UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-QUALITY INVESTIGATION NEAR THE CHICO AND HUNTERS GEOTHERMAL LEASE-APPLICATION AREAS, PARK AND SWEET GRASS COUNTIES, MONTANA

Open-File Report 78-199

Prepared for the U.S. Bureau of Land Management

Helena, Montana

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FACTORS FOR CONVERTING ENGLISH UNITS TO METRIC UNITS

The following factors may be used to convert English units in this report to the International System of Units (SI).

Multiply English units	By	To obtain SI units
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
foot (ft)	.3048	meter (m)
gallon per minute (gal/min)	.06309	liter per second (L/s)
mile (mi)	1.609	kilometer (km)

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ABSTRACT

Water quality in and adjacent to geothermal lease-application areas near Chico and Hunters Hot Springs was investigated during two surveys in October 1976 and April 1977. The resulting data were needed to evaluate the effects of proposed geothermal exploration and development on the Yellowstone River and its tributaries.

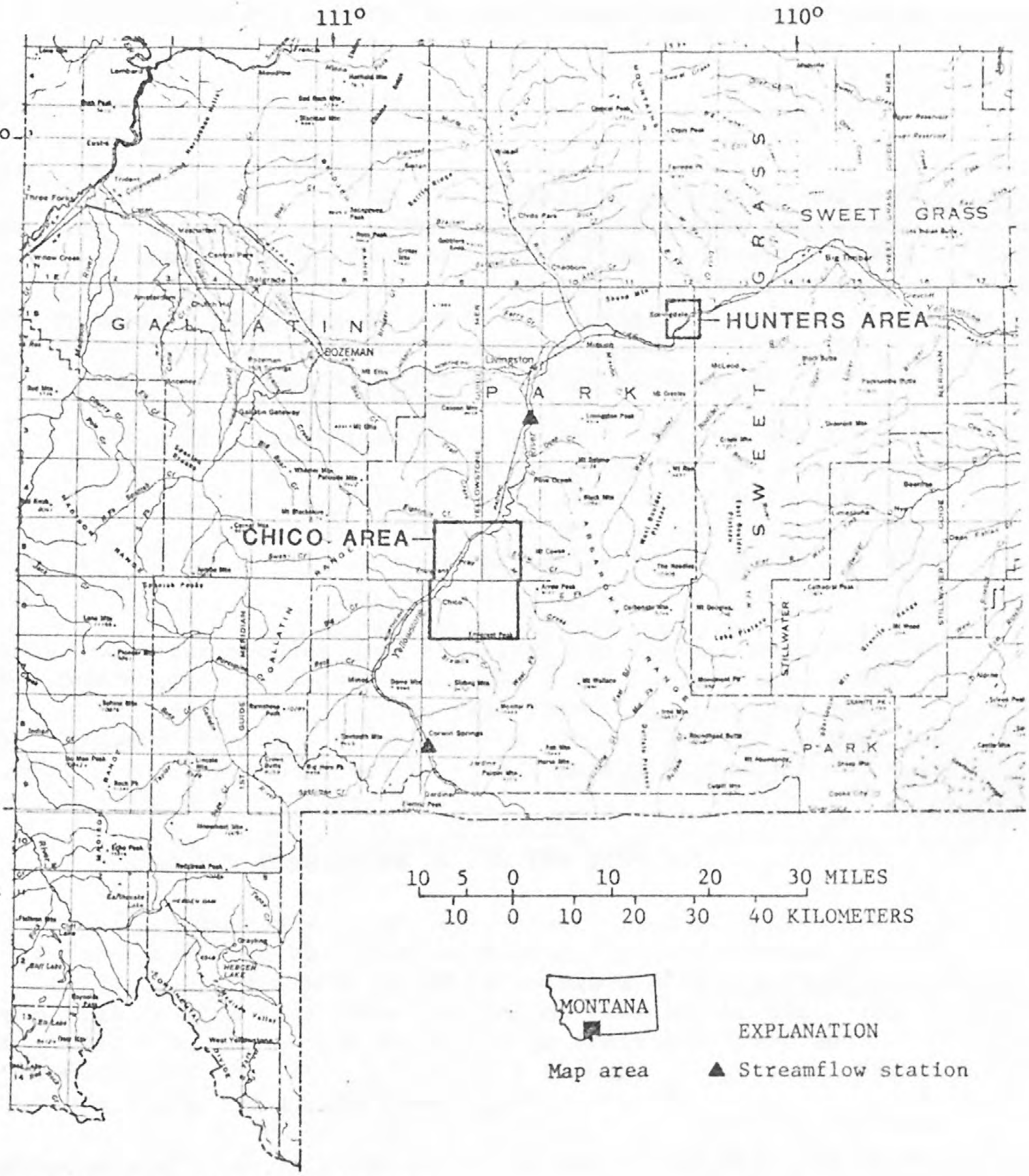
Waters from the two hot springs, the Yellowstone River, and its tributaries that drain the proposed lease areas are generally suitable for drinking, except for excessive concentrations of fluoride and hydrogen sulfide in waters from Hunters Hot Springs. The water from Chico Hot Springs is suitable for irrigation, but the water from Hunters Hot Springs presents a very high sodium and a medium salinity hazard and is generally unsatisfactory for irrigation.

The effect of the thermal waters on streamflow and chemical discharge of the Yellowstone River during the surveys was negligible and less than the accepted error of measurement. Production of higher volumes of more concentrated water can be expected to accompany testing and development of the geothermal resource.

INTRODUCTION

Degradation of water quality in receiving streams by thermal waters is the most probable hazard to the environment posed by geothermal exploration and development. In 1976 the U.S. Bureau of Land Management requested that the U.S. Geological Survey conduct a study to define baseline water quality in and adjacent to proposed geothermal lease areas near Chico and Hunters Hot Springs in southwestern Montana (fig. 1). The resulting data could then be used to evaluate the effects of proposed geothermal exploration and development on the chemical quality of the Yellowstone River and its tributaries near the lease areas.

The purpose of this report is (1) to describe the natural discharge from the hot springs and in selected tributaries near or crossing the lease-application areas, and (2) to describe the effect of that discharge on flow of the Yellowstone River during two surveys conducted in October 1976 and April 1977.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1968

Figure 1.--Locations of areas of investigation and streamflow stations.

APPROACH

Chico and Hunters Hot Springs are the only known sources of geothermal discharge in the areas of investigation. Thus, discharge, temperature, and chemical water-quality data for water from the hot springs and streams would be adequate to describe baseline conditions.

Current-meter measurements of flow of the hot springs and streams were made at the sites shown in figures 2 and 3 for the Chico and Hunters areas, respectively. Water samples were collected at the time of each measurement using methods approved by the Geological Survey (Brown and others, 1970; Guy and Norman, 1970), with some modifications suggested for thermal spring samples by Presser and Barnes (1974). Routine field measurements included temperature, specific conductance, pH, and alkalinity. The water samples were sent for chemical analysis to the National Water Quality Laboratory of the Geological Survey in Denver, Colorado. The results of chemical analysis are given in tables 1-4.

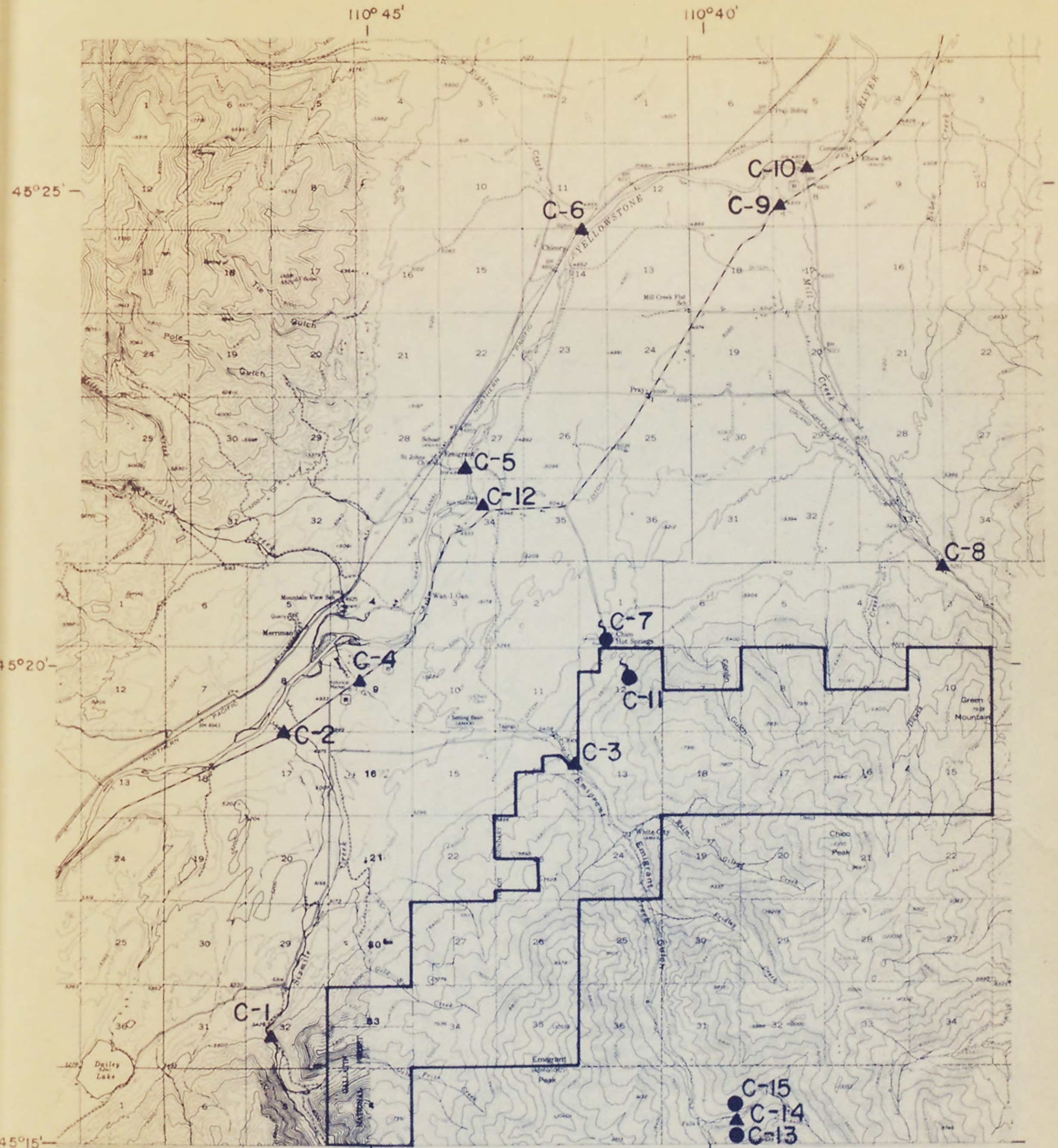
Samples of water from the hot springs were tested for gross alpha and gross beta activities by the Montana Department of Health and Environmental Sciences (MDHES). The radioactivity levels in all samples were far below the maximum contaminant levels established by the U.S. Environmental Protection Agency (1976) for public water supplies (Larry Lloyd, MDHES, oral commun., 1977).

In July 1976, water samples were collected and thermal gradients were measured in flowing test holes drilled by the Duval Corporation in the Gallatin National Forest (fig. 2). The data resulting from chemical analysis of the water samples are included in tables 1 and 2. Subsurface temperatures of 9-10°C were measured to a maximum depth of about 400 feet, below which the holes had collapsed.

STREAMFLOW CONDITIONS DURING THE SURVEYS

At the streamflow gaging station Yellowstone River at Corwin Springs, 25 river miles upstream from the Chico area (fig. 1), the average flow is about 3,140 ft^3/s and the minimum is 389 ft^3/s based on 70 years of record. At the station Yellowstone River near Livingston between the Chico and Hunters areas (fig. 1), the corresponding flows are about 3,790 and 590 ft^3/s, respectively, based on 51 years of record. Flows were above average for 2 years preceding this investigation.

During periods of base flow the effect of geothermal effluent on the temperature and chemical quality of streamflow would be greater than during periods of higher flow when the thermal discharge would be diluted by surface runoff. Therefore, surveys were scheduled to describe baseline conditions prevailing at or near the 50-percent duration level (high base flow) and the 90-percent duration level (low base flow), during the 1977 water year.



Base from U.S. Geological Survey
Emigrant and Fridley Peak,
1:62,500, 1955

1 ½ 0 1 2 3 4 MILES
1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

- Lease-application area
- C-4 Data-collection site and number
  - ▲ Stream
  - Spring
  - ● Exploration drill hole

Figure 2.--Locations of data-collection sites in the Chico area.

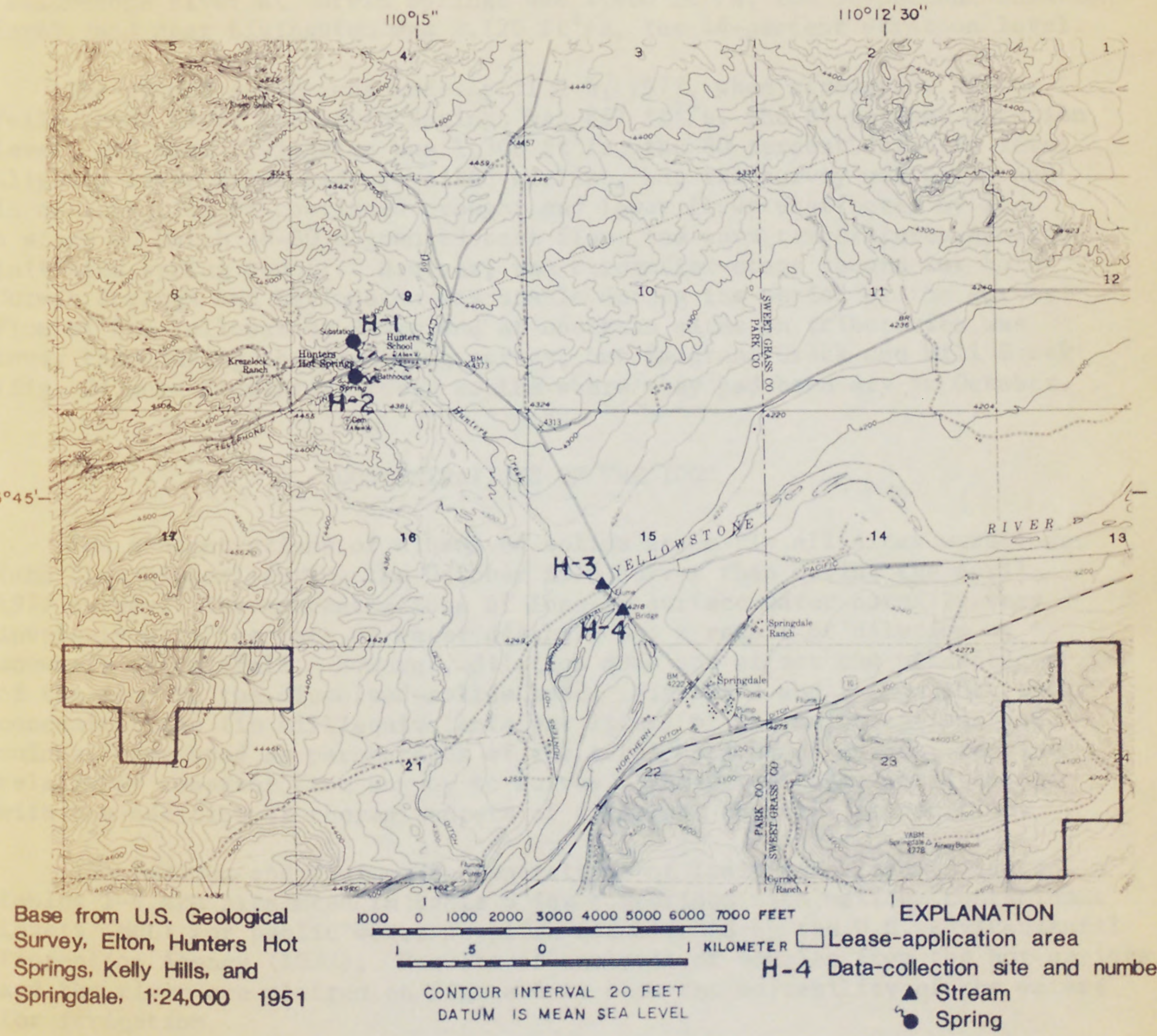


Figure 3.--Locations of data-collection sites in the Hunters area.

High base flow in the Yellowstone River normally occurs in the fall (September-November), and low base flow normally occurs immediately before spring runoff (February-April). Ice cover generally interferes with precise discharge measurements in tributaries from December through March, and diversions for irrigation and drainage from irrigated fields in both areas complicate hydrologic interpretation during April-September.

The first survey was made October 28-29, 1976, when streamflow of the Yellowstone River at Corwin Springs was 1,400 ft^3/s, the 50-percent duration level, and near Livingston was 2,120 ft^3/s, the 44-percent duration level.

The second survey was made April 5-6, 1977, when streamflow of the Yellowstone River at Corwin Springs was 867 ft^3/s, the 84-percent duration level, and near Livingston was 1,300 ft^3/s, the 80-percent duration level. Slightly lower flows had prevailed earlier, but the survey was postponed in anticipation of continued drought and lower flows unaffected by ice. A storm on March 28-30 augmented base flow, and warm temperatures April 6-8 initiated spring runoff. However, the streamflow-stage record for both Corwin Springs and Livingston was stable during the period of the survey. Flow of the Yellowstone River and at upstream sites on tributaries was lower than during the preceding survey, but Emigrant Creek and Mill Creek (fig. 2) were flowing at their mouths where they had been dry in October.

CONCENTRATIONS OF THE IONS

The concentrations of dissolved solids at nearly all sites were lower (and flow higher) during the October 1976 survey than during the April 1977 survey. The concentrations of ions in surface water normally vary inversely with the rate of water discharge as a result of dilution by snowmelt or rainfall. However, dilution does not affect the percentages of the ions in the dissolved-solids load. Figures 4 and 5 show that the concentrations (in milliequivalents per liter) of the major cations and anions, expressed as percentages of the total cations or anions, remained relatively constant from survey to survey. The percentages would change with the addition of thermal waters of different chemical composition.

The maximum and minimum concentrations of ionic constituents listed in tables 1-4 are presented in table 5 for comparison with maximum contaminant levels (MCL) for public water supplies established by the U.S. Environmental Protection Agency (1977). Results of analyses of samples from the hot springs and the river are plotted on figure 6 to show the suitability of the waters for irrigation.

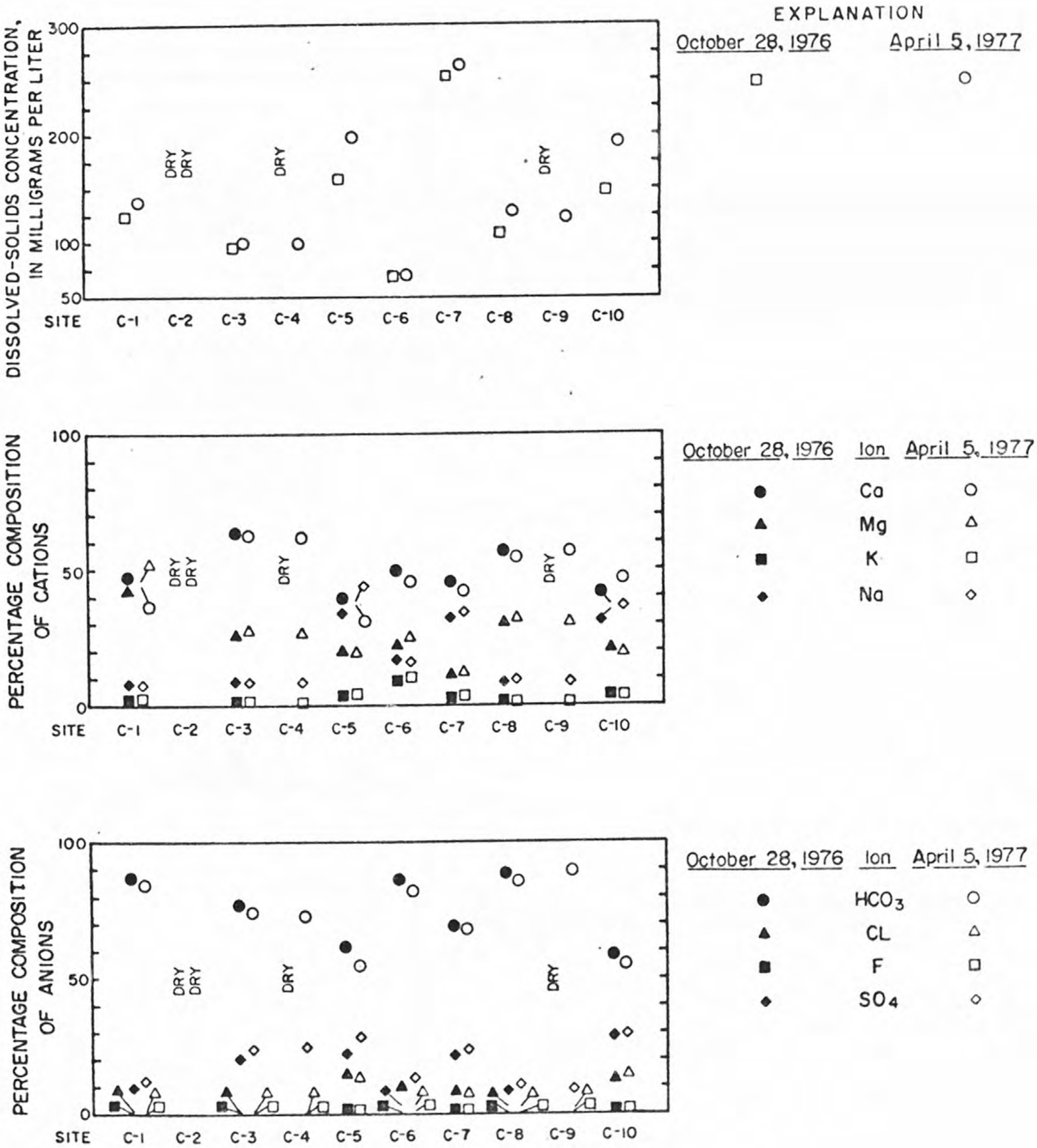


Figure 4.--Concentration of dissolved solids and percentage composition of waters in the Chico area. Percentage composition is based on concentrations in milliequivalents per liter. Site descriptions are given in table 1.

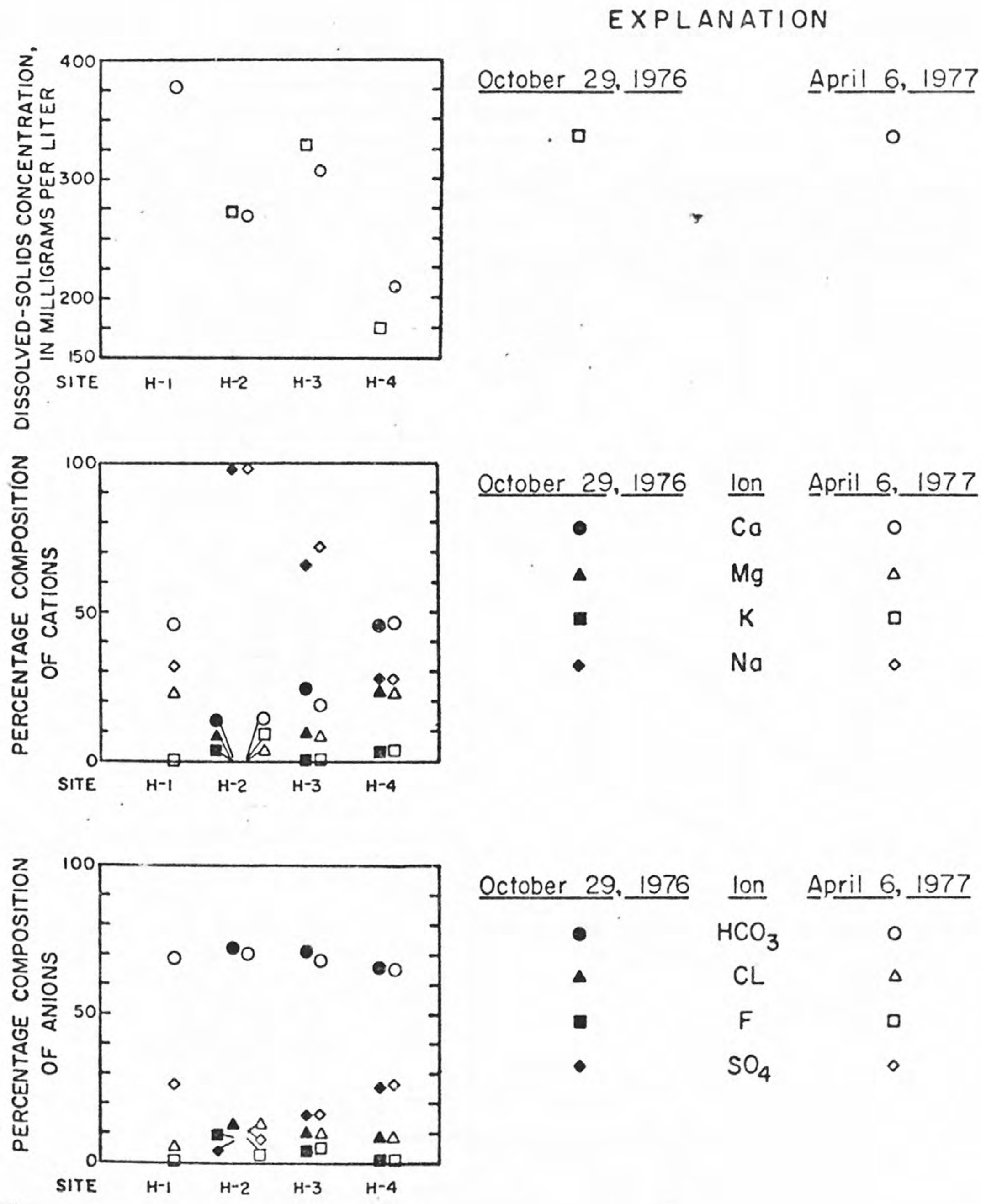


Figure 5.--Concentration of dissolved solids and percentage composition of waters in the Hunters area. Percentage composition is based on concentrations in milliequivalents per liter. Site descriptions are given in table 3.

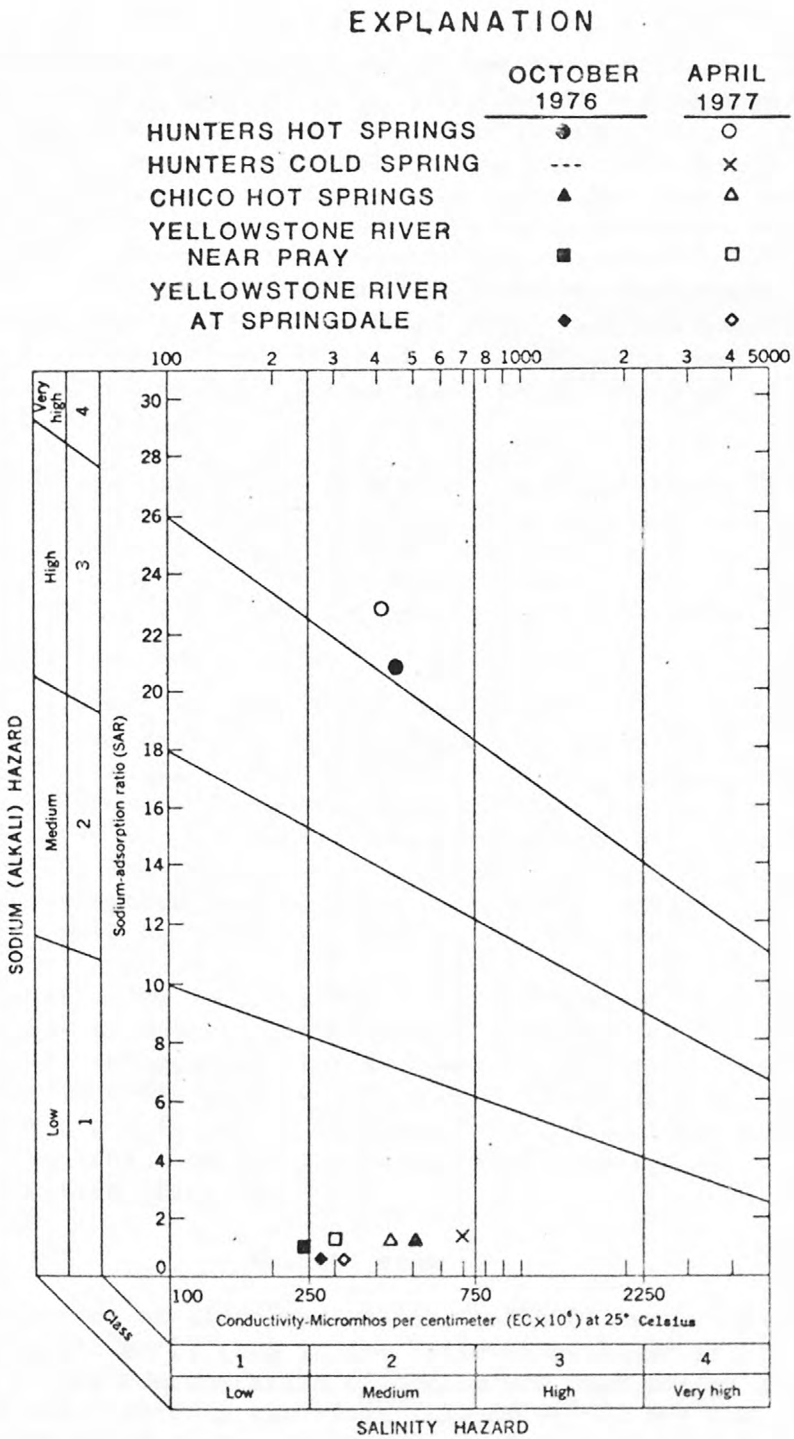


Figure 6.--Classification of water for irrigation. Diagram adapted from U.S. Salinity Laboratory Staff (1954).

Chico area

The concentration of dissolved solids and the specific conductance were higher in Chico Hot Springs (site C-7) than in the adjacent Yellowstone River or any of the tributaries (table 1). Calcium and bicarbonate were the predominant ions in all waters except during the April survey, when the percent magnesium in Sixmile Creek (site C-1) and percent sodium in the Yellowstone River at Emigrant (site C-5) slightly exceeded the percent calcium (fig. 4). The percent sodium exceeded the percent magnesium only in the hot springs and the river. Sulfate was more abundant than chloride in all but one sample (site C-6) in the Chico area. Sulfate was the predominant anion in water from the Chico LC-3 drill hole and in the east fork of Emigrant Creek. Sulfate concentration was also relatively high in the Chico No. 11 drill hole (table 1).

Strontium was the only trace constituent present in samples from the hot springs at concentrations appreciably higher than in samples from the river (table 2). The exceptionally high concentration of strontium in the samples from Sixmile Creek (360, 350 μg/L, micrograms per liter) suggests that water similar to the hot springs enters the channel upstream from the sampling site.

Concentrations of the major ionic constituents in all samples were lower than the MCL for drinking water (table 5). The pH of the river water (8.6-8.9) exceeded the MCL of 8.5 (table 1). None of the trace-constituent concentrations determined during the study exceeded the MCL for drinking water (table 5). However, a sample of water from the hot springs collected by Mariner, Presser, and Evans (1976) contained 0.6 mg/L (milligrams per liter) hydrogen sulfide, compared to the MCL of 0.05 mg/L. Water samples collected during this study were not analyzed for hydrogen sulfide.

Tributary streamflow in the area is used extensively for irrigation. On the basis of boron concentration, water from Chico Hot Springs (50, 60 μg/L) would be classified as excellent for irrigation, and streamflow of the Yellowstone River (330-540 μg/L) would be good for irrigating sensitive crops and excellent for semitolerant or tolerant crops (U.S. Salinity Laboratory Staff, 1974). The sodium hazard is low and the salinity hazard is low to medium for both waters (fig. 6).

Hunters area

The concentration of dissolved solids (table 3) was higher in Hunters Hot Springs (273, 268 mg/L) than in the Yellowstone River at Springdale (174, 210 mg/L). The concentration of sodium was much higher in the hot springs (86, 85 mg/L) than in the river (18, 21 mg/L), but the concentrations of the other major cations were lower. Sodium comprises about 98 percent of the cations in Hunters Hot Springs (site H-2), but less than 30 percent in the river (site H-4), where calcium is the predominant cation (fig. 5). Bicarbonate comprises more than 65 percent of the anions in all waters sampled in the Hunters area (fig. 5). Unlike the waters sampled at most other sites during the surveys, at the hot springs the percent chloride exceeded the percent sulfate and the percent fluoride exceeded 5 percent.

The similarity in percentage composition of samples from the river and from Hunters cold spring (site H-1) may suggest a common source. However, the river water is a mixture of waters from diverse sources and the cold spring is about 200 feet above the river level; therefore, the similarity probably is coincidental.

The concentrations of individual major ions, with the exception of fluoride, were lower than the MCL for drinking water (table 5). The maximum concentration of lead in the hot springs (49 µg/L) was near the MCL for drinking water (50 µg/L). A sample collected by Mariner, Presser, and Evans (1976) contained 5.3 mg/L hydrogen sulfide, about 100 times the MCL.

Although the concentration of boron (table 4) in Hunters Hot Springs (720 µg/L) exceeded the concentration in the river, (250, 350 µg/L), the level would be tolerable for sensitive plants and good for semi-tolerant plants if the water were used for irrigation. Unlike Chico Hot Springs, the sodium hazard is classified as very high and the salinity hazard is medium (fig. 6).

CHEMICAL DISCHARGE

The chemical discharge (load), D, of an ionic constituent is defined by the equation:

$$D = K \times Q \times C$$

where K is a unit constant, Q is the measured discharge, and C is the concentration of the constituent. D is defined in terms of kiloequivalents (thousands of equivalent weights) per day (ke/d) when Q is in cubic feet per second, C is in milliequivalents per liter (me/L), and K equals 2.446 (Leonard and Morgan, 1970). If analyses are accurate, the loads of the cationic and anionic constituents should be nearly equal.

If Ds and D2 are the ionic loads at the source and the downstream site, respectively, the relative effect of each source on the stream with respect to a particular ion can be expressed as a percentage, Ds/D2 x 100. In tables 6 and 7, the water and chemical discharges of the hot springs and selected tributaries are expressed as percentages of corresponding quantities measured in the Yellowstone River.

Springs

Measured flow of the hot springs represented a small percentage of the discharge of the river. At times the flow of Chico Hot Springs increases as the head is reduced by pumping to fill a swimming pool. Intermittent pumping during the October 1976 survey precluded measurement of the flow. Therefore, a discharge of 0.64 ft^3/s measured in July 1976 under similar conditions was used as a basis of calculation for the October survey. However, during both surveys the natural flow from Chico Hot Springs probably did not exceed 0.30 ft^3/s. Using the maximum figure (0.64 for the October survey), flow of the hot springs represented only 0.04 and 0.03 percent of the discharge of the Yellowstone River near Pray (site C-10) during the October and April surveys, respectively (table 6). Most flow from the hot springs percolates into the alluvium before reaching the river. Because the chemical composition of the hot springs and the river is somewhat similar, the respective contributions of chemical discharge also were relatively small.

The discharge of Hunters Hot Springs represented only 0.07 and 0.11 percent of the measured flow of the Yellowstone River at Springdale during the October and April surveys, respectively (table 7). However, the fluoride load at the hot springs represented 0.64 and 0.80 percent, respectively, of the fluoride load of the river.

Tributaries

Changes in the chemical quality of streamflow in tributaries as a result of geothermal activity probably would precede less-apparent changes in the quality of streamflow in the Yellowstone River. A subsequent increase in chemical discharge of ions characteristic of geothermal waters would constitute evidence of release of geothermal water to the tributary. Variations in water discharge were the major causes of variations in the chemical discharge of tributaries during the surveys (tables 6 and 7).

Proposed leases in the Chico area lie along the mountain front as much as 7 miles from the Yellowstone River. As a result of ground-water interchange where tributaries cross permeable alluvial and colluvial deposits, the rate and chemical composition (and hence, chemical discharge) of streamflow at the mouth generally differed from streamflow near the mountain front.

Losses to the alluvium were observed during both surveys. During the October 1976 survey, most of the tributaries in the Chico area were dry at the mouth. The losses presumably enter the river as underflow. During the October survey, flow at the mouth of Hunters Creek (2.2 ft^3/s) exceeded discharge of Hunters Hot Springs (1.6 ft^3/s). In April, the discharges were equal (1.7 ft^3/s). Because discharge of Hunters Creek near the mouth normally is a mixture of discharge of the hot springs plus inflow from Dog Creek (fig. 3), the equal discharges in April are evidence that part of the discharge of the springs is lost to the alluvium along Hunters Creek.

Yellowstone River

The ideal locations for data-collection sites to be established on the main stem of the Yellowstone River are at the upstream and downstream ends of the reaches that would receive surface and subsurface drainage from the proposed leases. The quantity and quality of that drainage, then, presumably could be determined by difference, using precise measurements and analyses of streamflow at successive stations.

If the water and chemical discharges at the downstream and upstream sites are Q2, Q1, D2, and D1, respectively, the net gain in the reach is Q2-Q1 for water discharge and D2-D1 for chemical discharge. Negative values (net losses) represent losses or withdrawals from the channel, changing stage, erroneous analyses, or inaccurate measurements of discharge. The difference between net gain and tributary inflow to the reach is defined as net seepage into that reach. Changes caused by geothermal activities should be more apparent in seepage or net gain than in streamflow at the downstream site, because the effects of fluctuations in the rate and chemical composition of streamflow in the main stem upstream from the drainage area of interest are minimized by the calculation.

Because no bridges spanned the river at the most desirable sites, precise measurements and integrated samples of streamflow at those sites on the main stem would have been difficult to obtain. Preliminary calculations suggest that even during periods of extreme low flow, when wading measurements might have been made, the accepted error of measurement would have exceeded natural tributary contributions plus seepage into the reaches. Because the accepted error of precise discharge measurements is about 5 percent, a net gain of less than about 10 percent of the discharge at the downstream station might be more apparent than real. Therefore, only two data-collection sites were established to determine baseline conditions on the Yellowstone River: at bridges near Pray (site C-10) for the Chico area and at Springdale (site H-4) for the Hunters area. Another site (C-5) was established on the Yellowstone River at Emigrant to determine the magnitude of net gain in the reach that would include most of the drainage from proposed lease areas in the Chico area.

The results suggest that additional sites on the main stem probably would have added little significant information, even if the discharge had been lower than measured in April. During the October survey the net loss in the Yellowstone River from Emigrant to near Pray was 90 ft^3/s. In April, the net loss was only 30 ft^3/s. The net losses represented only 6 and 3 percent, respectively, of the measured discharge at the downstream station (table 6)--well below the accepted error of the combined measurements; therefore, the losses may not be real. Net losses in chemical discharge were recorded for most ions, but small gains in magnesium and sulfate during the October survey suggest seepage into the channel of water relatively rich in those constituents.

The measured discharge of Hunters Hot Springs represented only about 0.1 percent of the measured discharge of the Yellowstone River at Springdale during the surveys (table 7). Even if precise measurements at additional bridge sites had been available, net gains of a magnitude less than about 70 times the recorded water and chemical discharge of most ions, and 10 times the chemical discharge of fluoride by Hunters Hot Springs would fall within the confidence limits of precision of the combined measurements. Releases of greater magnitude accompanying geothermal activities probably could be detected near the source and would justify additional sites on the main stem upstream and downstream from the suspected outfall.

COMPOSITION OF GEOTHERMAL FLUID

Geothermal fluids suitable for economic development generally have a much higher temperature and contain higher concentrations of ions than are found in either of the hot springs. It is reasonable to assume that higher concentrations of the ions would be found at depth at both sites and that higher flows would be produced during testing of geothermal wells. The application of chemical geothermometers (Fournier and Truesdell, 1973, 1974) applied to the analyses of the hot springs suggests that subsurface temperatures are less than about 80°C. The waters appear to have been in chemical equilibrium with amorphous silica (Mariner and others, 1976). If discharge of the springs is a mixture of hot water in equilibrium with amorphous silica (chalcedony) at depth and of water similar to the discharge of nearby cold springs, mixing calculations (Truesdell and Fournier, 1977) suggest that the temperature of the hot-water fraction may be about 70°C for Chico and 140°C for Hunters. If the hot water were in equilibrium with quartz, the estimated temperatures would be about 120 and 190°C, respectively. Under the conditions of equilibrium with quartz, the concentration of fluoride and lead in the hot-water fraction at Hunters Hot Springs probably would be more than 17 mg/L and 150 μg/L, respectively.

On the basis of available data, estimates of the concentration, temperature, or volume of thermal water that might be released are purely speculative. However, net gains or tributary inflow containing those fluids would constitute higher percentages of the chemical discharge of characteristic ions in streamflow than were recorded during the surveys. When preliminary test data become available, the potential effect of releases of the geothermal water on streamflow in tributaries and the river can be estimated by using the methods described in this report to define departures from the baseline conditions described herein.

SUMMARY

Water quality in and adjacent to the Chico and Hunters geothermal lease-application areas was investigated during two surveys in October 1976 and April 1977, periods when high to low base flow of the Yellowstone River and its tributaries was representative of natural baseline conditions. The percentage composition of the sampled waters at each site remained relatively constant from survey to survey, although the concentrations of dissolved solids and rates of streamflow differed.

The discharges of Chico Hot Springs, the Yellowstone River, and tributaries in the Chico area are generally suitable for drinking water and irrigation with respect to inorganic constituents. With the exception of fluoride and hydrogen sulfide, the major and trace chemical constituents in samples from Hunters Hot Springs and Hunters Creek do not exceed maximum contaminant levels specified for drinking water by the U.S. Environmental Protection Agency. The discharge of Hunters Hot Springs presents very high sodium and medium salinity hazards for irrigation.

The effects of the hot springs and of individual tributaries that drain the proposed lease areas on streamflow and chemical discharge of the Yellowstone River during the surveys were negligible and less than the accepted error of the measurements. Larger volumes of more concentrated thermal waters can be expected to accompany testing and development of the geothermal resource. The potential effect of releases of geothermal water on the receiving streams can be estimated from preliminary test data by using the methods described in this report to compare then-existing conditions with the baseline conditions described herein.

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Table 1.--Chemical analyses of water samples from the Chico area
[Constituents are dissolved and in milligrams per liter, except as indicated.]

Sample location number (fig. 2)	Source	Location: Latitude	Location: Longitude	Date of collection	Time (hrs)	Depth (ft)	Instantaneous discharge (ft^3/s)	Flow rate (gal/min)	Specific conductance (micromhos/cm)	Field pH (units)	Temperature (deg C)	Hardness as $CaCO_3$ (Ca,Mg)	Noncarbonate hardness	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Percent sodium
C-1	Sixmile Creek nr Daily Lake	45 16 09	110 46 28	10/28/76	1510	--	14	--	(2)	8.1	4.0	96	0	20	11	3.8	8
				4/05/77	1430	--	8.8	--	227	8.1	8.5	110	6	22	14	4.4	8
C-3	Emigrant Creek at Old Chico	45 18 59	110 41 58	10/28/76	1400	--	12	--	(2)	7.5	3.5	67	6	19	4.7	3.0	9
				4/05/77	1530	--	8.9	--	169	7.8	7.5	76	14	21	5.6	3.3	9
C-4	Emigrant Creek nr mouth	45 19 51	110 45 10	4/05/77	1345	--	2.2	--	166	7.6	10.5	75	13	21	5.4	3.6	9
C-5	Yellowstone River at Emigrant	45 22 05	110 43 29	10/28/76	1545	--	1,690	--	260	8.9	7.0	72	0	19	5.8	19	35
				4/05/77	1610	--	1,090	--	302	8.7	11.0	85	0	22	7.2	26	38
C-6	Eightmile Creek near Chicory	45 24 31	110 41 51	10/28/76	1245	--	17	--	(2)	7.7	5.6	24	0	6.7	1.8	2.6	17
				4/05/77	1300	--	14	--	68	7.4	11.5	23	0	5.9	2.0	2.4	16
C-7	Chico Hot Springs	45 20 13	110 41 27	10/28/76	1745	--	[3].64	--	518	7.2	42.5	130	0	37	8.0	31	34
				4/05/77	1700	--	.29	--	438	7.3	43.5	130	0	36	8.4	34	36
C-8	Mill Cr upstream fr Diversion Sta 4	45 21 03	110 36 30	10/28/76	1030	--	40	--	191	8.1	17.5	81	0	21	6.9	4.0	10
				4/05/77	1050	--	36	--	210	8.2	4.0	99	1	25	8.9	5.3	10
C-9	Mill Creek nr mouth	45 24 49	110 38 49	4/05/77	1150	--	8.6	--	213	8.5	7.8	100	1	26	8.7	5.1	10
C-10	Yellowstone River near Pray	45 25 10	110 38 28	10/28/76	1110	--	1,600	--	242	8.7	6.0	71	3	18	6.2	19	35
				4/05/77	1245	--	1,060	--	308	8.6	9.0	84	2	22	7.1	25	37
C-11	Chico Cold Springs[1]	45 19 55	110 41 08	7/09/76	1030	--	--	--	200	8.1	9.5	78	0	25	3.6	6.4	15
C-12	Yellowstone Fish Hatchery	45 21 41	110 43 17	10/28/76	1700	--	1.0	--	(2)	7.6	9.0	120	13	34	9.1	8.4	13
C-13	Chico LC-3 flowing drill hole[1]	45 19 09	110 39 37	7/08/76	1600	400	--	4.5	297	7.2	9.2	130	67	36	8.6	9.5	14
C-14	East Fork Emigrant Creek[1]	45 15 17	110 39 37	7/08/76	1325	--	20	--	73	7.7	8.0	21	10	6.4	1.1	1.8	16
C-15	Chico No. 11 drill hole[1]	45 15 24	110 39 37	7/23/76	1300	--	--	20	556	--	10.0	270	98	77	18	21	15

Sample location number (fig. 2)	Date of collection	Sodium adsorption ratio	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity, total as $CaCO_3$	Carbon dioxide (CO_2)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids (sum of constituents)	Dissolved solids (tons per ac-ft)	Dissolved solids (tons per day)	Nitrite plus nitrate, total as N	Nitrite plus nitrate (N)	Phosphorus (P)	Ortho phosphorus (P)	Ortho phosphate (PO_4)
C-1	10/28/76	0.2	1.6	124	0	102	1.6	12	0.8	0.1	10	121	0.16	4.70	--	0.09	0.00	--	--
	4/05/77	.2	2.1	130	0	107	1.5	15	1.2	.1	10	134	.18	3.18	--	.09	--	--	--
C-3	10/28/76	.2	.7	75	0	62	3.4	16	.4	.2	11	93	.13	3.09	--	.08	.00	--	--
	4/05/77	.2	.9	75	0	62	1.7	19	.6	.1	10	98	.13	2.36	--	.08	--	--	--
C-4	4/05/77	.2	.8	75	0	62	2.7	20	.5	.1	10	99	.13	.59	--	.08	.00	--	--
C-5	10/28/76	1.0	4.2	93	0	76	.2	27	13	.8	23	158	.21	721	--	--	.00	--	--
	4/05/77	1.2	5.8	98	3	85	.3	43	15	1.1	29	201	.27	592	--	--	.00	--	--
C-6	10/28/76	.2	2.6	43	0	35	1.2	1.1	2.9	.1	29	68	.09	3.19	--	.03	.14	--	--
	4/05/77	.2	2.8	32	0	26	2.0	4.2	.8	.1	36	70	.10	2.72	--	.01	--	--	--
C-7	10/28/76	1.2	6.6	172	0	141	15	42	12	.9	31	255	.35	.69	--	.26	--	--	--
	4/05/77	1.3	6.9	170	0	140	14	47	10	1.0	34	263	.36	.14	--	.21	.00	--	--
C-8	10/28/76	.2	1.3	107	0	88	1.4	8.2	1.4	.2	14	110	.15	11.9	--	.01	.03	--	--
	4/05/77	.2	1.5	120	0	98	1.2	12	2.0	.2	14	129	.18	12.8	--	.05	--	--	--
C-9	4/05/77	.2	1.4	120	1	100	.6	10	1.1	.1	13	126	.17	2.95	--	.04	.00	--	--
C-10	10/28/76	1.0	4.3	82	0	67	.3	31	10	.7	22	152	.21	657	0.03	--	.01	--	--
	4/05/77	1.2	5.6	100	0	82	.4	42	15	1.1	28	196	.27	561	.24	--	.00	--	--
C-11	7/09/76	.3	.6	105	0	86	1.2	5.0	1.5	.4	15	110	.15	--	--	.11	.01	--	--
C-12	10/28/76	.3	2.6	134	0	110	5.4	33	2.2	.2	18	175	.24	.48	--	.34	--	--	--
C-13	7/08/76	.4	2.0	72	0	59	7.3	88	1.2	.5	33	218	.30	.01	--	.01	.00	--	--
C-14	7/08/76	.2	.5	13	0	11	.4	14	.5	.1	12	43	.06	2.32	--	.07	.00	--	--
C-15	7/23/76	.6	1.1	208	-	171	-	120	.8	.8	30	375	.51	--	--	.01	--	.03	.09

[1]Site sampled during reconnaissance.
[2]Probable instrument malfunction.
[3]Estimated on the basis of measurement July 9, 1976, under similar conditions.

Table 2.--Trace-constituent concentrations of water samples from the Chico area
[Constituents are dissolved and in micrograms per liter.]

Sample location number (fig. 2)	Source	Location: Latitude	Location: Longitude	Date of collection	Time (hrs)	Instantaneous discharge (ft³/s)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Molybdenum (Mo)	Nickel (Ni)	Selenium (Se)	Strontium (Sr)	Vanadium (V)	Zinc (Zn)
C-1	Sixmile Creek nr Daily Lake	45 16 09	110 46 28	10/28/76	1510	14	0	0	5	0	0	60	2	0	0	0.0	2	6	0	360	0.9	0
				4/05/77	1430	8.8	--	--	2	--	--	160	--	10	10	--	--	--	--	350	--	--
C-3	Emigrant Creek at Old Chico	45 18 59	110 41 58	10/28/76	1400	12	0	0	7	1	2	140	18	0	0	.0	3	6	0	190	.9	10
C-4	Emigrant Creek nr mouth	45 19 51	110 45 10	4/05/77	1345	2.2	0	0	2	0	1	40	2	0	10	.0	2	4	0	180	.0	0
C-5	Yellowstone River at Emigrant	45 22 05	110 43 29	10/28/76	1545	1,690	25	0	340	0	2	30	1	100	0	.0	2	2	0	150	1.0	0
				4/05/77	1610	1,090	12	0	540	2	3	60	4	140	10	.0	2	4	0	170	.9	0
C-6	Eightmile Creek near Chicory	45 24 31	110 41 51	10/28/76	1245	17	0	0	7	2	0	100	18	0	0	.0	0	6	0	60	3.7	0
				4/05/77	1300	14	--	--	4	--	--	190	--	0	0	--	--	--	--	40	--	--
C-7	Chico Hot Springs	45 20 13	110 41 27	10/28/76	1745	[2] .64	--	--	50	--	--	90	--	30	0	--	--	--	--	380	--	--
				4/05/77	1700	.29	17	0	60	0	0	50	0	30	10	.0	.0	6	0	360	3.7	0
C-8	Mill Cr upstream fr Diversion Sta 4	45 21 03	110 36 30	10/28/76	1030	40	0	0	7	0	0	70	1	0	10	.0	1	7	0	170	1.0	0
				4/05/77	1050	36	--	--	7	--	--	130	--	10	0	--	--	--	--	200	--	--
C-9	Mill Creek nr mouth	45 24 49	110 38 49	4/05/77	1150	8.6	0	0	7	1	1	40	15	0	10	.0	0	6	0	180	.7	10
C-10	Yellowstone River near Pray	45 25 10	110 38 28	10/28/76	1110	1,600	10	0	330	0	1	40	2	90	0	.0	1	0	0	150	.0	10
				4/05/77	1245	1,060	12	0	510	1	4	60	5	140	10	.0	2	1	0	160	.8	10
C-11	Chico Cold Springs[1]	45 19 55	110 41 08	7/09/76	1030	--	--	--	8	--	--	30	--	0	--	--	--	--	--	210	--	--
C-12	Yellowstone Fish Hatchery	45 21 41	110 43 17	10/28/76	1700	1.0	--	--	9	--	--	90	--	0	0	--	--	--	--	240	--	--
C-13	Chico LC-3 flowing drill hole[1]	45 15 09	110 39 37	7/08/76	1600	--	--	--	6	--	--	3,100	--	10	--	--	--	--	--	330	--	--
C-14	East Fork Emigrant Creek[1]	45 15 17	110 39 37	7/08/76	1325	20	--	--	6	--	--	210	--	0	--	--	--	--	--	70	--	--
C-15	Chico No. 11 drill hole[1]	45 15 24	110 39 37	7/23/76	1300	--	--	--	4	--	--	1,200	--	50	70	--	--	--	--	2,000	--	--

[1]Site sampled during reconnaissance.
[2]Estimated on the basis of measurement July 9, 1976, under similar conditions.

Table 3.--Chemical analyses of water samples from the Hunters area
[Constituents are dissolved and in milligrams per liter, except as indicated.]

Sample location number (fig. 3)	Source	Location: Latitude	Location: Longitude	Date of collection	Time (hrs)	Instantaneous discharge (ft³/s)	Flow rate (gal/min)	Specific conductance (micromhos/cm)	Field pH (units)	Temperature (deg C)	Hardness as $CaCO_3$ (Ca,Mg)	Noncarbonate hardness	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
H-1	Hunters cold spring	45 45 35	110 15 05	4/06/77	1145	--	0.50	706	7.6	8.0	230	0	61	18	47
H-2	Hunters Hot Springs composite	45 45 26	110 15 26	10/29/76	1100	1.6	710	441	8.9	53.9	3	0	1.0	.2	86
				4/06/77	1000	1.7	776	430	8.5	56.5	3	0	1.0	.0	85
H-3	Hunters Creek near mouth	45 44 39	110 13 19	10/29/76	0900	2.2	--	518	8.4	17.5	87	0	25	5.8	78
				4/06/77	0835	1.7	--	463	8.4	16.0	68	0	19	4.9	80
H-4	Yellowstone River at Springdale	45 44 35	110 13 15	10/29/76	1000	2,360	--	287	8.2	5.5	99	5	26	8.1	18
				4/06/77	1100	1,540	--	324	8.5	9.5	120	1	31	9.2	21

Table 3.--Chemical analyses of water samples from the Hunters area--continued

Sample location number (fig. 3)	Date of collection	Percent sodium	Sodium adsorption ratio	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity, total as $CaCO_3$	Carbon dioxide (CO_2)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids (sum of constituents)	Dissolved solids (tons per ac-ft)	Dissolved solids (tons per day)	Nitrite plus nitrate, total as N	Nitrite plus nitrate (N)	Phosphorus (P)
H-1	4/06/77	31	1.4	0.3	280	0	230	10	84	13	0.3	10	375	--	--	--	0.44	--
H-2	10/29/76	98	21	.6	125	22	139	.3	16	17	5.8	59	273	0.37	1.16	--	.01	0.00
	4/06/77	98	23	1.4	150	4	130	.7	19	14	5.8	63	268	--	--	--	.04	--
H-3	10/29/76	66	3.7	.9	226	0	185	1.4	39	18	4.0	45	329	.45	1.95	--	.26	.01
	4/06/77	72	4.2	1.1	180	6	160	1.1	36	16	4.9	50	308	.42	1.42	--	.14	.00
H-4	10/29/76	28	.8	3.9	114	0	94	1.2	35	8.0	.6	18	174	.24	1,110	.00	--	.00
	4/06/77	27	.9	4.6	140	0	110	.7	43	11	.8	20	210	.29	873	.12	--	.00

Table 4.--Trace-constituent concentrations of water samples from the Hunters area
[Constituents are dissolved and in micrograms per liter.]

Sample location number (fig. 3)	Source	Location Latitude	Location Longitude	Date of collection	Time (hrs)	Instantaneous discharge (ft^3/s)	Flow rate (gal/min)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)
H-1	Hunters cold spring	45 45 35	110 15 05	4/06/77	1145	--	0.50	--	--	50	--
H-2	Hunters Hot Springs composite	45 45 26	110 15 26	10/29/76	1100	1.6	710	0	0	720	5
				4/06/77	1000	1.7	776	--	--	720	--
H-3	Hunters Creek near mouth	45 44 39	110 13 19	10/29/76	0900	2.2	--	0	0	530	4
				4/06/77	0835	1.7	--	0	0	590	1
H-4	Yellowstone River at Springdale	45 44 35	110 13 15	10/29/76	1000	2,360	--	18	0	250	0
				4/06/77	1100	1,540	--	18	0	350	1

Table 4.--Trace-constituent concentrations of water samples from the Hunters area--continued

Sample location number (fig. 3)	Date of collection	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Molybdenum (Mo)	Nickel (Ni)	Selenium (Se)	Strontium (Sr)	Vanadium (V)	Zinc (Zn)
H-1	4/06/77	--	130	--	20	0	--	--	--	--	1,600	--	--
H-2	10/29/76	21	70	49	40	10	0.0	8	7	0	60	0.7	10
	4/06/77	--	40	--	40	0	--	--	--	--	10	--	--
H-3	10/29/76	1	100	37	30	10	.0	8	7	0	310	1.2	0
	4/06/77	1	60	7	30	0	.0	6	6	0	220	.6	0
H-4	10/29/76	0	20	1	70	0	.0	0	2	0	210	.4	10
	4/06/77	3	30	2	100	20	.0	2	1	0	230	1.0	10

Table 5.--Summary of major-ion and trace-constituent concentrations in water samples

A. Major Constituents

Constituent	Concentration: Maximum (mg/L)	Concentration: Minimum (mg/L)	Concentration: EPA drinking water standard (mg/L)
	Chico Hot Springs area		
Bicarbonate	208	13	--
Calcium	77	5.9	--
Chloride	15	.4	[1]250
Fluoride	1.1	.1	[2,3] 2.0
Magnesium	18	1.1	--
Potassium	6.9	.5	--
Sodium	34	1.8	--
Sulfate	120	1.1	[1]250
	Hunters Hot Springs area		
Bicarbonate	280	114	--
Calcium	61	1.0	--
Chloride	18	8.0	[1]250
Fluoride	5.8	.3	[2,3] 2.0
Magnesium	18	.0	--
Potassium	4.6	.3	--
Sodium	86	18	--
Sulfate	84	16	[1]250

B. Trace Constituents

Constituent	Number of analyses	Number of non-zero values	Concentration: Maximum (μg/L)[4]	Concentration: EPA drinking water standard[3] (μg/L)[4]
		Chico Hot Springs area		
Arsenic	11	5	25	50
Boron	20	20	540	[5]<1,000
Cadmium	11	5	2	10
Copper	11	7	4	1,000
Lead	11	10	18	50
Mercury	11	0	0	2
Selenium	11	0	0	10
Zinc	11	4	10	5,000
		Hunters Hot Springs area		
Arsenic	5	2	18	50
Boron	7	7	720	[5]<1,000
Cadmium	5	4	5	10
Copper	5	4	21	1,000
Lead	5	5	49	50
Mercury	5	0	0	2
Selenium	5	0	0	10
Zinc	5	3	10	5,000

[1] U.S. Environmental Protection Agency (1977).
[2] Based on annual average of maximum daily air temperature in study area.
[3] U.S. Environmental Protection Agency (1975).
[4] Micrograms per liter.
[5] Satisfactory for irrigation of sensitive crops.

Table 6.--Water and chemical discharge at data-collection sites in the Chico area as percentages of corresponding quantities in the Yellowstone River near Pray

Location	Site number (fig.2)	Date	Flow	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
Sixmile Creek nr Daily Lake	C-1	10/28/76	0.88	0.99	1.6	0.18	0.33	1.4	0.34	0.07	0.14
		4/05/77	.83	.83	1.6	.14	.31	1.1	.29	.06	.08
Sixmile Creek nr mouth	C-2	10/28/76	[1].00	.00	.00	.00	.00	.00	.00	.00	.00
		4/05/77	[1].00	.00	.00	.00	.00	.00	.00	.00	.00
Emigrant Creek at Old Chico	C-3	10/28/76	.75	.80	.58	.12	.12	.70	.39	.03	.23
		4/05/77	.84	.80	.66	.11	.14	.63	.38	.03	.09
Emigrant Creek nr mouth	C-4	10/28/76	[1].00	.00	.00	.00	.00	.00	.00	.00	.00
		4/05/77	.21	.20	.16	.03	.03	.16	.10	.01	.02
Yellowstone Fish Hatchery	C-12	10/28/76	.06	.12	.09	.03	.04	.10	.06	.01	.02
Yellowstone River at Emigrant	C-5	10/28/76	106	111	98	105	103	119	92	136	122
		4/05/77	103	103	104	107	106	101	105	103	103
Eightmile Creek near Chicory	C-6	10/28/76	1.1	.40	.31	.15	.66	.56	.04	.31	.17
		4/05/77	1.3	.36	.38	.13	.68	.43	.13	.07	.14
Chico Hot Springs	C-7	10/28/76	.04	.08	.05	.06	.06	.08	.05	.05	.05
		4/05/77	.03	.04	.03	.04	.03	.04	.03	.02	.02
Mill Creek upstream from Diversion Sta 4	C-8	10/28/76	2.5	2.9	2.8	.52	.77	3.2	.66	.35	.74
		4/05/77	3.4	4.0	4.4	.74	.94	4.2	.99	.46	.66
Mill Creek near mouth	C-9	10/28/76	[1].00	.00	.00	.00	.00	.00	.00	.00	.00
		4/05/77	.82	.98	1.0	.17	.21	.99	.19	.06	.08
Yellowstone River nr Pray	C-10	10/28/76	100	100	100	100	100	100	100	100	100
		4/05/77	100	100	100	100	100	100	100	100	100
Net Gain (Loss) in Yellowstone River between Pray and Emigrant (sites C-10 and C-5)	C-10 minus C-5	10/28/76	(-6)	(-11)	2	(-5)	(-3)	(-19)	8	(-36)	(-22)
		4/05/77	(-3)	(-3)	(-4)	(-7)	(-6)	(-1)	(-5)	(-3)	(-3)

[1]No flow in stream.

Table 7.--Water and chemical discharge at data-collection sites in the Hunters area as percentages of corresponding quantities in the Yellowstone River at Springdale

Location	Site number (fig. 3)	Date	Flow	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
Hunters cold spring	H-1	4/06/77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hunters Hot Springs	H-2	10/29/76	.07	.00	.00	.32	.01	.07	.03	.14	.64
		4/06/77	.11	.00	.00	.45	.03	.12	.05	.13	.80
Hunters Creek near mouth	H-3	10/29/76	.09	.09	.06	.40	.02	.18	.10	.21	.61
		4/06/77	.11	.07	.06	.42	.03	.14	.09	.15	.66
Yellowstone River at Springdale	H-4	10/29/76	100	100	100	100	100	100	100	100	100
		4/06/77	100	100	100	100	100	100	100	100	100