LIMNOLOGICAL STUDY OF SHASTA LAKE, SHASTA COUNTY, CALIFORNIA, WITH EMPHASIS ON THE EFFECTS OF THE 1977 DROUGHT

By Stephen A. Rettig and Gilbert C. Bortleson

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CONVERSION FACTORS

The International System of Units (SI) is used in this report. For readers who prefer inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
cm (centimeters)	0.3937	inches
cm^2 (square centimeters)	0.1550	in^2 (square inches)
hm^3 (cubic hectometers)	810.7	acre-ft (acre-feet)
km (kilometers)	0.6214	mi (miles)
km^2 (square kilometers)	0.3861	mi^2 (square miles)
km^2 (square kilometers)	247.1	acres
m (meters)	3.281	ft (feet)
mm (millimeters)	0.0394	inches
m^3/s (cubic meters per second)	35.31	ft^3/s (cubic feet per second)
µS/cm at 25° (microsiemens per centimeter at 25°C)	1.000	µmho/cm at 25°C (micromhos per centimeter at 25°C)

Degrees Celsius (°C) are converted to degrees Fahrenheit (°F) by using the formula: Temp °F = 1.8 temp °C + 32.

Explanation of abbreviations:

mg/L (milligrams per liter)
mg C/(m^2/d) (milligrams of carbon per square meter per day)

ALTITUDE DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

TRADE NAMES

The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

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ABSTRACT

An intensive limnological study of Shasta Lake was made in cooperation with the California Department of Water Resources during the 1977 drought. Water-quality data were collected from March 1977 through September 1978 at six lake stations and at four lake tributary stations. Data collected during the 1977 drought were compared to post-drought water-quality data.

Shasta Lake stratifies thermally in summer and circulates freely in winter. Tributary inflow to the lake and outflow through the dam generate density currents that promote mixing at depth and development of an extensive metalimnion. By late summer the metalimnion is deepened and the hypolimnion is reduced or eliminated.

During the drought the depth of the reservoir was reduced an average of about 45 meters. The effects of the reduced inflows and lower lake levels were most pronounced on the dissolved-oxygen regime of the reservoir. During June 1977 most of the reservoir was between 50 to 70 percent of dissolved-oxygen saturation, and the hypolimnion in the upstream and downstream parts of the reservoir was reduced to anoxic conditions. In a normal year, such as 1978, the entire reservoir was above 70 percent of dissolved-oxygen saturation.

The low lake levels during the drought caused the exposure of extensive nearshore sediments that continually washed into the lake and decreased light penetration. In 1977 the reservoir showed increased dissolved-solids concentration and specific conductance, decreased dissolved-oxygen concentrations, and increased total phosphorous and inorganic nitrogen concentrations. The water-quality changes were the most pronounced in the upper tributary arms of the reservoir as compared to the more open expanse near the dam.

Diatoms were the dominant algal forms present in the reservoir during the drought. Tubificid worms were the dominant groups of benthic organisms at most stations; their abundance was attributed to low oxygen levels.

INTRODUCTION

Background

Shasta Lake has been used principally for flood control, water supply, and hydroelectric power generation, since completion of Shasta Dam in 1945. Additional beneficial uses include streamflow regulation for navigation and water-quality enhancement, irrigation, improvement of fisheries and wildlife, and contact and noncontact forms of recreation.

Shasta Lake is one of a number of reservoirs in California selected for monitoring by the California Department of Water Resources in cooperation with the California State Water Resources Control Board. The reservoirs being monitored are part of a primary network of surface-water stations in California where water-quality data are routinely collected (California Department of Water Resources, 1976). Shasta is one of several reservoirs that are owned and (or) operated by the Federal Government.

A program for studying the water quality of federally owned or operated lakes in the primary network was designed by the U.S. Geological Survey. This report, prepared in cooperation with the California Department of Water Resources, presents water-quality data collected from March 1977 through September 1978 as well as selected historical data collected prior to 1977.

Purpose and Scope

The purpose of this study is to describe water-quality conditions in Shasta Lake and in major tributaries to the lake.

The study involved the collection and interpretation of historical, hydrologic, and water-quality data collected during intensive and routine monitoring efforts.

By chance, an intensive study was done during the second year of the most severe 2-year drought to occur in the Western United States in more than 100 years of record. Monitoring continued into the period when the drought ended and Shasta Lake filled to capacity once again. Historical data depict hydrologic and water-quality conditions in Shasta Lake prior to the intensive sampling effort. Data from the intensive study represent water-quality conditions during the worst year of the drought. Finally, data obtained in 1978 describe water quality after the drought and represent conditions closer to a normal water year.

DESCRIPTION OF THE STUDY AREA AND SHASTA LAKE

Shasta Lake, formed by Shasta Dam and located in Shasta County, Calif., is a multipurpose impoundment reservoir and a major component of the Central Valley Water Project. The dam is 8 km downstream of the preimpoundment confluence of the Sacramento and Pit Rivers (fig. 1).

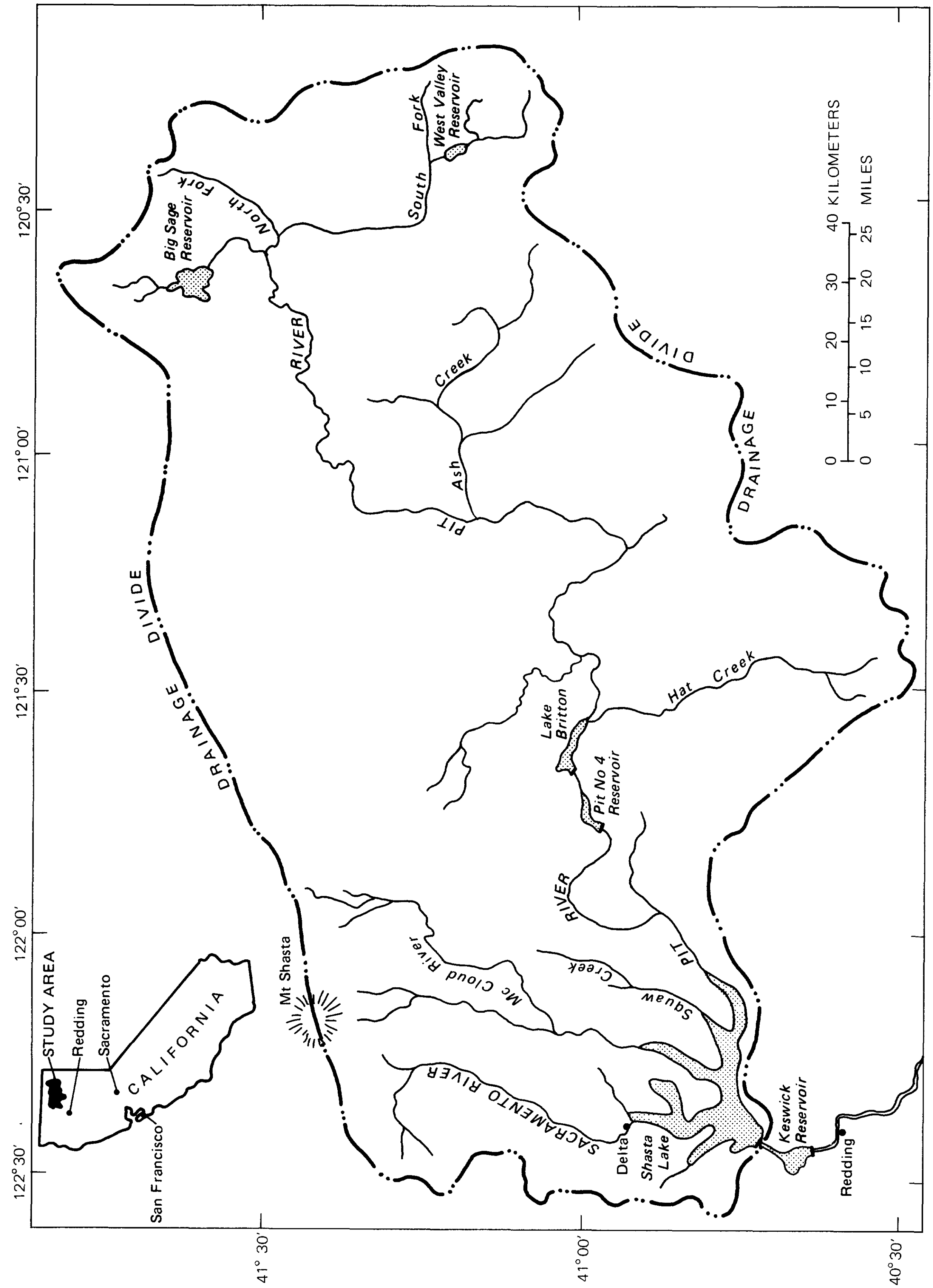

FIGURE 1. – Location of Shasta Lake and major tributaries draining to the lake.

Climate

The climate in the Shasta Lake drainage basin is of the dry-summer subtropical (Mediterranean) type. Precipitation is highly variable both temporally and spatially in the basin. Average annual precipitation at Shasta Dam is 1,530 mm. Maximum and minimum monthly precipitation occur during January (305 mm) and July (7 mm), respectively (fig. 2). Rainfall, which increases with elevation because of orographic effects, is the principal form of precipitation at Shasta Lake. Snow is the principal form of precipitation in the northern part of the basin where higher elevations are present.

The seasonal temperature regime at Shasta Lake is similar to that at Redding. The normal annual air temperature is 17.5°C. The normal monthly air temperatures in January and July are 7.8°C and 28.4°C, respectively (fig. 2).

The intense surface heating of Shasta Lake during the summer causes large evaporative water loss. Annual pan evaporation, measured using a standard 1.2-m-diameter pan at Shasta Dam, is about 186 cm (table 1) (0.75 times pan evaporation = lake evaporation). Thus lake evaporation is about 91 percent of the mean annual precipitation falling on the lake. Based on a surface area of 119 km^2, the annual average volume of water loss from Shasta Lake due to evaporation is about 165 hm^3 or 3 percent of the active lake storage volume (table 2). Actual evaporative loss will vary from these estimates depending on fluctuations in the lake's surface area. Maximum monthly evaporation occurs in July when about 24 cm of water are lost from the lake surface.

TABLE 1. - Mean monthly pan evaporation measured at Shasta Dam, 1941-70

[National Oceanic and Atmospheric Administration, 1976]

Month	Pan evaporation (cm)	Month	Pan evaporation (cm)
January	4.6	July	31.8
February	5.4	August	28.4
March	9.0	September	21.6
April	14.9	October	13.2
May	19.9	November	7.1
June	25.5	December	4.6
		Total	186

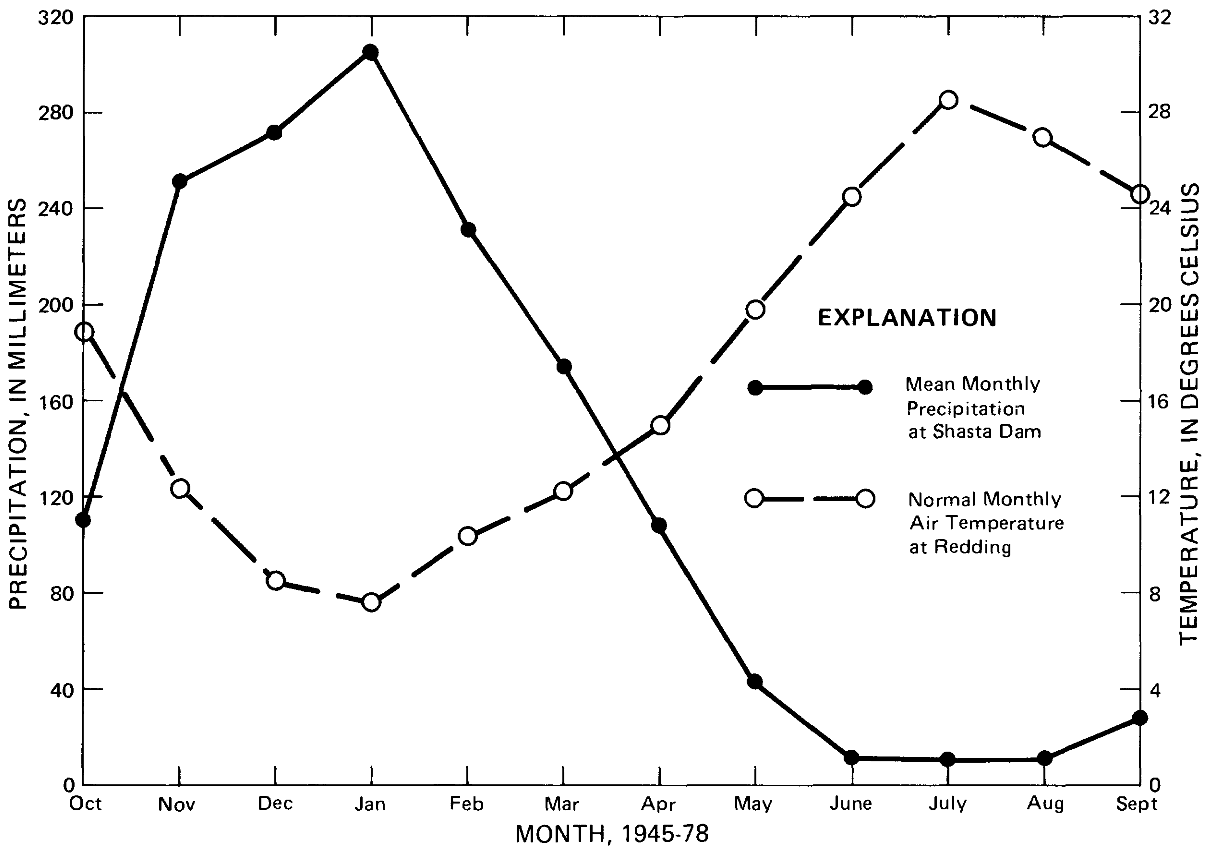

FIGURE 2. – Mean monthly precipitation and normal monthly air temperature near Shasta Lake.

Physical Characteristics and Lake Volume

The lake at full storage has a surface elevation of 325.22 m above sea level (NGVD of 1929), a surface area of 119 km^2, and a drainage area of 16,630 km^2 (excluding Goose Lake basin). The contributing drainage includes all the McCloud River, all the Pit River except the Goose Lake basin, and the headwaters of the Sacramento River above Delta, Calif. (fig. 1). Average annual surface inflow to Shasta Lake is about 6,780 hm^3. Total storage capacity of the lake to elevation 325.22 m NGVD of 1929 is about 5,610 hm^3, of which 140 hm^3 is inactive and 620 hm^3 is reserved for flood storage. The morphological characteristics of Shasta Lake are given in table 2.

TABLE 2. - Morphological characteristics of Shasta Lake

[Dimensions are referenced to elevation 325.22 meters NGVD of 1929]

Total storage capacity	5,610 hm^3
Active storage volume	5,470 hm^3
Surface area	119 km^2
Maximum length	56 km
Maximum depth	157 m
Length of shoreline	587 km
Mean depth	47 m
Mean breadth	2.1 km

Shasta Lake has a dendritic form (Hutchinson, 1957, p. 171) owing to the sinuous nature of the highly dissected contributing drainages. The high degree of shoreline exposure and the elongation of the lake suggest that nearshore processes may strongly affect water quality. The fetch provided by the long arms gives winds the opportunity to develop sizable waves which act on the extensive nearshore and resuspend bottom sediments. Therefore, considerable potential exists for sediment-water interactions in Shasta Lake.

Mean monthly storage volumes, and hence lake levels, are affected by the variability of surface runoff and of discharge operations at the dam. Variations in inflow volume and lake levels contribute to the seasonal and annual variations in water quality in Shasta Lake. Mean monthly storage volumes and the coefficient of variation for Shasta Lake are given in table 3. Mean monthly storage volume reaches a maximum in May of about 88 percent of total lake storage capacity and a minimum in November of about 62 percent of total storage capacity. The lake has reached or exceeded capacity only during the months of May and June. Based on the coefficients of variation shown in table 3 the greatest variability in mean monthly storage volume occurs during October and November, which is also the time when lake storage volumes are the lowest during the year. The least variability is in March. This pattern of variability in lake storage volume is characteristic of a reservoir designed for flood control.

TABLE 3. - Mean monthly water storage statistics for Shasta Lake, 1946-78

(Data from U.S. Geological Survey, 1948-51, 1964, 1970, 1976, 1972-75, 1976-79)

Month	Storage volume, in cubic hectometers			Coefficient of variation
	Mean	Minimum	Maximum	
October	3,445	807	4,428	26.3
November	3,422	779	4,428	25.7
December	3,499	1,027	4,243	22.3
January	3,690	1,906	4,465	18.1
February	3,886	1,845	4,539	15.5
March	4,224	1,820	5,031	14.8
April	4,728	1,685	5,424	15.9
May	4,907	1,402	5,572	17.7
June	4,826	1,292	5,535	18.6
July	4,439	989	5,338	20.6
August	3,676	754	4,957	22.7
September	3,658	717	4,576	23.7

Streamflow

The principal drainage basin contributing to Shasta Lake is the Pit River basin (table 4). This basin accounts for about 59 percent of the average annual surface runoff to Shasta Lake. The drainage area of the Pit basin is about 77 percent of the total Shasta Lake basin. The Pit River basin has a greater potential than any of the other areas for affecting lake-water quality because of the land and water uses in the basin.

For the entire Shasta Lake basin the mean annual runoff per unit area is 49 cm (table 4). Among the subbasins of the Shasta Lake drainage, the runoff per unit area is highly variable because of diversions and regulation of flow by dams. A good example is the Pit River drainage where a significant amount of water is diverted for consumptive use. The higher values of runoff per unit area for the Sacramento River and Squaw Creek correspond to drainages that receive a significant amount of precipitation in the form of snow at higher elevations (table 4). The value for the McCloud River drainage is lower than might be expected due to the transbasin diversion of runoff into the Pit River which commenced in 1968. A substantial amount of runoff is contributed by the numerous side drainages that flow directly into Shasta Lake (row labeled "other" in table 4).

Flow hydrographs, based on the historical record of discharge measurements (fig. 3), describe for the period of record the mean monthly discharge into Shasta Lake from the major tributaries shown in table 4. Seasonal runoff patterns are similar in all four tributary drainages. Generally, maximum discharge occurs during February, March, and April, and low flow occurs during August or September.

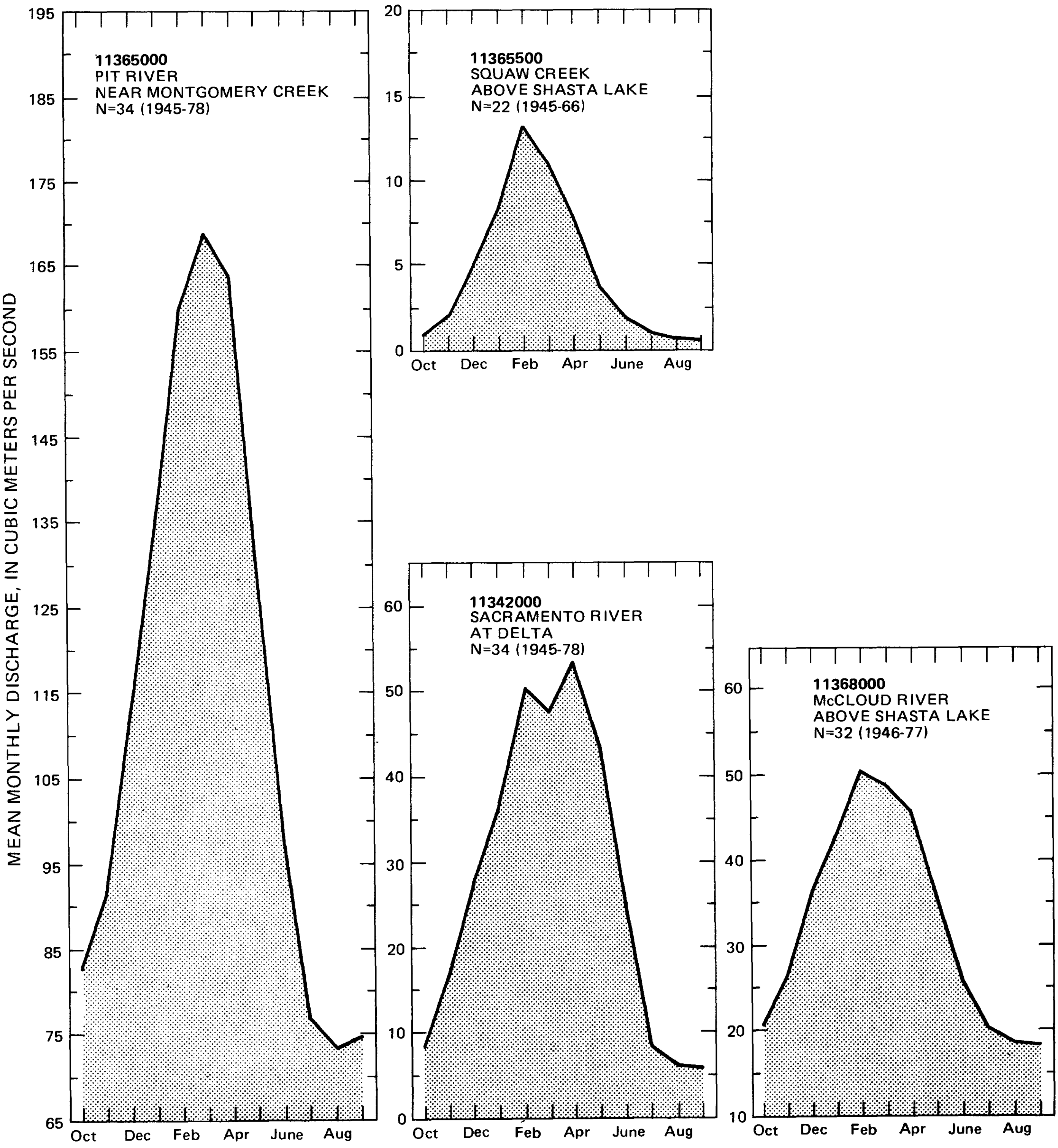

FIGURE 3. – Mean monthly discharge for the major tributaries to Shasta Lake.

TABLE 4. - Shasta Lake contributing drainage characteristics

Drainage basin	Contributing drainage area (km^2)	Total contributing area (percent)	Mean annual runoff (hm^3)	Mean annual runoff 1969-78 (hm^3)	Total runoff, 1969-78 (percent)	Mean annual runoff per unit area 1969-78 (cm)
Pit River (excluding Goose Lake basin) upstream from gaging station 11365000.	12,820	77.1	[1]3,840	4,800	59.5	37
McCloud River upstream from gaging station 11368000.	1,560	9.4	[1]1,230	750	9.3	48
Sacramento River upstream from gaging station 11342000.	1,100	6.6	[1]1,050	1,120	13.9	102
Squaw Creek upstream from gaging station 11365500.	170	1.0	[2]200	[3]240	3.0	141
Other	860	5.2	[4]340	[4]980	12.1	114
Lake surface	120	.7	[5]180	[5]180	2.2	153
Total for Shasta Lake basin (excluding Goose Lake basin).	16,630	100	6,840	8,070	100	49

[1]1947-79, U.S. Geological Survey (1948-51, 1964, 1970, 1976, 1972-75, 1976-79) surface-water records (water years 1946-78).

[2]1947-67, U.S. Geological Survey (1948-51, 1964, 1970, 1976) surface-water records (water years 1946-66).

[3]Estimated from Squaw Creek gage (11365500) and McCloud River gage (11367500); water years 1946-66.

[4]Estimated as the difference between total runoff and the summation of calculated tributary runoff volumes.

[5]Estimated using mean annual precipitation, 153 cm.

Drought of 1976 and 1977

Drought conditions prevailed throughout the study area during the intensive phase of this Shasta Lake water-quality study. The year 1977 was the second year of the worst drought that California experienced in more than 100 years of record (California Department of Water Resources, 1978). Precipitation recorded at Shasta Dam for the 6-month period preceding this study was only 27.4 cm or 18 percent of mean annual precipitation. Total annual precipitation recorded at Shasta Dam during the 1976 and 1977 water years was only about 50 percent of the mean annual (California Department of Water Resources, 1978). Persistence of the drought is shown by the two lowest consecutive 6-month mean storage volumes, which also occurred during the study period (fig. 4).

Shasta Lake surface elevations dropped during the drought (fig. 5). In terms of storage volume a historical minimum, 695 hm^3, was recorded in September 1977. This volume is 13 percent of the total lake capacity. Throughout the intensive study, lake storage averaged 22 percent of total lake capacity. During the 1978 water year Shasta Lake filled rapidly to above average levels as a result of greater than normal precipitation during November 1977 and January 1978.

The data in table 5 show that tributary inflow to Shasta Lake was well below normal (even less than the 25th percentile) for the period of record during the 1977 water year.

TABLE 5. - Tributary drought discharge statistics, October 1976-September 1977

Shasta Lake tributary	Discharge for period of record		Discharge for 1977 water year	
	Mean annual (m^3/s)	25th percentile (m^3/s)	Mean (m^3/s)	Percentage of mean annual
Sacramento River	[1]33.25	22.68	6.46	19.4
Pit River	[2]121.75	90.48	84.03	69.0
McCloud River	[1]39.05	26.93	6.51	16.7

[1]1947-79, U.S. Geological Survey surface-water records (water years 1946-78).
[2]1946-79, U.S. Geological Survey surface-water records (water years 1945-78).

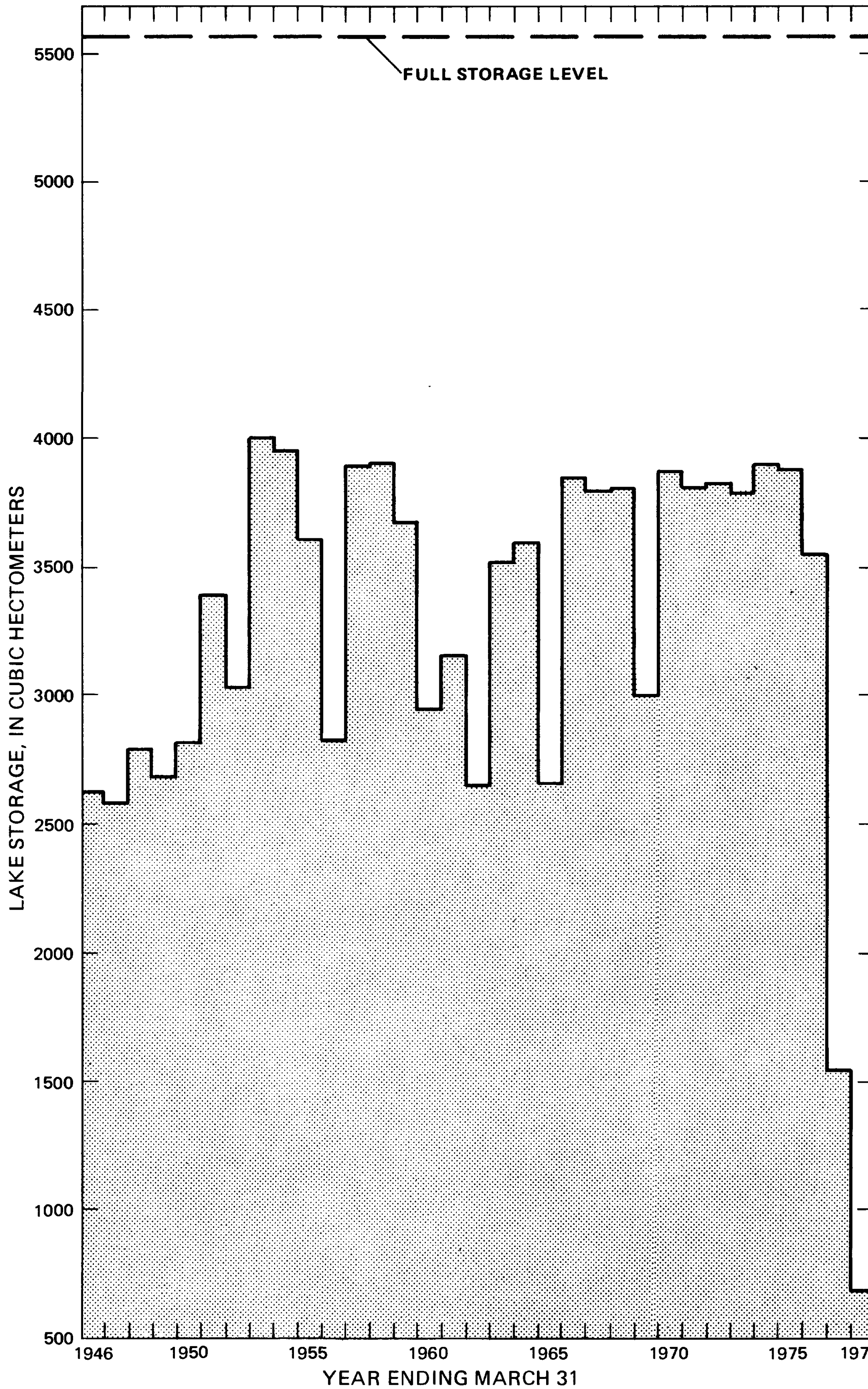

FIGURE 4. – Lowest 6-month consecutive mean lake storage for Shasta Lake, 1946-78.

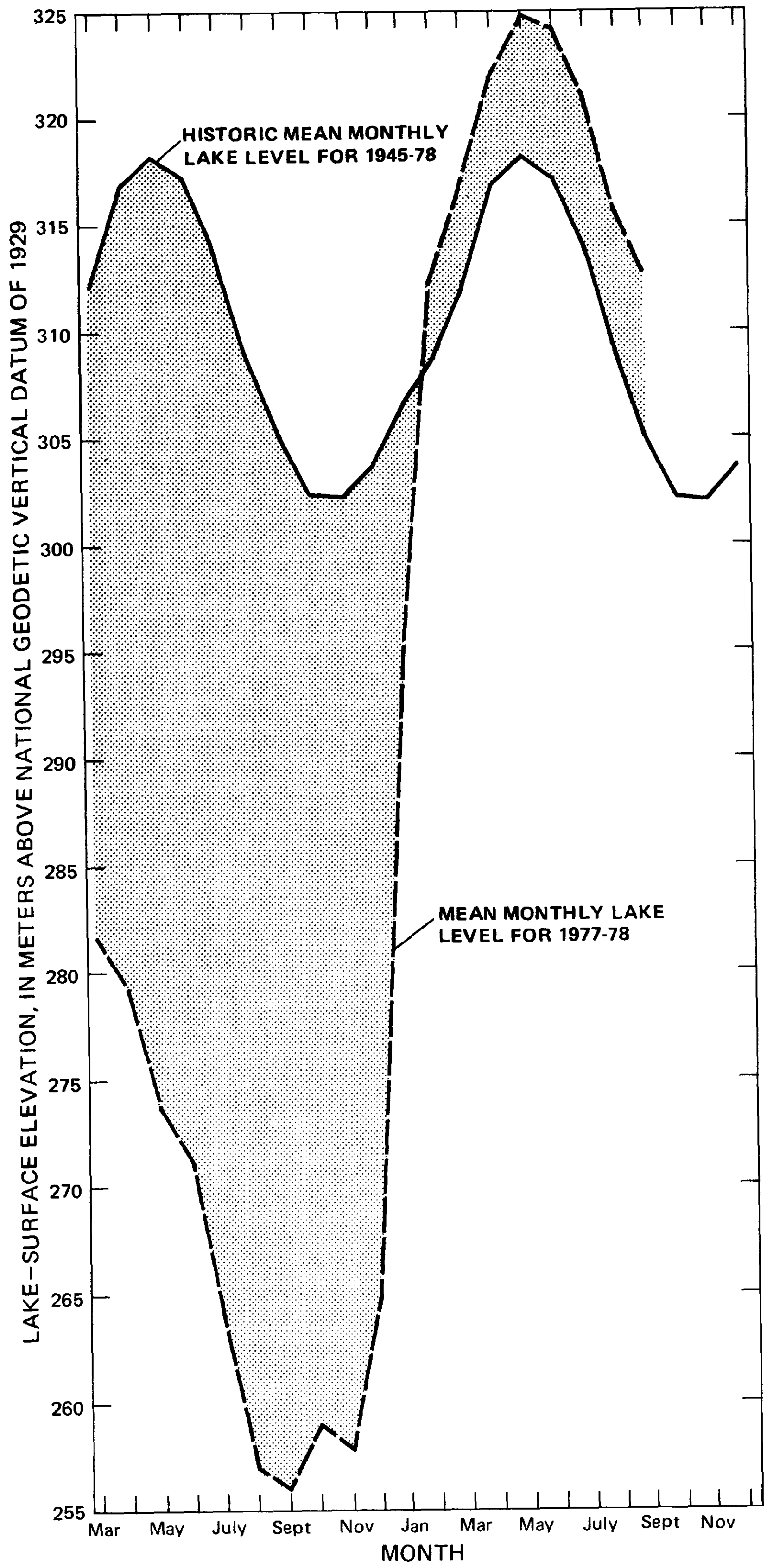

FIGURE 5. – Shasta Lake surface elevations, period of record compared to 1977-78 records.

DATA-COLLECTION METHODS

Historical water-quality data were assembled from published and unpublished sources. Field data and water samples for laboratory analysis were collected at six Shasta Lake stations and four tributary stations (fig. 6) according to a predetermined sampling schedule (table 6). At lake stations, measurements for temperature, pH, dissolved oxygen, and specific conductance were made with Martek water-quality instruments calibrated in the field. Light penetration was recorded using a Secchi disk. Lake samples were collected at depth with a Van Dorn sampler and composited to represent the entire water column when no stratified layers were present. Samples were obtained separately from the epilimnion, metalimnion, and hypolimnion when the lake was stratified.

At tributary stations, temperature was measured using a calibrated handheld thermometer. Specific conductance and pH were measured using portable meters. Field measurements at each station were made in the centroid of flow or nearshore where the stream was considered completely mixed. Stream discharge measurements were obtained from continuous stage records. Water samples were collected using a Van Dorn sampler at the centroid of flow or where the stream was considered completely mixed.

All samples for chemical analysis were filtered and processed in the field. Alkalinity was determined within 2 hours after collection by titration to pH of 4.5. Dissolved-oxygen concentration was measured using the azide modification of the Winkler method. Analyses of the major chemical constituents in Shasta Lake and tributaries were performed on samples collected in 1977 by Bryte Laboratory of the California Department of Water Resources. Samples collected in 1978 were analyzed by the U.S. Geological Survey Central Laboratory in Arvada, Colo. Nutrient samples were analyzed at the U.S. Geological Survey Central Laboratory.

Phytoplankton samples at lake stations were collected in the euphotic zone with a Van Dorn sampler. Procedures used for the collection, preservation, and analysis of phytoplankton samples followed those described by Slack and others (1973).

Primary productivity (light and dark bottle method) was determined using the techniques described by Slack and others (1973).

Benthic-invertebrate samples were collected using a Ponar grab with a jaw opening of 700 cm^2. Procedures for the preservation and analysis of benthic invertebrates followed those described by Slack and others (1973).

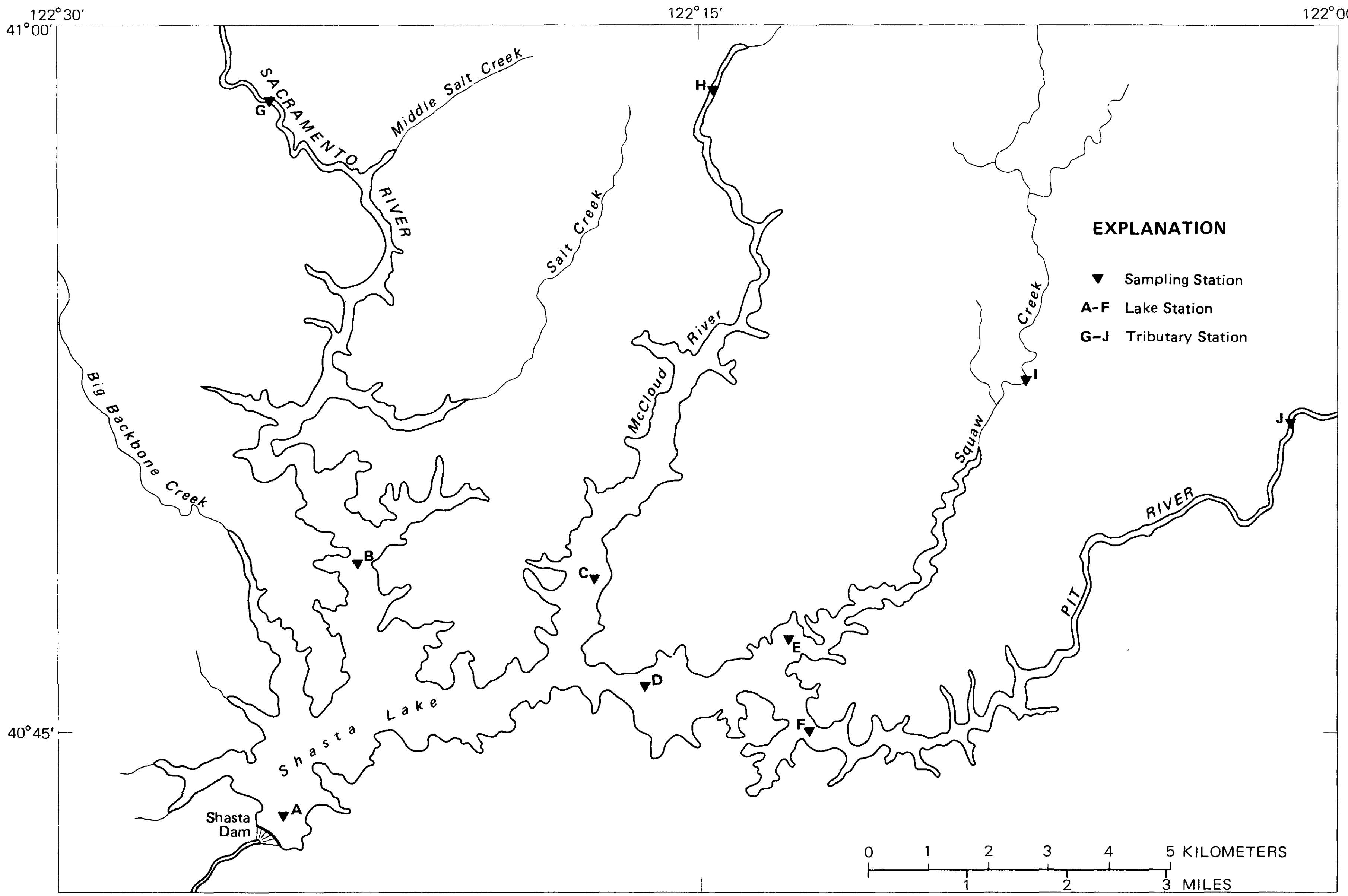

FIGURE 6. – Sampling stations for Shasta Lake and tributaries.

TABLE 6. - Location and sampling frequency of sampling stations

Map symbol (fig. 6)	Station name	Location	
		Latitude	Longitude
A	Shasta Lake near Shasta Dam, near Project City	40°43'33"	122°24'36"
B	Sacramento River arm of Shasta Lake near Lakehead.	40°48'08"	122°17'30"
C	McCloud River arm of Shasta Lake near Lakehead	40°48'30"	122°17'30"
D	Pit River arm of Shasta Lake at Allie Cover, near Lakehead.	40°45'50"	122°16'50"
E	Squaw Creek arm of Shasta Lake near Project City	40°46'35"	122°11'58"
F	Pit River arm of Shasta Lake below Brushy Canyon, near Project City.	40°44'59"	122°12'15"
G	Sacramento River at Delta	40°56'23"	122°24'58"
H	McCloud River above McCloud River Bridge, near Lakehead.	40°56'30"	122°14'38"
I	Squaw Creek above Shasta Lake	40°51'25"	122°07'08"
J	Pit River near Montgomery Creek	40°50'36"	122°00'58"

Water-quality measurement	Stations sampled for indicated month				
	Mar. 1977	June 1977	Sept.-Oct. 77	June 1978	Sept. 1978
Physical	ABCDEFGHIJ	ABCDEFGHIJ	ABCDEFGHIJ	ABCDEFGHI	ABCDEFGHIJ
Major chemical	ABCDEFGHIJ	ABCDEFGHIJ	--	ABCDEFGHI	ABCDEFGHIJ
Nutrients	ABCDEFGHIJ	ABCDEFGHIJ	ABCDEFGHIJ	ABCDEFGHI	ABCDEFGHIJ
Primary productivity.	A	A	--	--	--
Phytoplankton	ABCDEF	ABCDEF	ABCDEF	ABCDEFGHI	ABCDEFGHIJ
Benthic invertebrates.	--	A	ABCDEF	--	--

Tributary dissolved-oxygen concentrations do not appear to fit any seasonal patterns (table 7). Water was at or near saturation for most of the year at all stations; however, supersaturation occurred during summer low flows in the Pit and Sacramento Rivers.

Annual minimum water temperatures at all stations occurred during the winter months (table 7). The lowest temperature recorded was 4°C, measured in January 1977 at the Sacramento River at Delta. Maximum stream temperatures occurred in the summer during low flow and rarely exceeded 20°C. Stream and surface lake temperatures were most similar during the autumn months, but at no time did tributary stream temperatures exceed the temperature of the lake surface. Therefore, tributary inflow was consistently of greater density. Density differences between inflowing water and epilimnetic lake water in the tributary arms result in mixing at depth. Density currents appear to be strongest during the spring and early summer when discharge is high and the temperature difference is greatest.

The data in table 8 show the tributary nutrient concentrations. The Sacramento River usually had the lowest concentration of total nitrogen. Total phosphorous concentrations were higher in the Sacramento and Pit Rivers than in the McCloud River and Squaw Creek.

Nutrient data for Shasta Lake tributaries were also collected in 1974-75 by the U.S. Environmental Protection Agency for the National Eutrophication Survey. The results of this survey are presented in figure 7. Considerable variability in tributary nutrient concentrations is evident. The concentration of total ammonia and organic nitrogen ranged from a high of 5.0 mg/L to a low of 0.01 mg/L. Total phosphorous concentrations ranged from 0.07 mg/L to 0.01 mg/L. As expected, the variability of nutrient concentrations in the Pit River was less than in other tributaries. This can be explained by the degree of hydrologic control within the system. Data recorded at a station on the Sacramento River immediately downstream from Shasta Dam are included in figure 7. Nutrient concentrations in the outflow water of Shasta Dam also vary seasonally, especially the total phosphorus.

The pH at all tributary stations fluctuated between 7.3 and 8.3 (table 7). Higher pH values seem to be related to lower flows during the summer months. Elevated pH values during low flow may be the result of photosynthetic activity or the contribution of ground water of higher pH. Lower pH values were recorded during the winter-spring runoff period. At no time did the pH fall below 7.0.

TABLE 7. - Physical and chemical field measurements of tributaries to Shasta Lake

Date	Discharge (m^3/s)	Temperature (°C)	Dissolved oxygen concentration (mg/L)	Dissolved oxygen (percent saturation)	Specific conductance (µS/cm at 25°C)	pH
		McCloud River above McCloud River Bridge				
Feb. 28, 1977	6.77	8.0	11.2	98	107	7.7
June 20, 1977	6.00	19.0	--	--	--	--
		Sacramento River at Delta				
Jan. 7, 1976	8.61	5.0	12.5	100	137	8.0
Mar. 11, 1976	19.60	7.5	11.6	100	118	7.4
May 11, 1976	39.93	10.0	10.6	98	90	7.6
July 7, 1976	6.12	18.5	9.5	104	146	8.2
Sept. 2, 1976	5.10	23.0	10.0	120	159	8.2
Nov. 9, 1976	5.78	11.0	12.6	117	159	8.2
Jan. 6, 1977	5.83	4.0	14.0	109	162	8.0
Mar. 1, 1977	6.74	7.0	12.3	104	155	7.9
May 11, 1977	13.14	12.0	11.0	104	133	8.0
June 20, 1977	6.37	21.5	--	--	144	--
July 6, 1977	4.56	20.0	10.8	124	168	8.3
Sept. 13, 1977	3.37	17.0	9.8	104	180	8.0
Nov. 15, 1977	6.66	--	--	--	176	8.2
Jan. 4, 1978	155.2	8.0	10.9	96	80	7.4
Mar. 15, 1978	62.30	7.0	11.9	101	81	7.4
Apr. 1, 1978	73.07	11.0	11.1	104	82	7.6
May 3, 1978	67.12	13.0	10.4	101	91	7.4
July 5, 1978	18.75	16.5	9.8	103	95	7.5
Sept. 5, 1978	7.73	17.5	9.7	99	147	7.7
		Squaw Creek above Shasta Lake				
Feb. 28, 1977	0.623	7.0	12.2	104	216	8.0
June 20, 1977	.207	22.5	--	--	230	--
Sept. 26, 1977	.368	14.0	--	--	261	7.9
June 13, 1978	2.01	15.0	--	--	109	8.2
Sept. 11, 1978	.892	13.5	--	--	204	7.6
		Pit River near Montgomery Creek				
Jan. 1, 1976	102.8	7.0	11.5	98	147	8.0
Mar. 14, 1976	224.9	8.0	11.1	96	136	7.4
May 12, 1976	121.5	16.0	10.0	104	144	8.0
July 7, 1976	77.88	19.0	10.1	111	142	8.1
Sept. 2, 1976	145.8	17.0	10.1	107	137	7.8
Nov. 9, 1976	28.89	10.0	11.9	109	--	7.7
Feb. 28, 1977	99.40	9.0	11.4	100	133	7.5
Mar. 2, 1977	154.6	8.5	13.2	116	147	8.1
May 11, 1977	76.75	13.0	10.3	99	151	8.2
June 20, 1977	56.36	17.5	--	--	127	--
July 6, 1977	154.1	19.0	10.0	110	148	8.2
Sept. 14, 1977	102.2	17.0	9.6	102	142	8.0
Oct. 15, 1977	32.28	10.0	11.2	102	164	7.9
Jan. 4, 1978	222.6	7.0	11.0	94	143	8.0
Mar. 14, 1978	200.8	8.0	11.6	101	125	7.3
Apr. 12, 1978	238.5	11.5	10.8	102	127	7.6
May 3, 1978	228.3	13.0	10.0	99	136	7.6
July 6, 1978	113.0	19.0	10.1	111	133	8.0
Sept. 11, 1978	108.7	17.0	8.9	94	143	7.9

TABLE 8. - Nutrient concentrations in tributaries to Shasta Lake

11342000 SACRAMENTO RIVER AT DELTA

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN, AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
MAR												
01...	1005	.01	.01	.10	.00	.10	.11	.49	.00	.00	.06	22
MAY												
11...	1300	--	--	.10	.00	.10	--	--	.01	.03	.03	--
JUN												
20...	1455	.01	.02	.04	.05	.00	.06	.27	.02	.06	.03	29
JUL												
06...	1145	--	--	.13	.03	.10	--	--	.01	.03	.04	--
SEP												
13...	0845	--	--	--	--	--	--	--	.02	.06	--	--
26...	1530	.00	.24	.00	.00	.00	.24	1.1	.01	.03	.02	28

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN, AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
NOV												
15...	1145	--	--	.10	.00	.10	--	--	.01	.03	.02	--
MAR												
15...	0835	--	--	.00	.00	.00	--	--	.02	.06	.02	--
APR												
11...	0945	--	--	.22	.02	.20	--	--	.00	.00	.01	--
MAY												
03...	1300	--	--	.10	.00	.10	--	--	.02	.06	.02	--
JUN												
13...	1430	.06	.06	.13	.01	.12	.19	.80	.00	.00	.00	16
JUL												
05...	0825	--	--	.42	.02	.40	--	--	.01	.03	.01	--
SEP												
05...	0915	--	--	.40	.00	.40	--	--	.02	.06	.02	--
11...	1420	.04	.04	.21	.00	.21	.25	1.1	.03	.09	.03	27

TABLE 8. - Nutrient concentrations in tributaries to Shasta Lake--Continued

11365000 PIT RIVER NEAR MONTGOMERY CREEK

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
FEB												
28...	1345	.08	.13	.15	.01	.14	.28	1.2	.05	.15	.06	32
MAR												
02...	1000	--	--	.10	.00	.10	--	--	.03	.09	.06	--
MAY												
11...	0945	--	--	.10	.00	.10	--	--	.04	.12	.06	--
JUN												
20...	0900	.01	.02	.11	.06	.05	.13	.58	.03	.09	.06	33
JUL												
06...	0815	--	--	.24	.04	.20	--	--	.01	.03	.07	--
SEP												
14...	0915	--	--	.71	.01	.70	--	--	.04	.12	.05	--
26...	0930	.34	.16	.04	.01	.03	.78	3.4	.01	.03	.04	32

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
NOV												
15...	0855	--	--	.12	.02	.10	--	--	.02	.06	.04	--
JAN												
04...	1000	--	--	.13	.03	.10	--	--	.04	.12	.06	--
MAR												
14...	0750	--	--	.21	.01	.20	--	--	.03	.09	.07	--
APR												
12...	1030	--	--	.25	.05	.20	--	--	.04	.12	.05	--
MAY												
03...	0945	--	--	.54	.04	.50	--	--	.03	.09	.05	--
JUL												
06...	1015	--	--	.84	.04	.80	--	--	.01	.03	.05	--
SEP												
06...	0930	--	--	.30	.00	.30	--	--	.03	.09	.05	--
11...	0920	.01	.02	.26	.01	.25	.28	1.2	.03	.09	.04	17

TABLE 8. - Nutrient concentrations in tributaries to Shasta Lake--Continued

11368000 MCCLOUD RIVER ABOVE MCCLOUD RIVER BRIDGE NEAR LAKEHEAD

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
FEB 28...	1800	.05	.05	.20	.00	.20	.26	1.2	.05	.15	.02	29
JUN 20...	1400	.01	.01	.02	.05	.00	.03	.13	.02	.06	.02	30
SEP 26...	1400	.00	.55	.00	.01	.00	.55	2.4	.01	.03	.02	30

11365500 SQUAW CREEK ABOVE SHASTA LAKE

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
FEB 28...	1630	.01	.01	.54	.00	.54	.55	2.4	.02	.06	.01	11
JUN 20...	1240	.02	.03	.06	.05	.01	.09	.40	.01	.03	.02	15
SEP 26...	1145	3.4	.34	.08	.00	.08	.42	1.9	.01	.03	.01	11

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N)	NITRO-GEN,AM-MONIA + ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS N)	NITRO-GEN, TOTAL (MG/L AS NO3)	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P)	PHOS-PHATE, ORTHO, DIS-SOLVED (MG/L AS PO4)	PHOS-PHORUS, TOTAL (MG/L AS P)	SILICA, DIS-SOLVED (MG/L AS SIO2)
JUN 13...	1010	.01	.04	.26	.01	.25	.30	1.3	.00	.00	.00	15
SEP 11...	1105	.01	.01	.21	.00	.21	.22	.97	.02	.06	.02	12

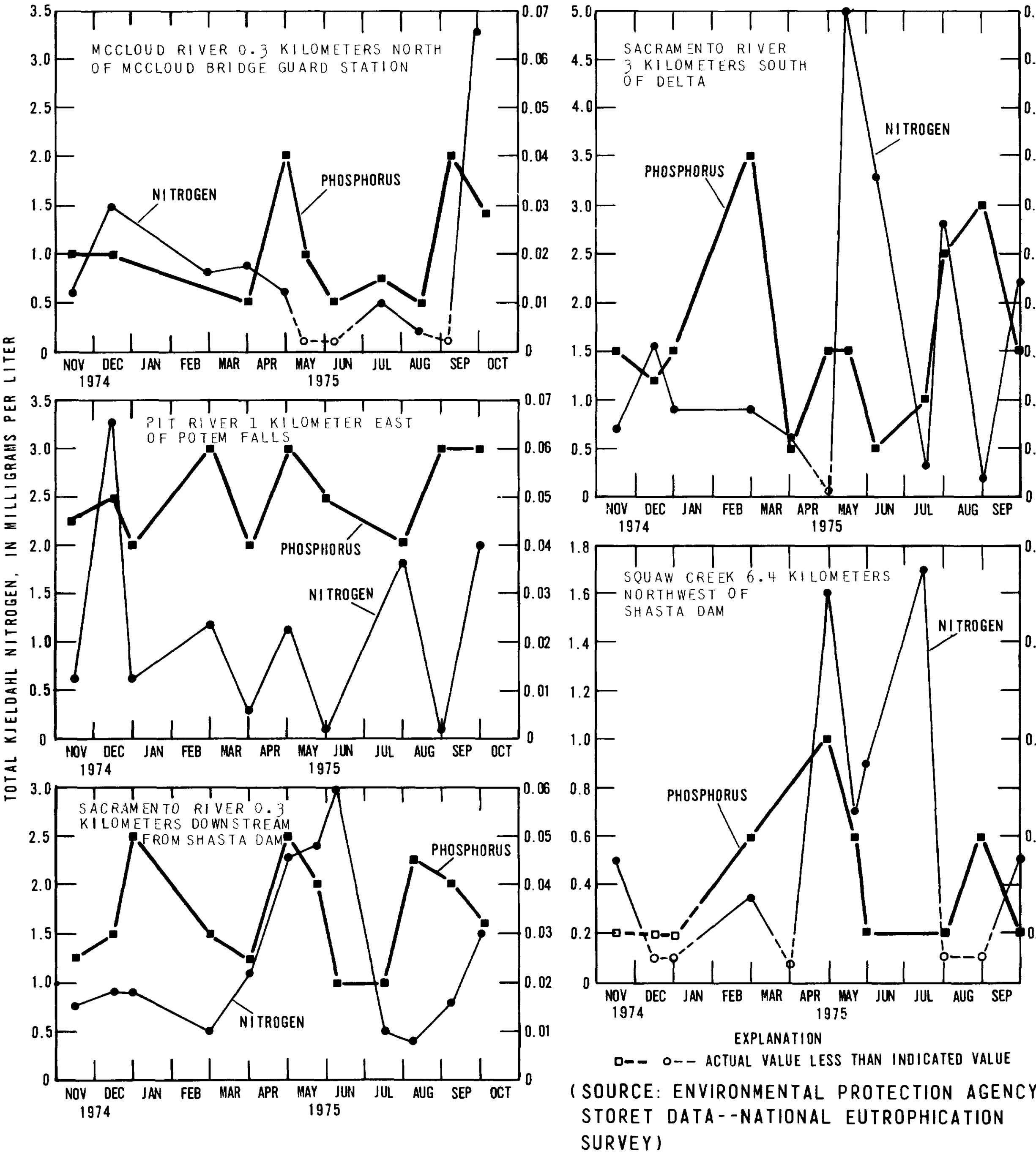

FIGURE 7. – Nutrient concentrations in tributaries and downstream from Shasta Dam.

Thermal Properties

Normal Year

Shasta Lake, a warm monomictic lake, as defined by Hutchinson (1957, p. 535), undergoes seasonal temperature variations and is thermally stratified during the summer and early autumn. Warm monomictic lakes, by definition, never attain a temperature of 4°C or less at any depth and circulate freely in winter at a temperature above 4°C. Lake stability, or resistance to mixing, usually reaches a maximum just prior to the period of maximum stratification, the time when the thermocline is displaced a maximum distance from the surface and before surface cooling begins. The period of maximum stability corresponds to the time at which the lake attains its maximum heat content; for Shasta Lake this occurs in July or August.

Temperature stratification in Shasta Lake is affected by the hydrologic influences of tributary inflows and outflow through the dam. The primary difference between Shasta Lake and a natural lake is in the extent of the metalimnion. Continuous release of water through the dam in the hypolimnetic region creates a flow-through condition, which, in conjunction with tributary inflows, provides turbulence at depth and promotes metalimnetic mixing.

Figure 8 shows monthend temperature profiles for Shasta Lake in 1962. This year was chosen because throughout the year monthly lake storage was very close to historical mean monthly storage.

Nearly isothermal conditions prevailed in winter (January-March) when the lake was uniformly mixed. Warming of surface layers commenced in March and continued through August with the development of an extensive metalimnion. This phenomenon is characteristic of lakes which are expansions of large rivers. Two factors are responsible for the extensive development of the metalimnion: the orientation of the lake with respect to prevailing winds and the flow of water through the lake at depth.

Tributary additions of cool water generate turbulence in the lake, especially in the region of the lower expanse of the metalimnion. Turbulence at depth produced by density currents acts to keep the metalimnion mixed at its deepest point and provide the energy needed to transfer heat energy from overlying layers thus deepening the metalimnion. Wind energy also aids in deepening the metalimnion during the early spring. Prevailing winds during the spring are oriented along the axis of maximum fetch, from the west and southwest.

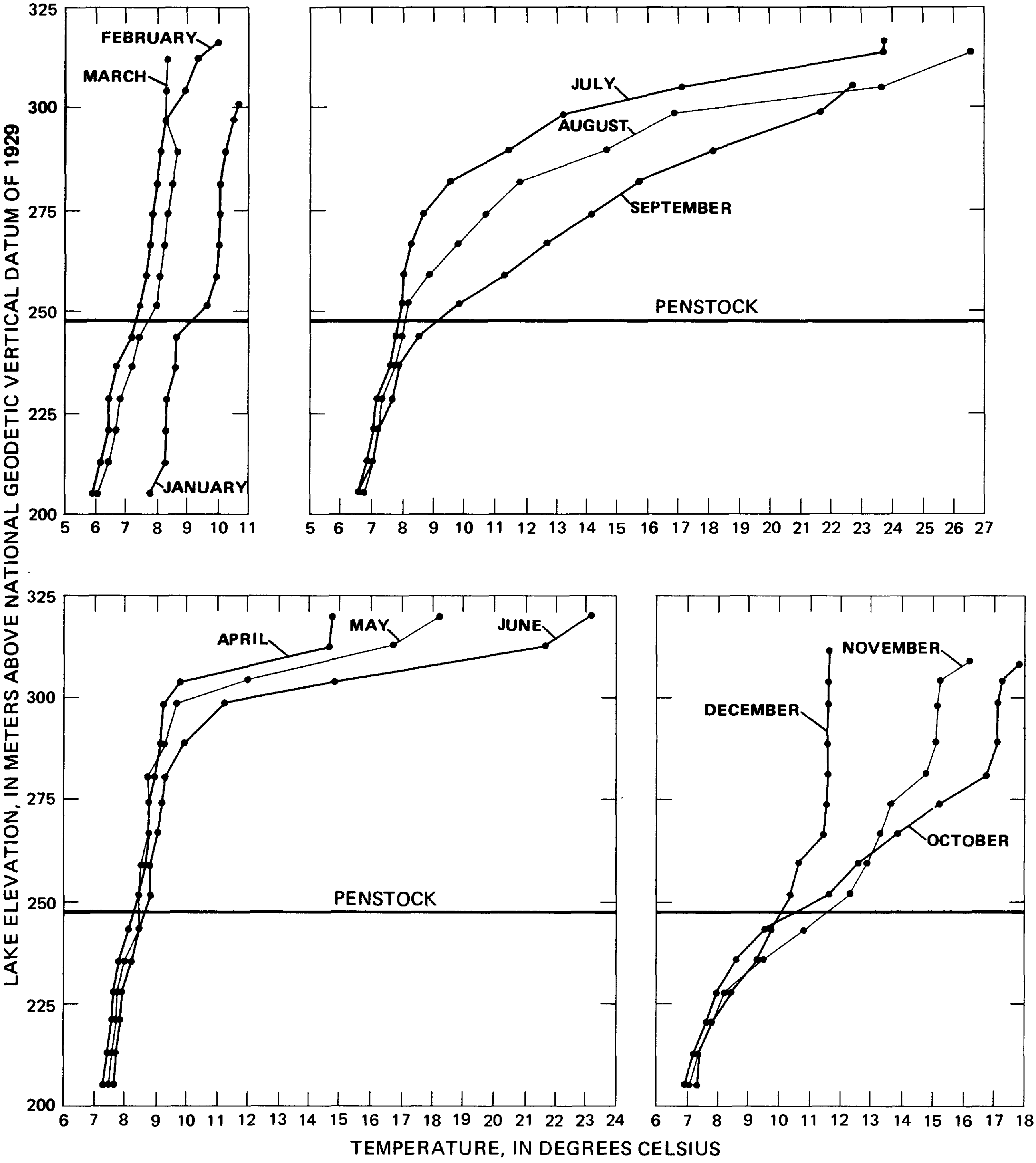

FIGURE 8. – Water temperature at Shasta Dam, 1962. (Data from files of the U.S. Bureau of Reclamation, Sacramento, California)

Progressive deepening of the metalimnion during the summer and autumn can be explained by the release of water through Shasta Dam. During a normal year, water is released at an elevation of 248 m above or about 80 m below the mean lake surface. (The release of water through the dam at elevation of 248 m is fixed and is governed by the intake requirements of the penstocks.) Removal of the cooler underlying water results in the progressive downward displacement of the metalimnion. Temperature profiles (fig. 8) show a very slight warming of bottom waters throughout the summer and into the autumn. By late autumn, the metalimnion extended to the bottom of the lake, thereby entirely eliminating the hypolimnion.

Temperature profiles in the autumn (October and November) of 1962 show the lake beginning to cool from the surface. Surface cooling usually continues through the early winter months and results in a gradual lowering of the uppermost limit of the metalimnion and an increase in the extent of the epilimnion. In February the lake reached a nearly isothermic condition. The temperature at the bottom of the lake continues to decrease after the nearly isothermic condition of midwinter is reached. This decrease is caused by the tributary inflow of cooler water at depth.

Temperature profiles during 1978 at Shasta Dam and tributary arms (figs. 9-14) show a pattern similar to the 1962 thermal condition. Surface-water temperatures recorded in June and September generally exceeded 21°C. Surface temperatures were somewhat higher at stations in the upstream expanses of the tributary arms. In 1978 the maximum summertime temperature measured was 24.5°C, recorded in the Pit River arm of the lake. Profiles at most stations showed in a normal year an extensive development of the metalimnion and reduction or elimination of the hypolimnion by late summer.

Drought of 1976 and 1977

The response of Shasta Lake to thermal loading during the drought was significantly different from conditions observed during the normal hydrologic periods of 1962 and 1978. Elevated summer surface temperatures, less downward displacement of the metalimnion, appearance of well-defined hypolimnion, and earlier commencement of turnover at some stations were the most notable differences (figs. 15-20).

Surface lake temperatures in June 1977 were mostly substantially higher than June 1978 measurements. Temperature profiles recorded in June 1977 at the Shasta Dam station (fig. 15a) showed the presence of a distinct isothermic hypolimnion zone. This can be explained by the lack of hypolimnetic withdrawal and less in-lake mixing caused by less tributary inflow. Release through the dam during the drought occurred principally within the region of the epilimnion because of reduced lake elevation. Temperature profiles of Squaw Creek arm and Pit River arm below Brushy Canyon, the two shallowest tributary stations, showed early breakup of stratification and nearly isothermal conditions by October (figs. 19b and 20b).

A comparison of 1977 and 1978 temperatures in the hypolimnion in June showed that during the drought average hypolimnion temperatures were 1.0-1.5°C higher (fig. 21) at all stations except for the upstream station F.

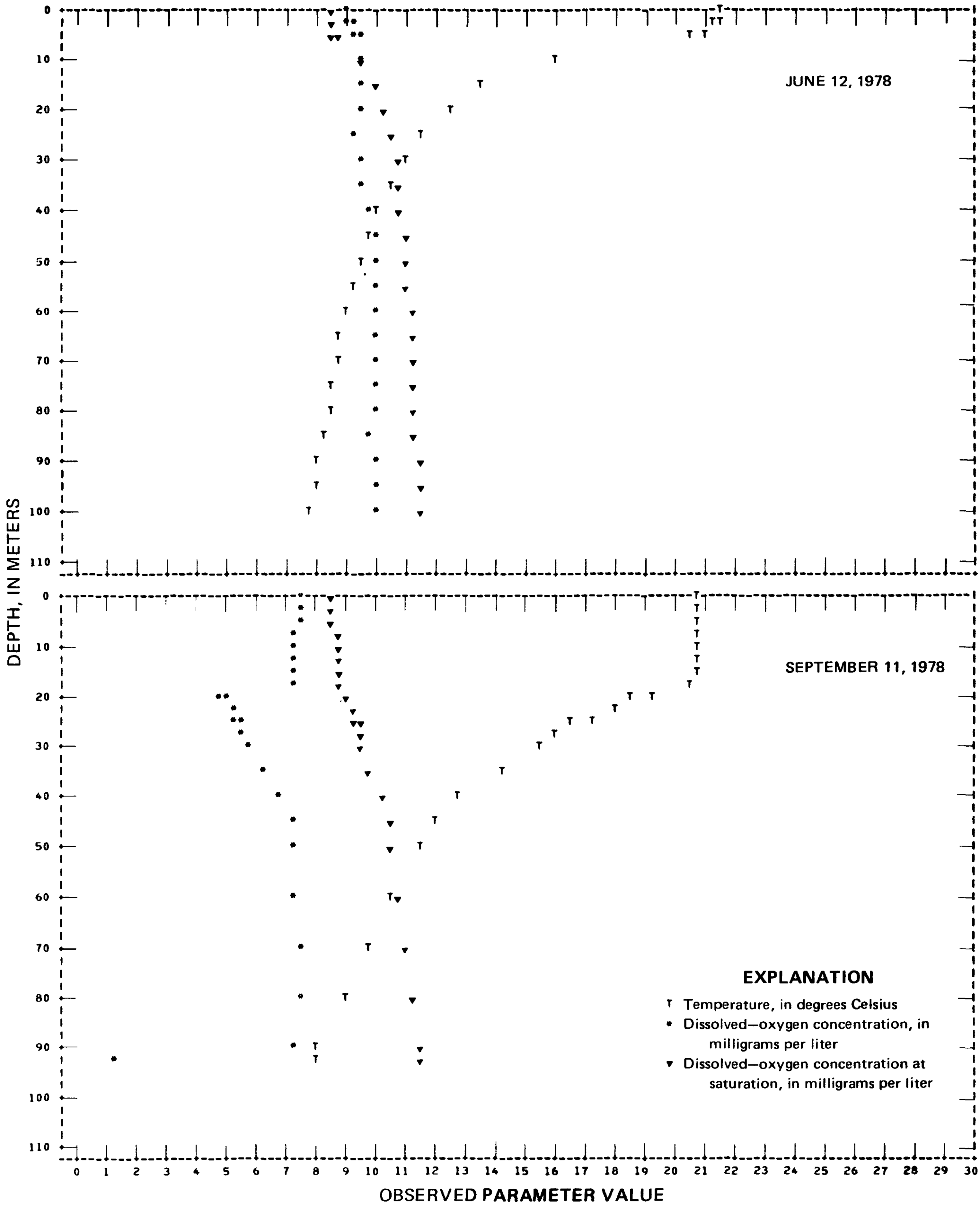

FIGURE 9. – Vertical dissolved-oxygen and temperature profiles for Shasta Lake near Shasta Dam (Station A), 1978.

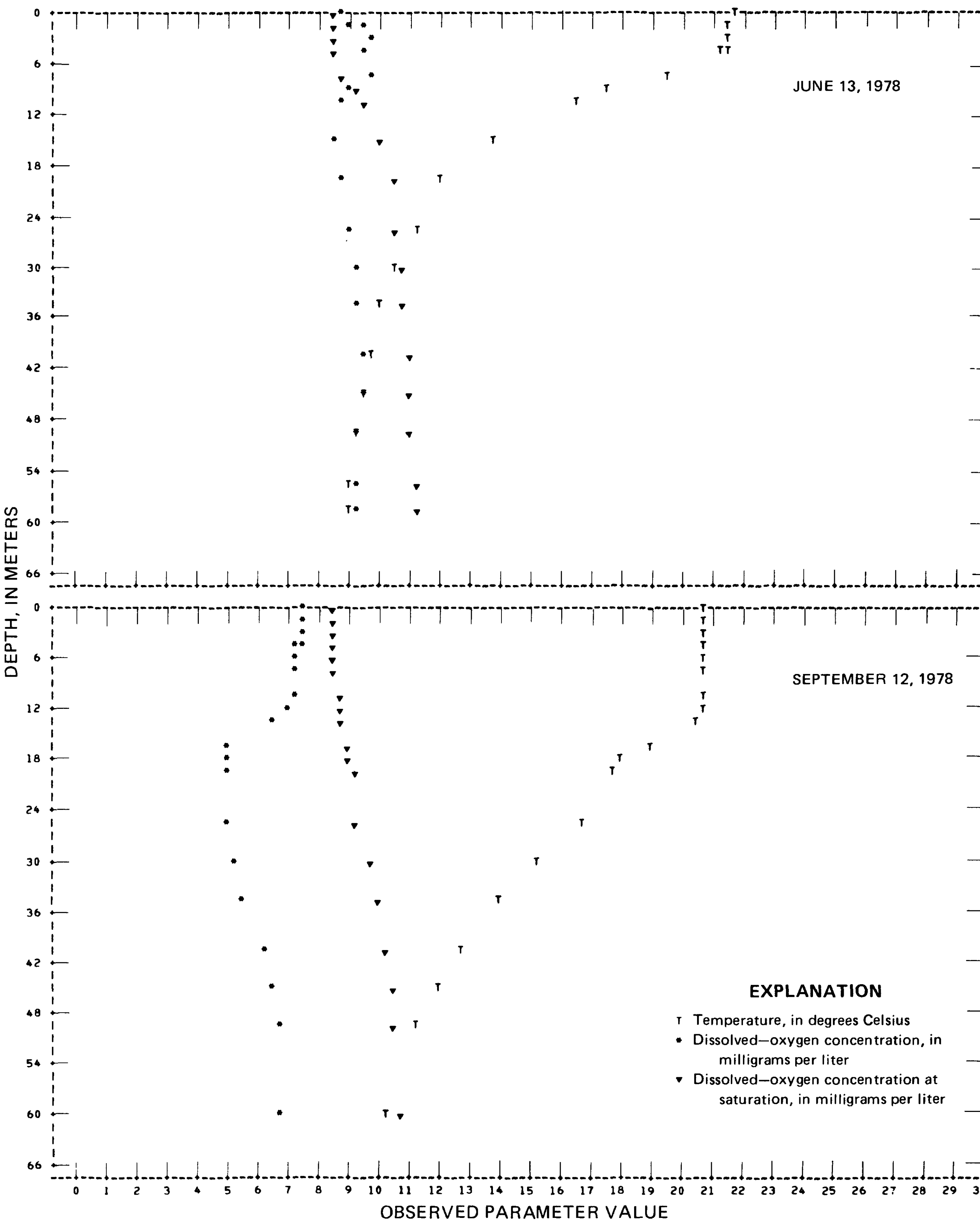

FIGURE 10. – Vertical dissolved-oxygen and temperature profiles for Sacramento River arm of Shasta Lake (Station B), 1978.

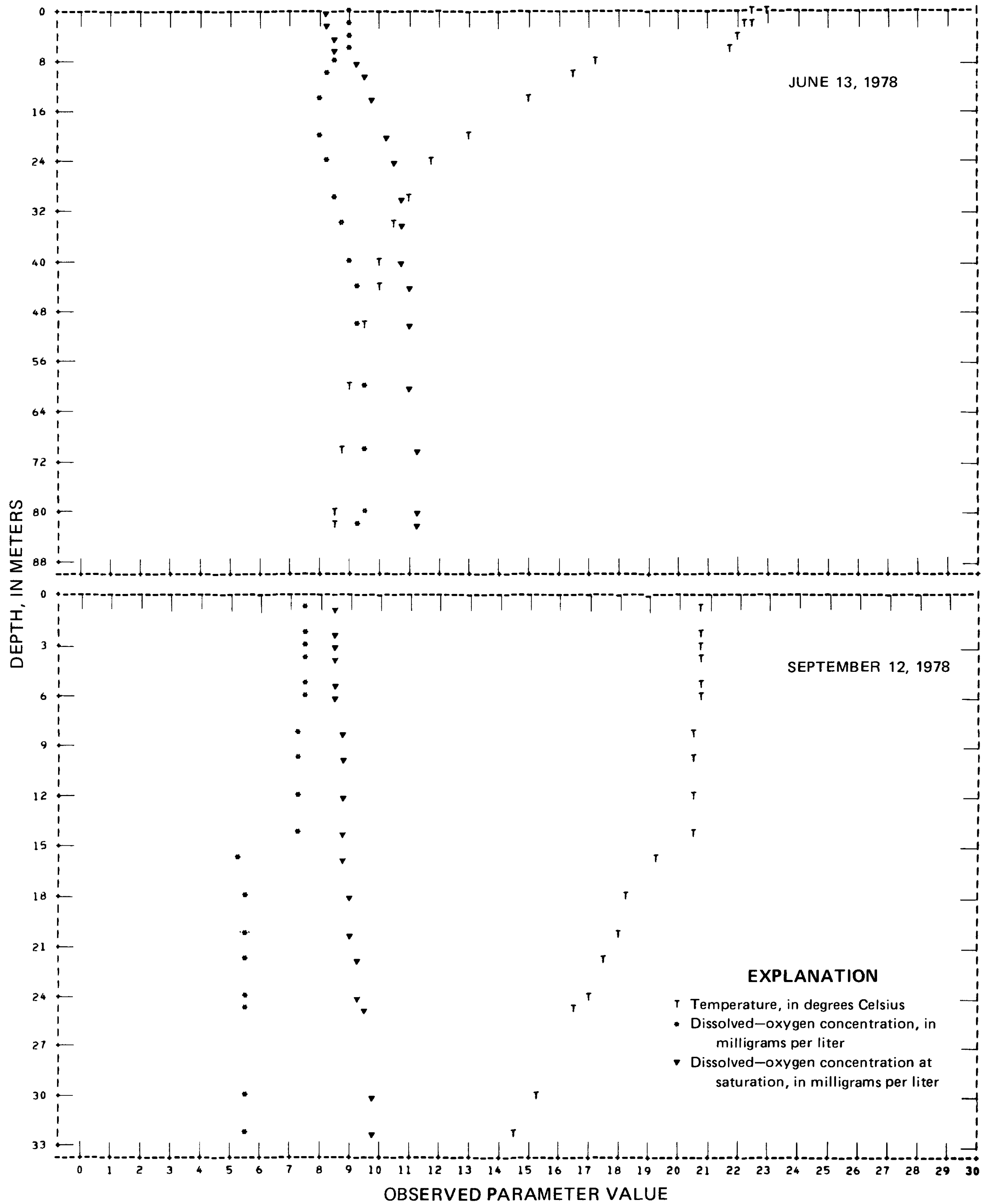

FIGURE 11. – Vertical dissolved-oxygen and temperature profiles for McCloud River arm of Shasta Lake (Station C), 1978.

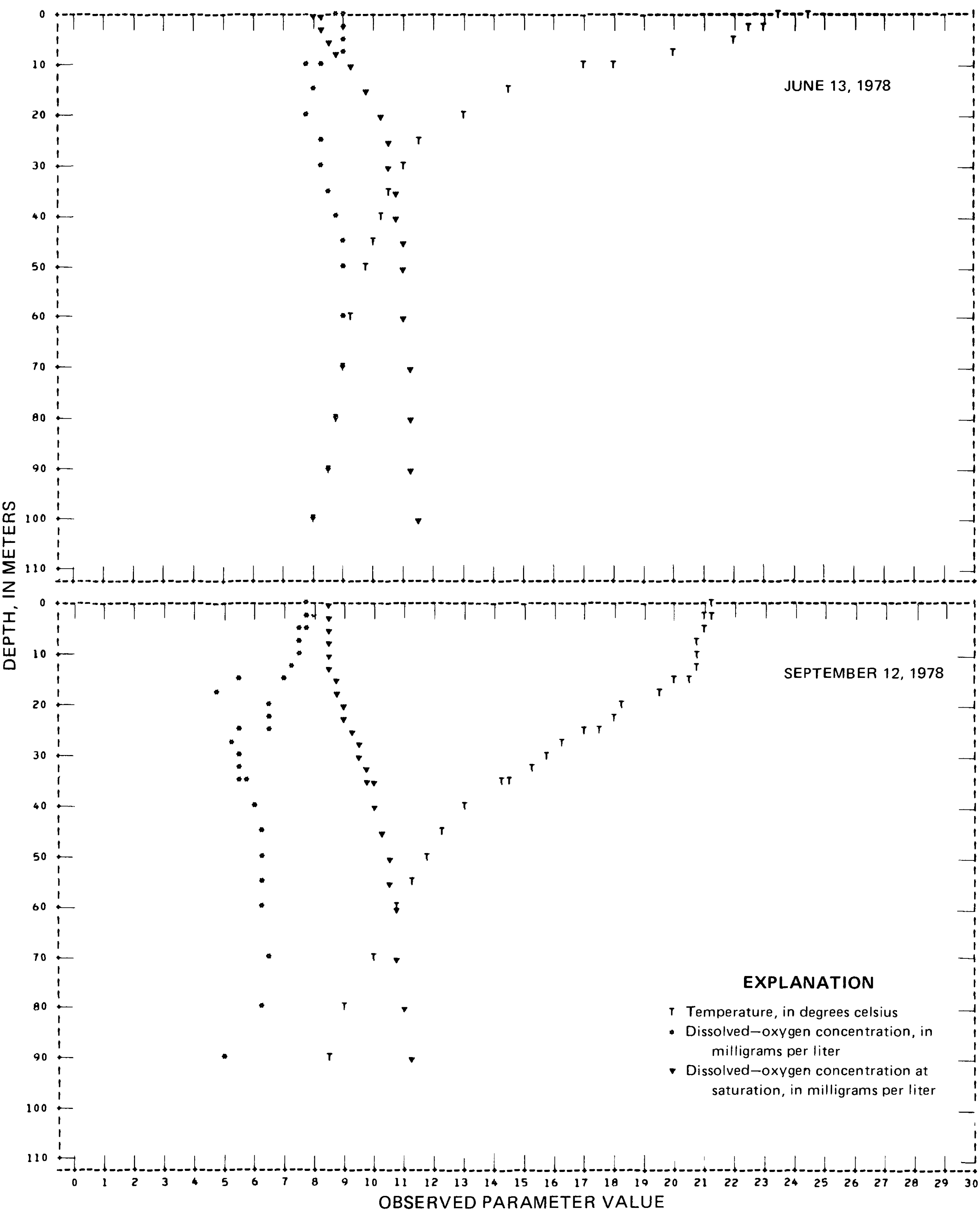

FIGURE 12. – **Vertical dissolved-oxygen and temperature profiles for Pit River arm of Shasta Lake at Allie Cove (Station D), 1978.**

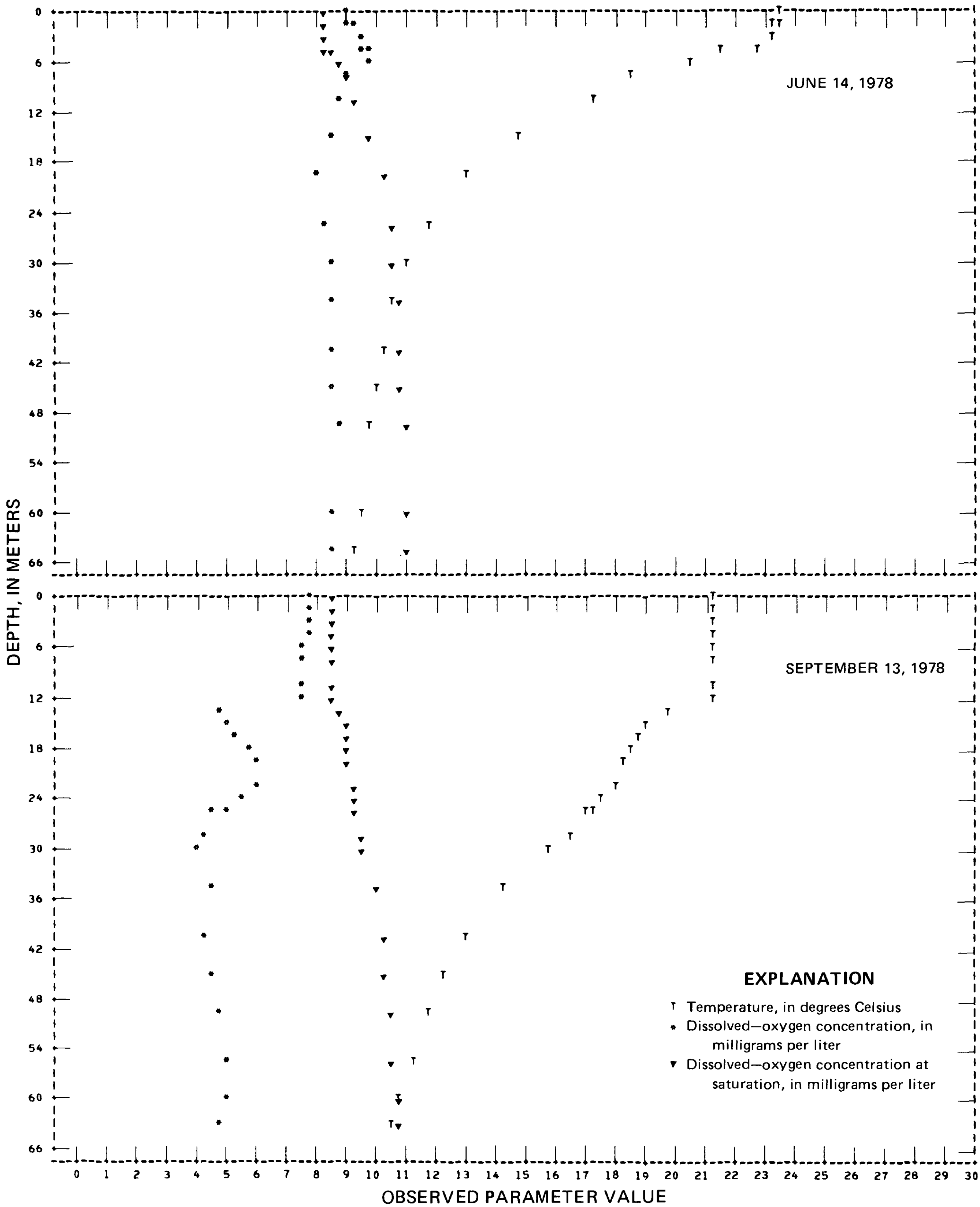

FIGURE 13. – Vertical dissolved-oxygen and temperature profiles for Squaw Creek arm of Shasta Lake (Station E), 1978.

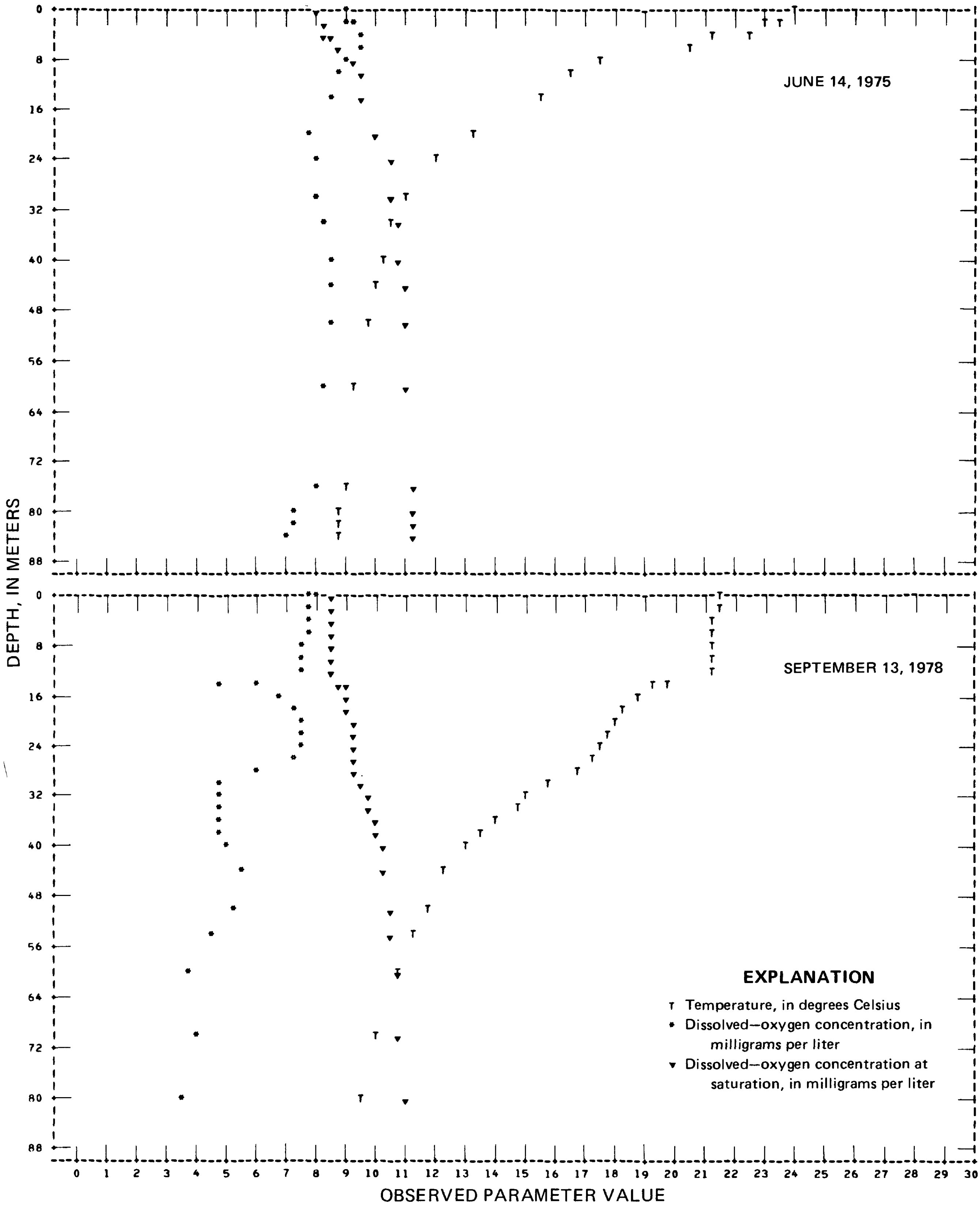

FIGURE 14. – Vertical dissolved-oxygen and temperature profiles for Pit River arm of Shasta Lake below Brushy Canyon (Station F), 1978.

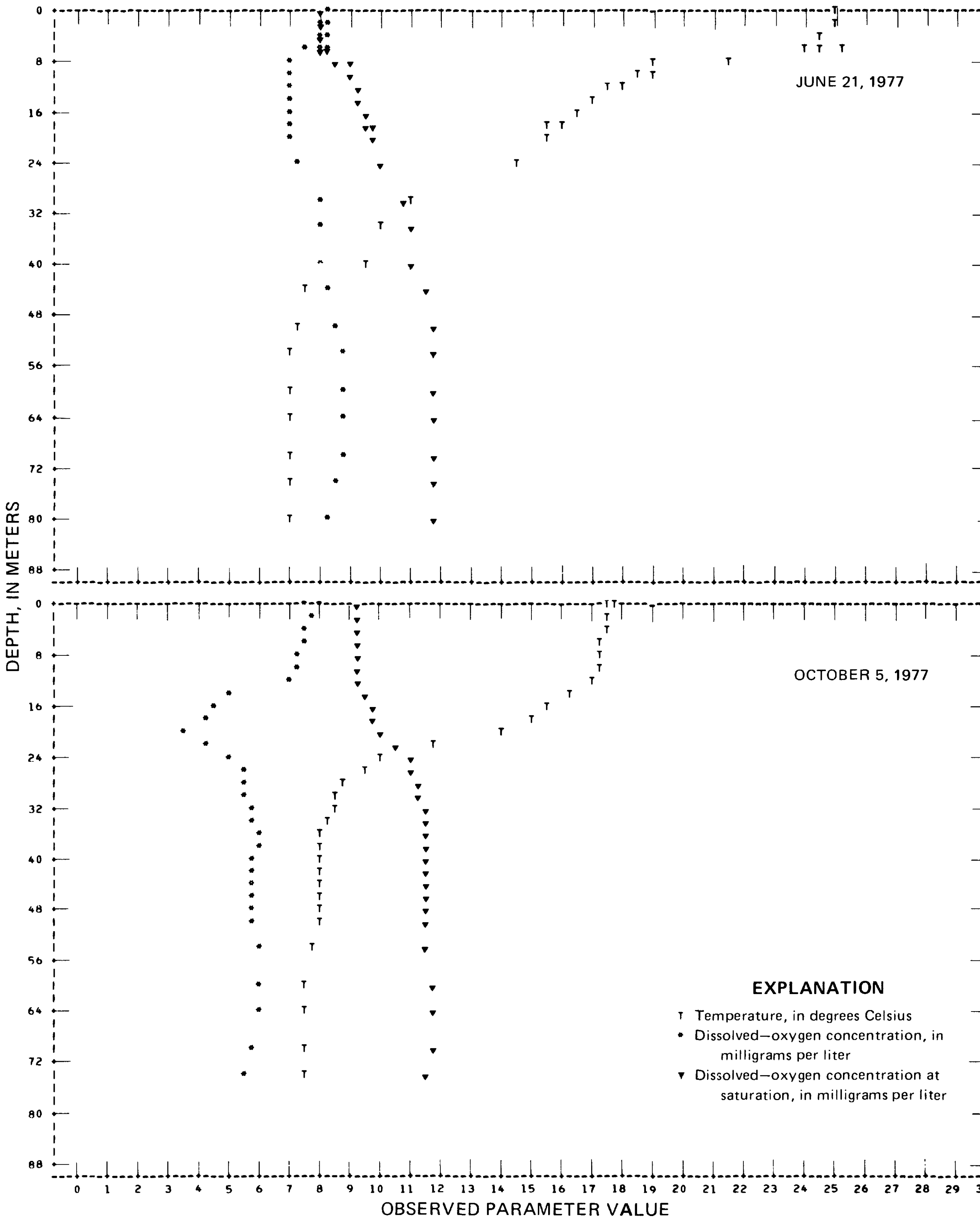

FIGURE 15. – Vertical dissolved-oxygen and temperature profiles for Shasta Lake near Shasta Dam (Station A), 1977.

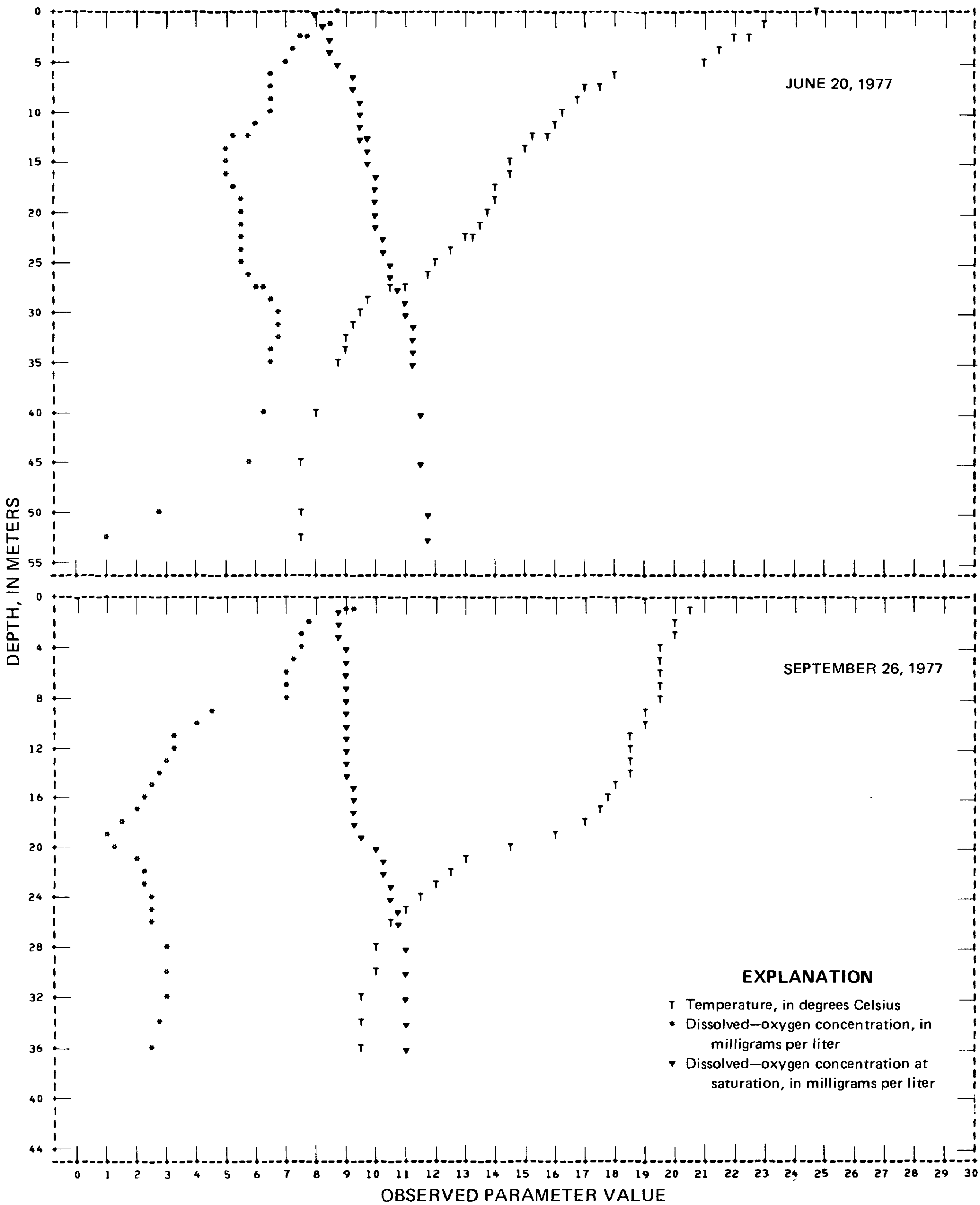

FIGURE 16. – Vertical dissolved-oxygen and temperature profiles for Sacramento River arm of Shasta Lake (Station B), 1977.

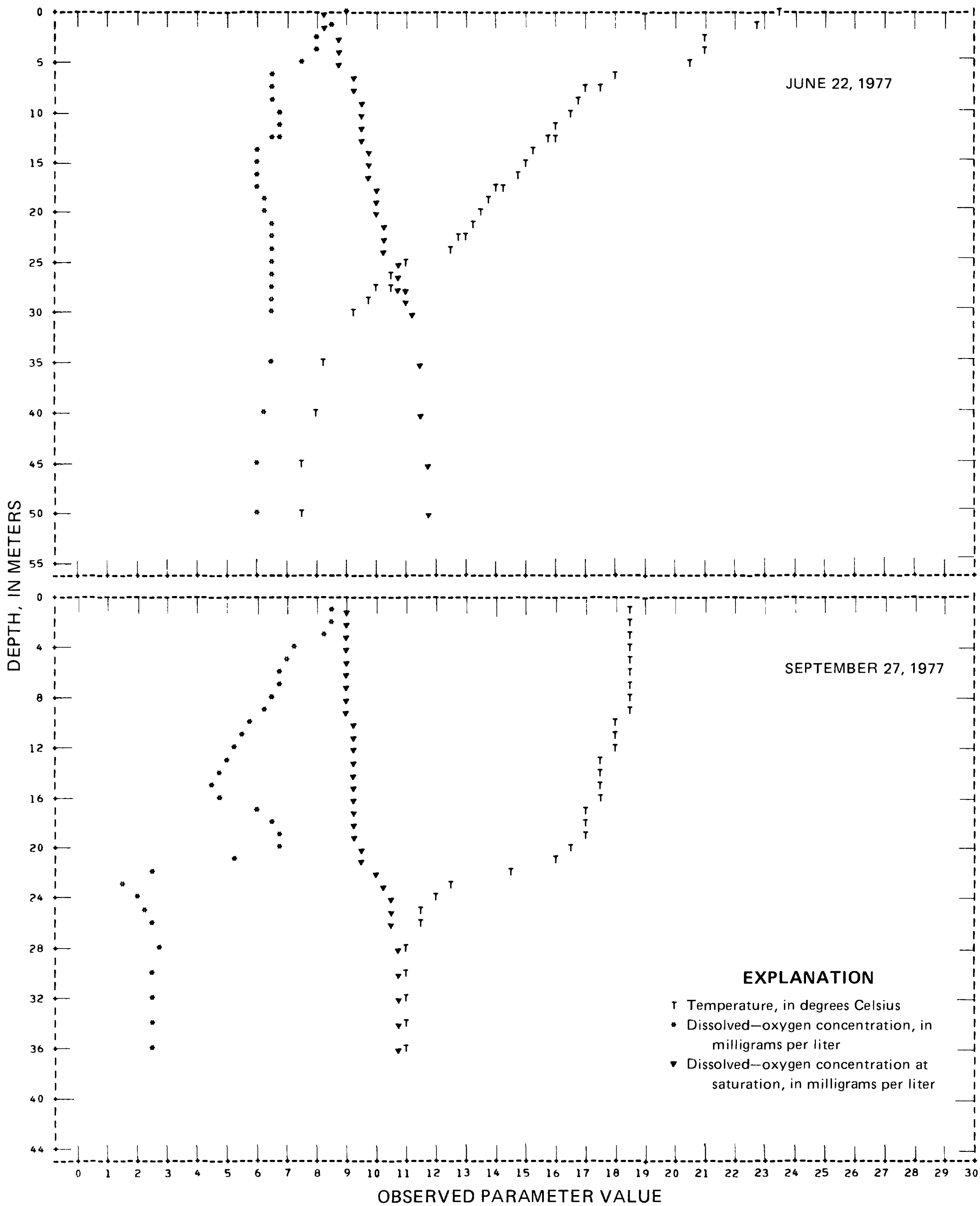

FIGURE 17. – Vertical dissolved-oxygen and temperature profiles for McCloud River arm of Shasta Lake (Station C), 1977.

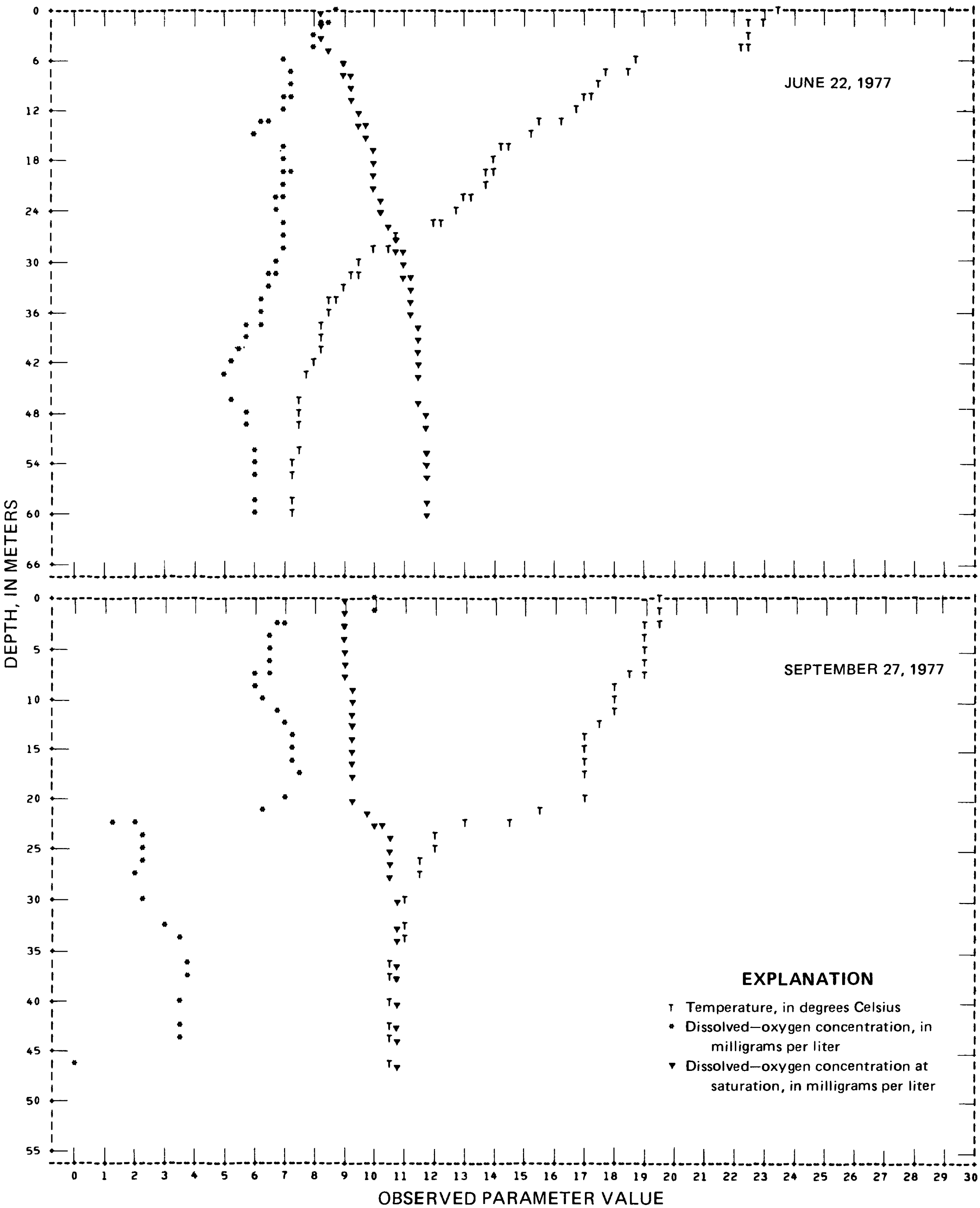

FIGURE 18. – Vertical dissolved-oxygen and temperature profiles for Pit River arm of Shasta Lake at Allie Cove (Station D), 1977.

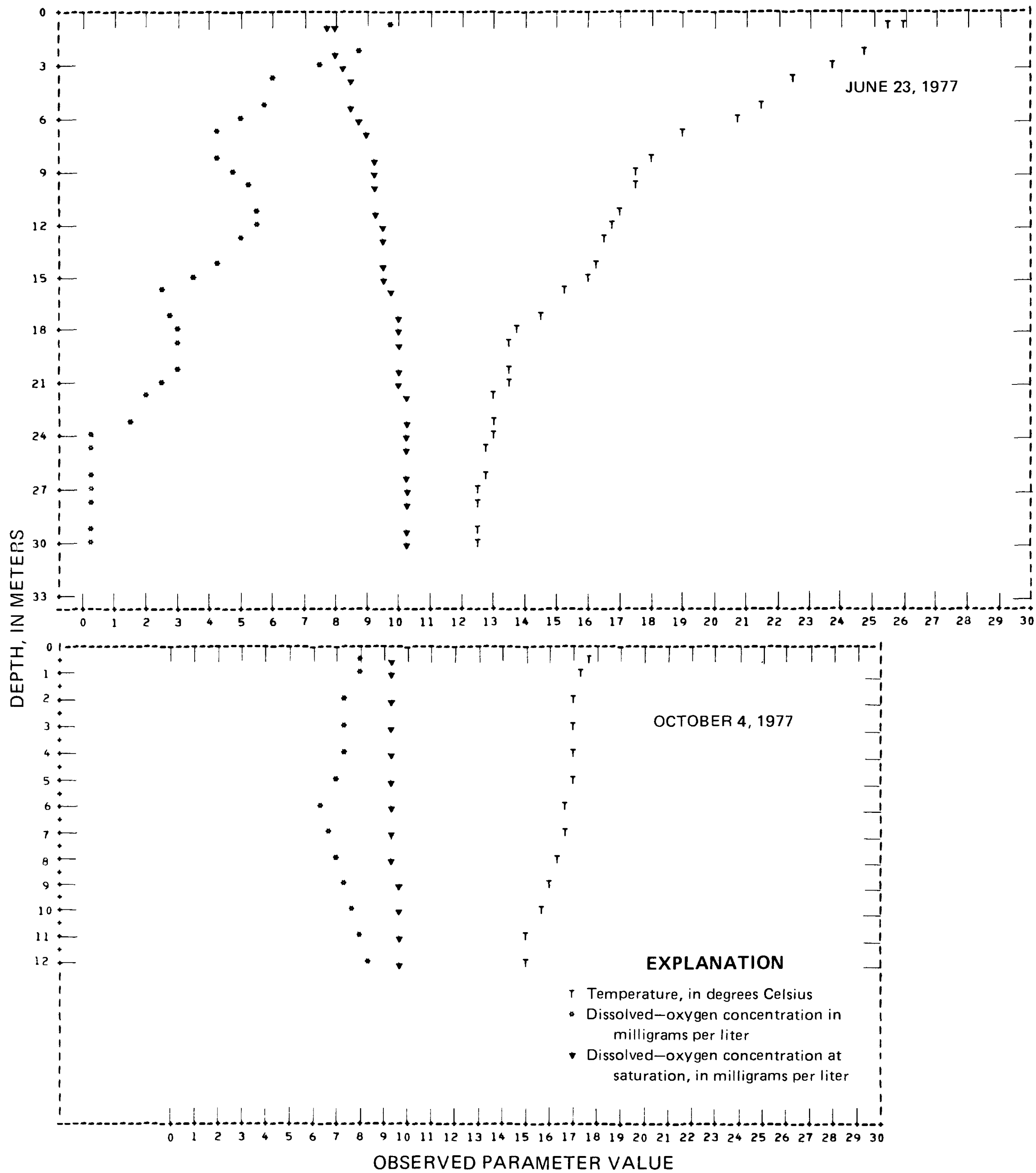

FIGURE 19. – Vertical dissolved-oxygen and temperature profiles for Squaw Creek arm of Shasta Lake (Station E), 1977

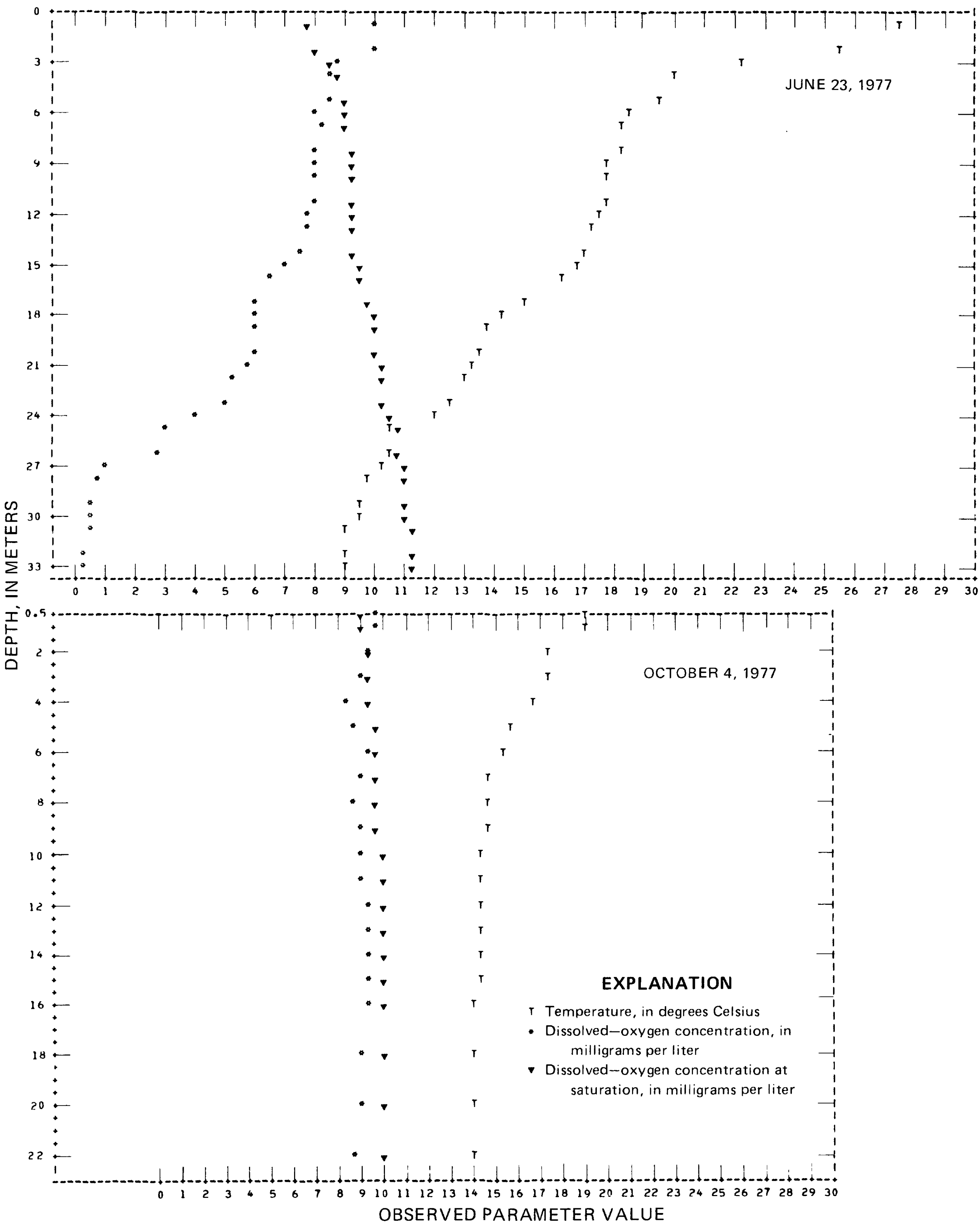

FIGURE 20. – Vertical dissolved-oxygen and temperature profiles for Pit River arm of Shasta Lake below Brushy Canyon (Station F), 1977.

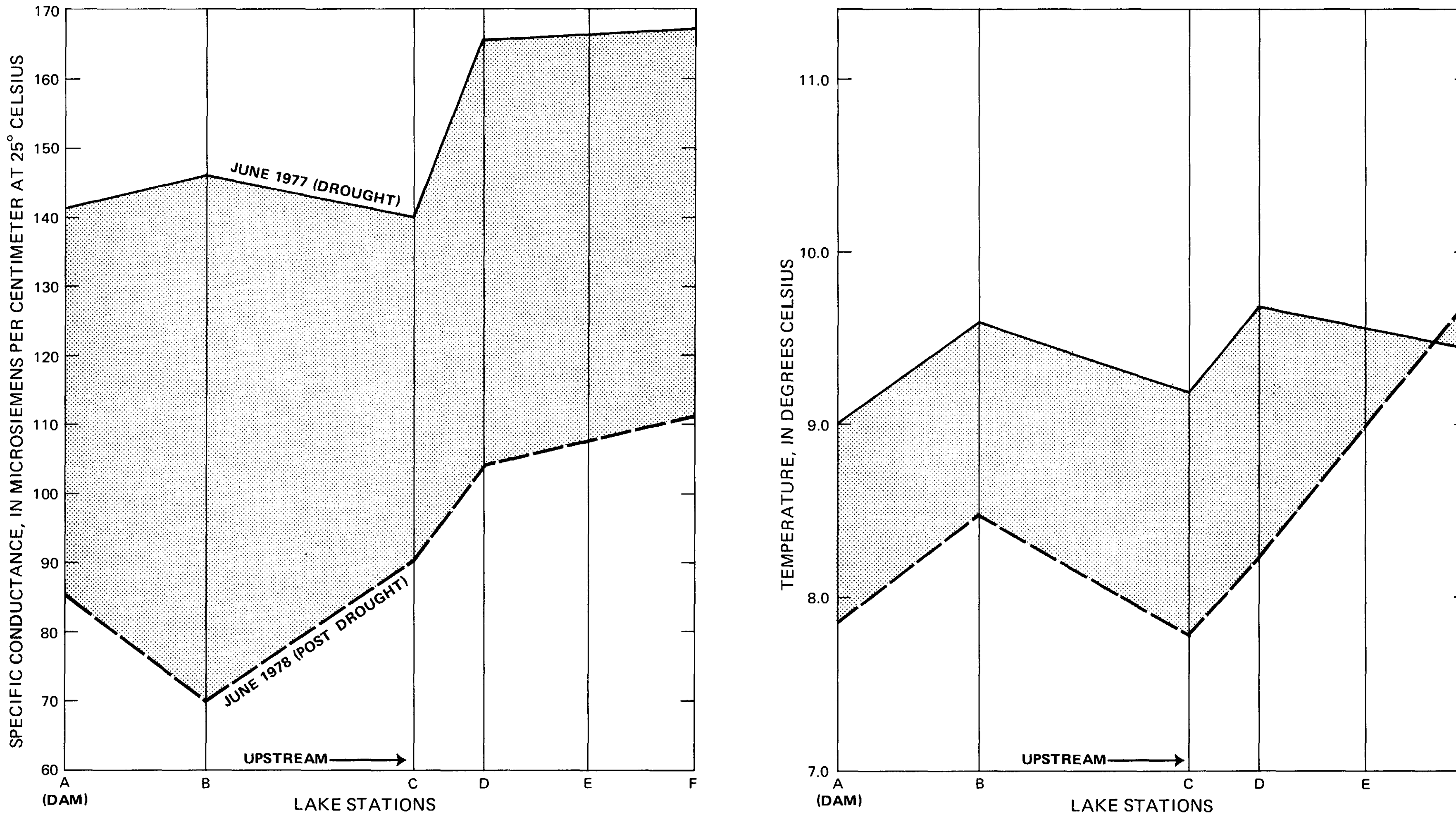

FIGURE 21. – Comparison of average summer hypolimnion values for specific conductance and temperature, June 1977 and June 1978.

Light Penetration

The seasonal variation in transparency between stations is a result of many factors that include the intensity and angle of incident light, the concentration of dissolved and suspended materials, and the abundance of planktonic organisms.

Light penetration recorded during the summer and autumn of 1977 was consistently low at all stations, between 0.5 and 1.0 m (table 9). Low Secchi-disk measurements were consistent with the turbid appearance of the lake during the drought. Reduced light penetration can be explained by the presence of suspended material. The extremely low lake level and increase in exposed nearshore area during the drought apparently resulted in the resuspension of sediment. Secchi-disk measurements made in June 1978 were 1.4 to 2.8 m higher than measurements in June 1977 (table 9).

TABLE 9. - Secchi-disk transparency in Shasta Lake

	Depth, in meters					
Station:	A	B	C	D	E	F
March 1977	2.0	2.0	2.0	2.0	3.0	2.5
June 1977	.7	.7	.5	.5	.5	.6
September 1977	--	1.0	.8	1.0	--	--
October 1977	.8	--	--	--	.7	1.0
June 1978	3.1	3.5	3.0	2.7	2.3	2.0

Dissolved Oxygen

Oxygen is a significant regulator of metabolic processes and chemical reactions within the lake and at the sediment-water interface. The relative abundance (degree of saturation) of oxygen with depth provides an estimate of the nature and extent of biological processes taking place at various depths. In productive lakes, it is common to find water at some depth significantly undersaturated as organic matter undergoes oxidation. Biochemical interactions in bottom water and at the sediment-water interface may also result in a decrease or complete elimination of dissolved oxygen in the hypolimnion. Dissolved-oxygen profiles for Shasta Lake are presented in figures 9 through 20.

During the drought, concentrations of dissolved oxygen (hence percent of saturation) were low in the reservoir (fig. 22). The lowest percent oxygen saturation (0 to 50 percent) was observed in the hypolimnion of the upstream and downstream parts of the reservoir during the drought; whereas, in 1978 the entire reservoir was above 70 percent dissolved-oxygen saturation. Depending on the station, the dissolved-oxygen saturation in the hypolimnion was about 15 to 60 percent less in 1977 than in 1978 (fig. 23). This corresponds to 1.0 to 7.0 mg/L less dissolved oxygen in 1977 than in 1978 at the same stations and lake depths. The lowest dissolved-oxygen concentrations were at the upstream stations at Pit River below Brushy Canyon and Squaw Creek arms of the reservoir. Lower dissolved-oxygen concentrations in the reservoir during the drought year may have resulted from less flushing, increased concentrations of organic particulates, and less dilution capacity as compared to a normal year.

Specific Conductance and pH

Specific conductance data selected at various depths for Shasta Lake are given in table 10. Spatial and seasonal changes in specific conductance were significant and may be explained by a number of factors that include tributary inflow and dilution effect, vertical mixing in tributary arms, and concentration through solute exchange between water and sediment. Evaporation may also affect specific conductance although the effects are difficult to separate from those of more pervasive phenomena.

Specific conductance of the uppermost tributary arms of the lake during the winter isothermal condition did not vary significantly among lake stations. The highest specific conductance values were observed in the tributary arms of the reservoir. Mean value of specific conductance at selected depths (table 10) during 1977 was 146 compared to 109 µS/cm in 1978. The most pronounced difference in specific conductance was observed in the bottom water. For example, the mean value of specific conductance in the hypolimnion was 50 to 75 µS/cm higher during the June 1977 drought period than in June 1978 (fig. 21). Mixing and exchange of solutes between the sediments and overlying water was probably responsible for the increase in specific conductance in the bottom water during the drought.

Values of pH at selected depths for 1977 and 1978 are shown in table 10. The pH generally ranged between 7.1 and 8.3. The pH of the bottom water tended to be slightly lower in 1977 compared to 1978.

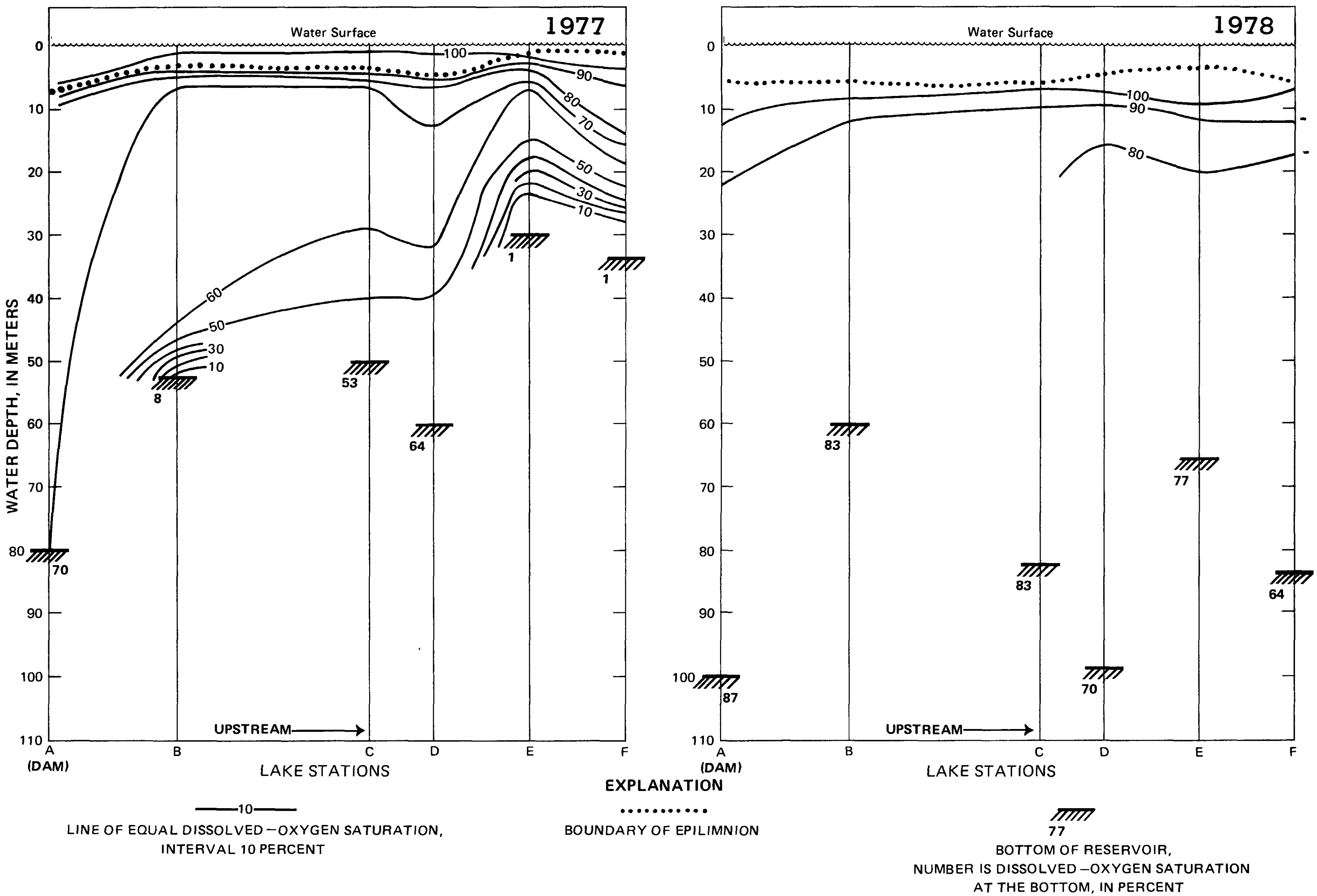

FIGURE 22. — Dissolved oxygen, in percent saturation, June 1977 and June 1978

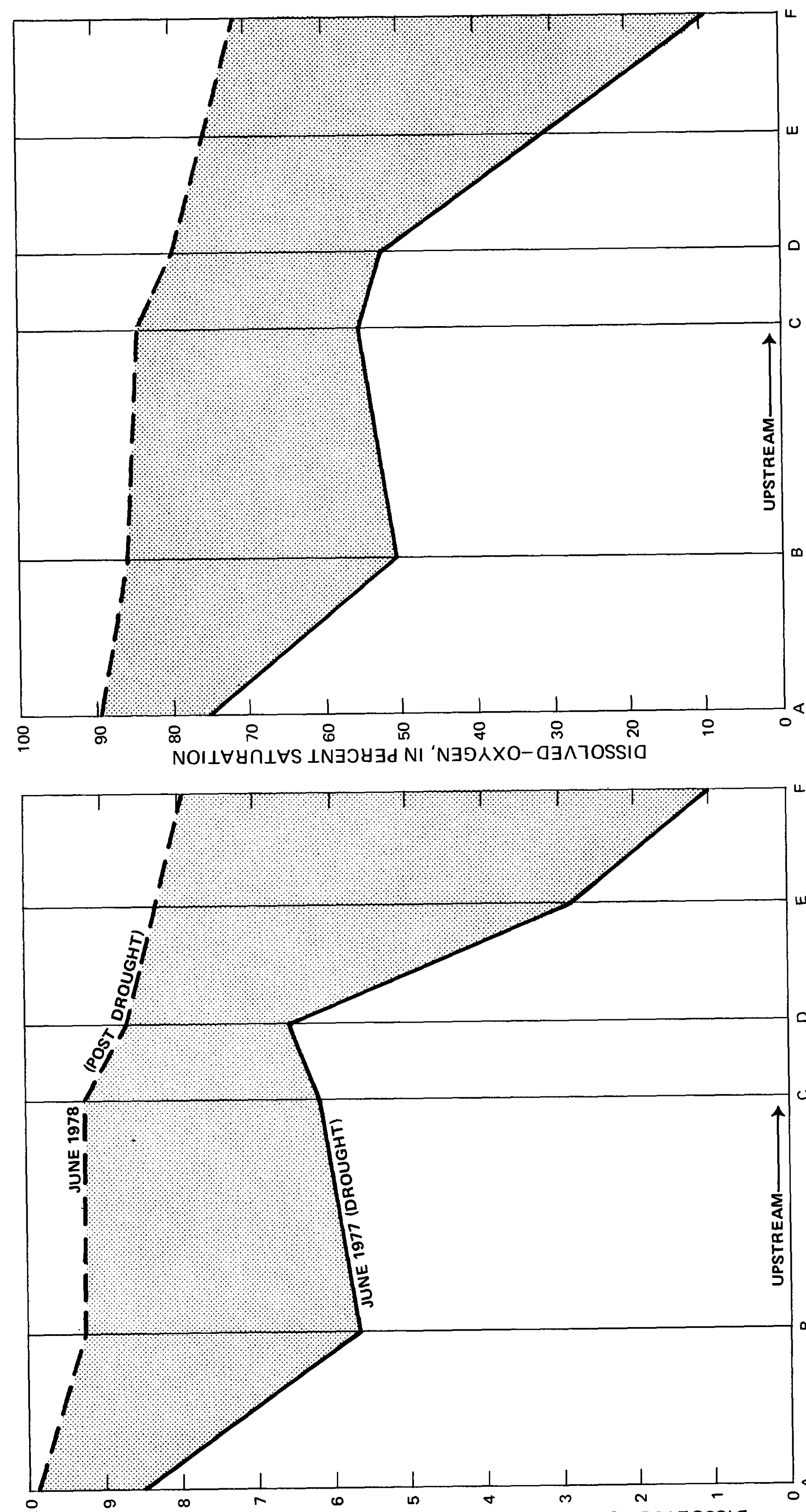

FIGURE 23. — Comparison of average summer hypolimnion values of dissolved-oxygen concentration and percent saturation, June 1977 and June 1978.

TABLE 10. - Specific conductance and pH in Shasta Lake

Date	Sampling depth (m)	pH	Specific conductance (μS/cm at 25°C)
Shasta Lake near Shasta Dam, near Project City			
June 21, 1977	8	8.2	140
	65	7.4	142
Oct. 5, 1977	1	8.2	72
	65	8.2	76
June 12, 1978	1	7.9	142
	15	7.4	142
	60	7.2	146
Sept. 11, 1978	1	8.1	100
	20	7.5	114
	60	7.3	97
Pit River arm of Shasta Lake below Brushy Canyon			
June 23, 1977	3	8.3	158
	18	7.2	155
Oct. 4, 1977	1	8.2	155
	5	7.7	150
	18	7.7	135
June 14, 1978	15	8.1	125
	50	7.7	110
Sept. 13, 1978	1	8.3	103
	15	7.7	120
	60	7.1	118
Pit River arm of Shasta Lake at Allie Cove, near Lakehead			
June 22, 1977	1	8.3	144
	6	7.8	154
	38	7.3	164
June 13, 1978	15	7.8	120
	60	7.7	100
Sept. 12, 1978	1	8.2	102
	20	7.6	123
	50	7.4	107
Sacramento River arm of Shasta Lake			
June 20, 1977	1	8.4	144
	6	7.8	151
	30	7.3	144
Sept. 26, 1977	1	8.0	148
	10	7.1	145
	20	6.9	145
June 13, 1978	1	8.4	72
	10	8.0	80
	50	7.7	68
Sept. 12, 1978	1	8.0	98
	20	7.6	115
	40	7.4	86

TABLE 10. - Specific conductance and pH in Shasta Lake--Continued

Date	Sampling depth (m)	pH	Specific conductance (μS/cm at 25°C)
	Squaw Creek arm of Shasta Lake		
Oct. 4, 1977	1	7.5	172
	8	7.3	188
	12	7.4	237
June 14, 1978	5	8.4	92
	15	7.9	120
Sept. 13, 1978	1	8.1	107
	14	7.6	119
	45	7.2	129
	McCloud River arm of Shasta Lake		
June 22, 1977	1	8.1	138
	6	7.6	151
	40	7.2	137
Sept. 27, 1977	1	8.1	130
	22	7.0	131
	32	7.0	140
June 3, 1978	20	7.8	110
	60	7.7	84
Sept. 12, 1978	1	8.0	102
	20	7.6	117

Chemical Constituents

Major Dissolved Chemical Constituents

Spatial and temporal differences in water chemistry were apparent (table 11) during selected sampling periods and can be explained, to some degree, by the variation in tributary inflow quality and lake conditions during and after the drought.

The lake was consistently of the calcium magnesium bicarbonate water type and the water is classified as soft (U.S. Environmental Protection Agency, 1976). Except for hardness values of more than 100 mg/L at the Squaw Creek station, hardness in the lake ranged from 26 to 68 mg/L.

TABLE 11. - Major chemical constituent concentrations in Shasta Lake

SHASTA LAKE NEAR SHASTA DAM NEAR PROJECT CITY

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
MAR													
03...	1445	50.5	10	6.0	50	0	10	2.0	4.5	3.4	.1	102	114
JUN													
21...	1145	1.0	11	5.8	51	0	9.0	1.7	4.9	4.6	.2	94	91
21...	1150	8.0	10	5.8	49	0	8.8	1.8	5.2	4.3	.1	95	93
21...	1200	65.0	11	6.7	55	0	9.5	2.0	4.5	3.1	.1	109	107

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
JUN													
12...	1500	1.0	9.0	3.5	37	0	3.8	.5	1.8	6.7	.0	63	
12...	1505	15.0	11	4.1	44	3	4.0	1.0	1.8	5.4	.1	74	
12...	1510	60.0	10	3.8	41	10	4.3	.8	1.2	6.1	.0	62	
SEP													
11...	1545	1.0	10	3.9	41	0	5.0	1.1	.7	3.3	.0	71	
11...	1550	20.0	10	4.7	44	10	7.2	1.5	2.3	4.6	.0	64	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

PIT RIVER ARM OF SHASTA LAKE BELOW BRUSHY CANYON NEAR PROJECT CITY

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
MAR													
02...	1330	25.0	11	6.5	54	0	10	2.4	4.8	3.0	.1	107	116
JUN													
23...	1330	1.0	12	5.8	54	0	10	2.0	4.5	4.8	.2	104	104
23...	1335	3.0	12	5.9	54	0	10	2.1	4.5	3.8	.2	107	106
23...	1340	18.0	11	6.0	52	0	11	2.0	4.5	4.1	.2	108	103

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
JUN													
14...	1245	1.0	12	3.5	44	3	4.7	.8	1.4	6.4	.1	72	
14...	1250	15.0	12	5.5	53	0	8.4	1.7	2.5	3.7	.1	98	
14...	1255	50.0	14	4.0	51	6	3.0	1.1	1.8	5.6	.0	78	
SEP													
13...	1405	1.0	11	3.9	44	0	5.5	1.1	1.8	5.4	.0	74	
13...	1410	15.0	11	5.1	48	0	7.8	1.8	2.6	3.1	.1	84	
13...	1415	60.0	12	4.4	48	0	6.7	1.4	2.0	5.2	.0	91	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

PIT RIVER ARM OF SHASTA LAKE AT ALLIE COVE NEAR LAKEHEAD

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
MAR													
02...	1600	32.0	10	6.2	51	0	10	2.0	4.6	3.6	.0	108	109
JUN													
22...	1115	1.0	12	5.5	53	0	9.0	2.0	4.2	3.8	.2	98	98
22...	1120	6.0	11	5.8	51	0	9.5	1.8	4.5	4.0	.2	100	98
22...	1125	38.0	12	6.0	55	0	10	2.0	4.6	4.3	.2	110	110

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
JUN													
13...	1530	1.0	10	3.6	40	1	3.9	.7	1.3	3.0	.0	62	
13...	1535	15.0	12	4.6	49	5	6.4	1.2	9.3	2.5	.0	87	
13...	1540	60.0	13	3.6	47	0	5.5	1.1	1.6	5.7	.1	--	
SEP													
12...	1535	1.0	10	3.9	41	0	5.7	1.1	1.6	6.0	.0	70	
12...	1540	20.0	11	5.2	49	0	8.6	1.9	2.6	1.7	.1	98	
12...	1545	50.0	12	4.0	46	0	5.9	1.2	1.7	6.2	.0	87	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

SACRAMENTO RIVER ARM OF SHASTA LAKE NEAR LAKEHEAD

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
MAR													
01...	1600	29.0	10	6.4	51	0	9.0	1.6	5.6	4.3	.0	101	115
JUN													
20...	1545	1.0	9.4	6.4	50	0	9.0	1.5	5.8	4.0	.1	93	92
20...	1550	6.0	10	6.2	51	0	9.0	1.7	5.1	4.1	.1	94	95
20...	1555	30.0	10	6.6	52	0	9.0	1.6	5.8	4.0	.2	99	99

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
JUN													
13...	1030	1.0	10	3.3	39	7	3.8	.6	1.8	6.0	.0	60	
13...	1035	10.0	8.9	3.5	37	1	4.0	.6	1.4	5.7	.0	63	
13...	1040	50.0	6.6	4.8	36	1	4.3	.4	1.4	4.1	.0	59	
SEP													
12...	1050	1.0	9.0	4.0	39	0	5.4	1.0	2.0	6.2	.1	74	
12...	1055	20.0	10	4.8	45	0	6.6	1.4	2.3	3.1	.0	68	
12...	1100	40.0	7.0	4.8	37	0	3.6	.6	1.4	4.4	.0	56	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

SQUAW CREEK ARM OF SHASTA LAKE NEAR PROJECT CITY

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	SAM-PLING DEPTH (M)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
MAR													
02...	0955	17.0	13	5.6	56	0	8.2	1.7	4.7	5.1	.1	96	100
JUN													
23...	1200	1.0	15	5.6	61	0	10	1.8	5.9	9.4	.2	108	114
23...	1210	6.0	12	5.8	54	0	10	1.9	5.2	5.6	.1	106	110
23...	1220	18.0	18	5.5	68	0	10	1.6	6.3	6.2	.1	115	120

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	SAM-PLING DEPTH (M)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
JUN													
14...	1030	1.0	11	3.5	42	4	4.5	.8	1.5	5.7	.1	68	
14...	1035	5.0	12	3.5	44	16	4.5	.7	1.5	7.5	.0	65	
14...	1040	15.0	12	5.1	51	0	7.6	1.5	2.2	4.3	.1	91	
SEP													
13...	1100	1.0	12	3.9	46	0	5.8	1.1	1.7	6.5	.0	75	
13...	1105	14.0	11	4.8	47	0	7.9	1.7	2.4	2.5	.1	89	
13...	1110	45.0	19	3.3	61	0	4.4	.8	1.2	11	.0	89	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

MCCLOUD RIVER ARM OF SHASTA LAKE NEAR LAKEHEAD

DATE	TIME	SAMPLING DEPTH (M)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)
Water Quality Data, Water Year October 1976 to September 1977													
MAR													
03...	0830	15.0	10	5.6	48	0	8.2	1.6	4.6	3.8	.1	92	86
JUN													
22...	1400	1.0	11	5.0	48	0	8.4	1.6	4.2	3.3	.3	92	92
22...	1405	6.0	11	5.9	52	0	10	2.0	4.5	4.1	.2	106	107
22...	1410	40.0	12	5.3	52	0	8.2	1.6	3.2	3.3	.1	101	102
Water Quality Data, Water Year October 1977 to September 1978													
JUN													
13...	1330	1.0	10	3.5	39	0	4.0	.7	1.2	3.0	.0	63	
13...	1335	20.0	12	4.8	50	0	6.8	1.4	8.3	1.3	.1	91	
13...	1340	60.0	12	3.1	43	3	3.8	.7	1.5	2.5	.0	66	
SEP													
12...	1345	1.0	11	3.9	44	0	5.2	1.1	1.5	4.6	.1	71	
12...	1350	20.0	11	4.7	47	0	7.4	1.6	2.0	2.3	.0	71	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

SACRAMENTO RIVER AT DELTA

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
NOV												
09...	1150	--	--	--	--	--	--	--	--	--	--	159
JAN												
06...	1345	9.2	8.8	59	0	12	1.2	9.9	2.6	--	--	108
MAR												
01...	1005	--	--	59	0	9.9	--	8.0	--	--	--	119
01...	1130	8.4	8.5	56	0	10	1.3	9.1	3.8	.1	--	104
MAY												
11...	1300	--	--	50	0	7.6	--	4.4	--	--	--	133
JUN												
20...	1455	8.3	8.5	56	0	10	1.1	8.4	4.0	.1	108	110
JUL												
06...	1145	--	--	57	0	12	--	9.2	--	--	--	168
SEP												
13...	0845	--	--	59	0	16	--	9.3	--	--	--	180
26...	1530	4.3	3.9	26	--	5.1	.6	4.0	--	.1	--	--

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
NOV												
15...	1145	--	--	56	--	10	--	5.8	--	--	--	--
APR												
11...	0945	--	--	36	--	2.5	--	--	--	--	--	--
JUN												
13...	1430	5.2	4.5	32	0	2.8	.3	1.8	2.4	.0	57	--
JUL												
05...	0825	5.7	6.5	40	--	5.0	.4	3.2	1.4	--	--	68
SEP												
05...	0915	--	--	--	--	10	--	5.8	--	--	--	--
11...	1420	13	3.3	46	0	4.4	1.1	1.4	4.8	.0	85	--

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

PIT RIVER NEAR MONTGOMERY CREEK

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
FEB												
28...	1345	9.8	6.6	52	0	10	2.5	4.3	2.8	.1	109	112
MAR												
02...	1000	--	--	54	0	10	--	2.6	--	--	--	121
JUN												
20...	0900	10	6.2	51	0	10	2.2	4.2	2.3	.2	108	107
SEP												
14...	0915	--	--	50	0	11	--	2.4	--	--	--	--
26...	0930	7.6	3.7	34	0	6.0	1.2	3.0	2.3	.1	80	92

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
APR												
12...	1030	--	--	46	--	7.7	--	.1	--	--	--	
SEP												
06...	0930	--	--	50	--	10	--	2.1	--	--	--	
11...	0920	10	5.6	48	0	8.6	2.0	2.9	2.7	.1	87	

TABLE 11. - Major chemical constituent concentrations in Shasta Lake--Continued

MCCLOUD RIVER ABOVE MCCLOUD RIVER BRIDGE NEAR LAKEHEAD

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
FEB 28...	1800	12	4.0	46	0	5.4	1.3	3.2	3.3	.0	90	92
JUN 20...	1400	12	3.8	46	0	5.5	1.2	2.3	3.3	.2	90	93
SEP 26...	1400	6.8	2.2	26	--	3.5	.8	1.5	--	.1	--	--

SQUAW CREEK ABOVE SHASTA LAKE

Water Quality Data, Water Year October 1976 to September 1977

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
FEB 28...	1630	38	3.8	110	15	4.6	.5	3.0	22	.1	140	133
JUN 20...	1240	40	3.8	120	14	4.8	.4	1.6	22	.2	149	157
SEP 26...	1145	17	1.4	48	--	1.8	.2	1.4	--	.1	--	--

Water Quality Data, Water Year October 1977 to September 1978

DATE	TIME	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L)
JUN 13...	1010	37	3.5	110	12	3.6	.2	.7	16	.1	135	
SEP 11...	1105	34	3.1	98	8	3.8	.3	1.1	20	.1	129	

Nutrients

Nitrogen and phosphorus are two of the nutrients most likely to limit plant growth in lakes and rivers. Silica is also important because it is necessary to the growth of diatoms. The concentration of nutrients required for continued algal growth depends on the type and physiological state of the phytoplankton. Phytoplankton in general require a water having a carbon-nitrogen-phosphorus atomic ratio of 100:15:1 for continued growth (Likens, 1972, p. 123). Exhaustion of a single nutrient element will cause a reduction in the rate of growth or a limiting condition and result in a shift in the nutrient ratio. Limiting nutrient concentrations for the species of phytoplankton in Shasta Lake are not known. Nutrient data were collected periodically at all Shasta Lake stations during the intensive study, and a summary of the phosphorous and nitrogen analyses is given in table 12.

Nitrogen in lakes usually occurs in two principal phases, dissolved and particulate. Within these phases, nitrogen is either in its reduced state as NH_4 (ammonium ion) and proteinaceous nitrogen or in its oxidized state as NO_2 (nitrite) and NO_3 (nitrate). The dissolved inorganic forms are more important to phytoplankton because they are readily assimilated.

Inorganic nitrogen and total nitrogen concentrations were low in the summer and about the same order of magnitude in 1977 and 1978 (table 12). However, in autumn of the drought year inorganic nitrogen concentrations, on a whole lake average, were about ten times higher than 1978. Differences in total nitrogen concentration in 1977 and 1978 were not as great as inorganic nitrogen, but during autumn total nitrogen was also higher in 1977 than 1978.

Phosphorus is also found in two phases with the principal forms consisting of dissolved orthophosphate (PO_4) and particulate phosphorus (P). Orthophosphate is the most readily available form for phytoplankton assimulation.

Dissolved orthophosphate showed little variation in either 1977 and 1978 (table 12). The average whole lake and epilimnion concentration of dissolved orthophosphate in 1977 was 0.01 mg/L in summer and autumn. Total phosphorous concentrations during summer and autumn were 2 to 4 times higher in the drought year than in 1978.

Higher concentrations of total phosphorus and total nitrogen during the drought year may be related to greater concentrations of suspended material in the water column and less dilution capacity.

TABLE 12. - Nutrient concentrations in Shasta Lake

[Values, in milligrams per liter, represent the mean of all stations]

Lake strata	Season	Total inorganic nitrogen as N		Total nitrogen as N		Dissolved orthophosphate as P		Total phosphorus as P	
		1977	1978	1977	1978	1977	1978	1977	1978
Whole lake	Spring	0.10	--	0.36	--	0.04	--	0.04	--
Epilimnion	Summer	.06	0.03	.23	0.33	.01	0.00	.04	0.01
Whole lake	do.	.10	.09	.22	.45	.01	.01	.04	.01
Epilimnion	Autumn	.87	.01	.98	.28	.01	.01	.03	.01
Whole lake	do.	.62	.06	.63	.38	.01	.02	.04	.02

Biological Characteristics

Phytoplankton

Species Composition.--In Lake Shasta, 38 genera and 42 species of algae were identified during the study period (table 13). Not included in the species count were representatives from 19 genera and a large number of flagellates which could not be identified any further. Diatoms (division Chrysophyta) were the most frequently collected group at all stations followed by green algae (division Chlorophyta) and then flagellates. Euglenophytes were also found in significant numbers during the summer.

Table 14 shows the relative abundance of the major algal divisions in Shasta Lake during the drought. All samples were obtained at a 1-m depth with a Van Dorn sampler. Total cell counts varied seasonally and at most stations were lowest in March and highest in June. No samples were obtained in late summer when maximum cell concentrations are usually recorded. As a result, the data in table 14 do not adequately represent the seasonal variation in algal concentrations. However, the data do provide information with respect to the phytoplankton composition of Shasta Lake during the drought.

The most abundant group of phytoplankton collected in March 1977 was diatoms. The dominant species was *Melosira italica*; however, in the Pit River arm, a significant concentration of *Stephanodiscus hantzchii* and *Asterionella formosa* was also found.

In June, diatoms again dominated over other algal forms. The most abundant species was *Melosira italica* at most stations except in Pit River arm where 84 percent of the Melosira sp. population consisted of *Melosira granulata*. Also found in abundance in the Pit River arm were *Nitzschia paleacea* and *Stephanodiscus hantzschii*.

A significant increase in the total number of green algae, euglenophytes, and flagellates was evident in June. Euglenophytes were more abundant than the other minor forms at the Shasta Dam station. A significant number were also found in the Pit River, McCloud River, Squaw Creek, and Sacramento River arms of the lake. The presence of a large number of euglenophyte phytoplankton also suggests the presence of organic material in the lake. Euglenoids have an ability to lose chloroplasts (cellular organelle containing chlorophyll) as a result of changing environmental conditions (Morris, 1967, p. 125) Many genera have been shown to be facultative heterotrophs. The turbid nature of the lake would have selectively favored the growth of euglenophytes during the drought. Euglenophytes are usually found in abundance only in polluted water containing a high organic nitrogen concentration.

In September and October, the number of phytoplankton was reduced from the concentrations recorded in June. Diatoms were still the most abundant group at most stations even though the population was more diversified. The principal diatoms collected were *Nitzschia paleacea*, *Skeletonema* sp., *Cyclotella pseudostelligera*, and *Nitzschia gracilis*.

Green algae reached a maximum concentration at most stations during September and October. The principal representatives included *Scenedesmus denticulatus*, *Mesostigma* sp., and *Ankistrodesmus falcatus*.

Flagellates also reached a maximum concentration during the autumn. A significant increase in cryptophytes, *Cryptomonas* sp., was evident in the Pit River and Sacramento River arms of the lake.

TABLE 13. - Phytoplankton species composition in Shasta Lake

[Samples obtained March, June, September, and October, 1977]

- DIVISION
  - Class
    - Order
      - Suborder
        - Family
          - *Genus species*

- CHLOROPHYTA
  - Chlorophyceae
    - Volvocales
        - Chlamydomonadaceae
          - *Mesostigma* sp.
          - *Chlorogonium elongatum*
          - *Coccomonas* sp.
    - Chlorococcales
        - Micractiniaceae
          - *Golenkinia radiata*
          - *Micractinium pusillum*
        - Oocystaceae
          - *Treubaria setigerum*
          - *Treubaria* sp.
          - *Oocystis* sp.
          - *Chodatella quadriseta*
          - *Ankistrodesmus faculatus*
          - *Tetraedron minimum*
          - *Tetraedron trigonum*
          - *Tetraedron* sp.
        - Scenedesmaceae
          - *Scenedesmus abundans*
          - *Scenedesmus denticula*
          - *Scenedesmus dimorphus*
          - *Scenedesmus opoliensis*
          - *Scenedesmus* sp.
          - *Tetrastrum staurogeniaeformae*
- EUGLENOPHYTA
  - Euglenophyceae
    - Euglenales
        - Euglenaceae
          - *Trachelomonas* sp.
- CHRYSOPHYTA
  - Chrysophyceae
    - Chrysomonadales
        - Chromulinaceae
          - *Dinobryon* sp.
  - Bacillariophyceae
    - Centrales
      - Coscinodiscineae
        - Coscinodiscaceae
          - *Melosira granulata*
          - *Melosira italica*
          - *Melosira varians*
          - *Cyclotella pseudostelligera*
          - *Skeletonema* sp.
          - *Stephanodiscus dubius*
          - *Stephanodiscus hantzchii*
          - *Stephanodiscus* sp.
      - Rhizosolenineae
        - Rhizosoleniaceae
          - *Rhizosolena longiseta*
    - Pennales
      - Fragilarineae
        - Tabellariaceae
          - *Tetracyclus lacustris*
        - Diatomaceae
          - *Diatoma vulgare*
        - Fragilariaceae
          - *Fragilaria crotonensis*

- CHRYSOPHYTA--Continued
  - Bacillariophyceae--Continued
    - Pennales--Continued
      - Fragilarineae--Continued
        - Fragilariaceae--Continued
          - *Fragilaria* sp.
          - *Synedra delicatissima*
          - *Synedra rumpens*
          - *Synedra ulna*
          - *Asterionella formosa*
      - Achnanthineae
        - Achnanthaceae
          - *Achnanthes minutissima*
          - *Rhoicosphenia curvata*
          - *Cocconies pediculus*
          - *Cocconies placentula*
      - Naviculineae
        - Naviculaceae
          - *Navicula salinarum*
          - *Navicula* sp.
        - Gomphonemataceae
          - *Gomphonema* sp.
        - Cymbellaceae
          - *Cymbella minuta*
          - *Cymbella* sp.
          - *Epithemia sorex*
      - Surirellineae
        - Nitzschiaceae
          - *Nitzschia acicularis*
          - *Nitzschia dissipata*
          - *Nitzschia fonticola*
          - *Nitzschia gracilis*
          - *Nitzschia holsatica*
          - *Nitzschia paleacea*
          - *Nitzschia* sp.
- PYRROPHYTA
  - Dinophyceae
    - Gymnodiniales
        - Gymnodiniaceae
          - *Gymnodinium* sp.
    - Peridiniales
        - Peridiniaceae
          - *Peridinium* sp.
        - Ceratiaceae
          - *Ceratium hirudinella*
- CYANOPHYTA
  - Myxophyceae
    - Oscillatoriales
      - Nostochineae
        - Nostocaceae
          - *Anabaena spiroides*
  - Cryptophyceae
    - Cryptomonadales
        - Cryptochrysidaceae
          - *Chroomonas* sp.
        - Cryptomonadaceae
          - *Cryptomonas* sp.

Miscellaneous flagellates

TABLE 14. - Relative abundance of phytoplankton in Shasta Lake

Date	Phytoplankton, in cells per milliliter					
	Chlorophyta (green)	Chrysophyta (diatoms)	Cyanophyta (blue-green)	Euglenophyta	Flagellates (Pyrrophyta, Cryptophyta, Chlorophyta)	Total
			Shasta Lake near dam			
Mar. 3, 1977	1	206	--	--	32	239
June 21, 1977	142	1,734	2	220	62	2,160
Oct. 5, 1977	527	1,184	--	--	704	2,415
			Pit River arm at Allie Cove			
Mar. 2, 1977	--	1,003	--	--	69	1,072
June 22, 1977	--	10,757	--	398	283	11,438
Sept. 27, 1977	657	--	--	72	1,466	2,195
			Pit River arm below Brushy Canyon			
Mar. 2, 1977	--	1,015	--	57	--	1,072
June 23, 1977	36	3,670	50	--	604	4,324
Oct. 4, 1977	892	2,476	--	144	846	4,358
			McCloud River arm			
Mar. 3, 1977	--	1,944	--	--	79	2,023
June 22, 1977	432	7,538	--	201	84	8,255
Sept. 27, 1977	136	402	--	--	--	538
			Squaw Creek arm			
Mar. 2, 1977	--	1,153	--	--	38	1,191
June 23, 1977	197	4,773	15	131	198	5,314
Oct. 4, 1977	1,856	1,999	--	118	441	4,414
			Sacramento River arm			
Mar. 1, 1977	3	631	--	--	22	656
June 20, 1977	260	3,759	--	229	7	4,255
Sept. 26, 1977	409	700	--	--	1,060	2,169

Primary Production.--Primary productivity determinations were made at the Shasta Dam station during March and June 1977. The productivity curves are shown in figure 24. Net production, that part of carbon that is produced in addition to the simultaneous needs for respiration, was higher in March than in June; net production for March 3 and June 21 was 261 and 65 mg C/(m^2/d), respectively. Reduced photosynthetic activity during June was probably due to the turbid nature of Shasta Lake. The Secchi-disk measurements for March 3 and June 21 were 2.0 and 0.7 m, respectively.

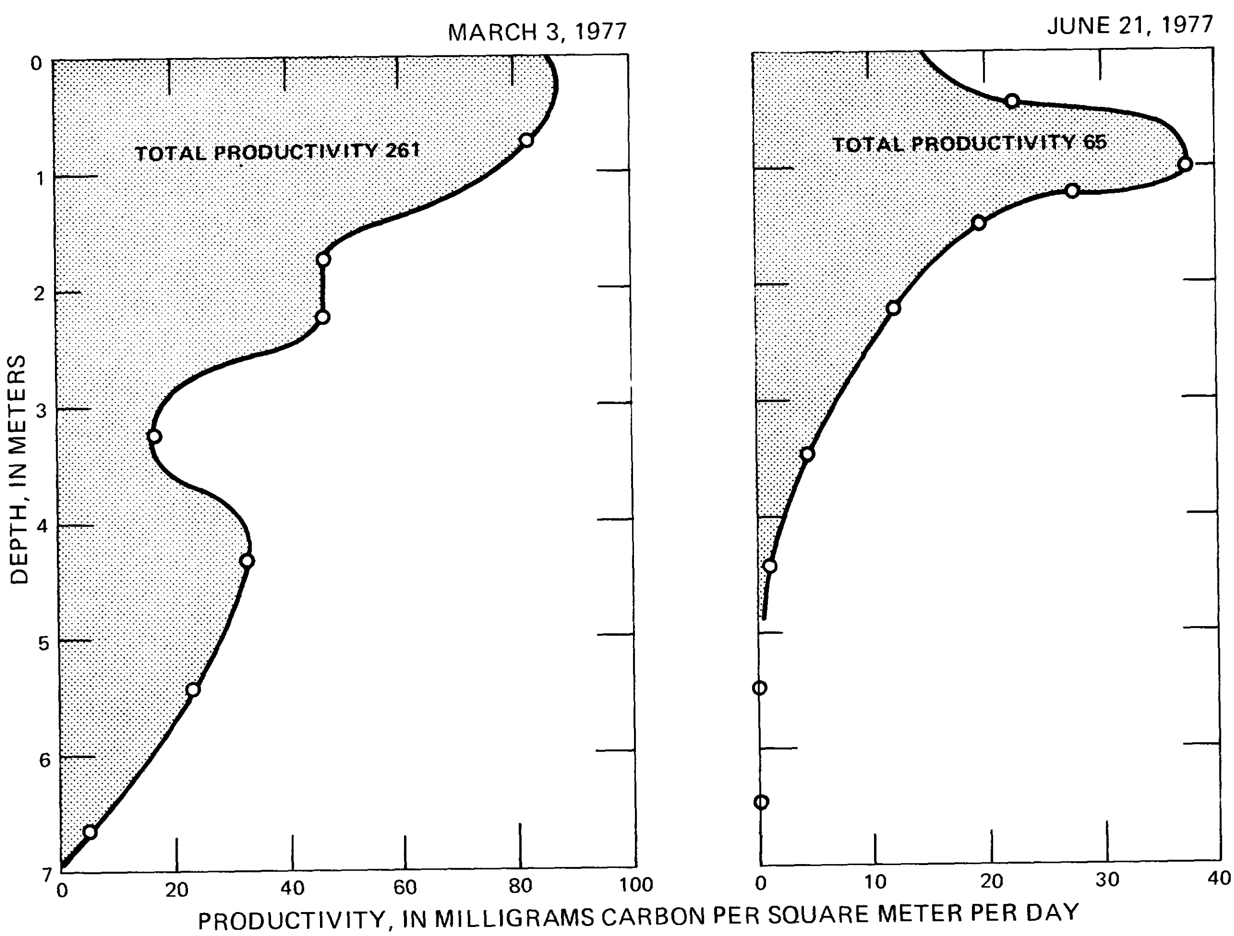

FIGURE 24. – Primary productivity at Shasta Dam.

Benthic organisms inhabit the sediments at the bottom of lakes where they feed on organic material deposited from above. The types and density of benthic organisms inhabiting the sediments depend on depth and on the internal chemistry of the hypolimnion. In general, high species diversity characterizes aerobic (oxygenated) sediments. More limited numbers of species are tolerant of extended anaerobic (deoxygenated) conditions. However, the tolerant species are more prolific and are commonly found in greater numbers. Table 15 shows the benthic faunal species found in Shasta Lake.

TABLE 15. - Benthic faunal species composition in Shasta Lake, 1977

PHYLUM Class Order Family Genus species	PHYLUM Class Order Family Genus species
ANNELIDA	ARTHROPODA--Continued
Oligochaeta (aquatic earthworms)	Insecta--Continued
Plesiopora	Diptera--Continued
Naididae	Muscidae
Dero sp.	*Lispe* sp.
Paranais sp.	*Chaoborus* sp.
Stylaria fossularis	Crustacea
Nais sp.	Ostracoda (subclass)
Tubificidae	Podocopoda
Ilyodrilus sp.	Cypridae
Limnodrilus hoffmeisteri	
Peloscolex sp.	NEMATA (nematodes)
Opisthopora	Nemas
Lumbriculidae	
Lumbriculus sp.	PLATYHELMINTHES (flatworms)
Sutroa sp.	Tubilellaria
	Tricladida
ARTHROPODA	Planariidae
Insecta	
Diptera (two-winged flies)	ENTOPROCTA
Ceratopogonidae	Phylactolaemata
Bezzia sp.	Plumatellina
Chironomidae	Lophopodidae
Calopsectra sp.	*Pectinatella magnifica* (statoblasts)
Chironomus sp.	*Lophopodella carteri* (statoblasts)
Parachironomus sp.	
Paracladopelma sp.	
Phaenopsectra sp.	
Procladius sp.	
Smittia sp.	
Stictochironomus sp.	

Table 16 summarizes the benthic faunal composition of the profundal (deep water) sediments in Shasta Lake. Three primary groups were found in Shasta Lake. The annelida phylum was represented by oligochaetes (aquatic earthworms), with tubificid worms making up the majority of organisms present. The other phylum of any significance was arthropoda, which consisted almost exclusively of the dipteran larvae representatives, Chironomidae (blood worms) and Chaoborus (midge flies). These organisms are adapted to living in unconsolidated sediments characterized by low levels of dissolved oxygen.

Spatial variation in organism composition was not marked. Subtle differences in profundal benthic community may be explained by the hypolimnetic dissolved-oxygen condition which prevailed during the drought. Generally, the tubificid worms were the dominant group at most stations, but an assemblage of midge flies was dominant at the deep water station near Shasta Dam. Tubificid worms are generally tolerant of hypolimnetic stagnation and deoxygenation (Welch, 1952, p. 337), and their abundance may have resulted from the low levels of oxygen which prevailed at most stations during the drought. The presence of a more balanced population, including midge flies at the Shasta Dam station, would indicate that these species may ordinarily inhabit the sediment throughout the lake in greater numbers during periods of elevated hypolimnetic dissolved-oxygen concentrations. Dissolved oxygen at the Shasta Dam station did not reach the low levels observed in the tributary arms during the drought.

Seasonal changes in species composition must be determined for Shasta Lake during a normal hydrologic period before the effect of the drought can be fully assessed.

TABLE 16. - Benthic faunal composition of profundal sediments in Shasta Lake

Map symbol (fig. 6)	Lake station	Date of collection (1977)	Number of organisms per square meter	Principal phylum represented and percent	Number of genera represented
A	Shasta Lake near Shasta Dam.	Oct. 5	108	Arthropoda (57) Annelida (42)	11
B	Sacramento River arm near Lakehead.	June 20 Sept. 26	90 180	Annelida (92) Annelida (90)	12 14
C	McCloud River arm near Lakehead.	Sept. 27	69	Annelida (95)	12
D	Pit River arm at Allie Cove.	Sept. 27	163	Annelida (97)	12
E	Squaw Creek arm near Project City.	Oct. 4	47	Annelida (53) Arthropoda (46)	14
F	Pit River arm below Brushy Canyon.	Oct. 4	406	Annelida (92)	15

SUMMARY AND SUGGESTIONS FOR FUTURE STUDIES

An intensive limnological investigation of Shasta Lake was done during the 1977 drought. Water-quality conditions during 1978, a more normal hydrologic year, were monitored and compared to the drought condition. Results of water-quality analyses and physical profile measurements indicated that hydrologic influences had a profound effect on lake water quality during the drought.

Shasta Lake reached an all-time record low storage volume of about 13 percent of normal capacity in September 1977. The water-quality condition during 1977, the year of the worst drought recorded in northern California in more than 100 years, was considered to be a worst case situation. The low lake levels recorded throughout the drought resulted in the exposure of extensive nearshore sediments. Sediments washed into the lake and resuspended by wind generated waves and seiches were responsible for decreased light penetration. Increased dissolved solids and specific conductance, reduced dissolved-oxygen concentrations, and increased inorganic nitrogen and total phosphorous concentrations were also among the more notable water-quality effects of the drought.

Shasta Lake stratifies thermally in summer and freely circulates in winter without ice cover. During normal years, density currents at depth result in the development of an extensive metalimnetic zone and almost complete elimination of the hypolimnion. During the drought the temperature profiles in summer showed fairly pronounced hypolimnetic and epilimnetic layers, but the shallower water in the tributary arms resulted in an earlier breakup of stratification in the autumn.

Dissolved-oxygen concentrations during the drought showed a significant reduction in the bottom layers, and a hypolimnetic anoxic condition was observed at most tributary stations.

Biological samples of phytoplankton and benthic invertebrates were obtained in 1977. Diatoms were the predominant phytoplankton group in spring, summer, and autumn. Tubificid worms were the dominant group of benthic organisms at most stations, and their abundance was attributed to low dissolved-oxygen levels.

Additional lake surveys during normal hydrologic years would be beneficial. More specifically, future studies could involve:

1. Elucidation of internal density currents at depth and assessment of flow patterns in each of the major arms of the lake.
2. Calculation of a nutrient budget related to lake productivity.
3. Characterization and dating of lake sediment cores for nutrient and trace metal accumulation.
4. Primary productivity and chlorophyll a measurements in each tributary arm throughout the year.
5. Seasonal identification and enumeration of phytoplankton and benthic invertebrates.
6. Fish tissue analysis for toxic organics and trace metals.

Additional data are needed to determine the trophic condition of the lake. The data collected during the drought, even though representing an extreme condition, indicate that Shasta Lake does show signs of lower dissolved-oxygen concentrations and higher temperatures when the system is stressed.

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