view: axial; Wavelength: 309.3 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature 2,300°C
Total dissolved iron (Fe(T))	Colorimetry	2%, *0.002*	Hewlett-Packard model 8452A diode array spectrometer with 1– and 5–cm cells	FerroZine method (Stookey, 1970; To and others, 1999)
Ferrous iron (Fe(II))	Colorimetry	2%, *0.002*	Hewlett-Packard model 8452A diode array spectrometer with 1– and 5–cm cells	FerroZine method (Stookey, 1970; To and others, 1999)
Manganese (Mn)	ICP-OES	3%, *0.001*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 257.610 nm, view: axial
Copper (Cu)	ICP-OES; GFAAS	2%, *0.003*; 3%, *0.0005*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 324.754 nm, view: axial; Wavelength: 324.8 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 2,000°C

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references—Continued.

Constituent	Analytical Technique	Typical RSD[1], detection limit (mg/L)	Equipment Used	Comments or Reference(s)
Zinc (Zn)	ICP-OES; GFAAS	2%, *0.004*; 3%, *0.0005*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 213.856 nm, view: axial; Wavelength: 213.9 nm, modifier: 5 µg $Mg(NO_3)_2$, atomization temperature 1,800°C
Cadmium (Cd)	ICP-OES; GFAAS	2%, *0.001*; 5%, *0.0001*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 214.438 nm, view: axial; Wavelength: 228.8 nm, modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,500°C
Chromium (Cr)	GFAAS	5%, *0.0005*	Perkin-Elmer model 4110ZL	Wavelength: 357.9 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2,300°C
Cobalt (Co)	ICP-OES; GFAAS	2%, *0.004*; 5%, *0.0007*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 228.616 nm, view: axial; Wavelength: 242.5 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2,400°C
Total dissolved mercury (Hg(T))	CVAFS	2%, *0.4 ng/L*	PS Analytical, model Galahad, direct cold-vapor atomic fluorescence spectrometry	Taylor and others (1997), Roth and others (2001)
Methylmercury (CH_3Hg)	CVAFS	2%, *0.04 ng/L*	Tekran Model 2500 CVAFS mercury detector	Distillation/ethylation/gas-phase separation method (Horvat and others, 1993; DeWild and others, 2002)
Nickel (Ni)	ICP-OES (2003); GFAAS (2004-2005)	2%, *0.002*; 3%, *0.0005*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 231.604 nm, view: axial; Wavelength: 232.0 nm, atomization temperature: 2,300°C
Lead (Pb)	ICP-OES; GFAAS	5%, *0.008*; 5%, *0.0008*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 220.353 nm, view: axial; Wavelength: 283.3 nm, modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,600°C
Beryllium (Be)	ICP-OES	2%, *0.001*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 313.042 nm, view: axial
Vanadium (V)	ICP-OES	3%, *0.005*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 292.401 nm, view: axial
Molybdenum (Mo)	ICP-OES	3%, *0.007*	Leeman Labs Direct Reading Echelle[3]	Wavelength: 277.540 nm, view: axial

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references—Continued.

Constituent	Analytical Technique	Typical RSD[1], detection limit (mg/L)	Equipment Used	Comments or Reference(s)
Total dissolved antimony (Sb(T))	GFAAS	5%, *0.001*	Perkin-Elmer model 4110ZL	Wavelength: 217.6 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,900°C
Antimonite (Sb(III))	HGAAS	3%, *0.0005*	Perkin-Elmer AAnalyst 300 atomic absorption spectrometer with a FIAS-100 flow injection analysis system, quartz cell, and furnace	Wavelength: 217.6 nm
Selenium (Se)	ICP-OES; GFAAS	5%, *0.04*; 5%, *0.001*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer model 4110ZL	Wavelength: 196.026 nm, view: axial; Wavelength: 196.0 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 2,100°C
Total dissolved arsenic (As(T))	ICP-OES; HGAAS	5%, *0.04*; 2%, *0.0001*	Leeman Labs Direct Reading Echelle[3]; Perkin-Elmer AAnalyst 300 atomic absorption spectrometer with a FIAS-100 flow injection analysis system, quartz cell, and furnace	Wavelength: 188.977 nm, view: axial; Pre-reduction of As(V) using KI + ascorbic acid + HCl (McCleskey and others, 2003)
Arsenite (As(III))	HGAAS	5%, *0.001*	Perkin-Elmer AAnalyst 300 atomic absorption spectrometer with a FIAS-100 flow injection analysis system, quartz cell, and furnace	(McCleskey and others, 2003)
Deuterium (δD)	MS	1 per mil[2]	V.G. Micromass model 602 mass spectrometer	Standardization against VSMOW ($\delta D = 0$ per mil) and SLAP ($\delta D = -428$ per mil) (Coplen and others, 1991)
Oxygen ($\delta^{18}O$)	MS	0.1 per mil[2]	DuPont model 21-491 mass spectrometer	Standardization against VSMOW ($\delta^{18}O = 0$ per mil) and SLAP ($\delta^{18}O = -55.5$ per mil) (Epstein and Mayeda, 1953)
Dissolved organic carbon (DOC)	TOC	2%, *0.1*	Oceanography International Model 700 TOC Analyzer	Wet oxidation method (Aiken, 1992)

[1] relative standard deviation expressed in percent (100 x standard deviation ÷ mean)

[2] precision or range, rather than RSD

[3] dual view, sequential multi-element, inductively coupled plasma spectrometer. Hildebrand grid nebulizer and glass Scott spray chamber

Sulfide Determinations

Three alternative methods were used to measure sulfide. Two methods were done on-site using colorimetry and a third method was done off–site on a preserved sample. For the first method, sample water was transferred into a measuring cuvette, and then color reagents were added. For the second method, sample water was transferred into a measuring cuvette to which color reagents and, for diluted samples, de-ionized water, had been added previously. After waiting for color development, the sample absorbance and temperature of the solution were measured. Dissolved sulfide concentration was measured on-site using a battery-operated, portable ultraviolet-visible spectrophotometer and the methylene-blue method (Hach Company, 1992; equivalent to Standard Method 4500-S^{2-} D for wastewater; APHA, 1985). To minimize the inclusion of atmospheric air, samples for sulfide determination were collected directly from the outflow of a thoroughly equilibrated 142-mm plastic filter with a 0.1-µm membrane filter. When dilutions were prepared, sample water was filtered continuously into an overflowing 25-mL polyethylene graduated cylinder from which aliquots were pipetted into de-ionized water in the measuring cuvette. For the third method, 15-mL Sulfide Anti-Oxidant Reagent (Sodium hydroxide-EDTA-ascorbic acid solution; Thermo-Orion #941609) was placed in a 30-mL polyethylene bottle followed by 15 mL of filtered sample water. Sulfide concentrations were determined within 24 hours by ion-specific electrode.

Thiosulfate, if present at concentrations exceeding 10 mg/L, can interfere with the colorimetric determination of sulfide by reacting with the color reagent and reducing or preventing color development (APHA, 1971). Although most S_2O_3 concentrations encountered in Yellowstone geothermal waters are less than this value, seven samples from four thermal features contained 12 to 42 mg/L S_2O_3. Sulfide concentrations determined by colorimetry likely were underestimated in these cases.

Ball and others (2006) presented strong circumstantial evidence that suddenly reducing the pH of a hot sample before the introduction of color reagent creates a condition that favors rapid degassing of H_2S and consequent underestimation of sulfide concentration. When the Hach standard method was modified by mixing Hach reagents 1 and 2 in the cuvette before introducing the sample, the measured sulfide concentrations were marginally higher (fig. 14). Notwithstanding this increase in measured concentrations, the color reagent appears to degrade rapidly after mixing with reagent 1; therefore, the short but variable elapsed times between reagent mixing and sample addition may add an enormous imprecision component to the measurements. The added step of cooling the hot sample by diluting 2.5 to 25 times (data not shown) does not appear to fully mitigate this source of error.

Sulfide concentrations measured with the ion-selective electrode were consistently higher than those measured on-site by colorimetry (fig. 15). These results strongly suggest that (1) the sulfide in samples issuing from the subsurface at elevated temperature is unstable with respect to oxidation and H_2S degassing and must be handled with care and dispatch to obtain accurate concentration estimates, and (2) the methylene-blue colorimetric method, regardless of any modifications made in an attempt to improve its accuracy, is not suitable for use in waters having temperatures exceeding ambient. Our results to date indicate that stabilizing the sulfide in geothermal water by immediately combining the hot sample with an alkaline solution containing sulfide anti-oxidant buffer (SAOB) oxidation preventative offers the best option for obtaining accurate estimates of sulfide concentrations.

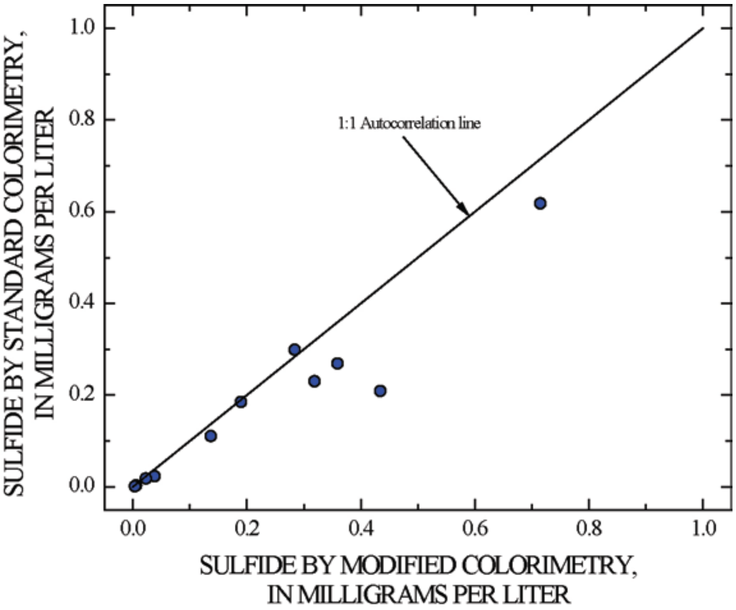


Figure 14. Comparison of results of sulfide determinations using standard and modified methylene–blue colorimetric methods.

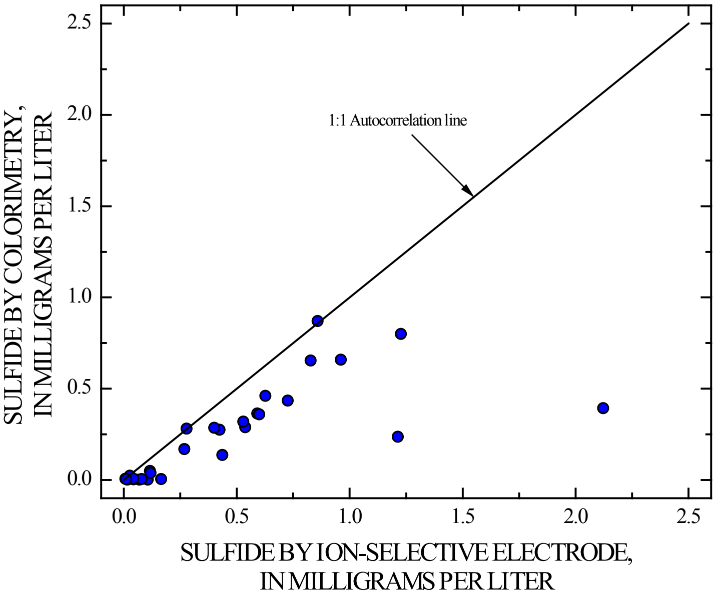


Figure 15. Comparison of results of sulfide determinations using the ion-selective electrode method and best values from the methylene–blue colorimetric method.

Major Cation and Trace Metal Determinations

Concentrations of major cations and trace metals were determined using inductively coupled plasma–optical emission spectrometry (ICP–OES) at the USGS laboratory in Boulder, Colorado. Major cations were determined using the radial plasma viewing orientation while the axial plasma viewing orientation was used for trace metals. A cesium chloride ionization buffer was added to the samples for ICP–OES measurement of Li and K concentrations. Wavelengths and plasma viewing orientations are specified in table 3.

Concentrations of Al, Sb, Cd, Cr, Co, Cu, Ni, Pb, Se, and Zn were measured using graphite-furnace atomic absorption spectrometry (GFAAS) with a transversely heated graphite atomizer (THGA) and Zeeman-effect background correction. Wavelengths, atomization temperatures, and matrix modifiers used are listed in table 3.

Hydride-generation atomic absorption spectrometry was used to measure total dissolved arsenic (As(T)), dissolved arsenite (As(III)), and total dissolved antimony (Sb(T)) concentrations in HCl-acidified samples. A flow-injection analysis system (FIAS) was used to generate arsine (McCleskey and others, 2003) or stibine. Total dissolved iron (Fe(T)) and ferrous iron (Fe(II)) concentrations were determined in samples preserved with HCl using a modification of the FerroZine colorimetric method (Stookey, 1970; Gibbs, 1976; To and others, 1999).

Samples were analyzed for total dissolved Hg at the USGS laboratory in Boulder, Colorado. Samples were analyzed for methylmercury (CH_3Hg) at the USGS Mercury Research Laboratory in Middleton, Wisconsin. Total dissolved Hg was determined by direct cold–vapor atomic fluorescence spectroscopy (CVAFS) following oxidation with chromate, reduction by $SnCl_2$, and purge and trap of the evolved zero-valent Hg onto gold-coated glass-bead columns (Taylor and others, 1997; Roth and others, 2001). The method detection limit was 0.4 nanograms per liter (ng/L).

Methylmercury concentrations were determined using the distillation/ethylation/gas-phase separation method of Olson and DeWild (1999) and detection by CVAFS (Horvat and others, 1993). The method detection limit was 0.04 ng/L. All samples were analyzed in duplicate and reanalyzed if the relative percent difference was greater than 10 percent. Analytical precision was about ±0.02 ng/L (DeWild and others, 2002).

Major Anion Determinations

Concentrations of Br, Cl, F, and SO_4 were determined at the USGS laboratory in Boulder, Colorado, by ion chromatography (IC) (Brinton and others, 1995). Fluoride concentrations were determined using an ion-selective electrode (ISE). Samples for F determination by ISE were mixed 1:1 with a total ionic strength adjustment buffer (TISAB III) (Barnard and Nordstrom, 1980). Alkalinity was determined in the mobile field laboratory or at the USGS laboratory in Boulder, Colorado, by automated titration using standardized H_2SO_4 (Barringer and Johnsson, 1996).

Nutrient and Dissolved Organic Carbon Determinations

Nutrient concentrations were determined at the USGS laboratory in Boulder, Colorado. Ammonium concentrations were determined by IC with 50 mN H_2SO_4 eluent. Nitrate was measured by IC with a 3.5 mM $NaHCO_3$ + 1.0 mM Na_2CO_3 eluent (Brinton and others, 1995).

Dissolved organic carbon concentrations were measured using the wet oxidation method (Aiken, 1992) with Oceanography International Model 700 TOC Analyzer. Potassium biphthalate was used to calibrate the instrument, and sodium benzoate was used as a different organic carbon source to check the calibration. Analyses of inorganic carbon, HCO_3, alongside the samples provided a daily verification that the acid valve was functioning properly.

Water Isotope Determinations

Hydrogen and oxygen isotope ratios were determined at the USGS Reston Stable Isotope Laboratory in Reston, Virginia (*http://isotopes.usgs.gov/*). Hydrogen isotope ratios were determined using a hydrogen equilibration technique (Coplen and others, 1991; Revesz and Coplen, 2008). Oxygen isotope ratios were determined using the CO_2 equilibration technique of Epstein and Mayeda (1953), which has been automated by Revesz and Coplen (2008). The isotopic concentration is reported in “delta notation,” which compares the isotope ratio of a sample to that of a reference standard. For the example of $^{18}O/^{16}O$ ratios, delta notation is:

$$\delta^{18}O‰ = \frac{\left({}^{18}O/{}^{16}O\right)_{\text{sample}} - \left({}^{18}O/{}^{16}O\right)_{\text{standard}}}{\left({}^{18}O/{}^{16}O\right)_{\text{standard}}} \times 1000 \qquad (1)$$

where ‰ is per mil, which is equivalent to parts per thousand.

Oxygen and hydrogen isotopic results are reported relative to the standard VSMOW (Vienna Standard Mean Ocean Water) and normalized (Coplen, 1994) on scales such that the oxygen and hydrogen isotopic values of SLAP (Standard Light Antarctic Precipitation) are –55.5 per mil and –428 per mil, respectively.

Acidity Determinations

Total acidity was determined in the mobile field laboratory or at the USGS laboratory in Boulder, Colorado, by titrating samples having pH less than 4 to pH greater than 7 using an autotitrator and standardized sodium hydroxide (NaOH) solution. The NaOH titrant (0.01–0.05 M) was standardized daily by titrating a known quantity of potassium hydrogen phthalate ($KHC_8H_4O_4$). The titrator was programmed for 50- to 100-µL constant-volume additions or constant change in millivolts (mV), typically 10 mV per addition. Equivalence points were determined using a modified Gran’s function (Gran, 1952; Barringer and Johnsson, 1996):

$$F_{acid} = (v_0 + v_{NaOH}) \times 10^{-pOH} \qquad (2)$$

where F_{acid} = the Gran function, v_0 = sample volume, v_{NaOH} = volume of NaOH titrant added, and pOH = 14 minus pH.

The principal components contributing to acidity were discussed by Ball and others (2006). Free H^+ was derived from the total acidity by subtracting the hydrogen ions produced by hydrolysis of SO_4, Fe, Al, As(V), and F, as calculated by PHREEQCi, a graphical-user-interface version (Charlton and others, 1997) of program PHREEQC (Parkhurst and Appelo, 1999) incorporating the WATEQ4F database, as follows:

$$\mathrm{Acidity}_{SO_4}=HSO_4^- \tag{3}$$

$$\mathrm{Acidity}_{Fe}=3(\mathrm{Fe}^{III}(\mathrm{tot})-\mathrm{Fe(OH)}_2^+)+2\mathrm{FeOH}^{2+}+\mathrm{Fe(OH)}_2^+ +2\mathrm{Fe}^{II}(\mathrm{tot}) \tag{4}$$

$$\mathrm{Acidity}_{Al}=3\left(\mathrm{Al(tot)}-\mathrm{AlOH}^{2+}-\mathrm{Al(OH)}_2^+\right)+2\mathrm{AlOH}^{2+}+\mathrm{Al(OH)}_2^+ \tag{5}$$

$$\mathrm{Acidity}_{As}=2\left(\mathrm{As}^{V}(\mathrm{tot})-\mathrm{H_2AsO_4^-}\right)+\mathrm{H_2\,AsO_4^-} \tag{6}$$

$$\mathrm{Acidity}_{F}=\mathrm{HF}^0 \tag{7}$$

$$\mathrm{Acidity}_{H^+}=\mathrm{Acidity}_{Total}-\mathrm{Acidity}_{SO_4}-\mathrm{Acidity}_{Fe}-\mathrm{Acidity}_{Al}-\mathrm{Acidity}_{As}-\mathrm{Acidity}_{F} \tag{8}$$

Concentrations for the above equations are expressed in moles per kilogram of water. Sample pH from the acidity titration (acidity pH) was calculated by computing the product of the H^+ activity coefficient (calculated by PHREEQCi) and the free H^+ molality (eq. 8, calculated using a spreadsheet) and computing the negative common logarithm of the resulting activity. This pH value was refined by repeating the PHREEQCi calculation and varying the input pH until the pH calculated from the PHREEQCi speciation was equal to the input pH. A flow-chart illustrating the process for refining the acidity pH is shown in figure 16.

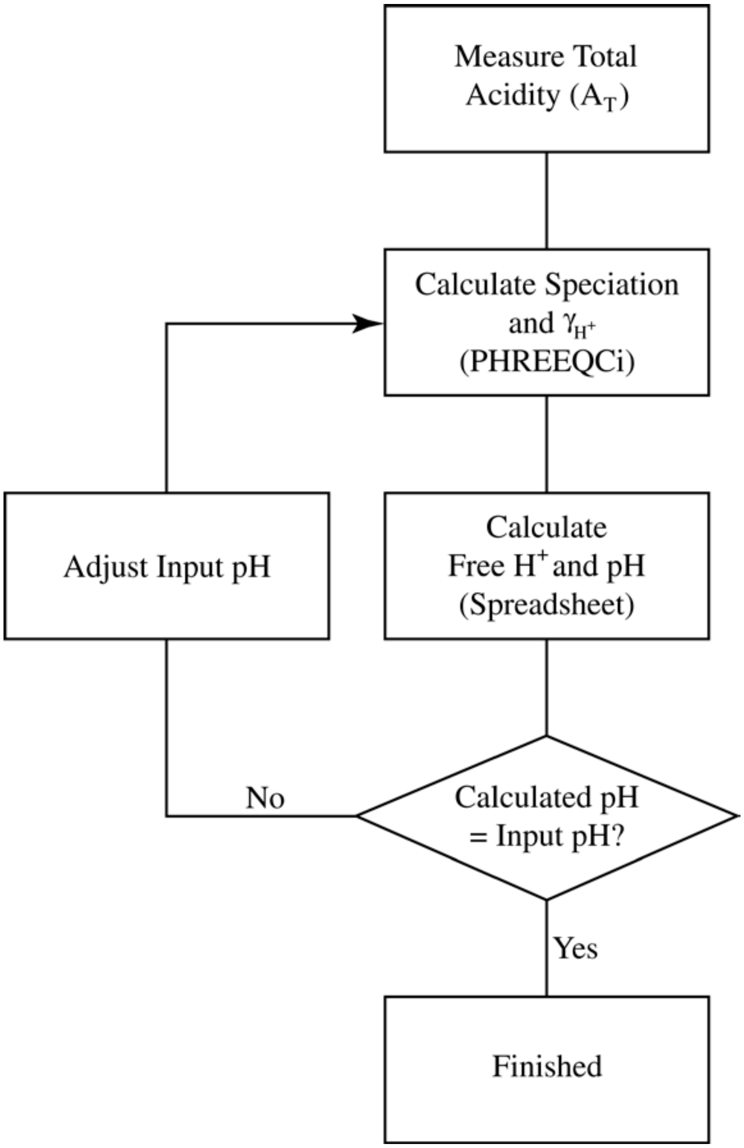


Figure 16. Flow chart illustrating the process for refining the acidity pH value.

Revised pH Measurements

Accurate measurement of pH is of primary importance for interpretation of aqueous chemical speciation. The free hydrogen ion (H^+) is usually the major cation in samples with pH less than 2.5 in geothermal waters (Ball and others, 2002), is important in controlling geochemical reactions, and is critical in calculating the charge imbalance (C.I.) for waters with pH<3. For the subset of 47 samples with pH<4, pH values determined using four different techniques are shown in table 4: (1) pH measured in the field; (2) pH measured at the USGS laboratory in Boulder, Colorado; (3) acidity pH (calculated as discussed in the previous section); and (4) pH calculated by adjusting the concentration of H^+ to yield a speciated C.I. of zero.

Comparison of pH values from the four sources allows evaluation of the measurements and estimation of more accurate pH values.

A flow chart showing the pH selection process is shown in figure 17. Field pH was considered to be the most accurate because pH measurements made in the laboratory may be biased from temperature changes and hydrolysis reactions, and the acidity pH calculation relies on measurements of SO_4, Fe, Al, As, and F, all of which are subject to analytical uncertainties. In this report, pH calculated by using the concentration of H^+ to adjust the speciated C.I. to zero was used only as a reference because C.I. pH relies on measurements of many constituents.

Differences between field and laboratory pH values were calculated by subtracting the laboratory pH value from the field pH value. Difference values were found to be greatest for samples with initial pH values between 5 and 8 (fig. 18). Laboratory pH measurements typically are made at about 22°C which can be as much as 70°C less than the temperature at which the sample pH was measured in the field. Differences in pH values between field and laboratory measurements are a function of the changes in sample temperature and composition that occur between the time of collection and the time that laboratory pH values are determined. For samples with pH less than 4.5, differences are greatest at pH greater than 3.0 and higher sample temperatures (fig. 19). For samples with pH greater than 4.5, many of the samples that had pH reductions most likely were poorly buffered, whereas samples that had pH increases likely were initially supersaturated with respect to atmospheric CO_2. Thus, positive differences, indicating laboratory pH values that are less than field pH values, likely are the result of Fe oxidation and hydrolysis (Nordstrom and Alpers, 1999) or oxidation of reduced S species, whereas negative values result from degassing of CO_2 (Nordstrom and others, 1990; fig. 20).

Charge imbalance variations also were found to be strong functions of temperature and pH. When comparing C.I. for samples calculated using pH measured in the field to C.I. for the same samples calculated using pH measured in the laboratory, the C.I. difference is seen to be greatest for samples with the lowest pH values and high temperatures. Figure 21 shows the difference between C.I. calculated at 22°C and C.I. calculated at field temperature as a function of field temperature. This difference can be attributed to the hydrolysis of SO_4, which is a function of both temperature and pH (Nordstrom and others, 2009) and possibly to other aspects of speciation such as the temperature dependence of activity coefficients.

Field pH was selected for all samples with pH greater than 3.5. For samples having a pH less than 3.5, field pH was selected unless the sample had a speciated C.I. greater than 10 percent using field pH. For samples with pH less than 3.5 and speciated C.I. greater than 10 percent using field pH, laboratory pH was selected if the speciated C.I. was less than 10 percent. For samples with pH less than 3.5 and speciated C.I. greater than 10 percent using both field and laboratory pH, acidity pH was selected if the speciated C.I. was less than 10 percent. For samples with pH less than 3.5 and having field, laboratory, and acidity pH values that produced speciated C.I.s all greater than 10 percent, the pH that produced the lowest speciated C.I. was selected from among field, laboratory, and acidity pH.

Using the process described above and illustrated in figure 17 for the subset of 47 samples, field pH was selected for 33 samples, laboratory pH was selected for 13 samples, and acidity pH was selected for one sample. Values of the selected pH are found in the tables of chemical data (tables 6–14) along with the speciated C.I. calculated using the selected pH and field temperature.

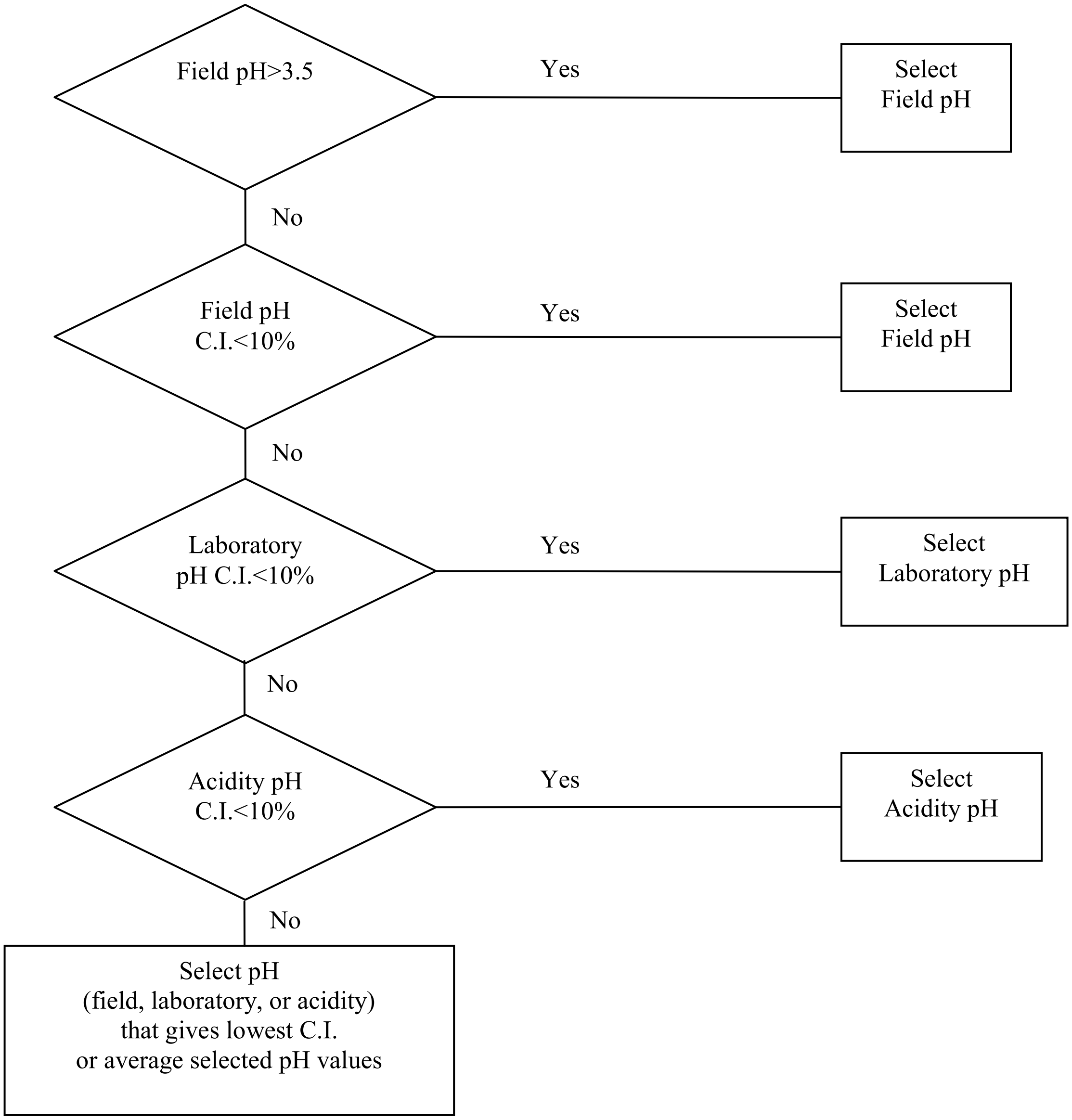


Figure 17. Flow chart showing the pH selection process. C.I., charge imbalance; >, greater than; <, less than.

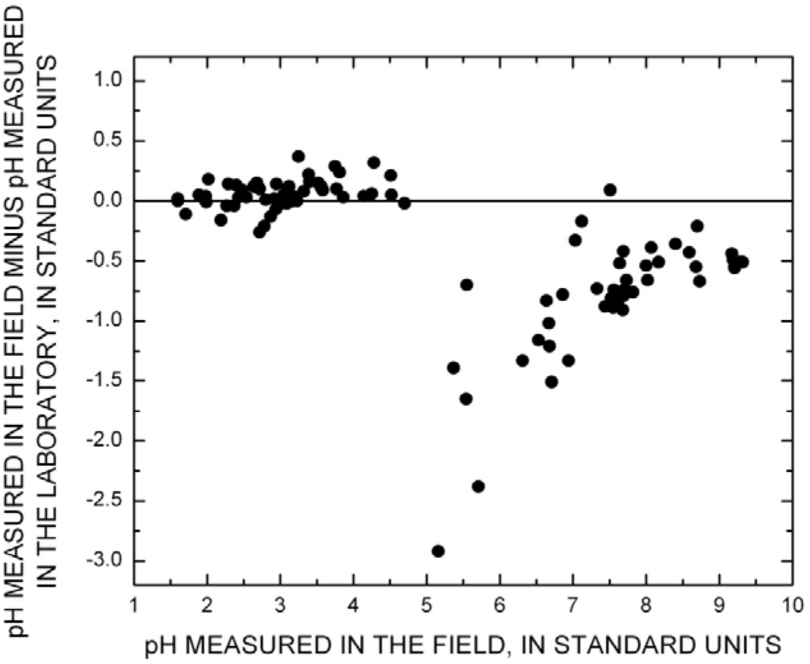


Figure 18. Difference between field and laboratory pH as a function of field pH.

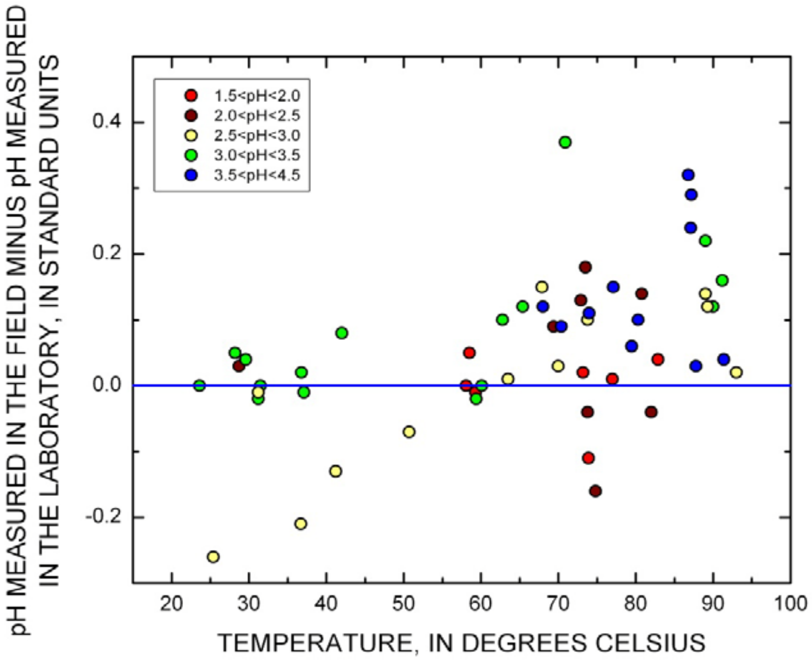


Figure 19. Difference between field and laboratory pH as a function of sample temperature, for samples with pH less than (<) 4.5.

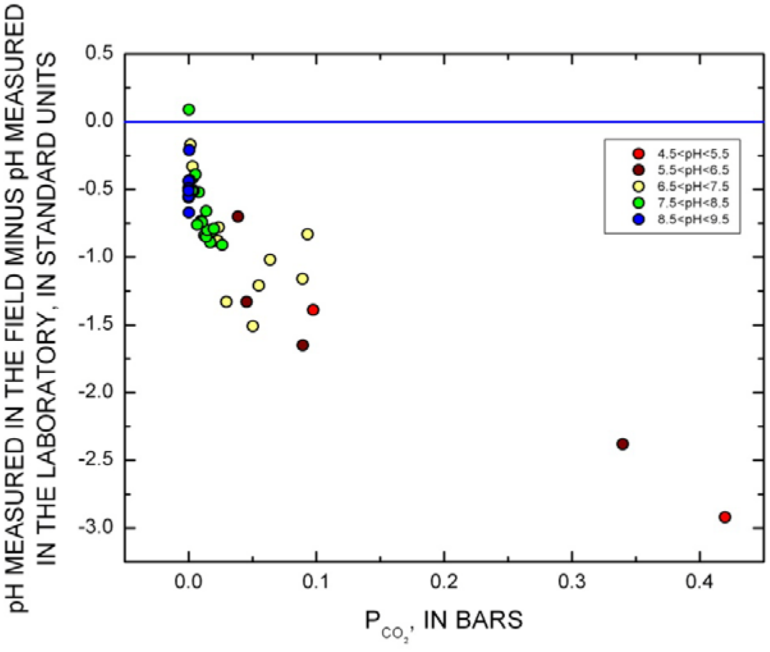


Figure 20. Difference between field and laboratory pH as a function of partial pressure of CO_2.

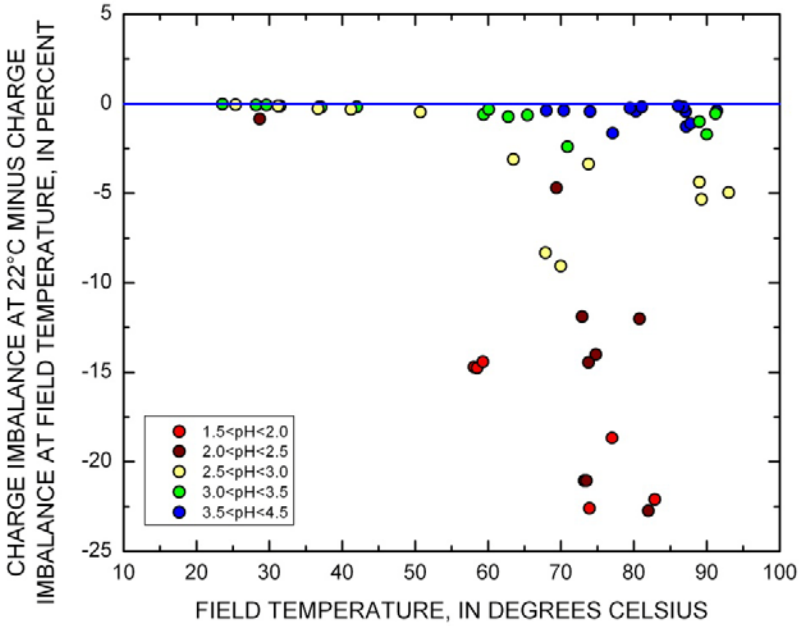


Figure 21. Difference between speciated charge imbalance at 22°C and speciated charge imbalance at field temperature in relation to field temperature.

Table 4. Sample pH measured in the field and laboratory and calculated from acidity titration and speciated charge imbalance, for samples with pH less than 4.

	- - - - - - - - - pH, in standard units - - - - - - - - -				
Sample	Measured In the field	Measured In the laboratory	Calculated from acidity titration	Calculated from charge imbalance	Selected
06WA106, Gibbon River inflow from Realgar Spring area	2.99	3.00	2.95	2.78	2.99
06WA107, Tantalus Creek at weir	3.09	3.11	3.07	2.76	3.09
06WA109, Unnamed thermal feature near Cinder Pool	3.56	3.45	3.41	3.32	3.56
06WA110, "Orpiment Puddle 3"	2.43	2.40	2.43	2.38	2.43
06WA111, Crystal Spring - western side	3.77	3.67	3.68	3.25	3.77
06WA117, "Titanic Spring"	3.56	3.44	3.42	3.06	3.56
06WA120, The Gap southwest outflow	3.08	3.06	3.06	3.24	3.08
06WA121, The Gap northeast outflow	3.32	3.24	3.21	2.78	3.32
06WA126, "Succession Spring"	3.12	3.00	2.97	2.88	3.12
06WA127, "Succession Spring" overflow channel	3.02	3.04	3.01	2.83	3.02
06WA128, "Succession Spring" overflow channel	2.94	3.01	2.98	2.79	2.94
06WA129, "Succession Spring" overflow channel	2.87	3.00	2.98	2.75	2.87
06WA130, "Succession Spring" overflow channel	2.78	2.99	2.96	2.77	2.78
06WA133, Unnamed acid spring near Perpetual Spouter	2.95	2.81	2.95	2.84	2.95
06WA134, Tantalus Creek at Back Basin exit	3.13	3.14	3.07	2.88	3.13
06WA139, Realgar Creek near mouth	3.05	3.00	2.99	2.70	3.05
06WA158, Tantalus Creek at weir	3.02	3.02	2.99	2.78	3.02
06WA164, Sulphur Caldron	2.02	1.84	2.06	1.99	2.02
06WA165, Turbulent Pool	1.89	1.84	1.88	1.82	1.84
06WA167, Washburn Inkpot #3	3.25	2.88	3.24	2.63	2.88
07WA105, "Persnickety Geyser"	3.39	3.17	3.28	3.15	3.39
07WA106, "Kaolin Spring"	2.37	2.41	2.41	2.41	2.37
07WA107, Hot spring next to "Orpiment Puddle 2"	3.12	3.00	3.08	3.02	3.12
07WA108, Unnamed thermal feature, Geyser Springs Group	2.19	2.35	2.45	2.44	2.35

Table 4. Sample pH measured in the field and laboratory and calculated from acidity titration and speciated charge imbalance, for samples with pH less than 4—Continued.

	pH, in standard units				
Sample	Measured In the field	Measured In the laboratory	Calculated from acidity titration	Calculated from charge imbalance	Selected
07WA109, Turbulent Pool	1.99	2.00	2.02	1.93	1.99
07WA110, Sulphur Caldron	1.71	1.82	1.77	1.63	1.71
07WA111, Sulphur Spring	3.86	3.83	3.31	2.83	3.86
07WA112, Unnamed thermal feature, Crater Hills area	2.27	2.31	2.36	2.14	2.36
07WA114, "Titanic Spring"	3.10	3.00	3.06	2.87	3.10
07WA115, "Lifeboat Spring"	2.48	2.39	2.50	2.47	2.48
07WA145, Unnamed acid spring near Perpetual Spouter	2.92	2.90	2.97	2.83	2.92
07WA146, Crystal Spring - western side	1.98	1.94	2.03	1.92	1.94
07WA147, Crystal Spring - eastern side	1.97	1.96	2.06	1.81	1.96
08WA105, Tantalus Creek at weir	3.06	3.06	3.06	2.45	3.06
08WA114, Sulphur Caldron	1.60	1.58	1.97	1.54	1.58
08WA115, Sulphur Spring	3.75	3.46	3.28	2.66	3.46
08WA116, Unnamed acid pool near Sulphur Spring	2.72	2.62	2.76	2.32	2.62
08WA117, Unnamed acid pool near "Bullseye Spring," Geyser Springs Group	2.68	2.53	2.90	2.18	2.53
08WA119, Deep circular pool	1.60	1.60	1.98	1.42	1.60
08WA120, Crystal Spring - western side	2.29	2.15	2.40	2.12	2.15
08WA121, Unnamed pool near The Gap	3.40	3.24	3.28	2.58	3.24
08WA122, Unnamed pool upslope from "Bullseye Spring," Geyser Springs Group	2.40	2.27	2.49	2.23	2.27
08WA123 40 cm diameter circular clay hot spring 2 meters from 08WA121	2.80	2.79	2.87	2.70	2.80
08WA124, Appendage side spring to "Lifeboat Spring"	2.64	2.52	2.74	2.38	2.52
08WA125 "Lifeboat Spring"	3.23	3.23	3.35	2.57	3.23
08WA126, Echinus Geyser	3.52	3.37	3.44	3.03	3.52
08WA131, "Kaolin Spring"	2.54	2.51	2.67	2.54	2.54

Water-Chemistry Data

Site data and water analyses for YNP thermal features, their overflow drainage channels, and surface waters sampled in 2006 to 2008 are presented in tables 1 and 5–13. To organize presentation of the results, samples are sorted first by basin, then alphabetically by spring, then by date of sample collection, and then by sampling site along the drainage channel, if present. Photographs of most of the sample sites are in the Appendix.

Overflow Drainage Chemical Profiles

Samples were collected from four overflow drainage channels to investigate changes in S, Fe, As, Sb, and N redox species and loss of solutes through volatilization or precipitation. Results are plotted on the same distance scales for each of the respective transects for comparison. For the 2006 Succession Spring transect sampling event, sample temperature, pH, specific conductance, and concentrations of Ca, SO_4, Cl, F, and Al are plotted as a function of distance from the discharge source (figs. 22 A, B, C, and D). Concentrations of Hg, As(total), Fe(total), Fe(II), Fe(III), Na, NH_4, and delta-deuterium and delta-oxygen-18 are plotted on figures 23 A, B, C, and D. Specific conductance, concentrations of SO_4, Cl, Al, and Fe(III), and δD and $\delta^{18}O$ increased with distance, whereas temperature, pH, and concentrations of Hg, As(total), NH_4, and Fe(II) decreased with distance, and concentrations of Ca, F, Na, and Fe(total) were essentially unchanged.

For the 2008 Ojo Caliente transect sampling event, sample temperature, pH, field and laboratory specific conductance, and concentrations of SO_4, Cl, Li, and B are plotted as a function of distance from the discharge source on figures 24 A, B, C, and D. Concentrations of Na, K, NO_3, dissolved oxygen, and As(total), and delta-deuterium and delta-oxygen-18 are plotted as a function of distance from the discharge source on figures 25 A, B, and C. Sample pH, field and laboratory specific conductance, and concentrations of SO_4, Cl, Li, and B, Na, K, NO_3, dissolved oxygen and As(total), and delta-deuterium and delta-oxygen-18 increased with distance, whereas temperature decreased with distance and K concentration was essentially unchanged.

For the upper Rabbit Creek area transect sampling event (06WA114), sample temperature, pH, specific conductance, concentrations of Ca, SO_4, Cl, F, Al, are plotted as a function of distance from the discharge source on figures 26 A, B, C, and D. Concentrations of Na, Li, B, Sb(total), Hg, and As(total), and delta-deuterium and delta-oxygen-18 are plotted on figures 27 A, B, C, and D. Sample pH, specific conductance, concentrations of Ca, SO_4, Cl, F, Al, Na, Li, B, and As(total), and delta-deuterium and delta-oxygen-18 increased with distance, whereas temperature and concentrations of Sb(total) and Hg decreased with distance.

For the lower Rabbit Creek area transect sampling event (06WA116), sample temperature, pH, specific conductance, concentrations of Ca, SO_4, Cl, F, Al, are plotted as a function of distance from the discharge source on figures 28 A, B, C, and D. Concentrations of B, Li, Na, HCO_3, Hg, and As(total), and delta-deuterium and delta-oxygen-18 are plotted on figures 29 A, B, C, and D. Sample pH, specific conductance, concentrations of Ca, SO_4, Cl, F, Al, Na, B, Na, alkalinity, and As(total), and delta-deuterium and delta-oxygen-18 increased with distance, whereas temperature and concentration of Hg decreased with distance.

Mercury results, plotted on figures 23 A, 27 C, and 29 C, illustrate generally decreasing Hg(T) concentrations with distance. Mercury concentration in the Succession Spring transect decreased from 127 to 21 ng/L, and mercury concentration in the lower Rabbit Creek transect decreased from 175 to 70 ng/L.

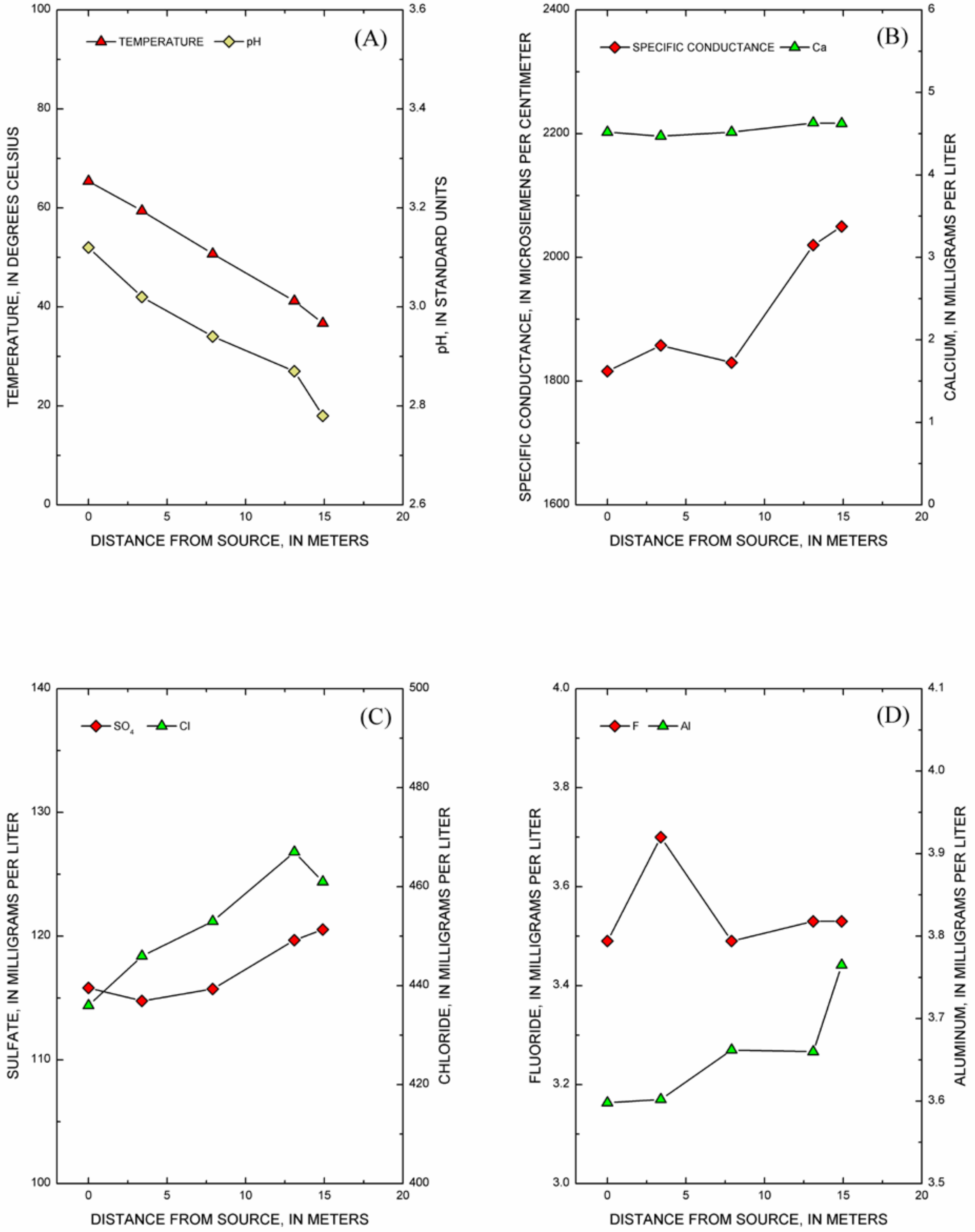


Figure 22. Sample temperature and pH (A), specific conductance and concentration of calcium (B), concentrations of sulfate and chloride (C), and concentrations of fluoride and aluminum (D) as a function of drainage distance for Succession Spring and its overflow drainage channel for samples collected in 2006.

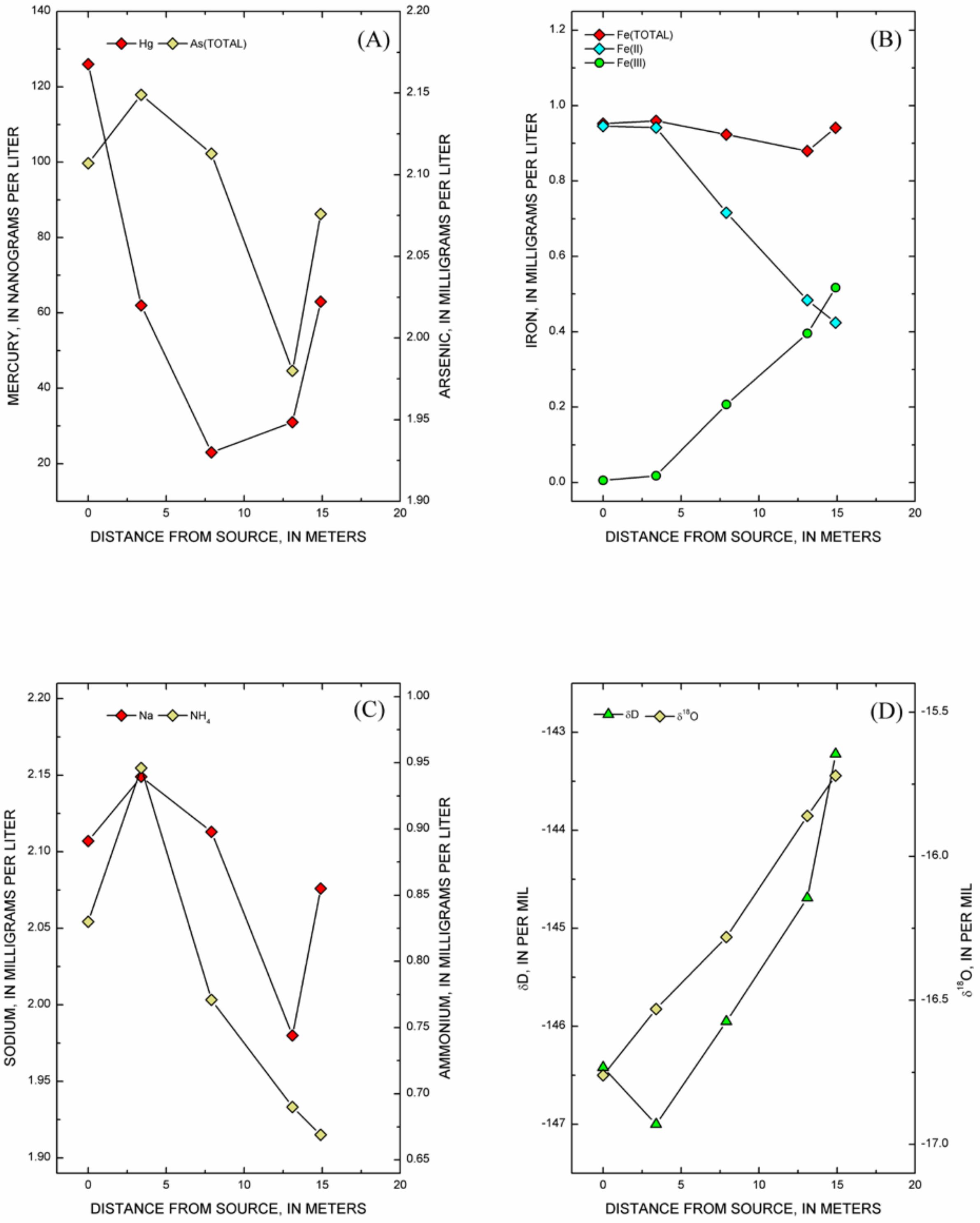


Figure 23. Concentrations of mercury and arsenic(total) (A), concentrations of iron (total), iron (II), and iron (III) (B), concentrations of sodium and ammonium (C), and delta deuterium and delta ^{18}O (D) as a function of drainage distance for Succession Spring and its overflow drainage channel for samples collected in 2006.

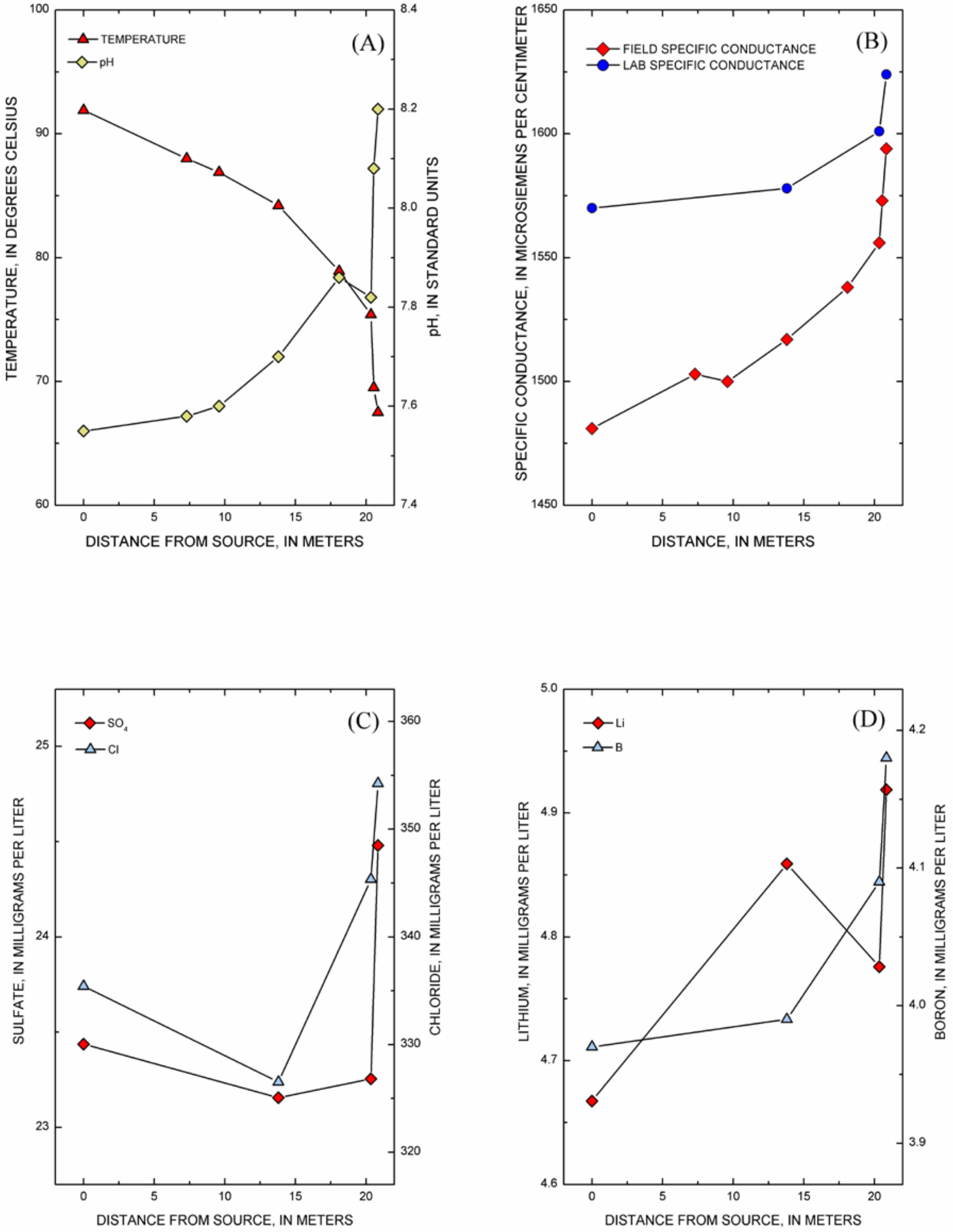


Figure 24. Sample temperature and pH (A), field and laboratory specific conductance (B), concentrations of sulfate and chloride (C), and concentrations of lithium and boron (D) as a function of drainage distance for Ojo Caliente Spring and its overflow drainage channel for samples collected in 2008.

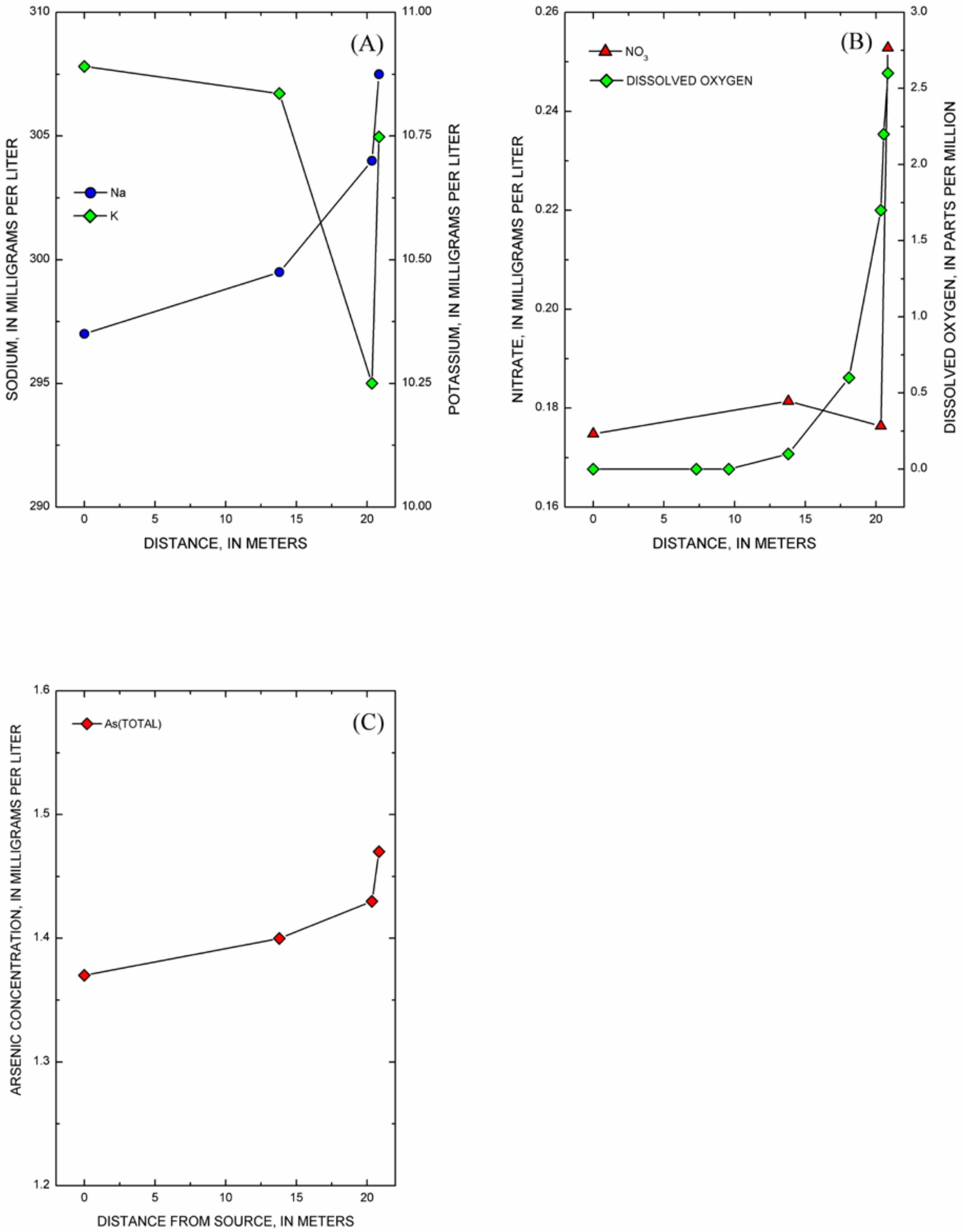


Figure 25. Concentrations of sodium and potassium (A), concentrations of nitrate and dissolved oxygen (B) and concentration of arsenic (total) (C) as a function of drainage distance for Ojo Caliente Spring and its overflow drainage channel for samples collected in 2008.

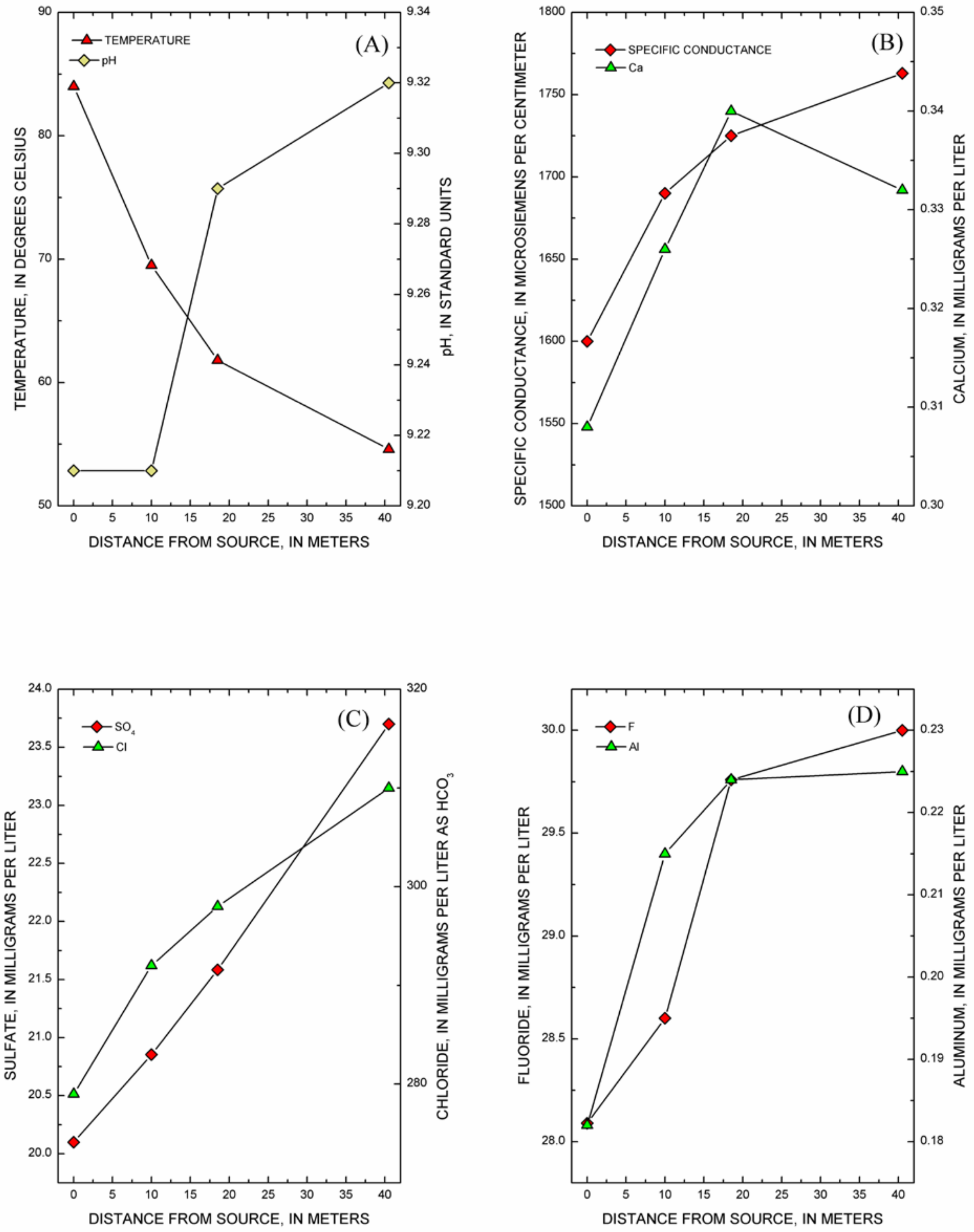


Figure 26. Sample temperature and pH (A), specific conductance and concentration of calcium (B), concentrations of sulfate and chloride (C) and concentrations of fluoride and aluminum (D) as a function of drainage distance for an unnamed thermal feature and its overflow drainage channel in the upper Rabbit Creek area for samples collected in 2006.

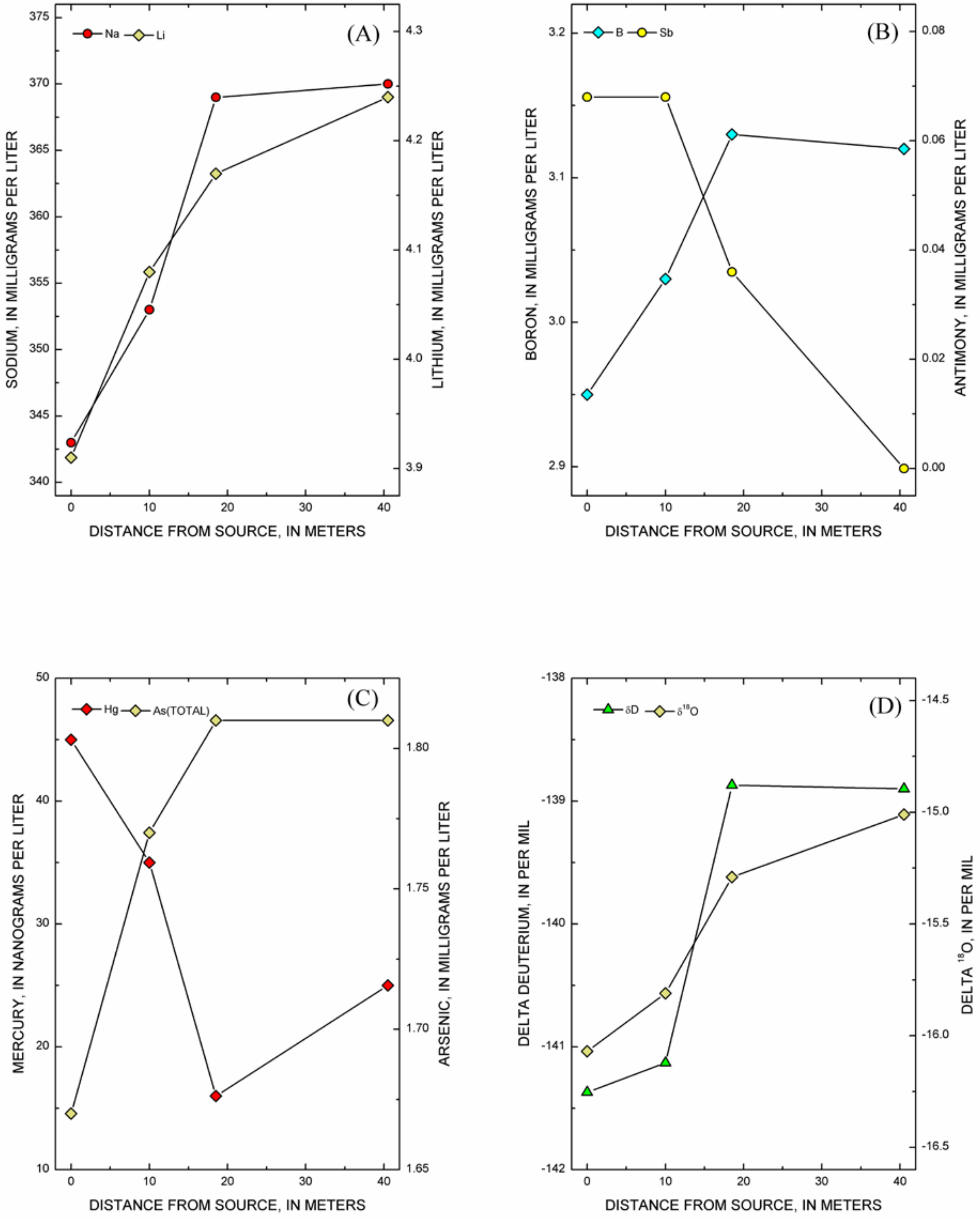


Figure 27. Concentrations of sodium and lithium (A), concentrations of boron and antimony (total) (B), concentrations of mercury and arsenic (total) (C), and delta deuterium and delta ^{18}O (D) as a function of drainage distance for an unnamed thermal feature and its overflow drainage channel in the upper Rabbit Creek area for samples collected in 2006.

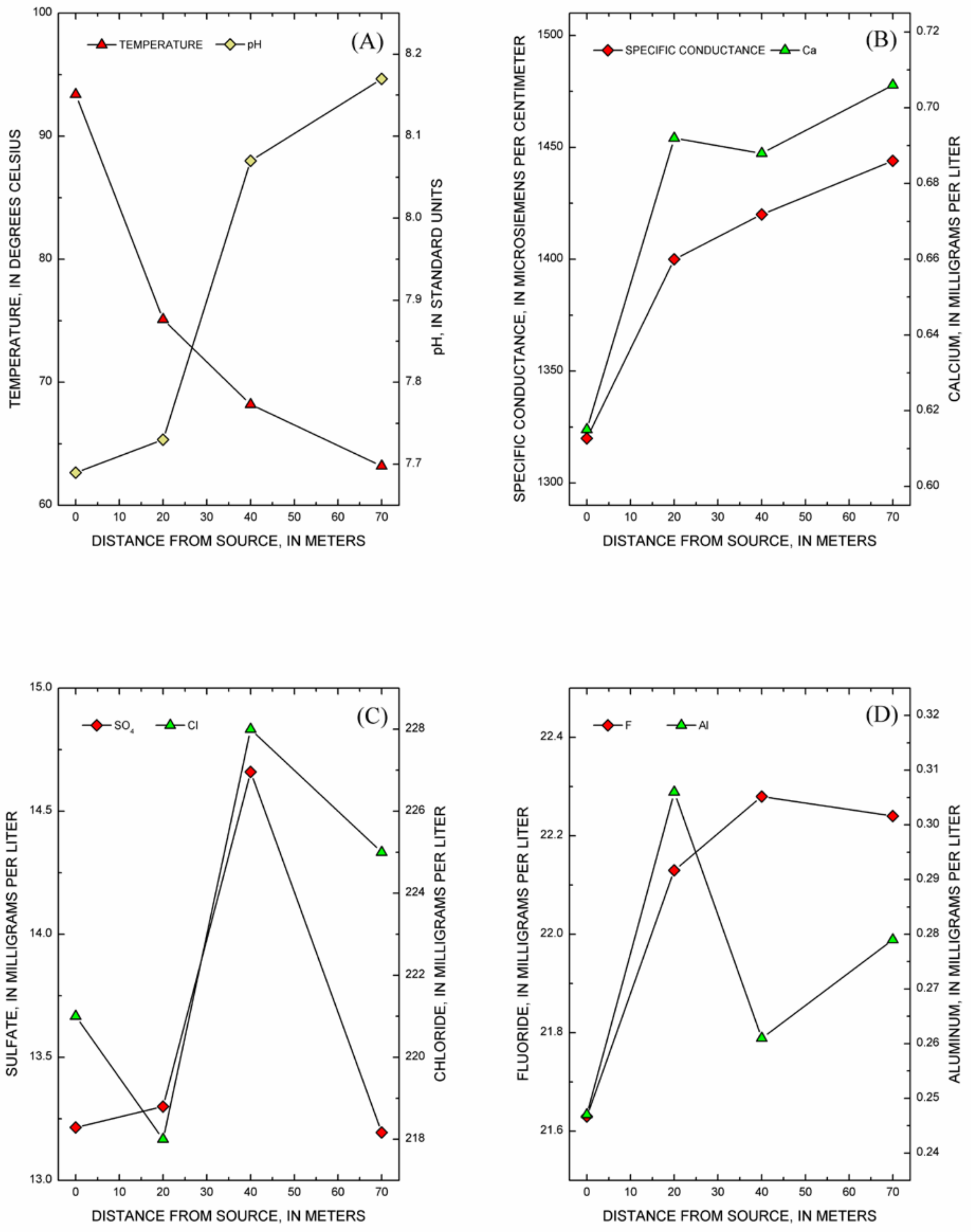


Figure 28. Sample temperature and pH (A), specific conductance, and concentration of calcium (B), concentrations of sulfate and chloride (C), and concentrations of fluoride and aluminum (D) as a function of drainage distance for an unnamed thermal feature and its overflow drainage channel in the lower Rabbit Creek area for samples collected in 2006.

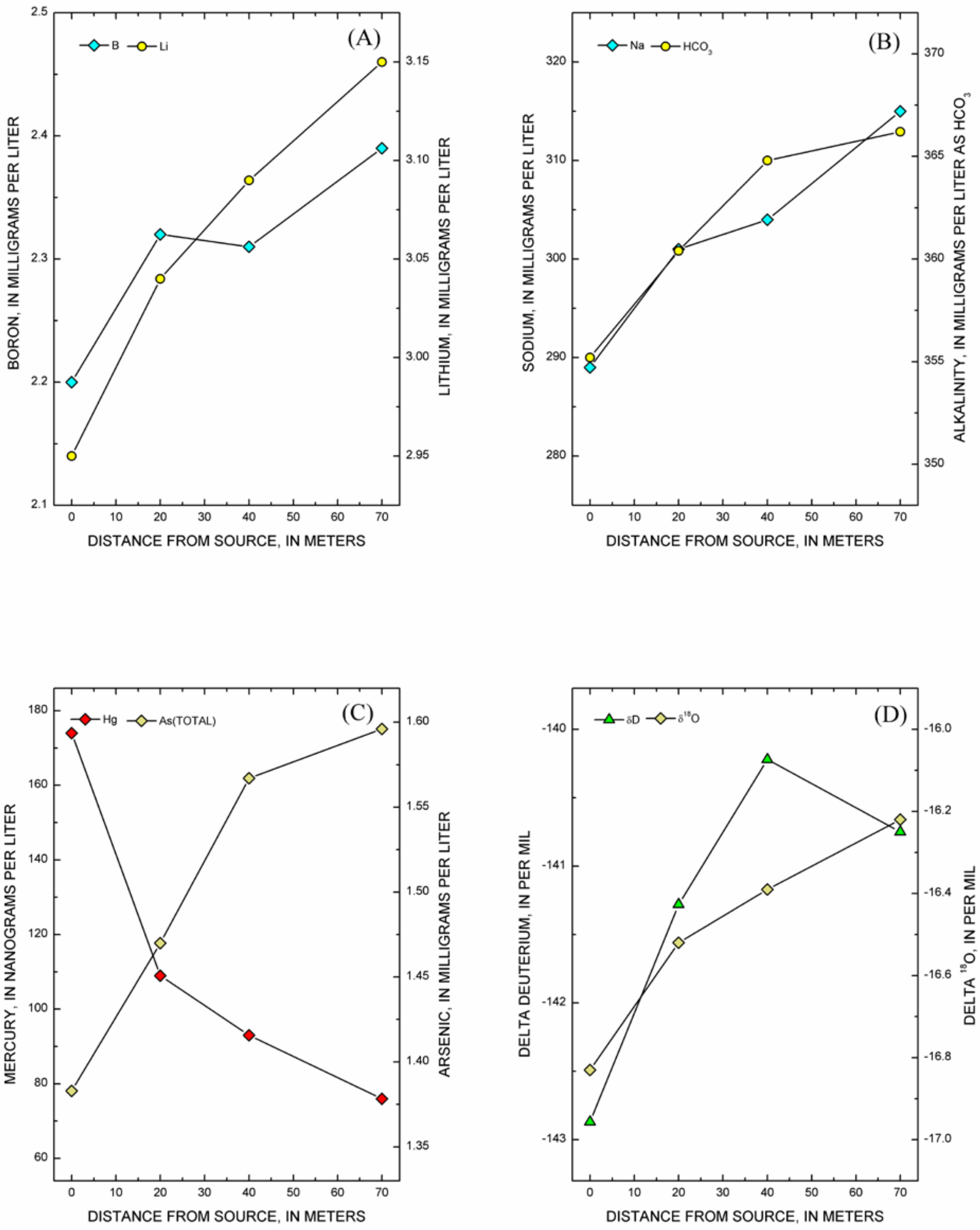


Figure 29. Concentrations of boron and lithium (A), concentrations of sodium and bicarbonate (B), concentrations of mercury and arsenic(total) (C), and delta deuterium and delta ^{18}O (D) as a function of drainage distance for an unnamed thermal feature and its overflow drainage channel in the lower Rabbit Creek area for samples collected in 2006.

Table 5. Results of water analyses for Norris-Mammoth corridor and the West Nymph Creek thermal area, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

	Norris-Mammoth Corridor		**West Nymph Creek Thermal Area**	
Location	**Apollinaris Spring**	**Nymphy Creek**	**Unnamed most upslope pool**	**Unnamed sunken circular pool**
Sample ID	06WA124	06WA136	08WA118	08WA119
Collection Date / Time	5/16/06 12:20	9/12/06 10:00	9/22/08 16:00	9/22/08 17:20
Temperature, °C	10.5	15.5	61.8	58.1
pH (field / laboratory)	5.16 / 8.08	6.86 / 7.64	5.71 / 8.09	1.60 / 1.60
Specific conductance (field / laboratory), µS/cm	138 / 136	741 / 739	347 / 350	7650 / 11,830
Eh, V	0.448	0.445	0.120	0.570
Density, g/mL at 20°C	0.9983	0.9987	0.9985	1.0004
Dissolved oxygen (DO), mg/L	---	7.0	---	---
Constituent, mg/L [1]				
Calcium (Ca)	13.8	11.4	6.05	4.32
Magnesium (Mg)	3.46	1.25	0.376	0.880
Sodium (Na)	6.94	137	58.6	25.5
Potassium (K)	3.06	13.2	4.67	32.2
Strontium (Sr)	0.047	0.027	0.011	0.018
Barium (Ba)	0.004	0.014	0.014	0.065
Lithium (Li)	0.021	0.649	0.303	0.048
Sulfate (SO_4)	5.15	64.3	46.0	2820
Thiosulfate (S_2O_3)	---	---	---	<0.1
Polythionate (S_nO_6), mM	---	---	---	<0.001
Hydrogen sulfide (H_2S)	---	---	---	---
Alkalinity (HCO_3)	71.3	198	95.9	---
Acidity (free / total), mM	---	---	---	34.2 / 42.4
Fluoride (F)	4.39	5.18	6.28	0.370
Chloride (Cl)	0.667	76.8	7.68	4.54
Bromide (Br)	<0.03	0.23	<0.03	<0.03
Nitrate (NO_3)	0.37	0.12	0.09	0.19
Ammonium (NH_4)	<0.07	<0.07	0.300	29.0
Silica (SiO_2)	54.5	115	96.8	202
Boron (B)	0.013	1.15	0.227	0.556
Aluminum (Al)	1.95	0.20	0.24	59.3
Iron total (Fe(T))	0.005	0.050	0.014	17.7
Ferrous iron (Fe(II))	<0.002	0.050	0.014	17.0
Manganese (Mn)	0.011	0.012	0.139	0.523
Copper (Cu)	0.0042	<0.0005	<0.0005	<0.0005
Zinc (Zn)	0.022	<0.004	<0.004	0.129
Cadmium (Cd)	0.0002	<0.0001	<0.0001	0.0002
Chromium (Cr)	0.0006	<0.0005	<0.0005	0.0042
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	11.0	11.0	94.4	140
Methylmercury (CH_3Hg), ng/L	---	0.21	0.15	0.05
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	0.040
Beryllium (Be)	0.004	<0.001	0.001	0.005
Vanadium (V)	<0.005	<0.005	<0.005	0.008
Molybdenum (Mo)	<0.007	<0.007	0.010	<0.007
Antimony (Sb)	<0.001	0.006	<0.001	<0.001
Selenium (Se)	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	0.0015	0.307	0.001	0.002
Arsenite (As(III))	0.0011	0.006	0.001	0.002
Dissolved organic carbon (DOC)	1.7	2.7	1.1	10.5
δD, per mil	-139.03	-134.74	-139.64	-103.66
$\delta^{18}O$, per mil	-18.39	-16.46	-17.13	-4.06
sum cations, meq/L	1.4	7.0	3.0	36.7
sum anions, meq/L	1.4	7.0	3.0	34.5
Charge imbalance, percent	4.7	1.0	0.8	6.1

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

	--------------------------------One Hundred Spring Plain--------------------------------			
Location	**Cinder Pool**	**Realgar Creek near mouth**	**Realgar Creek near mouth**	**Tantalus Creek at weir**
Sample ID	07WA113	06WA106	06WA139	06WA107
Collection Date / Time	9/12/07 13:00	5/13/06 11:30	9/12/06 15:00	5/13/06 13:15
Temperature, °C	86.8	31.2	28.2	31.2
pH (field / laboratory)	4.28 / 3.96	2.99 / 3.00	3.05 / 3.00	3.09 / 3.11
Specific conductance (field / laboratory), µS/cm	2090 / 2260	2210 / 2260	2330 / 2340	1998 / 2040
Eh, V	-0.042	0.329	0.702	0.381
Density, g/mL at 20°C	0.9994	0.9992	0.9993	0.9991
Dissolved oxygen (DO), mg/L	---	---	---	7.5
Constituent, mg/L [1]				
Calcium (Ca)	5.22	4.49	4.58	3.59
Magnesium (Mg)	0.020	0.226	0.210	0.242
Sodium (Na)	409	292	310	263
Potassium (K)	41.4	44.9	50.1	44.7
Strontium (Sr)	0.015	0.028	0.025	0.014
Barium (Ba)	0.015	0.101	0.111	0.076
Lithium (Li)	3.96	2.28	2.72	2.87
Sulfate (SO_4)	63.7	152	152	133
Thiosulfate (S_2O_3)	19.4	---	---	---
Polythionate (S_nO_6), mM	<0.001	---	---	---
Hydrogen sulfide (H_2S)	2.12	---	---	---
Alkalinity (HCO_3)	---	---	---	---
Acidity (free / total), mM	---	1.15 / 1.90	1.02 / 1.71	0.93 / 1.40
Fluoride (F)	6.83	4.12	4.31	3.75
Chloride (Cl)	633	456	499	426
Bromide (Br)	1.82	1.51	1.63	1.42
Nitrate (NO_3)	<0.05	0.11	<0.05	0.09
Ammonium (NH_4)	6.77	2.18	1.29	1.97
Silica (SiO_2)	383	250	261	315
Boron (B)	9.70	6.96	8.06	6.17
Aluminum (Al)	0.95	3.99	3.59	2.47
Iron total (Fe(T))	0.012	1.20	1.10	1.07
Ferrous iron (Fe(II))	0.012	0.527	0.296	0.437
Manganese (Mn)	0.004	0.038	0.037	0.066
Copper (Cu)	<0.0005	<0.0005	0.0006	<0.0005
Zinc (Zn)	<0.004	0.008	0.009	0.008
Cadmium (Cd)	<0.0001	0.0003	<0.0001	<0.0001
Chromium (Cr)	<0.0005	0.0006	<0.0005	0.0009
Cobalt (Co)	<0.0007	<0.0007	<0.0007	0.0007
Mercury total (Hg), ng/L	53.0	---	22.0	---
Methylmercury (CH_3Hg), ng/L	0.04	---	0.05	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	0.0008
Beryllium (Be)	<0.001	0.002	0.002	0.002
Vanadium (V)	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.108	<0.007	<0.007	0.048
Antimony (Sb)	0.019	0.033	0.041	0.050
Selenium (Se)	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	2.35	1.37	1.52	1.48
Arsenite (As(III))	1.09[2]	0.061	0.035	0.032
Dissolved organic carbon (DOC)	0.8	0.9	0.8	1.4
δD, per mil	-125.31	-135.89	-131.64	-132.16
δ^{18}O, per mil	-10.69	-13.94	-13.27	-13.61
sum cations, meq/L	20.1	15.9	16.6	14.3
sum anions, meq/L	19.4	15.9	17.1	14.7
Charge imbalance, percent	3.7	0.2	-3.0	-2.7

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and δ^{18}O (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	---------------------------One Hundred Spring Plain---------------------------		
Location	**Tantalus Creek at weir**	**Tantalus Creek at weir**	**Unnamed thermal feature northeast of Cinder Pool**
Sample ID	06WA158	08WA105	06WA109
Collection Date / Time	9/14/06 18:30	9/17/08 15:30	5/13/06 15:50
Temperature, °C	23.6	31.5	74.0
pH (field / laboratory)	3.02 / 3.02	3.06 / 3.06	3.56 / 3.45
Specific conductance (field / laboratory), µS/cm	2290 / 2300	2140 / 2150	1720 / 1880
Eh, V	---	0.670	0.142
Density, g/mL at 20°C	0.9993	0.9991	0.9991
Dissolved oxygen (DO), mg/L	---	---	---
Constituent, mg/L [1]			
Calcium (Ca)	4.09	3.49	3.41
Magnesium (Mg)	0.231	0.204	0.223
Sodium (Na)	310	330	269
Potassium (K)	56.3	53.5	46.8
Strontium (Sr)	0.016	0.014	0.019
Barium (Ba)	0.083	0.079	0.164
Lithium (Li)	3.93	3.54	2.92
Sulfate (SO_4)	155	152	91.2
Thiosulfate (S_2O_3)	---	---	<0.1
Polythionate (S_nO_6), mM	---	---	<0.001
Hydrogen sulfide (H_2S)	---	---	0.30
Alkalinity (HCO_3)	---	---	---
Acidity (free / total), mM	1.07 / 1.61	0.83 / 1.39	0.40 / 0.81
Fluoride (F)	4.27	4.61	3.33
Chloride (Cl)	490	480	417
Bromide (Br)	2.03	2.07	1.45
Nitrate (NO_3)	0.10	0.24	<0.05
Ammonium (NH_4)	1.40	2.56	2.65
Silica (SiO_2)	364	371	385
Boron (B)	7.63	7.06	6.16
Aluminum (Al)	2.47	2.24	1.57
Iron total (Fe(T))	1.27	0.944	1.48
Ferrous iron (Fe(II))	0.203	0.388	1.48
Manganese (Mn)	0.080	0.066	0.059
Copper (Cu)	0.0006	<0.0005	<0.0005
Zinc (Zn)	0.018	0.008	0.017
Cadmium (Cd)	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005
Cobalt (Co)	0.0019	<0.0007	0.0012
Mercury total (Hg), ng/L	17.0	35.3	---
Methylmercury (CH_3Hg), ng/L	0.04	0.16	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.002	0.002	0.002
Vanadium (V)	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.048	0.047	<0.007
Antimony (Sb)	0.060	0.053	0.001
Selenium (Se)	0.003	<0.001	<0.001
Arsenic (As)	1.85	1.70	1.39
Arsenite (As(III))	0.029	0.058	0.90
Dissolved organic carbon (DOC)	1.2	1.3	0.8
δD, per mil	-131.62	-132.49	-138.83
$\delta^{18}O$, per mil	-13.02	-13.03	-14.79
sum cations, meq/L	16.9	17.7	14.1
sum anions, meq/L	17.0	16.6	13.6
Charge imbalance, percent	-0.2	6.0	3.3

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	---------------------Back Basin---------------------				
Location	**Cistern Spring**	**Cistern Spring**	**Cistern Spring**	**Cistern Spring**	**Echinus Geyser**
Sample ID	06WA123	06WA159	07WA116	08WA127	08WA126
Collection Date / Time	5/16/06 12:20	9/15/06 11:20	9/13/07 13:35	9/24/08 10:15	9/24/08 9:30
Temperature, °C	85.7	84.5	81.1	79.5	77.1
pH (field / laboratory)	5.37 / 6.76	5.54 / 7.19	4.51 / 4.30	4.25 / 4.19	3.52 / 3.37
Specific conductance (field / laboratory), µS/cm	1792 / 1934	1995 / 2120	1643 / 1708	1660 / 1783	1136 / 1288
Eh, V	0.057	-0.052	0.019	0.140	0.480
Density, g/mL at 20°C	0.9993	0.9994	0.9991	0.9992	0.9989
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	2.13	2.50	1.80	1.54	4.28
Magnesium (Mg)	0.097	0.100	0.092	0.046	0.487
Sodium (Na)	335	353	318	280	176
Potassium (K)	45.5	63.6	33.6	38.4	48.1
Strontium (Sr)	0.008	0.010	0.006	0.006	0.007
Barium (Ba)	0.018	0.021	0.013	0.013	0.055
Lithium (Li)	3.52	4.46	3.08	3.38	0.874
Sulfate (SO_4)	69.3	57.7	98.3	69.7	282
Thiosulfate (S_2O_3)	12.1	13.8	22.2	---	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	---	<0.001
Hydrogen sulfide (H_2S)	0.32	0.63	0.53	0.73	0.10
Alkalinity (HCO_3)	9.1	12.7	---	---	---
Acidity (free / total), mM	---	---	---	---	0.46 / 0.96
Fluoride (F)	5.96	5.76	5.64	5.62	5.53
Chloride (Cl)	498	559	430	450	159
Bromide (Br)	2.00	1.83	1.19	1.44	0.45
Nitrate (NO_3)	<0.05	<0.05	<0.05	0.01	0.03
Ammonium (NH_4)	1.44	1.35	7.86	6.76	1.15
Silica (SiO_2)	649	609	412	432	297
Boron (B)	7.63	8.72	7.81	7.76	2.43
Aluminum (Al)	0.11	0.216	0.13	0.13	2.22
Iron total (Fe(T))	<0.002	0.009	0.010	0.024	2.21
Ferrous iron (Fe(II))	<0.002	0.009	0.010	0.024	2.15
Manganese (Mn)	0.039	0.048	0.059	0.037	0.255
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	0.005	<0.004	0.015
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Chromium (Cr)	<0.0005	0.0006	<0.0005	<0.0005	<0.0005
Cobalt (Co)	0.0035	0.0050	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	132	19.0	42.0	340	36.5
Methylmercury (CH_3Hg), ng/L	---	0.04	0.78	0.58	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001	0.007
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.096	0.125	0.071	0.103	<0.007
Antimony (Sb)	0.084	0.085	0.060	0.061	<0.001
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.77	2.09	1.49	1.52	0.257
Arsenite (As(III))	1.45[2]	1.58[2]	1.30[2]	1.27[2]	0.061
Dissolved organic carbon (DOC)	1.2	0.6	0.9	0.7	1.1
δD, per mil	-128.57	-128.47	-117.94	-121.06	-140.67
$\delta^{18}O$, per mil	-12.04	-12.30	-8.08	-8.48	-16.48
sum cations, meq/L	16.4	17.8	15.7	14.2	9.7
sum anions, meq/L	15.9	17.5	14.4	14.4	10.0
Charge imbalance, percent	3.0	2.0	8.6	-1.1	-3.8

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	--Back Basin--				
Location	**Perpetual Spouter**	**Perpetual Spouter**	**Perpetual Spouter**	**Porkchop Geyser**	**Porkchop Geyser**
Sample ID	06WA132	07WA144	08WA130	07WA143	08WA129
Collection Date / Time	5/17/06 14:15	9/18/07 15:15	9/24/08 13:21	9/18/07 14:10	9/24/08 12:07
Temperature, °C	90.7	78.1	88.0	86.1	80.1
pH (field / laboratory)	7.12 / 7.29	7.03 / 7.36	7.51 / 7.42	4.52 / 4.47	8.40 / 8.76
Specific conductance (field / laboratory), µS/cm	2450 / 2680	2440 / 2560	2350 / 2590	1925 / 2060	2210 / 2340
Eh, V	0.030	-0.102	0.060	-0.059	0.020
Density, g/mL at 20°C	0.9995	0.9994	0.9993	0.9992	0.9993
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	9.49	9.80	8.41	4.37	3.35
Magnesium (Mg)	0.070	0.065	0.059	0.018	0.004
Sodium (Na)	463	478	429	348	394
Potassium (K)	42.9	45.1	46.1	53.0	77.7
Strontium (Sr)	0.034	0.030	0.031	0.012	0.012
Barium (Ba)	0.013	0.013	0.010	0.008	0.007
Lithium (Li)	5.26	5.52	5.09	4.55	5.18
Sulfate (SO_4)	33.2	41.2	34.8	51.1	23.7
Thiosulfate (S_2O_3)	<0.1	<0.1	---	42.1	0.3
Polythionate (S_nO_6), mM	<0.001	<0.001	---	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.019	0.12	0.04	1.23	0.11
Alkalinity (HCO_3)	12.9	18.6	15.2	<1	55.9
Acidity (free / total), mM	---	---	---	---	---
Fluoride (F)	6.82	8.50	7.88	5.67	7.05
Chloride (Cl)	749	788	754	572	644
Bromide (Br)	2.73	2.67	2.48	1.86	2.19
Nitrate (NO_3)	0.26	0.12	0.27	0.11	0.24
Ammonium (NH_4)	0.718	1.47	0.620	11.3	1.58
Silica (SiO_2)	362	304	302	378	567
Boron (B)	11.2	12.4	11.5	8.98	9.66
Aluminum (Al)	0.183	0.165	0.131	0.041	0.015
Iron total (Fe(T))	0.072	0.108	0.013	0.030	<0.002
Ferrous iron (Fe(II))	0.009	0.072	0.006	0.030	<0.002
Manganese (Mn)	0.037	0.040	0.034	0.033	0.003
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	0.008	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.0039	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	0.0092	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	22.0	120	23.2	3.4	48.5
Methylmercury (CH_3Hg), ng/L	---	0.04	---	0.06	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.071	0.086	0.077	0.164	0.214
Antimony (Sb)	0.125	0.112	0.161	0.056	0.147
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	3.01	2.70	2.92	1.79	2.48
Arsenite (As(III))	1.28	2.26	1.98	1.76	2.02
Dissolved organic carbon (DOC)	0.7	0.3	0.9	0.5	1.0
δD, per mil	-139.42	-141.30	-140.54	-119.02	-143.14
$\delta^{18}O$, per mil	-14.85	-14.83	-14.93	-7.09	-15.00
sum cations, meq/L	22.5	23.3	21.1	18.0	20.2
sum anions, meq/L	22.5	23.9	22.8	17.5	20.8
Charge imbalance, percent	0.1	-2.5	-7.7	3.0	-3.3

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	---Back Basin				---
Location	**"Second Erupter"**	**"Second Erupter"**	**"Second Erupter"**	**Tantalus Creek - Back Basin Drainage**	**Unnamed hot spring near Perpetual Spouter**
Sample ID	06WA122	07WA142	08WA128	06WA134	06WA133
Collection Date / Time	5/16/06 11:30	9/18/07 13:10	9/24/08 11:10	5/17/06 14:20	5/17/06 16:00
Temperature, °C	89.3	83.3	89.1	37.1	89.0
pH (field / laboratory)	8.02 / 8.68	6.31 / 7.64	8.00 / 8.54	3.13 / 3.14	2.95 / 2.81
Specific conductance (field / laboratory), µS/cm	2230 / 2410	2420 / 2530	2170 / 2330	2040 / 2110	1380 / 1852
Eh, V	0.027	-0.130	0.010	0.659	0.432
Density, g/mL at 20°C	0.9995	0.9995	0.9995	0.9992	0.9990
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	4.04	6.11	3.63	3.63	3.14
Magnesium (Mg)	0.013	0.041	0.008	0.245	0.357
Sodium (Na)	398	453	368	285	163
Potassium (K)	71.2	70.1	76.8	52.4	59.7
Strontium (Sr)	0.014	0.018	0.013	0.012	0.017
Barium (Ba)	0.008	0.014	0.007	0.057	0.111
Lithium (Li)	5.37	5.91	5.08	3.41	1.000
Sulfate (SO_4)	21.0	61.4	23.6	126	214
Thiosulfate (S_2O_3)	<0.1	14.4	<0.1	---	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	---	<0.001
Hydrogen sulfide (H_2S)	0.13	0.60	0.36	---	0.008
Alkalinity (HCO_3)	55.5	39.8	54.2	---	---
Acidity (free / total), mM	---	---	---	0.87 / 1.33	1.85 / 2.17
Fluoride (F)	6.66	7.49	7.02	4.16	0.746
Chloride (Cl)	647	764	631	454	234
Bromide (Br)	2.32	2.40	2.13	1.53	0.84
Nitrate (NO_3)	<0.05	0.08	0.33	<0.05	0.15
Ammonium (NH_4)	0.351	2.33	1.02	1.32	0.09
Silica (SiO_2)	780	427	625	371	412
Boron (B)	9.75	11.8	9.57	7.05	3.92
Aluminum (Al)	0.011	0.015	0.014	2.06	0.57
Iron total (Fe(T))	<0.002	<0.002	<0.002	0.875	5.51
Ferrous iron (Fe(II))	<0.002	<0.002	<0.002	0.432	5.12
Manganese (Mn)	0.006	0.052	0.006	0.080	0.112
Copper (Cu)	<0.0005	<0.0005	0.0604	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	0.006	0.059
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.0008	<0.0005	<0.0005	0.0005	0.0006
Cobalt (Co)	0.0046	<0.0007	<0.0007	0.0028	0.0034
Mercury total (Hg), ng/L	174	512	38.7	41.0	36.0
Methylmercury (CH_3Hg), ng/L	---	0.06	0.04	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	0.0015
Beryllium (Be)	<0.001	<0.001	<0.001	0.002	0.004
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.215	0.222	0.221	0.079	<0.007
Antimony (Sb)	0.141	0.093	0.177	0.093	0.023
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	2.67	2.68	2.43	1.82	0.943
Arsenite (As(III))	2.41	2.53	2.23	0.104	0.444
Dissolved organic carbon (DOC)	5.0	0.5	0.4	1.5	0.7
δD, per mil	-142.98	-120.54	-143.55	-130.02	-136.35
$\delta^{18}O$, per mil	-15.54	-9.47	-15.64	-12.98	-15.38
sum cations, meq/L	20.1	22.8	19.0	15.4	10.3
sum anions, meq/L	20.3	23.9	19.7	15.4	10.4
Charge imbalance, percent	-0.9	-4.7	-3.6	0.1	-0.3

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	--------------------Back Basin--------------------			--------------------Ragged Hills--------------------	
Location	**Unnamed hot spring near Perpetual Spouter**	**Unnamed hot spring, North end of Elk Park**	**Unnamed hot spring, North end of Elk Park**	**Appendage side spring to "Lifeboat Spring"**	**Circular clay hot spring 2m from 08WA121**
Sample ID	07WA145	07WA140	07WA141	08WA124	08WA123
Collection Date / Time	9/18/07 15:55	9/18/07 9:50	9/18/07 10:40	9/23/08 15:40	9/23/08 15:09
Temperature, °C	93.0	68.3	91.4	89.3	63.5
pH (field / laboratory)	2.92 / 2.90	7.69 / 8.11	4.14 / 4.10	2.64 / 2.52	2.80 / 2.79
Specific conductance (field / laboratory), µS/cm	1325 / 1776	2150 / 2170	2050 / 2190	2020 / ---	840 / 1150
Eh, V	0.039	0.013	-0.070	0.460	0.170
Density, g/mL at 20°C	0.9991	0.9993	0.9993	---	0.9986
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	3.58	5.99	6.78	3.03	0.872
Magnesium (Mg)	0.360	0.051	0.109	0.174	0.059
Sodium (Na)	176	436	410	263	60.0
Potassium (K)	51.2	21.3	25.4	42.7	15.5
Strontium (Sr)	0.016	0.014	0.016	0.010	0.004
Barium (Ba)	0.113	0.009	0.035	0.069	0.081
Lithium (Li)	0.936	2.96	3.16	3.02	0.618
Sulfate (SO_4)	224	30.5	85.6	316	119
Thiosulfate (S_2O_3)	<0.1	<0.1	0.5	---	---
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	---	---
Hydrogen sulfide (H_2S)	0.03	0.007	0.44	---	---
Alkalinity (HCO_3)	---	92.8	---	---	---
Acidity (free / total), mM	1.97 / 2.13	---	---	3.13 / 4.36	1.51 / 1.95
Fluoride (F)	0.900	13.2	10.1	4.76	0.659
Chloride (Cl)	254	613	619	442	110
Bromide (Br)	0.86	2.07	1.99	1.27	0.32
Nitrate (NO_3)	0.12	0.11	0.10	0.24	<0.05
Ammonium (NH_4)	3.24	4.54	1.71	---	0.200
Silica (SiO_2)	426	304	303	238	211
Boron (B)	4.00	9.25	9.38	5.71	1.54
Aluminum (Al)	0.50	0.153	1.57	8.94	0.92
Iron total (Fe(T))	6.17	0.005	0.181	2.79	1.23
Ferrous iron (Fe(II))	6.17	0.005	0.181	2.61	1.21
Manganese (Mn)	0.118	0.044	0.269	0.023	0.014
Copper (Cu)	0.0006	<0.0005	<0.0005	0.0012	<0.0005
Zinc (Zn)	0.061	<0.004	<0.004	0.042	0.006
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	0.0009	0.0014	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	25.0	42.0	300	---	110
Methylmercury (CH_3Hg), ng/L	0.06	0.10	0.22	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	0.0009	<0.0005
Lead (Pb)	0.0012	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.004	<0.001	0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	<0.007	0.223	0.223	0.030	<0.007
Antimony (Sb)	0.034	0.082	0.075	0.142	0.018
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	0.949	1.76	1.86	1.75	5.54
Arsenite (As(III))	0.579	0.022	1.86	0.470	2.87
Dissolved organic carbon (DOC)	0.5	0.6	0.5	---	0.7
δD, per mil	-136.49	-141.73	-129.96	-132.11	-147.20
$\delta^{18}O$, per mil	-15.23	-14.49	-11.16	-10.25	-15.36
sum cations, meq/L	11.0	20.4	19.4	16.4	5.0
sum anions, meq/L	11.0	20.2	19.5	17.5	5.3
Charge imbalance, percent	-0.2	1.1	-0.2	-6.4	-5.1

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	Ragged Hills				
Location	**Crystal Spring, eastern side**	**Crystal Spring, eastern side**	**Crystal Spring, western side**	**Crystal Spring, western side**	**Crystal Spring, western side**
Sample ID	06WA112	07WA147	06WA111	07WA146	08WA120
Collection Date / Time	5/13/06 18:00	9/18/07 17:05	5/13/06 17:35	9/18/07 16:40	9/23/08 12:30
Temperature, °C	80.6	77.0	80.3	82.9	80.8
pH (field / laboratory)	5.55 / 6.25	1.97 / 1.96	3.77 / 3.67	1.98 / 1.94	2.29 / 2.15
Specific conductance (field / laboratory), µS/cm	2320 / 2490	3660 / 6550	2360 / 2550	3380 / 6500	2630 / 4340
Eh, V	0.047	0.500	0.143	0.180	-0.140
Density, g/mL at 20°C	0.9994	0.9996	0.9994	0.9995	0.9994
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	6.25	2.54	6.08	2.15	4.41
Magnesium (Mg)	0.005	0.212	0.005	0.212	0.323
Sodium (Na)	448	98.4	429	84.9	215
Potassium (K)	31.4	13.4	30.5	12.3	23.0
Strontium (Sr)	0.014	0.010	0.013	0.010	0.017
Barium (Ba)	0.007	0.058	0.009	0.054	0.045
Lithium (Li)	4.92	1.04	4.74	0.820	2.42
Sulfate (SO_4)	30.1	1180	51.1	1270	691
Thiosulfate (S_2O_3)	2.3	<0.1	1.6	<0.1	---
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	---
Hydrogen sulfide (H_2S)	0.14	0.04	0.09	0.17	0.12
Alkalinity (HCO_3)	6.1	---	---	---	---
Acidity (free / total), mM	---	20.5 / 23.5	0.29 / 0.52	20.7 / 23.3	7.67 / 9.93
Fluoride (F)	6.22	1.17	5.68	1.15	2.55
Chloride (Cl)	688	138	674	103	287
Bromide (Br)	2.95	0.49	2.36	0.47	1.01
Nitrate (NO_3)	<0.05	0.09	<0.05	0.09	0.14
Ammonium (NH_4)	1.19	14.8	1.39	14.6	14.8
Silica (SiO_2)	181	259	384	228	217
Boron (B)	10.2	2.37	9.78	1.90	4.56
Aluminum (Al)	0.24	25.7	0.67	22.8	14.2
Iron total (Fe(T))	0.020	4.23	0.034	3.10	2.10
Ferrous iron (Fe(II))	0.019	2.01	0.034	2.94	2.03
Manganese (Mn)	0.004	0.040	0.004	0.037	0.046
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	0.012	<0.004	0.015	0.021
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	0.0005
Chromium (Cr)	<0.0005	0.0032	<0.0005	0.0042	0.0016
Cobalt (Co)	0.0023	<0.0007	0.0020	<0.0007	<0.0007
Mercury total (Hg), ng/L	139	270	97.0	470	350
Methylmercury (CH_3Hg), ng/L	---	0.54	---	1.70	1.60
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	0.0069	<0.0008	0.0078	0.0044
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.209	0.127	0.203	0.072	0.045
Antimony (Sb)	0.180	0.146	0.141	0.107	0.077
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	2.78	0.708	2.69	0.701	1.27
Arsenite (As(III))	2.39[2]	0.074	2.46[2]	0.498	0.597
Dissolved organic carbon (DOC)	0.4	2.9	0.6	3.8	9.8
δD, per mil	-135.49	-115.91	-131.68	-117.42	-119.35
$\delta^{18}O$, per mil	-12.94	-6.30	-11.01	-7.61	-7.57
sum cations, meq/L	21.4	19.4	20.7	18.3	18.0
sum anions, meq/L	20.5	18.9	20.2	18.8	17.9
Charge imbalance, percent	4.4	2.6	2.4	-2.3	0.5

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	Ragged Hills				
Location	**The Gap northeast outflow**	**The Gap southwest outflow**	**Hot Spring next to "Orpiment Puddle 2"**	**"Kaolin Spring"**	**"Kaolin Spring"**
Sample ID	06WA121	06WA120	07WA107	07WA106	08WA131
Collection Date / Time	5/15/06 13:45	5/15/06 13:00	9/10/07 16:30	9/10/07 14:30	9/24/08 14:00
Temperature, °C	42.0	36.8	90.0	73.8	70.0
pH (field / laboratory)	3.32 / 3.24	3.08 / 3.06	3.12 / 3.00	2.37 / 2.41	2.54 / 2.51
Specific conductance (field / laboratory), µS/cm	2280 / 2350	1815 / 1880	1228 / 1502	1442 / 2430	690 / 1667
Eh, V	0.635	0.694	0.124	0.093	0.500
Density, g/mL at 20°C	0.9995	0.9991	0.9989	0.9988	0.9987
Dissolved oxygen (DO), mg/L	5.0	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	5.52	3.53	3.10	2.33	3.09
Magnesium (Mg)	0.154	0.381	0.065	0.480	0.612
Sodium (Na)	341	254	195	37.6	43.5
Potassium (K)	42.5	28.3	22.6	10.9	16.9
Strontium (Sr)	0.017	0.015	0.014	0.008	0.013
Barium (Ba)	0.094	0.118	0.162	0.035	0.046
Lithium (Li)	4.13	2.09	2.32	0.325	0.378
Sulfate (SO_4)	105	115	98.0	398	278
Thiosulfate (S_2O_3)	---	---	<0.1	<0.1	---
Polythionate (S_nO_6), mM	---	---	<0.001	<0.001	---
Hydrogen sulfide (H_2S)	---	---	0.04	0.54	0.001
Alkalinity (HCO_3)	---	---	---	---	---
Acidity (free / total), mM	0.71 / 1.08	1.01 / 1.51	1.13 / 1.66	6.40 / 7.65	3.06 / 4.28
Fluoride (F)	4.79	4.10	3.09	0.550	0.480
Chloride (Cl)	561	361	305	46.5	70.0
Bromide (Br)	1.91	1.24	1.02	0.15	0.22
Nitrate (NO_3)	<0.05	0.08	0.06	<0.05	0.24
Ammonium (NH_4)	1.04	0.930	<0.07	0.850	1.10
Silica (SiO_2)	399	302	258	239	241
Boron (B)	7.78	5.49	4.52	0.761	1.04
Aluminum (Al)	1.59	2.52	2.92	9.30	7.09
Iron total (Fe(T))	1.02	3.04	5.04	12.9	8.55
Ferrous iron (Fe(II))	0.402	1.23	4.97	12.9	8.55
Manganese (Mn)	0.034	0.077	0.015	0.065	0.086
Copper (Cu)	<0.0005	<0.0005	0.0074	0.0018	<0.0005
Zinc (Zn)	0.012	0.016	0.010	0.048	0.031
Cadmium (Cd)	<0.0001	<0.0001	0.0001	0.0002	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	0.0011	0.0006
Cobalt (Co)	0.0029	0.0017	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	89.0	26.0	260	540	68.1
Methylmercury (CH_3Hg), ng/L	---	---	0.19	0.40	2.60
Nickel (Ni)	<0.0005	<0.0005	<0.0005	0.0067	<0.0005
Lead (Pb)	<0.0008	<0.0008	0.0018	<0.0008	<0.0008
Beryllium (Be)	0.002	0.002	<0.001	0.002	0.002
Vanadium (V)	<0.005	<0.005	<0.005	0.006	<0.005
Molybdenum (Mo)	0.101	<0.007	<0.007	<0.007	<0.007
Antimony (Sb)	0.105	0.037	0.095	0.021	0.009
Selenium (Se)	<0.001	0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.77	0.874	11.2	0.295	0.251
Arsenite (As(III))	0.106	0.049	11.2	0.190[2]	0.188[2]
Dissolved organic carbon (DOC)	0.8	0.9	1.5	2.8	2.4
δD, per mil	-133.18	-138.80	-132.40	-125.11	-127.20
$\delta^{18}O$, per mil	-12.68	-14.82	-12.03	-7.92	-8.92
sum cations, meq/L	17.4	13.4	10.7	7.7	6.4
sum anions, meq/L	18.0	12.5	10.4	7.0	6.3
Charge imbalance, percent	-3.4	6.8	3.1	9.5	2.6

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	Ragged Hills				
Location	**"Lifeboat Spring"**	**"Lifeboat Spring"**	**"Lifeboat Spring"**	**"Orpiment Puddle 3"**	**"Persnickety Geyser"**
Sample ID	06WA118	07WA115	08WA125	06WA110	06WA119
Collection Date / Time	5/15/06 12:00	9/13/07 11:30	9/23/08 16:05	5/13/06 17:00	5/15/06 12:10
Temperature, °C	70.4	69.4	60.1	28.7	87.1
pH (field / laboratory)	3.58 / 3.49	2.48 / 2.39	3.23 / 3.23	2.43 / 2.40	3.81 / 3.57
Specific conductance (field / laboratory), µS/cm	2170 / 2320	2550 / 3330	2230 / 2380	2170 / 2360	2060 / 2240
Eh, V	---	0.124	0.620	0.273	---
Density, g/mL at 20°C	---	0.9994	0.9995	0.9987	---
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	5.41	4.19	5.27	1.25	5.54
Magnesium (Mg)	0.116	0.264	0.125	0.143	0.133
Sodium (Na)	365	282	376	75.2	353
Potassium (K)	47.5	35.9	58.7	18.0	49.1
Strontium (Sr)	0.014	0.014	0.014	0.009	0.017
Barium (Ba)	0.054	0.128	0.047	0.077	0.057
Lithium (Li)	4.48	2.86	4.65	0.803	4.25
Sulfate (SO_4)	70.8	405	100.0	307	84.4
Thiosulfate (S_2O_3)	---	1.2	---	0.9	---
Polythionate (S_nO_6), mM	---	<0.001	---	0.003	---
Hydrogen sulfide (H_2S)	---	0.08	---	1.80	---
Alkalinity (HCO_3)	---	---	---	---	---
Acidity (free / total), mM	---	5.81 / 6.98	0.40 / 0.90	4.85 / 5.72	---
Fluoride (F)	6.30	3.36	5.40	0.817	5.86
Chloride (Cl)	598	412	631	118	561
Bromide (Br)	1.99	1.09	3.17	0.38	1.80
Nitrate (NO_3)	<0.05	<0.05	1.70	<0.05	<0.05
Ammonium (NH_4)	---	1.80	0.890	<0.07	---
Silica (SiO_2)	464	369	452	318	436
Boron (B)	8.26	5.98	8.58	1.62	7.74
Aluminum (Al)	0.98	2.86	2.45	2.15	1.10
Iron total (Fe(T))	0.719	37.1	1.24	16.7	0.882
Ferrous iron (Fe(II))	0.363	37.1	0.940	16.7	0.698
Manganese (Mn)	0.023	0.054	0.026	0.020	0.031
Copper (Cu)	<0.0005	0.0007	0.0007	<0.0005	0.0017
Zinc (Zn)	0.095	0.034	0.008	0.023	0.400
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	0.0012	<0.0005
Cobalt (Co)	0.0031	<0.0007	<0.0007	0.0013	0.0027
Mercury total (Hg), ng/L	---	94.0	19.8	223	---
Methylmercury (CH_3Hg), ng/L	---	0.59	0.16	---	---
Nickel (Ni)	0.0007	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	0.0015	<0.0008	0.0011	0.0009
Beryllium (Be)	0.001	0.002	<0.001	<0.001	0.002
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.131	0.265	0.130	<0.007	0.123
Antimony (Sb)	0.057	0.062	0.141	0.003	0.051
Selenium (Se)	<0.001	<0.001	<0.001	0.001	<0.001
Arsenic (As)	1.32	14.6	1.40	1.75	1.65
Arsenite (As(III))	0.087[2]	1.95	0.026	0.746[2]	1.03[2]
Dissolved organic carbon (DOC)	---	1.6	1.2	2.3	---
δD, per mil	---	-127.47	-136.98	-121.62	---
$\delta^{18}O$, per mil	---	-10.97	-13.40	-11.34	---
sum cations, meq/L	18.3	18.8	19.7	8.6	17.7
sum anions, meq/L	18.4	18.1	19.9	8.8	17.6
Charge imbalance, percent	-0.5	3.6	-1.1	-2.4	0.4

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	---Ragged Hills---				
Location	**"Persnickety Geyser"**	**"Succession Spring"**	**"Succession Spring" drainage channel**	**"Succession Spring" drainage channel**	**"Succession Spring" drainage channel**
Sample ID	07WA105	06WA126	06WA127	06WA128	06WA129
Collection Date / Time	9/10/07 12:30	5/17/06 10:47	5/17/06 11:20	5/17/06 0:00	5/17/06 12:35
Temperature, °C	89.0	65.4	59.4	50.7	41.2
pH (field / laboratory)	3.39 / 3.17	3.12 / 3.00	3.02 / 3.04	2.94 / 3.01	2.87 / 3.00
Specific conductance (field / laboratory), µS/cm	1938 / 2220	1816 / 2040	1858 / 2030	1830 / 2070	2020 / 2130
Eh, V	-0.017	---	---	---	---
Density, g/mL at 20°C	0.9993	0.9989	0.9991	0.9990	0.9991
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	6.04	4.52	4.47	4.52	4.63
Magnesium (Mg)	0.171	0.282	0.281	0.282	0.291
Sodium (Na)	357	261	264	265	272
Potassium (K)	44.0	30.0	28.8	29.0	29.4
Strontium (Sr)	0.018	0.014	0.014	0.014	0.014
Barium (Ba)	0.063	0.105	0.103	0.104	0.106
Lithium (Li)	4.25	2.69	2.73	2.73	2.75
Sulfate (SO_4)	145	112	111	112	116
Thiosulfate (S_2O_3)	<0.1	<0.1	<0.1	<0.1	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.73	2.00	0.10	---	---
Alkalinity (HCO_3)	---	---	---	---	---
Acidity (free / total), mM	0.76 / 1.09	1.01 / 1.86	0.99 / 1.70	1.08 / 1.76	1.13 / 1.76
Fluoride (F)	5.09	2.72	2.74	2.83	2.84
Chloride (Cl)	520	415	425	431	445
Bromide (Br)	1.82	1.45	1.56	1.54	1.57
Nitrate (NO_3)	<0.05	0.08	0.10	<0.05	<0.05
Ammonium (NH_4)	1.72	0.830	0.946	0.771	0.690
Silica (SiO_2)	430	280	377	243	245
Boron (B)	8.21	6.13	6.22	6.22	6.55
Aluminum (Al)	1.68	3.60	3.60	3.66	3.66
Iron total (Fe(T))	2.95	0.952	0.960	0.923	0.880
Ferrous iron (Fe(II))	2.95	0.946	0.942	0.716	0.484
Manganese (Mn)	0.041	0.040	0.041	0.041	0.042
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	0.020	0.010	0.009	0.008	0.010
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	0.0008	0.0007	0.0009	0.0015
Mercury total (Hg), ng/L	100	126	62.0	23.0	31.0
Methylmercury (CH_3Hg), ng/L	0.49	---	---	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.002	0.001	0.001	0.001	0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.056	<0.007	<0.007	<0.007	<0.007
Antimony (Sb)	0.039	<0.001	<0.001	<0.001	<0.001
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	2.35	2.11	2.15	2.11	1.98
Arsenite (As(III))	2.32	0.896[2]	1.56[2]	0.416[2]	0.131
Dissolved organic carbon (DOC)	1.4	0.6	0.5	0.6	0.6
δD, per mil	-134.59	-146.42	-147.00	-145.95	-144.69
$\delta^{18}O$, per mil	-12.98	-16.76	-16.53	-16.28	-15.86
sum cations, meq/L	18.2	13.9	14.2	14.5	15.0
sum anions, meq/L	17.5	13.9	14.1	14.3	14.8
Charge imbalance, percent	4.1	0.2	0.9	1.2	1.6

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 6. Results of water analyses for Norris Geyser Basin, 2006–2008—Continued.

	------------------------------------Ragged Hills------------------------------------					
Location	**"Succession Spring" drainage channel**	**"Succession Spring" Mat**	**"Titanic Spring"**	**"Titanic Spring"**	**Unnamed pool near the Gap**	**Unnamed pool near "Succession Spring"**
Sample ID	06WA130	06WA131	06WA117	07WA114	08WA121	06WA125
Collection Date / Time	5/17/06 12:45	5/17/06 0:00	5/15/06 11:40	9/13/07 11:00	9/23/08 14:20	5/17/06 9:35
Temperature, °C	36.7	25.4	68.0	62.8	91.2	84.0
pH (field / laboratory)	2.78 / 2.99	2.72 / 2.98	3.56 / 3.44	3.10 / 3.00	3.40 / 3.24	4.70 / 4.72
Specific conductance (field / laboratory), µS/cm	2050 / 2150	2610 / 2780	2100 / 2250	2160 / 2310	1900 / 2170	2380 / 2560
Eh, V	---	---	0.321	0.151	0.190	0.242
Density, g/mL at 20°C	0.9990	---	0.9994	0.9993	0.9996	0.9994
Dissolved oxygen (DO), mg/L	---	---	---	---	---	1.1
Constituent, mg/L [1]						
Calcium (Ca)	4.62	5.47	5.55	6.04	4.73	6.97
Magnesium (Mg)	0.297	0.284	0.147	0.195	0.068	0.021
Sodium (Na)	271	400	358	348	312	447
Potassium (K)	29.7	50.4	48.5	43.3	38.5	34.8
Strontium (Sr)	0.014	0.022	0.017	0.018	0.016	0.023
Barium (Ba)	0.101	0.087	0.058	0.073	0.141	0.070
Lithium (Li)	2.74	3.98	4.32	4.09	4.25	5.14
Sulfate (SO_4)	117	135	89.5	176	78.9	27.2
Thiosulfate (S_2O_3)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	---	---	---	0.016	0.017	0.002
Alkalinity (HCO_3)	---	---	---	---	---	<1
Acidity (free / total), mM	1.18 / 1.81	---	0.46 / 0.78	1.21 / 1.62	0.53/ 1.14	---
Fluoride (F)	2.89	3.43	4.85	4.44	4.79	6.71
Chloride (Cl)	439	631	556	523	543	713
Bromide (Br)	1.54	1.89	1.86	1.44	1.80	2.49
Nitrate (NO_3)	<0.05	<0.05	<0.05	0.08	0.11	0.06
Ammonium (NH_4)	0.669	0.716	1.10	2.29	2.20	0.746
Silica (SiO_2)	246	280	513	432	265	400
Boron (B)	6.32	9.54	7.88	7.72	7.87	10.3
Aluminum (Al)	3.77	4.04	1.05	1.91	3.08	0.14
Iron total (Fe(T))	0.941	1.83	1.05	4.58	0.810	0.011
Ferrous iron (Fe(II))	0.424	1.81	0.607	4.16	0.810	0.009
Manganese (Mn)	0.042	0.039	0.034	0.046	0.017	0.004
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	0.009	0.113	0.014	0.027	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	0.0034	0.0005	<0.0005	0.0009	<0.0005
Cobalt (Co)	0.0008	0.0032	0.0033	<0.0007	<0.0007	0.0013
Mercury total (Hg), ng/L	63.0	71.0	30.0	38.0	100	41.0
Methylmercury (CH_3Hg), ng/L	---	1.61	---	0.10	0.39	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	0.0011	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.001	0.002	0.002	0.002	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	<0.007	<0.007	0.112	0.054	0.008	0.200
Antimony (Sb)	<0.001	<0.001	0.101	0.021	0.164	0.168
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	2.08	2.88	1.62	2.61	3.10	3.06
Arsenite (As(III))	0.076	0.521[2]	0.083	0.403	2.87	0.702
Dissolved organic carbon (DOC)	1.0	15.1	0.5	0.7	0.8	0.7
δD, per mil	-143.22	-128.86	-136.27	-129.61	-132.13	-141.89
$\delta^{18}O$, per mil	-15.72	-12.36	-13.62	-12.23	-12.34	-14.54
sum cations, meq/L	15.3	22.0	18.1	18.3	16.2	21.5
sum anions, meq/L	14.6	20.4	17.6	18.2	16.9	21.1
Charge imbalance, percent	4.7	7.6	2.9	0.8	-4.3	2.0

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 7. Results of water analyses for Gibbon Canyon and Geyser Springs Group, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

	---------Gibbon Canyon---------		------------------------------Geyser Springs------------------------------		
Location	**Beryl Spring**	**Beryl Spring**	**"Bullseye Spring"**	**Unnamed pool upslope from "Bullseye Spring"**	**Unnamed acid pool near "Bullseye Spring"**
Sample ID	06WA135	06WA157	07WA108	08WA122	08WA117
Collection Date / Time	5/17/06 19:45	9/14/06 16:45	9/10/07 17:10	9/20/08 12:00	9/20/08 12:45
Temperature, °C	90.7	91.2	74.8	72.9	67.9
pH (field / laboratory)	6.71 / 8.22	6.67 / 7.69	2.19 / 2.35	2.40 / 2.27	2.68 / 2.53
Specific conductance (field / laboratory), µS/cm	2040 / 2080	2040 / 2190	1868 / 2950	1940 / 3160	1479 / 2230
Eh, V	-0.030	-0.164	0.087	---	---
Density, g/mL at 20°C	0.9993	0.9993	0.9990	0.9990	0.9992
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	3.67	3.74	2.55	2.20	3.25
Magnesium (Mg)	0.012	0.008	0.125	0.151	0.426
Sodium (Na)	409	410	148	136	111
Potassium (K)	17.5	19.8	10.4	11.3	22.8
Strontium (Sr)	0.007	0.007	0.002	0.002	0.011
Barium (Ba)	0.001	0.001	0.001	<0.0008	0.028
Lithium (Li)	4.82	5.52	1.57	1.36	1.12
Sulfate (SO_4)	62.2	67.8	714	552	673
Thiosulfate (S_2O_3)	<0.1	0.2	<0.1	<0.1	---
Polythionate (S_nO_6), mM	<0.001	0.001	<0.001	<0.001	---
Hydrogen sulfide (H_2S)	0.39	0.42	0.07	---	---
Alkalinity (HCO_3)	97.0	111	---	---	---
Acidity (free / total), mM	---	---	6.42 / 7.05	6.01 / 6.96	3.45 / 7.47
Fluoride (F)	17.1	18.4	3.51	2.78	0.589
Chloride (Cl)	523	537	130	115	30.2
Bromide (Br)	1.79	1.66	0.41	0.32	0.09
Nitrate (NO_3)	0.18	<0.05	<0.05	0.19	0.09
Ammonium (NH_4)	0.697	0.08	4.25	4.01	---
Silica (SiO_2)	299	284	221	217	172
Boron (B)	7.14	7.41	1.87	1.55	0.499
Aluminum (Al)	0.16	0.19	5.00	5.05	38.0
Iron total (Fe(T))	<0.002	0.006	0.504	0.478	2.71
Ferrous iron (Fe(II))	<0.002	0.006	0.112	0.092	2.58
Manganese (Mn)	0.015	0.016	0.029	0.029	0.066
Copper (Cu)	<0.0005	0.0010	0.0007	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	0.016	0.011	0.135
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005	0.0029
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	88.0	71.0	130	28.3	---
Methylmercury (CH_3Hg), ng/L	---	0.06	0.06	0.13	---
Nickel (Ni)	<0.0005	0.0017	<0.0005	<0.0005	0.0080
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	0.0080
Beryllium (Be)	0.001	0.001	0.001	0.001	0.003
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.131	0.136	0.014	0.017	<0.007
Antimony (Sb)	0.080	0.095	0.032	0.081	0.003
Selenium (Se)	<0.001	0.004	<0.001	<0.001	<0.001
Arsenic (As)	2.90	2.79	0.637	0.501	0.086
Arsenite (As(III))	2.45[2]	2.49[2]	0.099	0.033	0.062
Dissolved organic carbon (DOC)	0.8	0.8	0.8	0.6	---
δD, per mil	-138.05	-137.33	-126.43	-128.22	---
δ^{18}O, per mil	-14.52	-14.57	-11.31	-11.95	---
sum cations, meq/L	19.1	19.3	14.8	11.4	9.9
sum anions, meq/L	18.6	19.3	14.0	11.9	10.7
Charge imbalance, percent	2.9	-0.2	5.7	-4.1	-8.0

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and δ^{18}O (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 8. Results of water analyses for the Crater Hills area, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

	---------------------------------------Crater Hills			---------------------------------------
Location	**Sulphur Spring**	**Sulphur Spring**	**Unnamed pool near Sulphur Spring**	**Unnamed acid pool near Sulphur Spring**
Sample ID	07WA111	08WA115	07WA112	08WA116
Collection Date / Time	9/11/07 15:15	9/19/08 13:30	9/11/07 16:30	9/19/08 15:00
Temperature, °C	87.8	87.2	82.0	73.8
pH (field / laboratory)	3.86 / 3.83	3.75 / 3.46	2.27 / 2.31	2.72 / 2.62
Specific conductance (field / laboratory), µS/cm	3450 / 3800	3440 / 3750	1680 / 3240	3460 / 4300
Eh, V	-0.029	0.110	0.179	0.210
Density, g/mL at 20°C	1.0004	1.0003	0.9988	1.0002
Dissolved oxygen (DO), mg/L	---	---	---	---
Constituent, mg/L [1]				
Calcium (Ca)	6.18	5.63	0.630	9.41
Magnesium (Mg)	0.343	0.300	0.231	6.53
Sodium (Na)	625	576	1.41	500
Potassium (K)	106	117	1.38	94.3
Strontium (Sr)	0.100	0.105	0.021	0.129
Barium (Ba)	0.071	0.076	0.060	0.056
Lithium (Li)	6.25	5.67	0.002	4.91
Sulfate (SO_4)	454	425	787	650
Thiosulfate (S_2O_3)	1.6	1.4	<0.1	0.2
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	1.21	1.03	0.16	0.73
Alkalinity (HCO_3)	---	---	---	---
Acidity (free / total), mM	0.81 / 1.79	0.67 / 1.88	8.50 / 8.77	2.62 / 5.66
Fluoride (F)	38.1	37.3	0.039	18.7
Chloride (Cl)	848	802	1.80	695
Bromide (Br)	2.50	3.04	0.08	2.88
Nitrate (NO_3)	0.07	0.34	0.42	0.05
Ammonium (NH_4)	17.3	16.8	83.1	16.9
Silica (SiO_2)	694	743	127	452
Boron (B)	25.2	23.5	0.174	19.8
Aluminum (Al)	6.15	5.92	2.97	17.9
Iron total (Fe(T))	0.154	0.141	0.588	0.704
Ferrous iron (Fe(II))	0.149	0.141	0.588	0.704
Manganese (Mn)	0.234	0.226	0.010	0.634
Copper (Cu)	<0.0005	<0.0005	0.0008	<0.0005
Zinc (Zn)	0.009	0.004	0.026	0.039
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.0011	0.0007	0.0031	0.0020
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	7.6	6.4	380	35.8
Methylmercury (CH_3Hg), ng/L	0.18	0.42	1.09	0.12
Nickel (Ni)	<0.0005	<0.0005	0.0045	<0.0005
Lead (Pb)	<0.0008	0.0050	0.0059	0.0080
Beryllium (Be)	0.014	0.013	<0.001	0.014
Vanadium (V)	<0.005	<0.005	<0.005	0.007
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Antimony (Sb)	0.150	0.090	0.001	0.002
Selenium (Se)	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	5.87	5.57	0.032	4.45
Arsenite (As(III))	5.61[2]	4.87[2]	<0.0005	3.86[2]
Dissolved organic carbon (DOC)	1.0	1.0	6.0	1.0
δD, per mil	-124.94	-126.58	-109.32	-116.88
$\delta^{18}O$, per mil	-12.31	-12.38	-6.83	-8.04
sum cations, meq/L	31.8	30.0	10.9	29.4
sum anions, meq/L	33.6	31.7	11.3	30.7
Charge imbalance, percent	-5.5	-5.3	-4.2	-4.4

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 9. Results of water analyses for Ojo Caliente Spring and its discharge channel, Lower Geyser Basin, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

Location	**Ojo Caliente Spring at discharge**	**Ojo Caliente Spring at pool exit**	**Ojo Caliente Spring 7.5 m downstream from pool exit**	**Ojo Caliente Spring 20.6 m downstream from pool exit**	**Ojo Caliente Spring at midpoint of pool**
Sample ID	06WA160	06WA161	06WA162	06WA163	08WA113
Collection Date / Time	9/16/06 9:52	9/16/06 9:55	9/16/06 9:59	9/16/06 15:10	9/18/08 17:20
Temperature, °C	93.2	91.4	86.8	74.8	93.2
pH (field / laboratory)	7.44 / 8.32	7.52 / 8.33	7.61 / 8.46	--- / 8.63	7.61 / 8.41
Specific conductance (field / laboratory), µS/cm	1470 / 1577	1495 / 1578	1530 / 1587	1590 / 1618	1470 / 1562
Eh, V	-0.125	---	---	---	---
Density, g/mL at 20°C	0.9991	0.9991	0.9992	0.9992	0.9990
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L[1]					
Calcium (Ca)	0.848	0.867	0.834	0.850	0.792
Magnesium (Mg)	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium (Na)	318	323	326	336	317
Potassium (K)	9.30	9.18	9.41	9.32	8.91
Strontium (Sr)	0.006	0.006	0.006	0.006	0.006
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Lithium (Li)	3.52	3.58	3.61	3.72	3.41
Sulfate (SO_4)	21.9	21.6	21.4	22.7	23.2
Thiosulfate (S_2O_3)	0.2	0.1	0.2	0.2	0.4
Polythionate (S_nO_6), mM	0.001	<0.001	<0.001	<0.001	---
Hydrogen sulfide (H_2S)	0.86	0.96	0.59	0.12	0.86
Alkalinity (HCO_3)	231	232	235	239	228
Acidity (free / total), mM	---	---	---	---	---
Fluoride (F)	30.7	34.5	34.5	31.4	35.2
Chloride (Cl)	310	318	319	324	320
Bromide (Br)	1.07	1.01	1.07	1.04	1.05
Nitrate (NO_3)	<0.05	<0.05	<0.05	<0.05	0.15
Ammonium (NH_4)	<0.07	<0.07	<0.07	<0.07	0.530
Silica (SiO_2)	259	257	263	263	270
Boron (B)	4.07	4.13	4.09	4.20	3.96
Aluminum (Al)	0.25	0.26	0.25	0.26	0.26
Iron total (Fe(T))	0.003	0.007	0.008	0.002	0.004
Ferrous iron (Fe(II))	0.003	0.007	0.006	0.001	0.004
Manganese (Mn)	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	0.0006
Zinc (Zn)	<0.004	<0.004	<0.004	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	200	60.0	51.0	31.0	31.6
Methylmercury (CH_3Hg), ng/L	0.04	0.04	0.04	0.04	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.001	0.001	0.001	0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.036	0.038	0.040	0.042	0.034
Antimony (Sb)	0.094	0.077	0.080	0.067	0.010
Selenium (Se)	<0.001	<0.001	<0.001	0.001	<0.001
Arsenic (As)	1.30	1.43	1.50	1.57	1.27
Arsenite (As(III))	1.02[2]	1.10[2]	1.24[2]	1.31[2]	0.831[2]
Dissolved organic carbon (DOC)	0.9	0.5	0.5	0.6	0.7
δD, per mil	-140.61	-140.82	-140.58	-139.61	-140.15
$\delta^{18}O$, per mil	-16.49	-16.52	-16.43	-16.18	-16.51
sum cations, meq/L	14.6	14.8	14.9	15.3	14.6
sum anions, meq/L	14.6	15.0	15.1	15.0	15.1
Charge imbalance, percent	-0.3	-1.4	-0.9	1.6	-3.5

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 9. Results of water analyses for Ojo Caliente Spring and its discharge channel, Lower Geyser Basin, 2006–2008—Continued.

Location	Ojo Caliente Spring source, 50 feet below surface	Ojo Caliente Spring at pool exit	Ojo Caliente Spring 13.8 m downstream from pool exit	Ojo Caliente Spring 20.4 m downstream from pool exit	Ojo Caliente Spring 25.9 m downstream from pool exit
Sample ID	08WA112	08WA111	08WA110	08WA109	08WA108
Collection Date / Time	9/18/08 15:15	9/18/08 14:00	9/18/08 12:00	9/18/08 11:00	9/18/08 10:20
Temperature, °C	---	91.9	84.2	75.4	67.5
pH (field / laboratory)	7.60 / 8.44	7.55 / 8.44	7.70 / 8.44	7.82 / 8.58	8.17 / 8.68
Specific conductance (field / laboratory), µS/cm	1523 / 1552	1481 / 1570	1517 / 1578	1556 / 1601	1594 / 1624
Eh, V	---	---	---	---	0.110
Density, g/mL at 20°C	0.9990	0.9990	0.9991	0.9990	0.9990
Dissolved oxygen (DO), mg/L	---	---	0.1	1.7	2.6
Constituent, mg/L [1]					
Calcium (Ca)	0.803	0.806	0.793	0.812	0.819
Magnesium (Mg)	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium (Na)	311	336	328	327	336
Potassium (K)	8.02	8.44	8.59	8.99	9.33
Strontium (Sr)	0.006	0.006	0.006	0.006	0.006
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Lithium (Li)	3.42	3.43	3.48	3.55	3.54
Sulfate (SO_4)	22.3	21.8	21.8	22.4	23.4
Thiosulfate (S_2O_3)	0.4	0.5	0.7	0.8	0.4
Polythionate (S_nO_6), mM	---	---	---	---	---
Hydrogen sulfide (H_2S)	0.95	0.88	0.63	0.06	0.03
Alkalinity (HCO_3)	226	229	230	233	236
Acidity (free / total), mM	---	---	---	---	---
Fluoride (F)	35.1	35.4	35.8	36.5	37.0
Chloride (Cl)	322	322	326	330	339
Bromide (Br)	1.16	0.98	1.00	1.00	1.24
Nitrate (NO_3)	0.17	0.17	0.18	0.18	0.25
Ammonium (NH_4)	0.540	0.620	0.550	0.450	0.370
Silica (SiO_2)	244	229	225	237	256
Boron (B)	3.88	3.97	3.99	4.09	4.18
Aluminum (Al)	0.27	0.28	0.26	0.27	0.27
Iron total (Fe(T))	<0.002	<0.002	0.005	<0.002	0.005
Ferrous iron (Fe(II))	<0.002	<0.002	0.005	<0.002	0.004
Manganese (Mn)	<0.001	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	30.0	33.4	35.6	27.0	20.2
Methylmercury (CH_3Hg), ng/L	---	---	---	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.001	0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.037	0.037	0.038	0.042	0.039
Antimony (Sb)	0.026	0.037	0.063	0.065	0.068
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.34	1.37	1.40	1.43	1.47
Arsenite (As(III))	0.566[2]	0.866[2]	1.15[2]	1.04[2]	0.307[2]
Dissolved organic carbon (DOC)	0.7	0.6	0.6	0.5	1.2
δD, per mil	-141.01	-140.03	-138.72	-137.48	-137.47
$\delta^{18}O$, per mil	-16.47	-16.41	-16.28	-16.09	-15.89
sum cations, meq/L	14.3	15.3	15.0	15.0	15.4
sum anions, meq/L	15.1	15.1	15.3	15.5	15.9
Charge imbalance, percent	-5.4	1.5	-1.8	-3.1	-3.0

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 10. Results of water analyses for the Porcupine Hills area, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

Location	**Snort Geyser**	**Unnamed hot spring, Morning Mist Group**	**Unnamed hot spring, Quagmire Group**	**Unnamed hot spring, Quagmire Group**
Sample ID	06WA173	06WA170	06WA171	06WA172
Collection Date / Time	9/19/06 14:35	9/19/06 10:45	9/19/06 12:15	9/19/06 13:55
Temperature, °C	92.0	75.2	93.8	65.9
pH (field / laboratory)	8.73 / 9.40	9.17 / 9.61	7.64 / 8.16	6.68 / 7.89
Specific conductance (field / laboratory), µS/cm	1450 / 1542	1557 / 1588	1310 / 1398	1638 / 1565
Eh, V	-0.185	-0.086	-0.145	0.136
Density, g/mL at 20°C	0.9991	0.9991	0.9990	0.9991
Dissolved oxygen (DO), mg/L	---	---	---	---
Constituent, mg/L [1]				
Calcium (Ca)	1.35	0.791	1.40	1.26
Magnesium (Mg)	<0.001	<0.001	<0.001	<0.001
Sodium (Na)	311	323	278	311
Potassium (K)	10.6	8.55	8.43	9.76
Strontium (Sr)	0.003	0.003	0.001	0.003
Barium (Ba)	<0.0008	0.001	<0.0008	0.001
Lithium (Li)	3.46	3.43	3.23	2.76
Sulfate (SO_4)	17.9	19.3	19.3	55.0
Thiosulfate (S_2O_3)	<0.1	0.3	<0.1	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.83	0.03	0.28	---
Alkalinity (HCO_3)	170	252	133	144
Acidity (free / total), mM	---	---	---	---
Fluoride (F)	30.8	31.0	29.0	28.6
Chloride (Cl)	335	302	310	330
Bromide (Br)	1.13	0.96	0.99	1.03
Nitrate (NO_3)	<0.05	<0.05	<0.05	<0.05
Ammonium (NH_4)	<0.07	0.170	<0.07	<0.07
Silica (SiO_2)	206	218	240	239
Boron (B)	4.46	4.10	4.07	4.43
Aluminum (Al)	0.12	0.12	0.15	0.13
Iron total (Fe(T))	0.006	0.011	0.007	0.005
Ferrous iron (Fe(II))	0.006	0.009	0.006	0.001
Manganese (Mn)	<0.001	<0.001	<0.001	0.001
Copper (Cu)	<0.0005	0.0020	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	0.007
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	100	73.0	118	47.0
Methylmercury (CH_3Hg), ng/L	0.04	0.04	0.04	0.04
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.164	0.105	0.149	0.095
Antimony (Sb)	0.093	0.062	0.081	0.123
Selenium (Se)	<0.001	0.001	<0.001	0.002
Arsenic (As)	1.69	1.35	1.56	2.08
Arsenite (As(III))	1.35[2]	0.402[2]	1.34[2]	0.069[2]
Dissolved organic carbon (DOC)	0.6	0.8	0.6	0.8
δD, per mil	-141.17	-140.51	-139.67	-132.92
δ^{18}O, per mil	-16.52	-16.18	-16.21	-13.13
sum cations, meq/L	14.2	14.6	12.8	14.2
sum anions, meq/L	14.2	14.5	12.9	14.3
Charge imbalance, percent	0.4	0.4	-0.4	-0.7

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and δ^{18}O (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 10. Results of water analyses for the Porcupine Hills area, 2006–2008—Continued.

Location	**Unnamed hot spring, Quagmire Group**	**Unnamed hot spring, Quagmire Group**	**Unnamed hot spring, Quagmire Group**	**Unnamed hot spring, Quagmire Group**
Sample ID	06WA174	08WA132	08WA133	08WA134
Collection Date / Time	9/19/06 15:20	9/24/08 16:15	9/24/08 17:08	9/24/08 18:00
Temperature, °C	84.8	92.9	65.6	92.3
pH (field / laboratory)	8.68 / 9.23	7.56 / 8.30	6.94 / 8.27	8.59 / 9.02
Specific conductance (field / laboratory), µS/cm	1400 / 1452	1303 / 1371	1500 / 1525	1340 / 1424
Eh, V	-0.124	0.000	---	-0.050
Density, g/mL at 20°C	0.9990	0.9989	0.9990	0.9989
Dissolved oxygen (DO), mg/L	---	---	---	---
Constituent, mg/L[1]				
Calcium (Ca)	1.17	1.38	1.21	1.15
Magnesium (Mg)	<0.001	0.001	0.001	0.002
Sodium (Na)	295	260	289	274
Potassium (K)	8.40	6.49	8.21	7.57
Strontium (Sr)	0.003	0.002	0.003	0.003
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008
Lithium (Li)	2.38	3.13	2.70	2.37
Sulfate (SO_4)	20.6	20.8	55.3	22.0
Thiosulfate (S_2O_3)	0.2	0.6	<0.1	0.2
Polythionate (S_nO_6), mM	<0.001	---	---	---
Hydrogen sulfide (H_2S)	0.27	0.44	0.001	0.50
Alkalinity (HCO_3)	196	128	143	187
Acidity (free / total), mM	---	---	---	---
Fluoride (F)	27.5	34.0	33.6	30.2
Chloride (Cl)	300	299	311	292
Bromide (Br)	0.95	1.04	1.02	0.90
Nitrate (NO_3)	<0.05	0.21	0.24	0.23
Ammonium (NH_4)	<0.07	0.140	0.190	0.170
Silica (SiO_2)	190	212	231	212
Boron (B)	3.88	3.86	4.23	3.78
Aluminum (Al)	0.16	0.15	0.18	0.17
Iron total (Fe(T))	0.009	<0.002	<0.002	<0.002
Ferrous iron (Fe(II))	0.006	<0.002	<0.002	<0.002
Manganese (Mn)	<0.001	0.002	0.002	<0.001
Copper (Cu)	<0.0005	<0.0005	<0.0005	0.0008
Zinc (Zn)	<0.004	<0.004	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	57.0	74.4	42.1	31.3
Methylmercury (CH_3Hg), ng/L	0.04	---	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.173	0.147	0.092	0.167
Antimony (Sb)	0.085	0.098	0.121	0.096
Selenium (Se)	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.56	1.50	1.95	1.52
Arsenite (As(III))	1.35[2]	1.28[2]	0.094[2]	1.16[2]
Dissolved organic carbon (DOC)	0.7	1.1	0.8	1.3
δD, per mil	-140.49	-139.59	-132.54	-142.38
$\delta^{18}O$, per mil	-16.14	-16.22	-13.01	-16.25
sum cations, meq/L	13.3	12.0	13.2	12.4
sum anions, meq/L	13.4	12.8	14.0	13.3
Charge imbalance, percent	-1.2	-6.4	-6.0	-7.0

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 11. Results of water analyses for Midway Geyser Basin and the Rabbit Creek area, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

	-Midway Geyser Basin-	----------Rabbit Creek area----------			
Location	**Excelsior Geyser Crater**	**Unnamed hot spring**	**Unnamed hot spring drainage channel**	**Unnamed hot spring drainage channel**	**Unnamed hot spring drainage channel**
Sample ID	07WA148	06WA113	06WA114	06WA114B	06WA114C
Collection Date / Time	9/19/07 10:30	5/14/06 11:15	5/14/06 13:00	5/14/06 13:00	5/14/06 13:00
Temperature, °C	88.7	85.8	84.0	69.5	61.8
pH (field / laboratory)	7.68 / 8.59	9.19 / 9.68	9.21 / 9.77	9.21 / 9.76	9.29 / 9.80
Specific conductance (field / laboratory), µS/cm	1663 / 1691	1530 / 1601	1600 / 1677	1690 / 1690	1725 / 1788
Eh, V	-0.165	0.068	0.046	---	---
Density, g/mL at 20°C	0.9993	0.9992	0.9991	0.9993	0.9992
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	1.54	0.347	0.308	0.326	0.340
Magnesium (Mg)	0.007	0.001	0.001	<0.001	<0.001
Sodium (Na)	374	323	343	353	369
Potassium (K)	12.3	10.5	10.3	10.7	11.1
Strontium (Sr)	0.006	0.002	0.002	0.002	0.002
Barium (Ba)	0.003	<0.0008	<0.0008	<0.0008	<0.0008
Lithium (Li)	2.37	3.60	3.91	4.08	4.17
Sulfate (SO_4)	15.0	21.6	19.5	20.2	21.0
Thiosulfate (S_2O_3)	<0.1	0.7	0.8	0.8	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.011	0.009	0.005	<0.002	---
Alkalinity (HCO_3)	503	339	349	363	377
Acidity (free / total), mM	---	---	---	---	---
Fluoride (F)	26.0	26.2	27.0	28.6	29.8
Chloride (Cl)	258	260	266	278	284
Bromide (Br)	0.84	1.98	1.06	1.12	1.13
Nitrate (NO_3)	0.14	0.18	0.38	0.11	<0.05
Ammonium (NH_4)	<0.07	0.317	0.415	---	---
Silica (SiO_2)	288	319	300	263	264
Boron (B)	3.01	2.73	2.95	3.03	3.13
Aluminum (Al)	0.27	0.18	0.18	0.22	0.22
Iron total (Fe(T))	<0.002	<0.002	<0.002	<0.002	<0.002
Ferrous iron (Fe(II))	<0.002	<0.002	<0.002	<0.002	<0.002
Manganese (Mn)	0.011	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	48.0	45.0	45.0	35.0	16.0
Methylmercury (CH_3Hg), ng/L	0.08	---	---	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	0.003	<0.001	<0.001	<0.001	<0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.031	0.030	0.029	0.030	0.019
Antimony (Sb)	0.067	0.082	0.086	0.000	0.000
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.87	1.54	1.67	1.77	1.81
Arsenite (As(III))	0.064	0.225[2]	0.250[2]	0.194[2]	0.084[2]
Dissolved organic carbon (DOC)	1.2	1.3	1.3	---	---
δD, per mil	-141.12	-141.24	-141.37	-141.13	-138.87
$\delta^{18}O$, per mil	-16.37	-16.14	-16.07	-15.81	-15.29
sum cations, meq/L	16.9	14.5	15.4	15.8	16.6
sum anions, meq/L	17.1	14.5	14.7	15.3	15.8
Charge imbalance, percent	-1.4	0.4	4.3	3.1	4.6

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 11. Results of water analyses for Midway Geyser Basin and the Rabbit Creek area, 2006–2008—Continued.

	---------------------------------------Rabbit Creek area					---------------------------------------
Location	**Unnamed hot spring drainage channel**	**Unnamed hot spring**	**Unnamed hot spring**	**Unnamed hot spring drainage channel**	**Unnamed hot spring drainage channel**	**Unnamed hot spring drainage channel**
Sample ID	06WA114D	06WA115	06WA116	06WA116B	06WA116C	06WA116D
Collection Date / Time	5/14/06 13:00	5/14/06 15:45	5/14/06 17:20	5/14/06 18:20	5/14/06 18:20	5/14/06 18:20
Temperature, °C	54.6	54.3	93.4	75.1	68.2	63.2
pH (field / laboratory)	9.32 / 9.83	8.70 / 8.91	7.69 / 8.48	7.73 / 8.39	8.07 / 8.46	8.17 / 8.68
Specific conductance (field / laboratory), µS/cm	1763 / 1800	1197 / 1198	1320 / 1426	1400 / 1427	1420 / 1454	1444 / 1468
Eh, V	---	0.275	0.083	---	---	---
Density, g/mL at 20°C	0.9992	0.9990	0.9990	0.9991	0.9990	0.9992
Dissolved oxygen (DO), mg/L	---	2.5	---	---	---	---
Constituent, mg/L [1]						
Calcium (Ca)	0.332	0.806	0.615	0.692	0.688	0.706
Magnesium (Mg)	<0.001	0.048	0.044	0.058	0.058	0.059
Sodium (Na)	370	236	289	301	304	315
Potassium (K)	11.7	9.70	8.47	8.55	8.55	8.89
Strontium (Sr)	0.002	0.002	0.003	0.004	0.004	0.004
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Lithium (Li)	4.24	2.43	2.95	3.04	3.09	3.15
Sulfate (SO_4)	23.0	16.4	12.8	12.9	14.2	12.8
Thiosulfate (S_2O_3)	<0.1	<0.1	0.9	0.7	<0.1	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	---	<0.002	0.007	---	---	---
Alkalinity (HCO_3)	378	252	355	360	365	366
Acidity (free / total), mM	---	---	---	---	---	---
Fluoride (F)	30.0	21.5	21.0	22.1	22.3	22.2
Chloride (Cl)	295	188	210	208	217	214
Bromide (Br)	1.10	0.76	0.76	0.82	0.78	0.75
Nitrate (NO_3)	1.60	0.84	0.11	0.09	<0.05	<0.05
Ammonium (NH_4)	---	0.173	0.261	---	---	---
Silica (SiO_2)	270	187	230	193	195	200
Boron (B)	3.12	2.02	2.20	2.32	2.31	2.39
Aluminum (Al)	0.23	0.096	0.25	0.31	0.26	0.28
Iron total (Fe(T))	<0.002	0.017	0.006	0.006	0.006	0.007
Ferrous iron (Fe(II))	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Manganese (Mn)	<0.001	<0.001	0.003	0.004	0.004	0.003
Copper (Cu)	<0.0005	<0.0005	0.0006	<0.0005	<0.0005	<0.0005
Zinc (Zn)	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	25.0	30.0	174	109	93.0	76.0
Methylmercury (CH_3Hg), ng/L	---	---	---	---	---	---
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	<0.001	0.001	0.001	0.001	0.001
Vanadium (V)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Molybdenum (Mo)	0.009	0.020	0.010	0.013	0.023	0.010
Antimony (Sb)	0.000	0.068	0.071	0.000	0.000	0.000
Selenium (Se)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic (As)	1.81	1.43	1.38	1.47	1.57	1.60
Arsenite (As(III))	0.027[2]	0.018[2]	0.111	0.061	0.036	0.025
Dissolved organic carbon (DOC)	---	2.1	3.0	---	---	---
δD, per mil	-138.90	-142.30	-142.87	-141.28	-140.22	-140.75
$\delta^{18}O$, per mil	-15.01	-16.77	-16.83	-16.52	-16.39	-16.22
sum cations, meq/L	16.7	10.8	13.2	13.7	13.8	14.3
sum anions, meq/L	16.3	10.9	13.1	13.1	13.5	13.4
Charge imbalance, percent	2.4	-0.5	0.5	4.3	2.5	6.7

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

[2] Likely formed arsenic - sulfide precipitate upon acidification; therefore, value may be biased low

Table 12. Results of water analyses for the Mud Volcano area, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

Location	**Sulphur Caldron**	**Sulphur Caldron**	**Sulphur Caldron**	**Turbulent Pool**	**Turbulent Pool**
Sample ID	06WA164	07WA110	08WA114	06WA165	07WA109
Collection Date / Time	9/17/06 14:43	9/11/07 11:45	9/19/08 10:00	9/17/06 16:30	9/11/07 11:00
Temperature, °C	73.5	73.9	73.2	58.5	59.3
pH (field / laboratory)	2.02 / 1.84	1.71 / 1.82	1.60 / 1.58	1.89 / 1.84	1.99 / 2.00
Specific conductance (field / laboratory), µS/cm	3950 / 7880	6480 / 12,410	6640 / 12,090	4360 / 7070	3660 / 5560
Eh, V	0.128	0.088	---	0.071	0.017
Density, g/mL at 20°C	1.0011	1.0014	1.0009	1.0000	0.9996
Dissolved oxygen (DO), mg/L	---	---	---	---	---
Constituent, mg/L [1]					
Calcium (Ca)	26.5	39.3	36.8	11.6	13.1
Magnesium (Mg)	8.94	10.5	9.12	3.77	5.94
Sodium (Na)	21.0	34.6	29.4	15.5	18.8
Potassium (K)	19.0	26.0	29.2	13.9	11.6
Strontium (Sr)	0.113	0.174	0.182	0.114	0.139
Barium (Ba)	0.045	0.061	0.080	0.052	0.055
Lithium (Li)	0.024	0.025	0.030	0.007	0.012
Sulfate (SO_4)	2580	3620	3490	1490	1370
Thiosulfate (S_2O_3)	<0.1	<0.1	---	<0.1	<0.1
Polythionate (S_nO_6), mM	<0.001	<0.001	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.016	0.019	---	---	0.04
Alkalinity (HCO_3)	---	---	---	---	---
Acidity (free / total), mM	43.5 / 46.0	44.5 / 60.0	35.3 / 45.6	29.1 / 30.0	17.8 / 23.3
Fluoride (F)	0.310	0.590	0.488	0.660	0.530
Chloride (Cl)	4.12	7.52	2.86	4.80	7.01
Bromide (Br)	<0.03	<0.03	0.03	<0.03	<0.03
Nitrate (NO_3)	<0.05	<0.05	0.26	<0.05	<0.05
Ammonium (NH_4)	59.0	62.7	86.6	15.2	14.2
Silica (SiO_2)	412	332	291	243	249
Boron (B)	3.97	2.61	3.28	1.05	0.850
Aluminum (Al)	203	131	81.6	37.8	41.7
Iron total (Fe(T))	22.8	31.8	20.4	6.74	20.0
Ferrous iron (Fe(II))	22.6	31.4	19.5	6.71	20.0
Manganese (Mn)	0.411	0.579	0.604	0.304	0.376
Copper (Cu)	0.0013	0.0018	0.0005	0.0079	<0.0005
Zinc (Zn)	0.205	0.303	0.174	0.069	0.097
Cadmium (Cd)	0.0005	0.0006	0.0003	0.0001	0.0002
Chromium (Cr)	0.089	0.079	0.045	0.014	0.028
Cobalt (Co)	0.0040	0.0085	0.0046	0.0020	0.0040
Mercury total (Hg), ng/L	127	210	65.0	80.0	39.0
Methylmercury (CH_3Hg), ng/L	0.78	10.3	9.30	5.04	5.82
Nickel (Ni)	0.043	0.050	0.028	0.0094	0.016
Lead (Pb)	0.0030	0.018	0.025	0.0058	0.0086
Beryllium (Be)	0.004	0.007	0.006	0.002	0.002
Vanadium (V)	0.044	0.045	0.039	0.011	0.029
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007	<0.007
Antimony (Sb)	<0.0005	0.006	<0.001	<0.0005	0.006
Selenium (Se)	0.005	0.001	<0.001	0.001	<0.001
Arsenic (As)	0.005	0.085	0.0037	0.0013	0.035
Arsenite (As(III))	0.002	0.004	0.0027	<0.001	0.001
Dissolved organic carbon (DOC)	7.7	5.8	5.8	4.0	6.1
δD, per mil	-108.43	-106.03	-108.69	-105.13	-102.14
$\delta^{18}O$, per mil	-8.77	-7.80	-8.37	-7.80	-7.55
sum cations, meq/L	27.5	38.1	43.3	19.3	16.9
sum anions, meq/L	27.5	40.8	39.9	19.5	18.1
Charge imbalance, percent	0.2	-7.0	8.2	-0.8	-7.0

[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

Table 13. Results of water analyses for Washburn Hot Springs, 2006–2008.

[δD and δ18O, isotopic composition of hydrogen and oxygen relative to VSMOW; m, meters; meq/L, milliequivalents per liter; mg/L, milligrams per liter; mM, millimolar; µS/cm, microsiemens per centimeter; ng/L nanograms per liter; V, volts; ---, not measured; °C, degrees Celsius; <, less than]

Location	**Inkpot #1**	**Inkpot #3**	**Unnamed, 160 feet elevation above inkpots**	**Upper large hot pool**
Sample ID	06WA166	06WA167	06WA169	06WA168
Collection Date / Time	9/18/06 11:45	9/18/06 13:25	9/18/06 16:32	9/18/06 14:45
Temperature, °C	80.2	70.9	88.2	74.5
pH (field / laboratory)	6.53 / 7.69	3.25 / 2.88	7.33 / 8.06	6.64 / 7.47
Specific conductance (field / laboratory), µS/cm	3140 / 3470	5750 / 6730	1330 / 1540	3450 / 3710
Eh, V	-0.164	-0.037	-0.078	-0.146
Density, g/mL at 20°C	0.9997	1.0010	0.9988	0.9998
Dissolved oxygen (DO), mg/L	---	---	---	---
Constituent, mg/L [1]				
Calcium (Ca)	24.0	53.4	2.76	28.7
Magnesium (Mg)	11.0	26.9	1.80	13.7
Sodium (Na)	34.2	37.8	3.45	29.6
Potassium (K)	13.5	14.4	3.09	12.4
Strontium (Sr)	0.146	0.225	0.029	0.167
Barium (Ba)	0.042	0.024	0.049	0.041
Lithium (Li)	0.011	0.045	<0.001	0.005
Sulfate (SO_4)	1360	2710	473	1330
Thiosulfate (S_2O_3)	2.1	<0.1	7.4	0.5
Polythionate (S_nO_6), mM	0.002	<0.001	<0.001	<0.001
Hydrogen sulfide (H_2S)	0.11	0.40	0.003	0.006
Alkalinity (HCO_3)	137	---	82.2	203
Acidity (free / total), mM	---	2.71 / 4.19	---	---
Fluoride (F)	0.650	0.790	0.05	0.400
Chloride (Cl)	1.61	1.49	0.35	1.67
Bromide (Br)	<0.03	<0.03	<0.03	<0.03
Nitrate (NO_3)	0.09	0.06	<0.05	<0.05
Ammonium (NH_4)	439	837	178	477
Silica (SiO_2)	124	268	84.3	130
Boron (B)	8.67	11.7	2.95	6.40
Aluminum (Al)	0.053	11.3	0.26	0.064
Iron total (Fe(T))	0.010	5.93	0.010	0.006
Ferrous iron (Fe(II))	0.010	5.93	0.010	0.006
Manganese (Mn)	0.173	0.773	0.042	0.241
Copper (Cu)	<0.0005	<0.0005	0.0013	<0.0005
Zinc (Zn)	<0.004	0.083	<0.004	<0.004
Cadmium (Cd)	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (Cr)	0.0015	0.0083	0.0006	0.0020
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Mercury total (Hg), ng/L	447	26.0	494	75.0
Methylmercury (CH_3Hg), ng/L	0.09	0.04	0.09	0.04
Nickel (Ni)	<0.0005	<0.0005	<0.0005	<0.0005
Lead (Pb)	<0.0008	<0.0008	<0.0008	<0.0008
Beryllium (Be)	<0.001	0.006	<0.001	<0.001
Vanadium (V)	<0.005	0.026	0.009	<0.005
Molybdenum (Mo)	0.007	0.014	<0.007	0.008
Antimony (Sb)	<0.0005	<0.0005	<0.0005	<0.0005
Selenium (Se)	0.001	<0.001	<0.001	0.001
Arsenic (As)	0.0017	<0.0005	0.004	0.0007
Arsenite (As(III))	<0.0005	<0.0005	0.001	<0.0005
Dissolved organic carbon (DOC)	---	5.4	2.3	7.0
δD, per mil	-110.40	-110.61	-119.65	-110.62
$\delta^{18}O$, per mil	-3.07	-3.76	-7.42	-2.39
sum cations, meq/L	24.7	47.5	7.2	26.7
sum anions, meq/L	27.9	46.9	10.8	28.1
Charge imbalance, percent	-12.1	1.4	-40.1	-4.9

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[1] Except for acidity (mM), mercury (ng/L), methylmercury (ng/L), and δD and $\delta^{18}O$ (per mil)

Quality Assurance and Quality Control

Several techniques were used to assure the quality of the analytical data. These techniques included calculation of charge imbalance (C.I.), analysis of USGS standard reference water samples (SRWS), replicate determinations in the laboratory, spike recovery determinations, and determination by alternative analytical methods.

The charge-balance calculation is one of the first and simplest of quality-assurance/quality-control procedures to check the accuracy of a water analysis. It is based on the principle that an aqueous solution containing electrolytes, or charged ions, must be electrically neutral overall. The equivalent concentration of cations must equal that of anions:

$$\sum_{i} {}_{i} \quad 0 \quad \sum_{i} {}_{i}^{+} - \sum_{i} c_{i}^{-} \qquad (9)$$

where c_i = the equivalent concentration (usually in milliequivalents per liter) for the ith ion, c_i^+ = the equivalent concentration for the i^{th} cation, and c_i^- = the equivalent concentration for the i^{th} anion. Before an accurate charge balance can be calculated for acid waters, equivalent hydrogen-ion concentrations must be calculated based on the pH measurement and thermodynamic speciation calculations (see the Revised pH Measurements section). The charge balance calculation is discussed in more detail by Ball and others (2006).

Major cations and anions were analyzed for 104 samples and the data were checked for C.I. using the geochemical code WATEQ4F (Ball and Nordstrom, 1991). WATEQ4F uses equation 10 to calculate C.I.:

$$C.I.(percent) = \frac{100 \times (sum\ cations - sum\ anions)}{(sum\ cations + sum\ anions)} \qquad (10)$$

where sum cations and sum anions are in meq/L.

The C.I., sum cations (meq/L), and sum anions (meq/L) are reported in tables 5–13 for samples having major cation and anion determinations. A frequency plot of C.I. for all samples with complete analyses is shown in figure 30. The Gaussian fit C.I. mean is –0.9 percent with a standard deviation of 5.0 percent. Analyses having a C.I. less than ±10 percent are considered reliable for speciation calculations (Nordstrom and Munoz, 1994). Two sample analyses out of 104 had a C.I. (–12.1 and –40.1 percent) greater than ±10 percent.

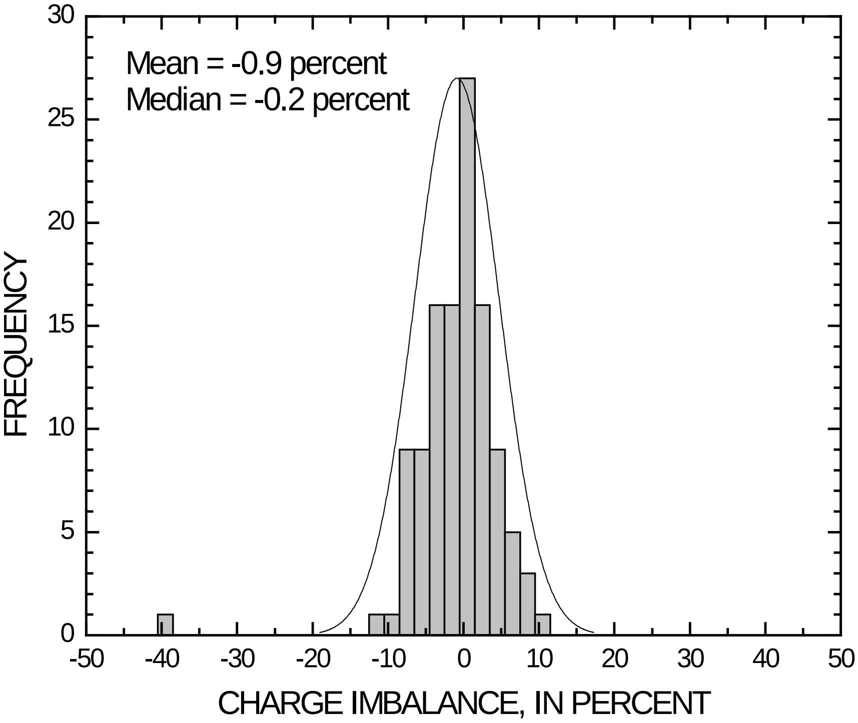

Figure 30. Frequency distribution of charge imbalance for samples having major cation and anion determinations.

U.S. Geological Survey SRWSs were analyzed as unknowns along with the samples to check for accuracy. Standard reference water samples AMW4, M150, M156, M158, M172, M182, T163, T179, T181, T183, T189, Hg7, and Hg22 were used to check the analytical methods for major and trace metals, anions, and Hg (Farrar, 2000; Connor and others, 2001). The SRWSs were analyzed several times during each analytical run. For each SRWS constituent, the analytical result, the most probable value (MPV), and the percent difference are presented in table 14. Additional information about the USGS SRWS program can be obtained at URL http://bqs.usgs.gov/srs.

Replicate determinations were performed for all methods and all constituents. Samples were diluted as necessary to bring the analyte concentration within the optimal range of the method and for each dilution at least two separate aliquots of each sample were analyzed. Replicate determinations minimize errors owing to dilution, contamination, and analytical imprecision. Reported concentrations are the means, excluding outliers, of the replicate determinations.

Concentrations of F, Al, Fe(T), Mn, Cu, Cd, Cr, Co, Ni, Pb, Sb(T), Se, and As(T) were determined by more than one method. Comparing analytical results from alternative methods can serve as an accuracy check, although in all cases one method was preferred over the other depending on sample matrix and proximity to the method detection limit. Concentrations of Al, As(T), Fe(T), Cd, Co, Cr, Cu, Ni, Pb, Sb(T), and Se were determined by ICP–OES as well as by the preferred HGAAS method for As(T) and Sb(T), FerroZine method for Fe(T), and GFAAS for

Al, Cd, Co, Cr, Cu, Pb, and Se. Concentrations of Al were measured by GFAAS only for samples that were below the ICP–OES detection limit and Cd, Co, Cr, Cu, Pb, and Se concentrations were near or below the ICP–OES detection limit for nearly all samples. Therefore, for these constituents comparison with the preferred method was of little value. The data reported in tables 5–13 were obtained using the preferred method unless there was insufficient sample volume to perform the determinations.

Comparison of analytical results from alternative methods for F, total dissolved As, and total dissolved Fe are shown in figures 31 A to C. The uncertainty line was calculated based on the method with the higher detection limit. At the method detection limit the uncertainty is ±100 percent and decreases to ±5 percent at 20 times the detection limit (quantitation limit).

Fluoride concentrations were determined by both IC and ISE (fig. 31A). Samples for F determination by ISE were mixed 1:1 with a total ionic strength adjustment buffer (TISAB III; Barnard and Nordstrom, 1980), which minimizes the effect of Al-F complexing on the analytical result. However, several of the samples that contained Al at concentrations greater than 5 mg/L yielded F concentrations by ISE that were substantially lower than those obtained by IC, suggesting that IC determinations for those samples were more accurate. For samples containing greater than 5 mg/L Al, the F concentrations determined by IC are reported.

Concentrations of As by HGAAS and Fe by FerroZine were determined on a subsample preserved with HCl, whereas As and Fe by ICP–OES were determined on a subsample preserved with HNO_3. Arsenic concentrations determined by ICP–OES were frequently higher than HGAAS. The difference in the As measurements most likely results from the difference in sample preservation. Samples containing high S^{2-} concentrations may form As-S precipitates when preserved with HCl (Planer-Friedrich and others, 2007). With only a few exceptions, Fe concentrations determined by FerroZine and by ICP–OES are in good agreement. The largest difference in Fe concentration was for a sample from Washburn Hot Springs (06WA135). Results for As and Fe are reported for the sample preserved with HCl because the redox species concentrations were obtained from this split. Considering the uncertainty of the measurements and that the analyses were performed on different splits, analytical results for total dissolved As and total dissolved Fe obtained by the alternative methods are in good agreement.

Table 14. Measurement of concentrations of dissolved constituents in standard reference water samples.

[CVAFS, cold vapor atomic fluorescence spectrometry; GFAAS, graphite furnace atomic absorption spectrometry; HGAAS, hydride generation atomic absorption spectrometry; IC, ion chromatography; ICP-OES, inductively coupled plasma-optical emission spectrometry; ISE, ion selective electrode; mg/L, milligrams per liter; n, number of analyses; ng/L, nanograms per liter; s, standard deviation; SRWS, standard reference water sample; USGS, U.S. Geological Survey; %RSD, percent relative standard deviation; <, less than; ---, no data]

Analyte	Analytical Method	USGS SRWS	n	mg/L[a]	s	Percent RSD	Most Probable Value, mg/L	Percent Difference
Calcium (Ca)	ICP-OES	T179	10	18.3	0.4	2	18.9±0.615	-3
Calcium (Ca)	ICP-OES	T181	14	13.2	0.8	6	13.4±0.556	-1
Calcium (Ca)	ICP-OES	T183	12	11.3	0.4	3	11.6±0.423	-2
Calcium (Ca)	ICP-OES	T189	16	29.7	1.2	4	30.6±1.11	-3
Magnesium (Mg)	ICP-OES	T179	7	4.55	0.12	3	4.59±0.185	-1
Magnesium (Mg)	ICP-OES	T181	9	3.07	0.27	9	3.05±0.115	1
Magnesium (Mg)	ICP-OES	T183	13	7.73	0.25	3	7.89±0.341	-2
Magnesium (Mg)	ICP-OES	T189	13	8.06	0.19	2	8.13±0.256	-1
Sodium (Na)	ICP-OES	T179	14	26.0	1.3	5	26.2±1.00	-1
Sodium (Na)	ICP-OES	T181	12	15.0	0.4	2	15.0±0.519	0
Sodium (Na)	ICP-OES	T183	16	12.8	0.6	5	12.7±0.530	1
Sodium (Na)	ICP-OES	T189	15	48.5	2.2	5	50.0±1.89	-3
Potassium (K)	ICP-OES	T179	15	1.43	0.12	8	1.40±0.148	2
Potassium (K)	ICP-OES	T181	13	1.40	0.05	4	1.52±0.090	-8
Potassium (K)	ICP-OES	T183	18	2.14	0.16	7	2.57±0.096	-17
Potassium (K)	ICP-OES	T189	20	3.63	0.21	6	3.84±0.193	-5
Strontium (Sr)	ICP-OES	T179	9	0.115	0.002	2	0.113±0.00404	2
Strontium (Sr)	ICP-OES	T181	9	0.083	0.003	4	0.0816±0.00319	2
Strontium (Sr)	ICP-OES	T183	13	0.084	0.002	3	0.0824±0.00248	2
Strontium (Sr)	ICP-OES	T189	15	0.188	0.004	2	0.187±0.00519	1
Barium (Ba)	ICP-OES	T179	6	0.036	0.001	3	0.036±0.0017	0
Barium (Ba)	ICP-OES	T181	6	0.025	0.001	4	0.0255±0.00126	0
Barium (Ba)	ICP-OES	T183	13	0.030	0.001	3	0.0299±0.0013	-1
Barium (Ba)	ICP-OES	T189	15	0.070	0.001	2	0.0715±0.00208	-2
Lithium (Li)	ICP-OES	T179	14	0.006	0.001	9	0.0065±0.000434	-1
Lithium (Li)	ICP-OES	T181	15	0.008	0.001	8	0.0084±0.00056	-6
Lithium (Li)	ICP-OES	T183	18	0.003	0.001	43	0.00333±0.000222	4
Lithium (Li)	ICP-OES	T189	19	0.005	0.000	7	0.00395±0.000289	17
Sulfate (SO_4)	IC	M150	2	5.57	0.16	2.8	5.50±0.54	1
Sulfate (SO_4)	IC	M156	8	42.2	0.4	0.9	43.0±1.78	-2
Sulfate (SO_4)	IC	M172	6	12.2	0.4	3.0	12.2±0.604	0
Sulfate (SO_4)	IC	M182	24	10.2	0.2	2.0	10.3±0.382	-1

Table 14. Measurement of concentrations of dissolved constituents in standard reference water samples—Continued.

Analyte	Analytical Method	USGS SRWS	n	mg/L[a]	s	Percent RSD	Most Probable Value, mg/L	Percent Difference
Alkalinity (HCO_3)	Titration	M156	15	73.5	1.2	1.6	75.4±3.1	-3
Alkalinity (HCO_3)	Titration	M158	1	75.6	---	---	77.6±3.1	-2
Alkalinity (HCO_3)	Titration	M182	14	41.3	0.6	1.5	42.6±1.9	-3
Fluoride (F)	IC	M156	6	0.57	0.06	11.4	0.523±0.045	9
Fluoride (F)	IC	M172	4	0.37	0.04	11.4	0.381±0.027	-2
Fluoride (F)	IC	M182	16	0.18	0.01	3.9	0.160±0.022	11
Fluoride (F)	ISE	M172	3	0.373	0.008	2.3	0.381±0.027	-2
Fluoride (F)	ISE	M182	3	0.173	0.004	2.4	0.160±0.022	8
Chloride (Cl)	IC	M150	2	19.0	0.3	1.5	17.0±1.5	12
Chloride (Cl)	IC	M156	6	67.4	1.8	2.7	64.7±1.9	4
Chloride (Cl)	IC	M172	6	15.5	0.2	1.4	16.0±0.37	-3
Chloride (Cl)	IC	M182	23	21.2	0.6	2.6	21.3±0.482	0
Bromide (Br)	IC	AMW4	16	0.41	0.04	9.1	0.430±0.037	-6
Silica (SiO_2)	ICP-OES	T179	14	14.9	0.5	3	14.9±0.604	0
Silica (SiO_2)	ICP-OES	T181	14	13.0	0.4	3	13.1±0.519	-1
Silica (SiO_2)	ICP-OES	T183	18	8.52	0.47	6	8.27±0.448	3
Silica (SiO_2)	ICP-OES	T189	21	12.6	0.6	5	12.2±0.667	3
Boron (B)	ICP-OES	T179	11	0.026	0.003	12	0.028±0.00182	-8
Boron (B)	ICP-OES	T181	9	0.019	0.002	9	0.021±0.00156	-11
Boron (B)	ICP-OES	T183	11	0.057	0.004	7	0.0606±0.00311	-6
Boron (B)	ICP-OES	T189	11	0.019	0.003	17	0.021±0.00289	-10
Aluminum (Al)	ICP-OES	T179	10	0.054	0.016	29	0.0517±0.00319	4
Aluminum (Al)	ICP-OES	T181	9	<0.08	---	---	0.0162±0.00119	---
Aluminum (Al)	ICP-OES	T183	14	0.122	0.013	10	0.127±0.0089	-4
Aluminum (Al)	ICP-OES	T189	21	<0.08	---	---	0.0167±0.00114	---
Aluminum (Al)	GFAAS	T179	4	0.052	0.002	3.1	0.517±0.00319	0.0
Aluminum (Al)	GFAAS	T181	4	0.015	0.000	3.3	0.162±0.00119	-8.7
Aluminum (Al)	GFAAS	T183	4	0.127	0.013	10	0.127±0.0089	0.0
Iron (Fe)	Colorimetric	T179	2	0.121	0.003	2.5	0.125±0.00815	-3
Iron (Fe)	Colorimetric	T183	4	0.206	0.003	1.2	0.206±0.0155	0
Iron (Fe)	ICP-OES	T179	9	0.122	0.005	4	0.125±0.00815	-2
Iron (Fe)	ICP-OES	T181	9	0.121	0.009	8	0.119±0.0089	2
Iron (Fe)	ICP-OES	T183	13	0.198	0.009	4	0.206±0.0155	-4
Iron (Fe)	ICP-OES	T189	14	0.032	0.006	18	0.0325±0.00408	-2

Table 14. Measurement of concentrations of dissolved constituents in standard reference water samples—Continued.

Analyte	Analytical Method	USGS SRWS	n	mg/L[a]	s	Percent RSD	Most Probable Value, mg/L	Percent Difference
Manganese (Mn)	GFAAS	T181	7	0.0127	0.0003	2.2	0.0116±0.000593	9
Manganese (Mn)	GFAAS	T189	7	0.0069	0.0003	5.0	0.00655±0.000397	6
Manganese (Mn)	ICP-OES	T179	6	0.043	0.002	4	0.0442±0.00156	-2
Manganese (Mn)	ICP-OES	T181	6	0.011	0.001	10	0.0116±0.000593	-4
Manganese (Mn)	ICP-OES	T183	13	0.051	0.003	6	0.0492±0.00156	4
Manganese (Mn)	ICP-OES	T189	8	0.006	0.000	5	0.00655±0.000397	-13
Copper (Cu)	GFAAS	T179	9	0.0034	0.0003	9.8	0.00386±0.000345	-11
Copper (Cu)	GFAAS	T181	16	0.0081	0.0006	6.9	0.00779±0.000452	4
Copper (Cu)	GFAAS	T189	18	0.0027	0.0004	13.7	0.00294±0.000189	-7
Copper (Cu)	ICP-OES	T179	5	0.003	0.002	55	0.00386±0.000345	-14
Copper (Cu)	ICP-OES	T181	5	0.007	0.001	16	0.00779±0.000452	-10
Copper (Cu)	ICP-OES	T183	9	<0.003	---	---	0.00306±0.000156	---
Copper (Cu)	ICP-OES	T189	11	0.003	0.001	32	0.00294±0.000189	-4
Zinc (Zn)	ICP-OES	T179	8	0.008	0.001	9	0.0085±0.000738	-11
Zinc (Zn)	ICP-OES	T181	9	0.009	0.001	10	0.0105±0.000741	-12
Zinc (Zn)	ICP-OES	T183	13	0.091	0.006	7	0.0864±0.00522	5
Zinc (Zn)	ICP-OES	T189	8	0.007	0.001	9	0.0078±0.000604	-9
Cadmium (Cd)	GFAAS	T179	17	0.0045	0.0001	2.7	0.0044±0.00017	1
Cadmium (Cd)	GFAAS	T183	17	0.0055	0.0002	2.9	0.0054±0.00029	2
Cadmium (Cd)	ICP-OES	T179	7	0.004	0.000	3	0.00442±0.00017	-1
Cadmium (Cd)	ICP-OES	T181	6	0.002	0.000	14	0.0016±0.000093	-6
Cadmium (Cd)	ICP-OES	T183	9	0.006	0.000	6	0.00535±0.000289	3
Cadmium (Cd)	ICP-OES	T189	12	0.002	0.000	14	0.00155±0.000067	4
Chromium (Cr)	GFAAS	T179	17	0.0046	0.0003	7.0	0.00422±0.000334	8
Chromium (Cr)	GFAAS	T179	19	0.0056	0.0005	8.3	0.00564±0.000222	0
Chromium (Cr)	ICP-OES	T179	7	0.004	0.001	27	0.00422±0.000334	-11
Chromium (Cr)	ICP-OES	T181	8	0.005	0.001	27	0.00564±0.000222	-10
Chromium (Cr)	ICP-OES	T183	9	<0.002	---	---	0.00211±0.000208	---
Chromium (Cr)	ICP-OES	T189	12	0.003	0.001	17	0.00325±0.000241	0
Cobalt (Co)	GFAAS	T179	17	0.0011	0.0004	36.5	0.00110±0.000052	-1
Cobalt (Co)	GFAAS	T181	19	0.0053	0.0006	11.1	0.00550±0.000267	-4
Cobalt (Co)	ICP-OES	T179	7	<0.007	---	---	0.0011±0.000052	---
Cobalt (Co)	ICP-OES	T181	7	<0.007	---	---	0.0055±0.000267	---
Cobalt (Co)	ICP-OES	T183	9	<0.007	---	---	0.00394±0.000222	---
Cobalt (Co)	ICP-OES	T189	12	<0.007	---	---	0.0023±0.000107	---

Table 14. Measurement of concentrations of dissolved constituents in standard reference water samples—Continued.

Analyte	Analytical Method	USGS SRWS	n	mg/L[a]	s	Percent RSD	Most Probable Value, mg/L	Percent Difference
Nickel (Ni)	GFAAS	T163	16	0.0154	0.0010	6.5	0.0154±0.00126	0
Nickel (Ni)	GFAAS	T181	16	0.0045	0.0002	3.9	0.00472±0.000252	-6
Nickel (Ni)	GFAAS	T183	15	0.0011	0.0002	14.3	0.00124±0.000185	-10
Nickel (Ni)	ICP-OES	T179	5	<0.002	---	---	0.00141±0.000445	---
Nickel (Ni)	ICP-OES	T181	5	0.004	0.001	35	0.00472±0.000252	-24
Nickel (Ni)	ICP-OES	T183	13	<0.002	---	---	0.00124±0.000185	---
Nickel (Ni)	ICP-OES	T189	16	<0.002	---	---	0.00073±0.000441	---
Lead (Pb)	GFAAS	T179	15	0.0017	0.0002	10.0	0.00186±0.000141	-8
Lead (Pb)	GFAAS	T183	16	0.0058	0.0002	4.0	0.00589±0.000304	-2
Lead (Pb)	ICP-OES	T179	8	<0.008	---	---	0.00186±0.000141	---
Lead (Pb)	ICP-OES	T181	7	0.009	0.003	38	0.0094±0.000482	-8
Lead (Pb)	ICP-OES	T183	13	<0.008	---	---	0.00589±0.000304	---
Lead (Pb)	ICP-OES	T189	16	<0.008	---	---	0.000117±0.000027	---
Beryllium (Be)	ICP-OES	T179	6	0.004	0.000	2	0.00374±0.000185	-1
Beryllium (Be)	ICP-OES	T181	6	0.004	0.000	8	0.0046±0.000263	-6
Beryllium (Be)	ICP-OES	T183	13	0.0008	0.000	10	0.00082±0.000043	1
Beryllium (Be)	ICP-OES	T189	16	0.004	0.000	4	0.00369±0.000248	0
Vanadium (V)	ICP-OES	T179	6	0.002	0.001	42	0.00284±0.000282	-25
Vanadium (V)	ICP-OES	T181	8	<0.005	---	---	0.00371±0.000156	---
Vanadium (V)	ICP-OES	T183	9	<0.005	---	---	0.00464±0.000222	---
Vanadium (V)	ICP-OES	T189	12	<0.005	---	---	0.00295±0.000326	---
Molybdenum (Mo)	ICP-OES	T179	7	<0.007	---	---	0.00218±0.000145	---
Molybdenum (Mo)	ICP-OES	T181	4	<0.007	---	---	0.00449±0.000345	---
Molybdenum (Mo)	ICP-OES	T183	13	<0.007	---	---	0.0021±0.000148	---
Molybdenum (Mo)	ICP-OES	T189	14	<0.007	---	---	0.0024±0.000133	---
Antimony (Sb)	HGAAS	AMW4	1	0.0032	---	----	0.0277±0.00089	16
Antimony (Sb)	HGAAS	T163	5	0.0307	0.0018	5.9	0.0325±0.00189	-5
Antimony (Sb)	ICP-OES	T179	4	<0.02	---	---	0.00366±0.000189	---
Antimony (Sb)	ICP-OES	T181	6	<0.02	---	---	0.00343±0.000141	---
Antimony (Sb)	ICP-OES	T183	13	<0.02	---	---	0.00481±0.000259	---
Antimony (Sb)	ICP-OES	T189	16	<0.02	---	---	0.00036±0.000028	---
Selenium (Se)	GFAAS	T189	9	0.0026	0.0008	32.6	0.00313±0.000497	-18
Selenium (Se)	ICP-OES	T179	2	<0.03	---	---	0.0013±0.000267	---
Selenium (Se)	ICP-OES	T181	7	<0.03	---	---	0.0013±0.000237	---
Selenium (Se)	ICP-OES	T183	9	<0.03	---	---	0.0021±0.000245	---
Selenium (Se)	ICP-OES	T189	12	<0.03	---	---	0.00313±0.000497	---

Table 14. Measurement of concentrations of dissolved constituents in standard reference water samples—Continued.

Analyte	Analytical Method	USGS SRWS	n	mg/L[a]	s	Percent RSD	Most Probable Value, mg/L	Percent Difference
Arsenic (As)	ICP-OES	T179	11	<0.02	---	---	0.0019±0.000189	---
Arsenic (As)	ICP-OES	T181	9	<0.02	---	---	0.0061±0.000319	---
Arsenic (As)	ICP-OES	T183	17	<0.02	---	---	0.0045±0.000289	---
Arsenic (As)	ICP-OES	T189	21	<0.02	---	---	0.00466±0.000315	---
Mercury (Hg)[a]	CVAFS	Hg7	151	256	22		220±80	16
Mercury (Hg)[a]	CVAFS	Hg22	69	1165	51		1240±130	-6

[a] Mercury concentrations are ng/L

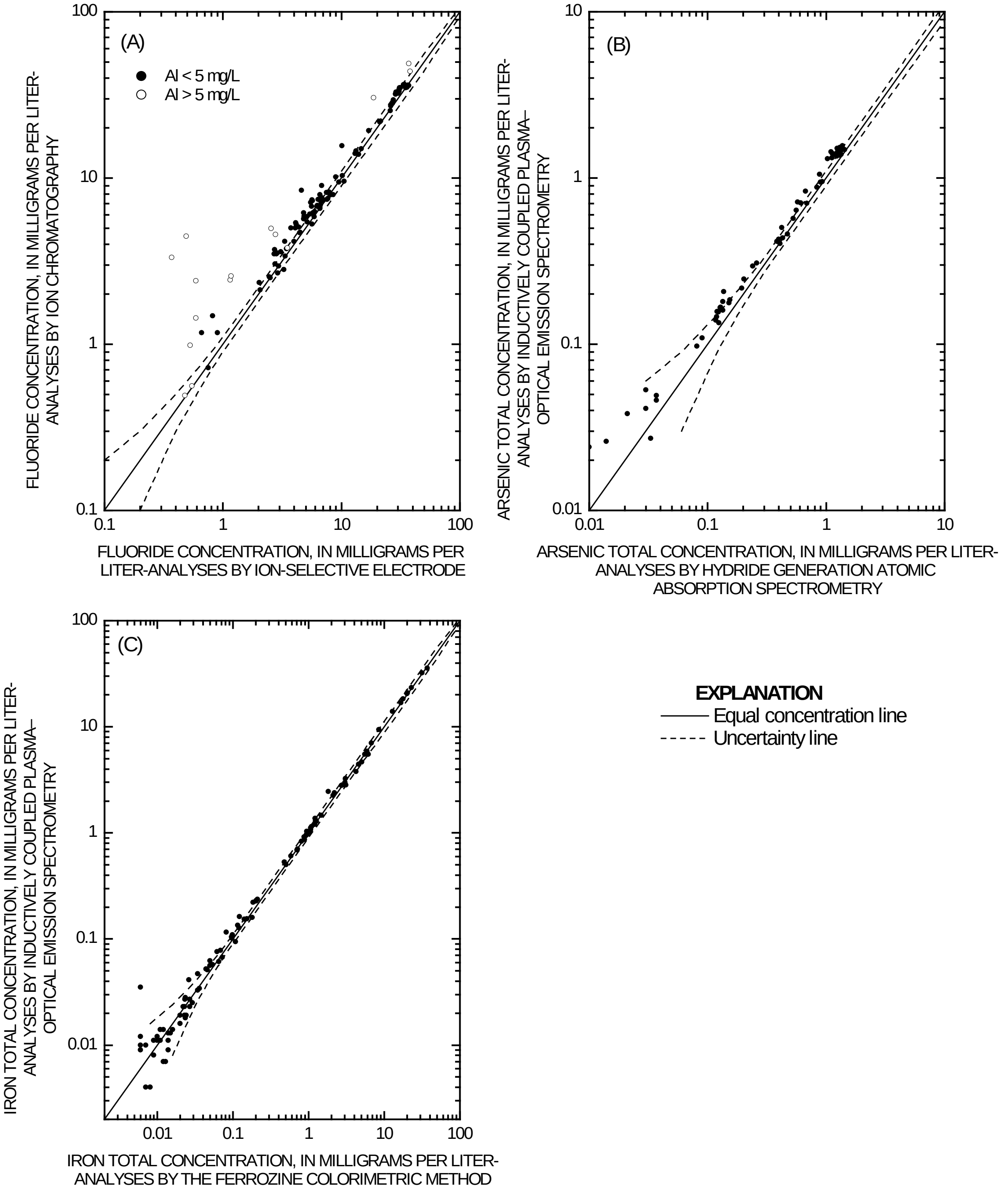

Figure 31. Fluoride (A), total dissolved arsenic (B), and total dissolved iron (C) concentrations determined by alternative methods.

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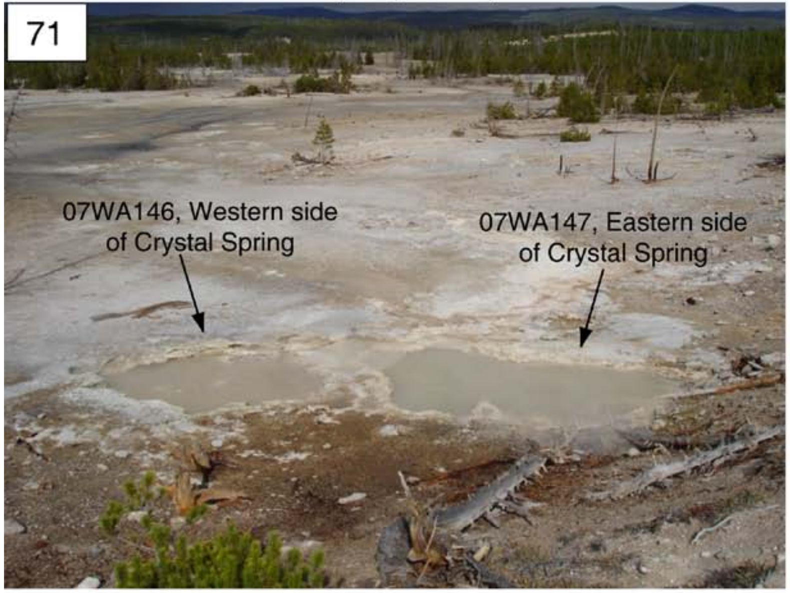

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