Water-Chemistry Data for Selected Springs, Geysers, and Streams in Yellowstone National Park, Wyoming, 1999-2000

Open-File Report 02-382

U.S. Department of the Interior
U.S. Geological Survey

Water-Chemistry Data for Selected Springs, Geysers, and Streams in Yellowstone National Park, Wyoming, 1999-2000

By James W. Ball, R. Blaine McCleskey, D. Kirk Nordstrom, JoAnn M. Holloway, and Philip L. Verplanck

U.S. Geological Survey

with a section on

Activity of Thermal Features of Norris Geyser Basin, 1998

By Sabin A. Sturtevant

Open-File Report 02-382

Front Cover Photography: View taken in 1999 of Ragged Hills at the summit, Norris Geyser Basin, Yellowstone National Park looking to the southwest. One Hundred Spring Plain is to the right (north). Photo by J.W. Ball

Back Cover Photography: The same view of Ragged Hills at the summit taken in 2000. Photo by J.W. Ball

Boulder, Colorado
2002

USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat Director

For additional information write to:

Chief, Branch of Regional Research
U.S. Geological Survey
Denver Federal Center
Box 25046, MS-418
Denver, Colorado 80225

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Denver Federal Center,
Box 25286
Denver, Colorado 80225-0286

CONTENTS

FIGURES

TABLES

Explanation of abbreviations

--- (not analyzed or not measured)
a.k.a. (also known as)
cm (centimeter)
COLOR (colorimetry)
COND or Spec Cond (specific conductance)
D.O. (dissolved oxygen)
δ^2H ($^2H/^1H$ ratio referenced to the VSMOW standard)
$\delta^{18}O$ ($^{18}O/^{16}O$ ratio referenced to the VSMOW standard)
EC (electro-chemical method)
FAAS (flame atomic absorption spectrometry)
FAES (flame atomic emission spectrometry)
FIAS (flow injection analysis system)
ft^3/s (cubic feet per second)
g/mL (grams per milliliter)
hr (hour)
IC (ion chromatography)
ICP (inductively-coupled plasma-optical emission spectrometry)
ISOT (stable isotope analysis)
kw (kilowatts)
m (meter)
meq/L (milliequivalents per liter)
mg/L (milligrams per liter)
min (minute)
mm (millimeter)
mM (millimoles per liter)
µm (micrometer)
µS/cm (microsiemens per centimeter at 25 degrees Celsius)
sec (second)
SLAP (Standard Light Antarctic Precipitation)
SRWS (standard reference water sample)
σ_{blank} (standard deviation of multiple analyses of a blank solution analyzed as an unknown)
TITR (titrimetry)
UN (unnamed)
UNG (unnamed geyser)
UNS (unnamed spring)
UV (ultraviolet)
V (volt)
v/v (volume/volume)
VSMOW (Vienna Standard Mean Ocean Water)
YNP (Yellowstone National Park)
ZGFAAS (Zeeman-corrected graphite furnace atomic absorption spectrometry)

Water-Chemistry Data for Selected Springs, Geysers, and Streams in Yellowstone National Park, Wyoming, 1999-2000

By James W. Ball, R. Blaine McCleskey, D. Kirk Nordstrom, JoAnn M. Holloway, and Philip L. Verplanck

ABSTRACT

Sixty-seven water analyses are reported for samples collected from 44 hot springs and their overflow drainages and two ambient-temperature acid streams in Yellowstone National Park (YNP) during 1990-2000. Thirty-seven analyses are reported for 1999, 18 for June of 2000, and 12 for September of 2000. These water samples were collected and analyzed as part of research investigations in YNP on microbially mediated sulfur oxidation in stream water, arsenic and sulfur redox speciation in hot springs, and chemical changes in overflow drainages that affect major ions, redox species, and trace elements. Most samples were collected from sources in the Norris Geyser Basin. Two ambient-temperature acidic stream systems, Alluvium and Columbine Creeks and their tributaries in Brimstone Basin, were studied in detail. Analyses were performed at or near the sampling site, in an on-site mobile laboratory truck, or later in a USGS laboratory, depending on stability of the constituent and whether or not it could be preserved effectively.

Water temperature, specific conductance, pH, Eh, dissolved oxygen (D.O.), and dissolved H_2S were determined on-site at the time of sampling. Alkalinity, acidity, and F were determined within a few days of sample collection by titration with acid, titration with base, and ion-selective electrode or ion chromatography (IC), respectively. Concentrations of S_2O_3 and S_xO_6 were determined as soon as possible (minutes to hours later) by IC. Concentrations of Br, Cl, NH_4, NO_2, NO_3, SO_4, Fe(II), and Fe(total) were determined within a few days of sample collection. Densities were determined later in the USGS laboratory.

Concentrations of Li and K were determined by flame atomic absorption spectrometry. Concentrations of Al, As(total), B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe(total), K, Li, Mg, Mn, Na, Ni, Pb, Se, Si, Sr, V, and Zn were determined by inductively-coupled plasma-optical emission spectrometry. Trace concentrations of Cd, Cr, Cu, Pb, and Sb were determined by Zeeman-corrected graphite-furnace atomic-absorption spectrometry. Trace concentrations of As(total) and As(III) were determined by hydride generation atomic-absorption spectrometry using a flow-injection analysis system. Concentrations of Cl, NO_3, Br, and SO_4 were determined by IC. Concentrations of Fe(II) and Fe(total) were determined by the ferrozine colorimetric method. Concentrations of NO_2 were determined by colorimetry using matrix-matched standards. Concentrations of NH_4 were determined by IC, with reanalysis by colorimetry where separation of Na and NH_4 peaks was poor. Dissolved organic carbon (DOC) concentrations were determined by the wet persulfate oxidation method.

INTRODUCTION

Investigations into the water chemistry of hot springs, geysers, streams, and rivers in YNP have been conducted primarily by the USGS, dating back to 1888. A list of these publications is presented in Table 1, and the complete citations are presented in References Cited.

Table 1. Publications describing investigations into the water chemistry of hot springs, geysers, streams, and rivers in Yellowstone National Park

Authors	Abbreviated title	Publication Date
Gooch and Whitfield	Analyses of waters of the Yellowstone National Park	1888
Allen and Day	Hot Springs of the Yellowstone National Park	1935
White, Hem, and Waring	Chemical composition of subsurface waters	1963
Rowe, Fournier, and Morey	Chemical analysis of thermal waters in YNP	1973
Thompson, Presser, Barnes, and Bird	Chemical analyses from YNP, 1965 to 1973	1975
Thompson and Yadav	Chemical analyses from YNP, 1974 to 1978	1979
Stauffer, Jenne, and Ball	Chemical studies of selected trace elements in hot spring drainages of YNP	1980
Thompson and Hutchinson	Chemical analyses from the Boundary Creek area, YNP	1981
White, Hutchinson, and Keith	Geology and thermal features of Norris Geyser Basin	1988
Fournier	Geochemistry and dynamics of the YNP hydrothermal system	1989
Kharaka, Mariner, Bullen, Kennedy, and Sturchio	Geochemical investigations at Corwin Springs and adjacent parts of YNP	1991
Fournier, Thompson, and Hutchinson	Geochemistry of hot spring waters at Norris Geyser Basin	1994
Thompson and DeMonge	Chemical analyses from YNP	1996
Ball, Nordstrom, Jenne, and Vivit	Chemical analyses from YNP, 1974-1975 data	1998a
Ball, Nordstrom, Cunningham, Schoonen, Xu, and DeMonge	Chemical analyses from YNP, 1994-1995 data	1998b
Ball, Nordstrom, McCleskey, Schoonen, and Xu	Chemical analyses from YNP, 1996-1998 data	2001
Kharaka, Thordsen, and White	Isotope and chemical compositions of meteoric and thermal waters and snow, YNP region	2002

Waters at YNP have pH values ranging from 1 to 10, temperatures from ambient to about 93°C (boiling at YNP's altitude), and high concentrations of As, H_2S, SO_4, and HCO_3 relative to many natural waters. Numerous redox reactions and mineral-precipitation reactions occur. As well as being valuable natural resources, active geothermal areas such as those in YNP provide insight into formation of mineral deposits, microbiological processes in extreme environments, and water-rock interactions.

Arsenic typically is present at high concentrations in most geothermal waters (Webster and Nordstrom, 2002). One objective of studying the chemistry of Yellowstone Park waters is to survey As redox species concentrations in a large number of thermal features to interpret the geochemical processes controlling the distribution, transport, and fate of As in a natural environment. Many thermal features in Norris Geyser Basin were sampled for Fe and As redox species, major and trace metal cations, and major anions. The remaining chemical determinations, including those for DOC, S_2O_3, S_xO_6, acidity, alkalinity, NO_2, and NH_4, were foregone for this subset of samples so that a maximum number of features could be sampled. These samples are identified in the tables with the letter Q following the sample ID number to identify them as "Quick" samples.

Purpose and Scope

The present study is the third phase of a collaborative research project between the USGS, the State University of New York (SUNY) at Stony Brook, and Northern Arizona University. The purpose of this investigation is to study the occurrence, origin, rates of formation and disappearance, and geochemical processes involving unstable redox species of sulfur in mineral springs and geothermal waters. Several papers have been published that report results of the first two phases of this project and of other collaborative research efforts (Ball and others, 1998b; 2001; Xu and Schoonen, 1995; Xu and others, 1996; 1998; 2000). Another purpose of this report is to present results of initial studies of arsenic in the mineral springs and geothermal waters of YNP, and the evolution and chemical composition of a large number of the hydrothermal features of the still-developing Ragged Hills Area of Norris Geyser Basin.

During 1999-2000, 67 water samples were collected and analyzed for major and trace constituents from two areas of YNP (fig. 1): Brimstone Basin and Norris Geyser Basin. In Brimstone Basin, water discharging from springs and flowing in Alluvium Creek and its tributaries provided a range of pH values and dissolved constituent concentrations that allowed study of low-temperature sulfur oxidation processes. The analyses for hot springs in Norris Geyser Basin are some of the most complete available, containing major ions, trace elements, and redox species such as Fe(II)/Fe(total), As(III)/As(total), H_2S, S_2O_3, and S_xO_6. A subset of Norris Geyser Basin samples was collected as a survey of As redox species in various geothermal features.

Acknowledgments

We extend our appreciation to the staff of Yellowstone National Park for permission to collect water samples and for their assistance on numerous occasions. In particular we extend our thanks to Ann Deutch and for her generous assistance, to Katie Duffy, Wes Miles, Brian Thorpe, John Tebby, Bill Wise, and all of the Ranger staff at Norris Geyser Basin for escorting us to and educating us about the many thermal features of Norris, and to Steve Miller of the Yellowstone Spatial Analysis Center for assistance on numerous occasions with precisely locating Yellowstone Park thermal features. We extend our appreciation to Irving Friedman (USGS, Denver, CO) for providing us with discharge data for Tantalus Creek and giving us permission to use the results in this report. We would also like to extend our appreciation to Yong Xu, Gordon Southam, Chris

Knickerbocker, Randy Mielke, and Bill Stanley for their assistance with sampling on numerous occasions. We are especially thankful to John Varley, Director of the Center for Natural Resources at YNP, for his continued encouragement of our work, and to Rick Hutchinson for his advice and his interest in our work from 1974 until his untimely death in 1997.

The authors are grateful to Sabin A. "Smokey" Sturtevant (smokeys@mail.usadig.com) for contributing the material in Appendix 2 containing his descriptions on the activity of thermal features of Norris Geyser Basin during 1998. We also thank T. B. Coplen (USGS, Reston, VA) for H and O isotope determinations and J. L. Weishaar (USGS, Boulder, CO) for DOC determinations.

SAMPLE LOCATIONS

Twenty-nine samples for complete analysis and 21 samples for As and Fe redox species and major cation and anion determinations were collected from Norris Geyser Basin (figs. 2, 3, 4, and 5), and 8 samples for complete analysis were taken from Nymph Creek Springs and Nymph Creek (figs. 6 and 7). Nine samples were collected at Brimstone Basin (fig. 8), with four of the samples collected from Alluvium Creek and its tributaries, and the remaining five samples collected from Columbine Creek and its tributaries. It has become increasingly apparent to us over the years that accurate location and description of sample sites, particularly geothermal features, is of the utmost importance. As a result, we have made every effort to include detailed verbal descriptions, accurate latitude and longitude measurements, and photographs taken by the authors of this report (Appendix 3) of all the sample sites for which analytical results are reported here.

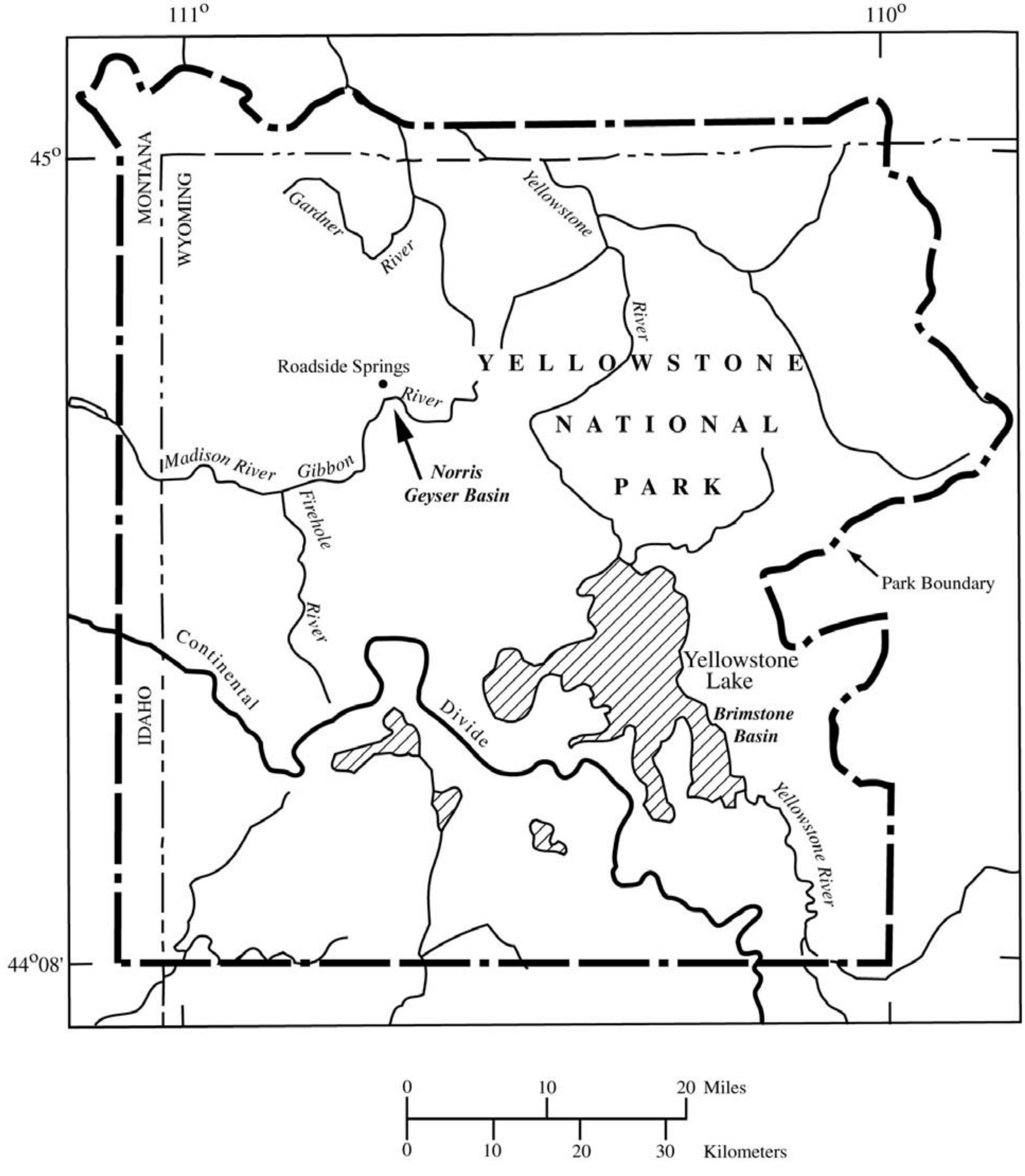
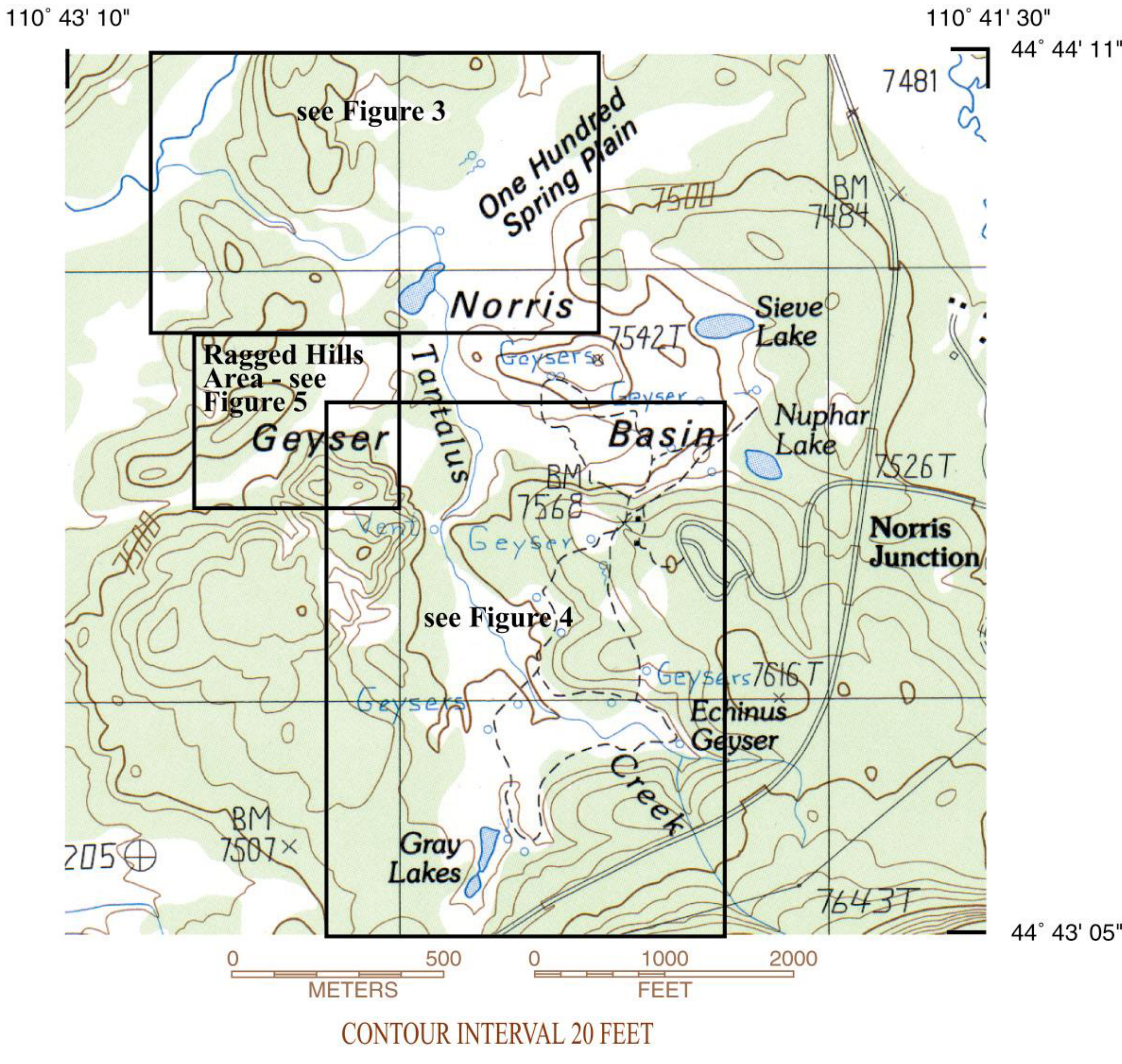
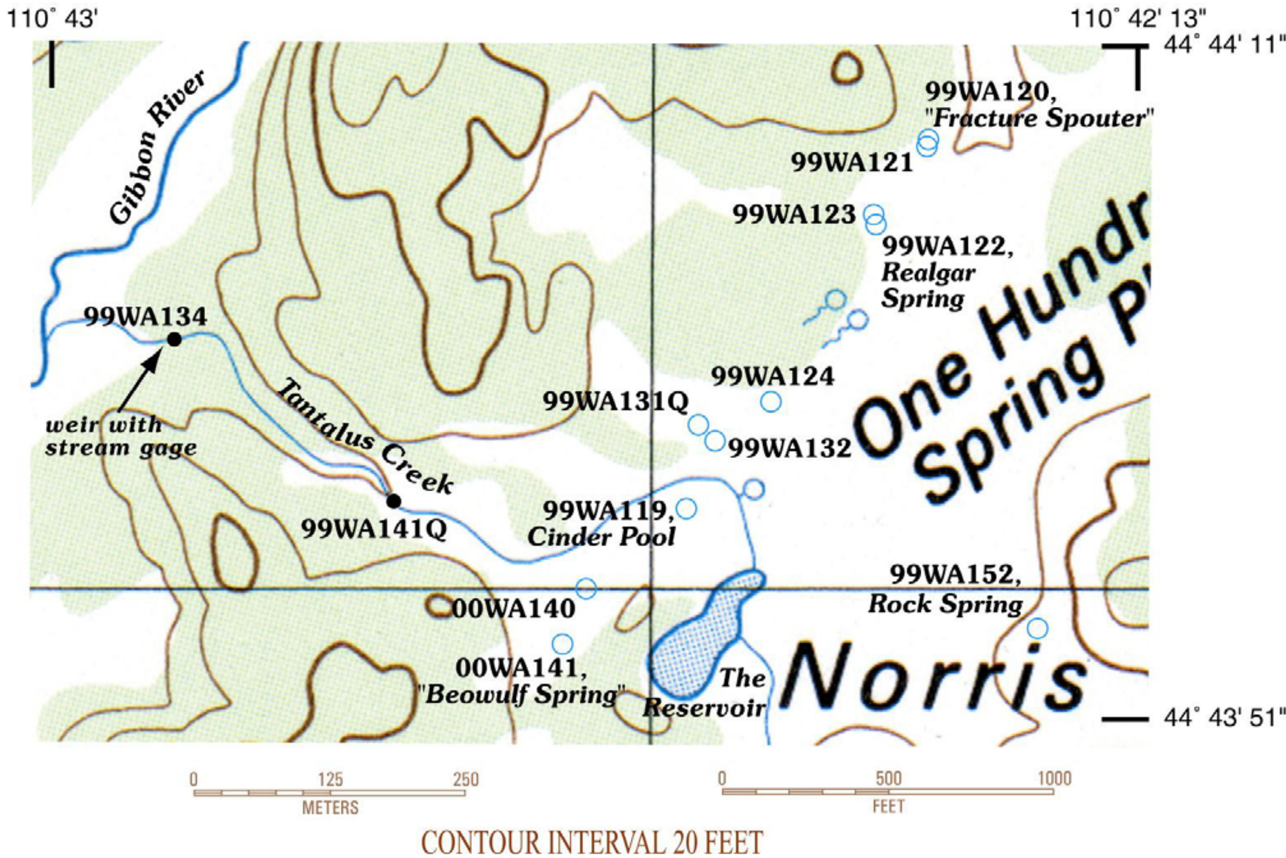


Figure 1. Location of sampling areas in Yellowstone National Park, Wyo.



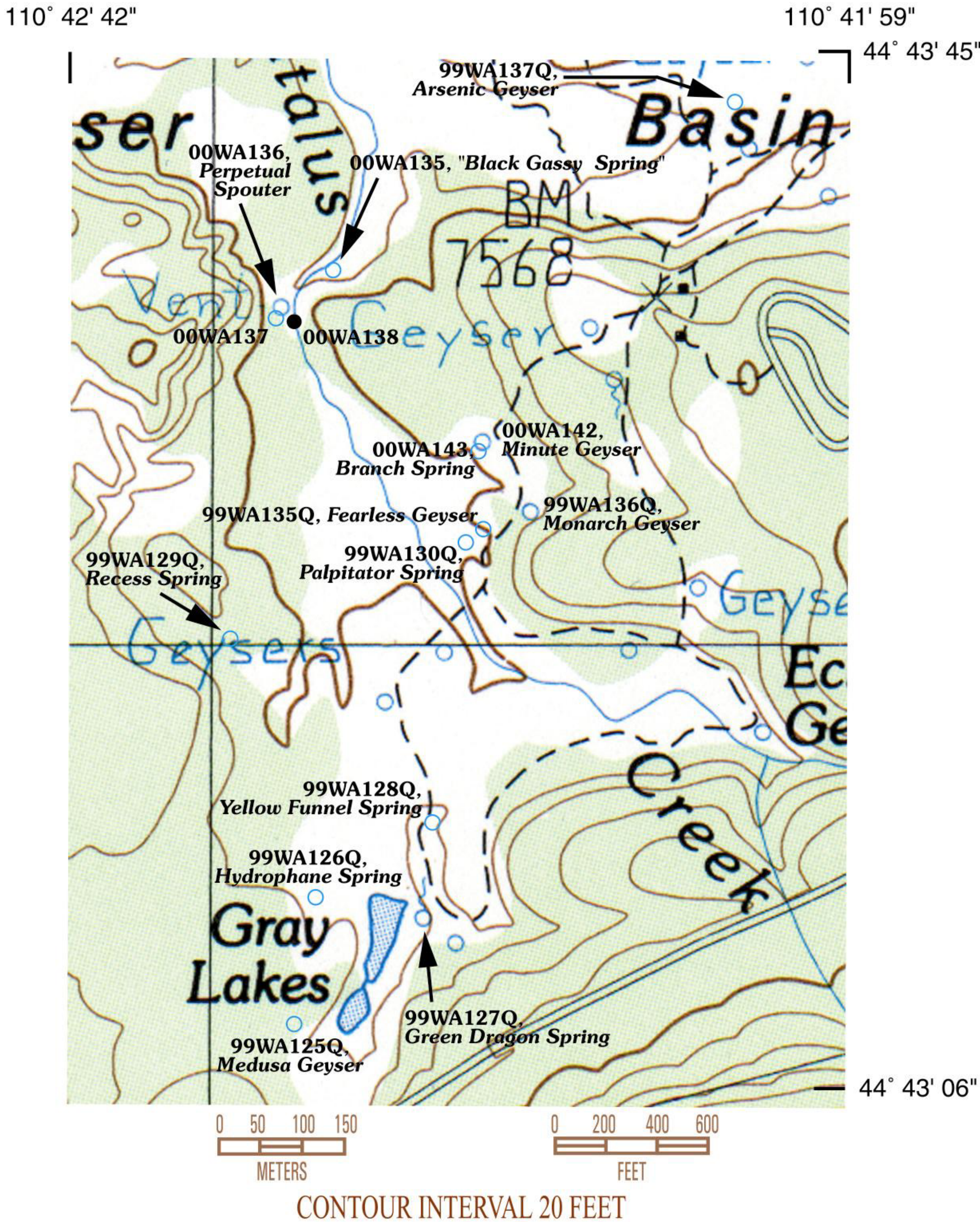
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 2. Sampling locations for hot springs and surface waters at Norris Geyser Basin, Yellowstone National Park, Wyo.



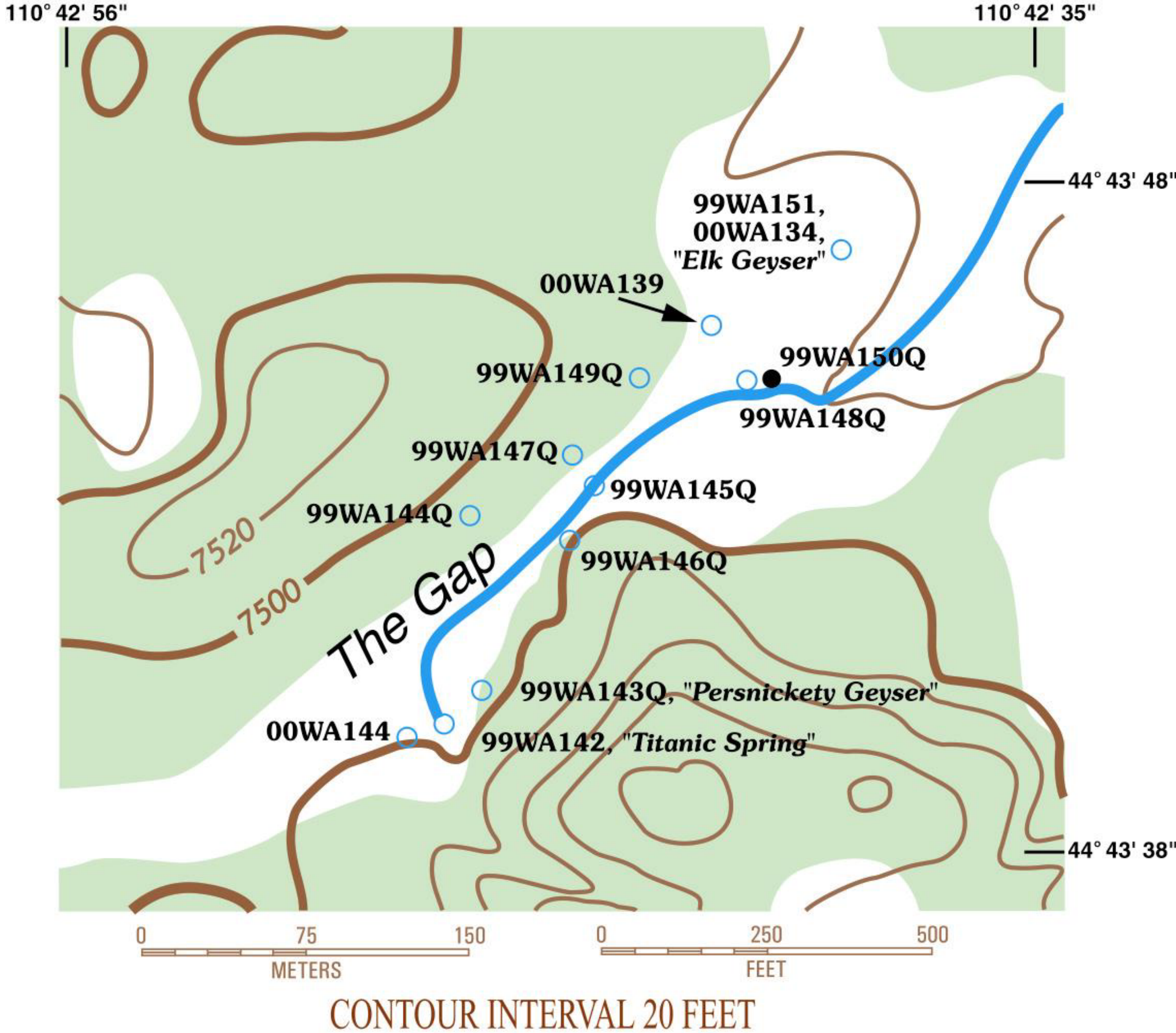
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 3. Sampling locations for hot springs and two surface water samples in the One Hundred Spring Plain area of Norris Geyser Basin, Yellowstone National Park, Wyo.



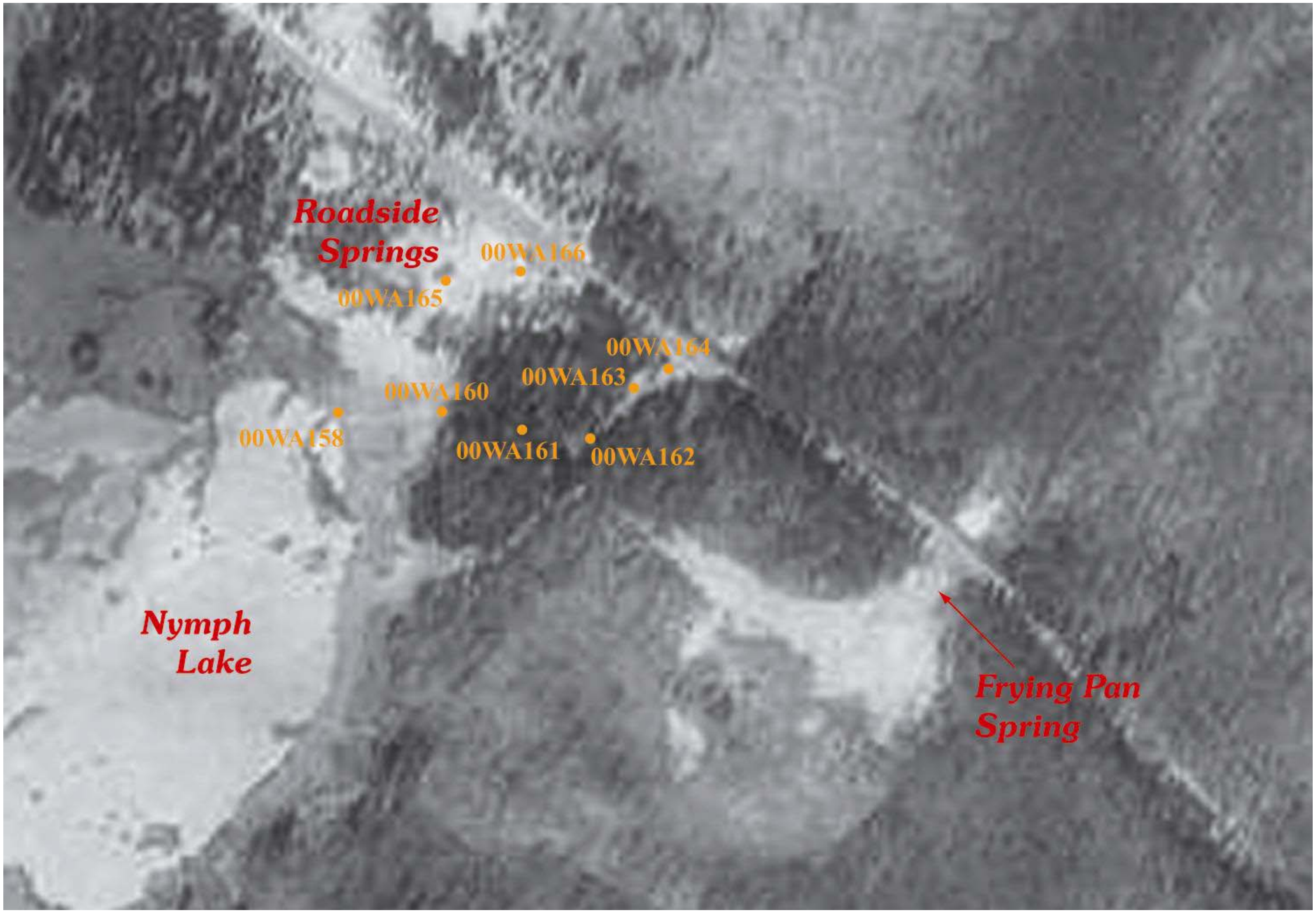
Base from U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 4. Sampling locations for hot springs and one surface water sample in the southern part of Norris Geyser Basin, Yellowstone National Park, Wyo. (see figure 2)



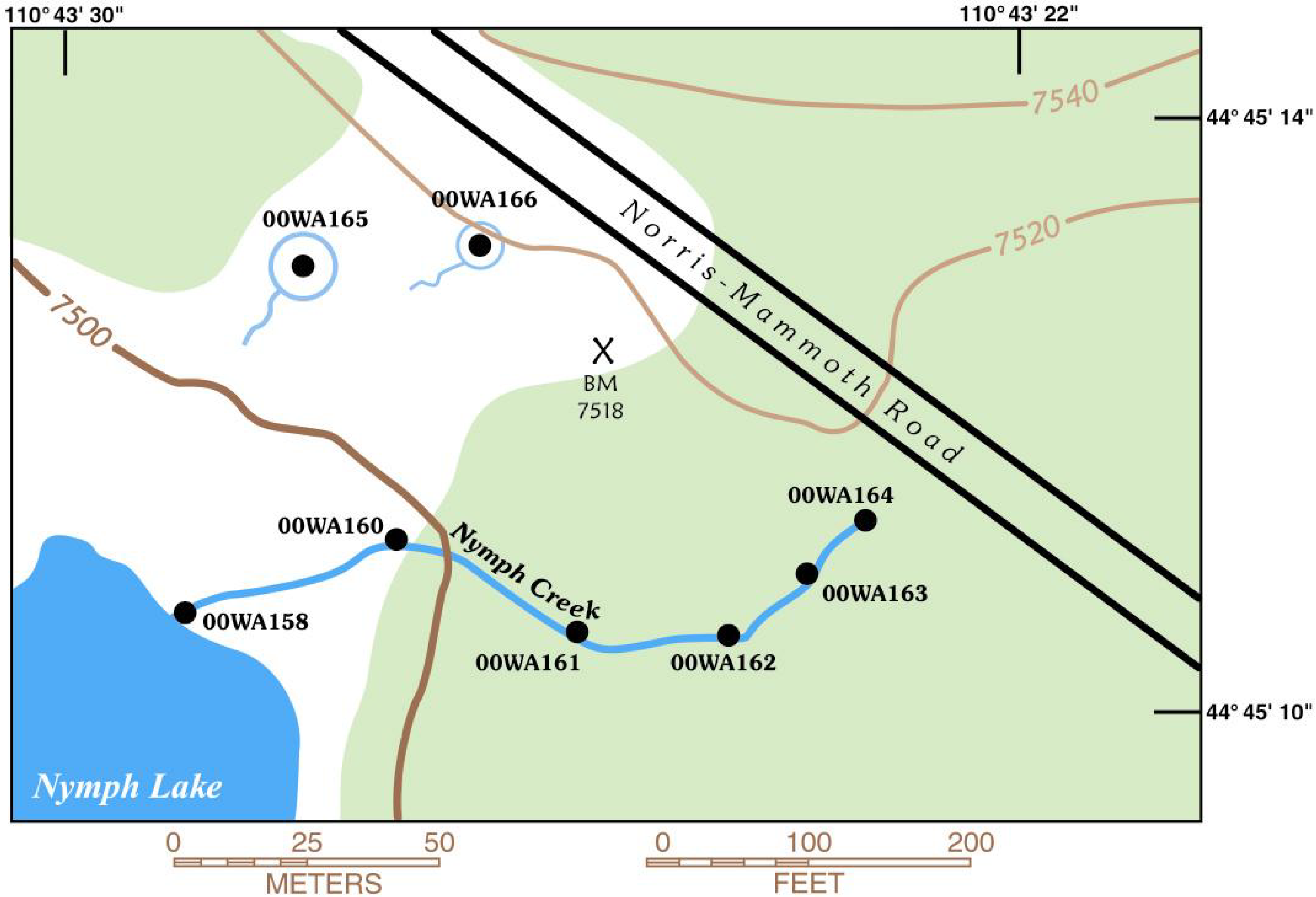
Sketch based on U.S. Geological Survey Norris Junction quadrangle, 1:24,000 (1986)

Figure 5. Sampling locations for hot springs and one surface water sample in the Ragged Hills area of Norris Geyser Basin, Yellowstone National Park, Wyo.



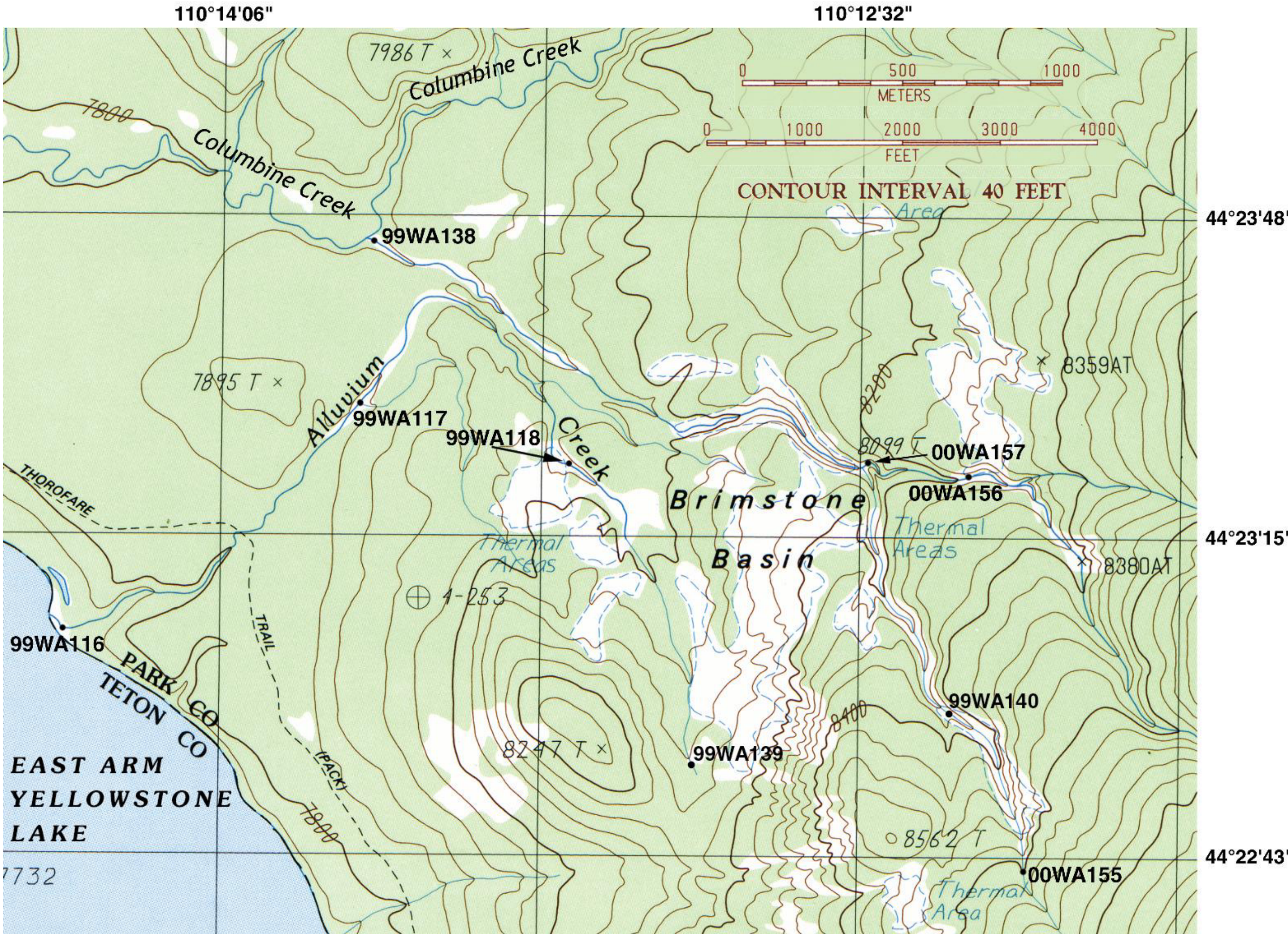
Base from U.S. Geological Survey Obsidian Cliff SW Digital Orthophoto Quarter Quadrangle, 1:12,000 (1994)

Figure 6. Sampling locations for Nymph Creek, two vents of Nymph Creek Springs, and two of the Roadside Springs near Nymph Lake, Yellowstone Park, Wyo.



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

Figure 7. Sampling locations for Nymph Creek, two vents of Nymph Creek Springs, and two of the Roadside Springs near Nymph Lake, Yellowstone Park, Wyo.



Base from U.S. Geological Survey Sylvan Lake quadrangle, 1:24,000 (1989)

Figure 8. Sampling sites for Alluvium and Columbine Creeks and their tributaries, Yellowstone National Park, Wyo.

GEOTHERMAL ACTIVITY IN THE RAGGED HILLS AREA

Beginning in 1995, an area of Norris Geyser Basin, centered about 400 m northwest of Perpetual Spouter (figs. 2 and 5), erupted with intense hydrothermal activity, with three small springs appearing in a 20- by 50-m area (fig. 5; Sturtevant, S.A., written commun., 2002). This area is known as Ragged Hills (Whittlesey, 1995, p. 577), and the area of most intense hot spring and geyser activity is known as The Gap (Whittlesey, 1995, p. 246). By the end of 2000, the area of hydrothermal activity at Ragged Hills had grown to approximately 270 by 2150 m. Preliminary shallow subsurface thermal monitoring studies have revealed a cyclic movement of heat and water between the higher elevation (west) and the lower elevation (east) with a period of about four months (Sturtevant, S.A., written commun., 2002).

Possible Relation of Seismic Activity to Ragged Hills Geothermal Activity

Ragged Hills, like all of Norris Geyser Basin, is located in a belt of significant seismic activity. Distribution of earthquake locations around Yellowstone National Park can be found at the University of Utah seismograph web site at http://www.seis.utah.edu/catalog/ynp.shtml. Figure 9 shows earthquake frequency by year recorded by the University of Utah Yellowstone seismograph network from 1995 to 2000. For the 1995 to 2000 time period, earthquake activity in the region increased significantly in 1999, with more than double the number of earthquakes of any one of the preceding four years (fig. 9). It is significant that during the 1999-2000 period the hydrothermal activity of the Ragged Hills area was evolving rapidly. The front and back cover photographs of this report, reproduced in figure 10, illustrate the changes that have occurred at the upper elevation of Ragged Hills, where three distinct hydrothermal features merged into one. The northernmost feature ("Persnickety Geyser") has changed from a sub-boiling to a violently surging spring, to a small geyser in 2001, and boiling has ceased in the next feature to the southwest ("Titanic Spring").

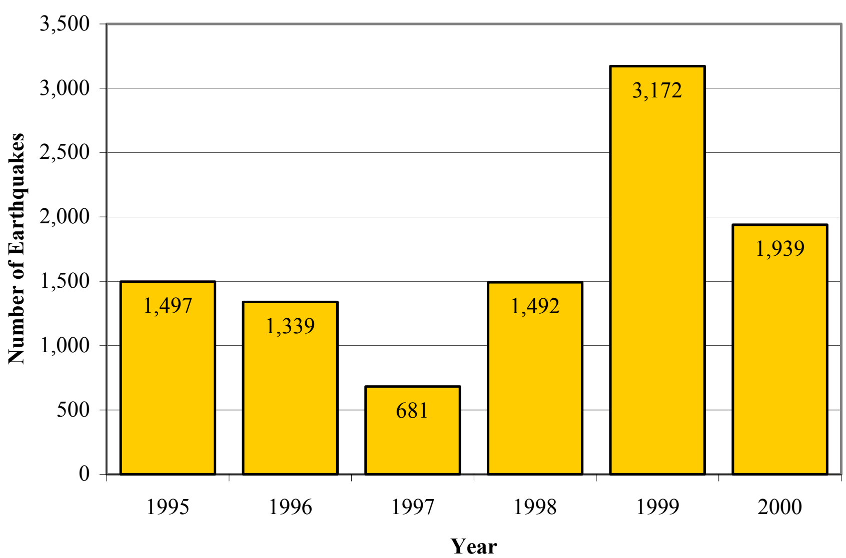


Figure 9. Annual number of earthquakes,Yellowstone National Park, 1995 - 2000

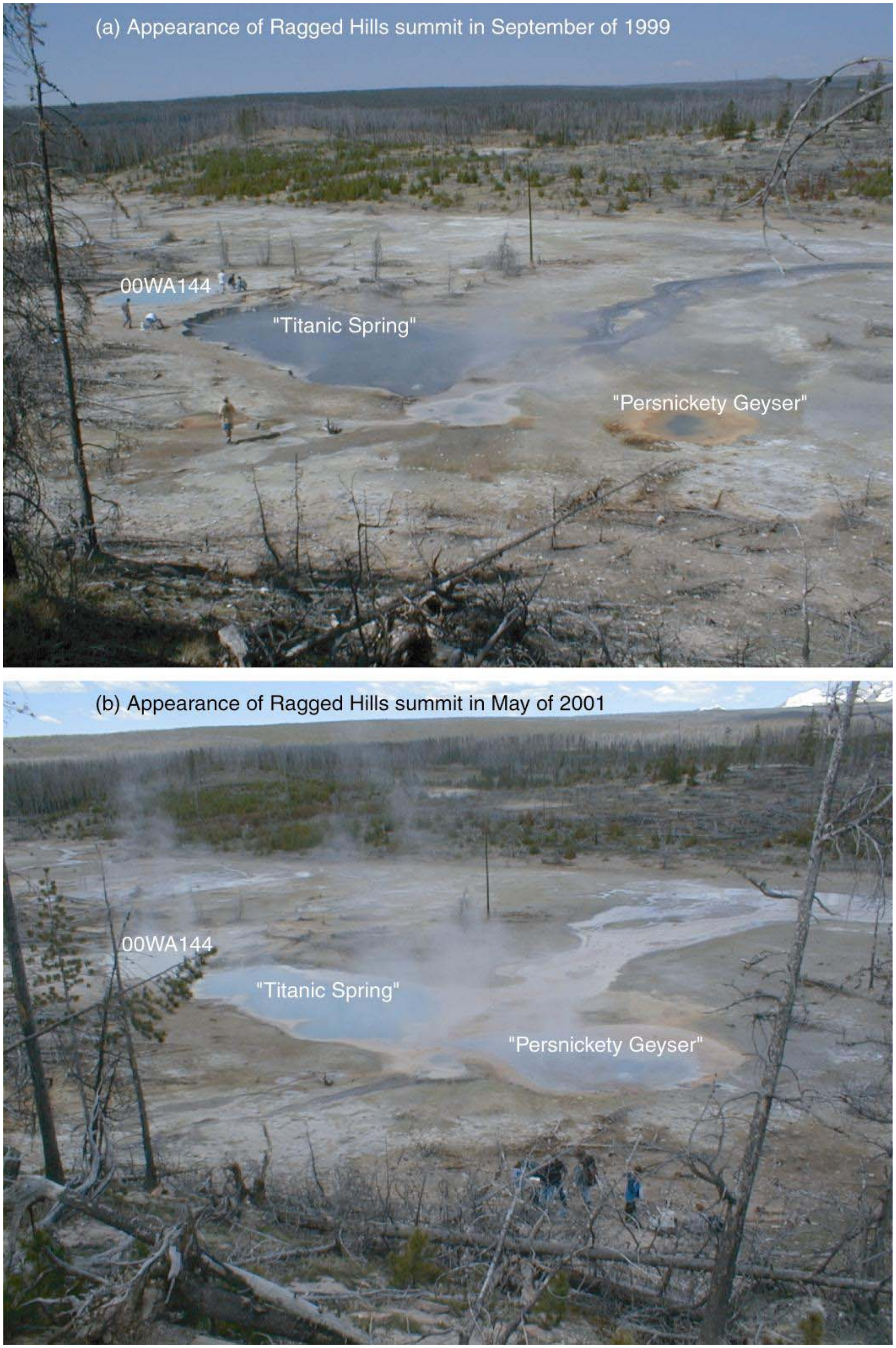


Figure 10. Photographs comparing development of thermal features at the crest of The Gap, Norris Geyser Basin

Effect of Ragged Hills Hydrothermal Effluent on Tantalus Creek Discharges

A weir with stream gaging telemetry was placed on Tantalus Creek about 125 m upstream of its confluence with the Gibbon River (fig. 3) in the summer of 1998. With the exception of some interruptions caused by equipment failures, stage data were transmitted to the USGS stream gaging network every ten to fifteen minutes thereafter. Results for the 8/5/1998 to 5/13/2000 time period, together with precipitation data for the Mammoth and Canyon Village weather stations (see fig. 1 for locations), are shown on figure 11. There are so many data points on this plot that short-term features cannot be identified.

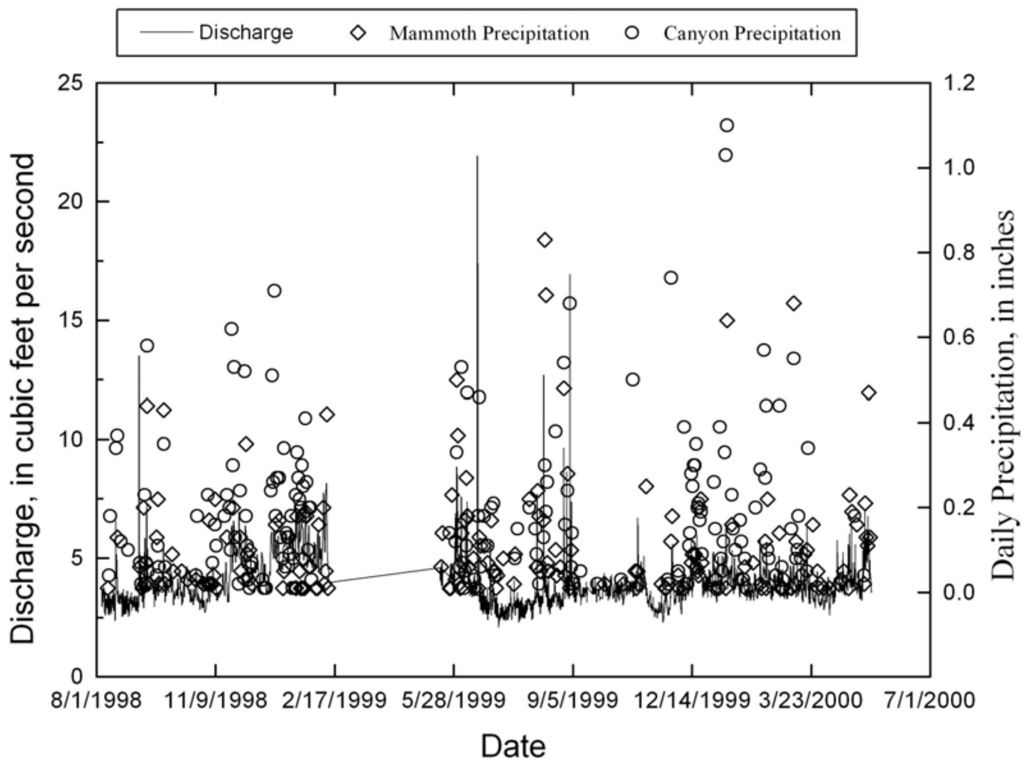


Figure 11. Local daily precipitation and Tantalus Creek discharge for August 5, 1998 to May 13, 2000 (Friedman, I. A., unpublished data)

Examination of the results for a shorter period (6/17-27/1998, fig. 12) reveals that the two principal phenomena affecting the discharge of Tantalus Creek are eruptions of Echinus Geyser and episodic rainstorm events. Although Echinus Geyser discharges are almost certainly dampened by the meandering of Tantalus Creek through The Reservoir and One Hundred Spring Plain, close examination of the hydrograph reveals regular, roughly hourly, pulses in Tantalus Creek's discharge ranging in magnitude from about 0.2 to about 0.5 cubic feet per second (ft^3/s). While many of the larger discharge increases (2 ft^3/s or more) documented by the Tantalus Creek stream gage are coincident with rainstorm events in the Mammoth-Norris-Canyon area, several of these peaks are not correlated with any known meteorological event. A 10-day hydrograph illustrating both of these effects is shown in figure 12, and an expanded-scale hydrograph showing the fine structure of the effect of Echinus Geyser eruptions on Tantalus Creek discharge is shown in figure 13. Figure 13 shows 26 spikes in Tantalus Creek discharge over the 24-hour period of June 21, 1998, which is consistent with regular Echinus Geyser eruptions with a periodicity of somewhat less than one hour.

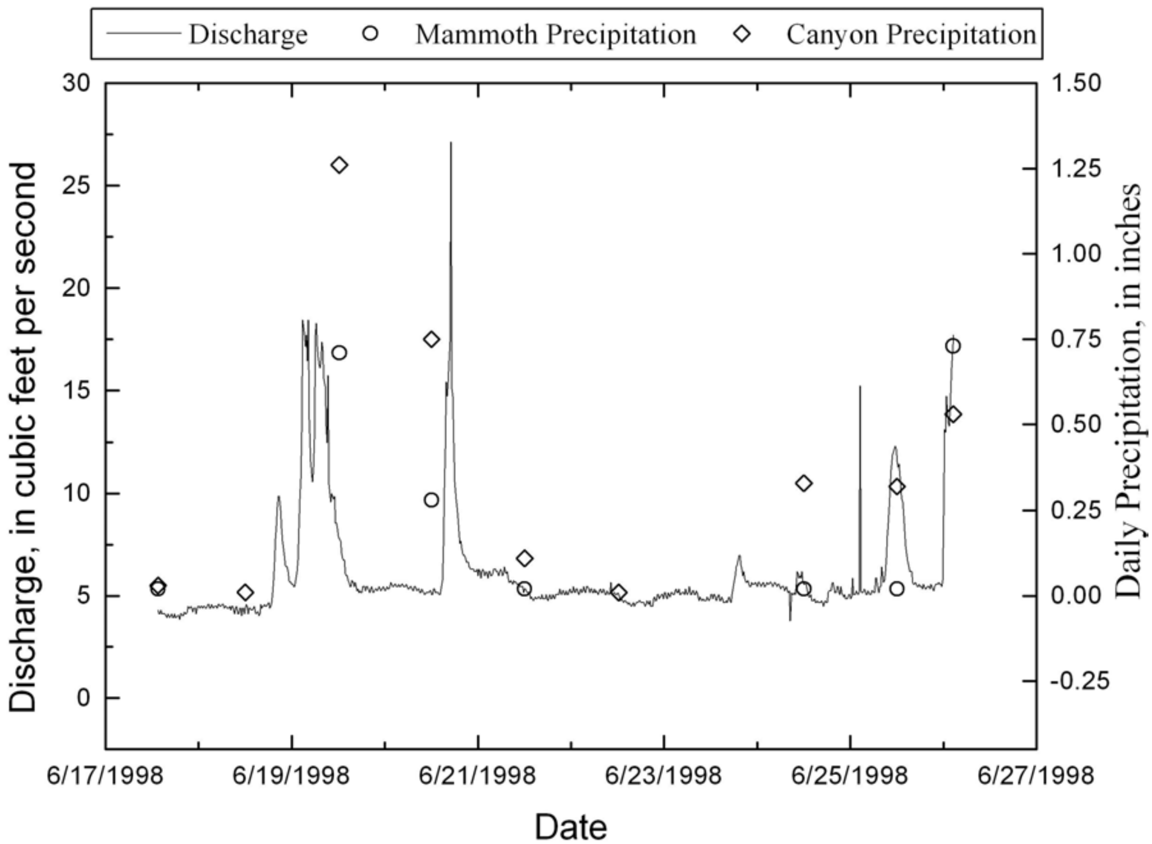


Figure 12. Local daily precipitation and Tantalus Creek discharge for June 17 to 27, 1998

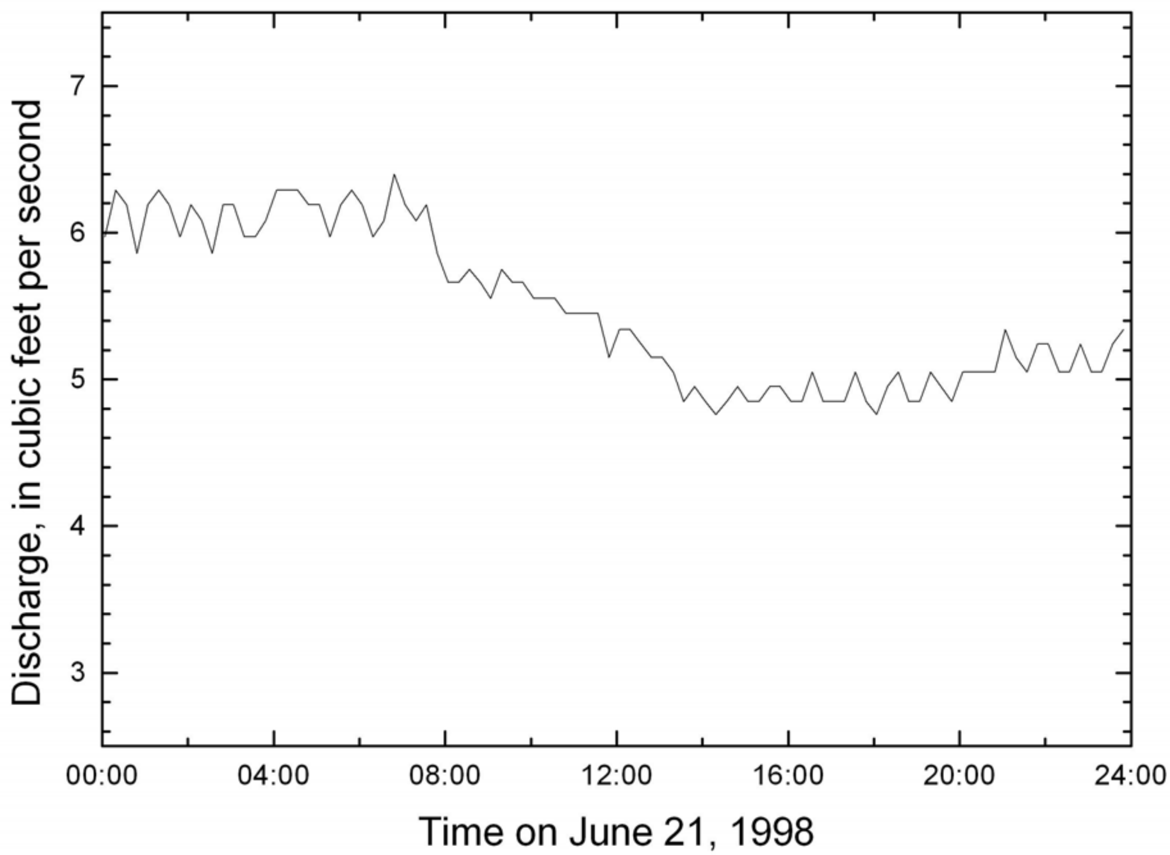


Figure 13. Tantalus Creek discharge for a 1-day period. Total precipitation for the day was 0.02 in at Mammoth and 0.11 in at Canyon Village

Because of the distances of the Mammoth and Canyon Village weather stations from Norris Geyser Basin, exact correspondence between precipitation events at these locations and Tantalus Creek discharge is not expected. Additional variations in Tantalus Creek's discharge appear unrelated to the above two phenomena. Although significant changes in Ragged Hills discharges are not well documented, no other sources of input to Tantalus Creek appear likely to contribute to the observed increases in discharge. Examples are the spikes in the hydrograph on June 18 and 24, 1998.

METHODS OF SAMPLE COLLECTION, STABILIZATION, AND ANALYSIS

Samples were collected directly from streams and tributaries using a peristaltic pump. For springs and geysers, samples were collected as close to the source of each feature as possible. 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 pools by positioning the sample tubing intake using an insulated stainless steel container 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 mobile laboratory truck containing an ion chromatograph, UV-visible spectrophotometer, autotitrator, and reagent-grade water system was set up as close to each sampling site as feasible so that unstable species such as redox species of Fe and intermediate sulfur oxyanions could be determined as soon as possible after collection.

Sample Collection

Samples for the determination of major cations, trace metals, As(III) and As(total), Fe(II) and Fe(total), major anions, intermediate sulfur species, alkalinity, density, NH_4, NO_2, and dissolved SiO_2, were filtered by pumping from the source with a portable peristaltic pump fitted with medical-grade silicone tubing through a 142-mm diameter all-plastic filter holder (Kennedy and others, 1976) containing a 0.1-µm mixed-cellulose-ester filter membrane. Stabilizing reagents for intermediate sulfur species were put into the sample bottle before the sample was collected. Samples for the determination of dissolved organic carbon were filtered either through a silver membrane housed in a stainless steel filter holder or through a 142-mm diameter all-plastic plate filter containing a 0.1-µm mixed-cellulose-ester filter membrane. At least 1 L of sample was passed through the all-plastic plate filter assembly before a DOC sample was collected. Equipment blanks processed in the field yielded DOC values similar to those measured in double-distilled water from our laboratory storage container. Filtrates were collected in glass bottles that had been fired at 600°C. Dissolved H_2S was determined onsite at the time of sample collection. Samples for H_2S determination were drawn into a plastic syringe to minimize the inclusion of atmospheric air, then forced through a syringe-mounted 25-mm-diameter, 0.45-µm membrane filter into a measuring cuvette in which the appropriate reagents were quickly mixed. Unfiltered samples for the determination of isotopes of H and O were either pumped or dipped from the source and stored in amber glass bottles. Container preparation as well as storage and stabilization of filtered samples are summarized in table 2. After washing and rinsing, sample containers were air-dried inside a Class-100 laminar flow air filtration unit.

A subset of samples was collected to evaluate the distribution and redox speciation of As in selected thermal features at Norris Geyser Basin. For these waters, the sample was aspirated into a 60-mL disposable syringe. A 25-mm-diameter, 0.2-µm-pore-size syringe filter was attached, and 60 mL of sample water was filtered into a translucent 125-mL polyethylene bottle that had been cleaned for samples for anion determinations. The process was repeated for an opaque 125-mL polyethylene bottle that had been pre-dosed with 60 mL 2% HCl and tared. At the mobile laboratory truck, the opaque bottles were re-weighed to allow calculation of dilution factors.

Temperature, specific conductance, and D.O. measurements were made by immersing probes directly into the source as close to the sampling point as possible, or into an unfiltered sample collected in a stainless steel insulated container. Measurements for Eh and pH were made on unfiltered sample water pumped from the source through an acrylic plastic flow-through cell in which contact with air was minimal. The flow-through cell contained a digital thermistor probe, Eh and pH electrodes, and test tubes containing buffer solutions for calibration of the pH electrode. All components were thermally equilibrated with the sample water prior to commencing measurements.

Field pH Measurements

Measurement of pH is of primary importance for most waters, and every effort was made to obtain the most accurate measurement possible. We have found that many pH electrodes perform poorly in near-boiling water and some fail after only a few immersions. Thus, it is important to use electrodes that are rated for boiling or near-boiling water temperatures. At each site, the pH measurement system, consisting of meter, temperature probe, and electrode, is calibrated using two bracketing standard buffers, chosen from among 1.68, 2.00, 4.00, 7.00, or 10.00, equilibrated and corrected to their values at the sample temperature. After calibration, the pH electrode is placed in the sample water in the flow-through cell and monitored until no drift in temperature or pH is detected for at least 30 seconds. Following sample measurement the electrode is immersed in the standard buffer of pH closest to that of the sample and allowed to equilibrate. If the measured value for the buffer differs by more than 0.05 standard units from its certified pH for the measured temperature the entire calibration and measurement process is repeated as many times as necessary until this criterion is met.

Analytical Methods

Analytical methods are summarized in tables 10 and 11 in Appendix 1. Because most constituents were determined using established procedures, the analytical methods are described only briefly in table 11. In the following section, only general conditions or variants of standard procedures are discussed.

All reagents were of purity at least equal to the reagent-grade standards of the American Chemical Society. For ICP, FAAS, and ZGFAAS analyses, external standards, blanks, sample dilutions, and spiking solutions usually were made with double-distilled deionized water, re-distilled acids, and commercial ICP elemental standard solutions. In some cases, standard solutions were prepared in the laboratory from elements or their compounds of the highest commercially available purity. USGS standard reference water samples (SRWS) were used as independent standards. Additional information about the USGS SRWS program can be obtained at http://bqs.usgs.gov/srs.

Samples were diluted as necessary to bring analyte concentrations within the optimal range of the analytical method. For major and trace cation analyses done by ICP, several dilutions of each sample, with the extremes of the range differing by dilution factors from 2 to 100, were analyzed to check for concentration effects on the analytical method.

Table 2. Container preparation and stabilization methods for filtered samples

Sample type(s)	Storage container and preparation	Stabilization treatment in addition to refrigeration
Major and trace metals	Polyethylene bottles, soaked in 5% HCl and rinsed 3 times with distilled water	1% (v/v) concentrated HNO_3 added
Fe(II) and Fe(total), As(III) and As(total)	Opaque polyethylene bottles, soaked in 5% HCl and rinsed 3 times with distilled water	1% (v/v) redistilled 6 N HCl added
Major anions, alkalinity, and density	Polyethylene bottles filled with distilled water and allowed to stand for >24 hours, then rinsed 3 times with distilled water	None
NH_4	Same as major and trace metals	1% (v/v) 1:9 H_2SO_4 added
NO_2	Same as major and trace metals	None
SiO_2	Same as major anions, alkalinity, and density	Immediately diluted 1:9 with distilled H_2O
S_2O_3, S_xO_6	30-mL polyethylene bottle	1.7% (v/v) 0.6 M $ZnCl_2$ plus 1% (v/v) 1 M NaOH added to precipitate S(-II), 1.7% (v/v) 1 M KCN added to S_xO_6 bottle
DOC	Baked glass bottle	None

Calibration curves were determined by using standards within each set of analyses. If matrix effects were evident, spike-recovery and/or standard-addition measurements were performed. USGS SRWS 67, 69, AMW4, T115, T143, T149, T155, and T159 were used to check the analytical methods for major and trace metals, and SRWS M102, M136, M140, and M150 were used to check the analytical methods for major anions. The SRWS data are presented in table 12 in Appendix 1. Estimates of ICP detection limits are reported in table 11 in Appendix 1 and were assumed equal to $3\sigma_{blank}$, where σ_{blank} is the standard deviation of several dozen measurements of the constituent in a blank solution treated as a sample. Also listed in table 11 are typical values of analytical reproducibility for each method of analysis in samples containing the analyte at concentrations at least ten times the detection limit. These parameters were estimated for FAAS and ZGFAAS in a similar manner, using about a dozen measurements of blanks.

Nitrogen species

Samples for NH_4 determination were transported and stored at 4°C to reduce the potential for biological oxidation of NH_4. Serial dilutions were analyzed for NH_4 using IC and 50 mN H_2SO_4 eluent. Samples containing elevated Na concentrations that yielded poor peak resolution required secondary determinations on diluted subsamples, neutralized with NaOH, by spectrophotometry (Solorzano, 1969; Antweiler and others, 1996). Laboratory NaOH blanks were run with samples. To demonstrate that results from both methods were equivalent, acceptable NH_4 values acquired using IC were compared with values from the same sample analyzed by spectrophotometry.

Nitrite samples were chilled to 4°C during transportation and storage (Patton and Gilroy, 1999). Samples were analyzed by spectrophotometry (U.S. Environmental Protection Agency, 1979; U.S. Geological Survey, 1984; Antweiler and others, 1996) within one week of collection. This method is appropriate for a range of 0.003 to 0.80 mg/L NO_2.

Sample Treatment for Thiosulfate and Polythionate Determinations

Because on-site determinations or special preservation techniques are critical for reliable determination of unstable species concentrations, unstable intermediate S redox species concentrations were determined within minutes to hours of sample collection in the USGS mobile laboratory truck described earlier. Detailed discussions of sampling and analysis techniques for the S redox species can be found in Xu and others (1996; 1998; 2000) and Ball and others (1998b; 2001).

To prevent over-estimation of the *in-situ* concentration of S_2O_3, S(-II) oxidation was minimized by filtering the sample into a 30-mL polyethylene bottle containing 0.5 mL 0.6 M $ZnCl_2$ and 0.3 mL 1 M NaOH. This technique caused the oxidation-resistant ZnS species to precipitate. A second 30-mL polyethylene bottle containing 0.5 mL 0.6 M $ZnCl_2$, 0.3 mL 1 M NaOH, and 0.5 mL 1 M KCN to convert S_xO_6 to SCN was used for samples to be analyzed for S_xO_6. Thiosulfate and S_xO_6 were determined by syringe-filtering the sample directly into the ion chromatograph on-site in the mobile laboratory.

Acidity Titrations

Acidity is the base-neutralizing capacity of a solution and is defined as the equivalent sum of all the acids that are titratable with a strong base (Stumm and Morgan, 1996). From 1 to 48 hours after collection, selected filtered, unacidified samples were titrated to a pH greater than 7 using an autotitrator and standardized NaOH. 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 mV, typically 10 mV per addition. Equivalence points were determined using a modified Gran's function:

$$F_{acid} = (V_0 + V_{NaOH}) \times 10^{-pOH}, \qquad (1)$$

where F_{acid} = the Gran function, V_0 = sample volume, V_{NaOH} = volume of NaOH titrant added, and pOH = 14 minus the pH.

The portion of the titration curve generated for total acidity will lie in the basic region where $[H^+]$ is negligible compared with $[OH^-]$. Therefore, OH^- substitutes for H^+, or 10^{-pOH} for 10^{-pH} in equation (1) (Barringer and Johnsson, 1996). The most important reactions contributing to total acidity are SO_4 hydrolysis:

$$H^+_{(aq)} + SO_4{}^{2-}{}_{(aq)} \Leftrightarrow HSO_4{}^-{}_{(aq)} \tag{2}$$

Fe hydrolysis:

$$Fe^{3+}{}_{(aq)} + 3H_2O_{(l)} \Leftrightarrow Fe(OH)_3{}^o{}_{(aq)} + 3H^+{}_{(aq)} \tag{3}$$

where the Fe^{3+} comes mostly from the oxidation of Fe^{2+}:

$$Fe^{2+}{}_{(aq)} + H^+{}_{(aq)} + 0.25O_{2(g)} \Leftrightarrow Fe^{3+}{}_{(aq)} + 0.5H_2O_{(l)} \tag{4}$$

and the hydrolysis of Al:

$$Al^{3+}{}_{(aq)} + 3H_2O_{(l)} \Leftrightarrow Al(OH)_3{}^o{}_{(aq)} + 3H^+{}_{(aq)}\ . \tag{5}$$

Free H^+ was derived by subtracting the hydrogen produced by hydrolysis of $SO_4{}^{2-}$, Fe, and Al from the total acidity. The $HSO_4{}^-$ concentration was estimated using an interactive version (PHREEQCI, Charlton and others, 1997) of the geochemical modeling code PHREEQC (Parkhurst and Appelo, 1999) in conjunction with the WATEQ4F (Ball and Nordstrom, 1991) database. Sample pH from the acidity titration was calculated by combining the H^+ activity coefficient determined by PHREEQCI with H^+ molality and computing the common logarithm of the resulting activity. This method provided a “corrected-acidity pH.”

Four pH values have been obtained for many of the acid samples in this study: (1) “corrected-acidity pH” calculated as discussed in the previous paragraph, (2) pH calculated from charge imbalance, (3) pH measured in the field, and (4) pH measured in the laboratory (table 3). From these pH values, a final pH was selected as the most accurate *in situ* pH for each sample. Graphs illustrating the mole percentage of total cations that is H^+ as a function of final pH, charge balance as a function of final pH, and the relation of lab pH, pH from acidity, and pH from the speciated charge imbalance calculation to final pH are shown in figures 14-19. In figures 14 and 15, the respective exponential and linear fits to the Brimstone and geothermal data reveal two relations between free H^+ / total cations ratios and measured pH. This apparent bimodal distribution may result from the significantly lower dissolved solids concentrations of the Brimstone waters compared with the geothermal waters. Comparison of the pH values allows us to evaluate our measurements in terms of these four constraints and to estimate a more accurate pH for these samples.

Table 3. Sample pH and acidity values

Sample code number	Acidity (mM) Total	Free H^+	pH: Calculated from acidity	Calculated from charge imbalance	Measured in the field	Measured in the laboratory[1]	Final
99WA116	8.7	2.6	2.63	2.92	2.81	2.96	2.96
99WA117	25	11	2.03	2.07	1.98	2.06	2.06
99WA118	28	13	1.95	2.03	1.99	2.05	1.99
99WA119	1.4	1.1	3.00	3.45	4.38	4.16	4.38
99WA120	0.50	0.30	3.61	3.57	3.71	---	3.71
99WA121	0.80	0.60	3.32	3.17	3.45	3.46	3.45
99WA122	3.3	2.1	2.74	2.76	2.75	---	2.75
99WA123	3.5	1.8	2.80	3.11	2.81	2.78	2.81
99WA124	8.6	4.4	2.40	2.41	2.40	2.30	2.40
99WA125Q	---	---	---	3.09	6.60	---	6.60
99WA126Q	---	---	---	2.92	4.90	---	4.90
99WA127Q	---	---	---	2.90	3.40	*2.87*	2.87
99WA128Q	---	---	---	3.20	4.40	---	4.40
99WA129Q	---	---	---	3.56	3.96	*3.57*	3.96
99WA130Q	---	---	---	2.93	6.90	---	6.90
99WA131Q	---	---	---	2.82	3.12	*2.68*	2.68
99WA132Q	---	---	---	5.06	3.05	*2.78*	3.05
99WA132	3.6	2.4	2.67	3.09	3.05	*2.92*	3.05
[2]99WA133	---	---	---	---	---	---	---
99WA134	1.4	1.0	3.08	3.53	3.11	3.16	3.11
99WA135Q	---	---	---	4.77	6.07	---	6.07
99WA136Q	---	---	---	8.29	4.50	---	4.50
99WA137Q	---	---	---	7.90	4.04	---	4.04
99WA138	5.1	2.5	2.66	2.63	2.54	2.76	2.66
99WA139	6.4	1.6	2.86	2.95	2.93	---	2.93
99WA140	3.2	2.2	2.70	2.74	2.66	2.85	2.70
99WA141Q	---	---	---	2.89	3.14	---	3.14
99WA142	0.20	0.10	3.88	7.74	5.63	5.21	5.63
99WA143Q	---	---	---	3.39	3.91	*3.54*	3.91
99WA144Q	---	---	---	2.57	2.74	*2.43*	2.74
99WA145Q	---	---	---	3.73	4.03	---	4.03
99WA146Q	---	---	---	3.17	3.21	*2.79*	3.21
99WA147Q	---	---	---	3.59	5.85	---	5.85
99WA148Q	---	---	---	3.05	3.44	*3.19*	3.44
99WA149Q	---	---	---	2.93	3.18	*2.85*	3.18
99WA150Q	---	---	---	3.25	3.70	---	3.70
99WA151	0.40	0.20	3.74	7.95	4.45	4.19	4.45
99WA152	1.4	0.90	3.13	3.26	3.20	3.11	3.20

Table 3. Sample pH and acidity values---Continued

Sample code number	Acidity (mM) Total	Free H^+	pH: Calculated from acidity	Calculated from charge imbalance	Measured in the field	Measured in the laboratory	Final
00WA134	0.38	0.26	3.65	3.55	4.21	3.96	4.21
00WA135	---	---	---	6.78	7.21	7.27	7.21
00WA136	---	---	---	6.15	6.78	6.77	6.78
00WA137	2.8	1.7	2.82	2.80	2.73	2.66	2.73
00WA138	1.6	1.2	2.98	3.05	2.92	2.97	2.92
00WA139	2.3	1.6	2.86	2.82	2.87	2.83	2.87
00WA140A	1.5	0.84	3.13	2.99	3.25	3.08	3.25
00WA140B	---	---	---	---	3.24	---	3.24
00WA140C	---	---	---	---	3.21	---	3.21
00WA140D	---	---	---	3.09	3.19	3.08	3.19
00WA141A	1.7	1.0	3.08	2.89	3.18	3.06	3.18
00WA141B	---	---	---	---	3.16	---	3.16
00WA141C	---	---	---	---	3.16	---	3.16
00WA141D	---	---	---	---	3.14	---	3.14
00WA141E	---	---	---	3.04	3.12	3.04	3.12
00WA142	---	---	---	7.00	7.63	7.61	7.63
00WA143	0.26	0.14	3.89	3.89	3.91	4.07	3.91
00WA144	1.7	0.87	3.12	3.00	3.05	3.09	3.05
00WA145	0.36	0.23	3.70	3.29	4.03	4.01	4.03
00WA155	---	---	---	7.70	6.68	7.11	6.68
00WA156	---	---	---	8.97	6.32	7.53	6.32
00WA157	0.47	0.15	3.85	3.81	3.89	3.89	3.89
00WA158	2.5	1.8	2.79	2.76	2.73	2.74	2.73
[2]00WA159	---	---	---	---	---	---	---
00WA160	2.5	1.7	2.80	2.74	2.76	2.74	2.76
00WA161	2.5	1.6	2.82	2.76	2.75	2.72	2.75
00WA162	2.5	1.6	2.82	2.77	2.79	2.75	2.79
00WA163	2.6	1.6	2.84	2.82	2.87	2.75	2.87
00WA164	2.7	1.8	2.78	2.73	2.77	2.70	2.77
00WA165	---	---	---	7.12	6.48	8.58	6.48
00WA166	---	---	---	8.09	4.49	4.36	4.49

[1]Laboratory pH values in italics were measured two years later and samples may have evaporated.
[2]Field blank

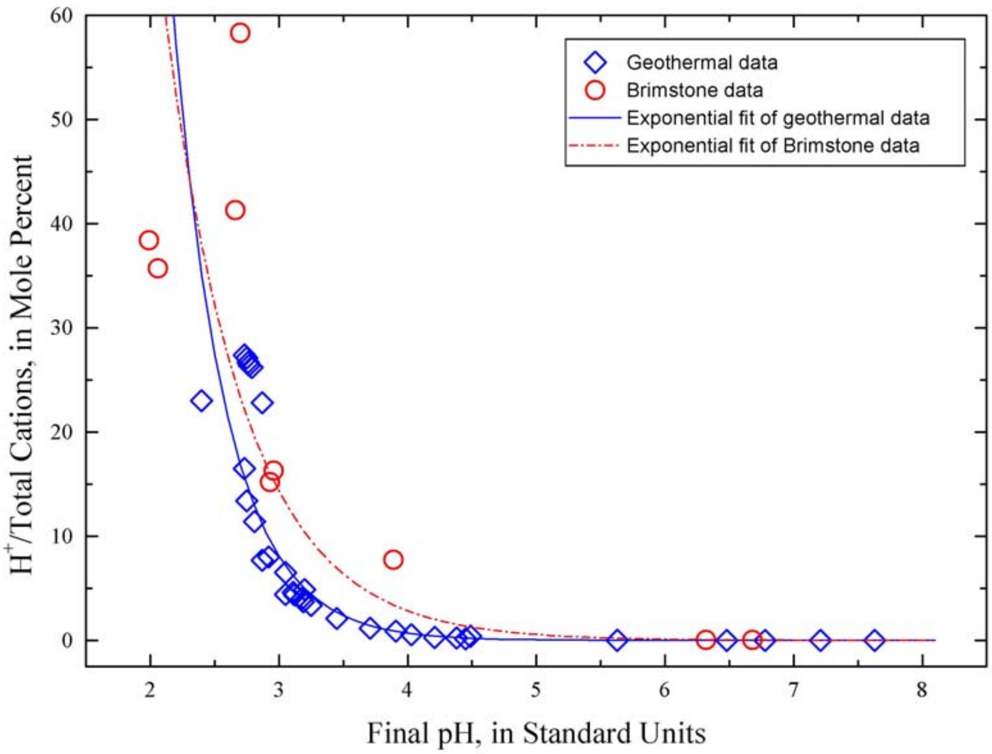


Figure 14. Mole percentage of H^+ comprising total cations as a function of final pH

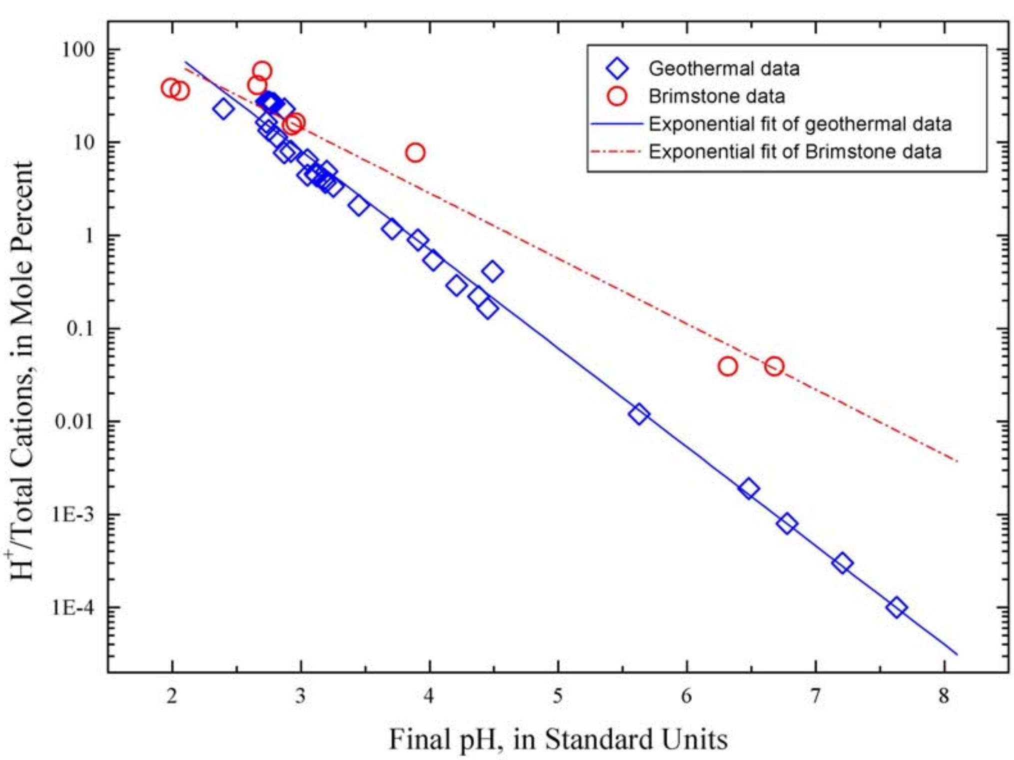


Figure 15. Semi-log plot of mole percentage of H^+ comprising total cations as a function of final pH

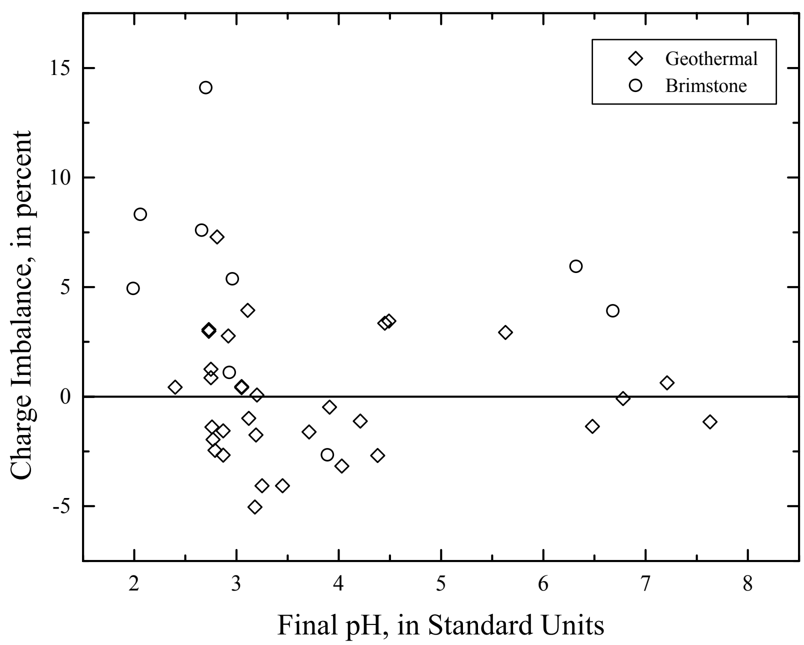


Figure 16. Speciated solution charge imbalance as a function of final pH

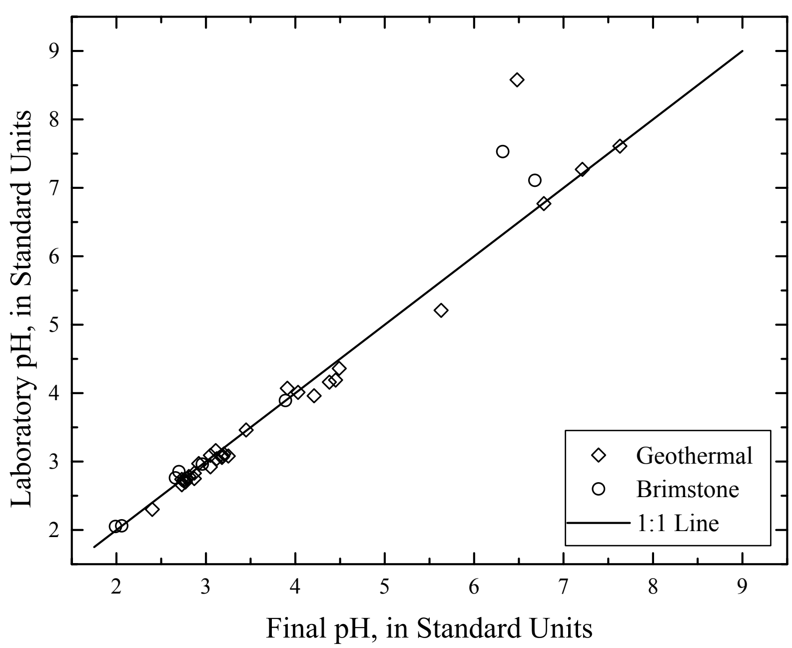


Figure 17. Laboratory pH as a function of final pH

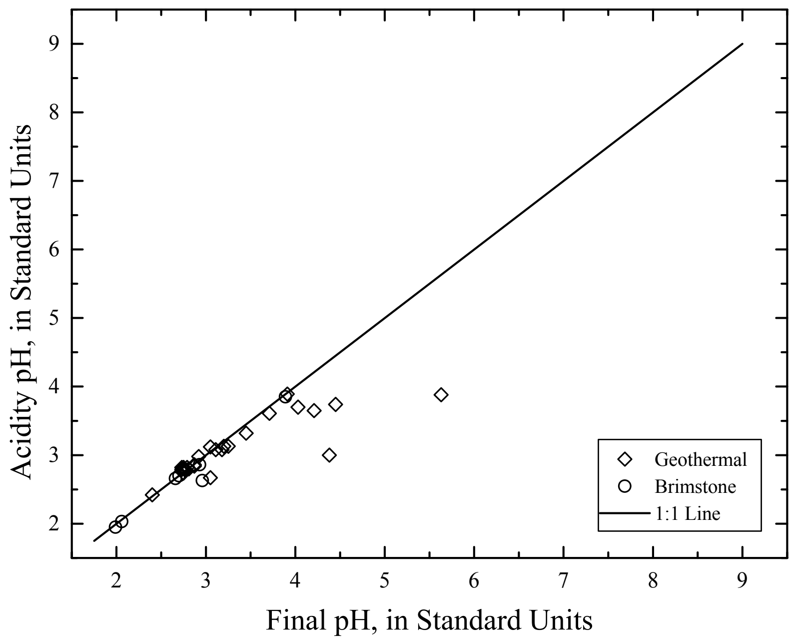


Figure 18. Acidity pH as a function of final pH

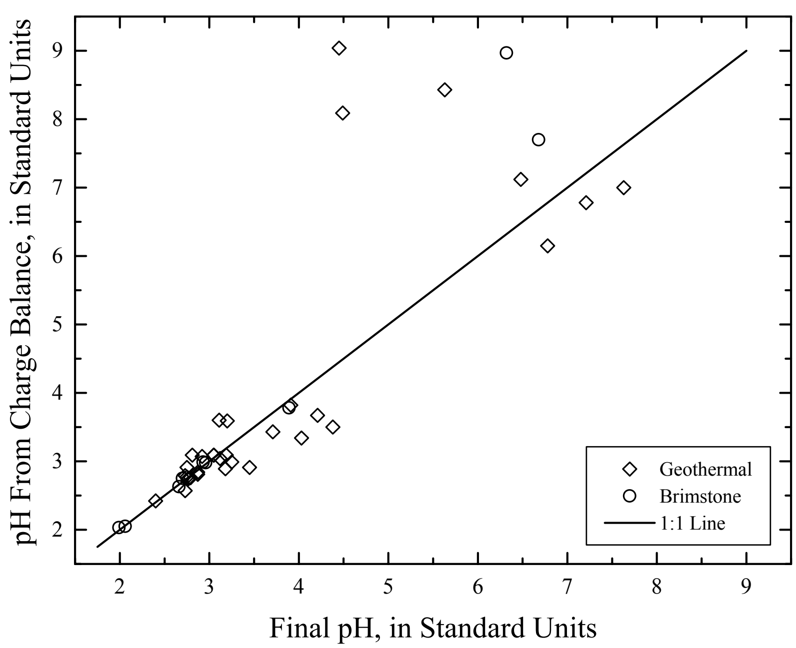


Figure 19. Charge balance pH as a function of final pH

Revised pH values

Typically, the field pH was considered to be the most accurate and precise unless the sample had a speciated charge imbalance greater than 5%, in which case laboratory pH and, for measured pH < 3.5, free H^+ pH from the acidity titration were considered as substitutes. If laboratory pH gave the best charge balance, then it was used for revised pH; if acidity pH gave the best charge balance, it was used. Laboratory pH was selected as the revised pH for samples 99WA116, 99WA117, 99WA127Q, and 99WA131Q, and acidity pH was selected as the revised pH for samples 99WA138 and 99WA140. Field pH was selected for the remaining 61 samples. Values of pH listed in table 3 as "Final" are the values found in the tables of chemical data (tables 5-7).

WATER-CHEMISTRY DATA

Table 4 contains detailed descriptions of all sample locations. The "GPS Codes" in column 2 are assigned by the YNP Thermal Inventory Project. Feature names enclosed in quotation marks are those assigned to the features by the authors, except for "Beowulf Spring" which was assigned by William Inskeep (Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT) and Heiko Langner (Department of Environmental Geology and Geochemistry, University of Montana, Missoula, MT), and "Elk Geyser" assigned by Smokey Sturtevant. Site data and water analyses for YNP springs sampled in 1999 and 2000 are presented in tables 5-7. Results of ^2H and ^{18}O isotope analyses are listed in table 8. Results for determinations on two field blanks are presented in table 9. Descriptions by Smokey Sturtevant of the thermal activity of many of the features of Norris Geyser Basin during calendar year 1998 are in Appendix 2. Photographs of most of the sample sites are in Appendix 3. Samples are sorted by spring, then by date of sample collection, and then by sampling site along the downstream overflow channel (if present). In the tables, "source" samples were collected at the origin of the spring, and "overflow channel" samples were collected at various distances downstream from the source. The WATEQ4F program (Ball and Nordstrom, 1991) was used to calculate ion sums and charge imbalance (C.I.), using the following calculation:

$$\text{C.I. (percent)} = \frac{100 \times (\text{meq/L cations} - \text{meq/L anions})}{(\text{meq/L cations} + \text{meq/L anions}) \div 2} \qquad (6)$$

Note that the result of this calculation is twice the value that typically would be reported by an analytical laboratory, because equation (1) relates the cation-anion difference to the average of the two rather than to the sum of the ions comprising them. In tables 5-7, meq/L cations and meq/L anions values are rounded to 3 significant figures, and percent difference values are rounded to 0.1 percent. This rounding may cause differences between the percent difference values shown and those calculated using equation (1) and the meq/L cations and meq/L anions values listed in tables 5-7.

Table 4. Detailed sample site descriptions

Sample code number	GPS Code	Site Description	N Latitude (± 1")	W Longitude (± 1")
99WA116	---	Alluvium Creek at Yellowstone Lake shore near Brimstone Basin	44°23'07.2"	110°14'26.1"
99WA117	---	Alluvium Creek ~610 m upstream from Thorofare Trail near Brimstone Basin		
99WA118	---	Alluvium Creek at base of sulfur mounds, Brimstone Basin	44°23'22.3"	110°13'12.9"
99WA119	NHSP103	Cinder Pool, Norris Geyser Basin	44°43'57.5"	110°42'32.7"
99WA120	NHSP95	"Fracture Spouter" north of Realgar Spring, Norris Geyser Basin	44°44'08.32"	110°42'22.6"
99WA121	NHSP96	Unnamed 2 by 6 m pool next to "Fracture Spouter" near Realgar Spring, pear-shaped and about 2 m deep, Norris Geyser Basin	44°44'08.31"	110°42'22.58"
99WA122	NHSP94	Realgar Spring 3 m from sign, Norris Geyser Basin	44°44'05.7"	110°42'24.3"
99WA123	NHSP94	Realgar Spring 20 m from sign, Norris Geyser Basin	44°44'06.0"	110°42'24.4"
99WA124	NHSP129	Unnamed spring near Horseshoe Spring, two vents 0.5 m apart, brown turbidity, Norris Geyser Basin	44°44'00.72"	110°42'28.82"
99WA125Q	NBB231	Medusa Geyser, Norris Geyser Basin	44°43'08.21"	110°42'29.93"
99WA126Q	NBB232	Hydrophane Spring, Norris Geyser Basin	44° 43'13.2"	110°42'28.5"
99WA127Q	NBB180	Green Dragon Spring, Norris Geyser Basin	44°43'12.46"	110°42'22.61"
99WA128Q	NBB184	Yellow Funnel Spring, Norris Geyser Basin	44°43'15.93"	110°42'22.43"
99WA129Q	NBB210	Recess Spring, 160 m NW of Pork Chop Spring, Norris Geyser Basin	44°43'22.9"	110°42'33.2"
99WA130Q	NBB216	Palpitator Spring, Norris Geyser Basin	44°43'26.55"	110°42'20.21"
99WA131	NHSP101	Unnamed round pool, NNW of Cinder Pool and SW of Horseshoe Spring, Norris Geyser Basin	44°43'59.54"	110°42'31.42"
99WA132, 99WA132D	NHSP100	Unnamed round pool, NNW of Cinder Pool and SW of Horseshoe Spring, 5 m diameter, black sediment, Norris Geyser Basin	44°43'59.94"	110°42'31.97"
99WA133	---	Field Blank	---	---

Table 4. Detailed sample site descriptions—Continued

Sample code number	GPS Code	Site Description	N Latitude (± 1")	W Longitude (± 1")
99WA134	NHSP130	Tantalus Creek at weir near confluence with Gibbon River, 9/23/99 Q=3.5±0.2 cfs	44°44'02.81"	110°42'54.61"
99WA135Q	NBB217	Fearless Geyser, Back Basin, Norris Geyser Basin	44°43'27.75"	110°42'17.31"
99WA136Q	NBB218	Monarch Geyser, Back Basin, Norris Geyser Basin	44°43'27.75"	110°42'17.31"
99WA137Q	NPB192	Arsenic Geyser, Porcelain Terrace, Norris Geyser Basin	44°43'43.10"	110°42'05.78"
99WA138	---	Tributary to Upper Columbine Creek near confluence, Brimstone Basin	44°23'46.5"	110°13'41.5"
99WA139	---	Headwaters of one tributary to Alluvium Creek, Brimstone Basin	44°22'51"	110°12'56"
99WA140	---	Headwaters of one tributary to Columbine Creek, Brimstone Basin	44°22'57"	110°12'19"
99WA141Q	---	Tantalus Creek at One Hundred Spring Plain exit, ~300 m above weir, Norris Geyser Basin	44°43'57.3"	110°42'43.7"
99WA142	NRHA6	"Titanic Spring", south end Ragged Hills, Norris Geyser Basin	44°43'39.9"	110°42'47.8"
99WA143Q	NRHA5	"Persnickety Geyser", ~5 m north of 99WA142, Ragged Hills, Norris Geyser Basin	44°43'40.4"	110°42'47.0"
99WA144Q	---	Unnamed spring, dark red precipitate along drainage channel, ~80 m north of Ragged Hills summit, Norris Geyser Basin	44°43'42.9"	110°42'47.1"
99WA145Q	NRHA3	Unnamed pool in main Ragged Hills drainage, Norris Geyser Basin	44°43'43.44"	110°42'44.59"
99WA146Q	NRHA4	Unnamed pool ~4 m east of main Ragged Hills drainage, fine-grained white sand at pool edge, Norris Geyser Basin	44°43'43.6"	110°42'43.2"
99WA147Q	---	Unnamed gray turbid pool 25 m north of 99WA146, 12 m west of creek, Ragged Hills, Norris Geyser Basin	44°43'44.6"	110°42'43.4"
99WA148Q	NRHA2	Unnamed 15-cm diameter pool with bright yellow precipitate, ~6 m west of creek, Ragged Hills, Norris Geyser Basin	44°43'45.10"	110°42'41.27"

Table 4. Detailed sample site descriptions—Continued

Sample code number	GPS Code	Site Description	N Latitude (± 1")	W Longitude (± 1")
99WA149Q	---	Unnamed pool, ~100 m downstream from 99WA147 and 20 m west of drainage, Ragged Hills, Norris Geyser Basin	44°43'45"	110°42'43"
99WA150Q	---	Main drainage, 5 m downstream of 99WA148, Ragged Hills, Norris Geyser Basin	44°43'45.3"	110°42'40.9"
99WA151	NRHA1	"Elk Geyser" ~80 m northwest of Ragged Hills, Norris Geyser Basin	44°43'46.97"	110°42'39.23"
99WA152	NHSP91	Rock Spring, southeast corner of 100 Spring Plain, Norris Geyser Basin	44°43'53.65"	110°42'18.09"
00WA134	NRHA1	"Elk Geyser", Norris Geyser Basin	44°43'46.97"	110°42'39.23"
00WA135		"Black Gassy Spring", Norris Geyser Basin	44°43'36.9"	110°42'27.8"
00WA136	NBB113	Perpetual Spouter, Norris Geyser Basin	44°43'36.0"	110°42'29.8"
00WA137	---	Unnamed acid clear spring near Perpetual Spouter, Norris Geyser Basin	44°43'35.8"	110°42'30.2"
00WA138	---	Tantalus Creek 10 m upstream of Perpetual Spouter, Norris Geyser Basin	44°43'35.76"	110°42'26.93"
00WA139	---	Small side drainage Near "Elk Geyser", Norris Geyser Basin	44°43'47.4"	110°42'41.4"
00WA140A	---	Unnamed spring, Norris Geyser Basin	44°43'55.1"	110°42'37.0"
00WA140B	---	Unnamed spring drainage	44°43'55.1"	110°42'37.0"
00WA140C	---	Unnamed spring drainage	44°43'55.1"	110°42'37.0"
00WA140D	---	Unnamed spring drainage	44°43'55.1"	110°42'37.0"
00WA141A	---	"Beowulf Spring", Norris Geyser Basin	44°43'53.7"	110°42'38.0"
00WA141B	---	"Beowulf Spring" drainage	44°43'53.7"	110°42'38.0"
00WA141C	---	"Beowulf Spring" drainage	44°43'53.7"	110°42'38.0"
00WA141D	---	"Beowulf Spring" drainage	44°43'53.7"	110°42'38.0"
00WA141E	---	"Beowulf Spring" drainage	44°43'53.7"	110°42'38.0"
00WA142	NBB220	Minute Geyser, Norris Geyser Basin	44°43'30.3"	110°42'19.5"
00WA143	NBB219	Branch Spring, Norris Geyser Basin	44°43'30.0"	110°42'19.7"
00WA144	---	Unnamed milky gray gently surging spring, southernmost of 3 at Ragged Hills summit; this feature merged with "Titanic Spring" in 2001	44°43'39.7"	110°42'48.6"

Table 4. Detailed sample site descriptions—Continued

Sample code number	GPS Code	Site Description	N Latitude (± 1")	W Longitude (± 1")
00WA145	NRHA5	"Persnickety Geyser", north end of Ragged Hills summit, Norris Geyser Basin	44°43'40.4"	110°42'47.0"
00WA155	---	Columbine Creek, headwaters of West fork of main tributary draining Brimstone Basin	44°22'42.1"	110°12'09.4"
00WA156	---	Columbine Creek, East fork of main tributary draining Brimstone Basin, 5 m upstream of beginning of bleached hillslope	44°23'20.7"	110°12'12.9"
00WA157	---	Columbine Creek, East fork of main tributary draining Brimstone Basin, 25 m upstream of confluence with West fork	44°23'22.8"	110°12'30.9"
00WA158	---	Unnamed roadside spring drainage, 3 m from lake shore	44°45'10.6"	110°43'29.4"
00WA159	---	Field Blank	---	---
00WA160	---	Nymph Creek, 61 m from Nymph Lake shore	44°45'11.1"	110°43'27.3"
00WA161	---	Nymph Creek, 99 m from Nymph Lake shore	44°45'10.5"	110°43'25.8"
00WA162	---	Nymph Creek, 138 m from Nymph Lake shore	44°45'10.5"	110°43'24.5"
00WA163	---	Nymph Creek Springs vent, 165 m from lake shore (Whittlesey, 1995, p. 511)	44°45'10.9"	110°43'23.9"
00WA164	---	Nymph Creek Springs vent, 172 m from lake shore	44°45'11.2"	110°43'23.3"
00WA165	---	Western of two unnamed springs, Roadside Springs area	44°45'13.0"	110°43'28.0"
00WA166	---	Eastern of two unnamed springs, Roadside Springs area	44°45'13.1"	110°43'26.6"

Explanation of coordinate data:

1. Map datum: North American Datum 1927 Continental United States (NAD 27-CONUS), compatible with USGS topographic maps.
2. No decimal digits on seconds, authors' approximation from topographic map.
3. One decimal digit on seconds, authors' reading using Garmin GPS III+ or authors' approximation using mapping software.
4. Two decimal digits on seconds, data from Steven Miller, National Park Service Yellowstone Spatial Analysis Laboratory, Mammoth, WY.

Table 5. Site data and water analyses for Brimstone Basin

Sample code number	99WA116	99WA117	99WA118	99WA138	99WA139
Description	Alluvium Creek at mouth	Alluvium Creek	Alluvium Creek at sulfur mounds	Tributary to Columbine Creek	Tributary to Alluvium Creek
Date collected	9/18/1999	9/18/1999	9/18/1999	9/22/1999	9/22/1999
Temperature (°C)	6.5	18	17.5	---[1]	---[1]
Density (g/mL) at 20°C	0.9993	1.0002	1.0006	0.9989	1.0039
pH	2.96	2.06	1.99	2.66	2.93
Spec Cond (µS/cm) field / lab	1470 / 1330	5740 / 5440	6070 / 5650	---[1] / 1310	---[1] / ---
Eh (V)	0.718	0.732	0.656	---[1]	---[1]
D.O. (mg/L)	9.85	6.0	9.7	---[1]	---[1]
Constituent (mg/L)					
Ca	42	83	84	22	34
Mg	34	94	95	16	23
Sr	0.58	0.99	1.0	0.24	0.65
Ba	0.010	0.010	0.012	0.018	0.012
Na	18	34	34	9.0	15
K	9.0	30	33	7.1	16
Li	0.018	0.041	0.043	0.017	0.019
SO_4	630	1800	1900	390	510
H_2S	---	---	---	---[1]	---[1]
Alkalinity (as HCO_3)	---	---	---	---	---
F	<0.3	0.3	0.3	<0.3	<0.3
Cl	1.5	3.7	3.9	1.5	1.2
Br	<0.5	<0.5	<0.5	<0.5	<0.5
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NH_4	---	---	---	---	---
SiO_2	98	90	85	59	85
B	<0.01	0.02	0.02	<0.01	0.01
Al	49	76	80	18	40
Fe (total)	2.39	15.2	14.7	4.16	1.76
Fe (II)	0.172	1.02	1.63	1.11	1.72
Mn	0.67	1.5	1.6	0.48	0.72
Cu	0.010	0.007	<0.001	0.001	0.013
Zn	0.040	0.056	0.055	0.020	0.002
Cd	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.077	0.14	0.14	0.27	0.036
Co	0.016	0.016	0.017	<0.001	0.005
Ni	0.028	0.020	0.020	0.006	0.004
Pb	0.011	0.015	0.018	0.013	0.012
Be	0.002	0.002	0.002	0.002	0.003
V	<0.01	0.07	0.07	<0.01	0.03
Sb	---	---	---	---	---
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	<0.0002	0.0005	0.0003	0.0004	<0.0002
As (III)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
DOC, mg/L	1.7	5.6	---	---	---
Sum cations (meq/L)	8.96	24.4	26.6	6.20	7.75
Sum anions (meq/L)	9.15	24.3	25.3	6.47	7.71
Charge imbalance (percent)	-2.1	0.7	4.9	-4.2	0.6

[1]Grab sample; no field parameters measured onsite.

Table 5. Site data and water analyses for Brimstone Basin -- Continued

Sample code number	99WA140	00WA155	00WA156	00WA157
Description	Tributary to Columbine Creek	Columbine Creek west headwaters	Columbine Creek east fork	Columbine Creek east fork
Date collected	9/22/1999	9/17/2000	9/17/2000	9/17/2000
Temperature (°C)	---[1]	7.3	11.8	11.3
Density (g/mL) at 20°C	1.0024	0.99833	0.99835	0.99835
pH	2.70	6.68	6.32	3.89
Spec Cond (µS/cm) field / lab	---[1] / 820	58 / 59	136 / ---	227 / 241
Eh (V)	---[1]	0.477	0.294	0.605
D.O. (mg/L)	---[1]	8.11	7.8	7.8
Constituent (mg/L)				
Ca	6.1	4.4	8.9	10
Mg	2.9	2.3	6.8	7.5
Sr	0.090	0.051	0.079	0.097
Ba	0.026	0.021	0.019	0.025
Na	4.5	2.2	4.3	5.3
K	4.0	1.4	1.6	2.3
Li	0.002	<0.008	<0.008	<0.008
SO_4	180	8.5	35	89
H_2S	---[1]	<0.001	---	---
Alkalinity (as HCO_3)	---	20.2	27.7	---
F	<0.3	<0.1	0.2	0.2
Cl	1.2	0.48	0.33	0.82
Br	<0.5	<0.05	<0.05	<0.05
NO_3	<0.4	<0.1	<0.1	<0.1
NH_4	---	<0.06	<0.06	<0.06
SiO_2	49	33	39	48
B	<0.01	<0.003	0.005	0.003
Al	6.9	<0.08	0.1	2.1
Fe (total)	1.24	0.005	0.602	1.58
Fe (II)	0.998	0.005	0.602	0.673
Mn	0.037	<0.001	0.20	0.24
Cu	0.0047	0.0010	0.0022	0.0014
Zn	0.010	0.008	0.005	0.006
Cd	0.0001	0.00005	<0.00005	<0.00005
Cr	0.0080	0.0006	0.0008	0.0024
Co	0.001	0.001	0.002	0.003
Ni	0.004	<0.002	0.003	<0.002
Pb	0.001	<0.0005	<0.0005	<0.0005
Be	0.002	<0.0001	0.0002	0.0006
V	<0.01	0.003	0.002	0.003
Sb	<0.001	<0.001	<0.001	<0.001
Se (total)	<0.05	<0.04	<0.04	<0.04
As (total)	<0.0002	<0.0005	<0.0005	<0.0005
As (III)	<0.0003	<0.001	<0.001	<0.001
DOC, mg/L	---	2.3	1.6	1.4
Sum cations (meq/L)	3.67	0.54	1.23	1.66
Sum anions (meq/L)	3.18	0.52	1.16	1.71
Charge imbalance (percent)	14.1	3.9	6.0	-2.7

[1]Grab sample; no field parameters measured onsite.

Table 6. Site data and water analyses for Norris Geyser Basin

Sample code number	99WA119	99WA120	99WA121	99WA122	99WA123
Description	Cinder Pool	"Fracture Spouter"	Near "Fracture"	Realgar Spring	Realgar Spring
Date collected	9/19/1999	9/20/1999	9/20/1999	9/21/1999	9/21/1999
Temperature (°C)	77	85.8	52.3	46.6	52.5
Density (g/mL) at 20°C	0.9996	1.0012	0.9993	1.0013	1.0002
pH	4.38	3.71	3.45	2.75	2.81
Spec Cond (µS/cm) field / lab	2080 / 2230	1800 / ---	2030 / 2090	1967 / ---	1780 / 2080
Eh (V)	0.118	0.144	0.595	0.253	0.321
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	5.7	3.9	3.6	2.9	3.7
Mg	0.070	0.23	0.23	0.26	0.43
Sr	0.019	0.020	0.021	0.021	0.025
Ba	0.024	0.16	0.18	0.058	0.052
Na	370	330	330	200	210
K	62	58	58	64	58
Li	4.7	3.1	3.2	3.2	2.9
SO_4	61	79	86	260	290
S_2O_3	---	---	---	---	---
H_2S	0.56	---	---	1.5	0.73
Alkalinity (as HCO_3)	---	---	---	---	---
F	5.5	3.8	5.1	2.0	1.7
Cl	630	540	550	300	260
Br	1.9	<0.5	1.8	1.0	0.9
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	370	260	270	290	240
B	9.8	8.3	8.7	5.0	4.5
Al	1.5	1.5	2.0	5.5	8.6
Fe (total)	0.030	0.69	0.429	2.6	4.7
Fe (II)	0.028	0.60	0.183	2.6	3.8
Mn	0.006	0.020	0.021	0.045	0.062
Cu	0.0009	<0.0006	<0.0006	<0.0006	0.0007
Zn	0.005	0.007	0.012	0.022	0.028
Cd	0.0001	0.0001	0.0001	0.0001	0.0002
Cr	0.0021	0.0007	0.0005	0.0025	0.0039
Co	<0.001	<0.001	<0.001	0.001	<0.001
Ni	0.003	<0.001	<0.001	<0.001	<0.001
Pb	0.003	0.003	0.003	0.002	0.003
Be	0.001	0.001	0.002	0.003	0.003
V	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	0.055	0.097	0.17	<0.001	<0.001
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	2.10	2.44	2.57	0.090	0.790
As (III)	1.64	2.09	0.151	0.060	0.012
DOC	---	---	---	---	---
Sum cations (meq/L)	18.7	16.7	16.9	13.3	13.5
Sum anions (meq/L)	19.2	16.8	17.4	13.2	12.4
Charge imbalance (percent)	-2.5	-0.6	-2.4	0.7	8.4

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA124	99WA125Q	99WA126Q	99WA127Q	99WA128Q
Description	NHSP129	Medusa Geyser	Hydrophane	Green Dragon	Yellow Funnel
Date collected	9/21/1999	9/21/1999	9/21/1999	9/21/1999	9/21/1999
Temperature (°C)	91.5	73	73.8	81.3	81.7
Density (g/mL) at 20°C	0.9997	---	---	---	---
pH	2.40	6.60	4.90	2.87	4.40
Spec Cond (µS/cm) field / lab	2360 / 3840	2170 / ---	2150 / ---	1750 / ---	2200 / ---
Eh (V)	0.306	---	---	---	---
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	3.2	6.2	3.2	3.6	4.7
Mg	0.25	0.27	0.021	0.22	0.10
Sr	0.020	0.026	0.014	0.012	0.016
Ba	0.064	0.078	0.028	0.044	0.024
Na	230	350	350	260	370
K	60	48	59	48	63
Li	3.6	5.5	5.7	1.5	5.0
SO_4	530	33	49	110	35
S_2O_3	---	---	---	---	---
H_2S	0.05	---	---	---	---
Alkalinity (as HCO_3)	---	---	---	---	---
F	2.6	5.2	6.1	5.1	6.0
Cl	340	630	640	440	660
Br	1.1	2.1	2.1	1.5	2.2
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	300	350	450	390	500
B	6.5	8.7	9.5	6.9	9.6
Al	9.4	<0.06	<0.06	2.1	0.35
Fe (total)	1.8	0.054	0.024	0.38	0.038
Fe (II)	1.7	0.054	0.022	0.36	0.038
Mn	0.041	1.2	0.028	0.12	0.13
Cu	<0.0006	<0.0006	<0.0006	<0.001	<0.0006
Zn	0.015	<0.001	0.018	0.026	0.012
Cd	0.0001	<0.00005	0.0001	<0.005	<0.00005
Cr	0.002	0.004	<0.001	<0.001	<0.001
Co	0.004	0.006	<0.001	<0.001	<0.001
Ni	<0.001	0.014	0.006	<0.001	0.004
Pb	0.003	0.003	0.003	0.044	0.003
Be	0.003	0.002	0.002	<0.0001	0.002
V	0.014	<0.01	0.022	<0.01	<0.01
Sb	0.020	0.072	0.13	---	0.29
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	1.00	1.98	2.55	1.62	2.59
As (III)	0.87	1.57	0.73	1.41	2.38
DOC	---	---	---	---	---
Sum cations (meq/L)	17.3	17.6	17.7	14.5	18.7
Sum anions (meq/L)	17.1	18.8	19.4	14.4	19.6
Charge imbalance (percent)	1.0	-6.4	-9.2	0.8	-4.7

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA129Q	99WA130Q	99WA131Q	99WA132Q	99WA132
Description	Recess Spring	Palpitator Spring	NHSP101	NHSP100	NHSP100
Date collected	9/21/1999	9/21/1999	9/22/1999	9/22/1999	9/22/1999
Temperature (°C)	84.5	85	84.7	81	81
Density (g/mL) at 20°C	---	---	---	---	0.9995
pH	3.96	6.90	2.68	3.05	3.05
Spec Cond (µS/cm) field / lab	1550 / ---	2260 / ---	1490 / ---	1730 / ---	1730 / 2040
Eh (V)	---	---	---	0.209	0.209
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	5.8	8.6	3.7	4.1	3.9
Mg	0.053	0.029	0.34	0.34	0.33
Sr	0.016	0.024	0.020	0.021	0.020
Ba	0.034	0.012	0.10	0.10	0.11
Na	350	400	190	270	250
K	38	42	44	57	44
Li	3.8	5.3	1.9	3.5	2.4
SO_4	59	34	220	200	200
S_2O_3	---	---	---	---	---
H_2S	---	---	---	---	---
Alkalinity (as HCO_3)	---	---	---	---	---
F	5.4	5.8	2.6	3.7	3.3
Cl	570	720	280	350	350
Br	1.9	2.3	0.9	1.2	1.2
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	420	360	340	310	260
B	9.0	10	4.4	6.4	5.9
Al	1.1	<0.06	2.6	3.4	3.4
Fe (total)	0.034	0.003	1.97	0.978	1.00
Fe (II)	0.034	0.002	1.96	0.978	0.984
Mn	0.016	0.024	0.066	0.088	0.082
Cu	0.0043	<0.0006	<0.001	<0.0006	<0.001
Zn	0.014	0.020	0.072	<0.001	0.047
Cd	<0.00005	0.0001	<0.005	0.0001	<0.005
Cr	<0.001	0.004	0.006	0.001	<0.001
Co	<0.001	<0.001	0.006	<0.001	<0.001
Ni	<0.001	<0.001	<0.001	<0.001	0.004
Pb	0.003	0.005	<0.006	0.002	<0.006
Be	0.002	0.002	0.004	<0.0001	0.002
V	<0.01	<0.01	0.024	<0.01	<0.01
Sb	0.37	0.059	---	0.006	---
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	2.28	2.51	1.00	0.78	0.90
As (III)	2.16	1.55	0.86	0.71	0.76
DOC	---	---	---	1.6	---
Sum cations (meq/L)	17.1	19.7	12.3	15.0	13.7
Sum anions (meq/L)	17.4	21.4	11.5	13.5	13.5
Charge imbalance (percent)	-1.5	-8.5	7.0	10.6	1.1

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA134	99WA135Q	99WA136Q	99WA137Q	99WA141Q
Description	Tantalus Creek	Fearless Geyser	Monarch Geyser	Arsenic Geyser	Tantalus Creek
Date collected	9/22/1999	9/22/1999	9/22/1999	9/22/1999	9/23/1999
Temperature (°C)	31	91.4	84.8	90	32
Density (g/mL) at 20°C	0.9995	---	---	---	---
pH	3.11	6.07	4.50	4.04	3.14
Spec Cond (µS/cm) field / lab	2100 / 2080	2290 / ---	1713 / ---	1850 / ---	2090 / ---
Eh (V)	0.663	---	---	---	---
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	3.9	10	3.8	2.1	3.9
Mg	0.22	0.026	0.17	0.090	0.23
Sr	0.015	0.024	0.012	0.016	0.016
Ba	0.081	0.014	0.02	0.13	0.092
Na	310	440	340	340	280
K	65	36	37	77	46
Li	4.3	4.7	3.5	5.4	3.0
SO_4	150	31	110	77	140
S_2O_3	---	---	---	---	---
H_2S	0.004	---	---	---	0.001
Alkalinity (as HCO_3)	---	---	---	---	---
F	3.8	5.7	5.1	4.9	4.8
Cl	470	720	460	540	450
Br	1.5	2.3	1.5	1.8	1.5
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	360	400	320	350	360
B	6.9	11	6.2	8.3	6.8
Al	2.0	<0.06	0.14	0.93	2.0
Fe (total)	1.39	<0.004	0.071	0.463	1.19
Fe (II)	0.662	<0.004	0.070	0.352	0.459
Mn	0.075	0.026	0.064	0.022	0.078
Cu	<0.0006	<0.0006	0.0015	<0.0006	0.0015
Zn	0.012	0.004	0.018	0.012	0.026
Cd	0.0001	0.0001	0.0002	0.0002	0.0002
Cr	0.0014	0.0003	<0.0004	0.0005	0.0015
Co	<0.001	<0.001	0.004	0.002	<0.001
Ni	<0.001	0.004	0.004	<0.001	<0.001
Pb	0.003	0.004	0.004	0.003	0.004
Be	0.002	<0.0001	0.002	<0.0001	0.002
V	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	0.065	0.10	0.13	0.14	0.068
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	1.74	2.33	1.46	2.21	1.77
As (III)	0.048	2.20	1.41	1.83	0.056
DOC	---	---	---	---	1.4
Sum cations (meq/L)	16.9	21.2	16.4	17.7	14.8
Sum anions (meq/L)	16.3	21.3	15.4	16.9	15.5
Charge imbalance (percent)	3.7	-0.3	6.1	4.8	-4.6

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA142	99WA143Q	99WA144Q	99WA145Q	99WA146Q
Description	"Titanic Spring"	"Persnickety Geyser"	Unnamed spring	NRHA3	NRHA4
Date collected	9/23/1999	9/23/1999	9/23/1999	9/23/1999	9/23/1999
Temperature (°C)	84	73.8	82	57	84
Density (g/mL) at 20°C	0.9996	---	---	---	---
pH	5.63	3.91	2.74	4.03	3.21
Spec Cond (µS/cm) field / lab	2080 / 2190	1790 / ---	1575 / ---	2270 / ---	1960 / ---
Eh (V)	0.133	---	---	---	---
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	5.0	4.5	4.9	5.2	6.0
Mg	0.07	0.21	2.5	0.11	0.24
Sr	0.015	0.016	<0.0001	0.018	0.022
Ba	0.045	0.10	0.012	0.082	0.21
Na	380	330	120	390	320
K	68	49	31	54	46
Li	5.8	3.6	0.98	5.4	3.2
SO_4	41	79	290	67	110
S_2O_3	---	---	---	---	---
H_2S	0.01	---	---	---	---
Alkalinity (as HCO_3)	<0.5	---	---	---	---
F	5.3	4.4	<0.3	5.6	3.1
Cl	630	540	190	640	520
Br	1.5	1.7	<0.5	2.1	1.7
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	500	440	230	540	330
B	9.6	8.2	2.5	8.5	8.4
Al	0.17	0.65	3.5	0.74	2.1
Fe (total)	0.069	2.11	5.75	0.933	2.56
Fe (II)	0.068	1.93	5.16	0.933	2.53
Mn	0.016	0.051	0.14	0.024	0.061
Cu	<0.0006	<0.0006	<0.001	0.076	0.086
Zn	0.002	0.034	0.022	0.036	0.049
Cd	0.0002	0.0002	<0.005	0.0001	<0.005
Cr	0.0004	0.0025	<0.001	0.0014	<0.001
Co	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	0.005	<0.001	<0.001	0.004	0.002
Pb	0.003	0.003	<0.006	0.004	<0.006
Be	0.002	0.002	<0.0001	0.002	0.006
V	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	0.17	0.11	---	0.16	---
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	2.76	1.62	0.15	2.91	3.63
As (III)	2.38	0.20	0.08	1.06	2.71
DOC	1.0	---	---	---	---
Sum cations (meq/L)	19.4	16.5	8.81	19.5	16.7
Sum anions (meq/L)	18.9	17.0	10.0	19.6	16.8
Charge imbalance (percent)	2.3	-2.6	-12.9	-0.6	-0.4

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA147Q	99WA148	99WA149	99WA150	99WA151
Description	Unnamed pool	NRHA2	Unnamed pool	Main drainage	"Elk Geyser"
Date collected	9/23/1999	9/23/1999	9/23/1999	9/23/1999	9/23/1999
Temperature (°C)	85	43	42	46	79
Density (g/mL) at 20°C	---	---	---	---	0.9997
pH	5.85	3.44	3.18	3.70	4.45
Spec Cond (µS/cm) field / lab	2060 / ---	1700 / ---	2240 / ---	2330 / ---	2300 / 2400
Eh (V)	---	---	---	---	0.194
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	5.0	3.2	3.6	5.8	6.7
Mg	0.025	0.057	0.10	0.14	0.01
Sr	0.016	0.012	0.016	0.018	0.024
Ba	0.17	0.15	0.28	0.13	0.098
Na	370	250	330	380	440
K	38	32	35	53	51
Li	3.9	2.3	3.0	4.5	6.0
SO_4	25	72	87	75	52
S_2O_3	---	---	---	---	---
H_2S	---	---	---	---	0.01
Alkalinity (as HCO_3)	---	---	---	---	---
F	5.9	2.6	3.7	8.6	4.8
Cl	620	420	550	630	700
Br	2.0	1.4	1.9	2.2	2.3
NO_3	<0.4	<0.4	<0.4	<0.4	<0.4
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	300	150	260	490	330
B	9.8	6.5	9.0	10	10
Al	<0.06	2.4	1.9	1.0	1.3
Fe (total)	0.012	0.283	1.48	1.33	0.077
Fe (II)	0.010	0.281	0.744	1.30	0.010
Mn	0.006	0.010	0.016	0.029	0.007
Cu	<0.0006	<0.0006	<0.0006	<0.0006	0.044
Zn	0.004	0.012	0.014	0.018	0.006
Cd	<0.00005	<0.00005	0.0001	0.0001	0.0001
Cr	<0.0004	0.0005	0.0015	0.0014	<0.0002
Co	0.004	<0.001	<0.001	<0.001	<0.001
Ni	<0.001	0.004	<0.001	<0.001	<0.001
Pb	0.003	0.002	0.003	0.004	0.003
Be	0.001	0.002	0.001	0.002	0.002
V	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	0.17	<0.001	0.008	0.17	0.22
Se (total)	<0.05	<0.05	<0.05	<0.05	<0.05
As (total)	2.80	0.321	5.8	4.2	2.9
As (III)	2.44	0.28	0.23	0.81	1.12
DOC	---	---	---	---	1.1
Sum cations (meq/L)	17.9	12.7	16.7	19.1	21.7
Sum anions (meq/L)	18.3	13.3	17.4	19.6	21.0
Charge imbalance (percent)	-2.6	-4.7	-4.0	-2.6	3.4

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	99WA152	00WA134	00WA135	00WA136	00WA137
Description	Rock Spring	"Elk Geyser"	"Black Gassy"	Perpetual Spouter	Unnamed spring
Date collected	9/23/1999	6/22/2000	6/23/2000	6/23/2000	6/23/2000
Temperature (°C)	85	79.3	90.4	89.4	88.4
Density (g/mL) at 20°C	---	1.0000	0.9997	0.9996	0.9992
pH	3.20	4.21	7.21	6.78	2.73
Spec Cond (µS/cm) field / lab	1570 / 1800	2410 / 2550	2370 / 2555	2440 / 2555	1440 / 1991
Eh (V)	0.191	0.248	0.035	0.056	0.647
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	1.6	8.3	11	10	2.8
Mg	0.065	0.010	0.13	0.093	0.32
Sr	0.011	0.027	0.040	0.037	0.016
Ba	0.17	0.058	0.031	0.026	0.12
Na	230	440	450	450	170
K	55	44	45	45	50
Li	4.5	5.2	5.6	5.9	1.6
SO_4	110	53	38	44	250
S_2O_3	---	<0.1	<0.1	<0.1	<0.1
H_2S	0.02	<0.001	0.003	0.013	0.004
Alkalinity (as HCO_3)	---	---	12.4	6.5	---
F	3.9	4.3	4.0	4.0	0.7
Cl	380	730	740	740	240
Br	1.3	0.85	0.86	0.88	0.32
NO_3	<0.4	<0.1	<0.1	<0.1	<0.1
NO_2	---	---	---	---	---
NH_4	---	0.39	0.37	0.35	1.7
SiO_2	330	420	310	330	460
B	5.7	11	16	13	4.3
Al	2.2	0.80	0.27	0.31	1.0
Fe (total)	0.614	0.057	0.012	0.078	3.36
Fe (II)	0.610	0.056	0.002	0.012	1.94
Mn	0.008	0.003	0.065	0.043	0.084
Cu	0.016	0.0013	0.0015	0.0008	0.0007
Zn	0.012	0.005	<0.001	0.001	0.054
Cd	<0.00005	0.00005	0.00006	<0.00005	0.00009
Cr	0.0008	0.0002	<0.0002	0.0001	0.0028
Co	<0.001	<0.001	0.002	0.001	0.001
Ni	<0.001	<0.02	<0.02	<0.02	<0.02
Pb	0.002	0.002	0.002	0.002	0.003
Be	0.002	0.0003	0.001	0.002	0.004
V	<0.01	<0.001	<0.001	<0.001	<0.001
Sb	0.077	0.20	0.16	0.15	0.024
Se (total)	<0.05	<0.02	<0.02	<0.02	<0.02
As (total)	1.89	3.0	2.9	2.9	0.57
As (III)	1.62	0.26	2.4	1.4	0.035
DOC	---	---	---	---	---
Sum cations (meq/L)	12.9	21.5	22.1	22.1	11.3
Sum anions (meq/L)	12.8	21.8	22.1	22.1	10.9
Charge imbalance (percent)	0.9	-1.4	0.1	-0.2	3.8

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	00WA138	00WA139	00WA140A	00WA140B	00WA140C
Description	Tantalus Creek	Unnamed spring	Unnamed spring	Unnamed spring	Unnamed spring
Date collected	6/23/2000	6/23/2000	6/24/2000	6/24/2000	6/24/2000
Temperature (°C)	37.5	29.8	58.7	47.4	41.9
Density (g/mL) at 20°C	0.9996	0.9993	0.9992	---	---
pH	2.92	2.87	3.25	---	---
Spec Cond (µS/cm) field / lab	1954 / 2010	2430 / 2430	2080 / 2240	2170 / ---	2230 / ---
Eh (V)	0.653	---	---	---	---
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	3.9	5.7	6.5	6.6	6.8
Mg	0.29	0.30	0.27	0.29	0.28
Sr	0.014	0.015	0.026	0.026	0.027
Ba	0.074	0.13	0.13	0.12	0.13
Na	270	320	320	320	320
K	40	37	39	41	40
Li	3.8	3.2	3.1	3.7	3.7
SO_4	140	140	120	---	---
S_2O_3	<0.1	<0.1	<0.1	<0.1	<0.1
H_2S	0.002	<0.001	0.9	0.45	0.05
Alkalinity (as HCO_3)	---	---	---	---	---
F	3.3	2.6	2.3	---	---
Cl	420	530	530	---	---
Br	0.59	0.79	0.73	---	---
NO_3	<0.1	<0.1	<0.1	---	---
NO_2	---	---	---	---	---
NH_4	0.30	0.44	---	---	---
SiO_2	400	310	240	250	250
B	6.8	8.7	8.5	8.6	8.7
Al	2.4	4.3	4.0	3.8	4.1
Fe (total)	1.00	2.96	2.93	3.18	2.83
Fe (II)	0.66	2.00	2.93	3.18	2.77
Mn	0.11	0.042	0.053	0.053	0.056
Cu	0.0007	0.0017	<0.0006	<0.001	<0.001
Zn	0.010	0.010	0.016	0.017	0.017
Cd	0.00008	0.00009	0.00009	<0.001	<0.001
Cr	0.0011	0.0028	0.0028	<0.001	<0.001
Co	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Pb	0.002	0.002	0.002	<0.008	<0.008
Be	0.002	0.002	<0.0001	<0.0001	<0.0001
V	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	0.037	0.001	0.001	---	---
Se (total)	<0.02	<0.02	<0.02	<0.02	<0.02
As (total)	1.5	5.4	0.21	1.3	1.9
As (III)	0.14	0.28	0.21	1.2	1.2
DOC	---	---	---	---	---
Sum cations (meq/L)	15.0	17.5	16.7	---	---
Sum anions (meq/L)	14.6	17.7	17.3	---	---
Charge imbalance (percent)	2.6	-1.0	-3.5	---	---

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	00WA140D	00WA141A	00WA141B	00WA141C	00WA141D
Description	Unnamed spring	"Beowulf Spring"	"Beowulf Spring"	"Beowulf Spring"	"Beowulf Spring"
Date collected	6/24/2000	6/24/2000	6/24/2000	6/24/2000	6/24/2000
Temperature (°C)	37.2	64	56	53.6	48.7
Density (g/mL) at 20°C	---	0.9993	---	---	---
pH	3.19	3.18	---	---	---
Spec Cond (µS/cm) field / lab	2290 / ---	2080 / 2215	2130 / ---	2140 / ---	2170 / ---
Eh (V)	---	---	---	---	---
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	6.8	5.7	5.8	5.7	5.7
Mg	0.28	0.18	0.18	0.21	0.21
Sr	0.027	0.022	0.022	0.023	0.023
Ba	0.13	0.12	0.13	0.13	0.13
Na	330	310	310	330	320
K	42	40	39	40	39
Li	3.9	3.9	3.8	3.2	3.2
SO_4	120	120	---	---	---
S_2O_3	<0.1	<0.1	<0.1	<0.1	<0.1
H_2S	0.01	0.9	0.3	0.09	0.01
Alkalinity (as HCO_3)	---	---	---	---	---
F	2.3	2.2	---	---	---
Cl	540	530	---	---	---
Br	0.63	0.69	---	---	---
NO_3	<0.1	<0.1	---	---	---
NO_2	---	---	---	---	---
NH_4	---	---	---	---	---
SiO_2	260	260	260	250	250
B	8.9	8.3	8.4	8.7	8.6
Al	4.0	4.0	4.1	4.1	4.1
Fe (total)	2.71	2.74	2.70	2.71	2.71
Fe (II)	2.67	2.74	2.70	2.71	2.65
Mn	0.055	0.028	0.029	0.039	0.04
Cu	<0.001	0.0016	<0.001	<0.001	<0.001
Zn	0.018	0.013	0.013	0.022	0.028
Cd	<0.001	<0.00005	<0.001	<0.001	<0.001
Cr	<0.001	0.0028	<0.001	<0.001	<0.001
Co	<0.001	<0.001	<0.001	0.001	<0.001
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Pb	<0.008	0.002	<0.008	<0.008	<0.008
Be	<0.0001	<0.0001	<0.0001	0.002	0.002
V	<0.001	<0.001	<0.001	0.002	<0.001
Sb	---	0.001	---	---	---
Se (total)	<0.02	<0.02	<0.02	<0.02	<0.02
As (total)	1.8	0.27	1.7	2.0	1.9
As (III)	0.93	0.24	1.7	1.8	1.3
DOC	---	---	---	---	---
Sum cations (meq/L)	17.4	16.4	---	---	---
Sum anions (meq/L)	17.6	17.2	---	---	---
Charge imbalance (percent)	-1.1	-4.8	---	---	---

Table 6. Site data and water analyses for Norris Geyser Basin --- Continued

Sample code number	00WA141E	00WA142	00WA143	00WA144	00WA145
Description	"Beowulf Spring"	Minute Geyser	Branch Spring	Unnamed spring	"Persnickety Geyser"
Date collected	6/24/2000	6/24/2000	6/24/2000	6/24/2000	6/24/2000
Temperature (°C)	46.9	93	79	82.5	89
Density (g/mL) at 20°C	0.9992	0.9994	0.9993	0.9995	0.9994
pH	3.12	7.63	3.91	3.05	4.03
Spec Cond (µS/cm) field / lab	2200 / 2260	1990 / 2095	1580 / 1662	2130 / 2490	2010 / 2130
Eh (V)	---	---	0.197	0.399	0.142
D.O. (mg/L)	---	---	---	---	---
Constituent (mg/L)					
Ca	5.7	6.1	5.3	5.9	5.2
Mg	0.22	0.046	0.17	0.13	0.072
Sr	0.023	0.015	0.012	0.014	0.014
Ba	0.13	0.013	0.022	0.12	0.061
Na	330	380	280	380	350
K	41	34	30	48	47
Li	3.2	3.8	3.2	4.9	3.7
SO_4	120	28	70	120	75
S_2O_3	<0.1	<0.1	6.8	0.3	<0.1
H_2S	<0.001	0.09	0.109	---	---
Alkalinity (as HCO_3)	---	7.8	---	---	---
F	2.1	4.5	3.4	3.8	3.7
Cl	540	610	440	640	580
Br	0.67	0.66	0.61	0.84	0.84
NO_3	<0.1	<0.1	<0.1	<0.1	<0.1
NO_2	---	---	---	---	---
NH_4	---	0.18	1.8	1.2	1.0
SiO_2	260	450	350	440	480
B	8.8	9.8	7.1	10	9.3
Al	4.1	<0.08	0.80	4.3	0.63
Fe (total)	2.63	0.003	0.124	2.27	0.380
Fe (II)	2.49	<0.002	0.124	2.08	0.370
Mn	0.041	0.018	0.042	0.026	0.018
Cu	<0.001	<0.0006	0.0008	0.0011	0.0006
Zn	0.022	<0.001	0.004	0.010	0.002
Cd	<0.001	<0.00005	0.00008	0.00009	0.00007
Cr	<0.001	<0.0002	0.0002	0.0032	0.0005
Co	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	<0.02	<0.02	<0.02	<0.02	<0.02
Pb	<0.008	0.002	0.002	0.003	0.003
Be	0.002	0.0006	0.001	0.001	<0.0001
V	0.002	<0.001	<0.001	<0.001	<0.001
Sb	---	0.11	0.068	0.15	0.10
Se (total)	<0.02	<0.02	<0.02	<0.02	<0.02
As (total)	1.9	2.3	1.4	2.6	1.8
As (III)	0.96	1.1	1.4	1.1	1.3
DOC	---	---	---	---	---
Sum cations (meq/L)	17.4	18.3	13.9	20.1	17.4
Sum anions (meq/L)	17.6	18.4	13.9	20.3	18.0
Charge imbalance (percent)	-1.1	-0.7	-0.1	-0.8	-3.4

Table 7. Site data and water analyses for Nymph Creek and Roadside Springs

Sample code number	00WA158	00WA160	00WA161	00WA162
Description	3 m from lake	61 m from lake	99 m from lake	138 m from lake
Date collected	9/20/2000	9/20/2000	9/20/2000	9/20/2000
Temperature (°C)	24.5	30.3	35.4	43.4
Density (g/mL) at 20°C	0.9988	0.9987	0.9988	0.9989
pH	2.73	2.76	2.75	2.79
Spec Cond (µS/cm) field / lab	1265 / ---	1240 / 1288	1197 / 1296	1120 / 1276
Eh (V)	0.745	0.741	0.732	0.670
D.O. (mg/L)	6.7	6.2	5.5	5.3
Constituent (mg/L)				
Ca	6.4	6.3	6.3	6.2
Mg	2.3	2.3	2.2	2.3
Sr	0.016	0.016	0.017	0.015
Ba	0.033	0.033	0.033	0.032
Na	67	66	69	65
K	46	42	37	37
Li	0.14	0.14	0.13	0.14
SO_4	300	300	300	290
S_2O_3	<0.3	<0.3	<0.3	<0.3
H_2S	<0.001	<0.001	<0.001	<0.001
Alkalinity (as HCO_3)	---	---	---	---
F	0.70	0.70	0.71	0.71
Cl	35	35	34	34
Br	<0.05	<0.05	<0.05	<0.05
NO_3	<0.1	<0.1	<0.1	<0.1
NO_2	0.033	0.010	0.010	0.046
NH_4	0.98	1.0	1.4	1.3
SiO_2	250	250	240	250
B	0.74	0.73	0.73	0.71
Al	2.6	2.5	2.5	2.4
Fe (total)	3.07	2.97	2.96	2.95
Fe (II)	0.402	0.291	0.429	1.05
Mn	0.11	0.11	0.11	0.11
Cu	0.0014	0.0011	<0.0006	<0.0006
Zn	0.032	0.034	0.025	0.040
Cd	0.00006	<0.00005	0.00005	0.00006
Cr	0.0028	0.0027	0.0025	0.0024
Co	<0.001	<0.001	0.002	<0.001
Ni	<0.002	<0.002	<0.002	<0.002
Pb	0.0008	0.0012	0.0009	0.0008
Be	0.003	0.003	0.003	0.003
V	<0.001	<0.001	<0.001	<0.001
Sb	0.002	0.002	0.002	0.002
Se (total)	<0.04	<0.04	<0.04	<0.04
As (total)	0.105	0.102	0.101	0.098
As (III)	0.003	0.003	0.004	0.019
DOC	1.3	1.1	1.0	0.9
Sum cations (meq/L)	6.80	6.50	6.55	6.20
Sum anions (meq/L)	6.59	6.57	6.51	6.28
Charge imbalance (percent)	3.3	-1.0	0.7	-1.3

Table 7. Site data and water analyses for Nymph Creek and Roadside Springs --- Continued

Sample code number	00WA163	00WA164	00WA165	00WA166
Description	Source 165 m	Source 172 m	W Roadside Spring	E Roadside Spring
Date collected	9/20/2000	9/20/2000	9/20/2000	9/20/2000
Temperature (°C)	62	40.7	69.5	68.9
Density (g/mL) at 20°C	0.9988	0.9988	0.9932	0.9989
pH	2.87	2.77	6.48	4.49
Spec Cond (μS/cm) field / lab	966 / 1255	1163 / 1330	1877 / ---	870 / 988
Eh (V)	0.327	0.714	0.055	0.231
D.O. (mg/L)	---	6.5	---	---
Constituent (mg/L)				
Ca	6.2	6.4	1.4	5.7
Mg	2.3	2.4	0.020	0.70
Sr	0.015	0.016	0.005	0.020
Ba	0.033	0.030	0.034	0.082
Na	65	68	380	140
K	38	38	7.4	48
Li	0.14	0.12	2.0	0.62
SO_4	290	310	70	180
S_2O_3	<0.3	<0.3	8.5	<0.3
H_2S	0.14	<0.001	0.15	0.017
Alkalinity (as HCO_3)	---	---	170	<1
F	0.69	0.67	18	2.4
Cl	33	32	430	130
Br	<0.05	<0.05	1.4	0.41
NO_3	<0.1	<0.1	<0.1	<0.1
NO_2	0.013	0.013	---	---
NH_4	1.7	1.0	0.30	2.8
SiO_2	250	240	310	280
B	0.71	0.71	7.4	2.4
Al	2.3	2.5	0.16	0.14
Fe (total)	3.02	2.71	0.010	0.621
Fe (II)	2.85	0.756	0.010	0.619
Mn	0.11	0.11	0.005	0.21
Cu	<0.0006	<0.0006	<0.0006	0.0037
Zn	0.023	0.024	0.003	0.005
Cd	0.00007	0.00007	0.00010	0.00008
Cr	0.0041	0.0024	<0.0002	0.0008
Co	<0.001	<0.001	<0.001	<0.001
Ni	0.003	0.002	<0.002	<0.002
Pb	0.0010	0.0013	0.0024	0.0012
Be	0.003	0.003	0.001	0.005
V	<0.001	<0.001	<0.001	<0.001
Sb	0.002	0.002	0.10	0.006
Se (total)	<0.04	<0.04	<0.04	<0.04
As (total)	0.100	0.090	3.42	0.313
As (III)	0.062	0.013	3.24	0.085
DOC	0.8	0.8	0.7	0.7
Sum cations (meq/L)	5.92	6.43	17.2	7.81
Sum anions (meq/L)	6.14	6.59	17.4	7.39
Charge imbalance (percent)	-3.8	-2.4	-1.2	5.6

Table 8. ^{2}H and ^{18}O isotope determinations
[in permil relative to VSMOW]

Site Description	Sample Code Number	$\delta^{2}H$	$\delta^{18}O$
Alluvium Creek at Yellowstone Lake shore	99WA116	-140	-18.6
Alluvium Creek 610 m upstream from Thorofare Trail	99WA117	-138	-21.3
Alluvium Creek at base of sulfur mounds	99WA118	-139	-21.9
Cinder Pool	99WA119	-129	-10.9
"Fracture Spouter"	99WA120	-142	-15.4
Pool next to "Fracture Spouter"	99WA121	-138	-13.8
Realgar Spring 3 m from sign	99WA122	-135	-14.9
Realgar Spring 20 m from sign	99WA123	-135	-15.0
Unnamed spring near Horseshoe Spring	99WA124	-120	-11.2
Unnamed pool NNW of Cinder Pool	99WA132	-125	-10.3
Tantalus Creek at weir	99WA134	-135	-13.6
Unnamed Spring, south end of Ragged Hills	99WA142	-142	-14.9
Unnamed Spring northwest of Ragged Hills	99WA151	-144	-14.9
Rock Spring	99WA152	-144	-16.5
"Black Gassy Spring"	00WA135	-142	-15.3
Perpetual Spouter	00WA136	-143	-15.1
Back Basin Drainage	00WA138	-133	-13.4
Small Side Ragged Hills Drainage	00WA139	-139	-14.6
Minute Geyser	00WA142	-141	-15.2
Branch Spring	00WA143	-133	-12.1
"Titanic Spring"	00WA144	-134	-12.8
"Persnickety Geyser"	00WA145	-140	-14.5
Columbine Creek, West fork headwaters	00WA155	-135	-18.1
Columbine Creek, East fork	00WA156	-138	-18.5
Columbine Creek, East fork above confluence with West fork	00WA157	-138	-18.4
Nymph Creek, 3 m from Nymph Lake	00WA158	-141	-17.3
Nymph Creek, 61 m from Nymph Lake	00WA160	-142	-17.4
Nymph Creek, 99 m from Nymph Lake	00WA161	-141	-17.4
Nymph Creek, 138 m from Nymph Lake	00WA162	-141	-17.7
Nymph Creek Springs vent, 165 m from Nymph Lake	00WA163	-143	-18.1
Nymph Creek Springs vent, 172 m from Nymph Lake	00WA164	-142	-17.6
Unnamed Western Roadside Spring	00WA165	-131	-12.4
Unnamed Eastern Roadside Spring	00WA166	-140	-16.2

Table 9. Results for field blanks

Sample code number	99WA133	00WA159
Date collected	9/22/1999	9/20/2000
Temperature (°C)	---	---
pH	---	---
Spec Cond (μS/cm) field / lab	--- / ---	--- / ---
Eh (V)	---	---
D.O. (mg/L)	---	---
Constituent (mg/L)		
Ca	0.06	<0.05
Mg	<0.009	0.001
Sr	<0.0001	<0.001
Ba	<0.0005	<0.0005
Na	0.3	0.044
K	0.2	0.027
Li	<0.001	<0.008
SO_4	<0.5	<0.1
S_2O_3	---	<0.3
H_2S	---	---
Alkalinity (as HCO_3)	---	---
F	<0.2	<0.1
Cl	1.1	0.44
Br	<0.5	<0.05
NO_3	<0.4	<0.1
NH_4	---	<0.05
SiO_2	0.16	0.021
B	<0.01	<0.003
Al	<0.06	<0.08
Fe (total)	0.003	<0.002
Fe (II)	<0.002	<0.002
Mn	<0.001	<0.001
Cu	<0.002	0.005
Zn	0.012	0.003
Cd	<0.0001	<0.00005
Cr	<0.0002	<0.0002
Co	<0.001	<0.001
Ni	<0.001	<0.002
Pb	0.003	<0.0005
Be	<0.0001	<0.0001
V	<0.001	<0.001
Sb	<0.001	<0.001
Se (total)	<0.05	<0.04
As (total)	<0.0002	<0.0005
As (III)	<0.0003	<0.001
DOC	1.5	0.7

REFERENCES CITED

Aiken, G.R., 1992, Chloride interference in the analysis of dissolved organic carbon by the wet oxidation method: Environmental Science and Technology, v. 26, p. 2435-2439.

Allen, E.T., and Day, A.L., 1935, Hot springs of the Yellowstone National Park: Carnegie Institution of Washington Publication Number 466, 525 p.

American Public Health Association (APHA), 1985, Method 428C. Methylene blue method for sulfide, *in* Standard methods for the examination of water and wastewater (14th ed.): American Public Health Association, p. 403-405.

Antweiler, R.C., Patton, C.P., and Taylor, H.E., 1996, Automated colorimetric methods for determination of nitrate plus nitrite, ammonium, and orthophosphate ions in natural water samples: U.S. Geological Survey Open-File Report 93-638, 123 p.

Ball, J.W., Nordstrom, D.K., Jenne, E.A., and Vivit, D.V., 1998a, Chemical analyses of hot springs, pools, geysers, and surface waters from Yellowstone National Park, Wyoming, and vicinity, 1974-1975: U.S. Geological Survey Open-File Report 98-182, 45 p.

Ball, J.W., Nordstrom, D.K., Cunningham, K.M., Schoonen, M.A.A., Xu, Y., and DeMonge, J.M., 1998b, Water-chemistry and on-site sulfur-speciation data for selected springs in Yellowstone National Park, Wyoming, 1994-1995: U.S. Geological Survey Open-File Report 98-574, 35 p.

Ball, J.W., Nordstrom, D.K., McCleskey, R.B., Schoonen, M.A.A., and Xu, Y., 2001, Water-chemistry and on-site sulfur-speciation data for selected springs in Yellowstone National Park, Wyoming, 1996-1998: U.S. Geological Survey Open-File Report 01-49, 42 p.

Ball, J.W., and Nordstrom, D.K., 1991, User's manual for WATEQ4F, with revised thermodynamic data base and test cases for calculating speciation of major, trace, and redox elements in natural waters: U.S. Geological Survey Open-File Report 91-183, 189 p.

Barringer, J.L., and Johnsson, P.A., 1996, Theoretical considerations and a simple method for measuring alkalinity and acidity in low-pH waters by Gran titration: U.S. Geological Survey Water-Resources Investigations Report 89-4029.

Barnard, W.R., and Nordstrom, D.K., 1980, Fluoride in precipitation-I. Methodology with the fluoride-selective electrode: Atmospheric Environment, v. 16, p. 99-103.

Charlton, S.R., Macklin, C.L., and Parkhurst, D.L., 1997, PHREEQCI--A graphical user interface for the geochemical computer program PHREEQC: U.S. Geological Survey Water-Resources Investigations Report 97-4222.

Coplen, T.B., Wildman, J.D., and Chen, J., 1991, Improvements in the gaseous hydrogen-water equilibrium technique for hydrogen isotope ratio analysis: Analytical Chemistry, v. 63, p. 910-912.

Epstein, S. and Mayeda, T., 1953, Variation of ^{18}O content of water from natural sources: Geochimica et Cosmochimica Acta, v. 4, p. 213-224.

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: Techniques of water-resources investigations of the U.S. Geological Survey, Book 5, Chapter A1, p. 55-56.

Fournier, R.O., 1989, Geochemistry and dynamics of the Yellowstone National Park hydrothermal system: Annual Review of Earth and Planetary Sciences, v. 17, p. 13-53.

Fournier, R.O., Thompson, J.M., and Hutchinson, R.A., 1994, The geochemistry of hot spring waters at Norris Geyser Basin, Yellowstone National Park: Geothermal Resources Council Transactions, v. 18, p. 177-179.

Gooch, F.A., and Whitfield, J.E., 1888, Analyses of waters of the Yellowstone National Park with an account of the methods of analysis employed: U.S. Geological Survey Bulletin 47, 84 p.

Kharaka, Y.K., Mariner, R.H., Bullen, T.D., Kennedy, B.M., and Sturchio, N.C., 1991, Geochemical investigations of hydraulic connections between the Corwin Springs Known Geothermal Resources Area and adjacent parts of Yellowstone National Park, *in* Sorey, M.L., ed., Effects of potential geothermal development in the Corwin Springs Known Geothermal Resources Area: U.S. Geological Survey Water-Resources Investigations Report 91-4052, p. F-1 - F-38.

Kharaka, Y.K., Thordsen, J.J., and White, L.D., 2002, Isotope and chemical compositions of meteoric and thermal waters and snow from the greater Yellowstone National Park region: U.S. Geological Survey Open-File Report 02-194, 72 p.

Kennedy, V.C., Jenne, E.A., and Burchard, J.M., 1976, Back-flushing filters for field processing of water samples prior to trace-element analyses: U.S. Geological Survey Open-File Report 76-126, 12 p.

Nordstrom, D.K., 1977, Thermochemical redox equilibria of ZoBell's solution: Geochimica et Cosmochimica Acta, v. 41, p. 1835-41.

Parkhurst, D.L., and Appelo, C.A.J., 1999, User's guide to PHREEQC (version 2)—a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Water-Resources Investigations Report 99-4259, 312 p.

Patton, C.J., and Gilroy, E.J., 1999, U.S. Geological Survey nutrient preservation experiment-experimental design, statistical analysis, and interpretation of analytical results: U.S. Geological Survey Water-Resources Investigations Report 98-4118, 73 p.

Rowe, J.J., Fournier, R.O., and Morey, G.W., 1973, Chemical analysis of thermal waters in Yellowstone National Park, Wyoming, 1960-65: U.S. Geological Survey Bulletin 1303, 31 p.

Solorzano, L., 1969, Determination of ammonia in natural waters by the phenolhypochlorite method: Limnology and Oceanography, v. 5, p. 799-801.

Stauffer, R.E., Jenne, E.A., and Ball, J.W., 1980, Chemical studies of selected trace elements in hot-spring drainages of Yellowstone National Park: U.S. Geological Survey Professional Paper 1044-F, 20 p.

Stookey, L.L., 1970, Ferrozine - a new spectrophotometric reagent for iron: Analytical Chemistry, v. 42, p. 779-781.

Stumm, W., and Morgan, J.J., 1996 Aquatic chemistry, 3rd edition: New York, Wiley-Interscience, John Wiley and Sons, 1022 p.

Thompson, J.M., and DeMonge, J.M., 1996, Chemical analyses of hot springs, pools, and geysers from Yellowstone National Park, Wyoming, and vicinity, 1980-1993: U.S. Geological Survey Open-File Report 96-68, 66 p.

Thompson, J.M., and Hutchinson, R.A., 1981, Chemical analyses of waters from the Boundary Creek Thermal Area, Yellowstone National Park, Wyoming: U.S. Geological Survey Open-File Report 81-1310, 15 p.

Thompson, J.M., Presser, T.S., Barnes, R.B., and Bird, D.B., 1975, Chemical analysis of the waters of Yellowstone National Park, Wyoming from 1965 to 1973: U.S. Geological Survey Open-File Report 75-25, 58 p.

Thompson, J.M., and Yadav, S., 1979, Chemical analysis of waters from geysers, hot springs and pools in Yellowstone National Park, Wyoming from 1974 to 1978: U.S. Geological Survey Open-File Report 79-704, 48 p.

U.S. Environmental Protection Agency, 1979, Cadmium reduction method: Federal Register 44(85) 25505.

U.S. Geological Survey, 1984, Chemical and physical quality of water and sediment, chap. 5 *in* U.S. Geological Survey, National handbook of recommended methods for water-data acquisition: p. 5-1 to 5-194.

Webster, J.G., and Nordstrom, D.K., 2002, Geothermal arsenic: the source, distribution and fate of arsenic in geothermal systems, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in groundwater: Kluwer, Amsterdam, Netherlands, in press.

White, D.E., Hem, J.D., and Waring, G.A., 1963, Chemical composition of subsurface waters, *in* Fleischer, M., ed., Data of geochemistry, 6th edition: U.S. Geological Survey Professional Paper 440-F, 67 p.

White, D.E., Hutchinson, R.A., and Keith, T.E.C., 1988, The geology and remarkable thermal activity of Norris Geyser Basin, Yellowstone National Park: U.S. Geological Survey Professional Paper 1456, 84 p.

Whittlesey, L.H., 1995, Wonderful Nomenclature: A history of the place names of Yellowstone National Park, being a description of and guidebook to its most important natural features together with appendices of related elements: Helena, MT, Montana Historical Society Press, 867 p.

Xu, Y., and Schoonen, M.A.A., 1995, The stability of thiosulfate in the presence of pyrite in low-temperature aqueous solutions: Geochimica et Cosmochimica Acta, v. 59, p. 4605-4622.

Xu, Y., Schoonen, M.A.A., and Strongin, D.R., 1996, Thiosulfate oxidation: catalysis of synthetic sphalerite doped with transition metals: Geochimica et Cosmochimica Acta, v. 60, p. 4701-4710.

Xu, Y., Schoonen, M.A.A., Nordstrom, D.K., Cunningham, K.M., and Ball, J.W., 1998, Sulfur geochemistry of hydrothermal waters in Yellowstone National Park: I. The origin of thiosulfate in hot spring waters: Geochimica et Cosmochimica Acta, v. 62, p. 3729-3743.

Xu, Y., Schoonen, M.A.A., Nordstrom, D.K., Cunningham, K.M., and Ball, J.W., 2000, Sulfur geochemistry of hydrothermal waters in Yellowstone National Park: II. Formation and decomposition of thiosulfate and polythionate in Cinder Pool: Journal of Volcanology and Geothermal Research, v. 97, p. 407-423.

ZoBell, C.E., 1946, Studies on redox potential of marine sediments: 8. Other methods: Bulletin of the American Association of Petroleum Geologists, v. 30, p. 477-509.

APPENDIX 1

METHODS OF ANALYSIS AND MEASUREMENTS OF STANDARD REFERENCE WATER SAMPLES

Table 10. Methods of analysis

Parameter or Element	Descriptor	Typical **rsd**[1], *detection limit (mg/L)*
pH	PH	**0.025 pH units**[2]
Spec Cond	COND	**~0.5%**
Eh	EC1	**~10%**
D.O.	EC2	**1%**
Ca	ICP	**~2%**, *0.05*
Mg	ICP	**~2%**, *0.001*
Sr	ICP	**~2%**, *0.0005*
Ba	ICP	**~2%**, *0.0005*
Na	ICP; FAAS	**~2%,** *0.4*; **~2%,** *0.040*
K	ICP; FAES	**~2%,** *0.05*; **~2%,** *0.025*
Li	ICP; FAAS	**~5%,** *0.008*; **~2%,** *0.003*
SO_4	IC1	**2-3%**, *0.2*
S_2O_3	IC2	**2-3%,** *0.3*
H_2S	COLOR1	**~3%,** *0.005*
Alkalinity (as HCO_3)	TITR1	**2%,** *0.4*
Acidity (mM) total / free H^+	TITR2	**2%,** *0.4*
F	IC1; EC3	**2-3%**, *0.2;* **~3%**
Cl	IC1	**2-3%**, *0.05*
Br	IC1	**2-3%**, *0.1*
NO_3	IC1	**2-3%**, *0.1*
NO_2	COLOR4	**2-3%***, 0.003*
NH_4	COLOR2; IC3; IC4	**3%**, *0.05*; **~2%**, *0.2*; **~2%**, *0.09*
SiO_2	ICP	**~2%**, *0.01*
B	ICP	**~2%**, *0.003*
Al	ICP	**~2%**, *0.08*
Fe (total)	ICP; COLOR3	**~2%**, *0.009*; **1-2%,** *0.002*
Fe (II)	COLOR3	**1-2%,** *0.002*
Mn	ICP	**~2%**, *0.001*
Cu	ICP	**~2%**, *0.002*
Zn	ICP	**~2%**, *0.001*
Cd	ICP; ZGFAAS	**~2%**, *0.001*; **~5%**, *0.0001*
Cr	ICP	**~2%**, *0.002*
Co	ICP	**~2%**, *0.001*
Ni	ICP; ZGFAAS	**~2%**, *0.02*; **~5%**, *0.0005*
Pb	ICP; ZGFAAS	**~2%**, *0.007*; **~5%**, *0.0001*
Be	ICP	**~2%**, *0.0001*
V	ICP	**~2%**, *0.001*
Sb	ZGFAAS	**2-3%***, 0.001*
Se (total)	ICP; ZGFAAS	**~5%**, *0.02*; **~5%**, *0.0003*
As (total)	ICP; FIAS; ZGFAAS	**2%**, *0.02*; **1-2%,** *0.0002*; **5%**, *0.003*
As (III)	FIAS	**~10%,** *0.001*
δ^2H	ISOT1	**1 per mil**[2]
$\delta^{18}O$	ISOT2	**0.1 per mil**[2]
DOC	DOC	**1-2%***, 0.1*

[1]relative standard deviation expressed in percent (100 × standard deviation ÷ mean)
[2]these values are expressions of precision, rather than rsd, of pH and isotope determinations; accuracy of pH determinations cannot be considered better than ±0.025 pH units

Table 11. Explanation of methods of analysis

Descriptor	Species Determined	Equipment Used	Reference(s) or comments
COLOR1	H_2S	Hach model DR-2000 UV-Vis absorption spectrometer and Hach method # 8131 reagents	Method based on APHA (1985)
COLOR2	NH_4	Alpkem model RFA-300 flow injection analyzer	Solorzano (1969), Antweiler and others (1996)
COLOR3	Fe(II) and Fe(total)	Hewlett-Packard model 8452A diode array spectrometer with 1 and 5 cm cells	Ferrozine method (Stookey, 1970)
COLOR4	NO_2	Hewlett-Packard model 8452A diode array spectrometer with 1 and 5 cm cells	U.S. Geological Survey (1984), Antweiler and others (1996)
COND	Spec Cond	Orion Research model 126 meter	Automatic temperature correction, conductance check with 0.0100 N KCl
DOC	DOC	Oceanography International Model 700 TOC Analyzer	Wet oxidation method (Aiken, 1992)
EC1	Eh	Orion Research model 96-78-00 Pt electrode	Electrode checked using ZoBell's solution (ZoBell, 1946; Nordstrom, 1977) at the sample temperature
EC2	D.O.	Orion Research model 840 DO meter and probe	Automatic sample temperature and barometric pressure correction
EC3	F^-	Orion Research model 96-09 combination F^- electrode	Barnard and Nordstrom (1980)
FAAS, FAES	Na and Li (FAAS) and K (FAES)	Perkin-Elmer AAnalyst 300 flame atomic absorption spectrometer with air/acetylene flame, single-slot burner head, and continuum background correction, in absorption (Li, Na) or emission (K) mode	1000 mg/L Cs ionization buffer.
FIAS	As(total) and As(III)	Perkin-Elmer AAnalyst 300 atomic absorption spectrometer in absorption mode with a FIAS-100 flow injection analysis system hydride generator, quartz cell, and furnace	Pre-reduction of As(V) using KI +ascorbic acid + HCl

Table 11. Explanation of methods of analysis--Continued

Descriptor	Species Determined	Equipment Used	Reference(s) or comments
IC1	F^-, Cl^-, SO_4^{2-} and Br^-	Dionex model 2010i ion chromatograph with AG4A guard and AS4A separator columns and an Anion Micromembrane Suppressor-II column	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent
IC2	$S_2O_3^{2-}$	Dionex model 2010i ion chromatograph with two AG4A guard columns and AS4A separator column and an Anion Micromembrane Suppressor-II column	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent
IC3	NH_4	Dionex model DX-300 ion chromatograph with CS12A IonPac column and 22 mN H_2SO_4 eluent	Analysis performed on year-old samples preserved in 1% HCl
IC4	NH_4	Dionex model DX-300 ion chromatograph with CS12A IonPac column and 50 mN H_2SO_4 eluent	Analysis performed on samples preserved with 1:9 H_2SO_4 within a week of collection
ICP	Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe(total), K, Li, Mg, Mn, Na, Ni, Pb, Se, Si, Sr, V, Zn	Leeman Labs Direct Reading Echelle, dual view, sequential, multi-element, inductively coupled plasma spectrometer. Hildebrand grid nebulizer and glass Scott spray chamber.	Analytical wavelengths - nanometers: Al: 308.25 Li: 670.80 As: 188.98 Mg: 279.08 B: 249.68 Mn: 257.61 Ba: 455.40 Na: 589.59 Be: 313.04 Ni: 231.60 Ca: 315.90 Pb: 220.35 Cd: 214.44 Se: 196.03 Co: 228.62 Si: 251.60 Cr: 206.142 Sr: 421.60 Cu: 324.75 V: 292.40 Fe: 238.20 Zn: 206.20 K: 766.46
ISOT1	δ^2H	V.G. Micromass model 602 mass spectrometer	Coplen and others (1991). Standardization against VSMOW (δ^2H = 0 per mil) and SLAP (δ^2H = -428 per mil)
ISOT2	$\delta^{18}O$	DuPont model 21-491 mass spectrometer	Epstein and Mayeda (1953). Standardization against VSMOW ($\delta^{18}O$ = 0 per mil) and SLAP ($\delta^{18}O$ = -55.5 per mil)

Table 11. Explanation of methods of analysis--Continued

Descriptor	Species Determined	Equipment Used	Reference(s) or comments
pH	[H^+]	Orion Research model SA 250 meter, Orion Ross combination electrode or Orion Resesarch model 1230 multi-parameter meter with pH triode	Two buffer calibration at sample temp. using 10.00, 7.00, 4.01, and 1.68 pH buffers
TITR1, TITR2	Alkalinity (as mg/L HCO_3) and acidity (total)	Orion Research model 960/940 autotitrator, potentiometric detection	Fishman and Friedman (1989)
ZGFAAS	Cd, As, Ni, Pb, Se	Perkin-Elmer model 4110ZL graphite furnace atomic absorption spectrometer, with pyrolytically coated graphite platform cell and Ar purge gas	Analytical wavelength, nm: Cd: 228.8 As: 193.7 Ni: 232.0 Pb: 283.3 Se: 196.0 Atomization temp., ºC: Cd: 1400 As: 2000 Ni: 2300 Pb: 1500 Se: 1900 Matrix modifier: Cd: $NH_4H_2PO_4$ / $Mg(NO_3)_2$ As: Pd / $Mg(NO_3)_2$ Ni: None Pb: $NH_4H_2PO_4$ / $Mg(NO_3)_2$ Se: Pd / $Mg(NO_3)_2$

Table 12. Measurements of standard reference water samples [s, sample standard deviation]

Analyte	Analytical Method	USGS SRWS	n	Measured concentration mg/L	Measured concentration s	Most probable value mg/L	Most probable value s
Al	ICP	69	5	0.60	0.02	0.62	0.137
Al	ICP	T143	2	<0.06	---	0.022	0.008
Al	ICP	T149	2	<0.06	---	0.0355	0.009
Al	ICP	T153	10	<0.06	---	0.035	0.005
Al	ICP	T155	4	0.062	0.03	0.066	0.009
Al	ICP	T159	11	<0.06	---	0.032	0.004
As(T)	ICP	67	9	<0.05	---	0.0175	0.0043
As(T)	ICP	69	5	<0.05	---	0.012	0.0018
As(T)	FIAS	AMW4	16	0.172	0.002	0.168	0.03
As(T)	ICP	T143	2	<0.05	---	0.0152	0.00012
As(T)	FIAS	T143	6	0.016	0.0002	0.0152	0.00012
As(T)	ICP	T149	2	<0.05		0.00098	0.00056
As(T)	FIAS	T149	6	0.0009	0.0001	0.00098	0.00056
As(T)	ICP	T153	10	<0.05	---	0.0005	0.00024
As(T)	ICP	T155	4	0.051	0.01	0.0329	0.0028
As(T)	FIAS	T155	6	0.034	0.001	0.0329	0.0028
As(T)	ICP	T159	11	<0.05	---	0.0284	0.0016
As(T)	FIAS	T159	24	0.027	0.0002	0.0284	0.0016
B	ICP	67	9	0.048	0.02	---	---
B	ICP	69	5	0.118	0.001	---	---
B	ICP	T143	1	0.028	---	0.035	0.0052
B	ICP	T149	2	0.124	0.03	0.128	0.01
B	ICP	T153	10	0.113	0.02	0.099	0.0074
B	ICP	T155	4	0.106	0.01	0.094	0.0042
B	ICP	T159	11	0.028	0.006	0.0264	0.003
Ba	ICP	67	9	0.222	0.1	0.219	0.045
Ba	ICP	69	5	0.036	0.0004	0.043	0.022
Ba	ICP	T143	2	0.077	0.009	0.0819	0.0045
Ba	ICP	T149	2	0.040	0.007	0.0425	0.0025
Ba	ICP	T153	10	0.198	0.003	0.184	0.008
Ba	ICP	T155	4	0.021	0.001	0.0218	0.0011
Ba	ICP	T159	11	0.040	0.0004	0.038	0.0019
Be	ICP	67	9	0.047	0.005	0.044	0.0032
Be	ICP	69	5	0.034	0.001	0.0318	0.0038
Be	ICP	T143	2	0.006	0.003	0.0085	0.00066
Be	ICP	T159	11	0.011	0.001	0.0108	0.0004

Table 12. Measurements of standard reference water samples – Continued

				Measured concentration		Most probable value	
Analyte	Analytical Method	USGS SRWS	n	mg/L	s	mg/L	s
Ca	ICP	T143	2	53	0.6	53.7	2.2
Ca	ICP	T149	2	42	0.7	42.3	1.9
Ca	ICP	T153	10	28	0.3	27.5	1.0
Ca	ICP	T155	4	43	1.0	42	1.9
Ca	ICP	T159	11	26	0.4	25.5	0.8
Cd	ICP	67	9	0.009	0.003	0.0095	0.0023
Cd	GFAAS	67	12	0.010	0.0006	0.0095	0.0023
Cd	ICP	T143	2	0.019	0.003	0.019	0.0015
Cd	ICP	T149	2	0.002	0.001	0.00218	0.0003
Cd	GFAAS	T149	17	0.002	0.00003	0.00218	0.0003
Cd	ICP	T153	10	0.017	0.0005	0.016	0.0011
Cd	ICP	T155	4	0.012	0.001	0.0114	0.0008
Cd	ICP	T159	11	0.026	0.0006	0.024	0.0016
Cl	IC	M6	2	16	0.1	13.1	0.7
Cl	IC	M102	1	42	---	44	2
Cl	IC	M136	3	94	3	92	2.5
Cl	IC	M140	44	25.5	0.6	25.8	1.4
Cl	IC	M150	3	18	1	17.0	1.5
Co	ICP	67	9	0.012	0.002	0.0116	0.0022
Co	ICP	69	5	0.011	0.002	0.0141	0.0041
Co	ICP	T143	2	0.015	0.004	0.017	0.0012
Co	ICP	T155	4	0.027	0.003	0.027	0.0016
Co	ICP	T159	11	0.013	0.003	0.0133	0.0009
Cr	ICP	67	9	0.026	0.009	0.0277	0.0064
Cr	ICP	69	5	0.002	0.001	0.005	0.0031
Cr	ICP	T143	2	0.036	0.005	0.037	0.0026
Cr	ICP	T149	2	0.048	0.007	0.0488	0.0029
Cr	ICP	T153	10	0.014	0.001	0.0149	0.0011
Cr	ICP	T153	10	0.014	0.001	0.0149	0.0011
Cr	ICP	T155	4	0.008	0.0005	0.00849	0.00078
Cr	GFAAS	T155	15	0.008	0.0003	0.00849	0.00078
Cr	ICP	T159	11	0.028	0.001	0.0268	0.0018
Cr	GFAAS	T159	10	0.025	0.001	0.0268	0.0018

Table 12. Measurements of standard reference water samples – Continued

Analyte	Analytical Method	USGS SRWS	n	Measured concentration mg/L	s	Most probable value mg/L	s
Cu	ICP	67	8	0.062	0.01	0.027	0.0064
Cu	ICP	69	5	0.300	0.01	0.297	0.018
Cu	GFAAS	T93	3	0.029	0.0007	0.0306	0.0036
Cu	ICP	T143	2	0.015	0.003	0.0223	0.0019
Cu	ICP	T149	2	0.006	0.003	0.008	0.00121
Cu	ICP	T153	10	0.023	0.002	0.024	0.0015
Cu	ICP	T155	4	0.039	0.01	0.038	0.0024
Cu	ICP	T159	11	0.035	0.003	0.0334	0.0025
Cu	GFAAS	T159	5	0.031	0.0021	0.0334	0.0025
F	IC	M6	4	0.84	0.07	0.85	0.06
F	IC	M102	7	0.81	0.06	1.1	0.1
F	IC	M136	2	0.90	0.04	1.04	0.07
F	IC	M140	9	0.53	0.02	0.53	0.037
F	IC	M150	2	0.92	0.02	1.00	0.07
Fe(T)	ICP	67	9	0.720	0.2	0.76	0.045
Fe(T)	ICP	69	5	0.183	0.02	0.223	0.033
Fe(T)	FerroZine	69	1	0.243	---	0.223	0.033
Fe(T)	FerroZine	AMW4	3	191	6	188	12
Fe(T)	ICP	T143	1	0.218	---	0.222	0.014
Fe(T)	FerroZine	T143	2	0.227	0.000	0.222	0.014
Fe(T)	ICP	T153	10	0.062	0.023	0.075	0.0059
Fe(T)	ICP	T155	4	0.087	0.003	0.088	0.0063
Fe(T)	FerroZine	T155	1	0.088	---	0.088	0.0063
Fe(T)	ICP	T159	10	0.050	0.009	0.0489	0.0062
K	FAAS	70	4	3.0	0.2	2.82	0.26
K	ICP	T143	2	2.4	0.1	2.50	0.21
K	ICP	T149	2	1.9	0.1	2.00	0.14
K	ICP	T153	10	1.6	0.1	1.60	0.11
K	ICP	T155	4	4.9	0.1	5.64	0.34
K	FAAS	T155	10	5.7	0.1	5.64	0.34
K	ICP	T159	11	1.8	0.1	1.52	0.13

Table 12. Measurements of standard reference water samples – Continued

Analyte	Analytical Method	USGS SRWS	n	Measured concentration mg/L	Measured concentration s	Most probable value mg/L	Most probable value s
Li	ICP	67	9	0.554	0.1	0.627	0.045
Li	ICP	69	5	0.433	0.02	0.397	0.031
Li	ICP	T143	2	0.024	0.005	0.018	0.0021
Li	ICP	T149	2	0.045	0.001	0.0442	0.0032
Li	ICP	T153	10	0.061	0.003	0.053	0.0036
Li	ICP	T155	4	0.034	0.002	0.0332	0.003
Li	FAAS	T155	7	0.038	0.001	0.0332	0.003
Li	ICP	T159	11	0.011	0.002	0.009	0.0019
Mg	ICP	T143	2	10	0.1	10.4	0.5
Mg	ICP	T149	2	13	2	13.1	0.7
Mg	ICP	T153	10	8.9	0.1	8.72	0.3
Mg	ICP	T155	4	11	0.7	11.1	0.4
Mg	ICP	T159	11	5.6	0.2	5.6	0.21
Mn	ICP	67	9	0.56	0.1	0.571	0.032
Mn	ICP	69	5	0.23	0.001	0.224	0.012
Mn	ICP	T143	2	0.012	0.007	0.0182	0.0019
Mn	ICP	T149	2	0.006	0.008	0.0118	0.001
Mn	ICP	T153	10	0.075	0.003	0.0745	0.0033
Mn	ICP	T155	4	0.051	0.003	0.0509	0.0024
Mn	ICP	T159	11	0.021	0.004	0.022	0.002
Na	FAAS	70	4	4.7	0.1	4.78	0.36
Na	ICP	T143	2	31	2	34	1.6
Na	ICP	T149	2	40	4	42.8	2.7
Na	ICP	T153	10	29	0.5	28.7	1
Na	ICP	T155	4	28	1	28.4	1
Na	FAAS	T155	4	28	1	28.4	1
Na	ICP	T159	11	104	2	100	4
Ni	ICP	67	9	0.004	0.005	0.0096	0.0076
Ni	ICP	69	5	0.015	0.002	0.0184	0.0074
Ni	ICP	T143	2	0.068	0.009	0.071	0.005
Ni	ICP	T149	2	0.028	0.008	0.0312	0.0022
Ni	ICP	T153	10	0.036	0.002	0.0322	0.0021
Ni	ICP	T155	4	0.008	0.001	0.0083	0.00146
Ni	ICP	T159	11	0.025	0.003	0.0222	0.0016

Table 12. Measurements of standard reference water samples – Continued

				Measured concentration		Most probable value	
Analyte	Analytical Method	USGS SRWS	n	mg/L	s	mg/L	s
Pb	ICP	67	9	0.007	0.006	0.0051	0.0037
Pb	ICP	69	5	0.016	0.007	0.0232	0.0164
Pb	ICP	T143	2	0.074	0.005	0.0834	0.0071
Pb	ICP	T149	2	0.007	0.006	0.00884	0.00117
Pb	GFAAS	T149	6	0.009	0.001	0.00884	0.00117
Pb	ICP	T153	10	0.046	0.007	0.0462	0.003
Pb	ICP	T155	4	0.020	0.002	0.0188	0.0017
Pb	GFAAS	T155	5	0.020	0.0005	0.0188	0.0017
Pb	ICP	T159	11	0.014	0.006	0.0166	0.0012
Sb	GFAAS	T153	5	0.027	0.0009	0.0257	0.0025
Sb	GFAAS	T155	4	0.017	0.0005	0.0168	0.0021
Se	ICP	T143	2	<0.05	---	0.00963	0.00164
Se	ICP	T149	2	<0.05	---	0.0021	0.0008
Se	ICP	T153	10	<0.05	---	0.009	0.0013
Se	ICP	T155	4	<0.05	---	0.00828	0.00128
Se	ICP	T159	11	<0.05	---	0.00549	0.00083
SiO_2	ICP	T143	2	21	0.7	23.4	1.7
SiO_2	ICP	T149	2	11	1	11.8	0.7
SiO_2	ICP	T153	10	5.9	0.2	5.79	0.22
SiO_2	ICP	T155	4	10	0.4	10.2	0.5
SiO_2	ICP	T159	11	12	0.5	11.5	0.7
SO_4	IC	M6	2	78	1	74.5	2.8
SO_4	IC	M102	1	432	---	420	16
SO_4	IC	M136	5	155	3	150	6
SO_4	IC	M140	52	153	3	150	7
SO_4	IC	M150	2	5.2	0.02	5.5	0.54
Sr	ICP	67	9	0.413	0.08	0.375	0.048
Sr	ICP	69	5	0.635	0.01	0.612	0.052
Sr	ICP	T143	2	0.281	0.03	0.306	0.015
Sr	ICP	T149	2	0.312	0.04	0.331	0.017
Sr	ICP	T153	10	0.323	0.003	0.311	0.013
Sr	ICP	T155	4	0.355	0.009	0.363	0.014
Sr	ICP	T159	11	0.192	0.003	0.190	0.007

Table 12. Measurements of standard reference water samples – Continued

Analyte	Analytical Method	USGS SRWS	n	Measured concentration mg/L	Measured concentration s	Most probable value mg/L	Most probable value s
V	ICP	T149	2	0.047	0.005	0.031	0.0028
V	ICP	T153	10	0.017	0.001	0.019	0.001
V	ICP	T155	4	0.027	0.01	0.0254	0.001
V	ICP	T159	11	0.013	0.001	0.014	0.0017
Zn	ICP	67	9	0.016	0.005	0.017	0.008
Zn	ICP	69	5	0.028	0.003	0.028	0.0079
Zn	ICP	T143	1	0.022	---	0.020	0.0022
Zn	ICP	T149	1	0.006	---	0.0058	0.00215
Zn	ICP	T153	10	0.072	0.007	0.0726	0.0051
Zn	ICP	T155	4	0.058	0.004	0.0587	0.0041
Zn	ICP	T159	11	0.019	0.003	0.0192	0.0019

APPENDIX 2

ACTIVITY OF THERMAL FEATURES OF NORRIS GEYSER BASIN, 1998

Activity of Thermal Features of Norris Geyser Basin, 1998

By Smokey Sturtevant

INTRODUCTION

Many of the thermal features of Norris Geyser Basin were surveyed during the 1990s, and changes in their water temperature and pH were monitored. This section consists of three tables (table 13-15) containing narrative descriptions of activity, appearance, pH, and temperature of these features from March through October 1998.

ANALYTICAL METHODS

Temperature and pH were measured using an Orion Model SA-250 pH/temperature meter. At sites where probes from this instrument could not be immersed in the feature because of distance or safety concerns, temperature only was measured using a Fluke Series 50 thermocouple and immersing in the water a J type probe attached to a 7-m extendable pole. This probe was factory-recalibrated annually. The pH meter and electrode were recalibrated after each reading. The electrode was cleaned well with reverse osmosis/distilled water in the office, and transported in reverse osmosis/distilled water in its protective case. At a thermal feature, the pH meter and electrode were calibrated with pH 7 and 4 buffers, using Orion "single use packet" buffers and automatic temperature compensation. Temperature and pH of the feature were measured, allowing the meter to equilibrate and lock. The measurement step was repeated while recording the initial reading. When the meter locked the second time, the two readings were compared. If the difference in readings was greater than 2 percent, the calibration and measurement steps were repeated.

Table 13. Temperature, pH, and activity of thermal features in Porcelain Basin

Feature Name	pH	Temperature [°C]	Comments
Boardwalk Intersection Area	---	---	This area showed little change in activity throughout the season. The steam vents near the original Black Growler vent increased their output and migrated a bit further under the boardwalk. The small red colored “sizzler” to the right of the boardwalk and below the old road had a temperature of 90.0°C.
Locomotive Spring	1.5	92.0	Variable activity, flow/overflow from different vents changed regularly. Extension under boardwalk and on north increased. Larger hole circumference under bridge expanded about 15 cm and depth about 200 cm. Temperature increased in March then stabilized near 38.4°C
Vermilion Spring “Red Vent”	1.6	90.0	Very dry early in the year, produced mostly heavy steam and beautiful color. Usual water levels disappeared in spring instead of late summer. Steam appeared under high pressure most of season. “White Vent” had no water for most of year. A constant, high-pressure steam release began in February and continued through late September, when some water returned to system. “WhiteVent” was boiling vigorously throughout the fall.
Congress Pool	2.2	89.5	Many variations seen. Water level was down in the spring, was relatively stable in July and August, and rose gradually into the summer and fall. Occasional heavy boiling occurred from at least five different areas in the pool. Water was muddy gray all year.
Carnegie Drill Site	5.5	91.5	Carnegie was dry and cold in March, April, and early May. Water and eruptive activity began in mid-May, with cyclic splashing on northwest side to about 45 cm. On May 30, water erupted from top of concrete cap to about three meters, with an interval of about 12 minutes and durations of 15 to 30 seconds. Height of eruptions diminished over the next month. From late June through September eruptions reached 45 to 50 cm from the top and 25 to 30 cm from the side. In early October water level dropped off and area became dry. Limited activity was observed at the northwest vent in November.

Table 13. Temperature, pH, and activity of thermal features in Porcelain Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Incline Geyser	---	95.5	Water level was high in the spring, with strong boiling and surging. Activity continued throughout most of the year. In May eruption appeared imminent, but none was observed. Water level and boiling increased in late September and remained high the rest of the year.
Unnamed Geyser northwest of Incline Geyser	---	---	This twin spouter was more active all season than in previous years, with each vent erupting from one to eight meters. Vents appeared to play individually in February and March, possibly caused by a low water level. Activity increased as the year progressed. In early October activity could be heard from the vicinity of Hurricane Vent. Twin spouts height was about 10 meters for several weeks. Noticeable deposition of red oxides was observed around the vents.
Blue Geyser	6.0	74.1 to 88.7	Exceptionally quiet this year, with water level down about three meters into vent. Water level increased in March with slight overflow for about two weeks, then decreased. Occasional heavy boil and surge over the vent was seen periodically.
Porcelain Terraces area South of Blue Geyser	---	---	Continual change was observed in this area, and numerous small geysers exist. A few were seen throughout the season, many for only a few days. One unnamed geyser was active throughout the season, with an interval of five minutes and maximum bursts reaching about one meter in height. The colors for this area ranged from the blue of the colloids through sulfur yellows, organic pinks, and oxide reds.
Primrose Spring	---	---	Water was never observed in main vent this season. Minimal activity was observed in May from #2 vent.
Hurricane Vent	---	---	Initially inactive. In March high-pressure steam discharged from a vent on northeast side of crater. Eruption was observed in June. Steam issued from vent for about 45 seconds, followed by discharge of water from a hole about two meters below the steam vent that drained into the crater. Water phase lasted 40 to 52 seconds, then steam phase and water ceased. Eruption occurred at intervals of 49 minutes to over 6 hours. Eruptions consisted of either a single eruption or a series of four eruptions approximately two minutes apart.
Sunday Geyser	3.7	63.0	No eruptive activity was observed from this feature, only light bubbling.

Table 13. Temperature, pH, and activity of thermal features in Porcelain Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Arsenic Geyser	4.6	91.0	The pH increased significantly from a value of 3.4 in 1995. Little activity observed. Eruptions were less powerful than in previous years, with height reaching only about one meter and no strong surging toward the end of the eruptions.
"Moxie" Geyser	---	32	Dry most of the year, with a small amount of water appearing in the vent in October.
Lava Pool Complex	2.6	61.7	No eruptions were observed in Lava Pool. Water level fluctuated less than last year. Coloration changed slightly. Color was reddish in the spring, and yellow in September. Complex #1 erupted to a height of 25 to 50 cm occasionally. Number 2 erupted occasionally to a height of 10 to 25 cm, and #3 erupted regularly to a height occasionally reaching 3 m.
Pinto Geyser	---	---	Last recorded eruption prior to this year was September 9, 1971. First eruption observed this year was February 4 at 13:41. Eruptions would start with pool slowly filling, similar to Echinus Geyser. Center of vent would surge and bubbles would break the surface. Then surging and splashes reaching around five meters occurred. Eruptions lasted 5 to 6 minutes, then vent would drain rapidly. Interval between eruptions ranged from 1.5 to 3 hours.
Fireball Geyser	7.5	92.0	Considerable activity. Intervals from 1 hr 14 min to 6 hr 55 min with durations from 5 to 84 min. Weaker eruptions in early spring, with height of 4 to 6 m and little surging at the end. By June activity stronger, with surging bursts to nearly 10 m. Activity decreased and intervals lengthened in September. Eruption intervals in October and November were fairly regular at about 2 hr with eruptions to heights of 9 to 11 m lasting 7 to 9 min.
Fan Geyser	---	---	No activity observed in 1998
Constant Geyser	3.5	90.0	Eruptions consisted of several bursts reaching about 13 meters in June, with mostly single and double bursts. Only a few three- and four-burst eruptions observed.
Whirligig Geyser	3.0	91.2	A few eruptions observed in spring, then quiet until an eruption was observed in July. A few more eruptions were observed in August and early October. By late October interval was steady near 8 hr. In November intervals were about 5 hr.
Little Whirligig	---	---	This feature appears to be dormant.

Table 13. Temperature, pH, and activity of thermal features in Porcelain Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Pinwheel and Splutter Pot Geysers		44 to 50	Both of these features receive water from Sieve Lake and Sand Spring. There was no activity from either of these features.
Scummy Pool	3.4	84.1	Pale blue color that was acquired in 1994 remains. Little activity of note.
“Scummy's Drain”	---	---	Received considerable water from Scummy Pool.
Basin Geyser	4.8	80.0 to 90.1	No eruptive activity was observed, however some water level and temperature changes occurred. Main activity was heavy boiling near east vent.
Jetsam Pool	2.8	59.5	No eruptive activity observed. Breakout of “Little Growler” this spring did not cause any changes in the waters of Jetsam, even though “Little Growler” is on the western edge of Jetsam. Apparently, there is no connection between the two.
“Little Growler”		94.7 to 96.9	This series of vents broke out in March. Main vent is located at eastern edge of Jetsam Pool and angled toward Ledge Geyser. A large crack system of vents extends along the rim of Jetsam Pool for about 15 meters. High-pressure steam released from this feature could be heard above Crackling Lake and from the museum.
Ledge Geyser	---	---	Quiet this season. In March water level dropped and Main Vent was dry. Surging from the Finger Vents was observed and the Hillside Vent splashed all year. There was algal growth in the runoff from the Hillside Vent down into Palm Pool. Water was observed in the system in September, but no organized activity or eruptions were observed.
Black Growler Steam Vent	---	109.3	Strong steam releases observed, with periodic increases in steam pressure and noise. Late in the season water level increased and large amounts of dark mud were splashing onto the hill above Ledge Geyser.
Guardian Geyser	5.0	96.2	Comparatively quiet this year. Only four eruptions were observed, two in February, one in August and one in November.
Valentine Geyser	---	90.0	No observed or recorded eruptions. Markers placed in 1996 are still in place.
New feature above Valentine Alcove	---	---	Sometime between 19:00 September 24 and 07:00 September 25, a new mud spring broke out above the Valentine Alcove, approximately 7 m northwest of the pathway. There was evident heavy overflow. It filled and overflowed slightly on September 27.

Table 13. Temperature, pH, and activity of thermal features in Porcelain Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Dark Cavern Geyser	5.6	92.0	A few eruptions occurred in March and April, with activity increasing in June - August. Intervals between eruptions 14 to 20 hr. Eruptions were powerful and loud, and durations between 5 and 14 min, much water ejected early in eruption. Eruptions ended with a strong, noisy, splashing surge. Very little indication that an eruption was imminent. Main vent would suddenly surge and fill, with secondary vent erupting strongly about 45 seconds into the eruption.
Area of Lewis Mudpots	---	---	The numerous pools and springs north of Dark Cavern/Guardian had changing activity.
Milky Complex	---	---	No unusual activity this season. Teal Blue Bubbler had a water level fluctuation in late September, and stabilized by early November.
Glacial Melt Geyser	3.4	92.0	This small (height 5 to 10 cm) geyser had fairly constant activity all year. Intervals were approximately 1 min with duration approximately 30 to 45 sec.
Crackling Lake Spring	7.5	92.5	Activity limited to surging and overflow. Build up of “terracing” continues to the north. There were temperature fluctuations in April.
Ebony/Bear Den Geysers	---	---	No activity was observed from this area.
“Wistful” Geyser	2.3	69.4	A sudden drop in pH at “Wistful” occurred in 1995, and the geyser has never recovered. Water level is down approximately one meter into the vent, and the sinter terrace is drying and becoming brittle.
Graceful Geyser	2.8	90.8	Activity increased throughout the season. Water never broke above the surface during the eruptions, but the sound and splashing were impressive.
Collapsed Cave Geyser	2.9	88.9	Heavy boiling was observed throughout the pool in the spring. By August water level had dropped about one meter and remained low through November. The small, superheated springs above Collapsed Cave were dry for most of the late season.
Northeast corner of Porcelain Basin	---	---	Several features were active. At least three active geysers and numerous acidic hot springs exist. One spring at the far north end of the area was the color of split pea soup in the spring. It turned to dirty yellow in the summer and stayed that way. The pH for most of these features was 2.5 or less.

Table 14. Temperature, pH, and activity of thermal features in Back Basin

Feature Name	pH	Temperature [°C]	Comments
Harding Geyser	---	---	No eruptive activity was observed. A small amount of water was observed in the system in June.
Steamvalve Geyser	3.2	76.5	No eruptive activity observed.
Bathtub Spring	2.4	91.2	Activity variable. Early in the season pool was full with light boiling. At times there was very little water and mostly steam was released. In August, water level was high enough that boiling splashed water out of the crater. Water level dropped again in October and remained low.
Emerald Spring	3.7	82.0	No eruptive activity was observed, but light to moderate overflow was observed all season.
Area of Dr. Allen's Paint Pots	---	---	There was no activity of significance from the 5 springs in this area.
Woodpecker Spring	4.3	88.0	Water level decreased in early June and was below vent surface for remainder of year.
Unnamed Spring above Steamboat Geyser	2.8	71.3	Some growth was observed this season. Surface was about 6 m by 4 m in March, and had grown to about 8 m by 6 m by September. Boiling remained essentially constant throughout the year. Moderate boiling over a vent toward the center of the pool occurred in October.
Steamboat Geyser	7.8	93.0	Activity consisted of occasional splashing. A rumor was started in August that Steamboat might erupt, but this never occurred. Splashing from the south vent reached 4 to 6 m above the splash zone, and the north vent had activity in October that reached 2 to 3 m.
Cistern Spring	6.2	82.6	Beautiful color, nice boil, heavy overflow and wonderful deposition. Very little changed here during the season. Since no sudden pH change occurred, the bacterial mat remained nicely colored. The overflow tended more to the west side.
Black Pit Spring	2.3	92.0	Water depth approximately 30 cm at start of season. By late July depth had decreased to a few cm in the western area. Several episodes of water level increase and decrease were observed.
Echinus Geyser	3.3 to 3.6	86.0 to 91.9	Characterized by short, weak eruptions throughout the season. Activity was similar to that observed in the 1960s and 1980s. Pool would fill to near overflowing, water would bubble over the vent, then a 3 to 6 min eruption would occur. Bursting activity was somewhat less than observed in earlier years.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Sulfur Pots	1.7	90.0	These small bubblers behind Echinus were dry and cold all of last year, and into the early part of 1998. In late June they reappeared and were active the remainder of the season. There was muddy gray flow from two vents. The south vent has a sulfur yellow rim.
Crater Spring, a.k.a. Collapsed Crater Spring	3.1	90.0	No eruptive activity this season. Water level remained low until late September, then increased by about 100 cm. Heaviest activity was from northwest vent.
Root Pool	2.8	69.3	No unusual activity.
Arch Steam Vent	---	92.0	No unusual activity.
Tantalus Geyser, a.k.a. Decker Geyser	3.0	72.0	No eruptive activity was observed. There was occasional heavier boiling from the different vents. Accurate temperature and pH readings are difficult to obtain because of the unsafe footing around the pool.
Large spring north of Dishwater Spring	2.8	62.0	Significant extension to the west was observed, breaking out several small areas near the boardwalk. Water level fluctuated throughout the season with the most dramatic change in the fall.
Dishwater Spring	3.0	77.8	Water level dropped about 75 cm in late September. Water was exceptionally clear this year.
New Mud Spring	3.0	89.5	A significant change in water level was observed.
Mystic Spring	2.8	75.0	No unusual activity was observed. The typical water level fluctuations over the year were observed.
Yellow Mud Spring	2.2	90.3	Water's color changed from light brown to a spectacular colloidal blue in the early spring, and remained this color throughout the year. Light boiling from two vents was observed.
Sizzle Pot, a.k.a. Toilet Bowl	1.7	53.7	This feature contained water only in January. Water disappeared by early February and never reappeared.
Puf 'n' Stuf	---	93.0	The only change in this feature was in the water level. Several times there was water visible along the entire length of the fissure.
Black Hermit Cauldron	2.8	86.2	Usually a lightly boiling pool of slate gray water. In November the water cleared up for a week. This had not been observed previously.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Green Dragon Spring	2.6	87.3	No unusual activity this year. The green algae growth is returning to the roof over the large vents. These all died off with the unusually high splashing that occurred during the 1993disturbance.
Grey Lakes	2.4	78.7	No unusual activity was observed here.
Grey Lakes Spring	---	32.1	Becoming more difficult to locate, because of thick grass growing around vent.
Big Alcove Spring	4.6	89.0	Big Alcove now is smaller than Little Alcove. Active almost continuously to heights of about 1 m.
Little Alcove Spring	6.0	91.9	Enlarged its vent with some very strong eruptive activity. The bursting type of eruptions slammed into south edge of vent, chipping away some of the rocks. Eruptions were erratic, reaching heights of3 to 5 m.
Phillip's Cauldron	2.1	78.5	Showed minor water fluctuations throughout the season. Activity normal. Muddy water did not change color or characteristics. Appears to be receiving considerable sedimentation from the walkway.
Hydrophane Springs area	---	---	Began year with low water level, returned to normal levels in March. Water remained colloidal blue all summer and fall. No characteristic water level drop from a disturbance occurred. Fluctuations of several cm were observed. Small vent on west side thumped loudly, but no eruptive activity was observed.
Medusa Geyser	5.4	90.2	No eruptive activity observed. Water level observed to slowly rise and overflow occasionally. Many sintered insects, dragonflies and other objects are present in the overflow area.
Recess Spring	2.7	86.8	No unusual activity was observed here.
Psychedelic Spring	---	---	A little water splashed from the vent early in March. This evaporated and the vent steamed lightly the remainder of the year.
Unnamed feature west of Recess Spring	---	---	Appeared in September 1995. Was erupting in April from largest of three vents to a height of about 1 m. Water was muddy gray and thick. Water level decreased to about 1 m below ground level in June. Minor splashing from larger vent occurred in October. No evidence of overflow from vents was observed.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Blue Mud Steam Vent	2.7	88.0	Water level remained high all year. Periods of heavy boiling over the main vent and minor bubbling from the south vent were observed. In November water filled all three vents to about 50 cm below overflow.
"Arrow Geyser"	---	---	This small geyser west of Blue Mud Steam Vent was quiet for most of the year, with some minor splashing in March and April.
Muddy Sneaker Complex	---	---	No unusual activity was observed here.
Yellow Funnel Spring	2.9	70.4	Maintained lower water level from previous year. Water remained muddy again this year. Water began to clear up for a short time in August, but became muddy again after a few weeks.
Son of Green Dragon Spring	1.9	88.1	Began year with lower water level and some eruptive activity. There was some splashing over the vent until mid-March. Water level slowly increased to nearly full by June and overflowing in September.
Unnamed spring below Son of Green Dragon	2.4	90.3	Showed no eruptive activity. Nearly full pool boiled almost continuously. In October it showed some of the "fill and drain" cycles in the same vent where this occurred in 1995.
Dabble Geyser	4.4	80.1 to 92.3	No eruptive activity this year. A few splashing episodes observed in April, May, and October.
Orby Geyser, a.k.a. Butch Geyser	---	---	No unusual activity was observed here. Most of the year the water was barely visible down in the vent.
"The Cousins"	---	---	No unusual activity was observed here. Some light steam was observed in September.
Four unnamed geysers northwest of Orby	---	---	No unusual activity was observed in this group of geysers that stretch to the northwest from Orby. The second geyser had minor splashing late in January. The deep crater geyser (Rick Hutchinson suggested the name "Xiuhtecuhbi" for this feature, the Aztec word for their God of Fire) erupted in April, May, and June, and was quiet for the remainder of the year.
Bastille Geyser	---	---	After impressive activity in 1995 and 1996, Bastille Geyser has almost completely sealed off its vent. Only light bubbling from a single 1-cm hole in the center was observed.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Unnamed Geyser north across boardwalk from Bastille	8.1	93.0	This small geyser and Bastille appear to be connected. They broke out at about the same time and are similar in pH. Had a long eruptive cycle and a short recovery interval most of the year. Cycles were 3 to 5 sec off, then on for hours. Eruption height was 100 cm or less. Temperature dropped off somewhat in October, only reaching 91.9°C. Rapid deposition of sinter is ongoing.
Area around Bastille	---	---	This area never reached the high ground temperatures seen here a few years ago. The area across the boardwalk to the east and south of Bastille was 88.2°C in September. The rest of the area varied from ambient air temperature to about 70°C.
Double Bulger, Active Vent	7.2	89.0	Inactive (north) vent T = 91.5°C at ground level. Active vent of Double Bulger was a perpetual spouter, with short periods of quiet, for most of the season, playing from a partially full crater. Activity fluctuated in strength, height ranged from 10 cm to about 50 cm. Water remained clear for entire year. water level essentially invariant in the active vent, no water observed in inactive vent.
Pearl Geyser	---	---	No unusual activity was observed here. Water filled crater over vent early in May but little eruptive activity observed. Afterward, water level dropped and remained low for most of the year. Occasionally, water half-filled vent and significant splashing over the crater rim occurred. No overflow observed.
Pork Chop Geyser	6.33	45 to 50	The pH has decreased to 6.33, water was clear. No colloidal blue/white, high-pH water that was present from 1994 through 1996 ws observed. The 45 to 50°C temperature wais lower than previously. From late September into October the water level overflowed to the south on several occasions. A few bubbles appeared over the vent, then the water level dropped. The cycle was about two hours, and was observed two to three times a day.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
"Second Erupter"	5.2	87.6 to 92.7	This is the small feature to the north of Pork Chop. Water would "burp" every second, on the second during eruption. Activity was steady when feature was active, but was observed only in May. For the remainder of the year, only a small, continuous flow was observed. A cyanobacteria mat is forming in the runoff channel.
Cyanidium Spring	2.3	82.4	Large mudflow issued from lower vent in late November, covering all Cyanidium growth in runoff channel for a few days. The Cyanidium recovered quickly with no apparent ill effects.
Vixen Geyser	---	---	Dormant all year. Water level increased in vent briefly in early October, but Vixen did not erupt.
Corporal and Dog Leg Geysers	3.8 and 3.7	88.9 and 83.6	Features are combined because of their obvious connection. Corporal was the more active of the two this season. During an eruption of Corporal, water level rises and splashes are 2 to 4 cm high. Water level drops after eruption. Water levels rise concurrently in Corporal and Dog Leg. Water disappears from Dog Leg as soon as eruption starts in Corporal. Dog Leg became a little steam vent on several occasions. A strong influx of sulfur-bearing water was observed in April. The water took on a distinctly yellow color.
Veteran Geyser	7.6	93.3	Eruptive cycles were weak early in the year. During eruption, water level rose and minor splashing from main vent and "burping" in pool occurred. After a few minutes water level decreased. By June water had appeared in fourth vent to east. Cycles became "hot" about every 20 min. Pool filled, splashing occurred, then water level dropped off, with succeeding cycles stronger. Eventually, a cycle was strong enough to trigger a large eruption. Water jetted from main vent to a height of about 10 m and third vent splashed toward trail. Pool vent surged and boiled. Water level surged in fourth vent. Eruption lasted 5 to 9 min, then entire system drained. Water then returned to the system within 20 to 40 min (one or two cycles).
Rubble Geyser	3.3	66.0	No eruptions were seen or inferred this year.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Unnamed thermal features in Tantalus Creek west of Palpitator Spring	---	---	Three active features were observed in Tantalus Creek near Recess Spring. Two features activated from old sinter cracks and vents. The third appeared to be a new feature. Two were geysers, the third flowed heavily. The taller of the two geysers reached a height of about 1 m for a few months.
Palpitator Spring	6.7	88.6	Starting with an empty crater, water level increased to heavy overflow, then palpitations started. The bubbles causing these surges occasionally reached the surface and erupted to about 10 cm. Duration of the palpitations were 1 to 4 hr. Vent then drained rapidly. Refill required 4 to 5 hr.
Fearless Geyser	5.7	92.3	Activity typical until October, when water level increased and overflowed to the west, an unusually high water level for this feature.
Mud Pots West of Fearless Geyser (a.k.a. “The Chocolate Pots”)	---	---	These small mud pots remained quiet all year.
Spiny Pebble Spring	2.3	48.5	Water level was low all season. No unusual activity seen.
Monarch Geyser	4.3 to 4.9	85.5 to 93.0	No eruptive activity this year. Light overflow and light boiling over the vents were observed most of the time. Somewhat heavier boiling was observed in October and November.
“The Thumper” (unnamed spring NW of Monarch)	4.6	88.0	Runoff from several active springs east of boardwalk washed sufficient silt into this feature to completely fill the crater. What was previously the crater is now an area of “frying pan” bubbling.
Branch Spring	2.6	91.1	Started out the season quiet; finished with heavy boiling and erratic water levels.
Minute Geyser	5.6	91.5	Remained a fairly perpetual geyser with eruption heights near 1 m for most of the season. There were pauses in activity of up to 4 min during at least three days in early April. No large eruptions observed this year. Increased activity observed in August. Drain pool to east side, which previously drained all overflow from Minute, remained full and overflowed to the south. A low water level was observed on one occasion, early in February.

Table 14. Temperature, pH, and activity of thermal features in Back Basin – Continued

Feature name	pH	Temperature [°C]	Comments
Rediscovered Geyser	---	---	Only deep boiling was observed; no water was seen.
“Acute Spouter”	5.6	90.8	Minor activity reached a height of about 30 cm. No interval or duration data were recorded.

Table 15. Temperature, pH, and activity of thermal features in One Hundred Spring Plain

Feature Name	pH	Temperature [°C]	Comments
Opalescent Spring (Temp°C, pH	5.7	. 89.8	Although is probably part of Porcelain Basin, Opalescent Spring is included here as the “break” between Porcelain Basin and 100 Spring Plain. Had significant overflow and sinter deposition. Small terraces in runoff showed substantial growth.
Receptacle Spring	---	---	No unusual activity was observed this season.
New Spring Northeast of Receptacle Spring	---	---	No further activity observed since spring broke out in 1995. Ground heating continues to spread to the east. Many trees have died because of this heat.
Rock Spring	4.8	90.2	Remained active all season, with occasional water level fluctuations. Water remained clear.
Unnamed spring on hillside Northeast of Rock Spring	2.5	87.8	This spring was observed flowing heavily in April, June, and September.
“Amethyst Geyser”	2.8	84.8	No activity was observed. Some changes in the heat and small frying pan activity around the vent were observed. Water level increase in October filled crater area.
Ledge Spring	2.6	85.9	Activity erratic. Water levels from 1 m below the rim to heavy overflow with boiling to heights of 400 to 500 cm were observed.
Large mud pot between Ledge Spring and Realgar Spring	---	---	Stayed very wet, but without the thick mud ejection observed in 1997.
Realgar Spring	2.4	47.0	No indication of the realgar color that this spring was named for. Sulfur strands and coloration are prominent.
“Fracture Spouter”	3.4	92.3	Active area has moved to the north, south end of spring is less active and cooler. Heavy boiling and superheated (93.7°C) temperatures were measured in the north vent on two occasions.
Sulfur Dust Pool	2.4	46.0	No unusual activity was observed here this season.
Horseshoe Spring	0.67	90.5	This spring has the lowest measured pH in the Park. The pH increased slightly in October to 0.73.
Unnamed geyser across Tantalus Creek from Cinder Pool	2.3	91.5	Activity was continuous early in the year. In June water level dropped and activity became erratic.

Table 15. Temperature, pH, and activity of thermal features in One Hundred Spring Plain – Continued

Feature name	pH	Temperature [°C]	Comments
Clear unnamed spring across Tantalus Creek from Cinder Pool	2.4	89.1	Boiled continuously and heavily all season.
Black unnamed spring north across Tantalus Creek from Cinder Pool	2.6	86.6	Boiled continuously and heavily all season.
Cinder Pool	4.1	90.0	Activity was regular. Covering of cinders fluctuated from ⅓ to ¾ of pool surface.
Verma Spring	2.8	67.5	No unusual activity observed here.
The Reservoir	3.0	33.0	No unusual activity observed here.
Unnamed spring at base of Ragged Hills west of Perpetual Spouter	2.1	93.0	Broke out in April. Coloration is white to dark red. Vents are oriented along a line running northeast. Overflow is milky gray/white. Welded phenocrysts occur around the vents.
New thermal area south of the hydrothermal explosion crater	---	---	Activity continues to spread to the east and south. Several new hot springs and mud pots are associated with this area. Several springs have superheated temperatures. Several frying-pan features have collapsed to become large, deep hot springs. Gray mud vent on west side of area has dried up. Area toward runoff channel is expanding and ground has become unstable. Close observation of this area is recommended.
Perpetual Spouter	7.3	90.5	No unusual activity observed.
Firecracker Spring	2.8	93.0	From the pH, there is little connection between Firecracker Spring and Perpetual Spouter, despite their proximity. No unusual activity was observed.
Area of Ragged Hills	---	---	Several hot springs and steam vents exist on and around the Ragged Hills; four new features were identified this season. They are scattered in different areas and will not be described individually. A NASA researcher suggested that some of the holes and depressions are from thermal reactions, while others are from glacial melting. This appears reasonable, given that some of these depressions are warm whereas many others are cold.

APPENDIX 3

PHOTOGRAPHS

99WA116, Alluvium Creek at mouth, Brimstone Basin

99WA116, Alluvium Creek at mouth, Brimstone Basin

Yong Xu at 99WA116, Alluvium Creek, Brimstone Basin

Blaine McCleskey and Yong Xu at 99WA117

Blaine McCleskey and Yong Xu (circled) at 99WA117

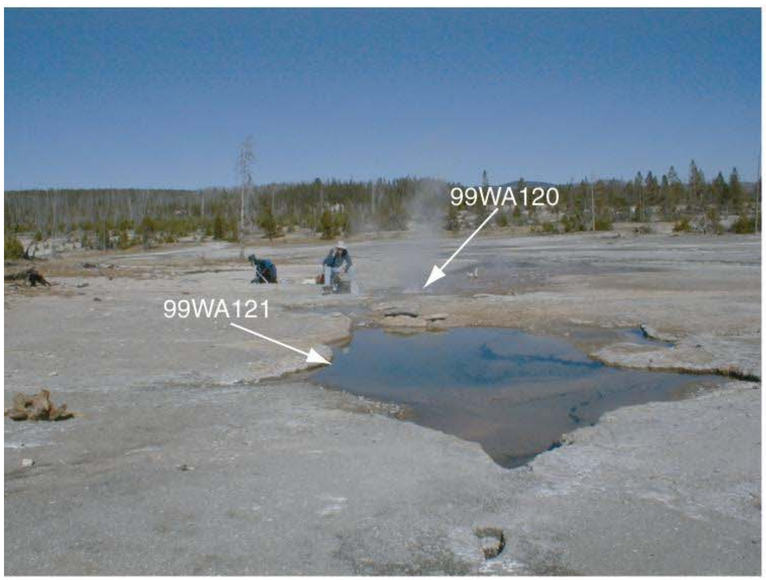
99WA117 in foreground (arrow); Philip Verplanck and Blaine McCleskey in background

Blaine McCleskey downstream from 99WA118

Closeup of 99WA118 (water source circled)

99WA119, Cinder Pool (photo taken 6/24/2000)

99WA120, "Fracture Spouter" (arrow), Realgar Springs area, 99WA121 in Background



Jim Ball at 99WA120, "Fracture Spouter" (arrow), Realgar Springs area; 99WA121 in Foreground

99WA122, Realgar Spring 3 m from sign

99WA123, Realgar Spring 20 m from sign

Jim Ball at 99WA124

99WA125, Medusa Geyser

99WA125, Medusa Geyser

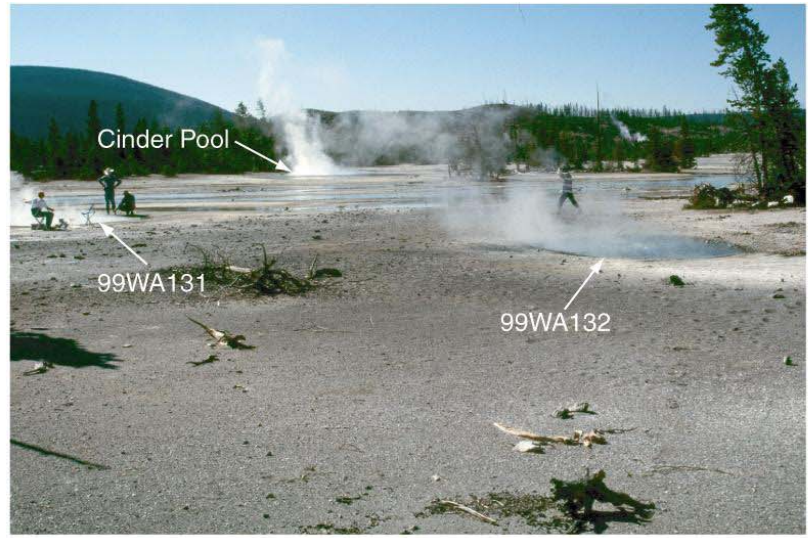
99WA126, Hydrophane Spring

99WA127, Green Dragon Spring

99WA128, Yellow Funnel Spring

99WA129, Recess Spring

John Tebby at 99WA130, Palpitator Spring, Back Basin



Blaine McCleskey, Kirk Nordstrom, Randy Mielke, and Yong Xu at 99WA131 and 99WA132

Jim Ball at 99WA131, NNW of Cinder Pool

99WA132, NNW of Cinder Pool

Blaine McCleskey, Randy Mielke, and Yong Xu at 99WA132

Kirk Nordstrom, Yong Xu, Randy Mielke, and Blaine McCleskey at 99WA132

99WA134, Tantalus Creek at weir

Kirk Nordstrom at 99WA135, Fearless Geyser


99WA136, Monarch Geyser


Kirk Nordstrom and Yong Xu at 99WA136, Monarch Geyser


99WA137, Arsenic Geyser


Drainage way of 99WA137, Arsenic Geyser

99WA138, Columbine Creek tributary above main stem confluence

Jim Ball at 99WA138

Jim Ball and NAU student Bill Stanley at 99WA141,
Tantalus Creek at 100-Spring Plain Exit

Jim Ball and Bill Stanley at 99WA142, Ragged Hills

"Titanic Spring" drainage (99WA142), Ragged Hills

Jim Ball and Bill Stanley at"Titanic Spring,
"Persnickety Geyser" in foreground

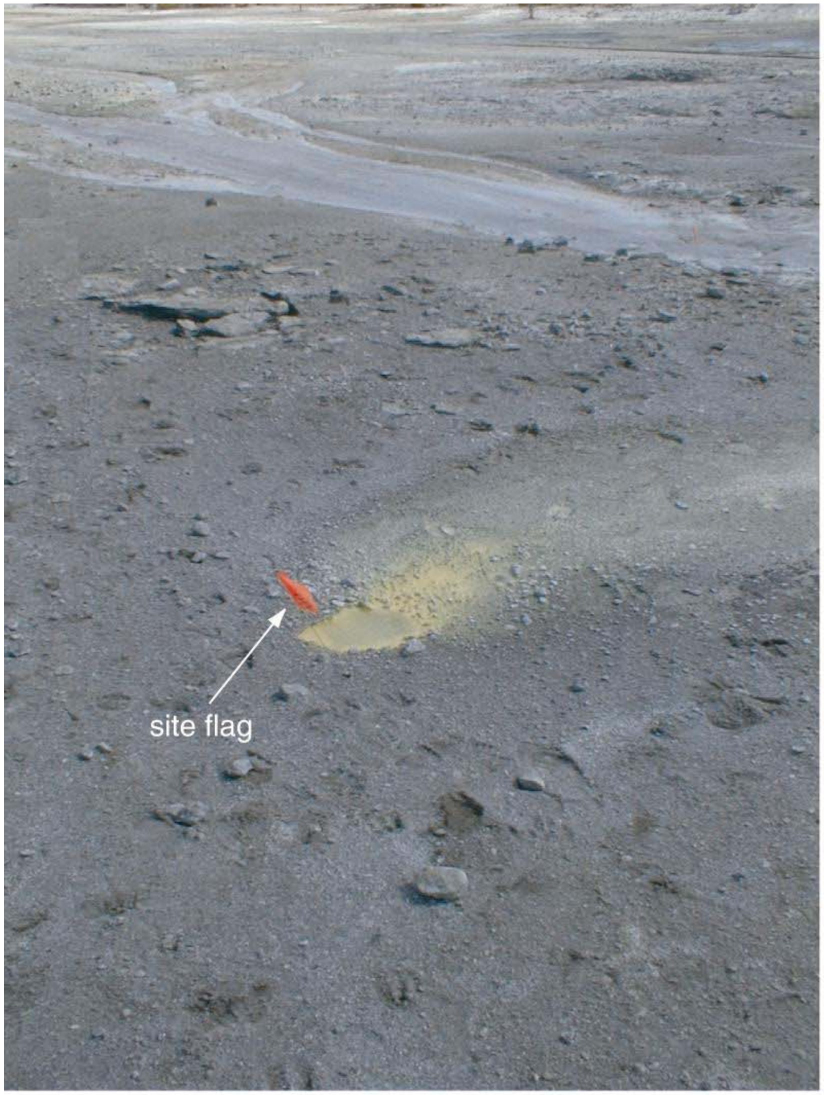
"Persnickety Geyser" (99WA143) north of 99WA142

"Persnickety Geyser" (99WA143) north of 99WA142

99WA144

99WA144

99WA144



99WA148

99WA148

"Elk Geyser" (99WA151)

Blaine McCleskey at 00WA134, "Elk Geyser"

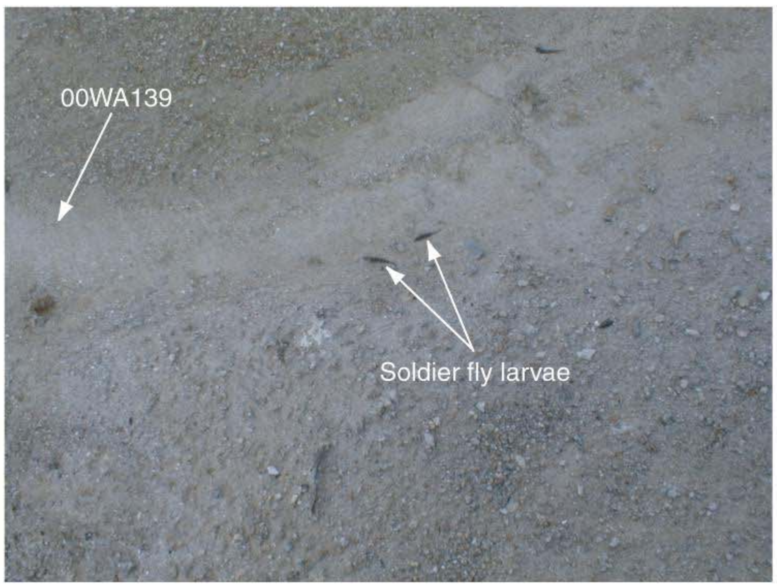
Kirk Nordstrom and Blaine McCleskey at 00WA134, "Elk Geyser"

Kirk Nordstrom at 00WA135, "Black Gassy Spring"

Blaine McCleskey at 00WA136, Perpetual Spouter

Kirk Nordstrom at 00WA137, Blaine McCleskey at Perpetual Spouter

Kirk Nordstrom at 00WA137, Blaine McCleskey at Perpetual Spouter



00WA139, Side drainage near "Elk Geyser"

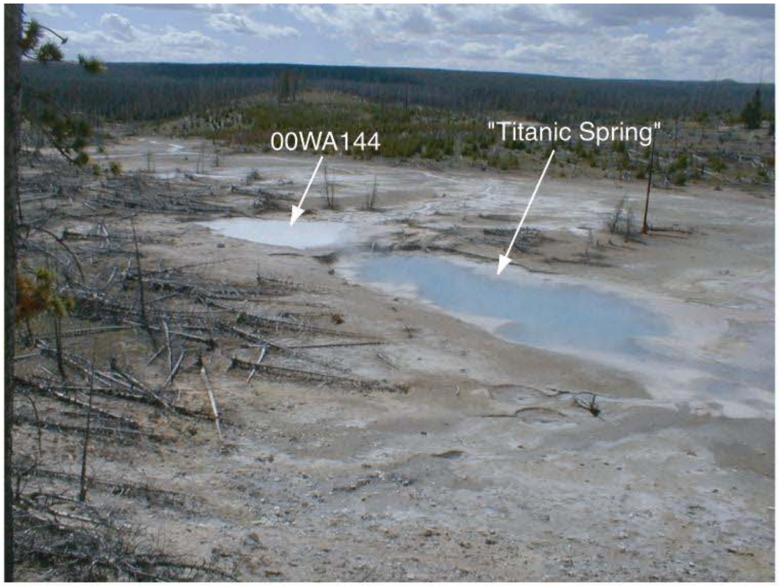
00WA140

00WA141, "Beowulf Spring"

00WA142, Minute Geyser

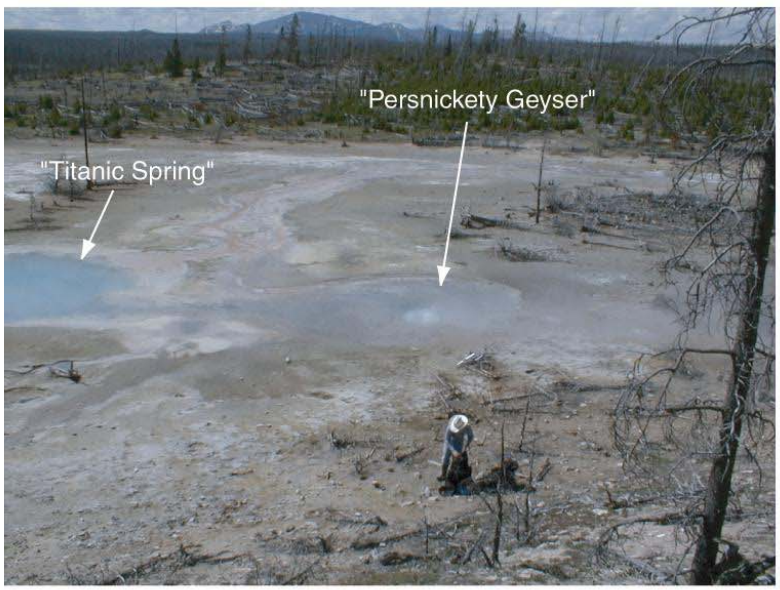
Kirk and Lars Erik Nordstrom at 00WA143, Branch Spring

00WA144, Unnamed Spring, Ragged Hills summit



Ragged Hills summit showing 00WA144 and "Titanic Spring"


"Titanic Spring" as it appeared in June of 2000



"Titanic Spring", Kirk Nordstrom at "Persnickety Geyser"


00WA145, "Persnickety Geyser"

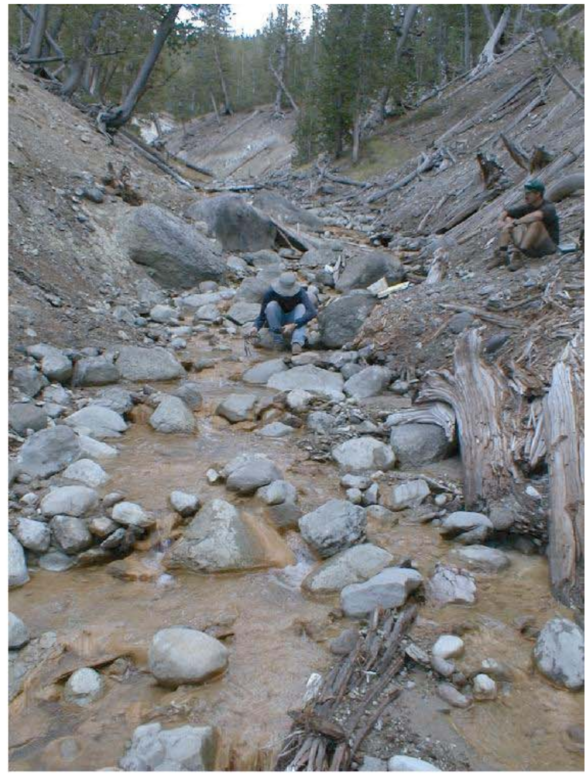
Blaine McCleskey at 00WA155

Blaine McCleskey at 00WA155

Looking downstream from 00WA155
at Blaine McCleskey and Philip Verplanck

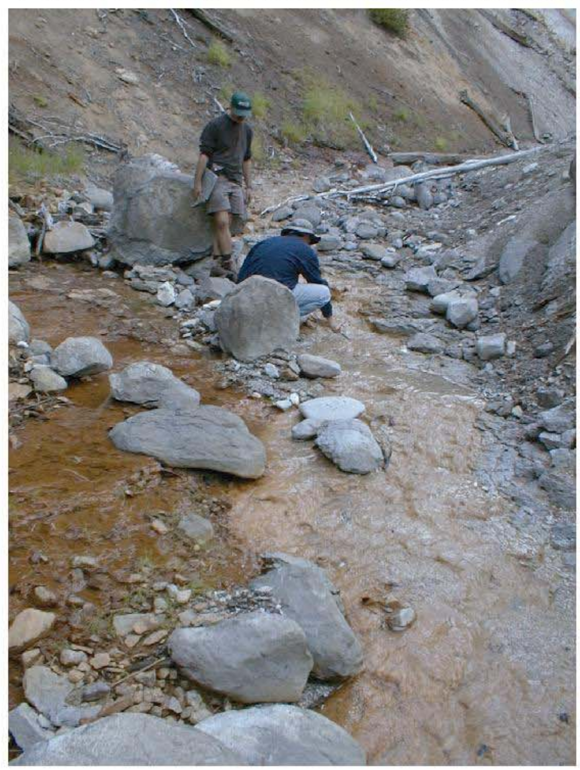
Blaine McCleskey at 1st tributary downstream of 00WA155

00WA156 looking downstream



Blaine McCleskey at 00WA156; looking upstream

Blaine McCleskey and Philip Verplanck
above 00WA156; looking toward Fe "bog"



Blaine McCleskey and Philip Verplanck
above 00WA156; Fe "bog" to left

JoAnn Holloway at 00WA158

Blaine McCleskey and JoAnn Holloway at 00WA160

JoAnn Holloway and Kirk Nordstrom at 00WA161

JoAnn Holloway and Kirk Nordstrom at 00WA162

JoAnn Holloway at 00WA163

00WA164

00WA165

00WA166