Hydrologic and Water-Quality Conditions at Newberry Volcano, Deschutes County, Oregon, 1991–95

By David S. Morgan, Dwight Q. Tanner, and Milo D. Crumrine

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97–4088

Prepared in cooperation with the
BONNEVILLE POWER ADMINISTRATION,
U.S. FOREST SERVICE, and
BUREAU OF LAND MANAGEMENT

Portland, Oregon
1997

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

For additional information contact:

District Chief
U.S. Geological Survey, WRD
10615 S.E. Cherry Blossom Drive
Portland, OR 97216
E-mail: info-or@usgs.gov
Internet: <http://oregon.usgs.gov>

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Federal Center
Denver, CO 80225-0046

CONTENTS

PLATE

[In pocket]

FIGURES

TABLES

CONVERSION FACTORS

[SI, International System of units, a modernized metric system of measurement]

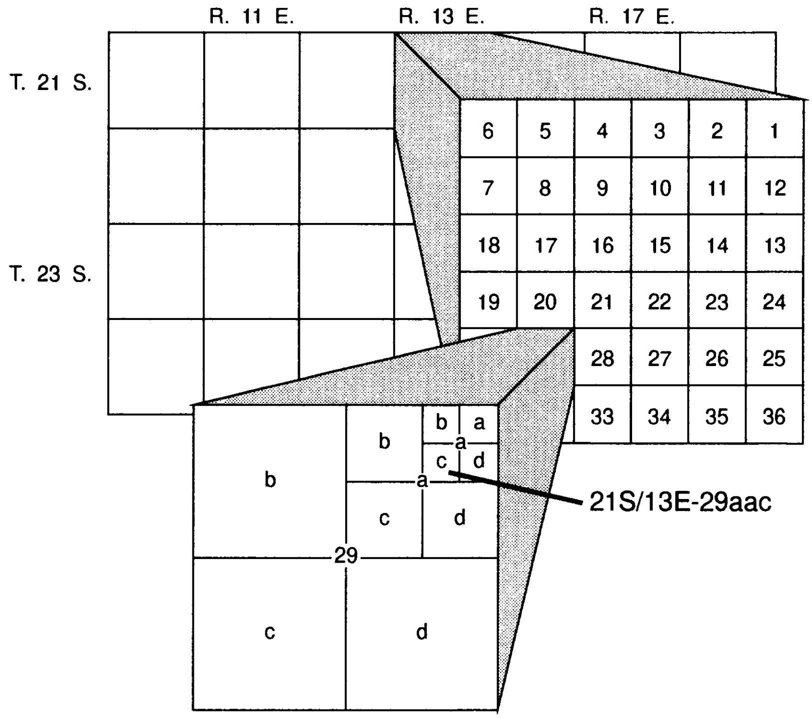
Multiply	By	To obtain
A. Factors for converting inch/pound units to SI metric units		
	Length	
inch (in)	2.54	centimeter
inch	25.4	millimeter
foot (ft)	0.3048	meter
	Area	
acre	0.4047	hectare
	Volume	
acre-foot	0.001233	cubic hectometer
	Volume per unit time (flow)	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
B. Factors for converting SI metric units to other miscellaneous units		
	Volume	
liter (L)	1.057	quart
liter (L)	0.2642	gallon
	Mass	
gram	0.03527	ounce, avoirdupois
kilogram (kg)	2.205	pound, avoirdupois
	Temperature	
degree Celsius (°C)	Temp degree F = 1.8 (Temp degree C) + 32	degree Fahrenheit (°F)
	Concentration	
milligram per kilogram mg/kg	1	parts per million
milligrams per liter (mg/L)	1	parts per million
micrograms per liter (µg/L)	1	parts per billion
nanograms per liter (ng/L)	1	parts per trillion (ppt)
nanograms per liter	0.000001	parts per million

Electrical conductivity is measured as specific electrical conductance, in units of microsiemens per centimeter (µS/cm) at 25 degrees Celsius.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based on the rectangular system for subdivision of public land. Each number-letter designation indicates the location of the well with respect to township, range, and section. Well 21S/13E-29aac is a well in T. 21 S., R. 13 E., sec. 29. Townships in that vicinity are numbered south and east of the Willamette Baseline and Meridian (for example 21S/13E). The letters indicate the location within the section; the first letter (a) identifies the quarter section (160 acres); the second letter (a), identifies the quarter-quarter section (40 acres); and the third letter (c) identifies the quarter-quarter-quarter section (10 acres). Well 29aac is in the southwest quarter of the northeast quarter of the northeast quarter of section 29, township 21 south, range 13 east (see figure below). Where more than one well is located within a 10-acre tract, a serial number is added following the letter sequence to distinguish them.



Hydrologic and Water-Quality Conditions at Newberry Volcano, Deschutes County, Oregon, 1991–95

By David S. Morgan, Dwight Q. Tanner, *and* Milo D. Crumrine

Abstract

Hydrologic and water-quality data were collected at Newberry Volcano from 1991 through 1995 as part of a program to establish baseline (predevelopment) conditions prior to construction and operation of a proposed geothermal power plant. Hydrologic data collected include hourly stage and discharge of Paulina Creek, hourly stages of East Lake and Paulina Lake, hourly meteorological data from a station near Paulina Lake, intermittent water-level measurements from nonthermal wells, intermittent and hourly water-level measurements from thermal wells, and intermittent and hourly water-level measurements from monitoring wells installed near hot springs. Water-quality data collected include major ions, nutrients, trace elements, stable isotopes and radioactivity, and field measurements of temperature, specific conductance, dissolved oxygen concentration, and alkalinity. Samples were collected at least biannually and as frequently as semiannually at some sites. Hourly measurements of specific conductance and temperature were also made on Paulina Creek.

The purpose of this report is to describe the hydrologic and water-quality conditions at Newberry Volcano, and particularly within the caldera of the volcano, during the baseline data collection period. Spatial and temporal trends in the data as well as relations between various components of the hydrologic system are identified. Comparisons are also made between hydrologic conditions and trends at Newberry Volcano and other areas during the baseline data-collection period.

INTRODUCTION

From June 1991 through October 1995, a hydrologic and water-quality data-collection program was conducted at Newberry Volcano (fig. 1) by the U.S. Geological Survey (USGS) in cooperation with the Bonneville Power Administration, U.S. Forest Service (USFS), and Bureau of Land Management. The purpose of the program was to characterize hydrologic and water-quality conditions at the volcano, principally within the caldera of the volcano, prior to development of geothermal resources. These data will be used to define baseline conditions for comparison with data collected as part of a long-term monitoring program. The collection of baseline data and the subsequent monitoring program were stipulated by the legislation that created the Newberry National Volcanic Monument in 1990 and the Geothermal Steam Act of 1970, which governs the development of geothermal resources on Federal lands. Monitoring of the hydrology and water quality of the area is also called for in the 1994 Environmental Impact Statement (U.S. Forest Service, 1994a) and Record of Decision (U.S. Forest Service, 1994b) for the Newberry Geothermal Pilot Project and in the management plan for the Monument (U.S. Forest Service, 1994c).

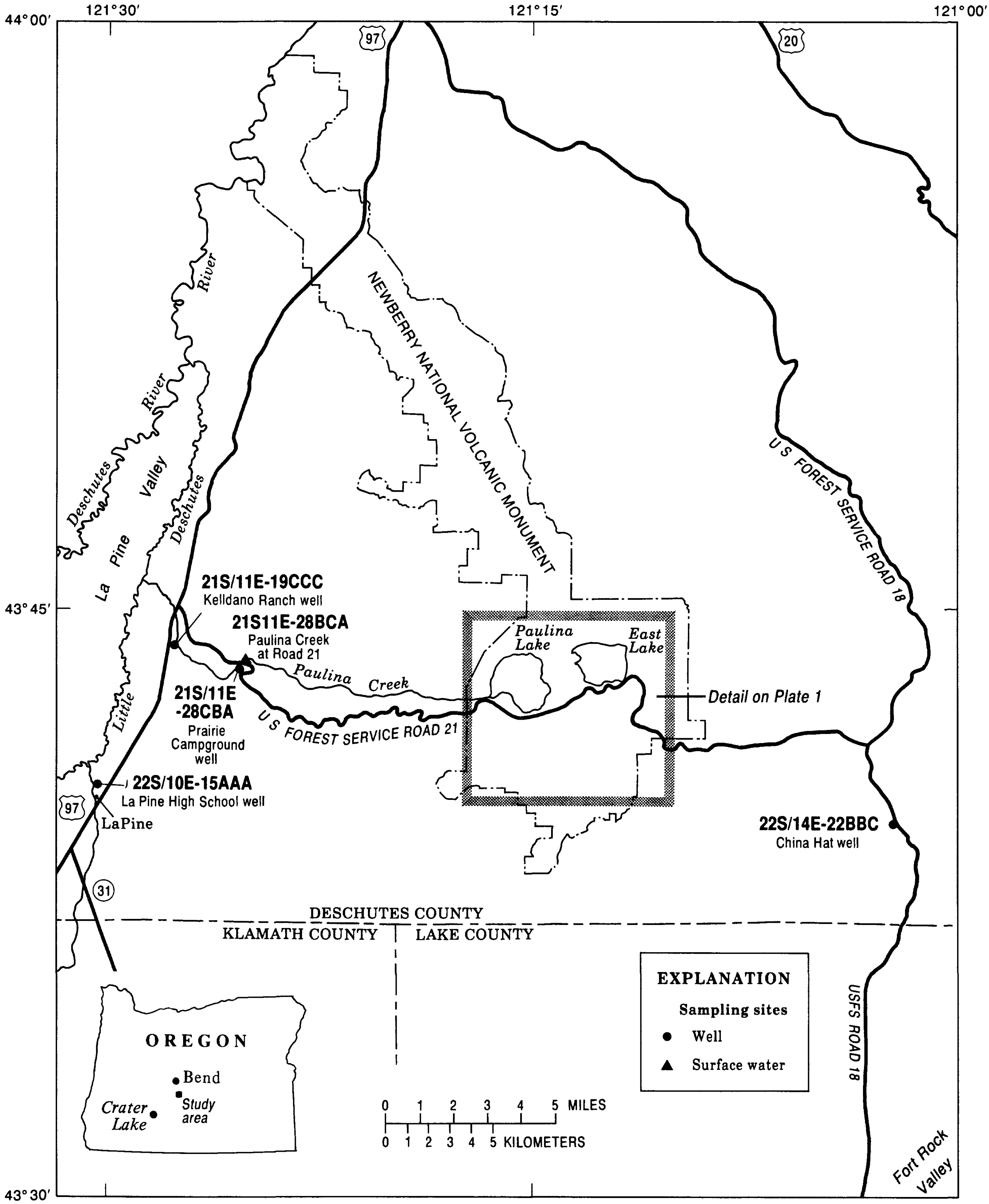


Figure 1. The location of hydrologic and water-quality data-collection sites in the vicinity of Newberry Volcano, Oregon.

Centered about 20 miles southeast of Bend, Oregon, Newberry Volcano (fig. 1) is one of the largest Quaternary volcanoes in the conterminous United States. The volcano covers an area in excess of 500 square miles and rises to an elevation of 7,984 feet at Paulina Peak. At the summit of Newberry Volcano is a 4 to 5-mile-wide caldera that contains Paulina and East Lakes (pl. 1). Newberry Volcano is the product of thousands of eruptions over the past 0.6 million years, with at least 25 eruptions during the last 10,000 years (Macleod and others, 1995). The most recent eruptions occurred only 1,300 years ago. The recognized geographic name for the caldera is Newberry Crater; however, the term caldera will be used in this report for consistency with most of the scientific literature about the area.

Purpose and Scope

The purpose of this report is to describe the hydrologic and water-quality conditions at Newberry Volcano from June 1991 through October 1995. Data collected from June 1991 through September 1993 (Crumrine and Morgan, 1994), along with data collected from October 1993 through October 1995, were used to develop a summary of baseline conditions. Hydrologic data for water years 1994 and 1995 are published by Hubbard and others (1995) and Hubbard and others (1996), respectively. Water-quality data for water years 1994 and 1995 are included in this report (Appendix).

A broad range of hydrologic, water-quality, and climatic parameters were measured in order to characterize components of the hydrologic system that could potentially be affected by geothermal development in the vicinity of the caldera. (See plate 1, figure 1, and table 1 for the locations and characteristics of the data-collection sites.) Hydrologic parameters measured include lake stage, ground-water levels, and discharge of Paulina Creek. Water-quality parameters included concentrations of major ions, nutrients, stable isotopes, and trace elements, as well as water temperature, specific conductance, dissolved oxygen concentration, and pH. Climatic data included precipitation, air temperature, humidity, wind speed, and solar radiation.

Acknowledgments

The authors would like to extend special thanks to Tom and Jeri Sly and Jim and Margie Burrow, U.S. Forest Service volunteers, who contributed many hours of work making water-level measurements in wells, collecting and preparing water-quality samples, and assisting with installation and maintenance of instrumentation. Their contributions added immeasurably to this study. The authors also would like to thank Linda Carlson of the U.S. Forest Service, Bend-Fort Rock Ranger District, for her work in facilitating and coordinating field activities as the liaison between the U.S. Geological Survey and the U.S. Forest Service. We also would like to acknowledge John and Leslie Hofferd, owners of Paulina Lake Lodge, for their help and cooperation in the study.

HYDROLOGIC CONDITIONS

Hydrologic conditions at Newberry Volcano, on the basis of data collected from 1991 through 1995, are described in the following sections. For each of the principal hydrologic features in the area, seasonal variations are described, long-term trends are identified, and hydrologic relations between features are described. A detailed description of the hydrology of the Newberry Volcano, including a water-budget analysis of the caldera, can be found in Sammel and Craig (1983); a brief summary of the important hydrologic features in the caldera is presented below.

The principal hydrologic features in the caldera of Newberry Volcano are East Lake and Paulina Lake. There are no perennial streams tributary to either lake, and all inflow to the lakes comes from precipitation, hot spring discharge, ground-water flow, and, during periods of heavy snowmelt, surface runoff. Water leaves the lakes by way of evaporation and ground-water flow. Also, an outlet from Paulina Lake allows surface outflow to Paulina Creek.

Paulina Creek is regulated by a control structure at the outlet of the lake that has raised the level of the lake and increased storage relative to natural conditions. This stored water is used for irrigation several miles downstream.

Climate

The elevation of Newberry Volcano and its position in the rain shadow of the Cascade Range combine to create a unique local climate. At an elevation of about 6,350 ft (feet), the floor of Newberry Caldera lies between 1,500 and 2,000 ft above the adjacent La Pine and Fort Rock Valleys to the west and southeast, respectively.

Table 1. Types and frequency of data collected, Newberry Volcano and vicinity, Oregon, 1991–95

[Location (locations are shown on plate 1 or figure 1). Frequency: A, Annually; B, Biannually; C, Continuously; I, Intermittently; M, Monthly; Q, Quarterly; SM, Semimonthly; S, Semiannually. --, not applicable; No., number; USFS, U.S. Forest Service; PL, Paulina Lake; EL, East Lake; OWRD, Oregon Water Resources Department]

Site location	Site name	Frequency: Water[1] quality	Frequency: Water-level/stage	Frequency: Water temperature and specific conductance	Remarks
			Hot Springs		
21S/12E-26AAB01	Paulina Lake Hot Springs No. 1	S	I	S	Original site. Discontinued 9-93
21S/12E-26AAB03	Paulina Lake Hot Springs No. 2B	S	I,C	S,C	New deeper hole. First sampled 10-93
21S/13E-29CDD01	East Lake Hot Springs No. 4	S	I	S	Original site. Destroyed by vandals 7-92
21S/13E-29CDD02	East Lake Hot Springs No. 3	S	I	S	Replacement site for No. 4. First sampled 10-92
21S/13E-29CDD06	East Lake Hot Springs No. 5B	S	I,C	S,C	New deeper hole. First sampled 10-93
			Wells		
21S/11E-28CBA	Prairie Campground	B	S	B	Campground supply well
21S/12E-34ABC	Paulina Lake Lodge No. 1	I	SM,I	I	Backup well for resort
21S/12E-34ACC	Paulina Guard Station	A	SM,I	A	Campground supply well
21S/12E-35DCB	Newberry Group Site Campground	A	SM,I	SM,I	Campground supply well
21S/12E-36BAA	Little Crater Campground No. 3	S	SM,I	S	Unused well
21S/13E-29AAC	Cinder Hill Campground No. 7	--	SM,I	SM,I	Campground supply well
21S/13E-29DCA	Geo-Newberry Well	A	SM,I	SM,I	Unused well
21S/13E-31CDB	Sandia Well	S	C,SM	S	Unused well
21S/13E-32ABB	Hot Springs Campground No. 1	A,S	SM,I	A	Unused well
21S/13E-32BBB	East Lake Campground No. 1	--	SM,I	SM,I	Campground supply well
22S/10E-15AAA	La Pine High School	B	Q	B	State observation well (level only)
22S/14E-22BBC	China Hat Guard Station	B	S	B	Campground, stock, and fire well
			Stream		
21S/11E-28BCA	Paulina Creek near USFS Road 21	S	S,I	S,I	Approximately 100 feet upstream of bridge
21S/12E-34BDA	Paulina Creek near La Pine	S	C	C	Sampled at stream gage site
			Lakes		
21S/12E-26ADA01	Paulina Lake PL-11-30	S	--	S	Depth of 30 feet
21S/12E-26ADA02	Paulina Lake PL-11-60	S	--	S	Depth of 60 feet
21S/12E-34ACB	Paulina Lake Gage	--	C	--	Stage recording gage
21S/13E-29CDA01	East Lake EL-08-30	S	--	S	Depth of 30 feet
21S/13E-29CDA02	East Lake EL-08-60	S	--	S	Depth of 65 feet
21S/13E-29CDA03	East Lake EL-08-85	S	--	S	Depth of 85 feet
21S/13E-29CDD07	East Lake Gage	--	C	--	Stage recording gage
			Weather		
21S/12E-34ACD	Paulina Lake Weather Station	--	--	--	Continuous measurements of precipitation, temperature, humidity, wind speed, and solar radiation
21S/12E-34DAC	Precipitation Gage	--	--	--	Annual measurements by OWRD

[1] See table 6 for constituents analyzed.

Its higher elevation relative to surrounding areas results in mean annual precipitation of approximately 30 in/yr (inches per year) in the caldera (fig. 2), compared with 18 in/yr in the La Pine Valley and less than 12 in/yr in the Fort Rock Valley (George Taylor, Oregon State Climatologist, written commun., August 1995). The rain shadow effect of the Cascade Range is evident from the disparity in annual precipitation at Newberry Volcano compared with areas at similar elevations in the Cascade Range. Mean annual precipitation on the east flank of the Cascade Range within the elevation range of the caldera floor at Newberry Volcano (6,300–6,400 ft) is approximately 70 in/yr (George Taylor, Oregon State Climatologist, written commun., August 1995), or more than twice that in the caldera.

Since 1966, the Oregon Water Resources Department (OWRD) has operated a storage precipitation gage near the southwest shore of Paulina Lake (pl. 1). Data from this gage were used to estimate a long-term mean annual precipitation for the caldera. Although the OWRD gage was in operation for 29 years, there were 5 years (1973, 1979, 1980, 1983, and 1995) in which records were poor (fig. 2). The mean precipitation for the 24 years of reliable data from 1966 through 1994 was 32 in/yr. To evaluate how well this value represents the true mean for the 1966–94 period, estimates of annual precipitation for the middle Deschutes Basin from 1962–94 were used for comparison (fig. 2). These estimates represent mean precipitation over the entire basin from 1962 through 1994 and are based on long-term records from several weather stations in the basin. The mean annual precipitation for the entire 29-year period (1962–94) was 28 in/yr; when the 5 years of missing data at the OWRD gage were removed, the 24-year mean was 27 in/yr. On the basis of the high degree of correlation between the OWRD record and the basinwide-precipitation estimates, and the small difference between the 29-year and 24-year basinwide means, the estimated mean annual precipitation in the caldera of 32 in/yr is reasonable.

In July of 1992, a weather station was installed near the southwestern shore of Paulina Lake (pl. 1). This station collected hourly measurements of precipitation, temperature, relative humidity, wind speed, and solar radiation. The purpose of the station was to collect detailed information on the climate within the caldera. The station provided information on the seasonal variability of climatic conditions in the caldera that are very important in interpreting changes in the hydrologic system. Data from the station for 1992 and 1993 were published by Crumrine and Morgan (1994). Data for water years 1994 and 1995 were published by Hubbard and others (1995, and 1996).

Annual precipitation measured at the USGS station was 31.1, 19.6, and 25.0 inches in water years 1993, 1994, and 1995, respectively (fig. 2). The 1993 and 1994 totals are 6.4 and 9.8 inches less than the totals measured at the OWRD gage in 1993 and 1994, respectively. As previously described, a reliable annual precipitation value was not available for 1995 from the OWRD gage. The differences between USGS and OWRD measurements in 1993 and 1994 are probably related to differences in the location, elevation, and type of precipitation gages. The OWRD gage is a 16.5 ft fiberglass standpipe fitted with a wind guard and located at the edge of a clearing at an elevation of 6,400 ft (pl. 1). The USGS gage, a 12-inch diameter, heated tipping bucket, is located approximately 0.25 miles northwest of the USGS gage in a small open area surrounded by lodgepole pine at an elevation of about 6,350 ft (pl. 1). At high elevations, where a large percentage of precipitation falls as snow, gage undercatch is a common problem because high winds tend to blow snow over the top of the gage orifice. The USGS gage had a smaller orifice than the OWRD gage and did not have a wind deflector, although it was situated in an area somewhat sheltered from high winds. Another reason for the apparent undercatch at the USGS gage is the possibility of evaporation caused by the heating element in the gage. The OWRD storage gage is also subject to undercatch and evaporative losses, but probably not to as great an extent. The primary advantage of the USGS gage is the ability to collect hourly precipitation data. Although the total from this gage may not reflect the actual quantity of precipitation, it does provide a reliable index to the relative amounts of precipitation seasonally and from year to year.

The cumulative departure from mean (normal) basinwide precipitation shows that, except for 1993, precipitation in the Deschutes Basin, and at Newberry Volcano, has been below normal every year since 1989 (fig. 2). Precipitation from the mid-1960's through the late 1970's was generally below the mean, as shown by the downward trend in the cumulative departure from mean curve. Very wet years occurred from 1981 through 1984, followed by a period of relatively normal precipitation between 1985 and 1989.

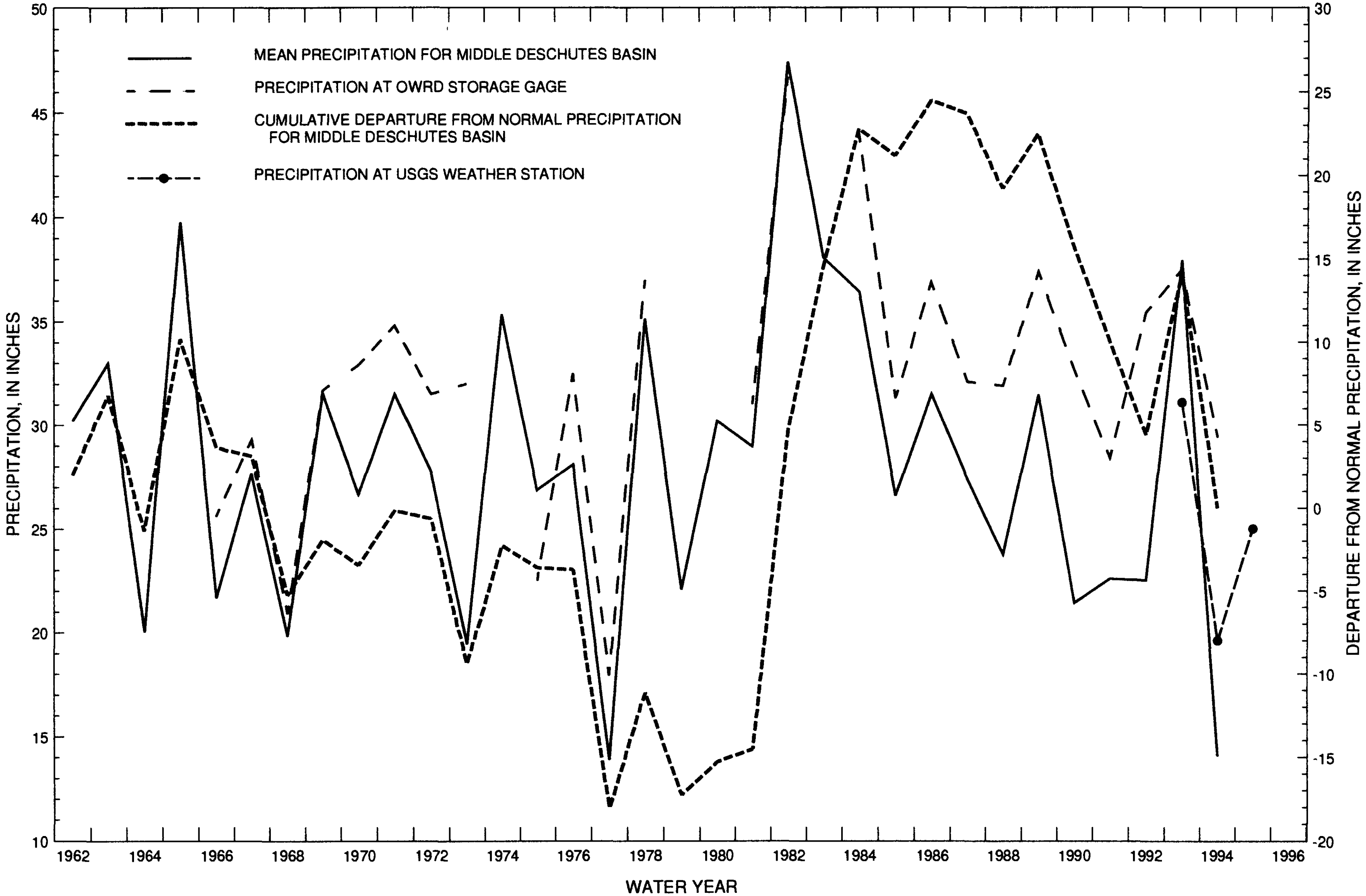


Figure 2. Annual precipitation measured at stations in Newberry Caldera, and estimated mean annual precipitation and cumulative departure from normal for the middle Deschutes Basin, Oregon. (Gaps in dashed line representing precipitation at the Oregon Water Resources [OWRD] storage gage indicate time periods for which records were poor. USGS, U.S. Geological Survey.)

During the baseline period, 75 percent of the mean annual precipitation fell between December and May (fig. 3A). From approximately November through March, most precipitation falls as snow in the caldera, with typical snow accumulations of 3 to 5 ft. Most precipitation between June and November falls as rain during convective storms.

The mean daily relative humidity of the caldera was generally highest between November and February, when it ranged from 75 to 90 percent; lowest humidity occurred between July and August and averaged about 55 percent (fig. 3B). Daily minimum and maximum values averaged about 20 percent and 95 percent, respectively, throughout the year. This wide range in daily relative humidity is a result of daytime evaporation from the lakes and the flushing action of winds through the caldera.

Solar radiation peaked in July and August, when total daily incident radiation ranged from 500 to 700 calories per square centimeter (fig. 3C); this corresponds to the time of year when there are fewest cloudy days and the sun is near its apex.

Mean daily minimum temperatures (averaged over each month) are lowest between November and March, ranging from -20 to -17°C (degrees Celsius). Mean daily minimum temperatures were never above 0°C during the entire baseline period. Mean daily maximum temperatures were highest between May and September, ranging from 22 to 27°C. The highest mean daily temperatures, 12 to 14°C, generally occurred in July, and lowest mean daily temperatures, -3 to -5°C, occurred between November and January. Mean daily temperatures were generally below freezing from November through February (fig. 3D). The difference between the mean monthly minimum and maximum temperatures was approximately 30°C throughout the baseline period.

During the first 18 months of data collection (July 1992–December 1994), a significant seasonal pattern was observed in wind speed within the caldera (fig. 3E). Highest wind speeds during this period occurred in late summer and winter, whereas lowest wind speeds occurred in fall and spring. In contrast, mean monthly wind speed was relatively constant after December 1994 except for fluctuations in winter and spring of 1995.

Lakes

Water surface elevation, or stage, in both East Lake and Paulina Lake was measured during the baseline period. Stages were measured and recorded at 1-hour intervals using a pressure transducer system attached to a nitrogen-purged orifice tube anchored on the lake bottom. The transducer sensed changes in lake stage by measuring the pressure required to force nitrogen through the orifice tube; this pressure, which is directly proportional to the lake stage, was recorded by an electronic datalogger. The lake-stage gaging station on East Lake (21S/13E-29CDD07, USGS Station ID 14063200) is located on the southeast shore near the hot springs (pl. 1). The lake-stage gaging station on Paulina Lake (21S/12E-34ACB, USGS Station ID 14063250) is located on the control structure at the outlet of the lake to Paulina Creek (pl. 1). Daily lake elevations have been published by Crumrine and Morgan (1994) and Hubbard and others (1993, 1994, 1995, and 1996).

East Lake

East Lake has a maximum depth of about 180 ft. Much of the north and northwestern part of the lake is more than 100 ft deep, whereas the southern and western parts of the lake are mostly less than 40 ft deep. The lake has an average depth of about 70 ft, an area of 1,040 acres, and a volume of 69,600 acre-feet.

The stage of East Lake generally rises between October and May, when evaporative losses are low and the precipitation rate is high. Water levels in wells (see section on "Ground Water") indicate that ground-water inflow to the lake also increases during this period as recharge from precipitation and, in the spring, snowmelt, raise the water table and increase flow toward the lake. The highest stage recorded during the baseline period was 6,375.6 ft in February 1992. The highest historic lake stage reported was 6,385.5 ft in 1958 (Phillips, 1968). Typically, the lake reaches its maximum annual stage in May or June, however, in years of very low precipitation the lake stage would be expected to peak earlier, as it did in February of 1992 (fig. 4).

Lake stage generally declines between May and October as outflow to evaporation and ground water exceeds inflow from precipitation and ground water. The annual minimum lake stage is usually reached in October or November. The lowest stage recorded during the baseline period was 6,371.8 ft in October 1994. The lowest historic lake stage reported was 6,366 ft in the early 1940's (Phillips, 1968).

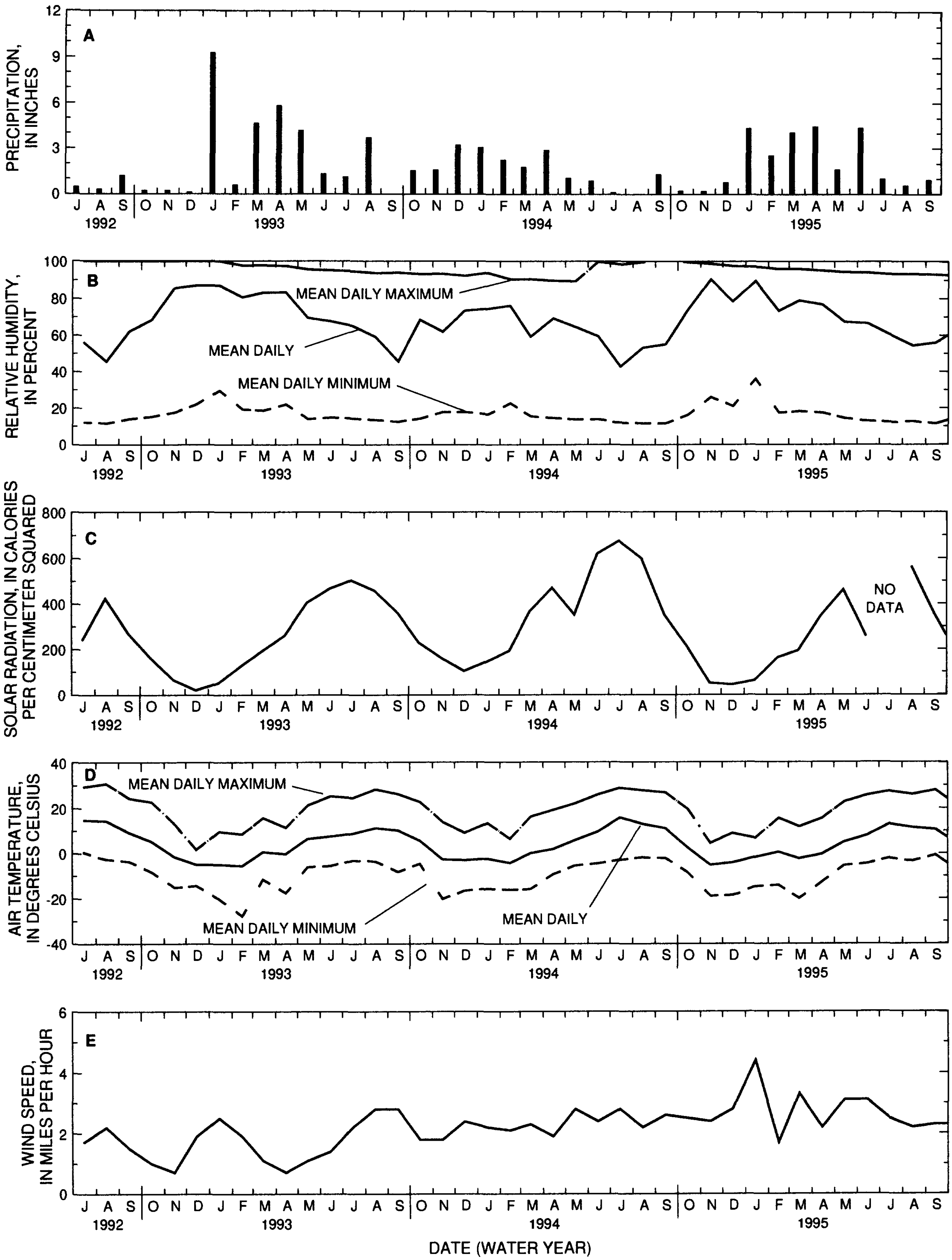


Figure 3. Meteorologic data for Newberry Caldera near La Pine, Oregon, July 1992 through September 1995: (A) Monthly total precipitation, (B) Monthly mean of daily relative humidity, (C) Monthly mean of daily solar radiation, (D) Monthly mean of daily air temperature, and (E) Monthly mean of daily wind speed.

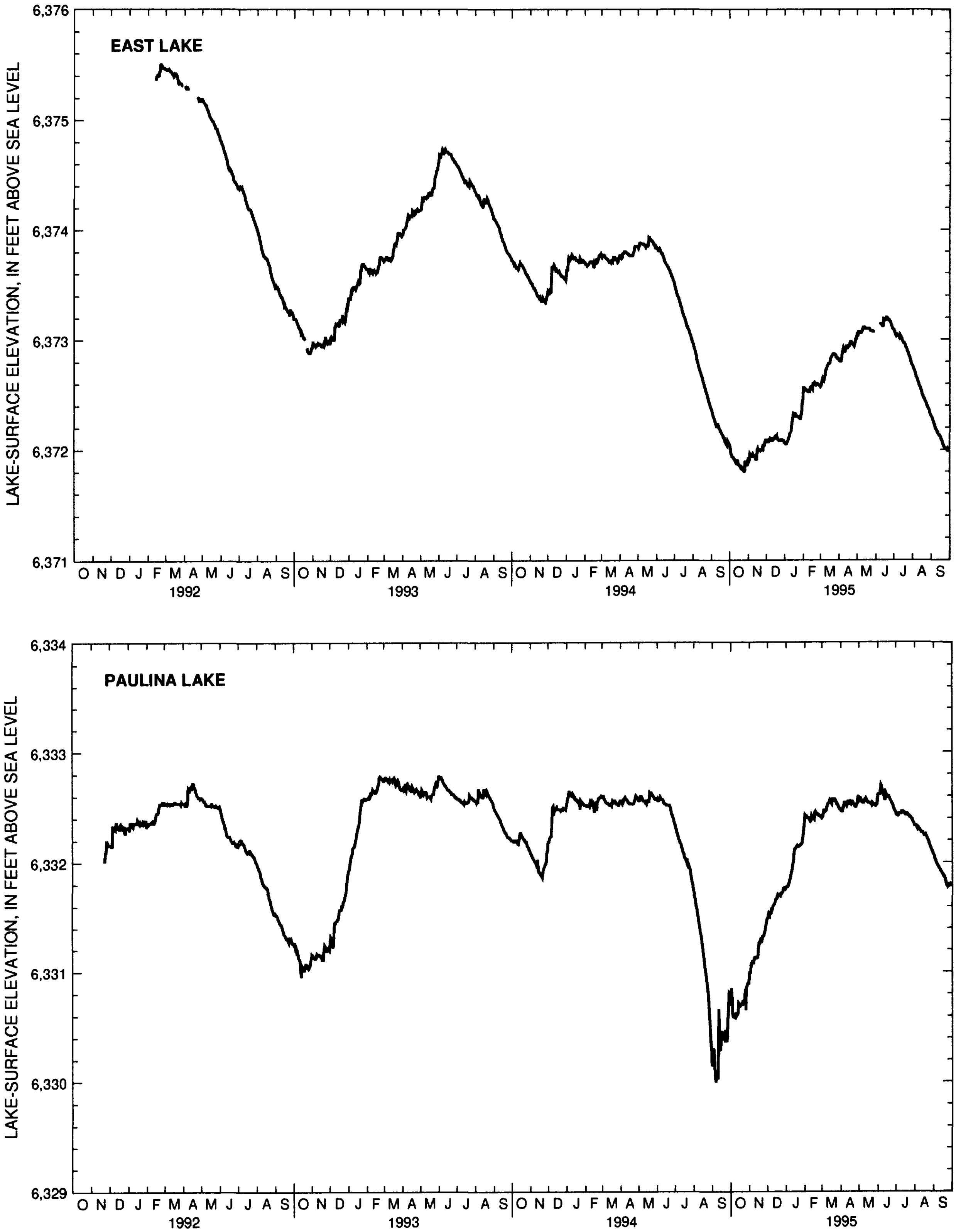


Figure 4. Lake-surface elevation of East and Paulina Lakes, Oregon, water years 1992–95.

Lake stage declined nearly 3 ft between February and October 1992 and more than 2 ft between May and October 1994 (fig. 4). The magnitude of these declines is apparently unprecedented, at least on the basis of data available through 1963, because Phillips (1968, p. 25) stated: "In any given calendar year, the observed fluctuation in lake level has not exceeded 2 feet."

The maximum stage of East Lake declined in each year of the baseline period from 6,376.6 ft in February 1992 to 6,373.2 ft in June 1995; the mean rate of decline was about 0.8 ft per year during this period. It is difficult to determine the normal range of fluctuation in stage for East Lake on the basis of the relatively short period of continuous monitoring record available. It appears, however, that in a slightly below normal precipitation year such as 1995, lake stage recovers about 1 ft, whereas in a slightly above normal precipitation year such as 1993, lake stage recovers more than 1.5 ft. In very dry years, such as 1991, 1992, and 1994, recovery of lake stage is 0.5 ft or less.

Paulina Lake

Paulina Lake has a maximum depth of about 250 ft. Much of the lake is more than 200 ft deep, whereas only a small part of the lake near the shore and on the southwestern corner is less than 40 ft deep. The lake has an average depth of about 165 ft, an area of 1,530 acres, and a volume of 249,800 acre-feet.

Paulina Lake is regulated by the control structure at the outlet to Paulina Creek at the southwest shore of the lake. Lake stage rises from October through January when it reaches the elevation of the spillway to Paulina Creek, 6,332.7 ft. This stage is maintained until late summer when downstream demand for irrigation water requires that the lake level be lowered in order to maintain flows in Paulina Creek. The lake stage declines until the end of the irrigation season (October–November), when the flow in Paulina Creek is reduced and the lake is allowed to refill. Typically, the lake refills to the level of the spillway by December or January. Low precipitation in 1994 reduced ground-water inflow to the lake and the stage reached its lowest level of the baseline period (6,330.0 ft) in September 1994. The discharge of Paulina Creek averaged 16.3 ft^3/s (cubic feet per second) during the irrigation season (May–September) of 1994, which is only slightly more that the 1992–95 mean irrigation season discharge of 15.4 ft^3/s. Therefore, the low stage reached in September 1994 did not result from increased irrigation diversion into Paulina Creek, but more likely from reduced ground-water inflow due to low precipitation in 1994.

In spite of below normal precipitation in recent years, the maximum annual stage of Paulina Lake and ground-water levels (see subsequent discussions in "Ground Water" and "Hot Springs and Thermal Wells") in the area have remained relatively stable, while the stage of East Lake and nearby wells have declined 2 ft or more. The stage of Paulina Lake is most likely sustained during low-precipitation years by ground-water flow from East Lake. A hydraulic gradient of about 40 ft per mile from East Lake toward Paulina Lake indicates there may be significant ground-water flow through the relatively permeable ash and pumice deposits that separate the lakes. Water-budget calculations by Phillips (1968) indicated there may be on the order of 2.3 ft^3/s of seepage loss from East Lake, much of which probably flows into Paulina Lake.

Paulina Creek

Paulina Creek begins at the west side of Paulina Lake at an elevation of about 6,330 ft and flows west for more than 13 miles to the Little Deschutes River. At an elevation of 4,180 ft, Paulina Creek exits the lake through a concrete spillway and fish-screen structure used for regulating streamflows for irrigation and to keep fish from exiting the lake. Records indicate that the concrete spillway has been in place since about 1903, and the fish-screen structure has been added sometime since.

A stream-gaging station on Paulina Creek, which was operated by OWRD from October 1982 to September 1989, was reactivated by the USGS in October 1991. The stream-gaging station is located 180 ft downstream from the Paulina Lake outlet (pl. 1). During the baseline period, a datalogger continuously monitored and stored stream stage, water temperature, and specific conductance. A stage-discharge relation was developed for this site by making stream-discharge measurements on a bimonthly basis for a range of discharge rates. Daily mean discharge was computed at the Paulina Creek stream-gaging station using standard USGS procedures (Buchanan and Somers, 1968; Buchanan and Somers, 1969). Daily values of discharge, temperature, and specific conductance for the baseline period have been published in Hubbard and others (1993, 1994a, 1995, and 1996). The mean annual discharge (1983–89, 1992–95) was 17.9 ft^3/s. Mean discharge for each of the baseline water years (1992–95) were 13.7, 15.6, 13.8, and 12.8 ft^3/s, respectively, all below the long-term annual mean. A general downward trend is reflected in the annual discharge for Paulina Creek (fig. 5).

The highest monthly mean discharge (15–25 ft^3/s) occurs when snowmelt is peaking and the lake has reached the elevation of the spillway, typically between March and June (fig. 6). Flows of 10–15 ft^3/s are generally sustained through the summer and early fall by releases from the lake. Minimum monthly mean flows of 5–10 ft^3/s occur in late fall when streamflow is reduced to refill the lake.

The temperature of Paulina Creek at the stream-gaging station is representative of the surface temperature of Paulina Lake. The temperature of the lake surface, and therefore the outflow to Paulina Creek, increases with increasing solar radiation from February through late July or early August, when mean temperatures reach 17–18°C (fig. 6). During this time, the lake becomes thermally stratified, with a thermocline at a depth of 35 to 40 ft (Crumrine and Morgan, 1994). As solar radiation decreases, the temperature of the lake surface, and therefore of Paulina Creek, drops rapidly. In late October or November the surface temperature of Paulina Lake falls to less than 5°C, increasing the density of the near-surface water. This increased density causes convective mixing or "turning over" of the lake.

The specific conductance of Paulina Creek is also indicative of conditions in Paulina lake, although the influence of ground-water inflow is also apparent when discharge is low. Specific conductance is usually very similar to that of the lake, in the range of 570 to 590 µS/cm (microsiemens per centimeter) (fig. 6). However, when stream discharge is reduced to less than 10 ft^3/s in the late fall, the influence of lower conductance ground water (less than 100 µS/cm) entering the stream channel from springs and seepage is evident as specific conductance values of the stream fall to below 540 µS/cm. Inflow from springs and seeps occurs immediately below the control structure.

Additional discharge measurements on Paulina Creek were made intermittently during the baseline period at a site approximately 8 miles downstream from the lake, where USFS Road 21 crosses the creek (fig. 1). Comparison of discharge at the lake outlet and at USFS Road 21 crossing show that Paulina Creek loses water to the ground water system over the 8-mile reach. Losses ranged from 11 to 35 percent of the discharge at the lake outlet and appear to be related to stream stage and discharge; a greater percentage of flow is generally lost at high stages due to the greater wetted perimeter of the stream channel and the greater head in the stream (fig. 7). The mean loss for the 11 measurements between October 1991 and October 1995 was 23 percent of discharge at the lake outlet.

Two series of gain/loss measurements were made on the 7.9-mile reach of Paulina Creek between the stream-gaging station near the lake outlet at river mile (RM) 13.1 and USFS Road 21 crossing at RM 5.2 to determine the location of losing reaches and to determine if the stream gained flow (received ground-water discharge) in any reaches above USFS Road 21. The first series of measurements were made on September 1, 1993, when discharge at the gage was 21.8 ft^3/s. The second series of measurements were made on October 6, 1994, when discharge was only 11.1 ft^3/s at the gage. Each series consists of nine measurements made approximately 1 mile apart, beginning at the stream-gaging station at the outlet of Paulina Lake (fig. 8).

Both series of measurements showed that there are reaches of the stream in the upper 3 miles that gain from the ground-water system. The gains and losses in the upper reaches are probably a result of geologic controls. Several large waterfalls with drops of 20–100 ft occur within the upper few miles of the stream. In general, streams will lose above water falls as the water table drops below the stream level and they will gain below the water falls where the stream level and the water table intersect. There is also a significant change in the permeability of the streambed in the vicinity of RM 11.0, where the geology of the streambed changes from relatively permeable andesitic tuff deposits to less permeable basaltic andesite lava flows (Macleod and others, 1995) (fig. 8).

During the first series of measurements, losses of 2 ft^3/s per mile were measured above RM 11.0; this rate was more than twice the mean loss of 0.75 ft^3/s per mile for the entire stream reach above USFS Road 21. Between RM 11.0 and 10.2 the stream gained 2.4 ft^3/s per mile. From RM 10.2 to USFS Road 21 (RM 5.2) the stream losses were constant at a rate of about 0.75 ft^3/s per mile. The high losses in the upper 2 miles of the stream may be caused by the higher permeability of the andesite tuffs that form the streambed.

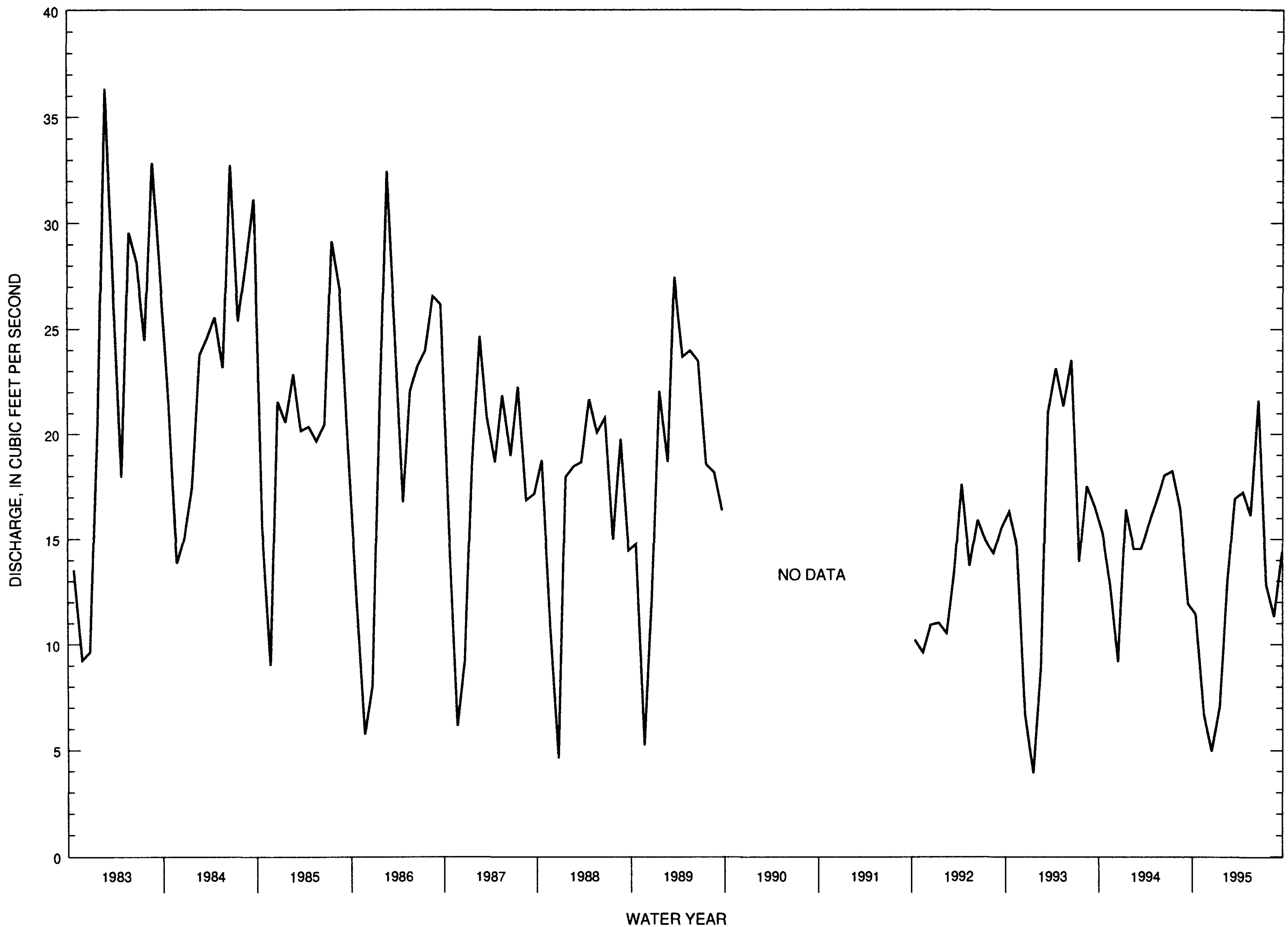


Figure 5. Monthly mean stream discharge for Paulina Creek near La Pine, Oregon, October 1982 (water year 1983) through September 1985.

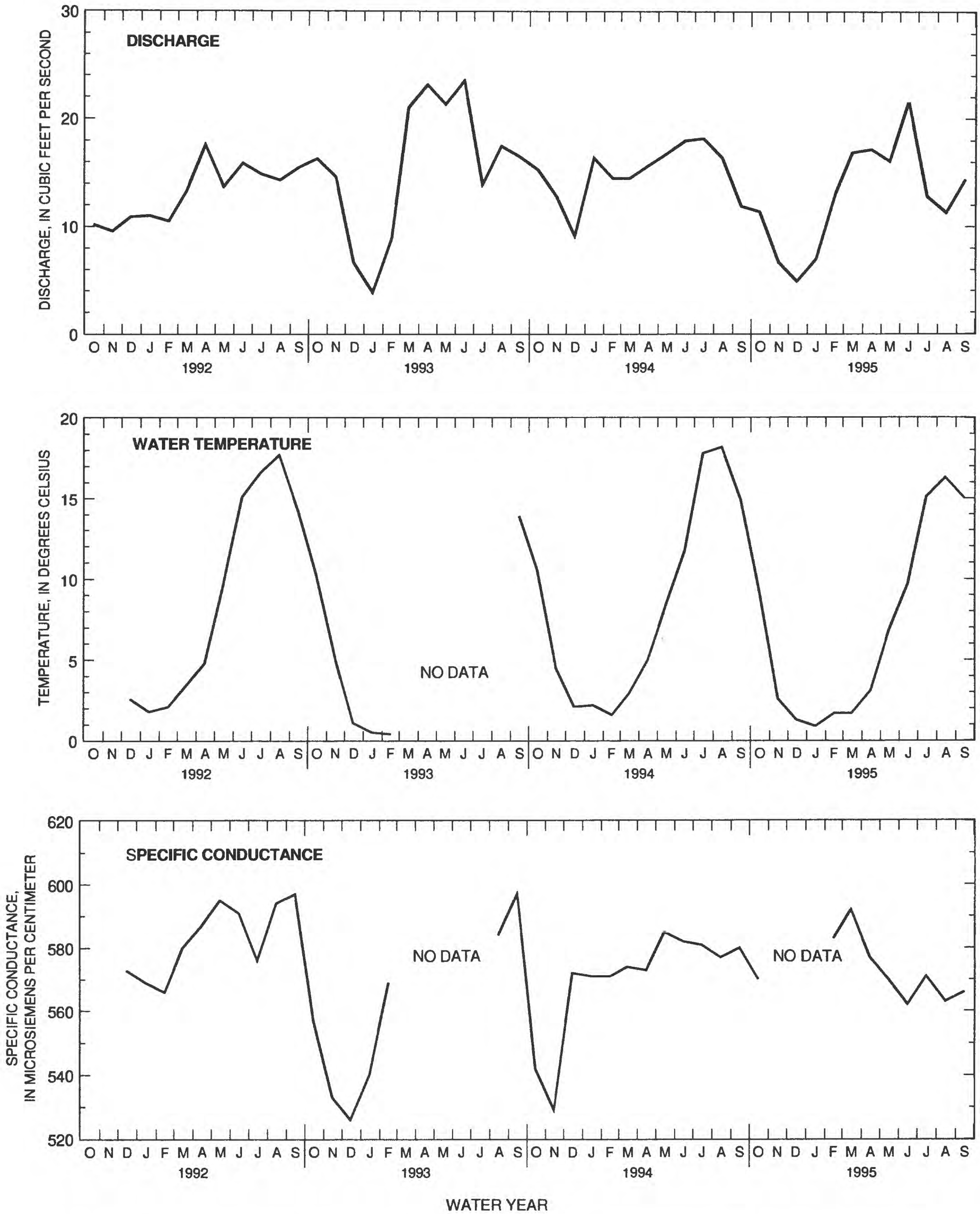


Figure 6. Monthly mean stream discharge, water temperature, and specific conductance for Paulina Creek near La Pine, Oregon, October 1991 (water year 1992) through September 1995.

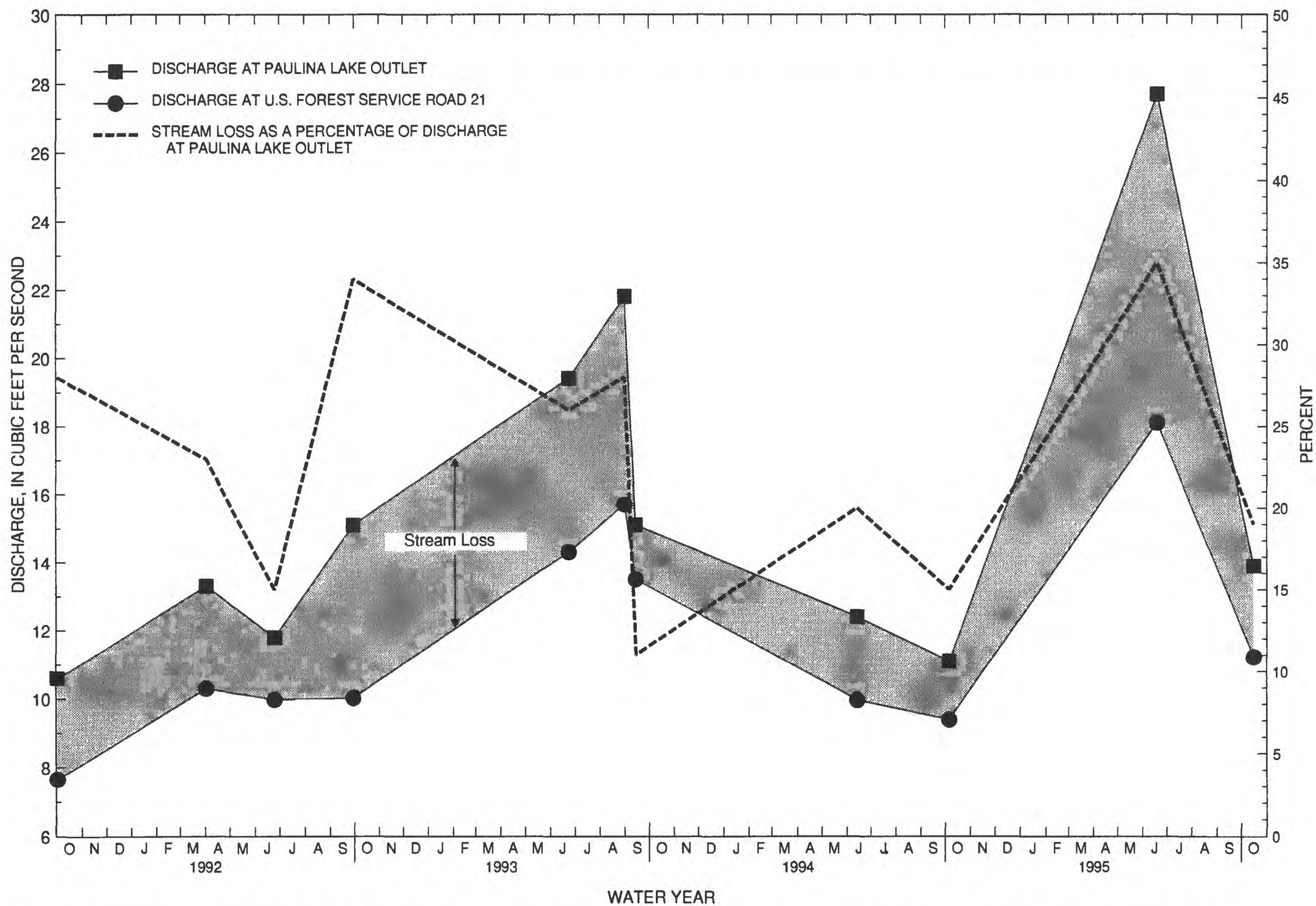


Figure 7. Measured stream losses on Paulina Creek between the Paulina Lake outlet and U.S. Forest Service Road 21, October 1991 (water year 1992) to October 1995 (water year 1996).

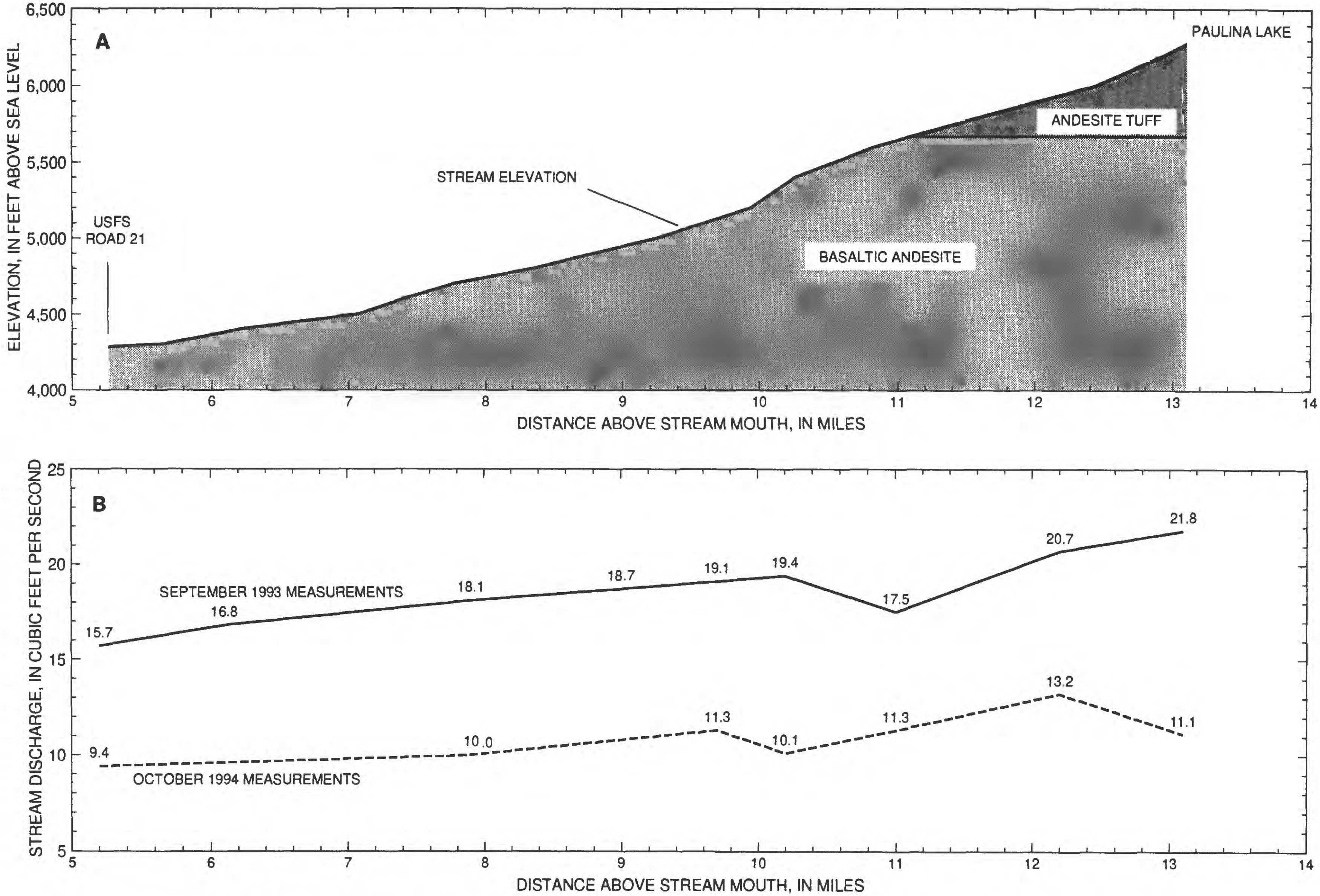


Figure 8. (A) Elevation profile of Paulina Creek showing geology and (B) gain/loss measurements made in September 1993 and October 1994. (USFS, U.S. Forest Service)

Below RM 11.0, the streamflows mostly over less permeable basaltic andesite flows (fig. 8). The second series of measurements showed gaining reaches between the lake outlet (RM 13.1) and RM 12.2 and between RM 10.2 and RM 9.7 (fig. 8).

Ground Water

Location, construction details, and other data for wells in the vicinity of Newberry Caldera are listed in table 2. Ground-water-quality data were collected at 11 wells in the caldera (pl. 1, table 3) and 4 wells outside the caldera (fig. 1, table 3). Most of the wells used for data collection were drilled to supply water for campgrounds; however, four shallow monitoring wells were constructed near the hot springs specifically for this study. Periodic water-level measurements were made in selected wells using a steel surveying tape. Measurements were recorded to the nearest 0.01 ft. For quality assurance, two successive measurements were required to be within 0.01 ft before a measurement was recorded. Water-level measurements were made at least semiannually in most wells; however, measurements were made twice monthly in nine wells in the caldera, when access permitted, between June and November (table 1). Two wells whose water temperature and chemistry indicate that they produce water with thermal components (the Sandia and Little Crater Campground wells) were instrumented in July 1993 with digital dataloggers and sensors to measure daily water levels and temperatures. Temperature and humidity conditions in the wellbores, however, caused the dataloggers and sensors to fail frequently until June of 1995 when sealed, vibrating-wire pressure transducers were installed.

Two wells outside the caldera in the vicinity of Newberry Volcano are part of a statewide monitoring network operated by the OWRD. A relatively shallow (100 ft) well at the Kelldano Ranch has been monitored since 1962, and a deep (1,460 ft) well at La Pine High School has been measured since 1985 (fig. 1).

Ground-water levels in the caldera show seasonal trends that are very similar to the trends in lake stages discussed previously. The hydrographs of three of the wells measured in the vicinity of East Lake show that annual maximum water levels are generally reached in June and annual minimum water levels typically occur in November (fig. 9). Most wells in the caldera have annual water-level fluctuations of about 2 ft. During the baseline data-collection period, ground-water levels generally declined in the vicinity of East Lake by 1 to 3 ft (fig. 9).

The Sandia Well (21S/13E-31CDB, pl. 1) is located more than 1 mile from the lakes, and its water level is probably influenced less by lake stage than that of the other wells, most of which are within a few hundred feet of the lakes. The greater range in annual water-level fluctuations in the Sandia Well and the lag of 1–2 months in the maxima and minima relative to other wells and the lake indicate that water levels in the Sandia Well are influenced primarily by seasonal recharge and less so by lake level fluctuations. A particularly large rise in water level (4 ft) occurred between November 1992 and July 1993 as the well recovered from 2 years of below normal precipitation (1991–92). The Hot Springs Campground well (21S/13E-32ABB) and the Geo-Newberry Well (21S/13E-29DCA) are located about 700 ft and 150 ft, respectively, from East Lake and their water-level fluctuations essentially mirror lake stage fluctuations (fig. 9). The minimum water levels measured during the baseline period occurred in October 1994 in all three East Lake area wells.

Ground-water levels in the Paulina Lake area are also strongly influenced by lake stage (fig. 10). Well hydrographs show that minimum water levels in this area typically occur in October. Maximum water levels probably occur in December to January on the basis of data from a continuous water-level recorder on the Little Crater Campground No. 3 well and lake stage; however, ground-water levels were not measured in most wells during this time of year due to deep snow. Annual ground-water-level fluctuations in this area were generally less than 2 ft. In contrast to wells in the East Lake area, ground-water levels in the Paulina Lake area did not show a long-term decline during the baseline period. Water-level changes between June 1991 and June 1995 were less than 0.2 ft in all three monitoring wells near Paulina Lake (fig. 10). Minimum water levels in these wells occurred in September–October 1994 following the very low precipitation in water year 1994.

Peak ground-water levels in the Paulina Guard Station well and the Newberry Group Site Campground well were measured in May and June of 1993 and 1995, which had above normal precipitation. These water levels do not appear to be related to the stage of Paulina Lake, which had reached its peak (the level of the spillway) at least 6 months earlier in both 1993 and 1995.

Table 2. Data for selected wells, Newberry Volcano and vicinity, Oregon

[See plate 1 or figure 1 for site location. Latitude and longitude are given in °, degrees; ’, minutes; ”, seconds. Key to primary use of site codes: C, standby or emergency supply; O, observation; U, unused; W, withdrawal. No., number, RV, recreational vehicle]

Site location	Site name	Owner name	Date constructed	Latitude	Longitude	Altitude of land surface[1] (feet)	Depth of well (feet)	Diameter of casing (inches)	Primary use of site (codes)
21S/11E-19CCC	Kelldano Ranch Well	Kelldano Ranch	10-06-64	43°44’00”	121°27’58”	4,220	100	6.0	U
21S/11E-28CBA	Prairie Campground	U.S. Forest Service	04-18-67	43°43’30”	121°25’21”	4,314	150	8.0	W
21S/12E-26AAB01	Paulina Lake Hot Springs No. 1	U.S. Geological Survey	08-14-91	43°43’56”	121°15’08”	6,331	5.14	1.25	O
21S/12E-26AAB02	Paulina Lake Hot Springs No. 2A	U.S. Geological Survey	09-14-93	43°43’56”	121°15’08”	6,335.20	7.85	1.00	O
21S/12E-26AAB03	Paulina Lake Hot Springs No. 2B	U.S. Geological Survey	09-15-93	43°43’56”	121°15’08”	6,335.20	8.55	1.00	O
21S/12E-34ABC	Paulina Lake Lodge No. 1	Paulina Lake Lodge	11-13-80	43°42’52”	121°16’33”	6,350	52	6.0	C
21S/12E-34ACC	Paulina Guard Station	U.S. Forest Service	09-08-83	43°42’42”	121°16’36”	6,360	85	6.0	W
21S/12E-35DCB	Newberry Group Site Campground	U.S. Forest Service	06-29-87	43°42’21”	121°15’22”	6,365	60	6.0	W
21S/12E-36BAA	Little Crater Campground No. 3	U.S. Forest Service	09-16-61	43°43’03”	121°14’21”	6,344.65	49.7	6.0	U
21S/13E-20CAD01	Cinder Hill Campground No. 1	U.S. Forest Service	10-09-59	43°44’17”	121°11’57”	6,420	38	6.0	U
21S/13E-20CAD02	Cinder Hill Campground No. 2	U.S. Forest Service	10-13-59	43°44’15”	121°11’59”	6,420	32	6.0	U
21S/13E-29AAC	Cinder Hill Campground No. 7	U.S. Forest Service	08-24-63	43°43’50”	121°11’37”		76	6.0	W
21S/13E-29ABA01	Cinder Hill Campground No. 5	U.S. Forest Service	09-20-61	43°43’56”	121°11’39”	6,400	30	6.0	U
21S/13E-29ABA02	Cinder Hill Campground No. 6	U.S. Forest Service	09-19-91	43°43’59”	121°11’39”	6,400	30	6.0	U
21S/13E-29CDD01	East Lake Hot Springs No. 4	U.S. Geological Survey	08-14-91	43°43’13”	121°11’57”	6,381	2.41	1.25	O
21S/13E-29CDD02	East Lake Hot Springs No. 3	U.S. Geological Survey	08-14-91	43°43’13”	121°11’57”	6,380	6.19	1.25	O
21S/13E-29CDD03	East Lake Hot Springs No. 2	U.S. Geological Survey	08-14-91	43°43’13”	121°11’57”	6,380	1.34	1.25	O
21S/13E-29CDD05	East Lake Hot Springs No. 5A	U.S. Geological Survey	09-16-93	43°43’13”	121°11’57”	6,377.70	9.10	1.00	O
21S/13E-29CDD06	East Lake Hot Springs No. 5B	U.S. Geological Survey	09-16-93	43°43’13”	121°11’57”	6,377.70	8.81	1.00	O
21S/13E-29DCA	Geo-Newberry Well	U.S. Forest Service	07-11-87	43°43’20”	121°11’42”	6,380	100	6.0	W
21S/13E-29DDB	East Lake RV Park	East Lake Resort	09-12-78	43°43’20”	121°11’36”	6,420	80	6.0	W
21S/13E-31CDB	Sandia Well	U.S. Forest Service	09-15-83	43°42’20”	121°13’21”	6,435	90	6.0	C
21S/13E-32ABB	Hot Springs Campground No. 1	U.S. Forest Service	09-21-61	43°43’05”	121°11’53”	6,400	32	6.0	W
21S/13E-32BBB	East Lake Campground No. 1	U.S. Forest Service	10-12-62	43°43’04”	121°12’30”	6,400	50	6.0	W
22S/10E-15AAA	La Pine High School	School District One	03-10-83	43°45’00”	121°15’00”	4,233	1,460	16	W
22S/14E-22BBC	China Hat Guard Station	U.S. Forest Service	01-18-85	43°39’34”	121°02’13”	5,180	853	8.0	W

[1] Surveyed elevations are reported to the nearest 0.05 feet; all other elevations were estimated from U.S. Geological Survey 7.5-minute scale topographic maps.

Table 3. Location, name, and type of water-quality sampling sites, Newberry Volcano and vicinity, Oregon
[Site number is the number used to specify the sites in this report. Locations are shown on plate 1 or figure 1. Samples from East Lake and Paulina Lake were taken from a depth of 30 feet. EL, East Lake; PL, Paulina Lake; USFS, U.S. Forest Service]

Site location	Site name	Site type
	East Lake Area	
21S/13E-29CDA01	East Lake, EL-8-30	Surface water
21S/13E-29CDD01	East Lake Hot Springs No. 4	Ground water
21S/13E-29CDD02	East Lake Hot Springs No. 3	Ground water
21S/13E-29CDD06	East Lake Hot Springs No. 5B	Ground water
21S/13E-29DCA	Geo-Newberry Well	Ground water
21S/13E-32ABB	Hot Springs Campground No. 1	Ground water
	Paulina Lake Area	
21S/12E-26AAB01	Paulina Lake Hot Springs No. 1	Ground water
21S/12E-26AAB03	Paulina Lake Hot Springs No. 2B	Ground water
21S/12E-26ADA01	Paulina Lake, PL-11-30	Surface water
21S/12E-34ACC	Paulina Guard Station	Ground water
21S/12E-34BDA	Paulina Creek near La Pine, Oregon	Surface water
21S/12E-35DCB	Newberry Group Site Campground	Ground water
21S/12E-36BAA	Little Crater Campground No. 3	Ground water
21S/13E-31CDB	Sandia Well	Ground water
	Outside Newberry Caldera	
SEE FIGURE 1	Crater Lake near Crater Lake, Oregon	Surface water
21S/11E-28BCA	Paulina Creek near USFS Road 21	Surface water
21S/11E-28CBA	Prairie Campground	Ground water
22S/10E-15AAA	La Pine High School	Ground water
22S/14E-22BBC	China Hat Guard Station	Ground water

The peak ground-water levels are most likely the result of a seasonal pulse of recharge from melting snowpack in the caldera. When the recharge pulses ended, ground-water levels receded to a level controlled by lake stage and followed the stage of the lake until the next seasonal recharge pulse. Dry years, like 1992 and 1994, did not generate enough snowpack to sustain a recharge pulse that could be detected in May–June water levels.

The Kelldano Ranch Well (21S/11E-19CCC [fig. 1]) and the La Pine High School well (22S/10E-15AAA[fig. 1]), long-term observation wells located outside the caldera, declined 1 and 2 ft, respectively, between 1992 and 1995 (fig. 11). These wells have shown steady declines of approximately 10 ft since 1984 in response to below normal precipitation. The shallower (100 ft) Kelldano Ranch Well is more responsive to seasonal variation in recharge than the deeper (1,460 ft) La Pine High School well.

Hot Springs and Thermal Wells

Hot springs at East and Paulina Lakes are the most significant surface thermal features at Newberry Volcano. These springs discharge mainly as diffuse seeps along the shorelines of the lakes; however, there are areas offshore from these seeps where gas bubbles and slightly elevated lake temperatures indicate additional inflow of thermal water. Hydraulic head and temperature data for the hot springs were collected from shallow monitoring wells installed for this study as described by Crumrine and Morgan (1994) (pl. 1, table 1).

East Lake Area

The hot springs at East Lake are located along the southeastern shore. Water level and temperature were measured in a monitoring well (21S/13E-29CDD06) drilled in September 1993 near the most active thermal discharge area (pl. 1, table 1). Measurements were made at least twice annually (fig. 12). The water level in the hot springs was generally a few tenths of a foot higher than the lake stage, indicating that there is a hydraulic gradient toward the lake. This gradient was greatest when the lake reached its lowest level in October 1994 and the head in the hot spring monitoring well remained approximately 1 ft above the lake stage. Temperature of the hot springs may vary with lake stage, with lower temperatures occurring at lower lake stages; however, more data are needed to establish this relation.

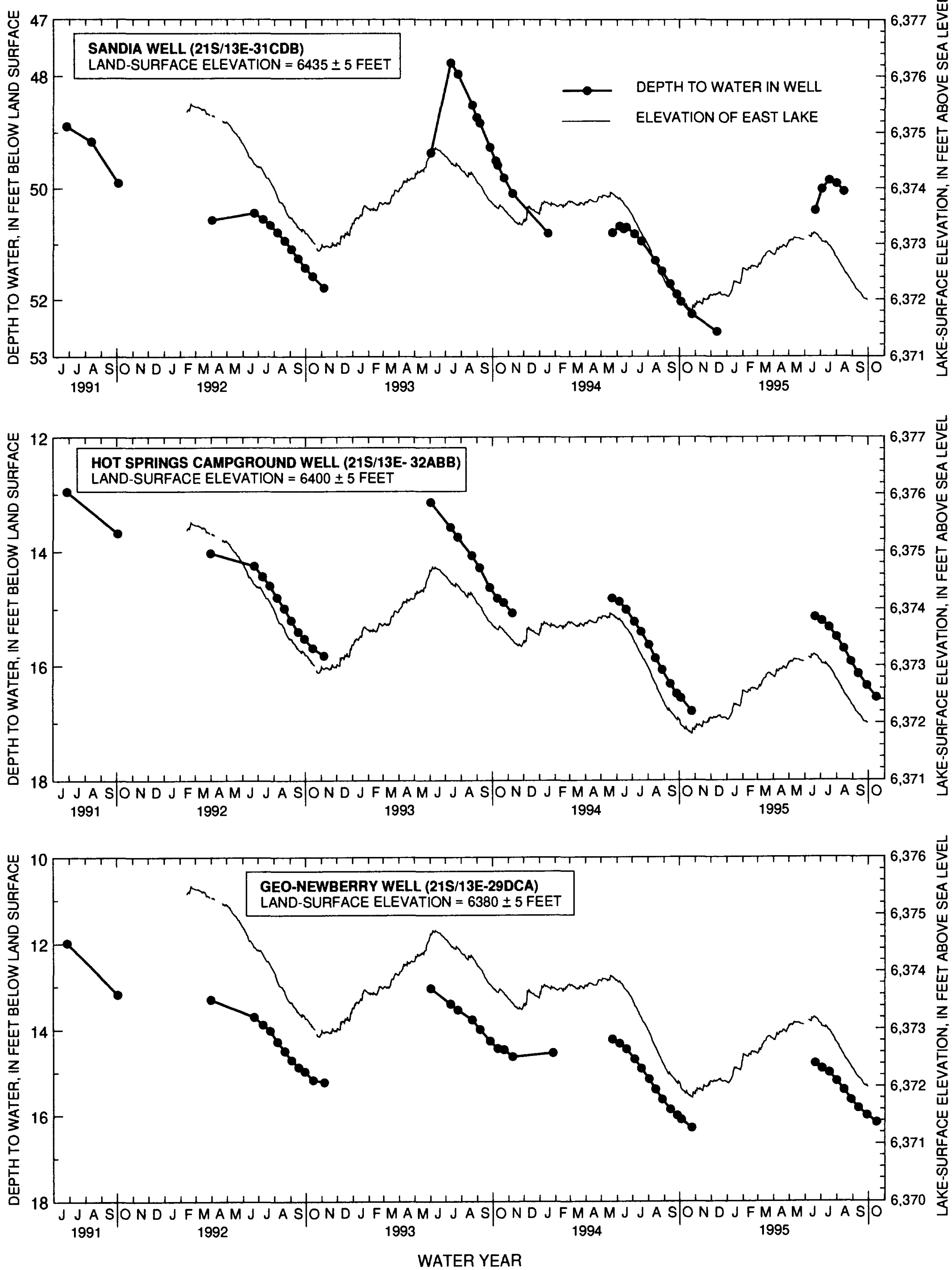


Figure 9. Water levels in wells near East Lake, Oregon, June 1991 to October 1995. (East Lake elevation is shown for comparison.)

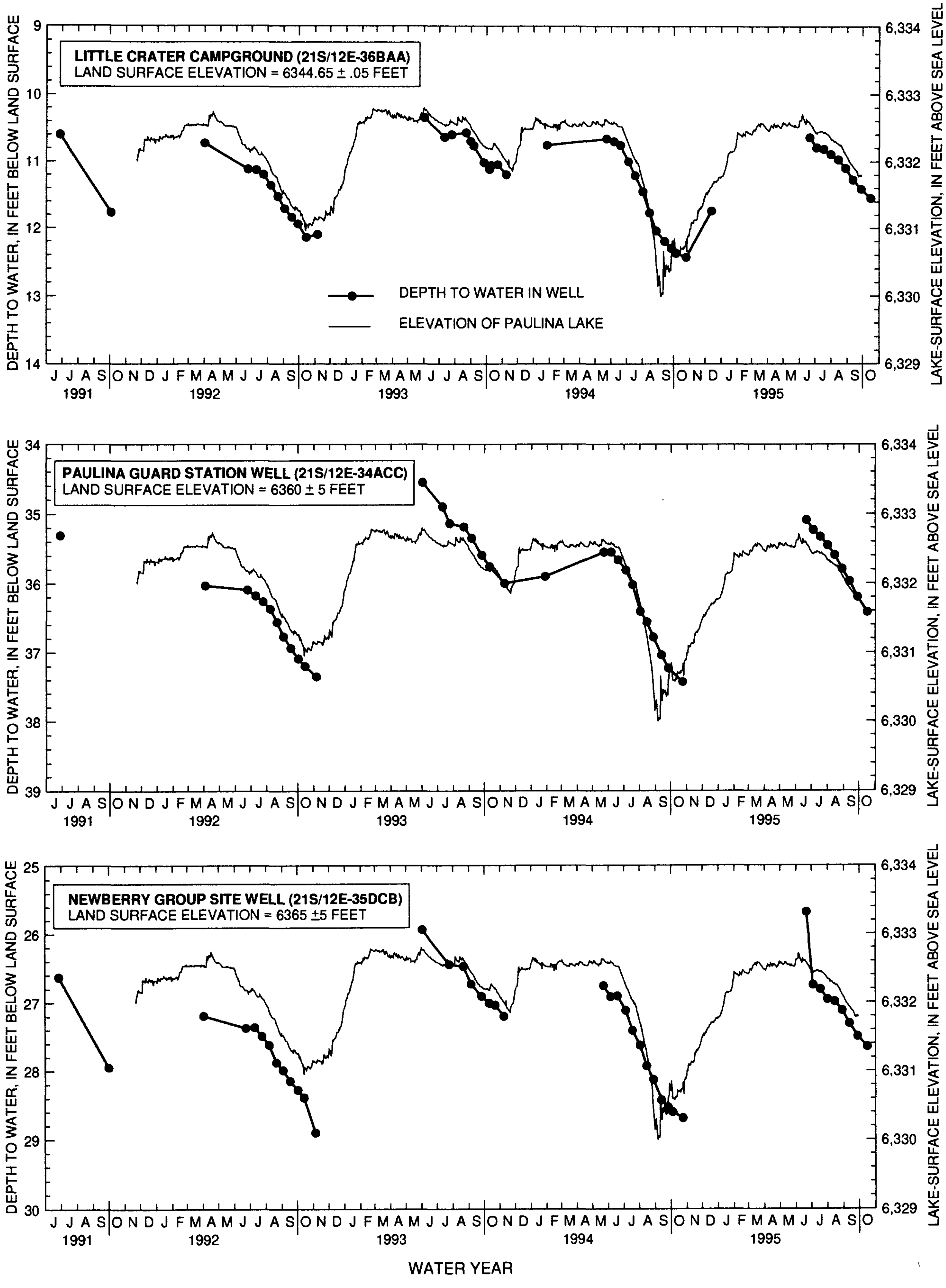


Figure 10. Water levels in wells near Paulina Lake, Oregon, June 1991 to October 1995. (Paulina Lake elevation is shown for comparison.)

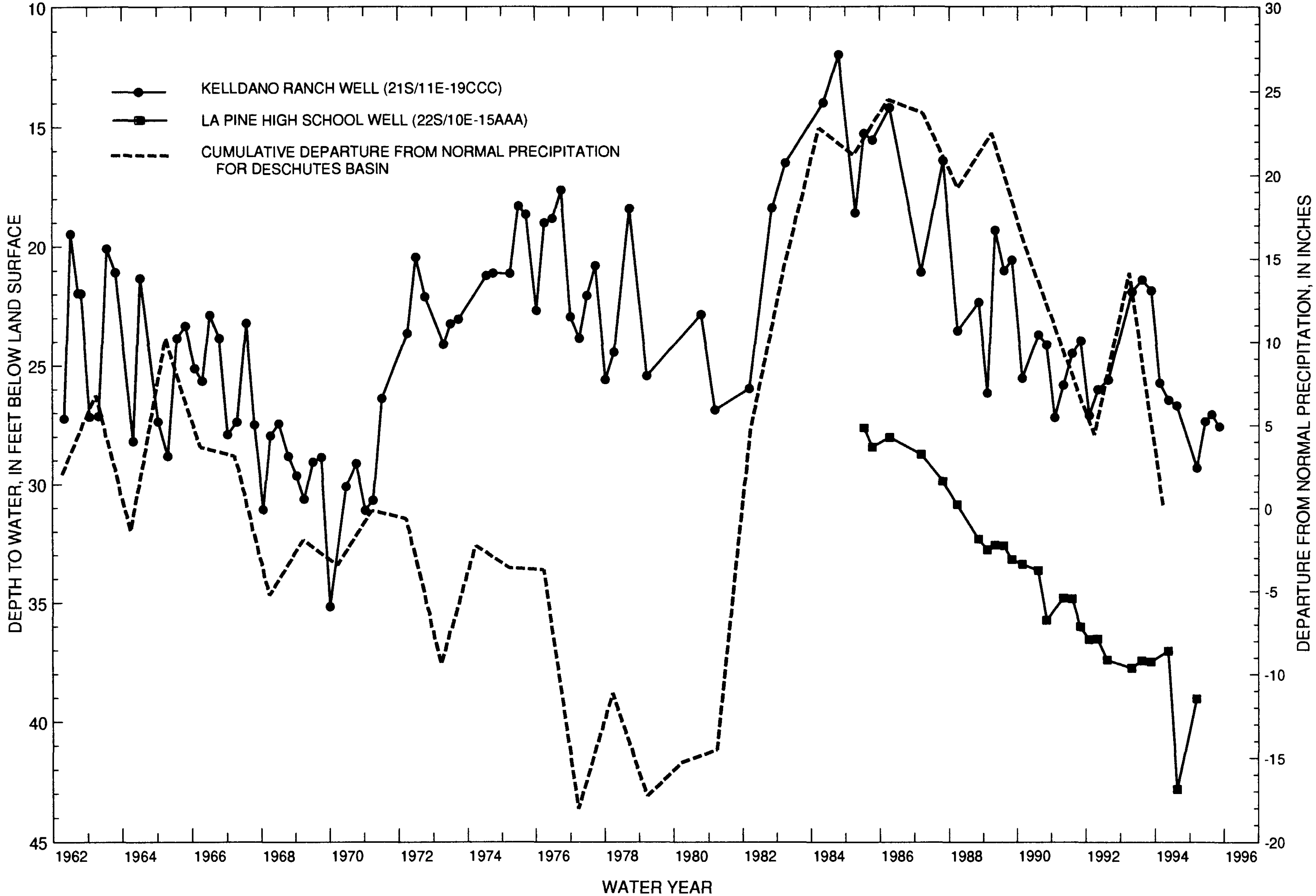


Figure 11. Water levels in long-term observation wells and cumulative departure from normal precipitation (1961–94) in the Deschutes Basin, Oregon.

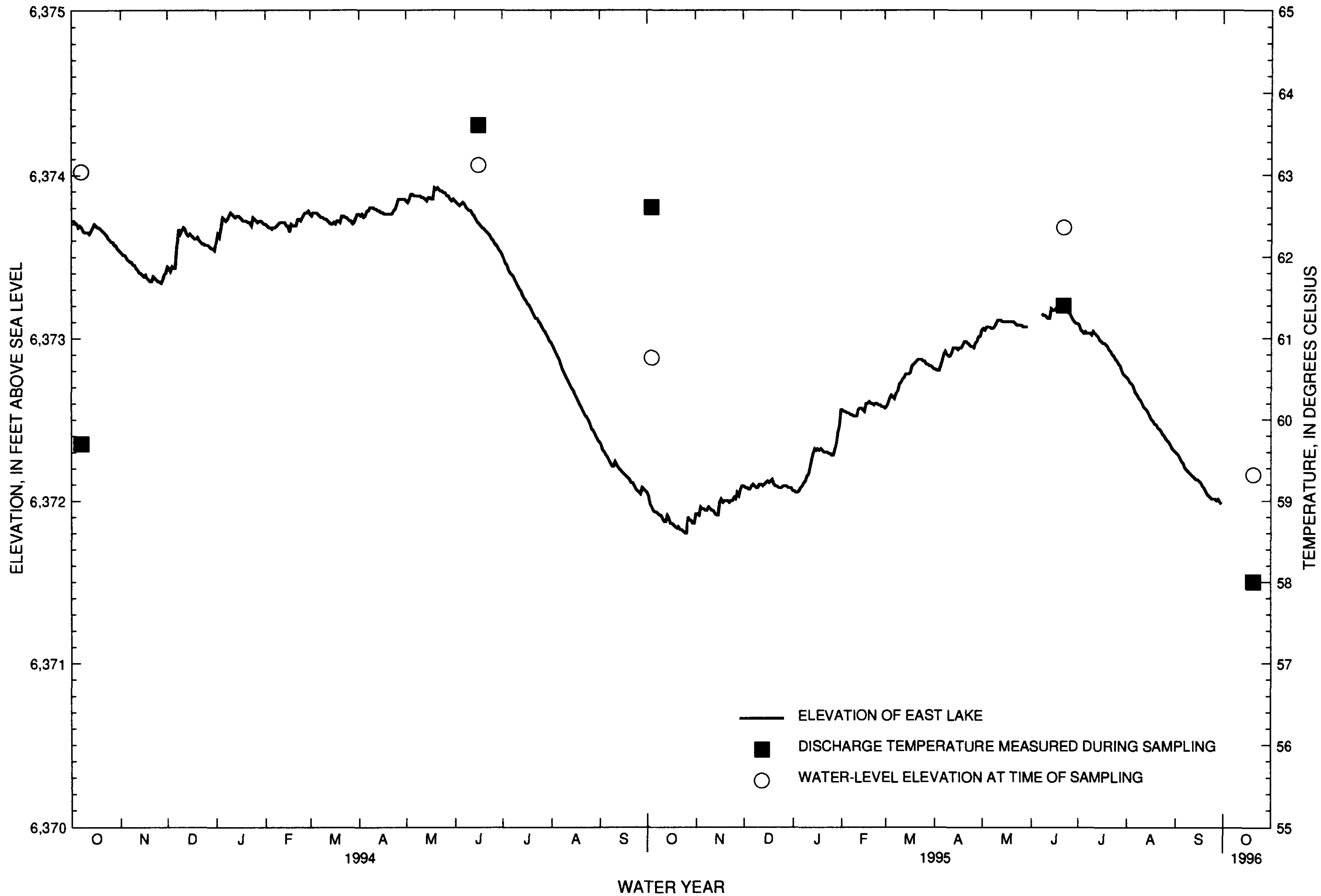


Figure 12. Temperature and water level in piezometer at East Lake Hot Springs No. 5B (21S/13E-31CDD06), Oregon, October 1993 (water year 1994) to October 1995 (water year 1996). (East Lake elevation is shown for comparison.)

The temperature and water chemistry of the Sandia Well (21S/13E-31CDB) indicate that it has a thermal component. Water level was measured semimonthly during periods when the well was accessible. In 1995, a pressure transducer and datalogger were installed to collect continuous water-level and temperature data (fig. 13). These data indicate a possible relation between water level and temperature; during years with normal or above average precipitation (1993, 1995), water levels recovered rapidly from April through June due to snowmelt. Temperatures were lower during this period, possibly as a result of the colder recharge water moving through the system. During the baseline period, the temperature ranged from 23.3 to 26.4°C, with a mean of about 25°C.

Paulina Lake Area

The hot springs at Paulina Lake are located along the northeastern and eastern shores. Most of the discharge occurs along the northeastern shore between the Interlake Obsidian Flow and the hot spring monitoring well (21S/12E-26AAB03) (pl. 1). Water level and temperature were measured at least twice annually in that well. In 1995, a pressure transducer and datalogger were installed to continuously monitor water level and temperature at the hot springs. A few months of data were lost when the datalogger malfunctioned, but good records of temperature and water level were obtained for several months (fig. 14).

The water level in the monitoring well was about 1 ft above the lake stage throughout the year, indicating that the hydraulic gradient, and hence ground-water flow, is always toward the lake. The magnitude of the gradient suggests that there is a strong upward component of ground-water flow near the hot springs. Much of the discharge near the monitoring well flows from fractures in silicified sands and gravels that are exposed near the shore. Temperature is generally about 58°C and is not sensitive to the water level in the monitoring well or lake stage. The first temperatures measured in the well (October 1993 and January 1994) were probably affected by cold water introduced into the hole during the drilling process.

Ground water at the Little Crater Campground No. 3 well (21S/12E-36BAA) also has a large thermal component on the basis of temperature and chemistry. Water level was measured semimonthly during periods when the well was accessible. In 1995, a pressure transducer and datalogger were installed to collect continuous water-level and temperature data (fig. 15). Movement of thermal ground water near Little Crater Campground No. 3 well is toward the lake, as indicated by the water level in the well, which is nearly 1.5 ft above lake stage under most conditions. The temperature in the Little Crater Campground well was very stable at about 36°C.

WATER-QUALITY CONDITIONS

This section describes the distribution of temperature, dissolved constituents, stable isotopes, and radioactivity in the Newberry Volcano area. The distribution of water-quality conditions in the Newberry Volcano area is highly complex due to the geothermal setting of the area. Previous work (Sammel, 1983) suggests that the heat source for thermal waters is of a near-surface origin. The heat source is probably conductive heat flow, as well as steam rising from a deep reservoir. Increased temperature raises the solubility of most rock minerals, resulting in raised concentrations of various water-quality constituents.

Water-quality data were collected from 19 sites in the vicinity of Newberry Volcano (table 3). These data represent baseline, or predevelopment, water-quality conditions in the area. As development of the geothermal resource occurs, resulting physical and chemical changes in the hydrologic system can be assessed with further monitoring.

For ease of discussion, water-quality sampling sites have been separated into three groups: the East Lake area, the Paulina Lake area, and the area outside of Newberry Caldera. There are three wells designated as "East Lake Hot Springs," and two wells designated as "Paulina Lake Hot Springs." The reason that these site names have more than one associated well is that some of the early wells were not satisfactory permanent installations or they were vandalized, necessitating new installations.

Data were collected at Crater Lake, Oregon, by the USGS as part of a separate project during the same time period as the Newberry Volcano study, using the same sampling and analysis methods. Although Crater Lake is outside of the study area, data are included in this report as an example of an alpine lake.

Water-quality data from the Newberry Volcano area for the first 2 years of baseline data collection (1991–93) were published by Crumrine and Morgan (1994); data for 1994–95 are listed in the Appendix of this report.

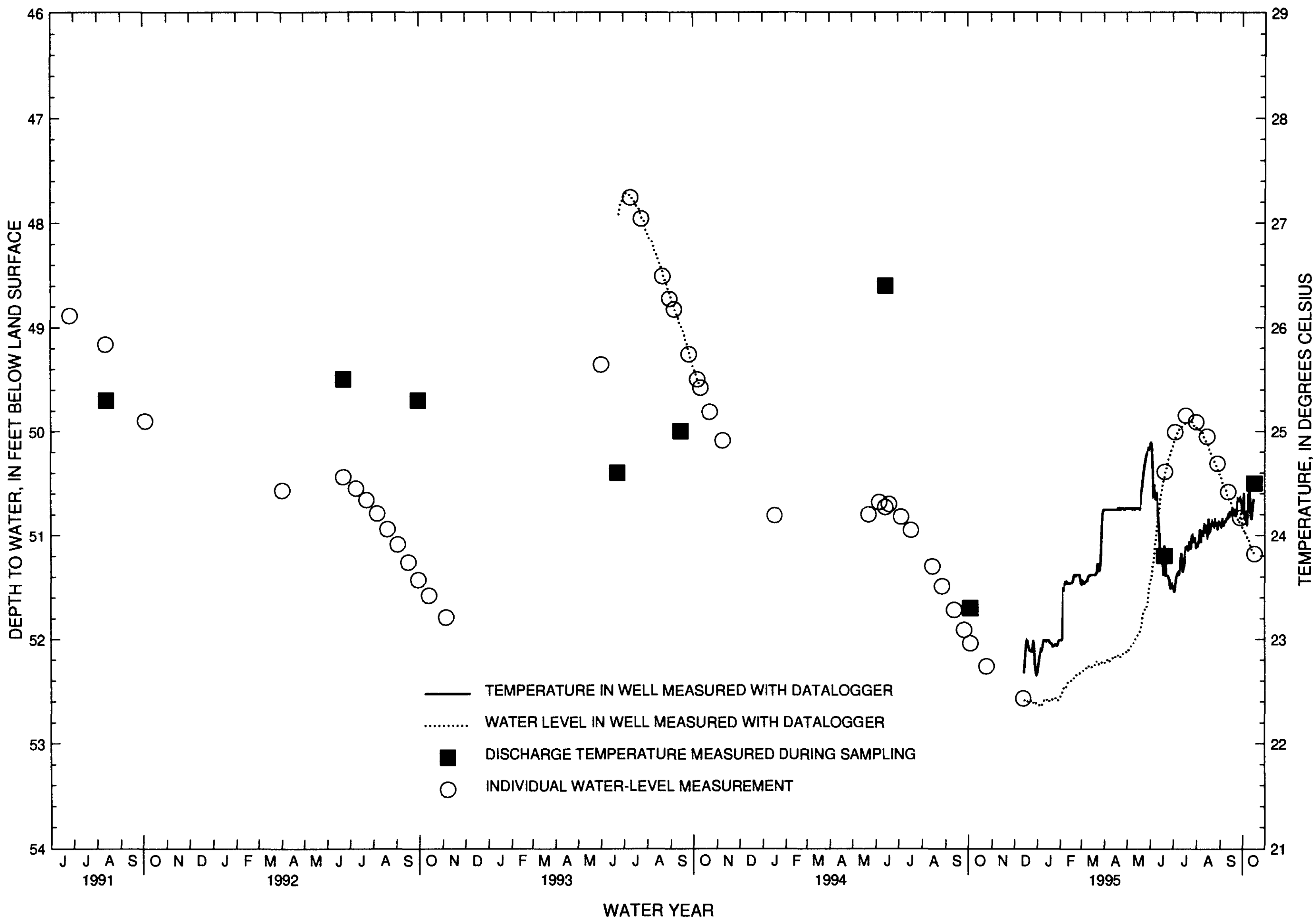


Figure 13. Temperature and water level in the Sandia Well (21S/13E-31CDB), June 1991 to October 1995.

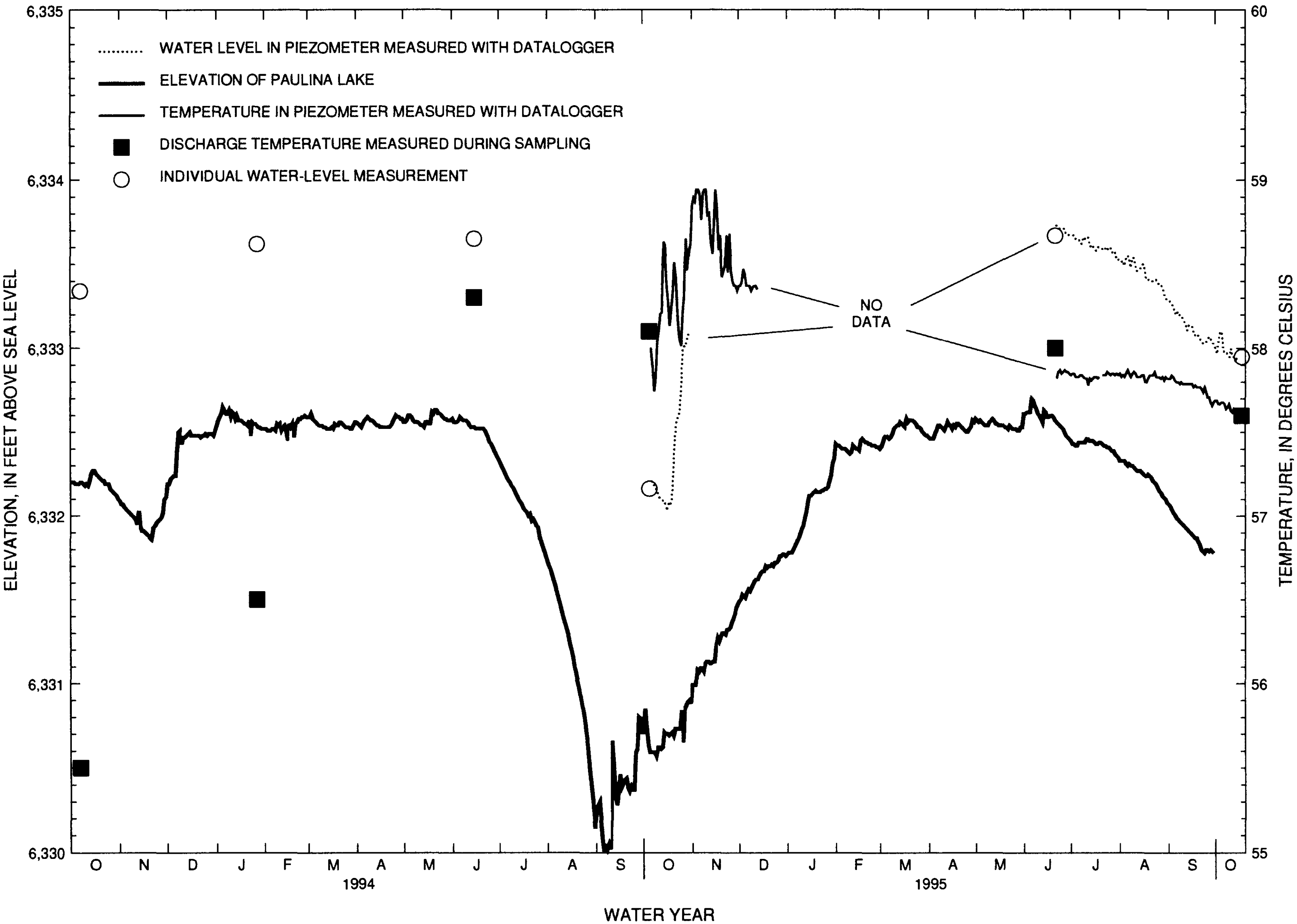


Figure 14. Temperature and water level in piezometer at Paulina Lake Hot Springs No. 2B (21S/12E-26AAB03), Oregon. (Paulina Lake elevation is shown for comparison.)

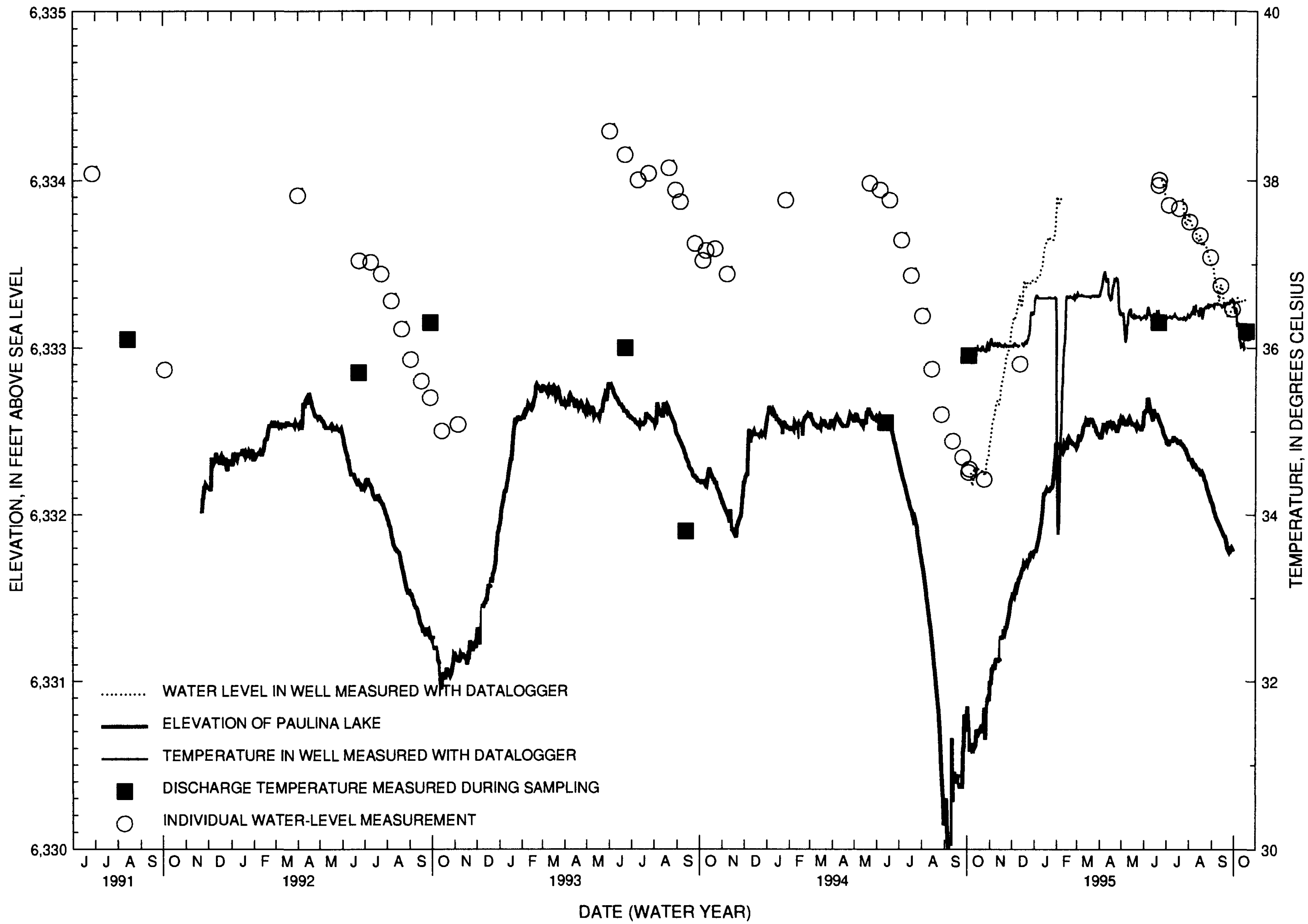


Figure 15. Temperature and water level in Little Crater Campground Well No. 3 (21S/12E-36BAA), Oregon, June 1991 to October 1995. (Paulina Lake elevation is shown for comparison.)

Data-Collection Methods

Samples for chemical analysis were collected in accordance with standard procedures of the U.S. Geological Survey (Brown and others, 1970; Presser and Barnes, 1974; Wood, 1976; Thatcher and others, 1977; Claassen, 1982; and Ward and Harr, 1990). Water temperature, pH, specific conductance, and dissolved-oxygen concentration were measured in the field using instruments that were calibrated daily.

Beginning in the fall of 1993, the protocol described by Horowitz and others (1994) was followed for the collection of samples for trace-element analysis of filtered water. This protocol was developed specifically to address problems inherent in processing samples with analyte concentrations in the parts-per-billion range. Latex gloves were worn by sampling personnel. All equipment used for sampling and processing was washed with Liquinox, and rinsed with hot tap water, with 5-percent (by volume) hydrochloric acid, and with distilled/deionized water. All sampling equipment was rinsed in the water to be sampled prior to sample collection. To further minimize sample contamination, by the fall of 1993, all hot-spring and thermal-well sampling sites consisted of either steel-cased wells with dedicated stainless-steel/teflon pumps or PVC-cased wells sampled with acid-rinsed tubing.

Water samples for laboratory analysis were processed within 2 hours of sampling. Processing included filtering through a 0.45-µm pore-size filter and dispensing into sample bottles. After the fall of 1994, filtered-water samples for trace-element analysis were preserved with ultrapure nitric acid following the methods of Horowitz and others (1994). Filtered-water samples for mercury analysis were preserved with nitric acid/potassium dichromate. Samples for nutrient analysis were preserved with mercuric chloride. Samples were shipped in ice-filled coolers to the USGS National Water Quality Laboratory in Denver, Colorado.

Water samples were analyzed for major ions according to methods of Fishman and Friedman (1989) and Fishman (1993). Nutrients were analyzed according to methods of Patton and Truitt (1992), Fishman (1993), and K.D. Pirkey (USGS, written commun., 1995). Samples for all trace elements except arsenic, selenium, and mercury were analyzed by atomic absorption spectrometry prior to the fall of 1994, and thereafter by inductively coupled plasma-mass spectrometry (Faires, 1993). Arsenic and selenium were analyzed by hydride generation-atomic absorption spectrometry, and mercury was analyzed by cold vapor-atomic absorption spectrometry (Fishman and Friedman, 1989).

On October 18, 1995, ultraclean techniques were used to collect water samples for mercury analysis at East Lake, East Lake Hot Springs, Paulina Lake, and Paulina Lake Hot Springs. Tyvek gowns and latex gloves were worn by sampling personnel, and samples were taken with specially cleaned containers. Grab samples were taken to avoid any contamination from pumps or tubing. These samples were analyzed by the USGS mercury research laboratory in Madison, Wisconsin.

Quality-Assurance Data

Quality-assurance samples were included with routine water-quality samples to access accuracy, precision, the presence of field or laboratory contamination, and analytical bias. The quality-assurance program included both replicate and equipment-blank samples.

To prepare replicate samples, volumes of ambient water were divided into two volumes which were processed separately and sent to the laboratory. Replicate samples provide an estimate of laboratory precision. If the constituent concentrations of the environmental sample and the replicate sample are equal, the laboratory has good measurement precision.

Equipment-blank samples are prepared in the field by processing a volume of distilled-deionized water through all equipment that an ambient water sample would contact (for example, the sampler, sample splitter, pump, tubing, filter, filter holder, and sample bottle). The blank sample is then preserved and analyzed with the batch of regular samples. Equipment-blank samples are used to determine whether (1) the equipment-cleaning protocol adequately removes contamination introduced from previous sampling, (2) the sampling and processing protocol introduces any contamination, and (3) the handling and transport of sampling equipment and supplies between sample collections introduces any contamination. Equipment-blank samples can indicate contamination if there are widespread detections of a constituent significantly larger than the minimum reporting level.

To aid with the interpretation of the environmental data, the quality-assurance data have been organized into the following groups: (1) major ions, (2) trace elements, and (3) nutrients. Although the quality-assurance data cover several constituent groups, the paucity of data within each group often precluded a conclusive analysis.

Replicate samples for major ions showed good laboratory precision over the range of constituent concentrations encountered (table 4). Few major ions were detected in the equipment-blank samples. There were detectable concentrations near the minimum reporting level for calcium, magnesium, chloride, sulfate, fluoride, and silica. However, with the exception of one chloride detection (2.5 mg/L [milligrams per liter]) from September 15, 1993 (table 4), concentrations of major ions in the equipment-blank samples were small relative to those in the environmental samples.

Replicate samples for trace elements also showed good laboratory precision (table 5). Few trace elements were detected in equipment-blank samples. However, detectable concentrations near the minimum reporting level were found for chromium, iron, silver, and zinc, and larger concentrations were detected for boron (40 μg/L [micrograms per liter]) on October 18, 1995 and aluminum (10 μg/L) on June 16, 1994 (table 5). The 40 μg/L detection of boron is small relative to environmental concentrations. However, the 10 μg/L detection of aluminum is in the range of environmental concentrations. It appears that random contamination occurred in the June 16, 1994, equipment-blank sample, because iron, silver, and zinc were detected along with aluminum on that date.

Replicate samples for nutrients and stable isotopes showed good laboratory precision (table 6). Nutrients were not detected in most equipment-blank samples, though ammonia and phosphorus were detected in a few samples at concentrations near the minimum reporting level (table 6).

Temperature

The principal factors controlling surface-water temperatures are energy-transfer processes: inflow of ground water, including geothermally heated water; radiative heat exchange with air (which varies with air temperature); convective and advective vertical and horizontal mixing (which vary with stream velocity, depth, and roughness of the stream channel); and evaporation. Surface-water temperature is important in a biological sense, because increased water temperatures are known to affect aquatic life (MacDonald and others, 1991).

The temperature of ground water reflects the energy transfer between the water and the surrounding rock, and the interaction between the conductive heat flow processes in the earth and convective movement of heat by the ground water itself. In volcanic geothermal areas such as Newberry Volcano, subsurface temperatures are greatly increased by the presence of hot volcanic rock or magma. The temperature of ground water increases as it moves through these areas of elevated temperature, in some case to the point of development of a vapor, or steam, phase. Hot springs and other geothermal features occur where such geothermally heated ground water returns to the surface. Ground water may include a mixture of waters that have followed a variety of paths in the subsurface, including geothermally heated water. Because of this, a wide range of ground-water temperatures can occur over small areas.

Ground- and surface-water temperatures in the Newberry Volcano area vary widely and are controlled, to a large extent, by geothermal sources (table 7). The highest median temperature (63.1°C) was at East Lake Hot Springs No. 5B (21S/13E-29CDD06). In contrast, the Geo-Newberry Well (21S/13E-29DCA; median water temperature, 3.5°C) and Hot Springs Campground No. 1 (21S/13E-32ABB; median water temperature, 8.4°C), both represent ground water in the East Lake area that is not greatly affected by geothermal sources. In the Paulina Lake area, Paulina Lake Hot Springs No. 1 and 2B (21S/12E-26AAB01,03), Little Crater Campground No. 3 (21S/12E-36BAA), and the Sandia Well (21S/13E-31CDB) are affected by geothermal water, as indicated by their median water temperatures. Outside of the Newberry Caldera area, median water temperatures were approximately equal to nonthermal waters inside the caldera area.

For the three surface-water sites in the Newberry Caldera, the largest median was 10.9°C and the smallest median was 10.2°C. These lower temperatures indicate that atmospheric and meteoric conditions were controlling surface-water temperature, and not geothermal ground-water sources.

Table 4. Quality-assurance data for major ions in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[The term "filtered water" is an operational definition referring to the portion of a water sample that passes through a nominal 0.45-micrometer filter. Values are reported in milligrams per liter; silica is reported as SiO_2; TDS, total dissolved solids at 180 degrees Celsius; --, not applicable, <, less than. See table 3 for site names]

Site location	Date	Time	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate	Fluoride	Silica	TDS
Replicate samples												
21S/12E-26AAB03	950621	1700	--	56	45	120	17	4.7	3.2	0.6	220	846
21S/12E-26AAB03	950621	1700	632	56	45	120	16	4.8	3.2	.6	220	854
21S/12E-26ADA01	951018	1502	342	26	38	49	5.8	2.3	2.2	.6	42	357
21S/12E-26ADA01	951018	1507	342	26	38	49	5.7	2.2	2.2	.6	42	356
21S/12E-34BDA	930624	1730	--	26	37	46	5.2	2.2	2.6	.6	40	--
21S/12E-34BDA	930624	1730	340	25	36	46	5.4	2.3	2.7	.6	40	--
21S/13E-31CDB	930914	1530	444	47	44	57	9.0	6.6	.1	.5	89	--
21S/13E-31CDB	930914	1530	444	47	44	57	9.1	6.2	.2	.5	88	--
21S/13E-31CDB	941005	1400	382	39	40	57	8.6	1.8	.3	.6	93	440
21S/13E-31CDB	941005	1408	382	38	39	56	8.5	1.7	.3	.6	90	439
Equipment-blank samples												
--	930625	0900	--	< .02	< .01	< .2	< .1	< .1	.2	< .1	.02	--
--	930915	1340	--	< .02	< .01	< .2	< .1	2.5	< .1	.1	.03	--
--	940616	1500	--	< .02	< .01	< .2	< .1	.1	< .1	< .1	.03	--
--	941006	1500	--	< .02	< .01	< .2	< .1	< .1	.2	< .1	< .01	< 1
--	950622	1130	--	.03	.01	< .2	< .1	< .1	< .1	< .1	< .01	< 1
--	951018	1330	--	< .02	< .01	< .2	< .1	< .1	< .1	.2	.15	< 1

Table 5. Quality-assurance data for trace elements in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[The term "filtered water" is an operational definition referring to the portion of a water sample that passes through a nominal 0.45-micrometer filter; values are reported in micrograms per liter; <, less than; --, not analyzed or not applicable; minimum reporting levels may not match values listed in table 10 if more than one minimum reporting level was used during period of record summarized in that table. See table 3 for site names]

Site location	Date	Time	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese
Replicate samples													
21S/12E-26AAB03	950621	1700	10	316	< 1	920	< 1	3	2	< 1	610	< 1	1,160
21S/12E-26AAB03	950621	1700	10	320	< 1	950	< 1	3	2	< 1	540	< 1	1,200
21S/12E-26ADA01	951018	1502	15	19	< 1	880	< 1	1	< 1	< 1	24	< 1	5
21S/12E-26ADA01	951018	1507	15	19	< 1	900	< 1	1	< 1	< 1	27	< 1	5
21S/12E-34BDA	930624	1730	15	17	< .5	950	< 1	< 5	< 3	< 10	7	< 10	8
21S/12E-34BDA	930624	1730	16	18	< .5	920	< 1	< 5	< 3	< 10	6	< 10	8
21S/13E-29CDD01	910815	1415	< 1	< 100	--	1,200	< 1	< 1	--	< 1	410	< 1	1,000
21S/13E-29CDD01	910815	1415	< 1	< 100	--	--	< 1	< 1	--	< 1	--	< 1	--
21S/13E-31CDB	930914	1530	19	13	< .5	910	< 1	< 5	< 3	< 10	11	< 10	7
21S/13E-31CDB	930914	1530	17	13	< .5	940	1	< 5	< 3	< 10	21	< 10	7
21S/13E-31CDB	941005	1400	20	14	< 1	590	< 1	4	< 1	< 1	32	< 1	3
21S/13E-31CDB	941005	1408	20	13	< 1	620	< 1	4	< 1	< 1	38	< 1	3
Equipment-blank samples													
--	921001	0900	< 1	< 100	--	--	< 1	2	--	< 1	--	< 1	--
--	930625	0900	< 1	< 2	< .5	< 10	< 1	< 5	< 3	< 10	< 3	< 10	< 1
--	930915	1340	< 1	< 2	< .5	< 10	< 1	< 5	< 3	< 10	< 3	< 10	< 1
--	940616	1500	< 1	< 2	< .5	< 10	< 1	< 5	< 3	< 10	3	< 10	< 1
--	941006	1500	< 1	< 1	< 1	< 10	< 1	< 1	< 1	< 1	3	< 1	< 1
--	950622	1130	< 1	< 1	< 1	< 10	< 1	< 1	< 1	< 1	< 3	< 1	< 1
--	951018	1330	< 1	< 1	< 1	40	< 1	< 1	< 1	< 1	< 3	< 1	< 1

Table 5. Quality-assurance data for trace elements in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Date	Time	Molybdenum	Nickel	Silver	Strontium	Vanadium	Zinc	Aluminum	Lithium	Selenium	Mercury
Replicate samples												
21S/12E-26AAB03	950621	1700	< 1	13	< 1	200	--	56	3	220	< 1	--
21S/12E-26AAB03	950621	1700	< 1	11	< 1	200	--	51	3	210	< 1	--
21S/12E-26ADA01	951018	1502	< 1	2	< 1	91	< 1	< 1	3	70	< 1	--
21S/12E-26ADA01	951018	1507	1	1	< 1	91	--	< 1	3	70	< 1	--
21S/12E-34BDA	930624	1730	< 10	< 10	< 1	82	< 6	< 3	--	69	--	< .1
21S/12E-34BDA	930624	1730	< 10	< 10	< 1	83	< 6	< 3	--	69	--	< .1
21S/13E-29CDD01	910815	1415	< 1	--	< 1	230	--	< 10	< 10	30	< 1	< 0.1
21S/13E-29CDD01	910815	1415	< 1	--	< 1	220	--	< 10	--	30	< 1	--
21S/13E-31CDB	930914	1530	20	< 10	< 1	140	27	3	--	89	--	.1
21S/13E-31CDB	930914	1530	< 10	< 10	< 1	140	27	4	--	89	--	< .1
21S/13E-31CDB	941005	1400	1	2	1	120	2	1	1	88	< 1	< .1
21S/13E-31CDB	941005	1408	< 1	1	< 1	120	--	1	1	86	< 1	< .1
Equipment-blank samples												
--	921001	0900	< 1	--	< 1	< 10	--	< 10	--	< 10	< 1	< .1
--	930625	0900	< 10	< 10	< 1	< 1	< 6	< 3	--	< 4	--	< .1
--	930915	1340	< 10	< 10	< 1	< 1	< 6	< 3	--	< 4	--	--
--	940616	1500	< 10	< 10	2	< 1	< 6	4	10	< 4	--	< .1
--	941006	1500	< 1	< 1	< 1	< 1	--	< 1	< 1	< 4	< 1	< .1
--	950622	1130	< 1	< 1	< 1	< 1	--	< 1	< 1	< 4	< 1	--
--	951018	1330	< 1	< 1	< 1	< 1	--	1	3	< 4	< 1	--

Table 6. Quality-assurance data for nutrients and stable isotopes in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[The term "filtered water" is an operational definition referring to the water sample that passes through a nominal 0.45-micrometer filter; values are reported in milligrams per liter, except for the isotope ratios which are in units of per mil deviations from Standard Mean Ocean Water (SMOW). <, less than; --, not analyzed or not applicable; minimum reporting levels may not match values listed in table 9 if more than one minimum reporting level was used during period of record summarized in that table. See table 3 for site names]

Site location	Date	Time	Ammonia	Nitrite	Nitrite plus nitrate	Orthophosphate	Phosphorus	Hydrogen isotope ratio	Oxygen isotope ratio
Replicate samples									
21S/12E-26AAB03	950621	1700	0.46	< 0.01	< 0.05	0.10	0.11	-111	-14.5
21S/12E-26AAB03	950621	1700	.46	< .01	< .05	.12	.12	-109	-14.5
21S/12E-26ADA01	951018	1502	< .015	< .01	< .05	.01	< .01	-91.3	-11.1
21S/12E-26ADA01	951018	1507	< .015	< .01	< .05	< .01	.01	-91.7	-11.0
21S/12E-34BDA	930624	1730	.02	< .01	< .05	.01	.01	-93.0	-11.6
21S/12E-34BDA	930624	1730	.02	< .01	< .05	.01	< .01	-93.8	-11.6
21S/13E-31CDB	930914	1530	.02	< .01	.21	.24	.23	-114	-15.2
21S/13E-31CDB	930914	1530	.02	< .01	.20	.24	.24	-113	-15.2
21S/13E-31CDB	941005	1400	< .015	< .01	.18	.27	.23	-114	-15.0
21S/13E-31CDB	941005	1408	--	--	--	--	--	-112	-15.1
Equipment-blank samples									
--	930915	1340	.02	< .01	< .05	< .01	< .01	--	--
--	940616	1500	< .010	< .01	< .05	< .01	.03	--	--
--	941006	1500	< .015	< .01	< .05	< .01	< .01	--	--
--	950622	1130	< .015	< .01	< .05	< .01	.01	--	--
--	951018	1330	< .015	< .01	< .05	< .01	< .01	--	--

Table 7. Statistical summary of water temperature at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[To avoid statistical bias that may be associated with constituents analyzed more than once at a site, only the mean value of each day was statistically summarized; values are reported in degrees Celsius; -- indicates fewer than 5 samples collected; therefore, percentile not calculated. See table 3 for site names]

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
			East Lake Area					
21S/13E-29CDA01	7	9.2	9.2	9.4	10.8	12.6	14.5	14.5
21S/13E-29CDD01	3	52.7	--	--	60.2	--	--	66.8
21S/13E-29CDD02	4	42.0	--	--	47.2	--	--	49.6
21S/13E-29CDD06	5	58.0	58.8	61.4	63.1	63.6	63.6	63.6
21S/13E-29DCA	6	3.4	3.4	3.4	3.5	3.6	3.6	3.6
21S/13E-32ABB	6	7.5	7.5	7.6	8.4	9.3	9.9	9.9
			Paulina Lake Area					
21S/12E-26AAB01	6	33.9	33.9	34.6	40.0	42.3	45.3	45.3
21S/12E-26AAB03	5	55.6	55.6	56.0	58.0	58.2	58.3	58.3
21S/12E-26ADA01	7	7.6	7.6	7.9	10.2	13.2	14.0	14.0
21S/12E-34ACC	6	4.8	4.8	4.8	4.8	5.0	5.1	5.1
21S/12E-34BDA	9	7.0	7.0	8.7	10.9	13.9	16.1	16.1
21S/12E-35DCB	5	5.7	5.7	5.7	5.8	6.5	6.9	6.9
21S/12E-36BAA	9	33.8	33.8	35.4	36.0	36.2	36.3	36.3
21S/13E-31CDB	9	22.9	22.9	23.6	24.6	25.4	26.4	26.4
			Outside Newberry Caldera					
CRATER LAKE (See fig. 1)	13	6.5	7.5	10.5	11.8	14.0	15.1	15.6
21S/11E-28BCA	9	3.5	3.5	9.8	12.4	14.4	18.7	18.7
21S/11E-28CBA	4	9.8	--	--	10.0	--	--	10.2
22S/10E-15AAA	2	8.3	--	--	8.8	--	--	9.4
22S/14E-22BBC	2	11.3	--	--	11.5	--	--	11.6

Major Ions and Related Measurements

Major cations in water include calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+}), and sodium (Na^{+}). Major anions include chloride (Cl^{-}), fluoride (F^{-}), and sulfate (SO_4^{-2}). Sources of major ions in water include the dissolution of minerals and organic compounds in rocks and soils.

In the Newberry Volcano area, major ions were present in higher concentrations in geothermal water (table 8). This is not surprising, because the solubility of most minerals increases with temperature. The highest median concentrations of calcium (larger than 55.0 mg/L) were in East Lake Hot Springs Nos. 4, 3, and 5B (21S/13E-29CDD01,02,06). The highest median concentrations of magnesium (larger than 38 mg/L), potassium (larger than 9.4 mg/L), and sodium (larger than 58.0 mg/L) were in Paulina Lake Hot Springs No. 1 and 2B (21S/12E-26AAB01,03), and Little Crater Campground No. 3 (21S/12E-36BAA). The largest median concentrations of chloride were in Paulina Lake Hot Springs No. 1 (21S/12E-26AAB01, 6.6 mg/L) and Crater Lake (fig. 1, 9.9 mg/L) (table 8). The largest median concentrations of sulfate were in East Lake EL-8-30 (21S/13E-29CDA01, 65.0 mg/L) and East Lake Hot Springs No. 5B (21S/13E-29CDD06, 10.0 mg/L).

The interrelationships among major ions can be illustrated using Piper diagrams (fig. 16). At most sites in the East Lake Area, bicarbonate is the predominant anion. The single exception is the surface-water site, East Lake, which has a considerable concentration of sulfate. "The higher sulfate concentrations [of East Lake Hot Spring water] are probably caused by oxidation of hydrogen sulfide gas dissolved in ground water" (Sammel and Craig, 1983, p. 26–27). In the Paulina Lake area, sodium, magnesium, and bicarbonate are the predominant ions (fig. 16). Outside of the Newberry Caldera, calcium, magnesium, and bicarbonate are the dominant major ions in surface water. The exception is Crater Lake, which is higher in sulfate and chloride, perhaps due to concentration by evaporation from the lake.

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995

[All measurements were performed on filtered-water samples, except specific conductance and pH, which were determined from unfiltered-water samples; the term "filtered water" is an operational definition referring to the chemical analysis of that portion of a water sample that passes through a nominal 0.45-micrometer filter; conversely, the term "unfiltered water" refers to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix; to avoid statistical bias that may be associated with constituents analyzed more than once at a site, only the mean concentration of each day was statistically summarized; for the purposes of calculating percentiles, censored values were assigned a value of one-half the minimum reporting level; if two different minimum reporting levels were used, the higher of the two was reported in this distribution; values are reported in milligrams per liter, except where shown to be otherwise; -- indicates fewer than 5 samples collected; therefore, percentile not calculated; <, less than. See table 3 for site names]

Site location	Number of samples	Minimum value	Value at indicated percentile: 10	25	50	75	90	Maximum value
Alkalinity								
East Lake Area								
21S/13E-29CDA01	7	97	97	100	101	103	104	104
21S/13E-29CDD01	3	456	--	--	462	--	--	488
21S/13E-29CDD02	2	350	--	--	374	--	--	398
21S/13E-29CDD06	3	442	--	--	450	--	--	450
21S/13E-29DCA	6	25	25	25	28	31	38	38
21S/13E-32ABB	6	60	60	82	123	142	142	142
Paulina Lake Area								
21S/12E-26AAB01	6	586	586	592	611	628	629	629
21S/12E-26AAB03	4	612	--	--	632	--	--	640
21S/12E-26ADA01	7	320	320	331	342	344	346	346
21S/12E-34ACC	6	32	32	33	33	37	40	40
21S/12E-34BDA	9	320	320	324	336	340	343	343
21S/12E-35DCB	4	42	--	--	46	--	--	46
21S/12E-36BAA	9	382	382	562	570	572	580	580
21S/13E-31CDB	9	284	284	348	382	427	444	444
Outside Newberry Caldera								
CRATER LAKE	12	28	28	28	29	30	31	31
21S/11E-28BCA	10	319	320	333	342	350	352	352
21S/11E-28CBA	5	35	35	35	38	38	39	39
22S/10E-15AAA	2	55	--	--	56	--	--	56
22S/14E-22BBC	2	49	--	--	50	--	--	50
Calcium								
East Lake Area								
21S/13E-29CDA01	7	24	24	24	25	26	26	26
21S/13E-29CDD01	3	67	--	--	68	--	--	76
21S/13E-29CDD02	3	48	--	--	56	--	--	57
21S/13E-29CDD06	5	61	61	68	72	76	78	78
21S/13E-29DCA	6	4.2	4.2	4.3	4.4	4.5	4.5	4.5
21S/13E-32ABB	6	9.9	9.9	13	21	25	25	25
Paulina Lake Area								
21S/12E-26AAB01	6	47	47	48	50	54	56	56
21S/12E-26AAB03	5	49	49	52	55	56	56	56
21S/12E-26ADA01	7	26	26	26	28	29	29	29
21S/12E-34ACC	6	3.3	3.3	3.4	3.5	3.5	3.6	3.6
21S/12E-34BDA	10	26	26	26	28	28	29	29
21S/12E-35DCB	5	6.9	6.9	7.0	7.2	7.4	7.5	7.5
21S/12E-36BAA	9	45	45	50	53	56	57	57
21S/13E-31CDB	9	27	27	36	39	42	47	47
Outside Newberry Caldera								
CRATER LAKE	14	6.5	6.6	6.6	6.8	6.9	7.0	7.1
21S/11E-28BCA	10	25	25	27	27	28	28	28
21S/11E-28CBA	5	3.9	3.9	4.0	4.0	4.1	4.2	4.2
22S/10E-15AAA	2	5.1	--	--	5.2	--	--	5.4
22S/14E-22BBC	2	4.1	--	--	4.2	--	--	4.4

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Chloride								
East Lake Area								
21S/13E-29CDA01	7	0.1	0.1	0.3	0.4	0.5	0.5	0.5
21S/13E-29CDD01	3	.9	--	--	2.3	--	--	6.9
21S/13E-29CDD02	3	.8	--	--	1.1	--	--	2.4
21S/13E-29CDD06	5	.8	.8	.8	.8	14	24	24
21S/13E-29DCA	6	<.1	<.1	.2	.3	1.1	3.3	3.3
21S/13E-32ABB	5	.4	.4	.4	.5	6.3	12	12
Paulina Lake Area								
21S/12E-26AAB01	6	4.9	4.9	5.4	6.6	11	12	12
21S/12E-26AAB03	5	4.7	4.7	4.8	5.1	6.2	7.1	7.1
21S/12E-26ADA01	7	1.9	1.9	2.2	2.3	2.5	4.5	4.5
21S/12E-34ACC	6	.5	.5	.6	.8	2.7	7.4	7.4
21S/12E-34BDA	9	1.7	1.7	2.1	2.2	3.5	5.2	5.2
21S/12E-35DCB	5	1.7	1.7	1.9	2.7	3.0	3.2	3.2
21S/12E-36BAA	9	.4	.4	5.4	5.6	6.4	7.1	7.1
21S/13E-31CDB	8	1.8	1.8	2.1	2.6	5.4	6.6	6.6
Outside Newberry Caldera								
CRATER LAKE	14	9.0	9.1	9.5	9.9	10	11	11
21S/11E-28BCA	9	1.6	1.6	2.2	2.4	3.2	4.8	4.8
21S/11E-28CBA	5	.1	.1	.4	.8	2.4	3.9	3.9
22S/10E-15AAA	2	.7	--	--	2.0	--	--	3.2
22S/14E-22BBC	2	1.8	--	--	3.0	--	--	4.1
Fluoride								
East Lake Area								
21S/13E-29CDA01	7	.1	.1	.1	.2	.2	.2	.2
21S/13E-29CDD01	3	<.1	--	--	.1	--	--	.2
21S/13E-29CDD02	3	.1	--	--	.2	--	--	.2
21S/13E-29CDD06	5	<.1	<.1	<.1	.1	.2	.2	.2
21S/13E-29DCA	6	<.1	<.1	<.1	<.1	.1	.2	.2
21S/13E-32ABB	6	<.1	<.1	<.1	<.1	.1	.2	.2
Paulina Lake Area								
21S/12E-26AAB01	6	<.1	<.1	.5	.6	.6	.8	.8
21S/12E-26AAB03	5	.5	.5	.6	.6	.6	.7	.7
21S/12E-26ADA01	7	.6	.6	.6	.7	.7	.7	.7
21S/12E-34ACC	6	.7	.7	.7	.7	.7	.8	.8
21S/12E-34BDA	10	.6	.6	.6	.6	.7	.8	.8
21S/12E-35DCB	5	<.1	<.1	<.1	.2	.2	.2	.2
21S/12E-36BAA	9	.4	.4	.5	.5	.6	.6	.6
21S/13E-31CDB	9	.5	.5	.5	.5	.6	.8	.8
Outside Newberry Caldera								
CRATER LAKE	14	<.1	<.1	<.1	.1	.1	.2	.2
21S/11E-28BCA	10	.6	.6	.6	.7	.7	.7	.7
21S/11E-28CBA	5	<.1	<.1	<.1	.1	.2	.2	.2
22S/10E-15AAA	2	.1	--	--	.1	--	--	.1
22S/14E-22BBC	2	.2	--	--	.2	--	--	.2
Magnesium								
East Lake Area								
21S/13E-29CDA01	7	11	11	11	12	12	13	13
21S/13E-29CDD01	3	33	--	--	33	--	--	37
21S/13E-29CDD02	3	23	--	--	25	--	--	28
21S/13E-29CDD06	5	31	31	32	34	36	37	37
21S/13E-29DCA	6	1.9	1.9	1.9	2.0	2.0	2.1	2.1
21S/13E-32ABB	6	4.2	4.2	5.4	8.8	10	10	10

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Magnesium—Continued								
Paulina Lake Area								
21S/12E-26AAB01	6	41	41	41	42	46	48	48
21S/12E-26AAB03	5	42	42	43	45	47	48	48
21S/12E-26ADA01	7	37	37	37	38	39	41	41
21S/12E-34ACC	6	2.7	2.7	2.7	2.8	2.9	2.9	2.9
21S/12E-34BDA	10	37	37	37	38	41	41	41
21S/12E-35DCB	5	4.0	4.0	4.0	4.1	4.3	4.4	4.4
21S/12E-36BAA	9	44	44	48	50	52	54	54
21S/13E-31CDB	9	25	25	34	37	42	44	44
Outside Newberry Caldera								
CRATER LAKE	14	2.5	2.5	2.6	2.6	2.6	2.6	2.7
21S/11E-28BCA	10	36	36	38	38	39.5	42	42
21S/11E-28CBA	5	2.9	2.9	2.9	3.1	3.2	3.3	3.3
22S/10E-15AAA	2	5.1	--	--	5.2	--	--	5.2
22S/14E-22BBC	2	3.6	--	--	3.6	--	--	3.7
pH, in standard units								
East Lake Area								
21S/13E-29CDA01	7	6.9	6.9	7.0	7.2	7.5	7.6	7.6
21S/13E-29CDD01	3	6.2	--	--	6.4	--	--	6.8
21S/13E-29CDD02	3	5.9	--	--	6.0	--	--	6.0
21S/13E-29CDD06	5	6.3	6.3	6.3	6.3	6.5	6.6	6.6
21S/13E-29DCA	6	8.1	8.1	8.3	8.5	8.6	8.7	8.7
21S/13E-32ABB	6	6.5	6.5	6.5	6.6	6.7	6.7	6.8
Paulina Lake Area								
21S/12E-26AAB01	6	6.3	6.3	6.3	6.3	6.5	6.7	6.7
21S/12E-26AAB03	5	6.2	6.2	6.3	6.4	6.8	7.2	7.2
21S/12E-26ADA01	7	8.0	8.0	8.1	8.3	8.4	8.4	8.4
21S/12E-34ACC	6	6.9	6.9	7.0	7.1	7.3	7.5	7.5
21S/12E-34BDA	10	8.2	8.2	8.4	8.5	8.7	8.8	8.8
21S/12E-35DCB	5	7.1	7.1	7.1	7.2	7.2	7.2	7.2
21S/12E-36BAA	9	5.8	5.8	5.8	6.0	6.0	6.0	6.0
21S/13E-31CDB	9	6.2	6.2	6.2	6.3	6.3	6.4	6.4
Outside Newberry Caldera								
CRATER LAKE	13	7.0	7.1	7.4	7.6	7.8	7.9	7.9
21S/11E-28BCA	10	8.5	8.5	8.7	8.8	8.8	9.0	9.1
21S/11E-28CBA	5	7.7	7.7	7.7	7.9	8.1	8.2	8.2
22S/10E-15AAA	2	7.9	--	--	8.2	--	--	8.4
22S/14E-22BBC	2	8.1	--	--	8.3	--	--	8.6
Potassium								
East Lake Area								
21S/13E-29CDA01	7	3.5	3.5	3.7	3.8	3.9	4.0	4.0
21S/13E-29CDD01	3	8.0	--	--	8.7	--	--	11
21S/13E-29CDD02	3	8.4	--	--	9.4	--	--	10
21S/13E-29CDD06	5	7.7	7.7	8.0	8.3	9.0	9.4	9.4
21S/13E-29DCA	6	.6	.6	.6	.7	.7	.7	.7
21S/13E-32ABB	6	2.5	2.5	2.9	3.2	4.1	4.3	4.3
Paulina Lake Area								
21S/12E-26AAB01	6	13	13	14	16	17	18	18
21S/12E-26AAB03	5	8.2	8.2	12	16	16	17	17
21S/12E-26ADA01	7	5.2	5.2	5.3	5.6	5.8	5.9	5.9
21S/12E-34ACC	6	1.6	1.6	1.6	1.6	1.6	1.7	1.7
21S/12E-34BDA	10	5.0	5.0	5.2	5.4	5.4	6.0	6.0
21S/12E-35DCB	5	1.6	1.6	1.6	1.6	1.6	1.7	1.7
21S/12E-36BAA	9	10	10	10	11	11	12	12
21S/13E-31CDB	9	7.2	7.2	7.6	8.3	8.8	9.0	9.0

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Potassium—Continued								
Outside Newberry Caldera								
CRATER LAKE	14	1.4	1.5	1.6	1.7	1.8	2.0	2.0
21S/11E-28BCA	10	4.1	4.2	5.2	5.4	5.4	5.5	5.5
21S/11E-28CBA	5	1.4	1.4	1.4	1.4	1.4	1.5	1.5
22S/10E-15AAA	2	1.7	--	--	1.8	--	--	1.8
22S/14E-22BBC	2	1.9	--	--	1.9	--	--	1.9
Silica								
East Lake Area								
21S/13E-29CDA01	7	8.7	8.7	9.1	9.9	11	11	11
21S/13E-29CDD01	3	140	--	--	210	--	--	230
21S/13E-29CDD02	3	150	--	--	160	--	--	170
21S/13E-29CDD06	5	200	200	200	220	225	230	230
21S/13E-29DCA	6	22	22	22	23	23	24	24
21S/13E-32ABB	6	41	41	43	48	50	53	53
Paulina Lake Area								
21S/12E-26AAB01	6	140	140	178	190	202	210	210
21S/12E-26AAB03	5	200	200	205	210	220	220	220
21S/12E-26ADA01	7	39	39	42	43	43	45	45
21S/12E-34ACC	6	43	43	44	44	47	48	48
21S/12E-34BDA	10	40	40	44	42	42	45	45
21S/12E-35DCB	5	43	43	44	45	47	47	47
21S/12E-36BAA	9	130	130	135	150	155	160	160
21S/13E-31CDB	9	77	77	82	90	92	93	93
Outside Newberry Caldera								
CRATER LAKE	14	17	17	17	17	18	18	18
21S/11E-28BCA	10	37	37	39	40	41	43	43
21S/11E-28CBA	5	34	34	34	35	37	37	37
22S/10E-15AAA	2	28	--	--	30	--	--	31
22S/14E-22BBC	2	37	--	--	38	--	--	40
Sodium								
East Lake Area								
21S/13E-29CDA01	7	23	23	23	24	26	26	26
21S/13E-29CDD01	3	53	--	--	58	--	--	59
21S/13E-29CDD02	3	51	--	--	53	--	--	54
21S/13E-29CDD06	5	52	52	52	54	55	56	56
21S/13E-29DCA	6	3.6	3.6	3.6	3.8	4.1	4.3	4.3
21S/13E-32ABB	6	9.1	9.1	10	15	16	17	17
Paulina Lake Area								
21S/12E-26AAB01	6	110	110	110	120	130	130	130
21S/12E-26AAB03	5	120	120	120	130	130	130	130
21S/12E-26ADA01	7	46	46	46	48	49	49	49
21S/12E-34ACC	6	6.5	6.5	6.6	6.8	6.8	7.0	7.0
21S/12E-34BDA	10	45	45	46	47	49	49	49
21S/12E-35DCB	5	5.7	5.7	5.7	5.7	6.3	6.4	6.4
21S/12E-36BAA	9	77	77	84	86	89	90	90
21S/13E-31CDB	9	46	46	48	57	58	59	59
Outside Newberry Caldera								
CRATER LAKE	14	10	10	10	10	11	11	11
21S/11E-28BCA	10	46	46	46	46	49	50	50
21S/11E-28CBA	5	7.2	7.2	7.2	7.4	7.8	8.0	8.0
22S/10E-15AAA	2	9.0	--	--	9.5	--	--	10
22S/14E-22BBC	2	11	--	--	11	--	--	11

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Specific conductance, in microsiemens per centimeter								
East Lake Area								
21S/13E-29CDA01	7	319	319	325	330	333	339	339
21S/13E-29CDD01	3	788	--	--	826	--	--	875
21S/13E-29CDD02	4	626	--	--	728	--	--	880
21S/13E-29CDD06	5	784	784	790	814	872	898	898
21S/13E-29DCA	6	46	46	46	49	52	53	53
21S/13E-32ABB	6	117	117	151	224	260	265	265
Paulina Lake Area								
21S/12E-26AAB01	6	1,034	1,034	1,037	1,070	1,080	1,111	1,111
21S/12E-26AAB03	5	1,100	1,100	1,112	1,145	1,154	1,158	1,158
21S/12E-26ADA01	7	571	571	577	590	592	601	601
21S/12E-34ACC	6	63	63	64	66	69	72	72
21S/12E-34BDA	10	561	562	568	587	591	597	598
21S/12E-35DCB	5	87	87	88	90	96	98	98
21S/12E-36BAA	9	959	959	964	981	1,014	1,035	1,035
21S/13E-31CDB	9	504	504	624	663	736	793	793
Outside Newberry Caldera								
CRATER LAKE	13	107	107	112	114	116	120	122
21S/11E-28BCA	9	444	444	548	566	574	593	593
21S/11E-28CBA	5	71	71	72	73	78	79	79
22S/10E-15AAA	2	106	--	--	106	--	--	107
22S/14E-22BBC	2	91	--	--	94	--	--	96
Sulfate								
East Lake Area								
21S/13E-29CDA01	7	64	64	64	65	66	68	68
21S/13E-29CDD01	3	.4	--	--	3.1	--	--	3.4
21S/13E-29CDD02	3	4.6	--	--	5.1	--	--	12
21S/13E-29CDD06	5	7.8	7.8	8.0	10	25	37	37
21S/13E-29DCA	6	.1	.1	.2	.2	.4	.4	.4
21S/13E-32ABB	6	.7	.7	1.3	3.2	5.3	6.3	6.3
Paulina Lake Area								
21S/12E-26AAB01	6	2.5	2.5	2.6	3.0	3.5	3.5	3.5
21S/12E-26AAB03	5	2.3	2.3	2.8	3.6	4.2	4.6	4.6
21S/12E-26ADA01	7	2.2	2.2	2.6	3.1	3.5	3.6	3.6
21S/12E-34ACC	6	.1	.1	.2	.3	.4	.5	.5
21S/12E-34BDA	10	1.8	1.9	2.8	3.2	3.5	3.6	3.6
21S/12E-35DCB	5	.3	.3	.4	.7	.8	.9	.9
21S/12E-36BAA	9	<.1	<.1	<.1	<.1	<.1	.7	.7
21S/13E-31CDB	9	<.1	<.1	<.1	.2	.6	3.9	3.9
Outside Newberry Caldera								
CRATER LAKE	14	9.2	9.3	9.6	9.9	10	12	12
21S/11E-28BCA	10	1.8	1.9	2.6	3.2	3.3	3.6	3.6
21S/11E-28CBA	5	<.1	<.1	.2	.6	.7	.8	.8
22S/10E-15AAA	2	1.1	--	--	1.2	--	--	1.2
22S/14E-22BBC	2	.7	--	--	.8	--	--	.8
Total dissolved solids, residue on evaporation at 180 degrees Celsius								
East Lake Area								
21S/13E-29CDA01	4	206	--	--	212	--	--	219
21S/13E-29CDD01	3	636	--	--	640	--	--	664
21S/13E-29CDD02	1	522	--	--	522	--	--	522
21S/13E-29CDD06	3	640	--	--	654	--	--	709
21S/13E-29DCA	5	34	34	36	42	46	50	50
21S/13E-32ABB	5	116	116	132	176	178	178	178

Table 8. Statistical summary of major ion concentrations and related measures in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–1995—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Total dissolved solids, residue on evaporation at 180 degrees Celsius—Continued								
Paulina Lake Area								
21S/12E-26AAB01	4	742	--	--	776	--	--	786
21S/12E-26AAB03	3	822	--	--	822	--	--	854
21S/12E-26ADA01	4	351	--	--	358	--	--	360
21S/12E-34ACC	5	56	56	62	78	80	81	81
21S/12E-34BDA	7	324	324	331	350	355	357	357
21S/12E-35DCB	5	86	86	87	90	92	94	94
21S/12E-36BAA	6	652	652	658	682	692	700	700
21S/13E-31CDB	6	398	398	406	438	452	468	468
Outside Newberry Caldera								
CRATER LAKE	14	62	64	67	77	82	87	90
21S/11E-28BCA	7	330	330	338	350	359	500	500
21S/11E-28CBA	4	56	--	--	70	--	--	74
22S/10E-15AAA	1	80	--	--	80	--	--	80
22S/14E-22BBC	1	83	--	--	83	--	--	83

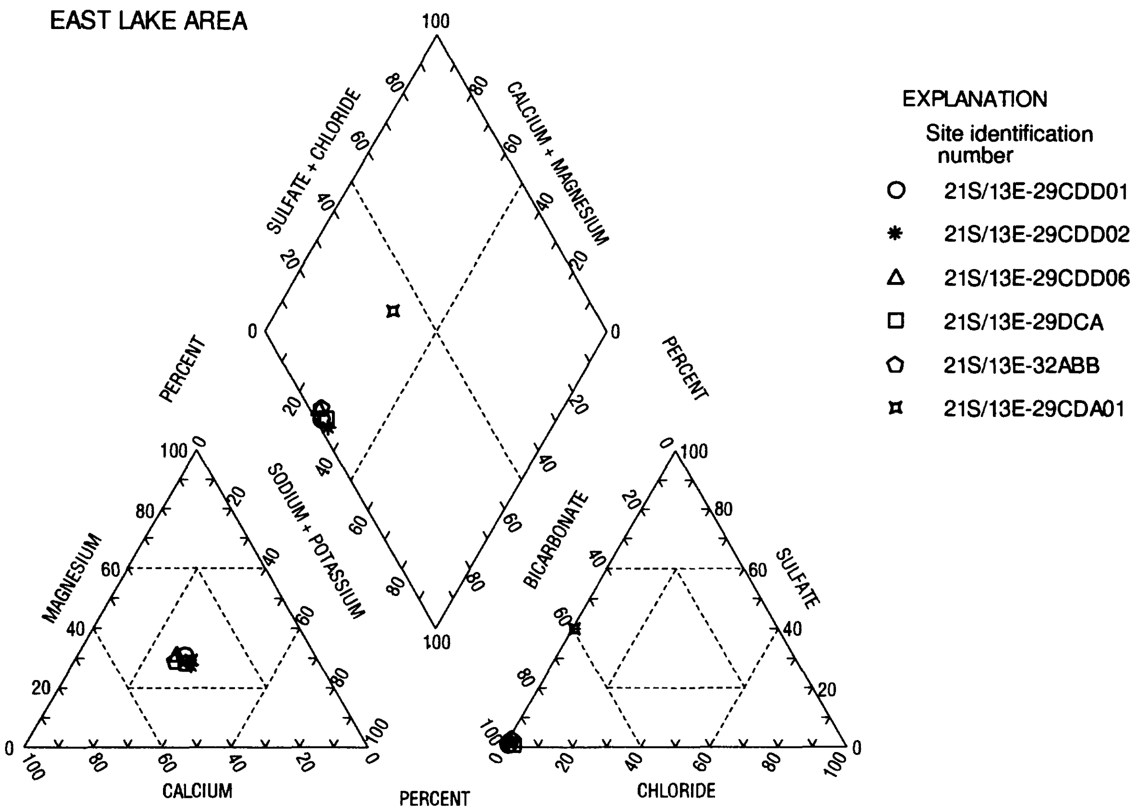
Measurements were also made of water-quality constituents related to major ions, including alkalinity, pH, total dissolved solids, specific conductance, and silica (table 8). Alkalinity is the capacity of a solution to react with and neutralize acid. The largest median alkalinity values (larger than 462 mg/L) were in geothermal areas: Paulina Lake Hot Springs No. 1 and 2B (21S/12E-26AAB01,03) and Little Crater Campground No. 3 (21S/12E-36BAA).

The pH of a water sample is a measure of its hydrogen-ion activity. Water is neutral at a pH of 7, and the pH of most natural waters in the United States generally ranges from 6.0 to 8.5 (Hem, 1989). Geothermal sources can affect the pH of surface water and ground water. The pH of water can be altered by many factors, including geothermal sources or photosynthesis and respiration of aquatic organisms (due to the daily cycles of release and uptake of carbon dioxide by aquatic plants).

The toxicity to aquatic organisms of several chemical constituents is affected by pH, both directly and indirectly. Toxicity to freshwater aquatic life can occur when the pH falls outside the range of 6.5 to 8.5. A pH range of 5 to 9 is necessary for water to be suitable for domestic-water supplies (U.S. Environmental Protection Agency, 1986). The dissociation of weak acids and bases is also influenced by pH, which in turn, indirectly affects aquatic life. For example, as pH increases, the ammonium ion is dissociated to the toxic un-ionized ammonia form.

The largest median pH values were in nonthermal areas: Paulina Creek near La Pine (21S/12E-34BDA, 8.5 pH units), Paulina Creek near USFS Road 21 (21S/11E-28BCA, 8.8 pH units), and in Geo-Newberry Well (21S/13E-29DCA, 8.5 pH units) (table 8). The smallest median pH value of 6.0 pH units was measured in thermal areas: East Lake Hot Springs No. 3 (21S/13E-29CDD02) and Little Crater Campground No. 3 (21S/12E-36BAA).

The largest values for total dissolved solids, specific conductance, and silica were in geothermal sources. The total concentration of dissolved material in water (inorganic salts and organic matter) is referred to as total dissolved solids (TDS). Specific conductance is a measure of the ability of water to conduct an electrical charge. In most waters, specific conductance can be related to the TDS concentration by multiplying by a factor in the range 0.55 to 0.75 (Hem, 1989, p. 67). The largest median values for TDS (822 mg/L) and for specific conductance (1,145 μS/cm) were measured in Paulina Lake Hot Springs No. 2B (21S/12E-26AAB03) (table 8). The smallest median value for specific conductance (49.0 μS/cm) was measured at Geo-Newberry Well (21S/13E-29DCA). Silica [$Si(OH)_4$] is an uncharged species. The largest median silica concentration (220 mg/L) was measured at East Lake Hot Springs No. 5B (21S/13E-29CDD06) (table 8).



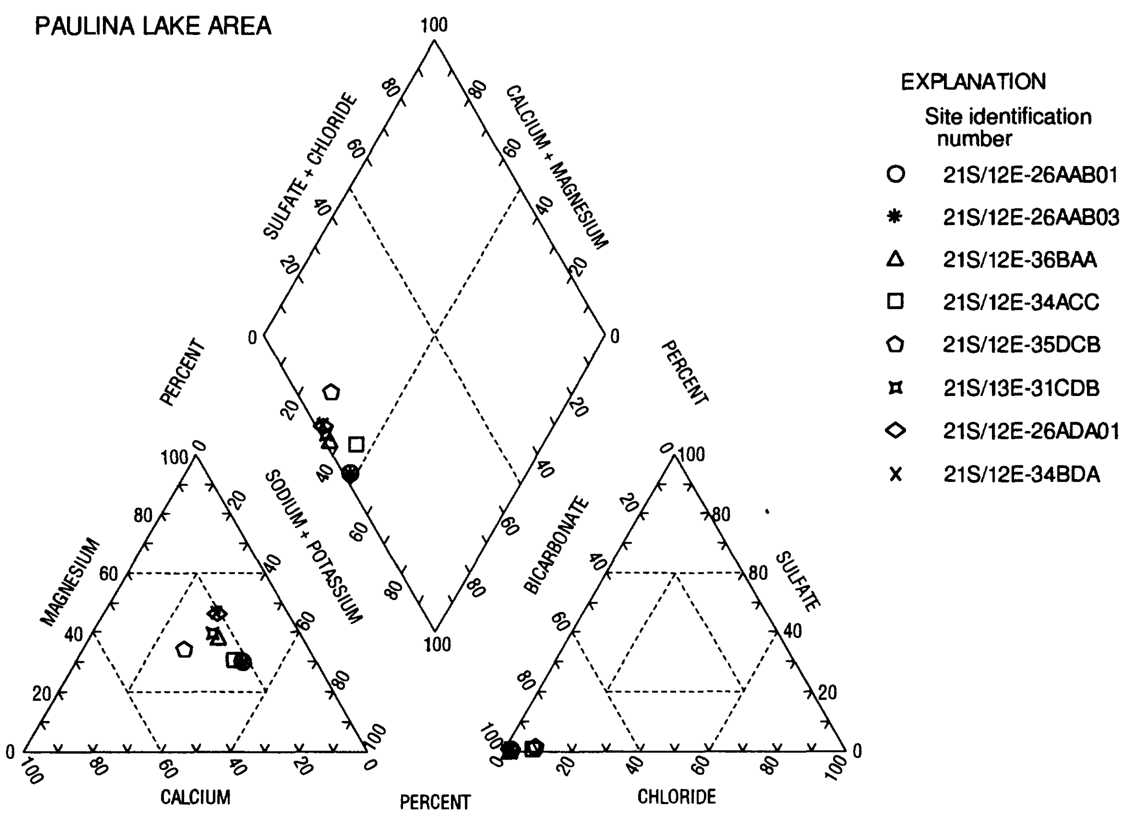


Figure 16. Major ion composition at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95.

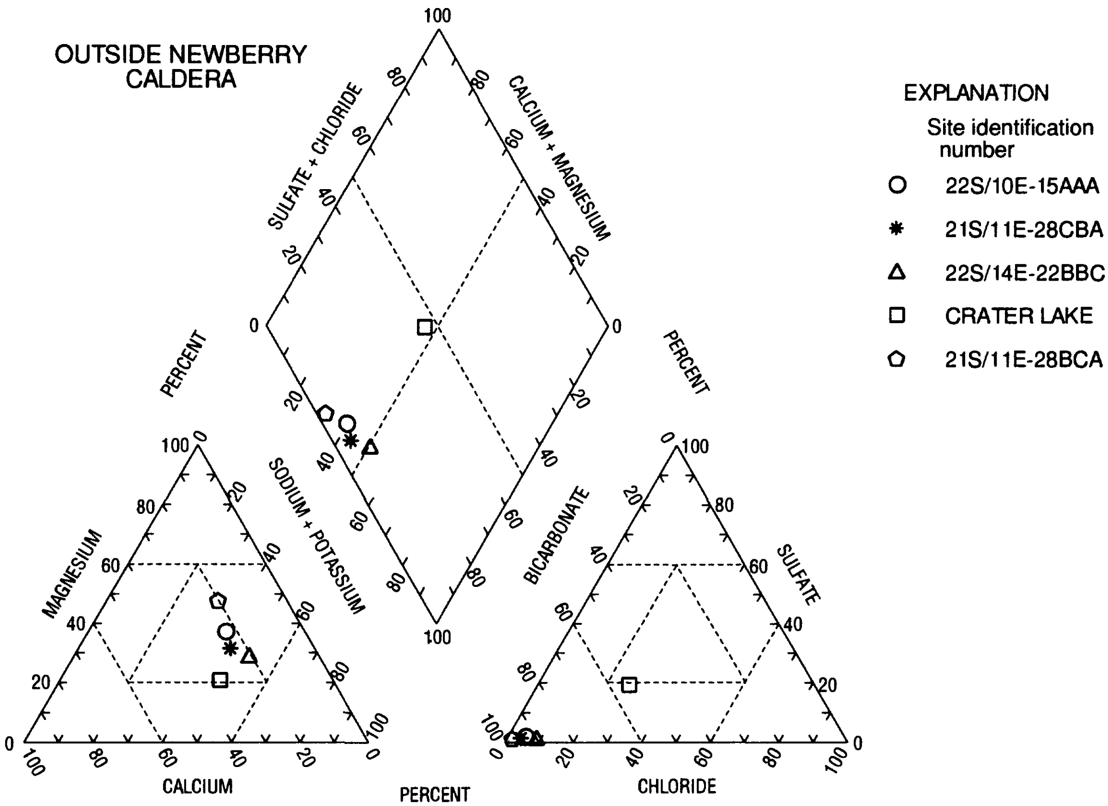


Figure 16. Major ion composition at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95 —Continued.

Nutrients

Nutrient concentrations in Newberry Volcano and vicinity were generally low (table 9). The largest median concentrations for filtered ammonia (0.96 mg/L), filtered orthophosphate (0.59 mg/L), and filtered phosphorus (0.54 mg/L) were found at either East Lake Hot Springs No. 3 or 5B (21S/13E-29CDD02,06). The largest median concentration of filtered nitrite plus nitrate (0.46 mg/L) was at Newberry Group Site Campground (21S/12E-35DCB), which could have been due to anthropogenic activities at that site.

Trace Elements

Trace elements in natural waters generally are considered to be those elements that occur in concentrations less than 1.0 mg/L (Hem, 1989, p. 129). Some trace elements are beneficial or essential to plants and animals in small concentrations, yet are toxic in large concentrations.

Arsenic is a common constituent of geothermal waters in volcanic areas (Hem, 1989), and was detected at Newberry Volcano (table 10). The largest median arsenic concentrations (12 to 19 µg/L) were measured at the following sites in the Paulina Lake area: Paulina Lake Hot Springs No. 1 and 2B (21S/12E-26AAB01,03), Sandia Well (21S/13E-31CDB), Paulina Lake (PL-11-30) (21S/12E-26ADA01), and Paulina Creek near La Pine (21S/12E-34BDA). The only other site with a median arsenic concentration in this range was Paulina Creek near USFS Road 21 (21S/11E-28BCA, 14 µg/L). It is likely that there is a geothermal source of arsenic in the wells listed above, and this source also contributes arsenic to Paulina Lake and Paulina Creek.

Waters with a geothermal component had higher concentrations of barium, lithium, boron, iron, and manganese. Barium and lithium had the highest median concentrations in Paulina Lake Hot Springs No. 1 (21S/12E-26AAB01; 56 and 200 µg/L, respectively) and in Paulina Lake Hot Springs No. 2B (21S/12E-26AAB03; 284 and 210 µg/L, respectively).

Table 9. Statistical summary of nutrient concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[All nutrient species are reported as either nitrogen or phosphorus. To avoid statistical bias that may be associated with constituents analyzed more than once at a site, only the mean element concentration of each day was statistically summarized; for the purposes of calculating percentiles, censored values were assigned a value of one-half the minimum reporting level; if two different minimum reporting levels were used, the higher of the two was reported in this distribution; values are reported in milligrams per liter; -- indicates fewer than 5 samples collected; therefore, percentile not calculated; <, less than. See table 3 for site names]

Site location	Number of samples	Minimum value	Value at indicated percentile: 10	25	50	75	90	Maximum value
Ammonia								
East Lake Area								
21S/13E-29CDA01	7	<0.015	< 0.015	< 0.015	0.020	0.030	0.93	0.93
21S/13E-29CDD01	3	.84	--	--	.88	--	--	.90
21S/13E-29CDD02	2	.33	--	--	.38	--	--	.42
21S/13E-29CDD06	4	.47	--	--	.96	--	--	.96
21S/13E-29DCA	6	< .015	< .015	< .015	< .015	< .015	.010	.010
21S/13E-32ABB	6	< .015	< .015	< .015	< .015	.020	.020	.020
Paulina Lake Area								
21S/12E-26AAB01	6	.090	.090	.10	.12	.14	.16	.16
21S/12E-26AAB03	4	.46	--	--	.48	--	--	.48
21S/12E-26ADA01	6	< .015	< .015	< .015	< .015	< .015	.030	.030
21S/12E-34ACC	6	< .015	< .015	< .015	< .015	< .015	.020	.020
21S/12E-34BDA	10	< .015	< .015	< .015	< .015	.020	.020	.020
21S/12E-35DCB	5	< .015	< .015	< .015	< .015	< .015	.020	.020
21S/12E-36BAA	9	.36	.36	.38	.39	.40	.40	.40
21S/13E-31CDB	9	< .015	< .015	< .015	< .015	.020	.030	.030
Outside Newberry Caldera								
CRATER LAKE	14	< .015	< .015	< .015	< .015	.020	.065	.090
21S/11E-28BCA	10	< .015	< .015	< .015	< .015	< .015	.020	.020
21S/11E-28CBA	5	< .015	< .015	< .015	< .015	.020	.020	.020
22S/10E-15AAA	2	.44	--	--	.46	--	--	.48
22S/14E-22BBC	2	< .015	--	--	< .015	--	--	.020
Nitrite								
East Lake Area								
21S/13E-29CDA01	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/13E-29CDD01	1	< .01	--	--	< .01	--	--	< .01
21S/13E-29CDD06	4	< .01	--	--	< .01	--	--	< .01
21S/13E-29DCA	3	< .01	--	--	< .01	--	--	< .01
21S/13E-32ABB	3	< .01	--	--	< .01	--	--	< .01
Paulina Lake Area								
21S/12E-26AAB01	2	< .01	--	--	< .01	--	--	< .01
21S/12E-26AAB03	4	< .01	--	--	< .01	--	--	< .01
21S/12E-26ADA01	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/12E-34ACC	3	< .01	--	--	< .01	--	--	< .01
21S/12E-34BDA	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/12E-35DCB	2	< .01	--	--	< .01	--	--	< .01
21S/12E-36BAA	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/13E-31CDB	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
Outside Newberry Caldera								
CRATER LAKE	14	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/11E-28BCA	6	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/11E-28CBA	2	< .01	--	--	< .01	--	--	< .01
22S/10E-15AAA	1	< .01	--	--	< .01	--	--	< .01
22S/14E-22BBC	1	< .01	--	--	< .01	--	--	< .01

Table 9. Statistical summary of nutrient concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile					Maximum value
			10	25	50	75	90	
Nitrite plus nitrate								
East Lake Area								
21S/13E-29CDA01	6	<0 .05	<0 .05	<0.05	<0 .05	<0.05	<0.05	<0.05
21S/13E-29CDD01	3	< .05	--	--	< .05	--	--	< .05
21S/13E-29CDD02	1	< .05	--	--	< .05	--	--	< .05
21S/13E-29CDD06	4	< .05	--	--	< .05	--	--	< .05
21S/13E-29DCA	6	< .05	< .05	< .05	< .05	< .05	< .05	< .05
21S/13E-32ABB	6	< .05	< .05	.05	.08	.11	.12	.12
Paulina Lake Area								
21S/12E-26AAB01	6	.21	.21	.22	.29	1.0	1.2	1.2
21S/12E-26AAB03	4	< .05	--	--	< .05	--	--	< .05
21S/12E-26ADA01	6	< .05	< .05	< .05	< .05	.27	.99	.99
21S/12E-34ACC	6	< .05	< .05	< .05	.06	.07	.07	.07
21S/12E-34BDA	10	< .05	< .05	< .05	< .05	< .05	.07	.08
21S/12E-35DCB	5	.21	.21	.26	.46	.60	.71	.71
21S/12E-36BAA	8	< .05	< .05	< .05	< .05	< .05	< .05	< .05
21S/13E-31CDB[1]	8	.14	.14	.15	.17	.20	.52	.52
Outside Newberry Caldera								
CRATER LAKE	14	< .05	< .05	< .05	< .05	< .05	< .05	< .05
21S/11E-28BCA	10	< .05	< .05	< .05	< .05	< .05	.57	.63
21S/11E-28CBA	5	< .05	< .05	< .05	.07	.08	.08	.08
22S/10E-15AAA	2	< .05	--	--	< .05	--	--	< .05
22S/14E-22BBC	2	.20	--	--	.21	--	--	.22
Orthophosphate								
East Lake Area								
21S/13E-29CDA01	7	< .01	< .01	< .01	< .01	.01	.01	.01
21S/13E-29CDD01	3	.34	--	--	.39	--	--	.40
21S/13E-29CDD02	2	.56	--	--	.59	--	--	.62
21S/13E-29CDD06	4	.19	--	--	.40	--	--	.41
21S/13E-29DCA	6	.05	.05	.06	.06	.06	.07	.07
21S/13E-32ABB	6	< .01	< .01	.02	.04	.06	.07	.07
Paulina Lake Area								
21S/12E-26AAB01	6	.12	.12	.14	.14	.15	.15	.15
21S/12E-26AAB03	4	.10	--	--	.14	--	--	.14
21S/12E-26ADA01	6	< .01	< .01	< .01	< .01	.01	.01	.01
21S/12E-34ACC	6	.09	.09	.09	.10	.10	.11	.11
21S/12E-34BDA	10	< .01	< .01	< .01	.01	.01	.07	.08
21S/12E-35DCB	5	.04	.04	.04	.05	.06	.06	.06
21S/12E-36BAA	9	.03	.03	.06	.07	.17	.19	.19
21S/13E-31CDB	8	.24	.24	.25	.25	.25	.26	.27
Outside Newberry Caldera								
CRATER LAKE	14	< .01	< .01	< .01	< .01	.02	.02	.02
21S/11E-28BCA	10	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/11E-28CBA	5	.01	.01	.04	.08	.08	.09	.09
22S/10E-15AAA	2	.29	--	--	.29	--	--	.29
22S/14E-22BBC	2	.07	--	--	.07	--	--	.07

Table 9. Statistical summary of nutrient concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Phosphorus								
East Lake Area								
21S/13E-29CDA01	7	<.01	<.01	<.01	<.01	<.01	.01	.01
21S/13E-29CDD01	3	.36	--	--	.37	--	--	.39
21S/13E-29CDD02	2	.53	--	--	.54	--	--	.55
21S/13E-29CDD06	5	.34	.34	.34	.36	.40	.40	.40
21S/13E-29DCA	6	.04	.04	.05	.06	.06	.06	.06
21S/13E-32ABB	6	<.01	<.01	.02	.04	.05	.07	.07
Paulina Lake Area								
21S/12E-26AAB01	6	0.11	0.11	0.12	0.12	0.13	0.14	0.14
21S/12E-26AAB03	4	.11	--	--	.12	--	--	.13
21S/12E-26ADA01	6	<.01	<.01	<.01	<.01	.01	.02	.02
21S/12E-34ACC	6	.07	.07	.07	.08	.11	.12	.12
21S/12E-34BDA	10	<.01	<.01	<.01	.01	.02	.10	.11
21S/12E-35DCB	5	.03	.03	.03	.04	.05	.05	.05
21S/12E-36BAA	9	.03	.03	.06	.10	.19	.33	.33
21S/13E-31CDB	8	.22	.22	.23	.24	.26	.26	.27
Outside Newberry Caldera								
CRATER LAKE	14	<.01	<.01	<.01	<.01	.01	.02	.03
21S/11E-28BCA	10	<.01	<.01	<.01	<.01	.02	.03	.03
21S/11E-28CBA	5	.07	.07	.07	.07	.12	.17	.17
22S/10E-15AAA	2	.28	--	--	.29	--	--	.30
22S/14E-22BBC	2	.07	--	--	.08	--	--	.08

[1] Summary for site 21S/13E-31CDB (Sandia Well) excludes a value of < 0.18 measured on 910813.

Median concentrations of boron were larger than 880 µg/L at all sites within the Newberry Caldera, with the exception of Geo-Newberry Well (21S/13E-29DCA), Hot Springs Campground No. 1 (21S/13E-32ABB), Paulina Guard Station (21S/12E-34ACC), and Newberry Group Site Campground (21S/12E-35DCB) (table 10). These low-boron sites were also sites that had lower median water temperatures (table 7), indicating a geothermal source of boron. Outside of Newberry Caldera, the largest median boron concentration was at Paulina Creek near USFS Road 21 (21S/11E-28BCA, 875 µg/L).

The highest concentrations of iron and manganese were found in geothermal water. The largest median concentration of iron was 4,600 µg/L at Little Crater Campground No. 3 (21S/12E-36BAA). The largest median concentrations of manganese were at Paulina Lake Hot Springs No. 2B (21S/12E-26AAB03, 1,570 µg/L), East Lake Hot Springs No. 4 (21S/13E-29CDD01, 1,000 µg/L), and East Lake Hot Springs No. 5B (21S/13E-29CDD06, 1,000 µg/L).

Mercury is commonly present in geothermal waters (Hem, 1989). Mercury was of special interest in the Newberry Volcano area because of several mercury concentrations larger than 1 mg/kg (milligram per kilogram) wet weight in salmonid fish in East Lake in May, June, and October 1994 (Doug Drake, Oregon Department of Environmental Quality, written commun., 1996). In Paulina Lake, the largest mercury concentration in salmonid tissue during May and June 1994 was 0.11 mg/kg wet weight.

Analysis of water samples collected and processed using ultraclean techniques (table 11) showed mercury to be present at low concentrations in the Newberry Volcano area. (Samples from East Lake Hot Springs and Paulina Lake Hot Springs were collected from hot spring pools located near East Lake Hot Springs No. 5B [21S/13E-29CDD06] and Paulina Lake Hot Springs No. 2B [21S/12E-26AAB03], respectively.) Mercury concentrations were higher in the East Lake area than in the Paulina Lake area, perhaps due to evaporation from East Lake. Mercury concentrations in samples collected before an ultraclean method of mercury sampling was developed (Crumrine and Morgan, 1994) may have been due to contamination; the distribution of detections is consistent with random contamination.

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95

[The term "filtered water" is an operational definition referring to the portion of a water-sample that passes through a nominal 0.45-micrometer filter; to avoid statistical bias that may be associated with constituents analyzed more than once at a site, only the mean-element concentration of each day was statistically summarized; for the purposes of calculating percentiles, censored values were assigned a value of one-half the minimum reporting level; if two different minimum reporting levels were used, the higher of the two was reported in this distribution; values are reported in µg/L, micrograms per liter; beryllium is not included in this table because no samples had values greater than the minimum reporting level; -- indicates fewer than 5 samples collected; therefore, percentile not calculated; <, less than; >, greater than; MRL, minimum reporting level. See table 3 for site names]

Site location	Number of samples	Minimum value	Value at indicated percentile					Maximum value
			10	25	50	75	90	
Aluminum								
East Lake Area								
21S/13E-29CDA01	4	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD01	3	< 10	--	--	< 10	--	--	20
21S/13E-29CDD02	1	10	--	--	10	--	--	10
21S/13E-29CDD06	4	< 10	--	--	< 10	--	--	< 10
21S/13E-29DCA	3	< 10	--	--	< 10	--	--	< 10
21S/13E-32ABB	4	< 10	--	--	< 10	--	--	< 10
Paulina Lake Area								
21S/12E-26AAB01	4	< 10	--	--	< 10	--	--	20
21S/12E-26AAB03	4	< 10	--	--	< 10	--	--	20
21S/12E-26ADA01	5	< 10	< 10	< 10	< 10	< 10	10	10
21S/12E-34ACC	3	< 10	--	--	< 10	--	--	< 10
21S/12E-34BDA	8	< 10	< 10	< 10	< 10	10	20	20
21S/12E-35DCB	3	< 10	--	--	< 10	--	--	< 10
21S/12E-36BAA	7	< 10	< 10	< 10	< 10	< 10	20	20
21S/13E-31CDB	7	< 10	< 10	< 10	< 10	< 10	10	10
Outside Newberry Caldera								
CRATER LAKE	14	< 10	< 10	< 10	< 10	22	45	50
21S/11E-28BCA	7	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/11E-28CBA	3	< 10	--	--	< 10	--	--	20
22S/10E-15AAA	1	< 10	--	--	< 10	--	--	< 10
22S/14E-22BBC	1	20	--	--	20	--	--	20
Arsenic								
East Lake Area								
21S/13E-29CDA01	7	2	2	2	2	2	3	3
21S/13E-29CDD01	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD02	3	2	--	--	2	--	--	2
21S/13E-29CDD06	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-29DCA	3	< 1	--	--	< 1	--	--	1
21S/13E-32ABB	4	< 1	--	--	< 1	--	--	< 1
Paulina Lake Area								
21S/12E-26AAB01	6	10	10	10	12	12	13	13
21S/12E-26AAB03	5	10	10	11	12	13	13	13
21S/12E-26ADA01	7	14	14	14	15	15	16	16
21S/12E-34ACC	3	3	--	--	3	--	--	3
21S/12E-34BDA	10	14	14	14	15	15	16	16
21S/12E-35DCB	2	< 1	--	--	< 1	--	--	< 1
21S/12E-36BAA	9	< 1	< 1	< 1	< 1	1	1	1
21S/13E-31CDB[1]	7	14	14	16	19	20	20	20
Outside Newberry Caldera								
CRATER LAKE	2	3	--	--	3	--	--	3
21S/11E-28BCA	8	13	13	14	14	15	16	16
21S/11E-28CBA	3	1	--	--	1	--	--	1
22S/10E-15AAA	2	< 1	--	--	< 1	--	--	< 1
22S/14E-22BBC	2	3	--	--	3	--	--	3

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile: 10	25	50	75	90	Maximum value
Barium								
East Lake Area								
21S/13E-29CDA01	7	16	16	17	17	19	21	21
21S/13E-29CDD01[2]	2	7	--	--	8	--	--	9
21S/13E-29CDD02	3	9	--	--	9	--	--	9
21S/13E-29CDD06	5	3	3	3	4	4	4	4
21S/13E-29DCA	3	< 2	--	--	< 2	--	--	< 2
21S/13E-32ABB	4	3	--	--	6	--	--	9
Paulina Lake Area								
21S/12E-26AAB01	6	34	34	44	56	63	72	72
21S/12E-26AAB03	5	280	280	280	284	308	316	316
21S/12E-26ADA01	7	16	16	17	18	19	20	20
21S/12E-34ACC	3	1	--	--	1	--	--	2
21S/12E-34BDA	10	15	15	17	17	17	19	19
21S/12E-35DCB	2	1	--	--	1	--	--	2
21S/12E-36BAA	9	23	23	24	25	26	27	27
21S/13E-31CDB	8	7	7	11	12	14	25	25
Outside Newberry Caldera								
CRATER LAKE	14	5	5	5	6	6	6	6
21S/11E-28BCA	8	15	15	15	16	17	18	18
21S/11E-28CBA	3	1	--	--	1	--	--	1
22S/10E-15AAA	2	3	--	--	3	--	--	3
22S/14E-22BBC	2	1	--	--	1	--	--	1
Boron								
East Lake Area								
21S/13E-29CDA01	7	920	920	930	960	990	1,000	1,000
21S/13E-29CDD01	3	1,100	--	--	1,200	--	--	1,200
21S/13E-29CDD02	3	850	--	--	880	--	--	880
21S/13E-29CDD06	5	1,200	1,200	1,200	1,200	1,250	1,300	1,300
21S/13E-29DCA	6	< 10	< 10	< 10	< 10	10	10	10
21S/13E-32ABB	6	100	100	107	125	140	140	140
Paulina Lake Area								
21S/12E-26AAB01	6	880	880	887	895	935	950	950
21S/12E-26AAB03	5	920	920	925	950	985	1,000	1,000
21S/12E-26ADA01	7	870	870	880	890	910	940	940
21S/12E-34ACC	6	20	20	20	20	30	30	30
21S/12E-34BDA	10	830	832	850	885	900	945	950
21S/12E-35DCB	5	< 10	< 10	< 10	< 10	< 10	10	10
21S/12E-36BAA	9	1,300	1,300	1,700	1,800	1,800	1,900	1,900
21S/13E-31CDB	9	590	590	660	770	885	930	930
Outside Newberry Caldera								
21S/11E-28BCA	10	830	832	850	875	902	964	970
21S/11E-28CBA	5	20	20	20	20	30	30	30
22S/10E-15AAA	2	20	--	--	25	--	--	30
22S/14E-22BBC	2	50	--	--	50	--	--	50
Cadmium								
East Lake Area								
21S/13E-29CDA01	7	< 1	< 1	< 1	< 1	1	2	
21S/13E-29CDD01	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD02	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD06	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-29DCA	3	< 1	--	--	< 1	--	--	< 1
21S/13E-32ABB	4	< 1	--	--	< 1	--	--	1

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile: 10	25	50	75	90	Maximum value
Cadmium–Continued								
Paulina Lake Area								
21S/12E-26AAB01	6	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-26AAB03	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-26ADA01	7	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-34ACC	3	< 1	--	--	< 1	--	--	2
21S/12E-34BDA	10	< 1	< 1	< 1	< 1	< 1	< 1	1
21S/12E-35DCB	2	< 1	--	--	< 1	--	--	< 1
21S/12E-36BAA	9	< 1	< 1	< 1	< 1	< 1	3	3
21S/13E-31CDB[3]	7	< 1	< 1	< 1	< 1	< 1	2	2
Outside Newberry Caldera								
CRATER LAKE	2	< 1	--	--	< 1	--	--	< 1
21S/11E-28BCA	8	< 1	< 1	< 1	< 1	< 1	1	1
21S/11E-28CBA	3	< 1	--	--	< 1	--	--	2
22S/10E-15AAA	2	< 1	--	--	< 1	--	--	< 1
22S/14E-22BBC	2	< 1	--	--	< 1	--	--	< 1
Chromium								
East Lake Area								
21S/13E-29CDA01	7	< 5	< 5	< 5	< 5	< 5	< 5	< 5
21S/13E-29CDD01	3	< 5	--	--	< 5	--	--	< 5
21S/13E-29CDD02	3	< 5	--	--	< 5	--	--	< 5
21S/13E-29CDD06	5	< 5	< 5	< 5	< 5	6	10	10
21S/13E-29DCA	3	< 5	--	--	< 5	--	--	< 5
21S/13E-32ABB	4	< 5	--	--	< 5	--	--	< 5
Paulina Lake Area								
21S/12E-26AAB01	6	< 5	< 5	< 5	< 5	< 5	< 5	< 5
21S/12E-26AAB03	5	< 5	< 5	< 5	< 5	8	9	9
21S/12E-26ADA01	7	< 5	< 5	< 5	< 5	< 5	< 5	< 5
21S/12E-34ACC	3	< 5	--	--	< 5	--	--	< 5
21S/12E-34BDA	10	< 5	< 5	< 5	< 5	< 5	< 5	< 5
21S/12E-35DCB	2	< 5	--	--	< 5	--	--	< 5
21S/12E-36BAA	9	< 5	< 5	< 5	< 5	9	14	14
21S/13E-31CDB	8	< 5	< 5	< 5	< 5	< 5	5	5
Outside Newberry Caldera								
CRATER LAKE	2	< 5	--	--	< 5	--	--	< 5
21S/11E-28BCA	8	< 5	< 5	< 5	< 5	< 5	< 5	< 5
21S/11E-28CBA	3	< 5	--	--	< 5	--	--	< 5
22S/10E-15AAA	2	< 5	--	--	< 5	--	--	< 5
22S/14E-22BBC	2	< 5	--	--	< 5	--	--	< 5
Cobalt								
East Lake Area								
21S/13E-29CDA01	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/13E-29CDD01	2	< 3	--	--	< 3	--	--	< 3
21S/13E-29CDD02	5	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/13E-29DCA	2	< 3	--	--	< 3	--	--	< 3
21S/13E-32ABB	3	< 3	--	--	< 3	--	--	< 3
Paulina Lake Area								
21S/12E-26AAB01	2	< 3	--	--	< 3	--	--	< 3
21S/12E-26AAB03	5	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/12E-26ADA01	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/12E-34ACC	2	< 3	--	--	< 3	--	--	< 3
21S/12E-34BDA	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/12E-35DCB	1	< 3	--	--	< 3	--	--	< 3
21S/12E-36BAA	6	< 3	< 3	< 3	< 3	4	7	7
21S/13E-31CDB	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Cobalt–Continued								
Outside Newberry Caldera								
CRATER LAKE	14	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/11E-28BCA	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/11E-28CBA	2	< 3	--	--	< 3	--	--	< 3
22S/10E-15AAA	1	--	--	--	--	--	--	< 3
22S/14E-22BBC	1	--	--	--	--	--	--	< 3
Copper—MRL = 1 µg/L, all 1991, 1992, 1995, October 1994								
East Lake Area								
21S/13E-29CDA01	4	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD01	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD02	1	--	--	--	--	--	--	< 1
21S/13E-29CDD06	3	< 1	--	--	1	--	--	1
21S/13E-29DCA	2	< 1	--	--	--	--	--	< 1
21S/13E-32ABB	3	< 1	--	--	< 1	--	--	2
Paulina Lake Area								
21S/12E-26AAB01	4	< 1	--	--	< 1	--	--	< 1
21S/12E-26AAB03	3	< 1	--	--	< 1	--	--	< 1
21S/12E-26ADA01	4	< 1	--	--	< 1	--	--	< 1
21S/12E-34ACC	2	< 1	--	--	< 1	--	--	< 1
21S/12E-34BDA	7	< 1	< 1	< 1	< 1	< 1	2	2
21S/12E-35DCB	2	< 1	--	--	< 1	--	--	< 1
21S/12E-36BAA	6	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-31CDB	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Outside Newberry Caldera								
CRATER LAKE	2	3	--	--	3	--	--	3
21S/11E-28BCA	5	< 1	< 1	< 1	< 1	< 1	< 1	1
21S/11E-28CBA	2	< 1	--	--	--	--	--	1
22S/10E-15AAA	1	--	--	--	--	--	--	< 1
22S/14E-22BBC	1	--	--	--	--	--	--	< 1
Copper—MRL = 10 µg/L, all 1993 and June 1994								
East Lake Area								
21S/13E-29CDA01	3	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD02	2	< 10	--	--	--	--	--	< 10
21S/13E-29CDD06	2	< 10	--	--	--	--	--	< 10
21S/13E-29DCA	1	--	--	--	--	--	--	< 10
21S/13E-32ABB	1	--	--	--	--	--	--	< 10
Paulina Lake Area								
21S/12E-26AAB01	2	< 10	--	--	--	--	--	< 10
21S/12E-26AAB03	2	< 10	--	--	--	--	--	< 10
21S/12E-26ADA01	3	< 10	--	--	< 10	--	--	< 10
21S/12E-34ACC	1	--	--	--	--	--	--	< 10
21S/12E-34BDA	3	< 10	--	--	< 10	--	--	< 10
21S/12E-36BAA	3	< 10	--	--	< 10	--	--	< 10
21S/13E-31CDB	3	< 10	--	--	< 10	--	--	< 10
Outside Newberry Caldera								
21S/11E-28BCA	3	< 10	--	--	< 10	--	--	< 10
21S/11E-28CBA	1	--	--	--	--	--	--	< 10
22S/10E-15AAA	1	--	--	--	--	--	--	< 10
22S/14E-22BBC	1	--	--	--	--	--	--	< 10

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Iron								
East Lake Area								
21S/13E-29CDA01	7	< 3	< 3	< 3	< 3	3	4	4
21S/13E-29CDD01	3	30	--	--	34	--	--	410
21S/13E-29CDD02	3	53	--	--	250	--	--	260
21S/13E-29CDD06	5	< 3	< 3	< 3	4	24	30	30
21S/13E-29DCA	6	< 3	< 3	3	5	7	8	8
21S/13E-32ABB	6	57	57	127	165	472	1,200	1,200
Paulina Lake Area								
21S/12E-26AAB01[4]	5	< 3	< 3	< 3	9	9	9	9
21S/12E-26AAB03	5	< 3	< 3	< 3	10	375	610	610
21S/12E-26ADA01	7	5	5	9	10	11	24	24
21S/12E-34ACC	6	7	7	7	10	11	11	11
21S/12E-34BDA	10	5	5	5	11	17	21	21
21S/12E-35DCB	5	3	3	4	8	10	11	11
21S/12E-36BAA	9	3,800	3,800	4,500	4,600	4,800	5,000	5,000
21S/13E-31CDB	9	5	5	8	17	26	990	990
Outside Newberry Caldera								
CRATER LAKE	14	< 3	< 3	< 3	4	8	12	15
21S/11E-28BCA	10	< 3	< 3	3	6	8	49	54
21S/11E-28CBA	5	< 3	< 3	< 3	< 3	6	8	8
22S/10E-15AAA	2	53	--	--	57	--	--	61
22S/14E-22BBC	2	< 3	--	--	2	--	--	4
Lead								
East Lake Area								
21S/13E-29CDA01	7	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-29CDD01	3	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD02	3	< 10	--	--	< 10	--	--	10
21S/13E-29CDD06	5	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-29DCA	3	< 10	--	--	< 10	--	--	< 10
21S/13E-32ABB	4	< 10	--	--	< 10	--	--	< 10
Paulina Lake Area								
21S/12E-26AAB01	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-26AAB03	5	< 10	< 10	< 10	< 10	20	20	20
21S/12E-26ADA01	7	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-34ACC	3	< 10	--	--	< 10	--	--	< 10
21S/12E-34BDA	10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-35DCB	2	< 10	--	--	< 10	--	--	< 10
21S/12E-36BAA	9	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-31CDB	8	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Outside Newberry Caldera								
CRATER LAKE	2	< 10	--	--	< 10	--	--	< 10
21S/11E-28BCA	8	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/11E-28CBA	3	< 10	--	--	< 10	--	--	10
22S/10E-15AAA	2	< 10	--	--	< 10	--	--	< 10
22S/14E-22BBC	2	< 10	--	--	< 10	--	--	< 10
Lithium								
East Lake Area								
21S/13E-29CDA01	7	9	9	9	11	13	13	13
21S/13E-29CDD01	3	30	--	--	35	--	--	39
21S/13E-29CDD02	3	25	--	--	26	--	--	27
21S/13E-29CDD06	5	28	28	29	33	34	34	34
21S/13E-29DCA	4	< 4	--	--	< 4	--	--	< 4
21S/13E-32ABB	4	< 4	--	--	< 4	--	--	< 4

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Lithium—Continued								
Paulina Lake Area								
21S/12E-26AAB01	6	180	180	180	200	220	220	220
21S/12E-26AAB03	5	200	200	205	210	220	220	220
21S/12E-26ADA01	7	63	63	70	71	75	75	75
21S/12E-34ACC	4	16	--	--	17	--	--	18
21S/12E-34BDA	10	66	66	68	70	72	75	75
21S/12E-35DCB	3	17	--	--	19	--	--	19
21S/12E-36BAA	9	110	110	115	120	130	130	130
21S/13E-31CDB[5]	7	76	76	86	88	89	93	93
Outside Newberry Caldera								
CRATER LAKE	14	42	43	44	46	47	47	47
21S/11E-28BCA	8	62	62	68	70	73	74	74
21S/11E-28CBA	3	< 4	--	--	< 4	--	--	5
22S/10E-15AAA	2	< 4	--	--	< 4	--	--	< 4
22S/14E-22BBC	2	4	--	--	5	--	--	6
Manganese								
East Lake Area								
21S/13E-29CDA01	7	5	5	5	8	10	11	11
21S/13E-29CDD01	3	870	--	--	1,000	--	--	1,000
21S/13E-29CDD02	3	530	--	--	570	--	--	630
21S/13E-29CDD06[6]	5	990	990	995	1,000	1,125	1,220	1,220
21S/13E-29DCA	6	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-32ABB	6	9	9	13	20	70	98	98
Paulina Lake Area								
21S/12E-26AAB01	6	320	320	425	525	700	760	760
21S/12E-26AAB03	5	1,160	1,160	1,330	1,570	1,600	1,600	1,600
21S/12E-26ADA01	7	< 1	< 1	1	2	5	8	8
21S/12E-34ACC	6	< 1	< 1	< 1	< 1	< 1	1	1
21S/12E-34BDA	10	2	2	3	4	6	12	13
21S/12E-35DCB	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-36BAA	9	230	230	240	250	276	280	280
21S/13E-31CDB	9	2	2	3	5	10	90	90
Outside Newberry Caldera								
CRATER LAKE	14	< 1	< 1	< 1	< 1	1	2	2
21S/11E-28BCA	10	< 1	< 1	< 1	< 1	< 1	< 1	1
21S/11E-28CBA	5	< 1	< 1	< 1	< 1	1	2	2
22S/10E-15AAA	2	13	--	--	14	--	--	14
22S/14E-22BBC	2	< 1	--	--	< 1	--	--	< 1
Mercury								
East Lake Area								
21S/13E-29CDA01	5	< .01	< .01	< .01	< .01	.08	.10	.10
21S/13E-29CDD01	3	< .01	--	--	< .01	--	--	.40
21S/13E-29CDD02	3	< .01	--	--	< .01	--	--	< .01
21S/13E-29CDD06	3	< .01	--	--	< .01	--	--	< .01
21S/13E-29DCA	2	< .01	--	--	< .01	--	--	< .01
21S/13E-32ABB	3	< .01	--	--	< .01	--	--	< .01
Paulina Lake Area								
21S/12E-26AAB01	6	< .01	< .01	< .01	< .01	.09	.20	.20
21S/12E-26AAB03	3	< .01	--	--	< .01	--	--	< .01
21S/12E-26ADA01	5	< .01	< .01	< .01	< .01	< .01	< .01	< .01
21S/12E-34ACC	2	< .01	--	--	< .01	--	--	< .01
21S/12E-34BDA	8	< .01	< .01	< .01	< .01	< .01	.20	.20
21S/12E-35DCB	1	< .01	--	--	< .01	--	--	< .01
21S/12E-36BAA	7	< .01	< .01	< .01	< .01	.10	.30	.30
21S/13E-31CDB	7	< .01	< .01	< .01	< .01	.20	.20	.20

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Mercury—Continued								
Outside Newberry Caldera								
CRATER LAKE	2	< 0.01	--	--	< 0.01	--	--	< 0.01
21S/11E-28BCA	6	< .01	< 0.01	< 0.01	< .01	0.11	0.30	.30
21S/11E-28CBA	2	< .01	--	--	< .01	--	--	< .01
22S/10E-15AAA	2	< .01	--	--	< .01	--	--	< .01
22S/14E-22BBC	2	< .01	--	--	.08	--	--	.10
Molybdenum								
East Lake Area								
21S/13E-29CDA01	7	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-29CDD01	3	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD02	3	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD06	5	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-29DCA	3	< 10	--	--	< 10	--	--	< 10
21S/13E-32ABB	4	< 10	--	--	< 10	--	--	< 10
Paulina Lake Area								
21S/12E-26AAB01	6	< 10	< 10	< 10	< 10	12	20	20
21S/12E-26AAB03	5	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-26ADA01	7	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-34ACC	3	< 10	--	--	< 10	--	--	< 10
21S/12E-34BDA	10	< 10	< 10	< 10	< 10	< 10	< 10	10
21S/12E-35DCB	2	< 10	--	--	< 10	--	--	< 10
21S/12E-36BAA	9	< 10	< 10	< 10	< 10	< 10	10	10
21S/13E-31CDB	8	< 10	< 10	< 10	< 10	< 10	20	20
Outside Newberry Caldera								
CRATER LAKE	14	< 10	< 10	< 10	< 10	< 10	15	20
21S/11E-28BCA	8	< 10	< 10	< 10	< 10	< 10	20	20
21S/11E-28CBA	3	< 10	--	--	< 10	--	--	< 10
22S/10E-15AAA	2	< 10	--	--	< 10	--	--	< 10
22S/14E-22BBC	2	< 10	--	--	< 10	--	--	< 10
Nickel								
East Lake Area								
21S/13E-29CDA01	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/13E-29CDD01	2	< 10	--	--	< 10	--	--	< 10
21S/13E-29CDD02	5	< 10	< 10	< 10	< 10	< 10	10	10
21S/13E-29DCA	2	< 10	--	--	< 10	--	--	< 10
21S/13E-32ABB	3	< 10	--	--	< 10	--	--	< 10
Paulina Lake Area								
21S/12E-26AAB01	2	< 10	--	--	< 10	--	--	< 10
21S/12E-26AAB03	5	< 10	< 10	< 10	< 10	< 10	13	13
21S/12E-26ADA01	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-34ACC	2	< 10	--	--	< 10	--	--	< 10
21S/12E-34BDA	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/12E-35DCB	1	< 10	--	--	< 10	--	--	< 10
21S/12E-36BAA	6	< 10	< 10	< 10	< 10	< 10	12	12
21S/13E-31CDB	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Outside Newberry Caldera								
CRATER LAKE	14	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/11E-28BCA	6	< 10	< 10	< 10	< 10	< 10	< 10	< 10
21S/11E-28CBA	2	< 10	--	--	< 10	--	--	< 10
22S/10E-15AAA	1	< 10	--	--	< 10	--	--	< 10
22S/14E-22BBC	1	< 10	--	--	< 10	--	--	< 10

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Selenium								
East Lake Area								
21S/13E-29CDA01	4	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD01	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD02	1	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD06	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29DCA	2	< 1	--	--	< 1	--	--	< 1
21S/13E-32ABB	3	< 1	--	--	< 1	--	--	< 1
Paulina Lake Area								
21S/12E-26AAB01	4	< 1	--	--	< 1	--	--	< 1
21S/12E-26AAB03	3	< 1	--	--	< 1	--	--	< 1
21S/12E-26ADA01	4	< 1	--	--	< 1	--	--	< 1
21S/12E-34ACC	2	< 1	--	--	< 1	--	--	< 1
21S/12E-34BDA	7	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-35DCB	2	< 1	--	--	< 1	--	--	< 1
21S/12E-36BAA	6	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-31CDB	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Outside Newberry Caldera								
CRATER LAKE	14	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/11E-28BCA	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/11E-28CBA	2	< 1	--	--	< 1	--	--	< 1
22S/10E-15AAA	1	< 1	--	--	< 1	--	--	< 1
22S/14E-22BBC	1	< 1	--	--	< 1	--	--	< 1
Silver								
East Lake Area								
21S/13E-29CDA01	5	< 1	< 1	< 1	< 1	1	2	2
21S/13E-29CDD01	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD02	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29CDD06	3	< 1	--	--	< 1	--	--	< 1
21S/13E-29DCA	3	< 1	--	--	< 1	--	--	< 1
21S/13E-32ABB	4	< 1	--	--	< 1	--	--	< 1
Paulina Lake Area								
21S/12E-26AAB01	6	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-26AAB03	5	< 1	< 1	< 1	< 1	< 1	1	1
21S/12E-26ADA01	7	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-34ACC	3	< 1	--	--	< 1	--	--	< 1
21S/12E-34BDA	10	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/12E-35DCB	2	< 1	--	--	< 1	--	--	< 1
21S/12E-36BAA	9	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/13E-31CDB	8	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Outside Newberry Caldera								
CRATER LAKE	14	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/11E-28BCA	8	< 1	< 1	< 1	< 1	< 1	< 1	< 1
21S/11E-28CBA	3	< 1	--	--	< 1	--	--	< 1
22S/10E-15AAA	2	< 1	--	--	< 1	--	--	< 1
22S/14E-22BBC	2	< 1	--	--	< 1	--	--	< 1
Strontium								
East Lake Area								
21S/13E-29CDA01	7	92	92	93	98	100	100	100
21S/13E-29CDD01	3	220	--	--	220	--	--	230
21S/13E-29CDD02	3	130	--	--	140	--	--	160
21S/13E-29CDD06	5	330	330	335	360	360	360	360
21S/13E-29DCA	4	10	--	--	11	--	--	11
21S/13E-32ABB	4	35	--	--	58	--	--	88

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Strontium—Continued								
Paulina Lake Area								
21S/12E-26AAB01	6	170	170	178	190	195	210	210
21S/12E-26AAB03	5	200	200	200	200	205	210	210
21S/12E-26ADA01	7	5	5	83	84	89	91	91
21S/12E-34ACC	4	11	--	--	12	--	--	12
21S/12E-34BDA	10	81	81	83	86	87	90	90
21S/12E-35DCB	3	20	--	--	20	--	--	21
21S/12E-36BAA	9	180	180	180	190	190	200	200
21S/13E-31CDB	8	80	80	110	120	138	140	140
Outside Newberry Caldera								
CRATER LAKE	14	54	54	57	58	58	60	60
21S/11E-28BCA	8	78	78	82	83	84	86	86
21S/11E-28CBA	3	17	--	--	18	--	--	19
22S/10E-15AAA	2	21	--	--	22	--	--	22
22S/14E-22BBC	2	20	--	--	20	--	--	20
Vanadium								
East Lake Area								
21S/13E-29CDA01	3	< 6	--	--	< 6	--	--	< 6
21S/13E-29CDD01	2	< 6	--	--	< 6	--	--	< 6
21S/13E-29CDD02	2	< 6	--	--	< 6	--	--	< 6
21S/13E-29DCA	1	14	--	--	14	--	--	14
21S/13E-32ABB	1	9	--	--	9	--	--	9
Paulina Lake Area								
21S/12E-26AAB01	2	< 6	--	--	< 6	--	--	< 6
21S/12E-26AAB03	2	< 6	--	--	< 6	--	--	< 6
21S/12E-26ADA01	3	< 6	--	--	< 6	--	--	< 6
21S/12E-34ACC	1	7	--	--	7	--	--	7
21S/12E-34BDA	3	< 6	--	--	< 6	--	--	< 6
21S/12E-36BAA	3	< 6	--	--	< 6	--	--	< 6
21S/13E-31CDB	3	27	--	--	28	--	--	28
Outside Newberry Caldera								
CRATER LAKE	14	< 6	< 6	< 6	< 6	< 6	< 6	< 6
21S/11E-28BCA	3	< 6	--	--	< 6	--	--	< 6
21S/11E-28CBA	1	16	--	--	16	--	--	16
22S/10E-15AAA	1	< 6	--	--	< 6	--	--	< 6
22S/14E-22BBC	1	22	--	--	22	--	--	22
Zinc								
East Lake Area								
21S/13E-29CDA01	7	< 3	< 3	< 3	< 3	3	6	6
21S/13E-29CDD01[7]	2	< 3	--	--	6	--	--	13
21S/13E-29CDD02	3	< 3	--	--	< 3	--	--	3
21S/13E-29CDD06	5	< 3	< 3	< 3	< 3	4	5	5
21S/13E-29DCA	3	6	--	--	6	--	--	13
21S/13E-32ABB	4	10	--	--	21	--	--	32
Paulina Lake Area								
21S/12E-26AAB01	6	< 3	< 3	< 3	< 3	5	6	6
21S/12E-26AAB03	5	< 3	< 3	< 3	12	46	56	56
21S/12E-26ADA01	7	< 3	< 3	< 3	< 3	< 3	< 3	< 3
21S/12E-34ACC	3	15	--	--	21	--	--	27
21S/12E-34BDA	10	< 3	< 3	< 3	< 3	< 3	7	7
21S/12E-35DCB	2	22	--	--	25	--	--	28
21S/12E-36BAA	9	< 3	< 3	< 3	< 3	70	79	79
21S/13E-31CDB[8]	7	< 3	< 3	< 3	< 3	13	15	15

Table 10. Statistical summary of trace-element concentrations in filtered water samples at selected sites, Newberry Volcano and vicinity, Oregon, 1991–95—Continued

Site location	Number of samples	Minimum value	Value at indicated percentile 10	25	50	75	90	Maximum value
Zinc—Continued								
Outside Newberry Caldera								
CRATER LAKE	2	8	--	--	11	--	--	14
21S/11E-28BCA	8	< 3	< 3	< 3	< 3	7	9	9
21S/11E-28CBA	3	19	--	--	23	--	--	24
22S/10E-15AAA	2	< 3	--	--	< 3	--	--	< 3
22S/14E-22BBC	2	20	--	--	20	--	--	21

[1] A value of < 3 measured on 910813 was excluded from this summary.
[2] A value of < 100 measured on 910815 was excluded from this summary.
[3] A value of < 2 measured on 910813 was excluded from this summary.
[4] A value of < 33 measured on 920624 was excluded from this summary.
[5] A value of < 86 measured on 910813 was excluded from this summary.
[6] A value of > 1,000 measured on 941004 was excluded from this summary.
[7] A value of < 10 measured on 910815 was excluded from this summary.
[8] A value of < 77 measured on 910813 was excluded from this summary.

Table 11. Concentrations of mercury at selected sites, Newberry Volcano and vicinity, Oregon, October 1995
[Values are reported in nanograms per liter]

Location	Date	Mercury
East Lake Area		
East Lake Hot Springs	951018	3.36
East Lake, EL-8-30 21S/13E-29CDA01	951018	6.80
Paulina Lake Area		
Paulina Lake Hot Springs	951018	.63
Paulina Lake, PL-11-30 21S/12E-26ADA01	951018	.45

Stable Isotopes and Radioactivity

Certain elements may exist in a variety of forms each with a slightly different atomic weight. These different forms, which are chemically identical, are called isotopes. The hydrogen and oxygen that compose water each have multiple isotopes. The dominant hydrogen isotopes are hydrogen, with an atomic weight of 1, and deuterium, with an atomic weight of 2. The dominant oxygen isotopes have atomic weights of 16 and 18. The ratios of isotopes in water are changed by certain processes such as evaporation. The isotopic composition of water reflects its source and history.

Isotopic ratios are reported as the relative difference between the ratio in the sample and the ratio in standard mean ocean water in parts per thousand, or per mil. The more negative the number, the isotopically lighter the sample is with respect to ocean water.

Oxygen and hydrogen isotope data are usually plotted on a graph with oxygen-18 on the horizontal axis and deuterium on the vertical axis. Isotopes in meteoric water will plot on such a graph along a straight line known as the meteoric water line (Craig, 1961). Isotopes in ground water also generally plot along the meteoric water line. When water evaporates, water composed of light isotopes evaporates faster than water with heavier isotopes. Because of this, a lake or other water body from which water has evaporated will be relatively enriched in heavier isotopes. Isotopes in such waters usually do not plot along the meteoric water line.

Isotopes in ground water from all wells within Newberry Caldera plot in a cluster along the meteoric water line (fig. 17). Paulina Lake, Paulina Creek, and East Lake are isotopically heavier than ground water in the area and plot off the meteoric water line along an evaporation trend. Ground water from outside the caldera form their own cluster along the meteoric water line.

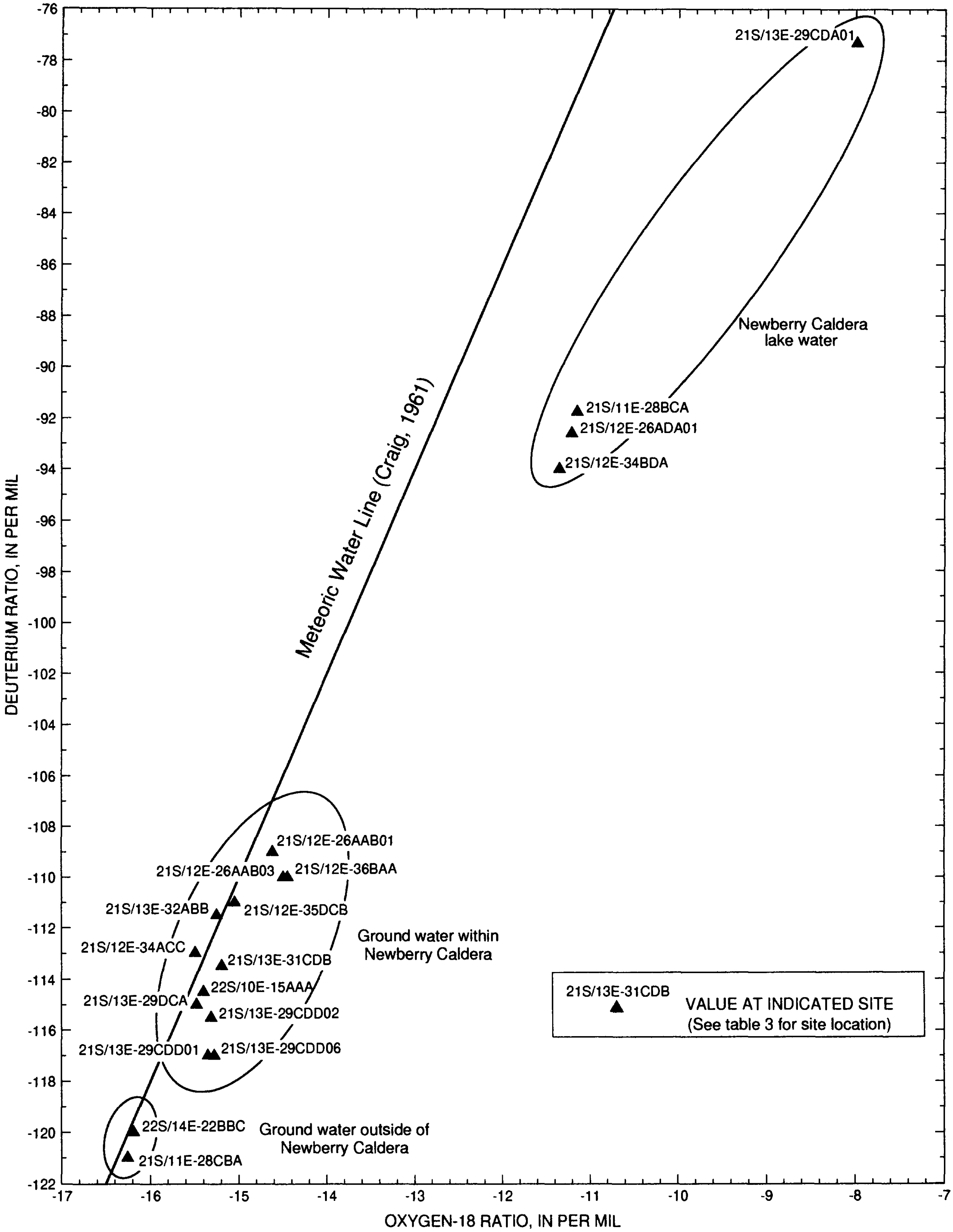


Figure 17. Median isotope ratios of oxygen-18 and deuterium in ground water and surface water, Newberry Volcano and vicinity, Oregon, 1991–95.

Certain isotopes are inherently unstable and spontaneously change to form more stable isotopes. Radioactivity is the release of energy and particles resulting from such changes. Radioactive energy can be released by (1) alpha radiation, (2) beta radiation, or (3) gamma radiation.

Concentrations of radon, gross alpha, and gross beta radioactivity were larger inside the Newberry Caldera than outside (table 12). The largest concentrations of radon were from samples from nonthermal sources: radon concentration was 540 pCi/L (picocuries per liter) at the Newberry Group Site Campground (21S/12E-35DCB), 300 pCi/L at Hot Springs Campground No. 1 (21S/13E-32ABB), and 260 pCi/L at Geo-Newberry Well (21S/13E-29DCA). The largest gross alpha concentration was at Paulina Guard Station (21S/12E-34ACC), which is also a nonthermal source. The gross alpha concentration of this well was 14 pCi/L, which was more than 10 times larger than any other measured concentration. The largest gross beta concentrations, on the other hand, were at thermal sources in the Paulina Lake area (19 pCi/L at Paulina Lake Hot Springs No. 1 [21S/12E-26AAB01], and 11 pCi/L at Little Crater Campground No. 3 [21S/12E-36BAA]).

Tritium, an unstable isotope of hydrogen, is present in the atmosphere and hydrosphere as a result of thermonuclear testing during and after the early 1950's (Drever, 1988, p. 379). In the Newberry Volcano area, the four tritium samples ranged from 2.0 pCi/L at East Lake Hot Springs No. 4 (21S/13E-29CDD01) to 22 pCi/L at both Sandia Well (21S/13E-31CDB) and La Pine High School (22S/10E-15AAA) (table 12). These values suggest that ground water in these wells is relatively modern water or contains some portion of relatively modern water that entered the ground as recharge some time after the 1950's.

Table 12. Concentrations of radionuclides at selected sites, Newberry Volcano and vicinity, Oregon, 1991–93

[Values are reported in picocuries per liter, except for gross alpha, which is in micrograms per liter as uranium; radon and tritium determinations were made on unfiltered water, whereas gross alpha and beta determinations were made on filtered water; USFS, U.S. Forest Service]

Site location	Site name	Date	Time	Radon 222	Gross alpha	Gross beta	Tritium
		East Lake Area					
21S/13E-29CDD01	East Lake Hot Springs No. 4	910815	1415	140	--	--	2.0
21S/13E-29CDD01	East Lake Hot Springs No. 4	920401	1030	< 80	--	--	--
21S/13E-29DCA	Geo-Newberry Well	910813	1730	260	< 0.60	0.90	--
21S/13E-32ABB	Hot Springs Campground No. 1	910815	1745	300	< .60	3.9	--
		Paulina Lake Area					
21S/12E-26AAB01	Paulina Lake Hot Springs No. 1	910815	1000	180	< .60	19	--
21S/12E-26AAB01	Paulina Lake Hot Springs No. 1	920401	1700	95	--	--	--
21S/12E-34ACC	Paulina Guard Station	910930	1530	220	14	1.2	--
21S/12E-34BDA	Paulina Creek near La Pine	911002	1020	140	.90	7.4	--
21S/12E-35DCB	Newberry Group Site Campground	911001	1415	540	< .60	1.4	--
21S/12E-36BAA	Little Crater Campground No. 3	910814	1230	< 80	.70	11	11
21S/12E-36BAA	Little Crater Campground No. 3	930914	1415	240	--	--	--
21S/13E-31CDB	Sandia Well	910813	1200	< 80	< .90	7.3	22
		Outside Newberry Caldera					
SEE FIGURE 1	Crater Lake near Crater Lake	910829	1200	--	< .60	2.2	--
SEE FIGURE 1	Crater Lake near Crater Lake	911007	1300	--	< .60	1.6	--
SEE FIGURE 1	Crater Lake near Crater Lake	920630	1230	--	< .60	1.5	--
SEE FIGURE 1	Crater Lake near Crater Lake	930712	1300	--	< .60	2.3	--
SEE FIGURE 1	Crater Lake near Crater Lake	931020	1330	--	< .60	1.6	--
21S/11E-28BCA	Paulina Creek near USFS Road 21	911002	1330	90	1.2	6.1	--
21S/11E-28CBA	Prairie Campground	911001	1015	100	.70	1.2	--
22S/10E-15AAA	La Pine High School	910816	1030	--	< .60	1.5	22
22S/14E-22BBC	China Hat Guard Station	910930	1100	170	< .60	1.9	--

SUMMARY

Hydrologic and water-quality data were collected at Newberry Volcano between 1991 and 1995 as part of a program to establish baseline, or predevelopment, conditions prior to construction and operation of a proposed geothermal power plant. Hydrologic data collected included hourly stage and discharge of Paulina Creek, hourly stages of East Lake and Paulina Lake, hourly meteorological data from a station near Paulina Lake, intermittent water-level measurements from nonthermal wells, intermittent and hourly water-level measurements from thermal wells, and intermittent and hourly water-level measurements from monitoring wells installed near hot springs. Water-quality data collected included major ions, nutrients, trace elements, stable isotopes, and field measurements of temperature, specific conductance, dissolved oxygen concentration, pH, and alkalinity; samples were collected at least biannually and as frequently as semiannually at some sites. Hourly measurements of specific conductance and temperature were also made on Paulina Creek.

Newberry Volcano is located 40 miles east of the crest of the Cascade Range and consequently receives about one-half of the precipitation that areas of equivalent elevation in the Cascade Range receive. The mean annual precipitation is approximately 36 in/yr. Precipitation in the caldera of the volcano is reasonably well correlated with precipitation estimated for Deschutes Basin from nearby weather stations. Records indicate that precipitation at the volcano has been below normal in every year of the baseline period except 1993.

The stage of East Lake ranged from a low of 6,371.8 ft (feet) in October 1994 to a high of 6,375.5 ft in February 1992. Historic lake levels range from 6,366 to 6,385.5 ft. Seasonal fluctuations in East Lake were 1 to 2.5 ft and there was a net decline in lake level of 2.6 ft between 1992 and 1995. Paulina Lake stage ranged from a low of 6,330.0 ft in September 1994 to a high of 6,332.8 ft, the elevation of the spillway, in each year of data collection. There are no published historic data on the elevation of Paulina Lake for comparison with the baseline period. There was no net decline in lake level during the baseline period as inflow to the lake from precipitation and ground water was sufficient to refill the lake to the level of the spillway in each year of the baseline years.

The long-term mean discharge of Paulina Creek is 17.9 ft^3/s (cubic feet per second); the mean for the baseline period, 13.9 ft^3/s, is significantly below the long-term mean. Paulina Creek loses an average of 23 percent of the flow at the lake outlet within the first 8 miles from the outlet. Measurements show that there are gains in streamflow in the upper 3 miles that are probably related to ground water flow around waterfalls.

Ground-water levels have seasonal trends that are similar to those of lake levels. Wells nearest East Lake had net declines in water level during the baseline period that were similar to those in long-term monitoring wells outside the caldera near La Pine. Water levels fell 1–2 ft in the long-term monitoring wells between 1992 and 1995 and have fallen about 10 ft since 1984. The Sandia Well (21S/13E-31CDB), located nearly 1 mile from East Lake, has larger seasonal fluctuations than the lake and is probably more strongly affected by annual recharge and less affected by East Lake than other wells. Paulina Lake area wells showed seasonal fluctuations similar in magnitude to those of the lake but, like Paulina Lake, did not experience net declines during the baseline period.

Hot springs discharge to both lakes, but total discharge cannot be measured directly because the discharge emanates from many dispersed orifices and seeps, some of which are underwater. Water levels in piezometers drilled in the hot spring discharge areas show that there is a consistent hydraulic gradient toward the lakes. The water levels in the piezometers fluctuate with lake level and a nearly constant hydraulic gradient between the ground-water system and the lakes is maintained throughout the year.

Water-quality data were collected from 19 sites in the vicinity of Newberry Volcano. Samples for chemical analysis were collected and analyzed in accordance with standard procedures of the U.S. Geological Survey, and water temperature, pH, specific conductance, and dissolved oxygen concentration were measured in the field.

Water temperatures in the Newberry Volcano area vary widely and are controlled, to a large extent, by geothermal activity. The highest median temperature (63.1°C) was at East Lake Hot Springs No. 5B (21S/13E-29CDD06). In the Paulina Lake area, Paulina Lake Hot Springs No. 1 and 2B (21S/12E-26AAB01,03), Little Crater Campground No. 3 (21S/12E-36BAA), and Sandia Well (21S/13E-31CDB) are affected by geothermal water, as indicated by their median water temperatures. Outside of the Newberry Caldera area, median water temperatures were approximately equal to nonthermal waters inside the caldera area.

In the Newberry Caldera area, major ions were present in higher concentrations in geothermal water. In the East Lake Area, there is a predominance of bicarbonate. The single exception is East Lake, which has a considerable concentration of sulfate, which may be due to the oxidation of hydrogen sulfide gas dissolved in ground water. In the Paulina Lake area, sodium, magnesium, and bicarbonate are the predominant ions. Outside of the Newberry Caldera, calcium, magnesium, and bicarbonate are the dominant major ions in surface water. The largest median values for alkalinity, total dissolved solids, specific conductance, and silica were in geothermal water, whereas the largest median pH values were measured in nonthermal water. Nutrient concentrations in Newberry Volcano and vicinity were generally quite low.

There is arsenic of probable hydrothermal origin in several wells in the Paulina Lake area; this source also contributes arsenic to Paulina Lake and Paulina Creek. There were lower arsenic concentrations in the East Lake area and outside Newberry Caldera. Barium and lithium also had high concentrations in wells in the Paulina Lake area. The highest concentrations of boron, iron, and manganese were found in geothermal water.

Analysis of samples collected and processed using ultraclean techniques showed mercury to be present at low concentrations. Mercury concentrations were higher in the East Lake area than in the Paulina Lake area. Mercury concentrations in samples collected before an ultraclean method of mercury sampling was developed may have been due to contamination; their distribution is consistent with random contamination.

Paulina Lake, Paulina Creek, and to a larger extent East Lake are enriched in the heavy stable isotopes oxygen-18 and deuterium. The enrichment of heavy isotopes in lake water is probably due to evaporation from the lake surface.

Concentrations of radon, gross alpha, and gross beta radioactivity were larger inside the Newberry Caldera than outside. The largest concentrations of radon and gross alpha radioactivity were from samples from nonthermal sources; whereas the largest gross beta radioactivities were from thermal sources in the Paulina Lake area. Tritium concentrations in the Newberry Volcano area suggest that ground water in wells is relatively modern water that entered the ground as recharge some time after thermonuclear weapons testing in the early 1950's.

REFERENCES CITED

Brown, E., Skougstad, M.W., and Fishman, M.J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. Al, 160 p.

Buchanan, T.J., and Somers, W.P., 1968, Stage measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A7, 28 p. (reprinted 1974).

———1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p.

Claassen, H.C., 1982, Guidelines and techniques to obtain valid ground-water quality samples: U.S. Geological Survey Open-File Report 82–1024, 54 p.

Craig, Harmon, 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702–1703.

Crumrine, M.D., and Morgan, D.S., 1994, Hydrologic, water-quality, and meteorologic data for Newberry Volcano and vicinity, Deschutes County, Oregon, 1991–93: U.S. Geological Survey Open-File Report 94–122, 70 p.

Drever, J., 1988, The geochemistry of natural waters (2d ed.): Englewood Cliffs, New Jersey, Prentice Hall, 437 p.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92–634, 28 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for the determination of inorganic substances in water and fluvial sediments (3d ed.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Horowitz, A.J., Demas, C.R., Fitzgerald, K.K., Miller, T.L., and Rickert, D.A., 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94–539, 57 p.

Hubbard, L.E., Herrett, T.A., Kraus, R.L., Ruppert, G.P., and Courts, M.L., 1993, Water resources data—Oregon—Water year 1992: U.S. Geological Survey Water-Data Report OR–92–1, 474 p.

———1994, Water resources data—Oregon—Water year 1993: U.S. Geological Survey Water-Data Report OR–93–1, 498 p.

———1995, Water resources data—Oregon—Water year 1994: U.S. Geological Survey Water-Data Report OR–94–1, 473 p.

———1996, Water resources data—Oregon—Water year 1995: U.S. Geological Survey Water-Data Report OR–95–1, 452 p.

MacDonald, L.H., Smart, A.W., and Wissmar, R.C., 1991, Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska: U.S. Environmental Protection Agency, EPA-910/9-91-001, 166 p.

MacLeod, N.S., Sherrod, D.R., Chitwood, L.A., and Jensen, R.A., 1995, Geologic map of Newberry Volcano, Deschutes, Klamath, and Lake Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–2455.

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92–146, 39 p.

Phillips, K.E., 1968, Hydrology of Crater, East, and Davis Lakes, Oregon: U.S. Geological Survey Water-Supply Paper 1859–E, 60 p.

Presser, T.S., and Barnes, Ivan, 1974, Special techniques for determining chemical properties of geothermal water: U.S. Geological Survey Water-Resources Investigations Report 22–74, 11 p. [Available only through National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161 as NTIS Report PB–235 148/AS.]

Sammel, E.A., 1983, The shallow hydrothermal system at Newberry Volcano, Oregon—A conceptual model: Transactions of the Geothermal Resources Council, October, v. 7, p 325–330.

Sammel, E.A., and Craig, R.W., 1983, Hydrology of the Newberry Volcano Caldera, Oregon: U.S. Geological Survey Water-Resources Investigations Report 83–4091, 52 p.

Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A5, 95 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water: EPA-440/5-86-001, [variously paged].

U.S. Forest Service, 1994a, Newberry Geothermal Pilot Project, Environmental Impact Statement (executive summary), 18 p.

———1994b, Newberry Geothermal Pilot Project, Record of Decision, 28 p.

———1994c, Newberry National Volcanic Monument comprehensive management plan, 177 p.

Ward, J.R., and Harr, C.A., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analysis: U.S. Geological Survey Open-File Report 90–140, 75 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

APPENDIX

WATER-QUALITY DATA, NEWBERRY VOLCANO AND VICINITY, 1994–95

Appendix—Water-quality data, Newberry Volcano and vicinity, 1994–95

[GW, ground water; SW, surface water; LK, lake; deg C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; pH, hydrogen-ion activity; $CaCO_3$, calcium carbonate; --, no data; lab, laboratory; <, less than; >, more than; USFS, U.S. Forest Service; H, hydrogen; mil, per one thousand; O, oxygen. See plate 1 for site location. See table 3 for all site names except 21S/12E-26ADA02, Paulina Lake PL-11-60, from table 1]

Site location	Station number	Type site	Date	Time	Temperature water (deg C)	Specific conductance (µS/cm)	pH water whole field (standard units)	Oxygen, dissolved (mg/L)	Hardness total (mg/L as $CaCO_3$)
21S/11E-28BCA	434339121245600	SW	06-14-94	1515	14.0	551	8.8	9.5	230
			10-06-94	1015	3.5	573	9.1	11.1	240
			06-20-95	1530	11.0	546	8.7	9.9	230
			10-16-95	1800	8.5	593	8.9	9.3	220
21S/11E-28CBA	434330121252101	GW	10-19-95	1349	10.0	79	7.9	9.1	22
21S/12E-26AAB03	434356121150803	GW	06-15-94	1130	58.5	1,120	6.4	--	320
			10-05-94	1045	58.0	1,160	7.1	--	340
			06-21-95	1700	58.0	1,150	6.5	--	330
			10-18-95	1420	56.5	1,100	6.3	.7	300
21S/12E-26ADA01	434343121150430	LK	06-15-94	1015	9.0	571	8.1	9.2	220
			10-05-94	1000	12.0	601	8.4	9.0	240
			06-21-95	1100	7.5	582	8.2	9.5	230
			10-18-95	1502	10.0	592	8.5	8.8	220
21S/12E-26ADA02	434343121150460	LK	06-15-94	1030	7.0	560	8.1	9.7	230
21S/12E-34ACC	434242121163601	GW	10-06-94	0830	5.0	65	7.5	9.4	20
			10-17-95	0815	5.0	67	7.1	9.2	20
21S/12E-34BDA	14063300	SW	06-13-94	1810	10.5	568	8.5	9.0	230
			10-06-94	0915	9.0	588	8.8	8.8	240
			06-19-95	1645	8.5	561	8.3	9.6	230
			10-16-95	1515	11.0	583	8.7	8.8	220
21S/12E-35DCB	434221121152201	GW	10-05-94	1630	5.5	88	7.2	9.5	34
			10-17-95	1730	5.5	90	7.1	9.0	35
21S/12E-36BAA	434303121142101	GW	06-14-94	1000	35.0	999	6.0	.0	340
			10-04-94	0900	36.0	1,040	6.0	.1	360
			06-20-95	1100	36.5	959	6.0	.1	340
			10-17-95	1131	36.0	981	5.9	.1	290
21S/13E-29CDA01	434325121115730	LK	06-16-94	0945	10.5	319	7.2	8.8	110
			10-04-94	1500	12.5	339	7.6	8.5	120
			06-22-95	0930	9.5	330	7.0	9.0	110
			10-18-95	1000	9.0	333	7.4	8.3	110
21S/13E-29CDD06	434313121115706	GW	06-16-94	1115	63.5	795	6.3	.8	320
			10-04-94	1700	62.5	814	6.3	.4	330
			06-22-95	1130	61.5	898	6.6	.6	350
			10-18-95	0925	58.0	784	6.4	.5	280
21S/13E-29DCA	434320121114201	GW	10-04-94	1200	3.5	48	8.6	10.9	19
			10-17-95	1430	3.5	50	8.5	11.4	19
21S/13E-31CDB	434220121132101	GW	06-14-94	0900	26.5	504	6.4	4.4	170
			10-05-94	1400	23.5	663	6.3	3.5	260
			06-20-95	0930	24.0	660	6.3	2.6	240
			10-17-95	1001	24.5	714	6.2	1.9	250
21S/13E-32ABB	434305121115301	GW	10-04-94	1000	10.0	195	6.7	7.0	77
			10-17-95	1551	8.0	162	6.8	8.9	59

Site location	Date	Bromide dis-solved (mg/L as Br)	Calcium dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Alkalinity, water, dis-solved, total, incremental titration, field mg/L as $CaCO_3$	Alkalinity, water, dis-solved, total incremental titration, lab (mg/L as $CaCO_3$)	Sulfate dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)
21S/11E-28BCA	06-14-94	--	28	38	46	5.5	334	322	3.3	2.5
	10-06-94	0.020	27	41	48	5.4	344	350	3.2	2.4
	06-20-95	.030	28	38	46	5.2	350	338	3.1	2.1
	10-16-95	.020	27	38	47	5.4	340	342	1.8	2.3
21S/11E-28CBA	10-19-95	<.010	4.0	2.9	7.7	1.4	38	39	.30	.80
21S/12E-26AAB03	06-15-94	--	54	44	130	16	612	649	4.6	5.4
	10-05-94	.070	55	48	130	8.2	640	647	3.6	5.1
	06-21-95	.080	56	45	120	16	632	653	3.2	4.8
	10-18-95	.060	49	42	120	17	632	641	2.3	4.7
21S/12E-26ADA01	06-15-94	--	28	37	46	5.2	320	342	3.5	2.5
	10-05-94	.030	28	41	48	5.9	346	352	3.1	2.2
	06-21-95	.010	28	38	46	5.3	331	344	2.9	1.9
	10-18-95	.020	26	38	49	5.8	342	347	2.2	2.3
21S/12E-26ADA02	06-15-94	--	29	38	47	5.3	316	342	3.5	2.3
21S/12E-34ACC	10-06-94	<.010	3.5	2.8	7.0	1.6	33	36	.30	.70
	10-17-95	<.010	3.4	2.7	6.7	1.6	40	35	.10	.80
21S/12E-34BDA	06-13-94	--	28	38	46	5.2	338	336	3.6	2.3
	10-06-94	.020	29	41	48	5.4	343	348	3.1	2.2
	06-19-95	.040	28	38	49	5.0	327	339	3.1	2.0
	10-16-95	.020	26	37	46	5.4	338	343	1.8	2.2
21S/12E-35DCB	10-05-94	<.010	6.9	4.1	5.7	1.6	46	47	.70	2.1
	10-17-95	<.010	7.2	4.1	5.7	1.6	46	47	.30	1.7
21S/12E-36BAA	06-14-94	--	53	50	84	11	572	571	.10	5.9
	10-04-94	.16	55	53	88	10	570	572	<.10	5.6
	06-20-95	.33	53	51	88	11	560	568	<.10	5.2
	10-17-95	.13	45	44	77	11	564	569	<.10	5.5
21S/13E-29CDA01	06-16-94	--	26	11	24	3.5	97	103	66	.50
	10-04-94	<.010	25	13	26	3.8	100	103	68	.50
	06-22-95	<.010	26	11	23	3.9	101	103	64	.30
	10-18-95	<.010	24	12	26	4.0	102	103	65	.10
21S/13E-29CDD06	06-16-94	--	71	34	53	8.2	432	446	11	.80
	10-04-94	<.010	71	36	54	7.7	442	442	8.2	.80
	06-22-95	<.010	78	37	56	8.3	450	445	37	.80
	10-18-95	<.010	61	31	52	8.6	450	443	7.8	.80
21S/13E-29DCA	10-04-94	<.010	4.4	1.9	3.8	.70	25	28	.20	.30
	10-17-95	<.010	4.5	2.0	3.8	.70	29	29	.10	.40
21S/13E-31CDB	06-14-94	--	27	25	46	7.6	284	285	.20	2.8
	10-05-94	.030	39	40	57	8.6	382	389	.30	1.8
	06-20-95	.050	37	36	58	7.7	376	388	3.9	2.0
	10-17-95	.050	39	37	57	8.5	416	428	.10	2.3
21S/13E-32ABB	10-04-94	.010	18	7.7	14	3.4	112	110	2.1	.40
	10-17-95	.040	14	5.8	11	3.0	90	85	.70	.50

Site location	Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 deg C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus dissolved (mg/L as P)
21S/11E-28BCA	06-14-94	0.70	40	--	358	<0.010	<0.010	--	<0.050	<0.010
	10-06-94	.70	41	359	380	<.015	<.010	--	<.050	<.010
	06-20-95	.70	42	350	369	.020	<.010	<.20	<.050	<.010
	10-16-95	.60	40	346	368	<.015	<.010	<.20	<.050	.020
21S/11E-28CBA	10-19-95	.20	35	68	76	<.015	<.010	<.20	.070	.070
21S/12E-26AAB03	06-15-94	.70	210	--	858	.480	<.010	--	<.050	.130
	10-05-94	.60	220	822	863	.480	<.010	--	<.050	.110
	06-21-95	.60	220	854	862	.460	<.010	.50	<.050	.110
	10-18-95	.50	200	822	824	.480	<.010	.40	<.050	.120
21S/12E-26ADA01	06-15-94	.70	39	--	368	.010	<.010	--	<.050	.020
	10-05-94	.70	45	360	386	<.015	<.010	--	<.050	<.010
	06-21-95	.70	43	351	373	<.015	<.010	<.20	<.050	.010
	10-18-95	.60	42	357	375	<.015	<.010	<.20	<.050	<.010
21S/12E-26ADA02	06-15-94	.70	40	--	372	.020	<.010	--	<.050	.020
21S/12E-34ACC	10-06-94	.80	45	81	84	<.015	<.010	--	.060	.070
	10-17-95	.70	44	68	82	<.015	<.010	<.20	.070	.080
21S/12E-34BDA	06-13-94	.80	41	--	367	.020	<.010	--	<.050	.010
	10-06-94	.70	45	357	384	<.015	<.010	--	<.050	<.010
	06-19-95	.70	42	351	372	<.015	<.010	<.20	<.050	.020
	10-16-95	.60	41	350	367	<.015	<.010	<.20	<.050	.030
21S/12E-35DCB	10-05-94	.10	45	90	96	<.015	<.010	--	.300	.030
	10-17-95	.20	45	86	95	<.015	<.010	<.20	.210	.040
21S/12E-36BAA	06-14-94	.60	140	--	694	.380	<.010	--	<.050	.030
	10-04-94	.50	160	682	--	.400	<.010	--	<.050	.150
	06-20-95	.50	150	689	--	.390	<.010	.40	<.050	.100
	10-17-95	.40	130	660	--	.400	<.010	.40	<.050	.170
21S/13E-29CDA01	06-16-94	.10	11	--	206	.930	<.010	--	<.050	<.010
	10-04-94	.10	9.9	212	209	<.015	<.010	--	<.050	.010
	06-22-95	.10	11	213	202	.020	<.010	.20	<.050	<.010
	10-18-95	.20	8.7	206	203	<.015	<.010	.20	<.050	<.010
21S/13E-29CDD06	06-16-94	.10	200	--	651	.920	0.010	--	<.050	.390
	10-04-94	<.10	230	640	677	.960	<.010	--	<.050	.350
	06-22-95	.10	220	709	709	.950	<.010	.90	<.050	.340
	10-18-95	.20	200	654	632	.960	<.010	.90	<.050	.400
21S/13E-29DCA	10-04-94	<.10	24	43	52	<.015	<.010	--	<.050	.050
	10-17-95	.20	23	42	52	<.015	<.010	<.20	<.050	.040
21S/13E-31CDB	06-14-94	.80	91	--	374	.020	<.010	--	.140	.260
	10-05-94	.60	93	440	476	<.015	<.010	--	.180	.230
	06-20-95	.60	91	447	471	<.015	<.010	<.20	.150	.240
	10-17-95	.50	83	468	487	<.015	<.010	<.20	.150	.270
21S/13E-32ABB	10-04-94	<.10	49	149	161	.020	<.010	--	.070	.040
	10-17-95	.20	46	116	134	<.015	<.010	<.20	<.050	.030

Site location	Date	Phos phorus ortho, dis-solved (mg/L as P)	Alum-inum, dis-solved (µg/L as Al)	Iron, dis-solved (µg/L as Fe)	Manga-nese, dis-solved (µg/L as Mn)	Anti-mony, dis-solved (µg/L as Sb)	Arsenic dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Beryl-lium, dis-solved (µg/L as Be)	Boron, dis-solved (µg/L as B)
21S/11E-28BCA	06-14-94	0.010	<10	5	<1	--	14	16	<0.5	870
	10-06-94	<.010	<1	8	<1	<1	16	17	<1	900
	06-20-95	<.010	1	<3	<1	<1	14	18	<1	900
	10-16-95	<.010	3	4	<1	<1	15	16	<1	850
21S/11E-28CBA	10-19-95	.070	7	<3	<1	<1	1	1	<1	30
21S/12E-26AAB03	06-15-94	.140	20	<3	1,500	--	12	280	<.5	970
	10-05-94	.140	2	<3	1,600	<1	13	300	<1	950
	06-21-95	.100	3	610	1,200	<1	10	320	<1	920
	10-18-95	.130	4	140	1,600	<1	13	280	<1	1,000
21S/12E-26ADA01	06-15-94	.010	<10	9	4	--	14	18	<.5	870
	10-05-94	<.010	<1	11	<1	<1	16	19	<1	890
	06-21-95	<.010	<1	10	2	<1	14	20	<1	880
	10-18-95	.010	3	24	5	<1	15	19	<1	880
21S/12E-26ADA02	06-15-94	.010	10	9	3	--	14	19	<.5	870
21S/12E-34ACC	10-06-94	.110	--	11	<1	--	--	--	--	30
	10-17-95	.090	7	7	<1	<1	3	2	<1	20
21S/12E-34BDA	06-13-94	.010	10	5	4	--	14	17	<.5	850
	10-06-94	<.010	<1	16	4	<1	16	19	<1	900
	06-19-95	<.010	1	11	3	<1	14	18	<1	890
	10-16-95	.010	3	21	3	<1	15	17	<1	850
21S/12E-35DCB	10-05-94	.050	--	8	<1	--	--	--	--	10
	10-17-95	.040	4	3	<1	<1	<1	2	<1	<10
21S/12E-36BAA	06-14-94	.030	<10	4,500	230	--	<1	24	<.5	1,800
	10-04-94	.160	3	5,000	250	<1	<1	27	<1	1,700
	06-20-95	.070	4	4,900	270	<1	1	26	<1	1,800
	10-17-95	.130	4	4,700	1,300	<1	<1	25	<1	1,700
21S/13E-29CDA01	06-16-94	<.010	--	<3	8	--	2	17	<.5	930
	10-04-94	<.010	<1	3	5	<1	2	18	<1	920
	06-22-95	<.010	2	<3	11	<1	2	19	<1	980
	10-18-95	<.010	3	<3	5	<1	2	21	<1	990
21S/13E-29CDD06	06-16-94	.380	<10	35	990	--	<1	3	<.5	1,200
	10-04-94	.410	3	4	>1,000	<1	<1	3	<1	1,200
	06-22-95	.390	4	<3	1,200	<1	<1	4	<1	1,300
	10-18-95	.400	4	<3	1,000	<1	<1	3	<1	1,200
21S/13E-29DCA	10-04-94	.060	--	8	<1	--	--	--	--	10
	10-17-95	.050	9	<3	<1	<1	<1	<1	<1	10
21S/13E-31CDB	06-14-94	.250	<10	12	5	--	20	7	<.5	720
	10-05-94	.270	<1	32	3	<1	20	14	<1	590
	06-20-95	.250	1	20	2	<1	16	12	<1	810
	10-17-95	.250	3	21	3	<1	19	14	<1	860
21S/13E-32ABB	10-04-94	.050	<1	230	15	<1	<1	5	<1	110
	10-17-95	.020	4	1,200	61	<1	<1	6	<1	120

Site location	Date	Cadmium dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Cobalt, dis-solved (µg/L as Co)	Copper, dis-solved (µg/L as Cu)	Lead, dis-solved (µg/L as Pb)	Lithium dis-solved (µg/L as Li)	Mercury dis-solved (µg/L as Hg)	Molyb-denum, dis-solved (µg/L as Mo)	Nickel, dis-solved (µg/L as Ni)
21S/11E-28BCA	06-14-94	<1.0	<5	<3	<10	<10	71	<.1	<10	<10
	10-06-94	<1.0	3	<1	<1	<1	74	<.1	<1	<1
	06-20-95	<1.0	2	<1	1	<1	72	--	<1	4
	10-16-95	<1.0	2	<1	<1	<1	68	--	1	<1
21S/11E-28CBA	10-19-95	<1.0	1	<1	<1	<1	<4	--	<1	<1
21S/12E-26AAB03	06-15-94	<1.0	<5	<3	<10	20	210	<0.1	<10	<10
	10-05-94	<1.0	6	2	<1	<1	220	<.1	<1	3
	06-21-95	<1.0	3	2	<1	<1	220	--	<1	13
	10-18-95	<1.0	9	2	<1	<1	200	--	<1	4
21S/12E-26ADA01	06-15-94	<1.0	<5	<3	<10	<10	71	<.1	<10	<10
	10-05-94	<1.0	4	<1	<1	<1	75	<.1	<1	1
	06-21-95	<1.0	1	<1	<1	<1	73	--	<1	4
	10-18-95	<1.0	1	<1	<1	<1	70	--	<1	2
21S/12E-26ADA02	06-15-94	<1.0	<5	<3	<10	<10	73	<.1	<10	<10
21S/12E-34ACC	10-06-94	--	--	--	--	--	18	--	--	--
	10-17-95	<1.0	<1	<1	<1	<1	17	--	4	<1
21S/12E-34BDA	06-13-94	<1.0	<5	<3	<10	<10	68	<.1	<10	<10
	10-06-94	<1.0	1	<1	<1	<1	74	<.1	1	2
	06-19-95	<1.0	2	<1	<1	<1	75	--	<1	4
	10-16-95	<1.0	2	<1	<1	<1	68	--	<1	1
21S/12E-35DCB	10-05-94	--	--	--	--	--	19	--	--	--
	10-17-95	<1.0	<1	<1	<1	<1	17	--	<1	<1
21S/12E-36BAA	06-14-94	<1.0	<5	<3	<10	<10	120	<.1	10	<10
	10-04-94	<1.0	10	<1	<1	<1	130	<.1	<1	6
	06-20-95	<1.0	7	<1	<1	<1	130	--	<1	12
	10-17-95	<1.0	10	<1	<1	<1	110	--	<1	7
21S/13E-29CDA01	06-16-94	<1.0	<5	<3	<10	<10	13	<.1	<10	<10
	10-04-94	<1.0	<1	<1	<1	<1	13	<.1	<1	<1
	06-22-95	<1.0	<1	<1	<1	<1	13	--	<1	6
	10-18-95	<1.0	<1	<1	<1	<1	11	--	<1	<1
21S/13E-29CDD06	06-16-94	<1.0	<5	<3	<10	<10	34	<.1	<10	<10
	10-04-94	<1.0	10	<1	<1	<1	34	<.1	<1	2
	06-22-95	<1.0	3	<1	1	<1	33	--	<1	10
	10-18-95	<1.0	3	<1	1	<1	28	--	<1	2
21S/13E-29DCA	10-04-94	--	--	--	--	--	<4	--	--	--
	10-17-95	<1.0	<1	<1	<1	<1	<4	--	<1	<1
21S/13E-31CDB	06-14-94	<1.0	<5	<3	<10	<10	76	<.1	<10	<10
	10-05-94	<1.0	4	<1	<1	<1	88	<.1	1	2
	06-20-95	<1.0	2	<1	<1	<1	88	--	<1	4
	10-17-95	<1.0	5	<1	<1	<1	86	--	<1	<1
21S/13E-32ABB	10-04-94	<1.0	2	<1	<1	<1	<4	<.1	<1	2
	10-17-95	<1.0	<1	<1	<1	<1	<4	--	<1	<1

Site location	Date	Sele-nium, dis-solved (µg/L as Se)	Silver, dis-solved (µg/L as Ag)	Stron-tium, dis-solved (µg/L as Sr)	Uranium natural dis-solved (µg/L as U)	Vana-dium, dis-solved (µg/L as V)	Zinc, dis-solved (µg/L as Zn)	H-2 / H-1 stable isotope ratio per mil	O-18 / O-16 stable isotope ratio per mil
21S/11E-28BCA	06-14-94	--	<1.0	83	--	<6	9	--	--
	10-06-94	<1	<1.0	84	<1.0	--	<1	-91.2	-10.95
	06-20-95	<1	<1.0	83	<1.0	--	4	-93.8	-11.41
	10-16-95	<1	<1.0	86	<1.0	--	<1	-90.0	-10.85
21S/11E-28CBA	10-19-95	<1	<1.0	19	<1.0	--	24	-122.0	-16.08
21S/12E-26AAB03	06-15-94	--	<1.0	200	--	<6	<3	--	--
	10-05-94	<1	<1.0	210	<1.0	--	2	-110.0	-14.50
	06-21-95	<1	<1.0	200	<1.0	--	56	-111.0	-14.51
	10-18-95	<1	<1.0	200	<1.0	--	36	-109.0	-14.47
21S/12E-26ADA01	06-15-94	--	<1.0	87	--	<6	<3	--	--
	10-05-94	<1	<1.0	89	<1.0	--	<1	-92.1	-11.00
	06-21-95	<1	<1.0	84	<1.0	--	<1	-94.4	-11.42
	10-18-95	<1	<1.0	91	<1.0	--	<1	-91.3	-11.07
21S/12E-26ADA02	06-15-94	--	2.0	88	--	<6	<3	--	--
21S/12E-34ACC	10-06-94	--	--	12	--	--	--	-113.0	-15.37
	10-17-95	<1	<1.0	12	<1.0	--	27	-111.0	-15.21
21S/12E-34BDA	06-13-94	--	<1.0	85	--	<6	<3	--	--
	10-06-94	<1	<1.0	90	<1.0	--	<1	-94.3	-11.06
	06-19-95	<1	<1.0	86	<1.0	--	1	-94.0	-11.49
	10-16-95	<1	<1.0	87	<1.0	--	<1	-92.0	-10.99
21S/12E-35DCB	10-05-94	--	--	20	--	--	--	-110.0	-14.93
	10-17-95	<1	<1.0	21	<1.0	--	22	-109.0	-14.78
21S/12E-36BAA	06-14-94	--	<1.0	180	--	<6	<3	--	--
	10-04-94	<1	<1.0	190	<1.0	--	1	-110.0	-14.34
	06-20-95	<1	<1.0	190	<1.0	--	<1	-110.0	-14.28
	10-17-95	<1	<1.0	190	<1.0	--	<1	-109.0	-14.30
21S/13E-29CDA01	06-16-94	--	2.0	98	--	<6	3	--	--
	10-04-94	<1	<1.0	100	<1.0	--	<1	-75.8	-7.71
	06-22-95	<1	--	93	<1.0	--	<1	-77.7	-8.25
	10-18-95	<1	--	100	<1.0	--	1	-77.3	-7.76
21S/13E-29CDD06	06-16-94	--	<1.0	360	--	<6	<3	--	--
	10-04-94	<1	<1.0	360	<1.0	--	<1	-117.0	-15.28
	06-22-95	<1	--	360	<1.0	--	<1	-117.0	-15.29
	10-18-95	<1	--	340	<1.0	--	2	-112.0	-15.16
21S/13E-29DCA	10-04-94	--	--	11	--	--	--	-113.0	-15.28
	10-17-95	<1	<1.0	11	<1.0	--	6	-113.0	-15.23
21S/13E-31CDB	06-14-94	--	<1.0	80	--	28	<3	--	--
	10-05-94	<1	<1.0	120	1.0	--	2	-114.0	-15.04
	06-20-95	<1	<1.0	110	<1.0	--	<1	-113.0	-15.07
	10-17-95	<1	<1.0	130	<1.0	--	<1	-112.0	-14.99
21S/13E-32ABB	10-04-94	<1	<1.0	66	<1.0	--	14	-111.0	-15.10
	10-17-95	<1	<1.0	51	<1.0	--	28	-112.0	-15.33

☆ U.S. GOVERNMENT PRINTING OFFICE: 1997 - 589-114 / 41726 REGION NO. 10