HYDROLOGY OF THE NEWBERRY VOLCANO CALDERA, OREGON

by Edward A. Sammel and Robert W. Craig

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CONTINUED)

TABLES

CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch (in)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)

Most temperatures are reported in degrees Celsius (°C); for conversion to degrees Fahrenheit (°F), use the formula, °F = 9/5 °C + 32.

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ABSTRACT

Precipitation in the Newberry caldera is nearly in balance with evaporation, evapotranspiration, and streamflow. A small surplus of water, estimated to be in the range 2,500 to 6,500 acre-feet, is available annually for recharge to deep aquifers beneath the caldera floor.

Precipitation in the caldera is estimated to be about 35 inches annually (31,900 acre-feet) on the basis of multiple-regression analyses of records from 5 weather stations in the region and intermittent records from a storage gage in the caldera. Paulina Creek, the only surface outlet from the caldera, discharges at least 13,000 acre-feet per year (18 cubic feet per second) from Paulina Lake. Annual evaporation from two lakes, Paulina and East, is about 19 inches and 28 inches (2,100 acre-feet and 2,300 acre-feet), respectively, and annual evapotranspiration from vegetated areas in the caldera is about 13 inches (8,000 acre-feet). Evaporation was estimated by means of an empirical expression on the basis of measurements at the lakes during the summer of 1981 and by correlation with annual records at high-altitude lakes in the western United States.

Nonthermal ground and surface water in the caldera has small concentrations of dissolved solids in which calcium, magnesium, and bicarbonate ions predominate. Thermal waters from springs and wells have dissolved solids concentrations of 900 milligrams per liter or more and are characterized by high concentrations of sodium and sulfate.

Maximum temperatures measured in the Paulina and East Lake Hot Springs are 52°C and 62°C, respectively. Attempts to account for the origin of the hot springs on the basis of mixing relations and isotopic analyses were inconclusive. The springs probably represent mixtures of thermal and nonthermal water that are altered by hydrogen sulfide and carbon dioxide gases rising from sources beneath the caldera floor.

Temperatures in the lakes are higher than normal in the vicinity of the hot springs and at other places, apparently due to inflows of thermal water through

the lake bottoms. The contributions of thermal water probably amount to no more than a few hundred acre-feet per year and are neglected in the hydrologic budget.

East Lake loses water by seepage to the shallow ground-water system at rates that vary seasonally in response to precipitation and ground-water inflow. Lake levels are self-regulating within fairly narrow limits. Paulina Lake probably loses little water by seepage and its surface outflow is maintained by ground-water inflow from the East Lake sub-basin.

Observations in a Geological Survey drill hole in the caldera suggest that part of the surplus water in the caldera flows to aquifers at depths as much as 1,900 feet beneath the caldera floor. Potential recharge from the caldera to a deep geothermal reservoir is likely to be small and is probably limited to permeable flow paths in faults and ring fractures.

INTRODUCTION

Newberry Volcano is one of many large volcanic structures built during Quaternary time in the Cascade Range of Oregon. Situated on the eastern margin of the Range in west central Oregon, Newberry is impressive more for its areal extent (about 500 square miles) than for its height (less than 4,000 feet above adjacent terrain). Newberry is characterized by a large collapsed summit caldera similiar to those of two other Cascade Range volcanos, the former Mount Mazama in Oregon, and Medicine Lake Volcano in California. The caldera contains two scenic lakes, Paulina and East, and has been set aside as a recreational area within the Deschutes National Forest.

Newberry has been studied by geologists since the early years of this century, and interest has increased during the past 10 years as a result of its potential as a source of geothermal energy. This interest has led to the drilling of two research core holes as a part of the Geothermal Studies Program of the U.S. Geological Survey (USGS) and has been the impetus for the hydrologic study described in this paper.

The discovery of high temperature and heat flow in the caldera (Sammel, 1981; MacLeod and Sammel, 1982) has encouraged the belief that a high-temperature geothermal resource may exist at Newberry, but has left many unanswered questions regarding the nature of the resource. One of these questions concerns the possible recharge of meteoric water to an underlying hydrothermal reservoir. This report gives tentative conclusions as to the magnitude and nature of recharge beneath the caldera.

A previous study by Phillips (1968) of three lakes in the Cascade Range of Oregon, including East Lake, provided valuable background information as well as preliminary estimates of the hydrologic terms evaluated in the present study. Phillips drew his conclusions largely on the basis of extrapolations of data from other areas, some of them distant from Newberry. Our estimate of possible ground-water recharge does not differ greatly from that of Phillips, and we commend his hydrologic acumen which led to apparently valid conclusions on the basis of minimal and uncertain evidence.

We also acknowledge the following agencies and individuals whose support was essential to our work; George I. Chesley, District Ranger, Fort Rock Ranger District, Deschutes National Forest, and his staff for friendly cooperation and support of our test drilling and hydrologic studies over a period of 4 years; J. E. Vaughn, Silviculturist of the Fort Rock Ranger District, for the estimate of evapotranspiration; Robert Pennington of the Oregon Department of Fish and Wildlife and Robert Main, Water Master, District 11, Oregon Water Resources Department, for aid in interpreting streamflow records; and Joe Kipp, owner of the Paulina Lake Resort, and Robert Saling and Al Nesbitt, former and present owners, respectively, of the East Lake Resort for aid and helpful interest during our work at Newberry.

SCOPE AND METHODS OF THE STUDY

The study was conducted during the summer and fall of 1981 and was confined to the approximately 17 square miles within the caldera (fig. 1). Prior reconnaissance had showed that no springs exist on the flanks of Newberry, that only a few wells are located on the lowermost flanks, and that surface discharge of water from the mountain normally occurs only in Paulina Creek, a westward-flowing stream draining Paulina Lake.

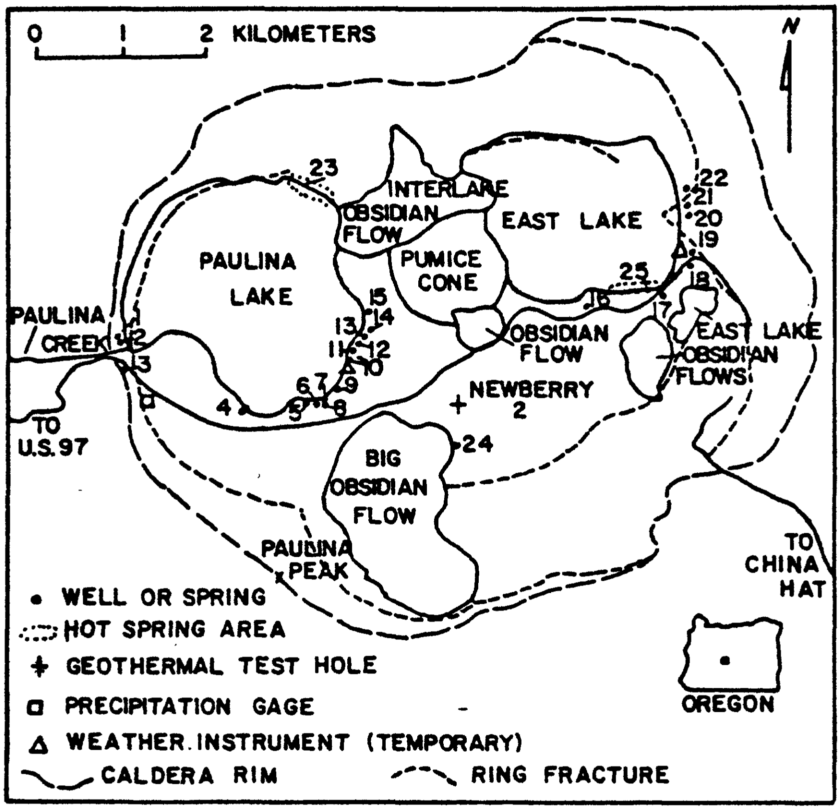

Figure 1. — Sketch map of the caldera at Newberry Volcano.

Information on ground water was collected from 22 water wells, two groups of warm springs, and two USGS drill holes. The hydrologic budget was estimated from data obtained both in the caldera and elsewhere in the region. The estimate of precipitation, based on multiple-regression analyses of records at Newberry and nearby stations, is thought to be the most reliable of the several estimates. All others involved a degree of subjective judgement that introduced large uncertainties into the estimates. Because the largest uncertainties pertain to the smallest terms in the budget equation, the results of the budget analysis are believed to be qualitatively correct and sufficiently accurate to justify the overall conclusions.

DESCRIPTION OF THE CALDERA

The physical characteristics of the caldera and its setting were described in detail by Phillips (1968), and the geology of the volcano was described in MacLeod and others (1981) and MacLeod and Sammel (1982). Only essential details are repeated here.

Newberry Volcano is a composite structure, made up of basalt and basaltic-andesite flows, andesitic to rhyolitic ash-flow and ash-fall tuffs and other pyroclastic deposits, dacite to rhyolite domes and flows, and alluvial sediments (MacLeod and others, 1981). The flows extend for tens of miles, principally toward the north and south. Massive tuffaceous deposits crop out on the flanks and probably underlie many of the younger basalt and basaltic-andesite flows.

The rim of the caldera lies at altitudes that range from 7,000 feet to 7,500 feet or more on the north, south, and east sides, but decrease to 6,330 feet on the west side at the outlet of Paulina Lake. The highest point on the rim, Paulina Peak, has an altitude of 7,985 feet, and is part of a large rhyolite dome.

The caldera is a steep-walled basin, about 5 miles long (east-west) and 4 miles wide. The rim of the caldera lies at altitudes that range from 6,330 feet on the west side to 7,985 feet at Paulina Peak on the south. Two lakes occupy much of the caldera floor. Paulina Lake has a surface altitude of about 6,333 feet, a maximum depth of 252 feet, and covers 1,345 acres. East Lake is smaller (980 acres) and shallower (170 feet depth) than Paulina Lake and lies at a higher altitude (about 6,375 feet). A large pumice cone and two obsidian flows separate the two lakes (fig. 1).

The caldera floor is a highly irregular surface formed largely of rhyolitic rocks, including domes, flows, and pumiceous tephra deposits. Basaltic-andesite and andesite flows and palagonite tuff rings occur in several places (MacLeod and others, 1981). Below these rocks, a few dacitic flows and thick sequences of alluvial and lacustrine sediments form the caldera fill which extends to a depth of at least 1,600 feet. Below the caldera fill are flow rocks that are similar in appearance and composition to the flank flows (MacLeod and Sammel, 1982).

Most of the caldera is densely forested with lodgepole pine, some yellow pine, fir, and alder, but nearly 20 percent of the land area is unvegetated rock, ash, or pumice. Depressions in the surface are mostly covered by pumice or other volcanic ejecta, fallen or washed in from adjacent slopes. Overland runoff from precipitation is nearly absent, even during heavy rainfalls. Ground-water flow probably occurs readily in the upper few tens of feet of permeable sediments, breccias, and the fractured tops of volcanic flows. Underlying flow rocks and tuffaceous deposits, exposed at the western end of the caldera, appear to have lower permeabilities and probably act as barriers to deep percolation.

CLIMATE

Summer daytime temperatures in the caldera reach 100°F at times, but nights are normally cool. Winter temperatures normally are below freezing, and sub-freezing temperatures can occur in any month. The mean annual temperature is about 32°F. Prevailing windy conditions in the caldera cause high evapotranspiration during sunny periods and rapid cooling as storm fronts pass.

Precipitation patterns at Newberry are similar to those in most of the semi-arid region east of the Cascade Range in central Oregon, where most precipitation falls during the months of October through April. But orographic effects are significant at Newberry, and the volcano creates its own microclimate to a large degree. Rain or snow may fall in the caldera at times when the lower slopes and the adjacent valleys are in sunshine. The contrast between the climate at Newberry and that of the surrounding region is indicated by differences in the average annual precipitation at the three nearest weather stations. Annual precipitation at Newberry is about 35 inches, whereas that at Bend, 24 miles north, is 11.7 inches; at Fremont, 26 miles south, 10.9 inches; and at Wickiup Dam, 26 miles west, 20.5 inches. The nearby weather stations are at altitudes that range from 1,900 to 2,900 feet lower than the caldera.

THE HYDROLOGIC BUDGET

Estimation of Terms

The basic equation for the hydrologic budget of the caldera at Newberry Volcano is

$$P = OF + E + ET + S, \quad (1)$$

where P = precipitation in the caldera
OF = outflow to Paulina Creek
E = evaporation from lake surfaces
ET = evapotranspiration from land surfaces
S = seepage out of the near-surface hydrologic system.

The first four terms of the equation can be measured or estimated. The fifth term, S, is assumed to be equal to the residual needed to balance the equation.

In the absence of evidence for long-term trends in any of the terms, the seepage term, S, is assumed to be a long-term average seepage rate. As S is the residual in the equation, it contains all errors of measurement or estimation in other terms of the equation.

Precipitation

Records of precipitation at Newberry are available from a snow course and a precipitation storage gage. The snow course was maintained from 1955 to 1968 under the Cooperative Snow Surveys Program of the U.S. Department of Agriculture, Soil Conservation Service. Measurements were summarized in George and Haglund (1973). The precipitation storage gage, installed in 1965, is located south of Paulina Lake at an altitude of 6,400 feet (fig. 1). Records are published annually by the Oregon Water Resources Department. The average annual precipitation cannot be determined directly from the storage-gage data because of the difficulty of obtaining reliable winter measurements.

In order to estimate the average annual precipitation at Newberry Volcano the storage-gage measurements were supplemented by data from National Weather Service records at five stations in the region (table 1). Multiple-regression analysis of the data shows that two stations, Chemult and Wickiup Dam, have a significant correlation with reliable periods of record at Newberry despite being at lower altitudes (table 2, end of report).

The regression equation used to estimate precipitation at Newberry is

$$P = -0.137 + 0.246 (P_c) + 1.42 (P_w), \quad (2)$$

where

P = average annual precipitation at Newberry, in inches

P_c = 30-year normal" (1959-1980) determined by the National Weather Service for the station at Chemult (25.6 inches per year)

P_w = "30-year normal" (1950-1980) at Wickiup Dam (20.49 inches per year).

The average annual precpitation at Newberry Volcano calculated from the regression equation is 35.3 inches. The coefficient of determination for the equation is 0.956. Reports from observers indicate that precipitation is virtually uniform over the caldera.

Phillips (1958) estimated the average annual precipitation at Newberry to be 35 inches on the basis of a comparison of the snow course records and National Weather Service records at Bend. J. E. Vaughn, Silviculturist with the Deschutes National Forest (written commun., 1982), estimated the annual precipitation at Newberry as 35.1 inches on the basis of records at six local stations, including the five used in this report, and unpublished U.S. Forest Service data. The precipitation estimate for Newberry is the most reliable of the terms in the hydrologic budget, with a probable error of less than 15 percent.

Surface-Water Outflow

Paulina Creek, which drains Paulina Lake on the west side of the caldera, is the only surface outlet from the caldera. The flow from the lake is partly controlled by a small concrete dam at the outlet except for periods during the winter and spring when lake levels exceed the spillway elevation of 6,332.8 feet. During the period April 1 to October 31, a sluice gate is used to maintain flow in order to satisfy water rights of a ranch located at the base of the mountain. During the late fall and winter, efforts are made to maintain a minimum flow of 2-3 cubic feet per second (ft^3/s) until the lake rises above the spillway (Robert Main, Water Master, Bend--written commun., 1982).

Table 1.-- National Weather Service stations in the vicinity of Newberry Volcano

Station	Location				Distance, direction from Newberry (miles)	Altitude (feet)	Average annual precipitation (inches)
	Latitude		Longitude				
Bend	44°	04'	121°	19'	24,N	3,599	11.7
Chemult	43°	14'	121°	47'	44,SW	4,760	25.6
Crater Lake	42°	54'	122°	08'	68,SW	6,475	67.4
Fremont	43°	20'	121°	10'	26,S	4,512	10.9
Wickiup Dam	43°	41'	121°	41'	26,W	4,358	20.5

Unpublished stream-flow records are available from 1966 to the present. Measurements were made by the Oregon Department of Fish and Wildlife between 1966 and 1974, and by the U.S. Forest Service from 1975 to the present. Flow estimates based on the measurements are shown in table 3. Most of the measurements were made in the months May through September and the estimates for this period given in table 3 are averages calculated after elimination of the high and low values for each month. These estimates are considered fairly reliable.

The data available for the winter months may be unreliable and misleading. A few lake-stage measurements indicate that flows during the winter can be as great as 30 or 35 ft^3/s, but reports from observers suggest that flows are normally below these values. Calculations show that a discharge rate of 30 ft^3/s for 5 winter months would lower the lake level 6.7 feet unless replaced by ground-water inflow. It is unlikely that winter ground-water discharge to the lake could replace the approximately 9,000 acre-feet of water that would be lost during so long a period of sustained high flow. Estimates for the period October through April in table 3 represent the calculated distribution of discharge on the basis of an average annual flow of $18^3/s$.

Table 3. -- Measured and estimated discharges, in cubic feet per second, from Paulina Lake to Paulina Creek

[Based on measurements by the Oregon Department of Fish and Wildlife (1967-1974) and the U.S. Forest Service (1975-1981). See text for explanation of estimated averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1967	---	---	---	---	22	---	---	---	---	---	---	---	
1970	49	---	---	21	22	20	16	15	15	---	---	25	
1971	---	---	34	32	38	---	---	---	15	---	---	22	
1972	---	---	---	---	23	25	---	---	---	---	8	18	
1973	---	34	---	---	---	10	13	---	---	---	16	20?	
1974	---	---	34	---	---	35	36	24	15	12	4	30?	
1975	---	---	---	---	29	40	30	22	21	12	---	26?	
1976	---	---	---	---	---	---	26	15	15	15	15	---	
1977	---	---	---	---	22	14	15	15	14	---	3	---	
1979	---	---	---	30	30	21	24	14	14	5	2	---	
1980	---	---	---	---	26	20	16	---	---	---	---	---	
1981	11	---	---	---	---	---	22	22	---	---	---	---	
Estimated monthly average	15	16	20	30	25	22	21	17	15	10	10	15	18

Phillips (1968) estimated the annual discharge as 20 ft^3/s on the basis of seven measurements made in summer months between 1903 and 1962. His distribution of monthly averages is similar to that in table 3. Personnel of the U.S. Forest Service and the Oregon Department of Fish and Wildlife who are familiar with the area agree that the annual figure probably is close to 20 ft^3/s, with a probable lower limit of 18 ft^3/s (J. E. Vaughn and Robert Pennington, personal commun., 1982).

Evaporation from Lake Surfaces

Evaporation from lake surfaces in the caldera has not been directly measured. Evaporation from nearby lakes at altitudes of about 4,000 feet was estimated to be 33 inches annually (Farnsworth and others, 1982). As the lakes at Newberry are at altitudes greater than 6,300 feet, they probably have lower evaporation rates, primarily because of cooler temperatures and greater humidity due to increased precipitation. Phillips (1968) estimated an annual evaporation rate of 28 inches partly on the basis of a comparison with Crater Lake, Odell Lake, Wickiup Dam, and Davis Lake, and partly by means of an adjustment for altitude to a rate of 34 inches determined by Kohler and others (1959) for lakes elsewhere in the western United States.

During July, August, and September, 1981, measurements of windspeed and direction, temperature, and relative humidity were made at each lake in order to estimate evaporation by means of a quasi-empirical mass-transfer expression (Harbeck, 1962):

$$E = Nu_z(e_o - e_a), \qquad (3)$$

where E = evaporation from lake surface, inches per day (in/d),

N = Mass-transfer coefficient, constant for a specific lake (dimensionless),

u_z = windspeed at some height z above the water surface, miles per hour (mi/hr),

e_o = saturation vapor pressure in millibars (mb) calculated from temperature of the water surface, and

e_a = vapor pressure of the incoming air mass (mb).

Ideally N is calibrated by an energy budget study over a period of one or more years. If this is not possible, Harbeck suggests using the empirical relationship

$$N = \frac{0.00338}{A^{0.05}} , \quad (4)$$

where A = surface area of the lake in acres. The windspeed, u_z, should be measured at a height of 2 meters above the lake surface at mid-lake. The saturation vapor pressure, e_o, preferably is calculated using daily water-surface temperatures at mid-lake. The vapor pressure of the air is taken from a station that best represents the incoming air mass unaffected by evaporation from the lake.

In this study, windspeed was measured at stations on the east banks of the lakes rather than at mid-lake. Water-surface temperatures are average monthly values for Paulina Lake obtained prior to 1981 by the Oregon Department of Fish and Wildlife. The measurements were assumed to be representative of East Lake also. The vapor pressure of the incoming air mass was calculated from daily minimum relative humidity and maximum-temperature measurements supplied by the U.S. Forest Service, Deschutes National Forest, for the Cabin Lake Guard Station at an elevation of 4,493 feet. The mass-transfer coefficient was calculated from equation (4), using a surface area of 980 acres for East Lake and 1,345 acres for Paulina Lake.

Measurements of windspeed and direction at Paulina Lake were made on the shore of the lake near Campsite No. 1 in Little Crater Campground. The East Lake site was on the east shore of the lake just north of the East Lake Resort boat ramp. Both sites were selected so that prevailing winds would be least affected by topography. Measurements were made by a single recording rotating-cup anemometer set approximately ten feet above lake level at each lake during alternate weeks.

During the 7 weeks of measurement at Paulina Lake, between 7:00 a.m. and 7:00 p.m. the winds were from the west, northwest, or north 83 percent of the time at an average speed of 5 1/2 miles per hour (mi/hr). From 7:00 p.m. to 7:00 a.m. the winds were from the east or southeast 80 percent of the time and averaged 1 1/2 mi/hr. During 6 weeks of measurements at East Lake, winds were from the west, northwest, or north 80 percent of the time during the day and from the east 65 percent of the time at night. Windspeeds during the day averaged about 7 mi/hr and at night about 4 mi/hr.

The daily average windspeed at Paulina Lake during periods of measurement was 3.9 mi/hr and at East Lake was 5.6 mi/hr. The ratio of these values, 0.70, was used to estimate average windspeed at each lake for weeks in which measurements were not obtained.

After substitution of the calculated value of the mass-transfer coefficient for East Lake, the equation of evaporation (3) becomes

$$E = 0.00240\ u\ (e_o - e_a),$$

where e_o = 17.77 mb for July, 19.19 mb for August, and 15.16 mb for September, and

u and e_a = daily measured values.

The equation for Paulina Lake is

$$E = 0.00236\ u\ (e_o - e_a),$$

with u, e_o, and e_a as above. The estimated total evaporation for July, August and September, 1981 is 13.3 inches at East Lake and 9.14 inches at Paulina Lake (table 4, end of report).

In order to relate the three-month total to an annual amount, evaporation measurements for 39 stations in California and Oregon were obtained from Blaney and Corey (1955) and Phillips (1968). Trials using multiple-regression analysis showed that total annual evaporation is reliably predicted by the three-month total if latitude and altitude are incorporated with data from stations at altitudes greater than 2,000 feet. Altitudes at 6 stations used ranged from 2,525 feet to 4,800 feet and latitudes ranged from approximately 35.0° to 43.6° north. The linear regression analysis indicated that 48 percent of the annual evaporation at Newberry occurs in the three-month period of actual measurement. The coefficient of determination for the regression was 0.60.

If it is assumed that the measurements in 1981 are typical of long-term conditions, the annual evaporation at Paulina Lake is 19 inches and at East Lake, 28 inches. The evaporation estimate for East Lake agrees with Phillips' (1968) estimate. The lower rate for Paulina Lake is due almost entirely to the lower average windspeed at Paulina Lake. Unknown windspeeds in the late fall and spring are a major cause of uncertainty in these estimates, and the measurement methods at the lakes also introduce large uncertainties. The resulting error of estimate is highly uncertain but probable compensating errors may place it in the range ± 20 percent.

Evapotranspiration

Evapotranspiration in the caldera was estimated J. E. Vaughn, U.S. Forest Service, on the basis of potential evaporation (PET) calculated by means of the equation (Hamon, 1961):

$$PET = 0.195\ D\ P_t, \qquad (5)$$

where PET = potential evaporation (inches/month),

D = possible hours of daylight in units of 30 12-hour days, and

P_t = saturated absolute humidity (gm/m^3) at the mean monthly temperature.

Estimated annual PET is 13.6 inches (table 5). The actual evapotranspiration (AET) will be less than PET at any time during the year when adequate soil moisture is not available. The monthly soil-moisture balance calculated for the caldera (table 6) indicates that an average deficit of 0.06 inches occurs during August and 0.39 inches during September. Consequently, the annual evapotranspiration is estimated to be 13.1 inches.

Equation 5 is likely to underestimate evapotranspiration under the conditions that prevail at Newberry (Donald R. Satterlund, Washington State University, personal commun., 1982). Because of consistently high wind speeds in the caldera, evapotranspiration during summer months could be as much as 3 inches more than the estimate in table 6, and the budget term for evapotranspiration in table 8 may be low, therefore, by as much as 2,000 acre-feet.

Budget Calculation

In calculating the hydrologic budget, the value for precipitation was applied to the total caldera area and the evapotranspiration rate was applied only to the vegetated area (table 7). For the area without vegetation, all precipitation is assumed to result in recharge to shallow ground water. The calculations of the budget equation are shown in table 8 for each topographic basin and the total caldera. The apparent residual, 6,500 acre-feet annually for the caldera, is 20 percent of the total precipitation.

If the probable positive errors listed in table 8 were all additive, about 12,000 acre-feet of water would be available for seepage to the deep

Table 5.-- Calculation of potential evapotranspiration at Newberry caldera using the Hamon equation (Hamon, 1961)

[Calculated by J. E. Vaughn, Silviculturist, Deschutes National Forest. P_t = saturated absolute humidity, in grams per cubic meter; D = possible hours of daylight; PET = potential evapotranspiration]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Temperature, (°C)	-10.3	-6.6	-6.6	-1.6	+2.5	+5.4	+10.6	+9.5	+6.9	0.8	-3.3	-6.7	
P_t (gm/m^3)	2.13	2.85	2.86	4.30	5.72	6.91	9.71	9.12	7.62	5.10	3.71	2.81	
D (1 = 30 12-hour days of daylight)	.81	.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	.95	.80	.76	
PET (inches)	.34	.46	.57	.95	1.42	1.74	2.46	2.13	1.55	.94	.58	.42	13.56

Table 6.-- Calculation of soil-moisture balance at Newberry caldera

[For coarse soil with assumed maximum available soil moisture of 6 inches. Calculated by J. E. Vaughn, Silviculturist, Deschutes National Forest]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Precipitation (inches)1/	6.03	5.20	4.24	2.27	2.23	1.18	0.24	0.21	0.58	1.17	5.50	6.22	35.07
PET (inches)2/	.34	.46	.57	.95	1.42	1.74	2.46	2.13	1.55	.94	.58	.42	13.56
AET (inches)3/	.34	.46	.57	.95	1.42	1.74	2.46	2.07	1.16	.94	.58	.42	13.11
Change in soil moisture (inches)	0	0	0	0	0	-.56	-2.22	-1.86	-.58	.23	4.92	.07	----
Soil moisture (inches)	6.00	6.00	6.00	6.00	6.00	5.44	3.22	1.36	.78	1.01	5.93	6.00	----
Deficit (inches)	0	0	0	0	0	0	0	.06	.39	0	0	0	.45
Runoff (inches)4/	5.69	4.74	3.67	1.32	.81	0	0	0	0	0	0	5.73	21.96

1/ Estimates by U. S. Forest Service based on records at 6 nearby weather stations.

2/ Potential evapotranspiration from table 5.

3/ Estimated actual evapotranspiration.

4/ Water available for ground-water recharge.

Table 7.-- Areas used in calculating the hydrologic budget

Area used	Paulina Lake topographic basin (acres)	East Lake topographic basin (acres)	Total caldera (acres)
Total	6,368	4,482	10,850
Vegetated	4,108	3,197	7,305
Nonvegetated	915	305	1,220
Lake surface	1,345	980	2,325

ground-water system. The summing of negative probable errors results in a negative seepage term and implies that there is an annual decrease of about 1,700 acre-feet of water in the lakes and the shallow ground-water system.

The thorough study by Phillips (1968) of levels of East Lake during the last 130 years shows rather conclusively that, although the lake has been at least 7 feet higher than at present during two abnormally wet periods, its mean level probably has not changed significantly in historic times. We assume, therefore, that the entire caldera is in a state of hydrologic balance, and that the long-term hydrologic budget must have at worst a zero net loss to deep ground-water percolation.

The apparent imbalance between the two basins probably is real, although it could be greater or smaller than the estimated one. If probable errors in estimates of evapotranspiration and the outflow to Paulina Creek are considered, it is likely that the Paulina Lake sub-basin has an annual deficit even if precipitation is 15 percent greater than the estimate. This deficit is presumably made up by ground-water inflow from the East Lake sub-basin, where there would be a surplus of water under almost any reasonable assumptions about probable errors in its budget. Westward movement of surplus ground water is virtually assured by the hydraulic gradient of at least 45 feet per mile between the two basins.

Table 8.-- Average annual hydrologic budget, Newberry caldera

[See text, "Budget Calculation" and "Discussion of Results", for an explanation of probable errors and most likely values]

	Paulina Lake basin (acre-feet)	East Lake basin (acre-feet)	Caldera (acre-feet)	Probable error (percent)
Precipitation 1/	(+)18,700	(+)13,200	(+)31,900	(+15,-10)
Evaporation from lakes 2/	(-) 2,100	(-) 2,300	(-) 4,400	(±20)
Evapotranspiration 3/	(-) 4,500	(-) 3,500	(-) 8,000	(+20,-0)
Outflow to Paulina Creek 4/	(-)13,000	----	(-)13,000	(+20,-0)
Residual 5/	(-) 900	(+) 7,400	(+) 6,500	(+45,-60)

1/ 35.3 inches

2/ Paulina Lake, 18.9 inches; East Lake, 27.8 inches

3/ 13.1 inches

4/ 18 ft^3/s

5/ Water assumed to be available for deep percolation.

During its residence and movement, a fraction of the ground water infiltrates the volcanic rocks beneath the surficial deposits and is removed from the shallow hydrologic system. Infiltration rates for the rhyolitic rocks in the caldera are probably high; those for the tuffaceous rocks may be low. A rate of 0.3 foot per year probably is a reasonable minimum value for the caldera, and this results in a lowest probable seepage estimate of about 2,500 acre-feet. This amount is about 10 percent of the annual precipitation on land surfaces.

An estimate of the highest probable value of the seepage term was calculated by assuming 15 percent greater precipitation, 20 percent less lake evaporation, 10 percent greater evapotranspiration, and 10 percent greater stream flow. The probable maximum amount of water available for deep percolation on this basis is about 10,000 acre-feet. (See below, "Discussion of Results", for a downward revision of this preliminary figure.)

CHEMISTRY OF SURFACE AND GROUND WATER

Major Ionic Constituents

Eleven of 22 wells in the caldera (table 9, end of report), three springs and gas vents (table 10, end of report), and the two lakes were sampled for chemical analysis. The results of the chemical analyses are shown in table 11. The identifying sequence numbers given in tables 9, 10, and 11 are used in the remainder of the report to refer either to the chemical analysis or to the well or spring from which the sample came.

Total concentrations of dissolved solids in the waters sampled range from 79 to 907 milligrams per liter (mg/L). Predictably, warm waters from wells and springs contain the higher concentrations. The lake waters are intermediate in concentration between these waters and the more dilute cold ground waters.

Water quality diagrams, modified from Stiff (1951), provide a convenient means for depicting relationships among the Newberry samples (fig. 2).

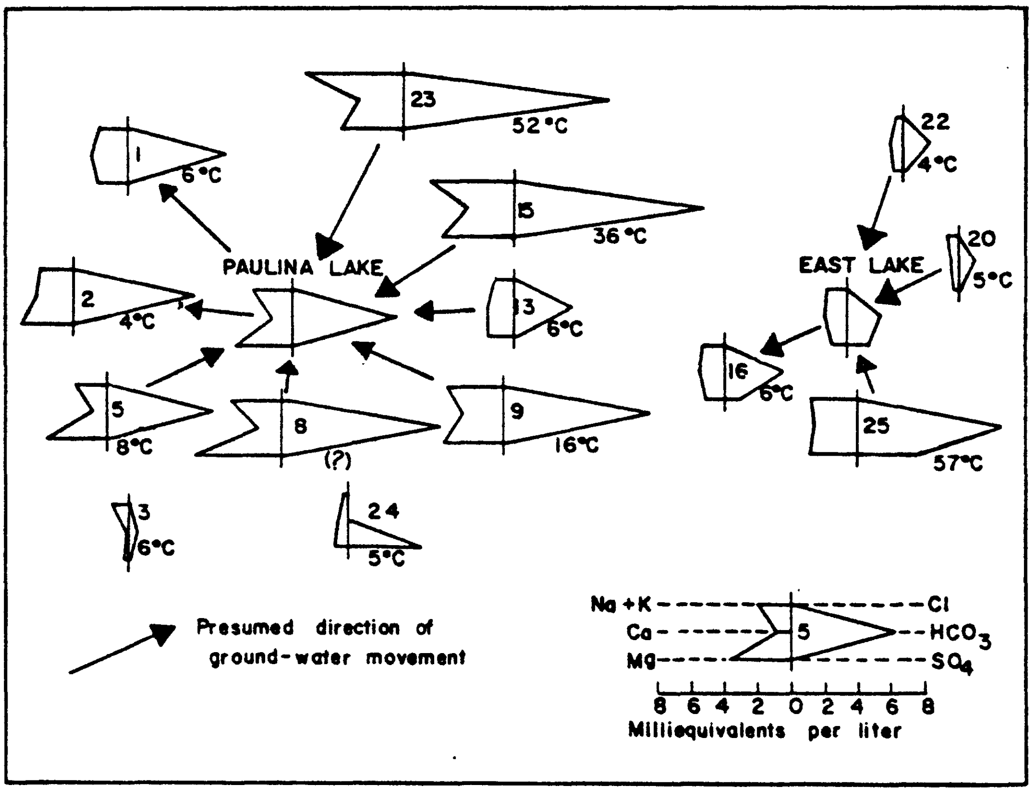

Figure 2. -- Stiff diagrams of the major chemical constituents in ground and surface water.

Table 11.-- Chemical analyses of ground and surface water

[Concentrations in milligrams per liter unless otherwise indicated. µg/L = micrograms per liter; µmho/cm = micromhos per centimeter]

Sequence Number[1]	Owner/ name	Temp. (°C)	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	SiO_2	As (µg/L)	B (µg/L)	Fe (µg/L)	Li (µg/L)	Mn (µg/L)	Dissolved solids[2]	Specific cond. (µmho/cm)	pH	Date sampled	Source[3]
1	Paulina Lake Resort	5	35	24	28	6.1	315	5.0	2.8	0.3	29	1	460	120	13	11	286	400	6.95	10/07/81	A
		6.7	39	35	38	7.7	398	1.9	2.7	.4	33	2	700	180	--	1500	356	565	6.9	10/27/74	B
2	Paulina Lake Resort	4	44	39	44	6.4	450	6.0	3.1	.5	36	24	780	6700	88	2300	410	600	7.15	10/07/81	A
3	Paulina Guard Station (USFS)	6	3.3	2.6	6.5	1.8	27	5.0	.2	.7	46	3	20	23	17	<1	79	65	6.65	09/06/81	A
5	Mike Mathews (summer home)	8	18	41	41	5.0	376	2	2.6	---	90	--	--	--	--	--	--	(≈700[5])	6.97	06/30/82	E
8	Jack Hogg (summer home)	--	30	65	68	7.4	585	5.0	5.2	.8	110	39	1500	<10	120	2	581	900	6.15	09/06/81	A
9	Little Crater Picnic Area	16	42	44	64	8.3	535	5.0	4.6	.7	90	32	1600	180	100	30	532	710	6.80	10/07/81	A
13	Little Crater Camp Site 27	6	28	17	25	2.6	215	5.0	1.7	.3	46	16	570	43	29	10	232	360	7.10	10/07/81	A
15	Little Crater Camp Site 49	33	59	57	97	12	690	5.0	6.8	.5	156	<1	1800	360	140	270	733	900	6.21	09/06/81	A
		35.5	54	48	83	10	679	<1	5.1	.6	161	--	2500	4000	120	250	702	900	6.46	08/--/75	C
		36	56	51	96	12	691	2.5	4.5	.5	140	2	1000	5000	---	350	709	880	6.3	10/17/74	E
16	East Lake Campground well	6	33	15	26	6.0	200	43	2.8	.2	40	1	210	19	9	3	265	390	6.80	09/06/81	A
20	Cinder Hill Campground well	5	7.1	1.9	11	1.3	56	5.0	2.5	.4	30	5	10	27	8	5	87	110	6.70	09/06/81	A

Table 11.-- Chemical analyses of ground and surface water (Continued)

[Concentrations in milligrams per liter unless otherwise indicated. µg/L = micrograms per liter; µmho/cm = micromhos per centimeter]

Sequence Number[1/]	Owner/ name	Temp. (°C)	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	SiO_2	As (µg/L)	B (µg/L)	Fe (µg/L)	Li (µg/L)	Mn (µg/L)	Dis-solved solids[2/]	Spec-ific cond. (µmho/cm)	pH	Date sam-pled	Source[3/]
22	Cinder Hill Camp Site 34	4	14	7.2	6.3	3.5	88	5.0	<.1	.1	34	<1	10	120	<4	57	113	140	7.20	10/06/81	A
23	Paulina Hot Springs	--	56	60	140	17	856	<1	6.0	.6	205	--	870	--	220	--	907	--	6.82	07/00/77	C
		50	51	43	120	16	699	4.0	4.7	.5	190	16	840	90	--	1700	776	960	6.9	10/26/74	B
		52	50	42	110	13	689	2	5.0	--	184	--	--	--	--	--	--	--	7.26	06/30/82	E
24	Lost Lake gas vent	5	13	8.2	7.9	1.1	0	200	1.1	0.0	31	1	180	15000	--	450	--	400	3.4	10/27/74	B
25	East Lake Hot Springs	49	70	34	53	--	547	28	.7	.2	199	--	1100	660	40	900	658	767	6.42	08/00/75	C
		55	77	39	59	9.7	581	20	1.3	.1	120	1	260	500	--	1400	614	840	6.7	10/26/74	B
		57	73	33	56	9.7	413	120	1.3	--	197	--	--	--	--	--	--	--	6.10	06/30/82	E
--	Paulina Lake[4/]	--	26	39	47	5.2	352	3.8	2.8	.6	46	--	--	--	--	--	366	566	8.8	09/10/60	D
		6	28	38	47	5.0	402	4	2.4	--	--	--	--	--	--	--	--	--	8.38	06/30/82	E
--	East Lake[4/]	--	27	13	27	4.5	120	64	.3	.2	10	--	640	20	--	--	206	334	7.8	00/00/73	E
			26	10	23	3.7	125	59	.2	.1	13	--	--	--	--	--	197	323	8.1	09/11/60	D
		10	25	11	24	3.7	123	64	<1	--	8.8	--	--	--	--	--	--	--	8.07	06/30/82	E

1/ Sequence No. ---- Identifying number used in tables and illustrations.

2/ Estimated by summation of HCO_3 x 0.4917 and other ions listed (Hem, 1970).

3/ Source of data or collector (USGS): A: R. W. Craig; B: N. E. Voegtly; C: R. H. Mariner, and others (1980); D: K. N. Philips (1968); E: R. H. Mariner (unpub. data, 1981, 1982).

4/ Sample (6/30/82) obtained at a depth of 45 feet near the center of the lake.

5/ Estimated.

The diagrams are arranged in a pattern roughly corresponding to the locations of wells and springs in relation to the two lakes. Waters with similar chemical compositions have similar shapes, and the arrows connecting the diagrams indicate presumed flow relationships in the shallow hydrologic system.

As shown in the sketch map, figure 1, the wells in Newberry caldera are clustered near the two lakes. The diagrams in figure 2 show that each lake water is similar to adjacent ground water and that most samples obtained in the Paulina Lake topographic sub-basin differ in character from waters in the East Lake sub-basin. In ground waters sampled near Paulina Lake, dissolved sodium, magnesium, and bicarbonate predominate. Concentrations of chloride and sulfate are low and silica concentrations range from 29 mg/L in cold well water (No. 1) to 205 mg/L in the Paulina Hot Spring (No. 23) (table 11).

In contrast to most samples from the western half of the caldera, samples from the East Lake sub-basin are characterized as calcium bicarbonate waters. Total concentrations of dissolved solids are lower than those in the western sub-basin. Chloride concentrations also are lower, and even the hot-spring water (No. 25) has a lower chloride concentration than most cold waters in the Paulina Lake area. Silica concentrations in the eastern ground waters have a range similar to that in the western waters (30 to 197 mg/L), but sulfate concentrations in East Lake, the East Lake hot springs, and a cold well (No. 16) are significantly higher than any concentrations in the Paulina Lake area. Silica concentrations in both lakes are unusually low in relation to other constituents, probably as the result of diatom scavenging.

East Lake itself probably is a definitive indicator of the ground-water character in its sub-basin because it has no surface outlet and it acts as a sink for ground-water flow from a large proportion of the sub-basin. Relying on East Lake as an indicator, therefore, we conclude that most ground water in the eastern part of the caldera is more dilute than ground waters in the western part. In East Lake itself, it might be expected that the higher evaporation rate relative to Paulina Lake would lead to greater concentrations of dissolved solids. The observed lower concentrations in East Lake probably result from dilute ground water inflow that effectively balances the ground-water outflow plus evaporation. This conclusion is discussed further in the final section of this report.

Relations among major ions indicate that the water in East Lake could be produced by mixing ground water similar to that in samples 20 or 22 with thermal water similar to that in sample 25 (East Lake Hot Spring). The mixing ratios range from 2.3 to about 9 to 1, depending on the sample and the ions used in the mixing calculation. The relatively high chloride concentration in sample 20 does not fit this mixing model, however, and suggests that the hot-spring water might be produced by mixing the ground water of sample 20 with lake water in a ratio of 1.25 to 1. Evidence from isotope analyses, discussed below, casts doubt on both of these simple mixing models, however, and further discussion of the origin of the waters is deferred to the following section of this report.

Subsurface discharge may occur from both lakes. Evidence for subsurface discharge from East Lake occurs in well 16, where both the water chemistry and the water level suggest that ground water moves from the lake to this location. In the Paulina Lake sub-basin, the chemistry of samples 1 and 2 show that these well waters probably originate in the lake and are slightly altered by residence in lake-shore sediments. Water levels in these wells are at least 5 feet below lake levels, whereas levels on the north, south, and east shores of the lake appear to be higher than lake levels.

Thermal water occurs in at least two wells in the Paulina Lake area. Concentrations of both chloride and silica in samples 9 and 15 are greater than those in other waters and the temperatures are higher. The temperature in well 8 is unknown, but the concentrations of silica and chloride, as well as the total concentration of dissolved solids, suggest a thermal component in this water also. These three waters have compositions similar to that of the Paulina Hot Spring water, possibly indicating that thermal waters occur widely near the center of the caldera and perhaps beneath the lake. Measurements of temperature in Paulina Lake, described in the next chapter, delineate several areas where thermal waters probably enter through the lake bottom.

In the East Lake sub-basin, thermal water is known to discharge only in the East Lake Hot Springs, although temperature measurements in the lake suggest that small amounts of thermal discharge also occur elsewhere. The East Lake Hot Spring water is similar to the Paulina Hot Spring water in many respects, but has higher concentrations of calcium and sulfate. The higher sulfate concentrations are probably caused by oxidation of hydrogen sulfide gas dissolved in the ground water. The gas was not detected in the Paulina Hot Springs (R. H. Mariner, USGS, unpublished data 1982), and sulfate concentrations in the Paulina Lake sub-basin waters are uniformly low.

The apparent causal relationship between hydrogen sulfide gas and dissolved sulfate in the ground water is supported by the analysis of water from the Obsidian Flow gas vent (sample 24). The water is extremely dilute, but has the highest concentration of sulfate known in the caldera (table 11). The concentration of hydrogen sulfide in gas from this vent also is the highest measured in the caldera (R. H. Mariner, USGS, unpublished data 1982).

Graphs of conservative constituents that are not related as dissociation pairs may be useful as indicators of origins and mixing trends among ground waters. (See, for example, Sammel, 1980; Sammel and Craig, 1981.) Figure 3a shows the relations between chloride and silica in the waters of the caldera. These constituents are expected to reflect, more or less independently, the effects of water-rock interactions and exposure to heat in a geothermal environment as well as the degree of mixing of differing waters.

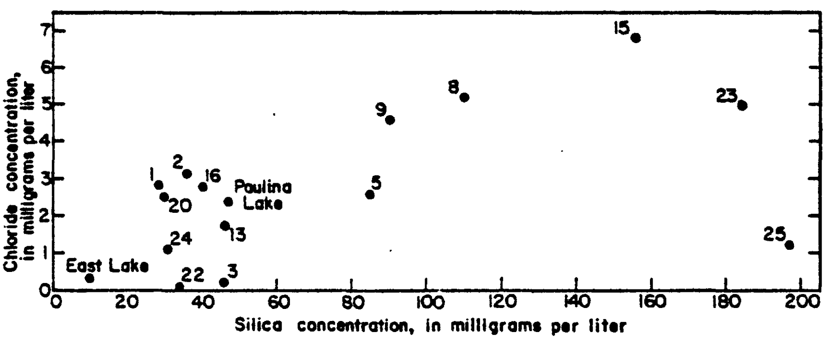

Figure 3a. -- Relations between concentrations of selected chemical constituents: chloride versus silica.

Several possible trend lines are suggested by the data of figure 3a. One such trend includes samples 9 and 15 from wells near Paulina Lake, together with samples 1 and 2 from cold wells near the lake, and sample 8, a water of unknown temperature which probably has a thermal component. However, two other ground waters near the lake, 13 and 5, have chloride concentrations that place them below the upper trend line, and the hot-spring water (23) has less chloride than the low-temperature waters, 8, 9, and 15. The chloride concentration in East Lake Hot Spring (25) is exceptionally low but is in keeping with that of well 22 near East Lake and with East Lake itself. Two cold waters near East Lake, 16 and 20, have higher chloride concentrations than the East Lake Hot Springs. The chloride-silica relations, therefore, do not consistently distinguish thermal waters from nonthermal waters. The small number of samples, the extremely small range of chloride concentrations, and differing times of sampling contribute to uncertainties in the data that may be as great as the differences between most of the samples.

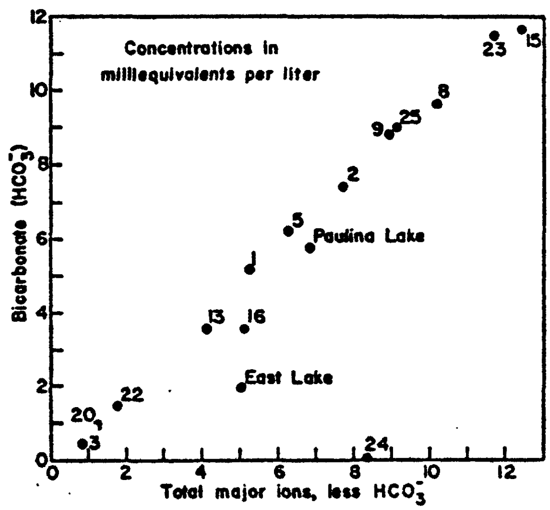

Figure 3b. — Relations between concentrations of selected chemical constituents: bicarbonate versus total major ions less bicarbonate.

Graphs of relations among other ionic species indicate that both thermal and nonthermal waters equilibrated in a low-temperature environment dominated by CO_2-HCO_3 reactions. One such graph is shown in figure 3b, where concentrations of bicarbonate, the dominant anion, are plotted versus the sum of concentrations of other major ionic species. The values occur in a nearly constant ratio through the range of total dissolved-solids concentrations. Departures from the linear trend occur only in well 16 and the Obsidian Flow gas vent (24), both of which have exceptional high sulfate concentrations, and in the two lakes, where carbonate reations probably differ from those in ground water. Ground waters in the caldera showed similar linear trends for all major ions except sulfate, thereby reinforcing the concept of a generally uniform chemical environment in which sulfate concentrations are controlled by an anomalous factor, presumably the contact with hydrogen sulfide gas.

Stable Isotopes in Surface and Ground Water

Concentrations of deuterium and oxygen-18 in meteoric water decrease with altitude and other factors in a relationship that is usually approximated by the expression, $\delta D = 8(\delta^{18}O) + 10$, where δD and $\delta^{18}O$ are ratios of these isotopes to ^{1}H and ^{16}O, respectively, expressed in parts per thousand (per mil) as departures from standard mean ocean water (SMOW) (Craig, 1961). The meteoric line resulting from the above expression is shown in figure 4, together with data from 14 samples. Results of the analyses are given in table 12.

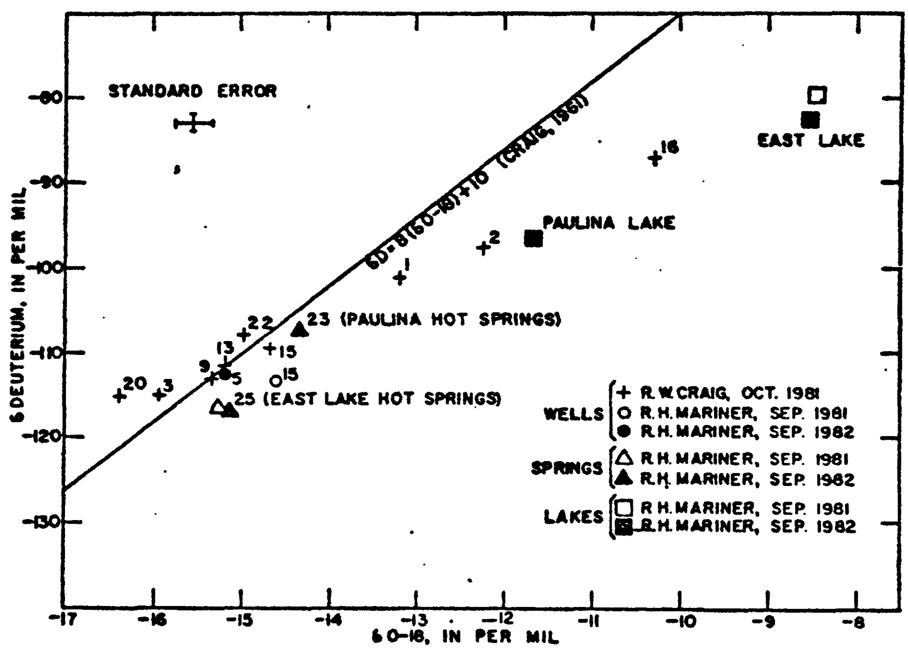

Figure 4. — Concentrations of oxygen-18 versus deuterium in ground and surface water.

Table 12.-- Concentrations of the isotopes oxygen-18 and deuterium in ground and surface water

[Concentrations of oxygen-18 and deuterium in parts per thousand as departures from standard mean ocean water (Craig, 1961)]

Sequence No.[1/]	Name/ owner	Date sampled	Oxygen-18 (± 0.2)	Deuterium (± 1)	Temperature (°C)	Source[2/]
1	Paulina Lake Resort	10/07/81	-13.20	-101.0	5	A
2	Paulina Lake Resort	10/07/81	-12.25	- 97.5	4	A
3	Paulina Guard Station (USFS)	10/07/81	-15.95	-115.0	6	A
5	Mike Mathews (summer home)	06/30/82	-15.18	-112.7	2	C
9	Little Crater picnic Area	10/07/81	-15.35	-113.0	16	A
13	Little Crater Camp Site 27	10/07/81	-15.20	-111.5	6	A
15	Little Crater Camp Site 49	10/07/81 08/00/75	-14.70 -14.60	-109.5 -113.4	33 35.5	A B
16	East Lake Campground well	10/07/81	-10.30	- 87.0	6	A
20	Cinder Hill campground well	10/06/81	-16.40	-115.0	5	A
22	Cinder Hill Camp Site 34	10/06/81	-15.00	-108.0	4	A
23	Paulina Lake Hot Springs	06/30/82 07/00/77	-14.33 ---	-107.3 -108.9	52 --	C B
25	East Lake Hot Springs	06/30/82 08/00/75	-15.12 -15.26	-116.9 -116.4	57 49	C C
--	Paulina Lake	06/30/82	-11.68	- 96.8	6	C
--	East Lake	06/30/82 00/00/73	- 8.54 - 8.44	- 82.8 - 79.7	10 --	C C

1/ Sequence number.-- Identifying number used in tables and illustrations.

2/ Source of data or collector: A: R. W. Craig (1981); B: R. H. Mariner and others (1980); C: R. H. Mariner (unpub. data, 1982).

The isotope results generally reinforce the relationships shown by the major-ion chemistry, but show additionally that both oxygen-18 and deuterium are concentrated in the two lakes as the expected result of surface evaporation. A line constructed through the Paulina Lake and East Lake sample points in figure 4 probably would represent this evaporative trend. Evaporation under low-temperature, nonequilibrium conditions should result in a trend with a slope of about 5 (Craig, 1961). The slope of the East Lake - Paulina Lake line is 4.6, which is reasonably close in view of the standard errors of estimate shown in figure 4.

The position of sample 16, a well water from the East Lake Campground, suggests that the sample contains a large proportion of evaporated water from East Lake. Similarly, samples 1 and 2 appear to have large proportions of Paulina Lake water. Both indications are in accord with the chemical analyses and water levels.

The isotope shift observed in the Paulina Hot Spring water (23) suggests that the spring water could be a mixture of thermal water such as samples 9, 13, or 15[1/] and Paulina Lake water. Temperatures of the waters as well as the major-ion chemistry make this simple mixing model unlikely however. In the East Lake Hot Spring water the isotope shift suggests that a mixing relation involving East Lake water would require a dilute end member having an isotopic composition with $\delta D < -127$ and $\delta^{18}O < -17$ and a volume fraction of at least 75 percent of the mixture. A water of this isotopic composition would probably have to originate at the high altitudes of the Cascades Range, if samples 20 and 3 represent the most nearly "meteoric" water in the caldera. It is unlikely that ground water from the Cascades could move through the intervening rocks and discharge from the Newberry geothermal system with the small concentrations of chloride, silica, and major cations observed in the East Lake hot springs. The small shift in oxygen-18 in the East Lake Hot Spring water seems most likely to

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[1/] The difference in deuterium concentrations between the sample obtained by Mariner and that obtained by Craig in well 15 is unexplained except as a possible effect of differing laboratory methods. The same explanation might account for the possibly anomalous deuterium concentrations in all samples collected by Craig in 1981. A decrease in deuterium of 2 to 4 per mil would place these samples in positions more consistent with the remainder of the isotope data as well as with the chemical analyses.

be caused by the injection of steam beneath the caldera. (See, for example Ellis and Mahon, 1977, for a discussion of this phenomenon.) The small chloride concentration in the spring water is consistent with this origin. The isotopic data are consistent with the major-ion chemistry in indicating that both thermal and nonthermal waters in the caldera are derived from local meteroic water and that thermal alterations occur at fairly shallow depths. The distinction between East Lake and Paulina Lake ground waters made on the basis of the major ionic constituents probably relates mainly to near-surface low-temperature phenomena rather than to deep-seated geothermal processes.

TEMPERATURES OF SURFACE AND GROUND WATER

Measured temperatures of shallow ground water in the caldera range from 4°C to 62°C. The highest temperatures (52°C and 62°C) were measured in the Paulina Lake and East Lake Hot Springs (Mariner and others, 1980; table 11, this report). Temperatures of well waters ranged from 2°C to 36°C; temperatures above 10°C occurred only near the east end of Paulina Lake. The range of seasonal fluctuations in ground-water temperatures is not known in the caldera, but because the average annual air temperature at Newberry is about 0°C, any ground-water temperature above 10°C probably implies the presence of a thermal component.

Temperatures of bottom water were measured in Paulina Lake and East Lake in an attempt to identify areas of high heat flow and possible inflows of thermal water (fig. 5). Additional measurements at a depth of 2 feet at each site indicated that near-surface temperatures were fairly uniform within each lake, but varied somewhat with daily metrological conditions. They are not shown in figure 5.

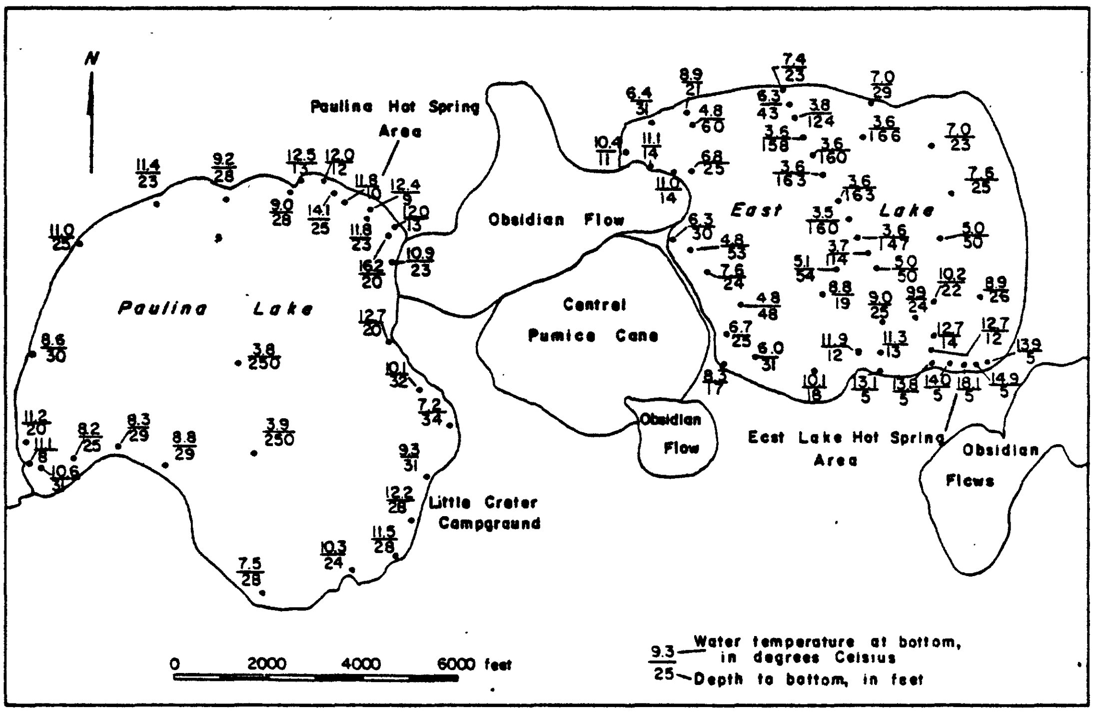

Figure 5. — Temperatures measured on the lake bottom in Paulina and East Lakes.

Offshore from both hot springs, there are sizeable areas in which temperatures are above normal and gas bubbles rise to the surface, indicating that spring activity is not confined to the shore. Temperature measurements along the east shore of Paulina Lake show that thermal water also enters the lake adjacent to Little Crater Campground. The low temperatures in most shallow wells in the Campground suggest that the thermal water does not flow laterally from the adjacent ground-water body but rather ascends vertically through the lake bottom.

Two additional areas, one in each lake, had temperatures that might indicate thermal inflow. The strongest possibility is in the northwest corner of Paulina Lake where temperatures of 11.0°C and 11.4°C were measured at depths of 25 and 23 feet respectively. In East Lake, temperatures of 11.0°C and 11.4°C were measured at a depth of 14 feet in the northwest part of the lake. In both cases, a more detailed investigation would be required to confirm a thermal influence.

The volume of thermal-water inflow to the lakes probably is small. Even if the amount of inflow were much greater than estimated, however, a deep geothermal origin is unlikely for most of the thermal water. The chemical and isotopic analyses indicate that a probable origin is the heating of meteoric water by rising steam. Thus, there may be only small additions of thermal fluid to the shallow ground-water system.

Two partly independent estimates of the inflow of warm water have been made as follows. Measurements in Paulina Lake show that about 25×10^6 ft^3 of lake water in the vicinity of the hot springs is warmed to an average 6°C above ambient temperature by the influx of thermal water[1/]. The average temperature of water contributed by hot springs and seeps on shore is about 40°C. Springs in the lake also are assumed to have an average temperature of 40°C. Calculations using a simple mixing model yield 0.23 as the fraction of thermal water in the affected volume of lake water. If the lake is assumed to turn over annually with complete mixing as a result, the inflow rate is about 11 ft^3/min or 130 acre-ft/yr.

[1/] Estimate based on temperature measurements made in 1977 by N. E. Voegtly and E. A. Sammel.

Along the Little Crater shore, there is no evidence of temperatures comparable to those near the Paulina Hot Springs, but the greater area involved leads to an estimate of inflow similar to the hot-spring area. Thus, the total thermal inflow in areas of Paulina Lake where temperatures have been measured is probably no more than 300 acre-ft/yr.

A partly independent estimate begins with discharge from the springs on shore which probably is no greater than 2 1/2 ft^3/min. Observations of gas vents offshore suggest that discharge in the lake could no more than double this figure. If the flows near the shore at Little Crater are again assumed to be comparable to those in the hot-spring area, the total inflow to the lake estimated in this way is similar to the previous estimate This amount would have no detectable effect on the large-scale temperature distribution in the lake.

The known areas of thermal discharge in East Lake are less extensive than those in Paulina Lake, and the total discharge is probably smaller. Even if a significant fraction of East Lake thermal water rises directly from a geothermal reservoir, the thermal water probably is a negligible addition to the groundwater influx. The hot springs in Paulina and East Lakes are the only ones known in the caldera and their apparently small contributions of thermal water have been ignored in the hydrologic budget.

DISCUSSION OF RESULTS

The summation of terms in the hydrologic budget for the caldera at Newberry Volcano shows an apparent annual surplus of water. The surplus, which is estimated to be at least 2,500 acre-feet and possibly as much as 10,000 acre-feet, is assumed to move downward to deep aquifers beneath the caldera floor.

Part of the recharge may move laterally out of the caldera and discharge through the flanks of the mountain. However, the absence of springs or surface flows other than Paulina Creek on the flanks of the volcano indicates that little ground water moves outward to the surface of the mountain, even though large amounts of recharge must occur on the upper flanks. Streamflow measurements by the Geological Survey in Paulina Creek in August, 1981, showed no gain in the stream between Paulina Lake and Paulina Prairie at the base of the mountain. Massive tuffaceous rocks exposed along Paulina Creek west of the caldera rim show no evidence of ground-water seepage, and only one small seep is known to occur below the outlet of Paulina Lake. A Geological Survey core hole (Newberry 1), located about 2 miles northeast of the caldera rim, encountered only minor flows of perched ground water at depths of about 200, 500, and 900 feet, and a temperature profile in the hole indicated that ground water recharge moves vertically downward through the upper 200 feet of rock at this site.

Within the caldera, data obtained in the Geological Survey's 3,057-foot core hole (Newberry 2) provide evidence of ground-water flow below the near-surface hydrologic regime. Small flows of ground water were detected in the core hole at depths ranging from 100 to 1,900 feet beneath the caldera floor (Sammel, 1981; and MacLeod and Sammel, 1982).

The ground water observed at depth probably originates in the caldera, but the present study does not indicate the areas from which it is derived. The presence of a surplus of water in the East Lake sub-basin (table 8) suggests that much recharge could occur there. However, the large hydraulic gradient between the two sub-basins undoubtedly causes much of the surplus water to flow from east to west across the caldera. Hydrologic studies in other volcanic areas of Oregon indicate that the topographic features of the present caldera floor would not be major obstacles to this near-surface ground-water flow (Sammel, 1980; Sammel and Craig, 1981) Thus the surplus of water from the East Lake sub-basin may be available for ground-water recharge anywhere in the caldera.

Waters sampled in the two sub-basins differ in their chemical characteristics, but the differences probably do not indicate separate hydrologic regimes. The occurrence of dilute waters such as those in samples 3, 20, and 22 (tables 9 and 11) in both sub-basins suggests that the chemical data may be biased by the preponderance of samples from the vicinity of the hot springs and the central pumice cone, which may represent only local chemical and thermal anomalies within the caldera.

A part of the ground-water contribution from the East Lake sub-basin to the Paulina Lake sub-basin probably originates as seepage from East Lake itself. Measurements of lake levels in East Lake during a 26-day period of no precipitation between August 11 and September 6, 1981 showed a decrease in stage of 0.45 feet. Evaporation from the lake surface during this period was estimated to be 0.32 feet. The seepage loss (ground-water inflow minus ground-water outflow), therefore, is 0.13 feet, from which is calculated a seepage rate of 2.5 ft^3/s, or about 5 acre-feet per day.

This figure is close to the estimate of 2.3 ft^3/s made by Phillips (1968, table 9) on the basis of fragmentary records for the period 1931 to 1961. Phillips concluded that annual seepage from East Lake is nearly constant and is fairly independent of lake levels. We conclude that the lake, at its historic and present levels, is largely self-regulating, and that seasonal or annual changes of ground-water inflow probably are balanced by similar increases or decreases in ground-water outflow. Thus, although our seepage estimate may be too high as the result of underestimating evaporation, the average annual rate should be higher than the figure obtained in the late summer at a time of low lake levels.

An average seepage rate from East Lake of 2.5 ft^3/s (1,800 acre-feet per year), exceeds the flow required to balance the estimated deficit in Paulina Lake (table 8). Observations of stages in Paulina Lake suggest, however, that the deficit may be higher than estimated. During the 26-day period, August 11 to September 6, 1981, the level of Paulina Lake declined 0.86 foot; estimated evaporation was 0.22 foot, and streamflow was equivalent to a decline of 0.84 foot. Therefore, if ground-water seepage out of the lake was small, about 0.2 foot of ground-water inflow entered the lake during this period. On the assumption that the estimated inflow rate for this period (5.2 ft^3/s) is close to the annual average, the net annual ground-water contribution to Paulina Lake is about 3,800 acre-feet.

An analysis of probable errors in these estimates leads to the following conclusions: (1) The streamflow estimate for the 26-day period has a small probable error due to the availability of precise flow measurements made by the USGS on August 20 and the generally uniform flow rate observed during the period; (2) estimated annual evaporation for Paulina Lake is extremely low, and the actual evaporation is likely to be higher than the estimate rather than lower; (3) ground-water inflow to the Paulina Lake sub-basin probably is several times greater than the deficit shown in table 8, and both evaporation from Paulina Lake and streamflow in Paulina Creek could be significantly greater than the estimated values without causing an actual deficit in the sub-basin. The subtraction of the required several thousand acre-feet per year from the budget of the East Lake sub-basin would still allow a surplus to remain in this area also. As a consequence of probable increases in evaporation and stream flow, however, the probable maximum amount of ground water available for deep recharge is reduced from 10,000 acre-feet to a figure close to the 6,500 acre-feet given in table 8.

Partly as a means of testing the general conclusions of this study, estimates of mean monthly values were made for all terms in the hydrologic budget. These estimates, and especially those for winter months, are not sufficiently reliable to warrant inclusion as a table in this report. However, seasonal aggregates of these figures seem to support the general conclusions and elucidate some aspects of the hydrologic regime.

At the end of a normal winter, for example, ground-water storage in the Paulina Lake sub-basin probably would have a deficit in the range 7,000 to 11,000 acre-feet, if not compensated by ground-water inflow from the East Lake sub-basin. In contrast, gains and losses in the East Lake sub-basin remain nearly in balance during winter months (assumed to be December through March).

During the period April through November, Paulina Lake sub-basin has an apparent surplus of about 3,000 acre-feet, all in ground-water storage. This surplus, carried over into the winter period, helps to support winter streamflows. However, observed lake levels and estimated streamflows could not be maintained through the winter in the absence of continued ground-water inflow from the East Lake sub-basin. The inflow probably reaches a peak in late spring or early summer and continues during the winter. Soil moisture, ground-water storage, and lake storage return to normal high levels during the winter and spring of most years.

Manipulation of the data in tables 7 and 8 shows that, of the 35 inches of precipitation that falls on land surfaces in the caldera, nearly 70 percent (24 inches) percolates below the evapotranspiration zone to recharge the shallow ground-water body. This percentage is exceptionally high when compared with more common volcanic terranes, but it is reasonable in view of the highly permeable land surface, which generally is either pumice- or ash-covered or consists of blocky, fractured obsidian or basaltic lava. Overland runoff is rarely observed except during brief periods of spring snowmelt.

Water that leaves the shallow ground-water flow system by infiltration to deeper zones beneath the caldera probably is in the range 0.3 to 0.7 foot annually, or 10 to 25 percent of precipitation on land surfaces. If the actual rate is near the upper end of the range, deep infiltration may occur uniformly over fairly large areas of the caldera floor. A value near the low end of the range, seemingly more likely in view of probable errors in the estimates, could imply that the conduits for deep recharge are restricted to major ring fractures and faults. The latter mode seems the more likely in view of the stratified aquifers and low vertical permeabilities observed in the caldera drill hole. These conclusions imply rather strongly that a deep hydrothermal convection system at Newberry could not be effectively recharged by vertical flow of meteoric water from the caldera. Sources of recharge for any such system probably must be sought in deep regional aquifers that intersect permeable zones beneath the mountain.

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Table 2.-- Precipitation recorded during selected periods at the Newberry Volcano, Chemult, and Wickiup Dam weather stations

Period	Newberry Volcano (inches)	Chemult (inches)	Wickiup Dam (inches)
11/23/65-05/31/66	18.65	14.63	10.37
06/01/66-07/26/66	2.25	2.04	1.86
08/12/66-11/14/66	4.75	5.17	3.38
11/15/66-06/18/67	26.55	21.04	14.54
06/19/67-10/15/67	2.75	2.73	2.29
10/16/67-01/31/68	8.20	7.89	6.55
02/01/68-04/14/68	6.95	4.96	3.10
04/15/68-06/17/68	3.90	2.02	1.92
06/18/68-10/06/68	1.85	2.91	2.12
10/07/68-01/07/69	12.00	11.50	7.16
01/08/69-04/08/69	15.10	7.71	6.37
09/08/69-10/09/69	1.60	0.87	1.75
10/10/69-01/21/70	25.00	14.53	10.17
04/07/70-06/04/70	1.10	0.66	0.67
06/05/70-07/15/70	1.80	1.71	1.49
10/10/70-03/09/71	32.30	25.78	18.96
03/10/71-09/28/71	10.65	9.36	6.79
09/29/71-10/19/71	1.85	0.68	0.73
10/20/71-05/04/72	31.50	28.02	18.70
11/02/72-02/22/73	13.05	13.48	7.76
02/23/73-06/13/73	5.75	3.43	2.01
07/17/75-09/01/75	2.00	0.75	0.60
11/21/75-07/01/76	24.70	14.75	12.49

Table 2.-- Precipitation recorded during selected periods at the Newberry Volcano, Chemult, and Wickiup Dam weather stations (Continued)

Period	Newberry Volcano (inches)	Chemult (inches)	Wickiup Dam (inches)
07/02/76-10/11/76	6.80	3.84	4.27
10/12/76-12/29/76	1.00	0.80	1.12
10/21/77-05/17/78	31.55	28.79	17.83
05/18/78-11/15/78	5.45	5.41	5.59
11/15/79-04/24/80	19.95	15.57	12.84

Table 4.-- Estimated daily evaporation at Paulina Lake and East Lake for the period July 1 to September 30, 1981

[Includes data from which estimate is derived. Saturation vapor pressure at water-surface temperature used is 17.77 millibars for July, 19.19 millibars for August, and 15.16 millibars for September. See text for explanation]

Date	Vapor pressure of incoming air (mbar)	Average 24 h wind, Paulina Lake (mi/h)	Average 24 h wind, East Lake (mi/h)	Estimated evaporation, Paulina Lake (in/d)	Estimated evaporation, East Lake (in/d)
7-1	5.72	3.1	4.5 1/	0.088	0.130
7-2	7.01	2.3	3.3 1/	.058	.085
7-3	8.36	3.1	4.5 1/	.069	.102
7-4	7.01	2.8	4.0 1/	.071	.103
7-5	7.30	5.7	8.2 1/	.141	.206
7-6	7.58	8.9 1/	12.8	.214	.313
7-7	3.49	3.3 1/	4.8	.111	.113
7-8	9.07	3.3 1/	4.8	.068	.100
7-9	9.07	4.7 1/	6.7	.096	.140
7-10	8.67	3.3 1/	4.8	.071	.105
7-11	6.57	2.9 1/	4.2	.077	.113
7-12	6.57	7.1 1/	10.2	.187	.274
7-13	7.38	3.7	5.3 1/	.091	.132
7-14	5.86	2.8	4.0 1/	.079	.114
7-15	7.55	2.5	3.6 1/	.060	.008
7-16	7.55	3.4	4.9 1/	.082	.120
7-17	7.14	5.0	7.2 1/	.125	.184
7-18	5.52	3.5	5.0 1/	.101	.147
7-19	5.35	3.1	4.5 1/	.091	.134
7-20	4.81	3.0 1/	4.3	.092	.134

Table 4.-- Estimated daily evaporation at Paulina Lake and East Lake for the period July 1 to September 30, 1981 (Continued)

Date	Vapor pressure of incoming air (mbar)	Average 24 h wind, Paulina Lake (mi/h)	Average 24 h wind, East Lake (mi/h)	Estimated evaporation, Paulina Lake (in/d)	Estimated evaporation, East Lake (in/d)
7-21	4.64	3.3 1/	4.8	0.102	0.151
7-22	5.18	3.3 1/	4.8	.099	.145
7-23	3.93	3.6 1/	5.1	.117	.169
7-24	3.93	4.5 1/	6.4	.147	.213
7-25	5.82	3.5 1/	5.0	.099	.143
7-26	6.57	2.2 1/	4.6	.084	.124
7-27	7.82	2.9	4.2 1/	.064	.100
7-28	6.94	7.5	10.8 1/	.192	.281
7-29	4.98	4.2	6.0 1/	.127	.184
7-30	4.67	2.7	3.9 1/	.083	.123
7-31	3.69	3.6	5.2 1/	.120	.176
8-1	5.72	3.0	4.3 1/	.095	.139
8-2	6.80	5.6	8.0 1/	.164	.238
8-3	6.47	3.5 1/	5.0	.105	.153
8-4	6.47	3.1 1/	4.4	.093	.134
8-5	6.37	2.7 1/	3.9	.082	.120
8-6	6.26	2.4 1/	3.5	.073	.109
8-7	6.70	2.6 1/	3.8	.077	.114
8-8	9.71	3.3 1/	4.7	.074	.107
8-9	7.79	3.8 1/	5.5	.102	.150

Table 4.-- Estimated daily evaporation at Paulina Lake and East Lake for the period July 1 to September 30, 1981 (Continued)

Date	Vapor pressure of incoming air (mbar)	Average 24 h wind, Paulina Lake (mi/h)	Average 24 h wind, East Lake (mi/h)	Estimated evaporation, Paulina Lake (in/d)	Estimated evaporation, East Lake (in/d)
8-10	4.33	2.9	4.2 1/	0.102	0.150
8-11	6.87	2.7	3.9 1/	.078	.115
8-12	7.92	3.3	4.7 1/	.088	.127
8-13	11.44	3.6	5.2 1/	.066	.097
8-14	7.16	3.3	4.7 1/	.094	.136
8-15	6.30	3.2	4.6 1/	.097	.142
8-16	4.20	2.7	3.9 1/	.095	.140
8-17	4.77	2.4 1/	3.5	.076	.112
8-18	5.82	3.6 1/	5.2	.113	.167
8-19	6.30	4.6 1/	6.6	.140	.204
8-20	3.01	3.8 1/	5.5	.145	.214
8-21	4.85	3.1 1/	4.4	.105	.151
8-22	6.50	2.9 1/	4.1	.087	.125
8-23	7.56	3.6 1/	5.1	.099	.142
8-24	13.28	3.4 1/	4.9	.047	.070
8-25	7.04	4.1	5.9 1/	.117	.172
8-26	5.16	4.6	6.6 1/	.152	.222
8-27	4.69	2.4	3.4 1/	.082	.118
8-28	5.72	3.8	5.5 1/	.121	.178
8-29	5.88	6.5	9.3 1/	.204	.297

Table 4.-- Estimated daily evaporation at Paulina Lake and East Lake for the period July 1 to September 30, 1981 (Continued)

Date	Vapor pressure of incoming air (mbar)	Average 24 h wind, Paulina Lake (mi/h)	Average 24 h wind, East Lake (mi/h)	Estimated evaporation, Paulina Lake (in/d)	Estimated evaporation, East Lake (in/d)
8-30	8.05	5.3	7.6 1/	0.139	0.203
8-31	6.36	3.3	4.7 1/	.100	.145
9-1	5.72	5.4 1/	7.7	.120	.174
9-2	7.02	2.5 1/	3.6	.048	.070
9-3	8.37	3.8 1/	5.4	.061	.088
9-4	4.54	3.8 1/	5.4	.095	.138
9-5	4.54	3.3 1/	4.7	.083	.120
9-6	6.03	2.7 1/	3.9	.058	.085
9-7	5.55	2.4 1/	3.4	.054	.078
9-8	8.87	2.1	3.0 1/	.031	.045
9-9	6.47	2.2	3.2 1/	.045	.067
9-10	6.50	2.3	3.3 1/	.047	.069
9-11	6.09	2.2	3.2 1/	.047	.070
9-12	9.55	3.6	5.2 1/	.048	.070
9-13	6.50	5.7	8.2 1/	.116	.170
9-14	6.70	4.4	6.3 1/	.088	.128
9-15	6.94	3.0 1/	4.3	.058	.085
9-16	5.82	2.6 1/	3.8	.057	.085
9-17	7.85	2.4 1/	3.5	.041	.061

Table 4.-- Estimated daily evaporation at Paulina Lake and East Lake for the period July 1 to September 30, 1981 (Continued)

Date	Vapor pressure of incoming air (mbar)	Average 24 h wind, Paulina Lake (mi/h)	Average 24 h wind, East Lake (mi/h)	Estimated evaporation, Paulina Lake (in/d)	Estimated evaporation, East Lake (in/d)
9-18	7.38	6.3 1/	9.1	0.116	0.170
9-19	7.07	6.5 1/	9.4	.124	.183
9-20	7.14	5.9 1/	8.5	.112	.164
9-21	5.45	9.2 1/	13.2	.211	.308
9-22	4.40	7.6	10.9 1/	.193	.282
9-23	3.35	4.0	5.7 1/	.111	.162
9-24	3.76	4.4	6.3 1/	.118	.172
9-25	4.50	7.3	10.5 1/	.183	.269
9-26	3.52	---	---	.460 2/	.670 2/
9-27	9.11	---	---	.460 2/	.670 2/
9-28	7.18	---	---	.460 2/	.670 2/
9-29	4.91	---	---	.460 2/	.670 2/
9-30	4.71	---	---	.460 2/	.670 2/
		Total Evaporation		9.14	13.32

1/ Not measured; estimated from measurement at alternate lake. See text for explanation.

2/ Estimated.

Table 9.-- Data from wells in Newberry caldera

[μmho/cm = micromhos per centimeter at 25°C]

Sequence No.[1/]	Owner/name	Latitude Longitude (deg)(min)	Date completed	Depth (ft)	Diameter (in)	Altitude[2/] (ft)	Depth to water[3/] (ft)	Temperature (°C)	Specific conductance (μmho/cm)	Date measured	Use[4/]	Other data[5/]
1	Paulina Lake Resort	43 42.90 121 16.55	1929	20	36	6,341.4	14.9 12.2	7 4	460 235	08/14/81 06/28/82	C,D	C,I(10/07/81)
2	Paulina Lake Resort	43 42.90 121 16.55	1980	65	8	6,340.1	15.1 11.0	4 5	600 550	10/07/81 06/28/82	C,D	C,I(10/07/81)
3	Paulina Guard Station (USFS)	43 42.70 121 16.60	----	45	6	6,356.3	30.7 28.3	9 4	90 80	09/03/81 06/30/82	D,R	C(09/06/81) I(10/07/81)
4	IOOF lodge	43 42.45 121 15.40	----	---	--	6,346.0	12.1	3	110	06/27/82	D	
5	Mike Mathews	43 42.45 121 14.90	1969	22	30	6,336.7	4.7 3.3	12 2	675 720	09/05/81 06/27/82	D	C,I(06/30/82)
6	Star (?)	43 42.45 121 14.85	----	5	24	6,334.2	.6	3	1,150	06/27/82	D	
7	Ulven	43 42.45 121 14.85	----	6	12	6,334.1	.1	2	650	06/27/82	D	
8	Jack Hogg	43 42.45 121 14.80	----	---	8	6,340	17.6	--	900	09/05/81	D	C(09/06/81)
9	Little Crater Picnic Area	43 42.50 121 14.70	----	12	6	6,342.1	10.5 8.8	16 13	710 530	10/07/81 06/28/82	U	C,I(10/07/81)
10	Little Crater Camp Site 4A	43 42.70 121 14.55	----	12	6	6,343.2	11.2 9.5	-- 9.5	--- 195	10/07/81 09/06/74	U	
11	Little Crater Camp Site 10	43 42.75 121 14.55	08/06/71	23	6	6,343.3	11.8 9.9	-- 4	--- 195	10/07/81 06/28/82	U	

Table 9.-- Data from wells in Newberry caldera (Continued)

[μmho/cm = micromhos per centimeter at 25°C]

Sequence No.[1/]	Owner/name	Latitude Longitude (deg)(min)	Date completed	Depth (ft)	Diameter (in)	Altitude[2/] (ft)	Depth to water[3/] (ft)	Temperature (°C)	Specific conductance (μmho/cm)	Date measured	Use[4/]	Other data[5/]
12	Little Crater Camp Site 20	43 42.80 121 14.45	----	---	6	6,341.6	9.5 8.1	9 7	430 330	08/18/81 06/28/82	U	
13	Little Crater Camp Site 27	43 42.90 121 14.40	09/18/61	36	6	6,342.7	11.2 9.4	6 5	360 240	10/07/81 06/28/82	U	C,I(10/07/81)
14	Little Crater Campground well	43 43.00 121 14.35	----	---	8	6,344.8	---- ----	-- --	240 220	08/19/81 06/28/82	R	
15	Little Crater Camp site 49	43 43.05 121 14.35	09/16/61	50	6	6,343.8	12.3 10.3	30 32	900 960	10/07/81 06/28/82	U	C(09/06/81) I(10/07/81
16	East Lake Campground well	43 43.05 121 12.50	10/12/62	50	6	6,396.2	23.7 20.9	6 3	390 325	09/06/81 06/27/82	R	C(09/06/81 I(10/07/81)
17	Hot Springs Campground	43 43.10 121 11.90	----	---	6	6,389.8	14.4 11.0	-- 6	--- 120	10/07/81 06/30/82	U	
18	East Lake Resort R V park	43 43.40 121 11.55	----	---	8	6,407.2	27.4 24.8	10 3	85 90	08/19/81 06/28/82	C	
19	East Lake Resort	43 43.40 121 11.60	----	27.5	96	6,395	17.9	3	105	09/19/74	C,D	
20	Cinder Hill Campground well	43 43.80 121 11.70	10/17/63	76	6	6,393.7	20.1 18.2	5 5	110 90	09/06/81 06/27/82	R	C(09/06/81) I(10/06/81)
21	Cinder Hill Camp Site 27	43 43.90 121 11.70	----	---	6	6,392.8	19.1 17.2	-- --	--- ---	09/02/81 06/27/82	U	
22	Cinder Hill Camp Site 34	43 44.00 121 11.70	----	---	6	6,392.5	18.6 16.3	4 3	140 93	10/06/81 06/27/82	U	C,I(10/06/81)

Table 9.— Data from wells in Newberry caldera (Continued)

[µmho/cm = micromhos per centimeter at 25°C]

Sequence No.[1]	Owner/name	Latitude Longitude (deg)(min)	Date completed	Depth (ft)	Diameter (in)	Altitude[2] (ft)	Depth to water[3] (ft)	Temperature (°C)	Specific conductance (µmho/cm)	Date measured	Use[4]	Other data[5]

1/ Sequence No. -- Identifying number used in tables and illustrations.

2/ Altitude -- Land surface at well, in feet above National Geodetic Vertical Datum of 1929.

3/ Depth to water — Feet below land surface.

4/ Use — C, commercial (resort); D, domestic; R, recreation; U, unused.

5/ Other data -- C, chemical analysis, table 11; I, isotope analysis, table 12.

Table 10.-- Data from springs and gas vents in Newberry caldera

[μmho/cm = micromhos per centimeter at 25°C]

Sequence No.[1/]	Owner	Name	Latitude Longitude (deg)(min)	Altitude[2/] (ft)	Probable water-bearing materials	Occurrence	Yield	Temperature (°C)	Specific conductance (μmho/cm)	Date	Other data [3/]
23	U.S. Forest Service	Paulina Lake hot springs	43 43.85 121 14.95	6,334	Volcanic breccia	Thermal	Many small diffuse flows	52	960	10/26/74	C,I(06/30/82)
24	U.S. Forest Service	Lost Lake gas vents	43 42.25 121 13.65	6,390	Volcanics (Obsidian flow ?)	Gravity	Very small to none	5	400	10/27/74	C(10/27/74 Evident H_2S gas
25	U.S. Forest Service	East Lake hot springs	43 43.20 121 11.95	Follows lake level	Pumice, ash, and lacustrine sediments, at surface	Thermal	Many small diffuse flows	57	840	10/26/74	C,I(06/30/82)

1/ Sequence No. -- Identifying number used in tables and illustrations.

2/ Altitude -- Land surface at spring, in feet above National Geodetic Vertical Datum of 1929. Paulina Lake Hot Spring and East Lake Hot Springs referenced to USGS benchmarks; altitude of Lost Lake gas vents estimated from Geological Survey topographic quadrangle map.

3/ Other data -- C, chemical analysis, table 11; I, Isotope analysis, table 12.