WATER QUALITY OF CALERO RESERVOIR,

SANTA CLARA COUNTY, CALIFORNIA, 1981-83

By Daphne G. Clifton and Isabel S. Gloege

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CONVERSION FACTORS

For readers who prefer to use International System (SI) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below. In this report, water-quality units are SI; all other units are inch-pound.

Multiply	By	To obtain
acre	0.4047	hectares
acre-ft (acre-foot)	1,233	cubic meter
foot	0.3048	meter
ft^3/s (cubic foot per second)	0.02832	cubic meter per second
inch	25.4	millimeter
in/yr (inch per year)	25.4	millimeter per year
mile	1.609	kilometer
mi^2 (square mile)	2.590	square kilometer
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

Additional abbreviations	
cell/mL	cell per milliliter
col/100 mL	colony per 100 milliliters
CO_2	carbon dioxide
m	meter
m^3/d	cubic meter per day
µm	micrometer
µg/L	microgram per liter
meq/L	milliequivalent per liter
mg/L	milligram per liter
$(mg\ O_2/m^3)/d$	milligram oxygen per cubic meter per day
µS/cm at 25°C	microsiemen per centimeter at 25 degrees Celsius
NTU	nephelometric turbidity unit
N	nitrogen
P	phosphorus
TSI	trophic state index
O_2	oxygen

WATER YEAR

A water year is a 12-month period, October 1 through September 30, designated by the calendar year in which it ends. In this report, years are water years unless otherwise noted.

TRADE NAMES

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

WATER QUALITY OF CALERO RESERVOIR, SANTA CLARA COUNTY, CALIFORNIA, 1981-83

By Daphne G. Clifton[1] and Isabel S. Gloege[2]

ABSTRACT

Data were collected from December 1980 to September 1983 to describe water-quality conditions of Calero Reservoir and the Almaden-Calero canal, Santa Clara County, California. Results show that water in Calero Reservoir and the canal generally met water-quality criteria, as identified by the California Regional Water Quality Control Board, San Francisco Bay Region, for municipal and domestic supply, water contact and noncontact recreation, warmwater fish habitat, wildlife habitat, and fish spawning. Water-temperature profiles show that Calero Reservoir can be classified as a warm monomictic reservoir. Water-transparency profiles showed rapid attenuation of light with depth in the water column. The depth of the euphotic zone ranged from 1.5 to 5.0 meters. In winter and spring, light-extinction values generally were high throughout the water column; in summer and fall, values generally were high near the reservoir bottom. Dissolved-oxygen concentrations were less than 5.0 milligrams per liter in about 22 percent of the measurements--primarily summer and fall samples in hypolimnetic water representing one- to two-thirds of reservoir volume. Median pH values were 7.9 in the reservoir and 8.4 in the canal. Mean specific-conductance values were 299 microsiemens per centimeter at 25 degrees Celsius in the reservoir and 326 in the canal.

Calcium and magnesium were the dominant cations and bicarbonate the dominant anion in Calero Reservoir. Concentrations of total recoverable mercury in the bottom sediments in Calero Reservoir ranged from 0.06 to 0.85 milligram per kilogram, but concentrations in the water column were generally less than 1 microgram per liter. Mean total nitrogen concentration in Calero Reservoir was 1.00 milligram per liter, much of it in dissolved form (mean concentration was 0.85 milligram per liter). Mean total organic nitrogen concentration in Calero Reservoir was 0.65 milligram per liter, and mean total nitrate concentration was 0.21 milligram per liter. Mean total phosphorus and dissolved orthophosphorus concentrations were 0.05 and 0.019 milligram per liter, respectively.

The blue-green alga *Anacystis* generated large blooms in Calero Reservoir in fall, and the diatom *Cyclotella* caused major spring blooms. Net primary productivity in the euphotic zone ranged from -2,000 to 10,000 milligrams of oxygen per square meter per day, and the median value in the euphotic zone was 930. Carlson's trophic-state index, calculated using water transparency, total phosphorus, and chlorophyll-*a* values, indicated that the reservoir was eutrophic.

Fecal-coliform bacteria concentrations were less than 20 colonies per 100 milliliters in the reservoir and less than 200

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[2]Santa Clara Valley Water District.

colonies per 100 milliliters in the canal. Fecal-streptococcal bacteria concentrations were generally less than 45 colonies per 100 milliliters in the reservoir and up to 260 colonies per 100 milliliters in the canal.

INTRODUCTION

Built in 1935 as part of a multiple-reservoir construction project in Santa Clara Valley, Calero Reservoir (fig. 1) is used for water conservation, flood control, and recreation. The drainage area is small in relation to reservoir storage capacity, so that supplemental water from the Almaden Reservoir is also stored in Calero Reservoir. The Santa Clara Valley Water District plans to augment water supplies with water from the San Luis Reservoir via a canal now under construction. This canal water will be temporarily stored in Calero Reservoir prior to conveyance to city reservoirs. Because little was known about current water quality in Calero Reservoir or the potential effects of introducing San Luis Reservoir water, the U.S. Geological Survey and the Santa Clara Valley Water District (SCVWD) began a cooperative sampling program to define current water quality of the Calero Reservoir prior to the introduction of San Luis Reservoir water.

PURPOSE AND SCOPE

The Calero Reservoir study is one of a series of intensive 3-year reservoir studies in Santa Clara Valley (Pederson and others, 1978). The purpose of this report is (1) to characterize water quality conditions in Calero Reservoir and the Almaden-Calero Canal for the period 1981-83, (2) to identify factors that influence water quality, (3) to estimate biological productivity in Calero Reservoir, and (4) to describe the suitability of the reservoir water for ground-water recharge for municipal and domestic supply, recreation, and fish and wildlife habitat.

Data collected at three reservoir stations and one canal station include vertical profiles of water temperature, specific conductance, pH, dissolved oxygen, light transmission, and transparency. Other data include major chemical ions, nutrients, selected trace elements, bacteria, phytoplankton, and primary productivity. An analysis of total recoverable mercury in the sediment and dissolved mercury in the water column is also presented, because mercury has been detected in high concentrations in tissues of fish collected from the reservoir (Britton and others, 1974).

DESCRIPTION OF THE STUDY AREA

Reservoirs

Calero Reservoir (fig. 1) is in the western foothills of northern Santa Clara County about 10 miles south of San Jose, California. Surrounding vegetation consists of oak and pine trees and annual grasses used for pasture. There are few residential dwellings and no commercial activities around Calero Reservoir. The main dam, which rises 90 feet above Arroyo Calero (Calero Creek) to a crest altitude of 490 feet, provides a maximum capacity of 10,160 acre-ft at the spillway crest at altitude 483.9 feet. At this altitude, the reservoir has an area of 358 acres, a length of 2.2 miles, and a 9-mile shoreline. The outlet works consist of a 36-inch steel conduit, which is 481 feet long, encased in concrete, and controlled by a butterfly valve mounted in a concrete intake structure near the base of the dam and hydraulically operated from the crest of the dam.

Because Calero Reservoir's capacity (10,160 acre-feet) exceeds the potential runoff from its small (6-9 mi^2) drainage basin, water from the Almaden drainage basin (12 mi^2) is also stored in Calero Reservoir. Water is conveyed from Almaden Reservoir (capacity 1,780 acre-feet) via the Almaden-Calero canal, which also intercepts hillside runoff. The

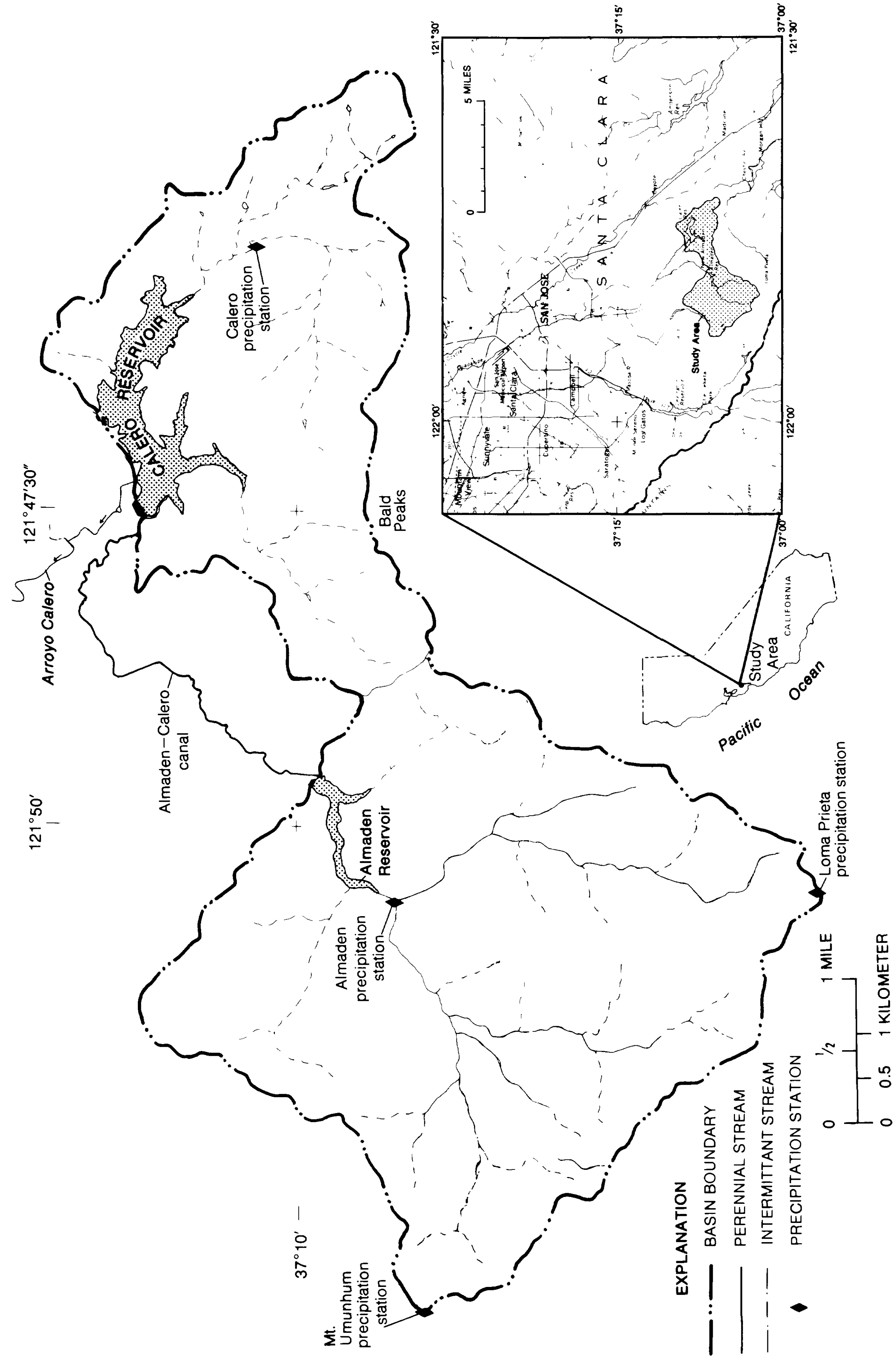


FIGURE 1.—Location of the study area.

canal enters Calero Reservoir about 500 feet south of the left abutment of the main dam and discharges water down a concrete chute. Water stored in Calero Reservoir is later released to groundwater recharge facilities during the summer months.

Geology and Soils

Slightly metamorphosed sedimentary and volcanic rocks of the Franciscan Complex of Jurassic and Cretaceous age constitute the main body of bedrock around Calero Reservoir. Locally, these rocks have been intruded by masses of serpentine, forming "silica-carbonate rock" in the sections altered by hydrothermal solutions.

Most of the rock around the reservoir is a type of sandstone (graywacke), although considerable shale and minor amounts of limestone and chert are also present. Metamorphosed volcanic rock occurs within the sedimentary rock near the dam and in large masses in the hills to the south. Masses of serpentine crop out in the hills west and southwest of the reservoir. Even though the erosion hazard in this area is moderate to high, sedimentation is not a major problem in Calero Reservoir because there are no major tributaries and because the drainage area is relatively small. Most of the sediment settles out in Almaden Reservoir, where the outlet works have been raised a total of 23 feet 4 inches since construction in 1935. Sedimentation along the Almaden-Calero canal is a problem, and frequent cleaning is necessary.

The soil around the reservoir is mainly Montara stony or rocky clay loam on 15- to 50-percent slopes, which are eroded to severely eroded. The dark-gray, alkaline surface soil ranges from 2 to 13 inches in thickness, holds 1 to 3 inches of moisture, and shows low fertility (U.S. Department of Agriculture, 1968; Gardner and others, 1958).

Climate

Air temperatures in the Calero Reservoir drainage basin generally are mild throughout the year. In summer, typical maximum daily temperatures average 85°F, and minimum daily temperatures average 54°F. In winter, maximum daily temperatures average 56°F and minimum daily temperatures average 37°F.

About 85 percent of the annual rainfall comes between November and March. The average annual rainfall was 28.8 inches at Calero precipitation station and 33.8 inches at Almaden precipitation station (fig. 1). Average annual rainfall for two other precipitation stations in the Almaden drainage area was 51.3 inches for Loma Prieta (altitude 3,791 feet) and 45.2 inches for Mount Umunhum (altitude 3,486 feet). Rainfall measured at Calero precipitation station during or up to one week prior to reservoir sampling was 4.2 inches during December 2-8, 1980; 0.1 inch during January 12-18, 1982; and 3.4 inches during April 26-May 2, 1983.

The mean annual evaporation rate at Calero Reservoir for the study period was 43.7 inches per year.

FIELD AND LABORATORY METHODS

Calero Reservoir

Vertical profiles of water temperature, specific conductance, pH, and dissolved oxygen were measured at sampling stations (fig. 2) by means of a Martek Mark 6 multiparameter water-quality instrument (1981-82) and a Hydrolab model 4041 multiparameter water-quality instrument (1983). A Martek transmissometer was used to measure light transmission and light extinction, and water transparency was measured using a Secchi disk and a Montedoro Whitney portable underwater solar illuminance instrument.

Water samples for chemical analyses and phytoplankton determinations were collected by a modified Van Dorn sampler.

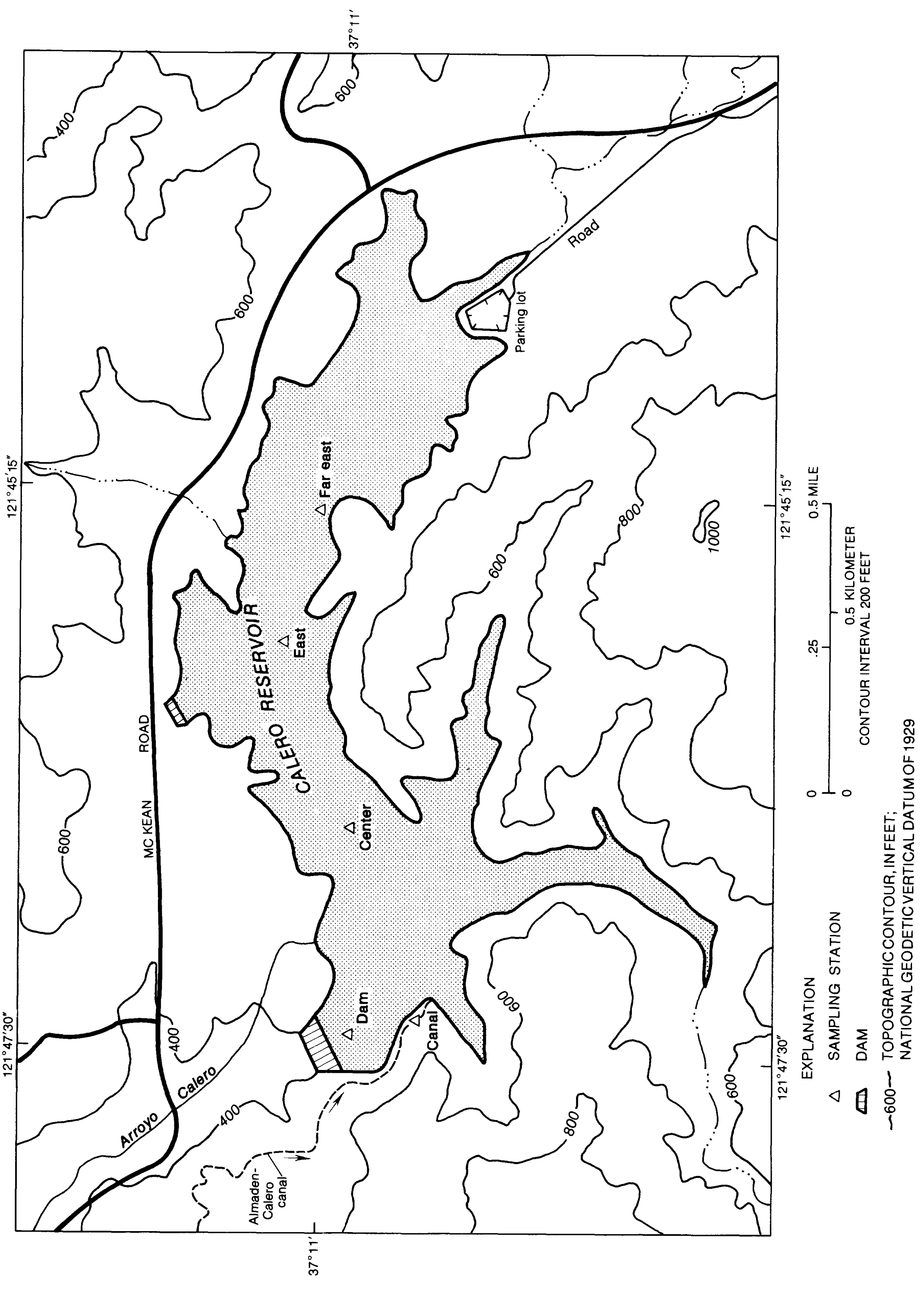


FIGURE 2.--Calero Reservoir and Almaden-Calero canal sampling stations.

Samples collected for chemical analyses in 1981-82 were sent to the SCVWD laboratory in Los Gatos, California, and analyzed by methods described by the American Public Health Association and others (1981). Samples collected for chemical analyses in 1983 were sent to the U.S. Geological Survey Denver Laboratory and analyzed by methods described by Brown and others (1970) and Skougstad and others (1979).

Phytoplankton samples collected in 1981-83 were identified to genus and enumerated at the U.S. Geological Survey Atlanta Laboratory according to methods described in Greeson and others (1977). Samples for chlorophyll analysis in 1981-82 were analyzed at SCVWD Los Gatos laboratory by methods described by the American Public Health Association and others (1981). Center-station chlorophyll samples from 1-m depth in 1981-82 and all phytoplankton samples collected in 1983 were analyzed at the Atlanta Laboratory according to methods described by Greeson and others (1977).

Water samples for fecal-coliform and fecal-streptococcal bacteria were collected in sterile bottles at shallow depth and analyzed by membrane-filter method. Primary productivity was estimated at center station using the oxygen light- and dark-bottle method (Greeson and others, 1977).

Bottom-sediment samples for analysis of total recoverable mercury were collected with an Eckman dredge. The SCVWD Los Gatos, California, laboratory analyzed 1981-82 whole-sediment samples by methods described in American Public Health Association and others (1981). The U.S. Geological Survey, Denver, Colorado, laboratory performed 1983 analyses by methods described by Skougstad and others (1979).

Almaden-Calero Canal

Water quality at the canal station was measured by portable field instruments, including a handheld mercury thermometer, a Leeds and Northrup pH meter, and a Yellow Springs Instruments specific-conductance meter. Dissolved-oxygen concentrations were determined by the alkali-iodide-azide modification of the Winkler method (Brown and others, 1970; Skougstad and others, 1979). Water discharge was measured according to procedures described by Buchanan and Somers (1969).

Water samples for chemical analyses were collected with a handheld depth-integrating sampler by the equal-width increment method (U.S. Geological Survey, 1977). Bacteria samples were collected in sterile bottles at the centroid of flow and analyzed in the same way as reservoir samples.

QUALITY-ASSURANCE PROGRAM

A quality-assurance program was developed to insure reliability of the water-quality data-collection program by the U.S. Geological Survey and the Santa Clara Valley Water District (SCVWD). Quality control was maintained throughout the field sampling and laboratory-analysis procedures, which followed standard U.S. Geological Survey methods (Skougstad and others, 1979; American Public Health Association and others, 1981). The on-site field instruments used to measure water-quality profiles, the Hydrolab and the Martek, were calibrated in the field during each sampling trip using standards and buffers from the SCVWD (1981-82) and U.S. Geological Survey (1983) laboratories.

Quality assurance for the SCVWD's dissolved-solids (DS) measurements were based on the calculated sum of the major constituents. The difference between the measured and calculated values ranged from 0 to 18 percent and had a median difference of 2 percent, which was within the 5-percent criterion.

Duplicate samples for trace-metals analysis collected on September 24, 1981, were analyzed by both the U.S. Geological Survey and Santa Clara Valley Water

District laboratories. Most dissolved constituents measured were low or were below detection limits. The differences in laboratory analyses were reasonably close, considering the different detection limits for each laboratory. The dissolved-mercury measurement made by the U.S. Geological Survey Denver laboratory, 4.7 µg/L, exceeded the criterion of 2 µg/L for drinking water (U.S. Environmental Protection Agency, 1976). A replicate analysis resulted in a concentration that was also high, 4.2 µg/L. The split sample analyzed by the SCVWD laboratory had a dissolved-mercury value of <1 µg/L. These differences between results might be explained by differences in sample treatment, such as length of time before analysis, refrigeration, or nearby storage of nutrients preserved with mercuric chloride.

Duplicate samples for nitrogen (as N) and phosphorus (as P) were collected at the center station at 1-m depth and analyzed by both laboratories. The median percent difference between the two laboratories for total N and dissolved N was 8 percent, which is outside the 5 percent criterion. The mean differences between measurements by the laboratories were 0.10 mg/L for total N and 0.06 for dissolved N. The difference between the two laboratories for total P and ortho-P showed much greater variability, partly because values are much closer to the detection limits. Concentrations ranged from 0.01 to 0.13 mg/L, and the mean differences between the values reported by the two laboratories were 0.02 mg/L for total P and 0.01 for dissolved P. Problems with the filtering apparatus for nutrients, which may have affected dissolved N and P concentrations for the 1982 samples, were noted at the Los Gatos laboratory.

SAMPLING DESIGN

Physical, chemical, and biological data were collected from December 1980 to September 1983 in the Calero Reservoir and Almaden-Calero canal. The three reservoir stations were selected to represent different depths: the dam station represents the deepest part of the reservoir; the center station, the middle depth; and the east station (or far east when reservoir water levels were high enough), the shallowest depth. Major ions, nutrients, and phytoplankton were collected from the epilimnion, metalimnion, and hypolimnion at each station during reservoir stratification and from equal increments below the water surface at other times. Samples for most constituents were collected four times each year. Samples collected in December and January represent the "winter" season; April and May represent "spring;" June samples represent "summer;" and August and September samples represent "fall." The canal station is located just upstream of the reservoir near the dam (fig. 2).

All data have been published by the U.S. Geological Survey (1982-84) and are not reprinted in this report except for purposes of interpretation.

PHYSICAL AND CHEMICAL CHARACTERISTICS

Reservoir Volume

Monthly mean and maximum reservoir volumes for Calero Reservoir for the period of record (1936-83) show a seasonal variation; volumes are greatest in spring and least in winter (fig. 3). The amount of variation depends mostly on precipitation, evaporation, and reservoir management.

Monthly mean reservoir volumes over the 3-year study ranged from a low of 200 acre-ft (2 percent of the total reservoir volume) in September 1982 to a high of 10,040 acre-ft (nearly 100 percent of the maximum storage capacity of 10,060 acre-ft) in May 1983 (fig. 4). Minimum volumes generally occurred in fall, and maximum volumes in spring. Monthly maximum reservoir volumes in 1982 and 1983 reached nearly 100 percent of reservoir capacity in spring, but in 1981 the maximum volume (7,020 acre-ft) was only 70 percent of reservoir capacity.

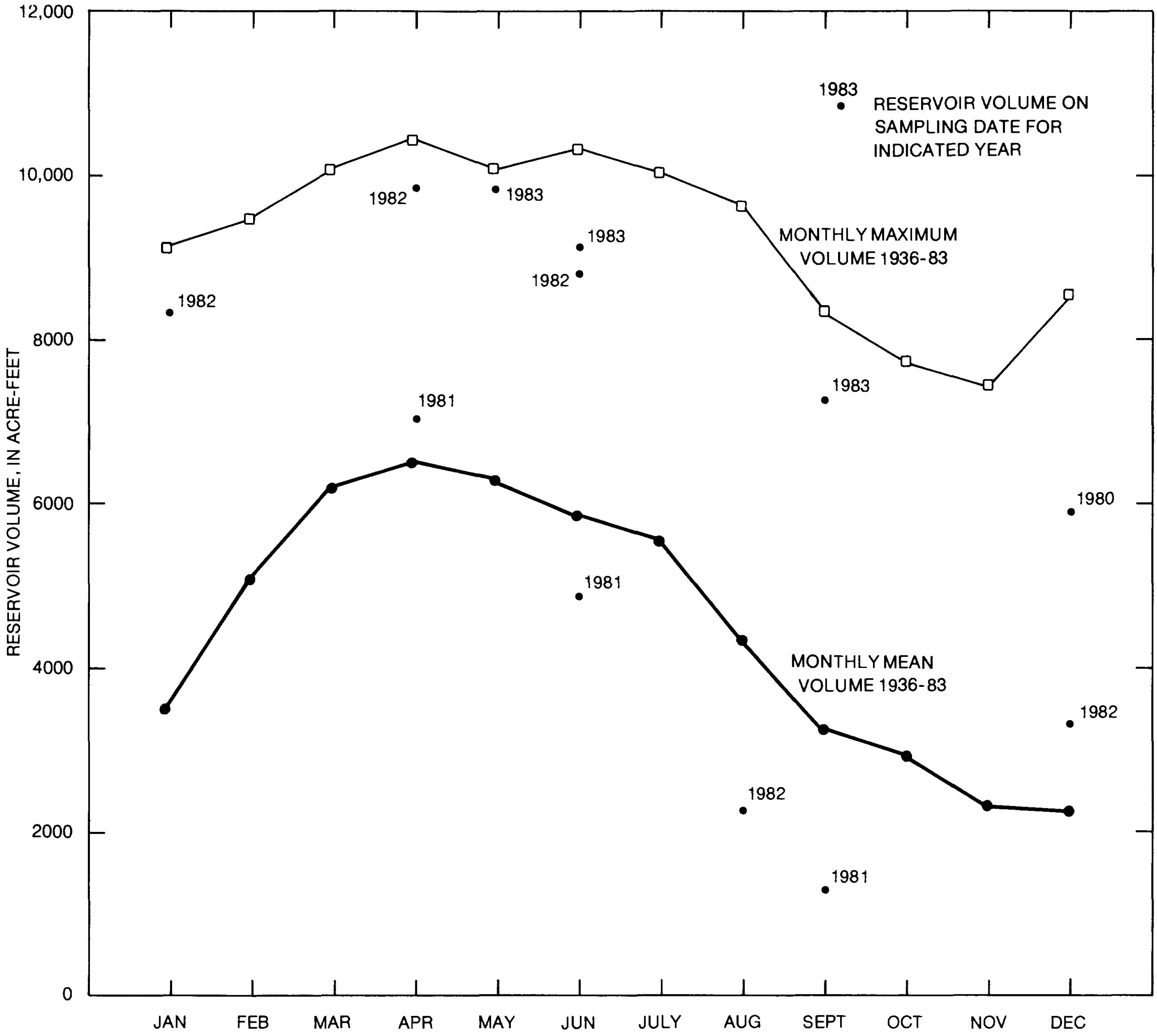


FIGURE 3.–Monthly maximum and monthly mean reservoir volume for Calero Reservoir, 1936-83.

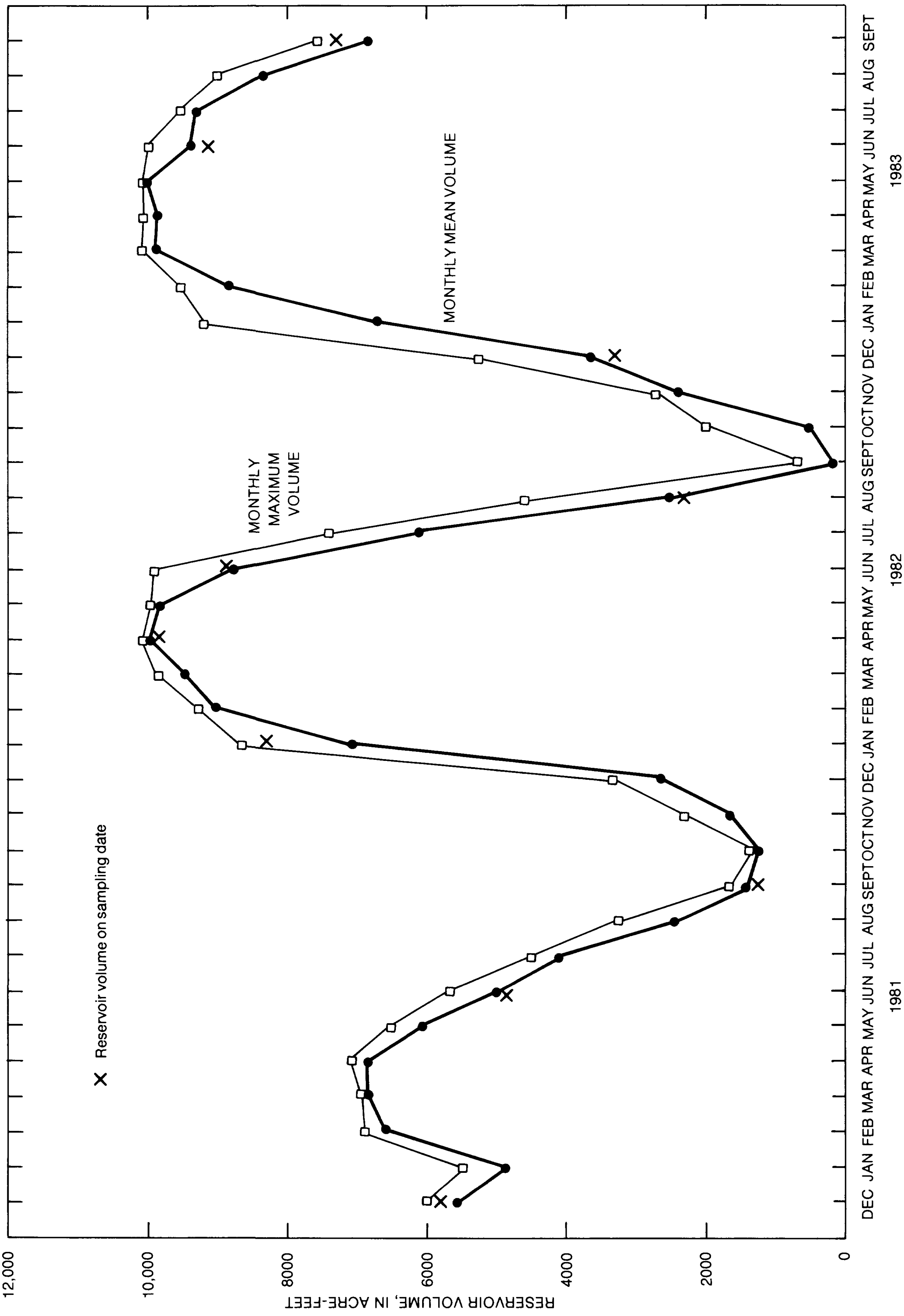


FIGURE 4.–Monthly maximum and monthly mean reservoir volume for Calero Reservoir, 1981-83.

Reservoir volume at time of sampling was compared to mean reservoir volume for the period of record, 1936-83, to determine whether the water-quality samples adequately represented the typical seasonal range of hydrologic conditions (fig. 3). Reservoir volume at spring and winter sampling dates exceeded the monthly mean volumes for the period of record by 5-30 percent in spring and 10-45 percent in winter. The 1982-83 summer and 1983 fall samples exceeded the monthly means for the period by 30-40 percent. These high volumes indicate that the 1982-83 samples probably represent water quality under the best conditions at high reservoir volume. Additional samples at lower reservoir levels are needed to better represent water quality.

Spring and summer 1981 and winter 1982 reservoir volumes differed by less than 10 percent from the mean for the period. Fall volumes for 1981-82 were 20 percent less than the mean for the period. Reservoir volume and management of reservoir volume affect the degree of thermal stratification and, consequently, water quality.

Water Temperature and Thermal Stratification

Water temperature is a major controlling factor for physical, chemical, and biological processes in a reservoir. Temperature affects the density of water, the solubility of oxygen, and the metabolic rate of organisms. High temperature is a contributing factor to nuisance algal blooms. Reservoir temperature can vary with depth or time of year and is directly influenced by solar radiation.

Thermal stratification (the layering of water of equal temperature) occurs when the overlying water is warmer and less dense than the underlying, cooler water, and when wind mixing occurs only in the less dense surface layer. These conditions usually result in the formation of three water layers: the epilimnion, an upper layer composed of warm water; the metalimnion, the middle layer of water, which decreases in temperature rapidly with depth; and the hypolimnion, the bottom, coolest layer (fig. 5) (Britton and Wentz, 1980). In a typical warm temperate monomictic lake with no ice cover, thermal stratification occurs in the summer, the entire water column circulates in winter, and surface temperature never drops below 4°C (Hutchinson, 1957; Ruttner, 1963). The water column in spring generally is in transition from a mixed to a stratified condition, and in fall the water column destratifies. Destratification (vertical mixing) releases nutrients from the hypolimnion, which may contribute to algal blooms. Temperature-stratification patterns in reservoirs in the San Francisco Bay area have been described by Britton and others (1974).

Water temperatures measured in Calero Reservoir over the 3-year sampling period ranged from 8.5 to 23.4°C. The maximum temperature was observed in September 1983 at the dam station in the epilimnion, and the minimum temperature was observed in January 1982 at the center station near the lake bottom. Thermal stratification in summer, lack of thermal stratification in winter, and minimum surface temperatures greater than 4°C indicate that Calero Reservoir is a warm monomictic water body. Water-temperature profiles during the study varied seasonally, as shown for center station in 1982 (fig. 6), and showed an increase from winter through fall. The water column was well mixed in winter, exhibited a gradual increase in temperature up to the surface in spring, and developed pronounced thermal stratification in summer from the differential warming of the surface layer. Fall profiles show lack of thermal stratification, probably because of the shallower, more easily mixed water. The 1982 seasonal temperature profiles are typical of 1981 and 1983 (not shown), except that the reservoir contained a fully developed thermocline in spring 1981, when reservoir volume was 70 percent of that in 1982-83, and in fall 1983, when volume was 3-4 times that in fall 1981-82. In both cases, reservoir volume was close to 7,000 acre-ft.

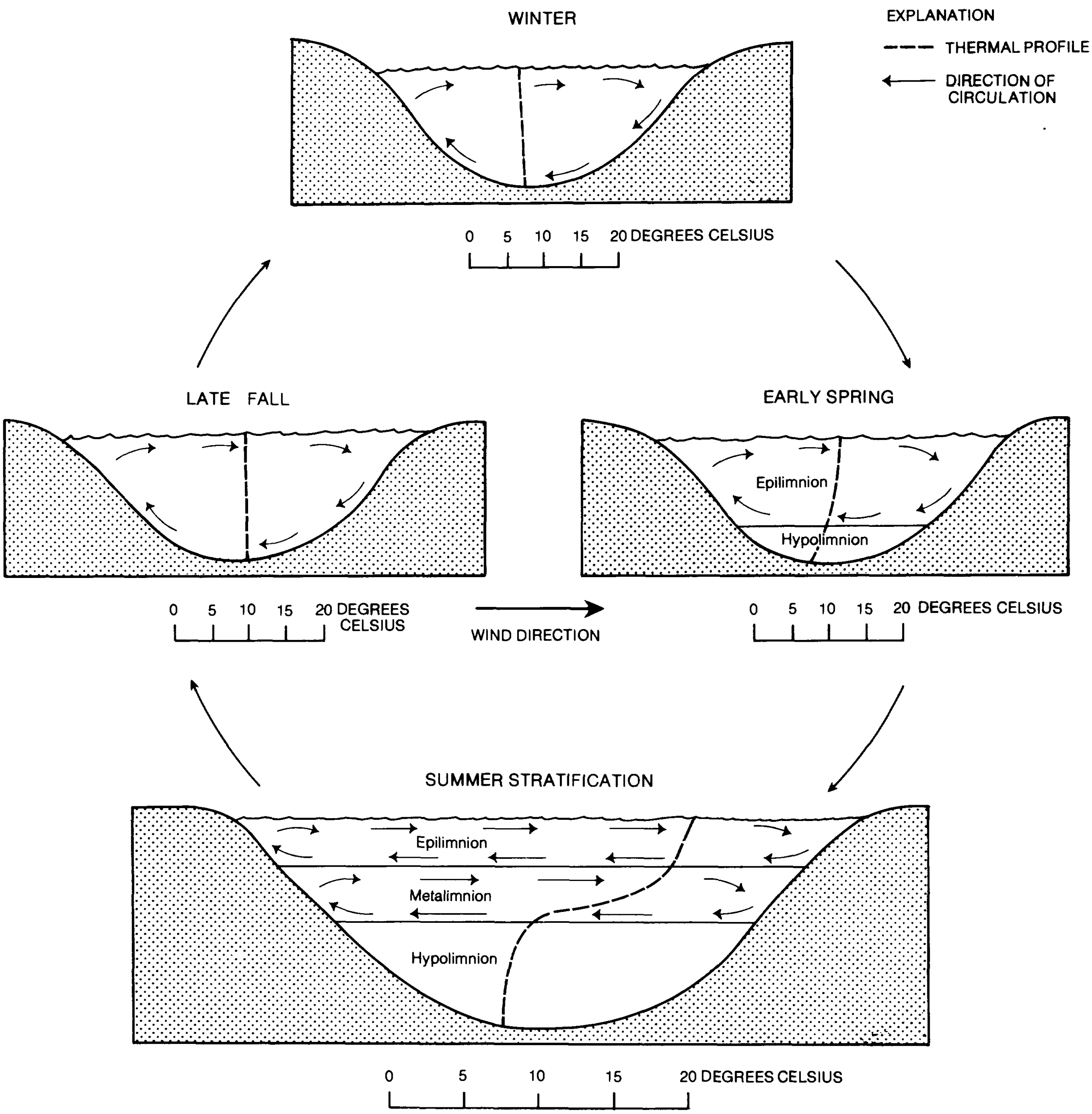
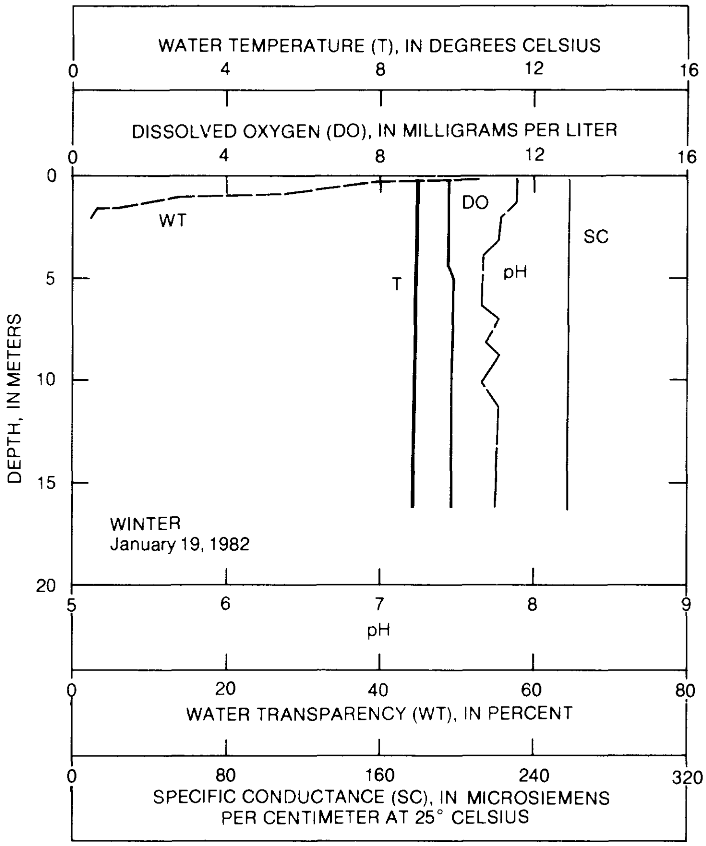


FIGURE 5.–Thermal stratification pattern in temperate lakes and reservoirs. (Modified from Britton and Wentz, 1980).



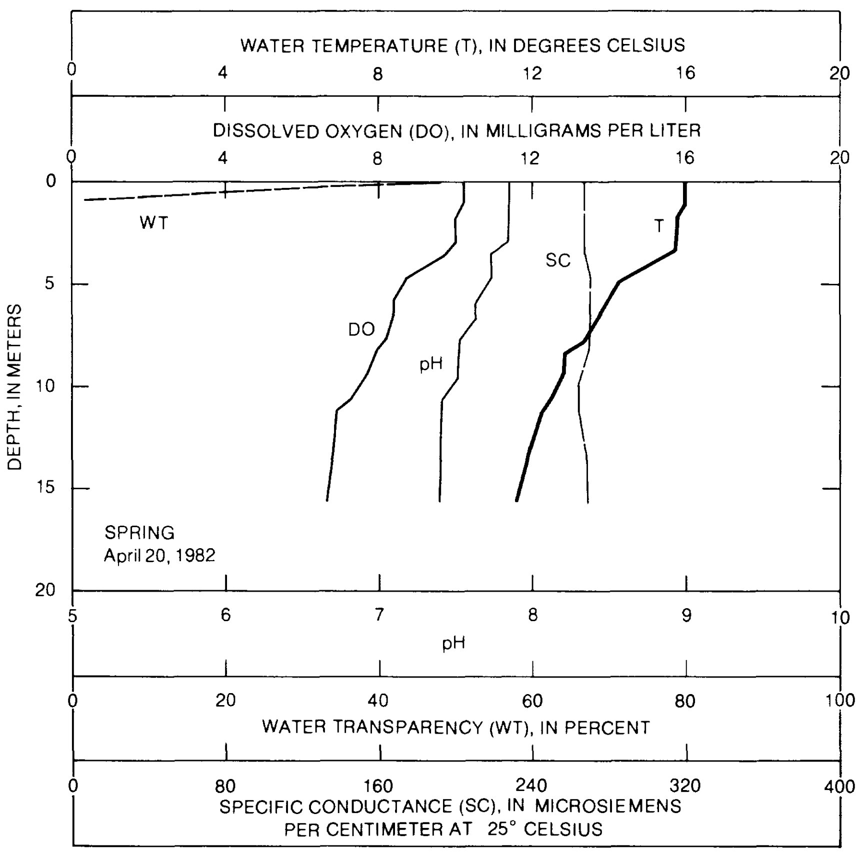
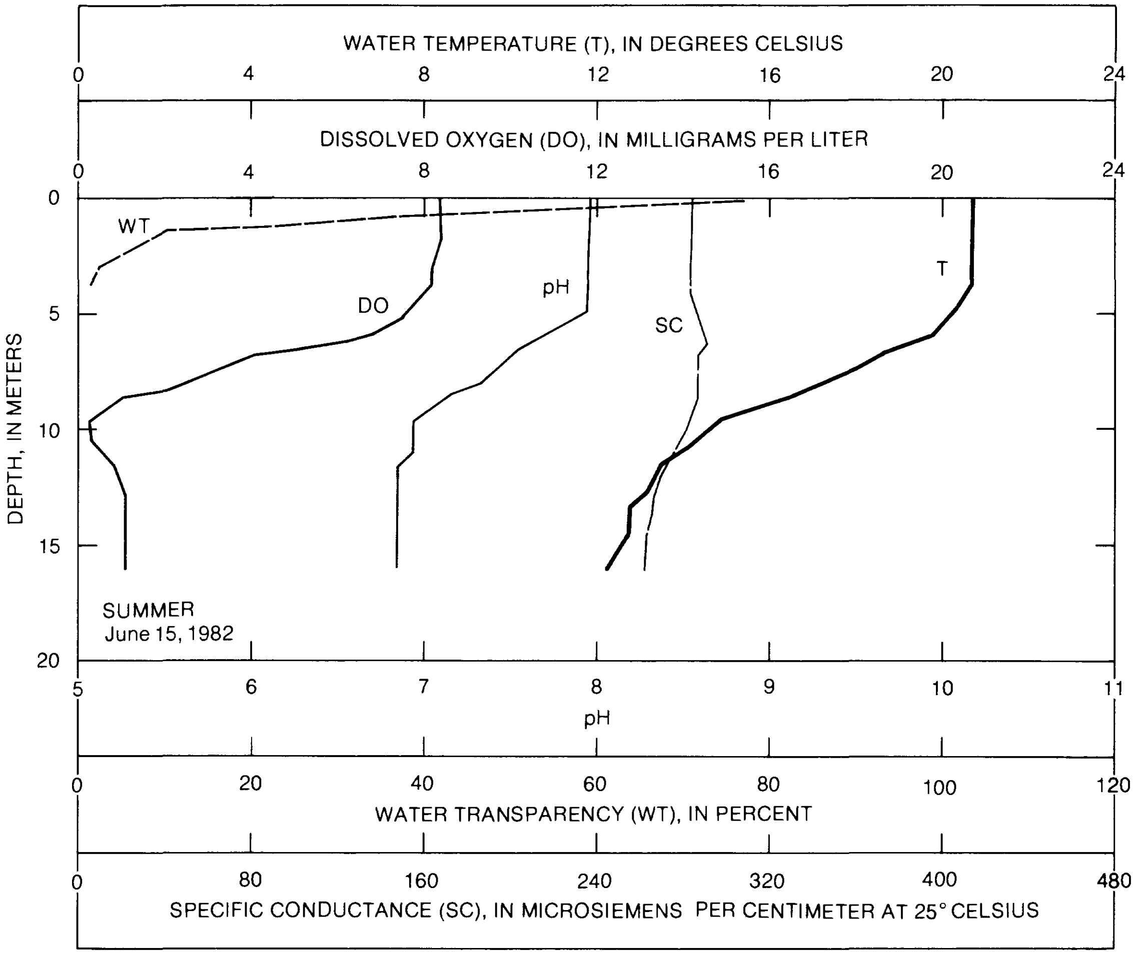


FIGURE 6.–**Seasonal water temperature, dissolved oxygen, pH, specific conductance, and water transparency for Calero Reservoir, center station, for 1982.**



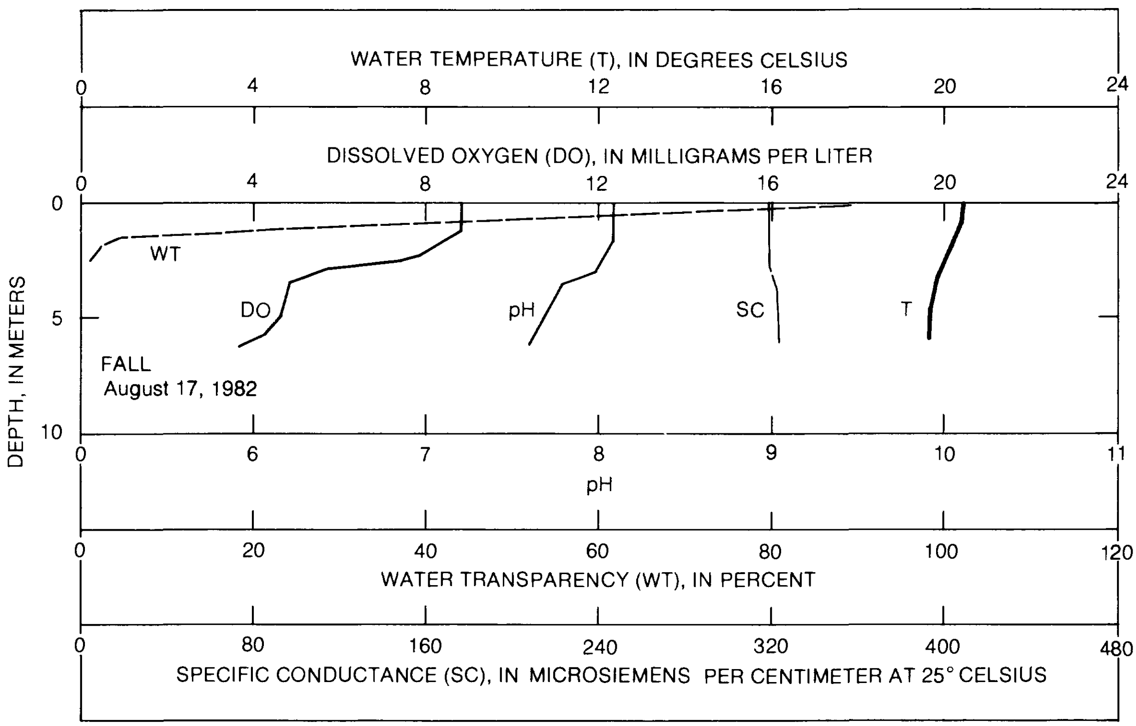


FIGURE 6.—Seasonal water temperature, dissolved oxygen, pH, specific conductance, and water transparency for Calero Reservoir, center station, for 1982--Continued.

Calero Reservoir dam station is about 7 m deeper than the center station, but temperature profiles follow a similar pattern at both stations. The water column at the east station mixed completely only in winter; a thermal gradient was present in the spring, summer, and fall. No hypolimnion was present in the shallow summer water at the east station. Bottom withdrawal of reservoir water for irrigation or recharge in the summer and early fall may reduce or eliminate the hypolimnion.

Water temperatures measured in the Almaden-Calero canal ranged from 7.5 to 34.0°C over the sampling period. The minimum temperature was measured in December 1982, and the maximum temperature was measured in June 1982, when streamflow was less than 0.01 ft^3/s.

When canal and reservoir water temperatures are the same, canal water intermixes with reservoir water. Differences in water temperature between the canal and reservoir water result in density differences. When canal water is warmer and less dense, it flows near the reservoir surface, and when canal water is cooler and more dense, it flows along the bottom of the reservoir. Thus water quality of canal water at different temperatures affects different layers in the reservoir, and cooler, turbid storm runoff may reach the bottom outlet of the dam more rapidly than warm runoff.

Water Transparency and Light Transmission

Because algal photosynthesis can only occur to depths where sufficient light is available, water transparency is an important factor governing biological activity in reservoirs. Measurements of water transparency, measured by a Secchi disk or photometer, show the percent of incident light or profiles of surface light remaining at depth. Algae, suspended sediment, and natural organic substances in water scatter light and reduce transparency. Values are also influenced by cloud cover and the angle of incidence of sunlight relative to the water surface (Wetzel, 1975).

Water transparency profiles in Calero Reservoir show a rapid attenuation (scattering or reflection) of light with depth at all stations and seasons. Transparency generally decreased to 5 percent by 3-m depth and showed little areal variation (fig. 6). Secchi-disk measurements indicated that water transparency was greatest in summer (table 1).

Measurement of light that passes through a given length (light transmission) in different water layers may be used to delineate zones of biological activity (algal or zooplankton blooms) or suspended sediment. The clearer the water, the greater the light transmission and the smaller the light extinction coefficient (see Glossary). As light extinction values increase, less light is available for photosynthetic organisms.

Light-extinction profiles for Calero Reservoir center station (fig. 7) show the effects of rainstorms, the thermocline, and algal populations. The upper figure represents light extinction profiles in a vertically well-mixed water column, which occurred in winter and spring during or after rainstorms and in one fall sample collected at unusually high water levels for the season. Maximum light-extinction values (23-32 η) occurred during or just after rainstorms and are probably associated with suspended material from storm runoff.

The lower figure (fig. 7) represents light-extinction profiles in thermally stratified or very shallow water. Spring 1981 and summer profiles showed minimum light extinction (3-7 η) near the surface. Light extinction increased with depth in summer and fall, when large algal populations also occurred (fig. 8; tables 2 and 3). High values near the reservoir bottom (10-20 η) may indicate zooplankton, sedimentation of phytoplankton cells, or disturbance of the reservoir bottom through biological activity, recreational use of the reservoirs, or bottom-water withdrawal from the reservoir. Light-extinction values at the dam were similar to those at the center station, and values at the east station generally showed no vertical change (U.S. Geological Survey, 1982-84).

Table 1.--Secchi disk, chlorophyll-*a*, and total phosphorus (P) concentrations; and trophic-state indices (TSI) for Calero Reservoir, 1981-83

[STSI = transparency TSI; CTSI = chlorophyll-*a* TSI; PTSI = total P TSI. All chlorophyll and total phosphorus samples collected at 1-m depth]

Date	Secchi disk (m)	STSI	Chloro-phyll-*a* (μg/L)	CTSI	Total P (mg/L)	PTSI
Center Station						
1980						
December 9	0.63	61	5.46	56	0.05	61
1981						
April 7	1.40	53	6.62	58	.06	64
June 16	1.10	55	4.79	55	.04	58
September 24	.50	63	15.50	66	.13	75
1982						
January 19	.40	66	.85	38	.05	61
April 20	.62	61	5.76	57	.04	58
June 15	1.29	54	2.90	50	.02	48
August 17	.80	59	16.00	67	.02	48
December 7	1.62	52	.70	36	.05	61
1983						
May 3	1.50	52	3.60	52	.05	61
June 15	2.28	48	.80	37	.02	48
September 7	1.40	53	--	--	.03	54
Dam Station						
1980						
December 9	.70	60	5.04	55	.04	58
1981						
April 7	1.70	51	5.56	56	.05	61
June 16	1.20	54	4.00	53	.03	54
September 24	.53	63	14.50	66	.06	64
1982						
January 19	.40	65	.68	36	.06	64
April 20	.65	61	3.23	51	.03	54
June 15	1.22	54	3.00	50	.02	48
August 17	1.17	55	16.00	67	--	--
December 7	1.37	53	.20	24	.06	64
Dam Station--Continued						
1983						
May 3	1.67	51	2.40	48	.04	58
June 15	2.19	48	.70	36	.01	38
September 7	1.20	54	--	--	.02	48
East Station						
1980						
December 9	.68	60	6.57	58	.04	58
1981						
April 7	1.20	54	7.46	59	.09	69
June 16	.80	59	6.49	58	.04	58
1982						
January 19	.50	63	3.09	51	.06	64
April 20	.57	62	18.80	68	.07	66
June 15	.94	57	3.20	51	.03	54
December 7[1]	1.65	51	1.00	40	.04	58
1983						
May 3	1.45	53	5.70	57	.04	58
June 15	1.70	51	1.60	44	.01	38
September 7	.96	57	--	--	.03	54
Mean TSI, by season						
Winter		59		44		61
Spring		55		56		61
Summer		53		48		49
Fall		58		66		57
Total		56		52		57

[1]Sample collected at far east station.

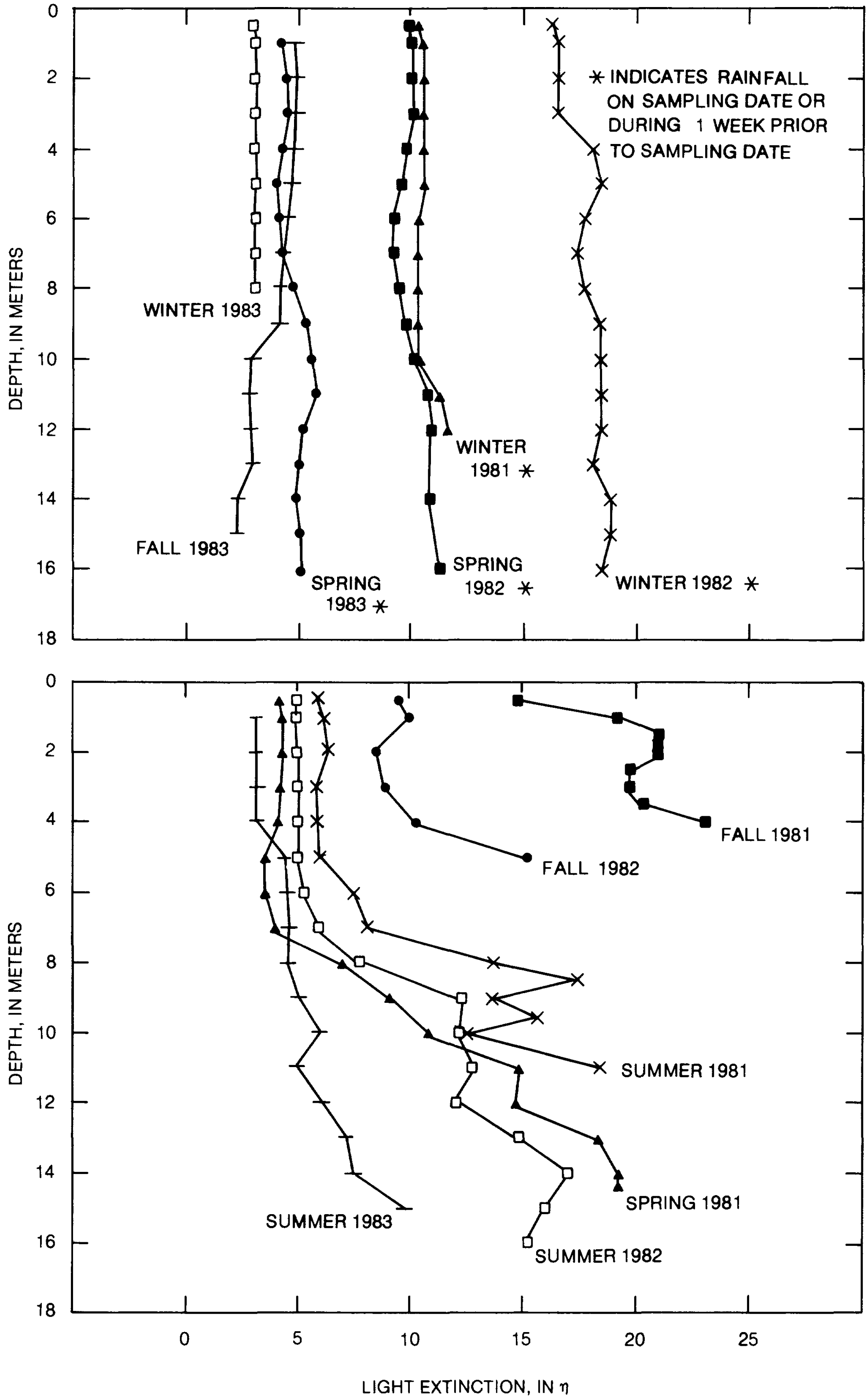


FIGURE 7.–Light extinction in Calero Reservoir, center station, 1981-83.

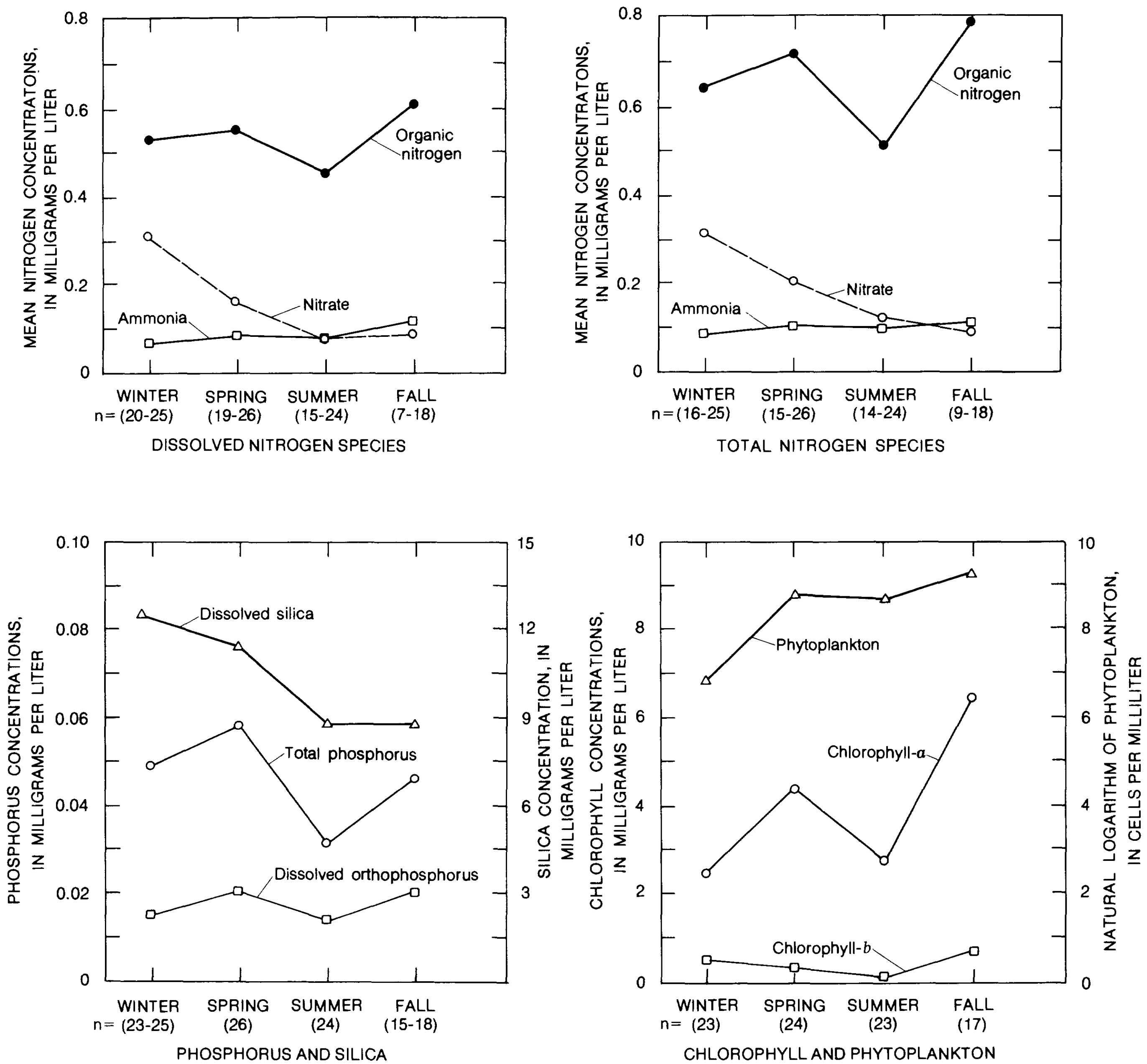


FIGURE 8.—Seasonal mean concentrations of dissolved and total nitrogen species, total phosphorus and orthophosphorus, dissolved silica, chlorophyll-*a* and -*b*, and phytoplankton concentrations for Calero Reservoir, 1981-83 (n= number of observations).

Table 2.--Taxonomy of dominant phytoplankton in Calero Reservoir[1]

[Dominant taxa ≥15 percent of a sample; phytoplankton identified to genus]

Chlorophyta   Green algae
-Chlorophyceae
--Volvocales
---Chlamydomonadaceae
----*Chlamydomonas*
--Chlorococcales
---Chlorococcaceae
----*Sphaerocystis*
----*Schroederia*
---Coelastraceae
----*Coelastrum*
---Oocystaceae
----*Closteriopsis*
----*Kirchneriella*
----*Oocystis*
----*Ankistrodesmus*
---Scenedesmaceae
----*Crucigenia*
----*Scenedesmus*
---Hydrodictyaceae
----*Pediastrum*
--Zygnematales
---Zygnemataceae
----*Mougeotia*

Euglenophyta   Euglenoids
-Euglenophyceae
--Euglenales
---Euglenaceae
----*Trachelomonas*

Cryptophyta
-Cryptophyceae
--Cryptomonadales
---Cryptomonadaceae
----*Chroomonas*
----*Cryptomonas*

Chrysophyta   Yellow-brown algae
-Xanthophyceae
--Heterocapsales
---Chlorosaccaceae
----*Ophiocytium*
-Bacillariophyceae   Diatoms
--Centrales   Centric diatoms
---Coscinodiscaceae
----*Cyclotella*
----*Melosira*
----*Stephanodiscus*
----*Coscinodiscus*
--Pennales   Pennate diatoms
---Fragilariaceae
----*Fragilaria*
----*Synedra*
----*Asterionella*
---Naviculaceae
----*Caloneia*
----*Navicula*
---Nitzschiaceae
----*Nitzschia*

Cyanophyta   Blue-green algae
-Myxophyceae
--Chroococcales
---Chroococcaceae
----*Anacystis*
--Oscillatoriales
---Oscillatoriaceae
----*Oscillatoria*
----*Lyngbya*
--Nostocales
---Nostocaceae
----*Aphanizomenon*

[1]Hierarchy or taxa is organized as follows:
Division
-Class
--Order
---Family
----Genus

Table 3.--Dominant phytoplankton and phytoplankton counts in Calero Reservoir, center station

[B, blue-green; C, cryptophyta; D, diatom; E, euglenoid; G, green; Y, yellow-brown. From left to right within each column, and top to bottom for each date, represents from greater to lesser abundance in sample]

Date	Total number of cells per milliliter at 1 m	Dominant taxa in water column	
		At 1-m depth	Below 1-m depth
1980			
December 9	3,100	*Pediastrum*(G)	*Pediastrum, Aphanizomenon*(B)
1981			
April 7	4,700	*Aphanizomenon*(B), *Pediastrum*	*Sphaerocystis*(G), *Scenedesmus*(G), *Aphanizomenon*, *Fragilaria*(D)
June 16	15,000	*Melosira*(D)	*Melosira, Pediastrum*, *Anacystis*(B), *Aphanizomenon*
September 24	5,300	*Lyngbya*(B), *Pediastrum*	*Pediastrum, Lyngbya*
1982			
January 19	43	*Trachelomonas*(E), *Nitzschia*(D)	*Nitzschia, Scenedesmus*(G), *Trachelomonas*
April 20	870	*Cyclotella*(D),	*Cyclotella, Coelastrum*(G), *Melosira*(D)
June 15	4,900	*Anacystis*(B), *Oscillatoria*(B)	*Melosira*
August 17	58,000	*Anacystis*	*Anacystis, Oscillatoria*
December 7	120	*Chlamydomonas*(G), *Ophiocytium*(Y)	*Chlamydomonas, Oocystis*(G), *Asterionella* (D)
1983			
May 3	13,000	*Cyclotella*(D)	*Cyclotella, Anacystis*(B)
June 15	2,800	*Schroederia*(G), *Anacystis*	*Cyclotella, Anacystis*, *Schroederia*
September 7	3,400	*Anacystis, Cyclotella*	*Anacystis, Cyclotella*

Dissolved Oxygen

Dissolved oxygen is essential to the metabolism of aerobic aquatic organisms; it also affects the use of many essential nutrients. Algal photosynthesis, respiration, bacterial decomposition, and chemical reactions continually change the oxygen concentration in water. Oxygen solubility is inversely related to temperature and directly related to barometric pressure. Oxygen saturation is defined as the theoretical maximum dissolved-oxygen concentration for a given temperature and pressure at equilibrium. Seasonal thermal stratification can also influence oxygen concentration (fig. 6). In winter, when the water column is well mixed, the oxygen is close to 100 percent saturation. During summer stratification, oxygen concentration may be high in the epilimnion from atmospheric exposure and algal productivity and low in the hypolimnion from lack of atmospheric exposure and losses through respiration and decomposition.

Dissolved-oxygen concentration measured in Calero Reservoir ranged from 0.0 mg/L in 2 percent of the hypolimnetic samples to 11.2 mg/L in some surface samples. The range of percent oxygen saturation was from 0 percent in many hypolimnetic samples to 118 percent at the east station near the surface.

The winter profile of dissolved-oxygen (DO) concentrations (fig. 6) at Calero Reservoir center station indicates that the water column was well mixed. In spring, dissolved oxygen decreased below the epilimnion. In summer, a zone of oxygen depletion formed in the hypolimnion, where DO concentrations were 0.0-0.5 mg/L. The metalimnetic oxygen minimum, which formed near 10-m depth, may have resulted from decomposition of suspended oxidizable material or from respiration by large populations of aquatic animals. DO concentrations generally decreased with depth in the fall. Depletion of oxygen below the 5.0 mg/L minimum required for warmwater fisheries habitat (California Regional Water Quality Control Board, San Francisco Bay Region, 1982) occurred in 22 percent of the samples, in hypolimnetic water representing one- to two-thirds reservoir volume in summer 1981-83 and one-third to one-half volume in fall 1982-83.

DO profiles at the dam station (not shown) were similar to the center-station profiles. Oxygen depletion was more advanced in spring 1981 at the dam station, perhaps because the reservoir was at 70 percent capacity, compared to nearly 100 percent in spring 1982 and spring 1983. A distinct thermocline and hypolimnetic oxygen depletion were observed at the dam station in fall 1983, when water was much deeper than average. Bottom withdrawal of water from near the dam may affect the DO distribution with depth through removal of water in the hypolimnetic zone. This phenomenon may explain the much less extensive hypolimnion in 1981-82 fall profiles.

DO profiles at the east station (not shown) generally had a fully mixed water column in winter. DO decreased only slightly with depth in spring samples. All values were greater than 5.0 mg/L. In spring 1983, DO was greatest at a depth of 2 m and was supersaturated, possibly because of oxygen produced by large algal populations. A bloom of the diatom *Cyclotella* produced 49,000 cells/mL at depths of about 1 and 4 m at the east station. Net primary productivity was 1,200 and -400 (mg O_2/m^3)/d at depths of 0.8 and 3.4 m, respectively (table 4). This increase in oxygen in the metalimnion during stratification is one of the most common divergences from the DO stratification pattern. DO concentrations are lower in the epilimnion because oxygen solubility decreases at higher temperatures, and lower in the hypolimnion because respiration reduces available oxygen. Summer profiles showed no hypolimnion, and only in 1983 was the DO concentration close to zero (0.7 mg/L).

DO concentrations measured at the Almaden-Calero canal station ranged from 7.5 mg/L in May 1983 to 14.6 mg/L in April 1982, and DO saturation ranged from 88 to 185 percent. DO was generally higher at the canal station than at the

Table 4.--Light- and dark-bottle estimates of primary productivity for Calero Reservoir, center station, 1981-83

[GP = gross primary productivity, NP = net primary productivity, R = respiration; resulting negative respiration values are indicated as 0]

Date	Time (hours)	Bottle depth (m)	Productivity [(mg O_2/m^3)/d]			Depth to 1 percent of surface light	
			GP	NP	R	Time (hours)	(m)
1980							
December 9	1400	1.0	1,900	960	960	1039	2.1
		2.0	1,400	1,400	0		
1981							
April 7	1615	1.0	1,800	1,800	0	0935	4.2
		2.0	930	930	0		
		3.0	740	740	0		
		4.0	0	0	0		
June 16	1515	1.0	3,800	2,400	1,400	0938	3.9
		2.0	3,300	1,400	1,900		
		3.0	950	-480	1,400		
		4.0	950	-1,400	2,400		
September 24	1230	1.0	2,700	1,600	1,100	1024	1.7
		1.7	530	0	530		
1982							
April 20	1330	1.0	2,600	2,600	0	0957	1.5
		1.7	870	0	870		
		2.5	0	-870	870		
June 15	1330	1.0	1,600	0	1,600	0923	3.8
		2.0	1,400	-400	1,800		
		3.0	600	-1,200	1,800		
		4.0	200	-2,000	2,200		
August 17	1237	.8	11,400	10,000	1,400	0945	2.5
		1.5	8,100	6,700	1,400		
		2.2	3,800	3,300	470		
		3.0	1,400	2,900	0		
December 7	1430	1.0	430	430	0	1100	3.9
		2.0	430	430	0		
		3.0	430	430	0		
		4.0	0	0	0		
1983							
May 3	1430	.8	1,600	1,200	400	1200	3.5
		1.6	1,600	1,200	400		
		2.6	0	0	0		
		3.4	400	-400	800		
June 15	1430	1.2	670	1,330	0	1030	5.0
		3.8	0	-670	670		
		5.0	0	0	0		
September 7	1430	1.0	1,360	1,820	0	0930	5.0
		2.0	2,270	2,270	0		
		3.0	0	0	0		
		4.5	450	910	0		

reservoir stations over the period of study, possibly because of the canal's large algal populations (not sampled) and its greater surface exposure relative to volume.

pH

The pH is defined as the negative logarithm of free hydrogen-ion activity (Hem, 1985). Solutions greater than 7 are termed basic (alkaline), less than 7 acidic, and equal to 7 neutral. In most lakes, pH ranges from 6 to 9. Although interaction of hydrogen and hydroxide ions with bicarbonate largely governs the pH of natural water, photosynthesis and respiration of aquatic plants and animals may also alter pH. The uptake of carbon dioxide (CO_2) during photosynthesis increases the pH of the water, and the release of CO_2 during respiration decreases the pH value. Seasonal changes in pH values also follow the thermal stratification pattern (fig. 6). In winter, when the water column is well mixed, pH values are similar from surface to bottom. When a reservoir is fully stratified in summer and early fall, algal productivity in the epilimnion and respiration throughout the water column generally result in higher epilimnetic pH values and lower hypolimnetic pH values.

The pH values in Calero Reservoir ranged from 6.8 to 8.6, and the median pH was 7.9. The pH profiles showed minimal areal variations between reservoir stations (U.S. Geological Survey, 1982-84). Except in winter, the pH values decreased with depth; the greatest decrease was observed when the reservoir was thermally stratified (fig. 6). In June 1981, the sharp decrease of pH in the hypolimnion, low DO concentration, and high levels of respiration indicated that bacteria or zooplankton may have been consuming the large phytoplankton populations, which included 8,000-23,000 cells/mL of *Melosira* and *Anacystis*. Low reservoir volume, 40 percent less than in June 1982 and 1983, might partly explain the higher phytoplankton densities in the June 1981 samples.

The pH in the Almaden-Calero canal samples ranged from 8.1 in June 1983 to 9.1 in June 1982, and median pH was 8.4. The higher pH and DO values measured in the canal compared to the reservoir may indicate large algal populations, although algae samples were not collected.

Specific Conductance

Specific conductance (SC), reported in microsiemens per centimeter at 25°C, is a measurement of a solution's ability to conduct an electric current (Hem, 1985). Because SC relates to the concentration of ionized minerals in water, it can be used to estimate the concentration of dissolved solids in water. Values generally increase in summer because of evaporation and decrease during rainstorms because of dilution.

SC in Calero Reservoir ranged from 250 to 366 µS/cm, and mean and median values were 299 and 296 µS/cm, respectively. The maximum SC value was observed in September 1981, when the reservoir was only 13 percent of maximum capacity; the minimum SC value was observed in January 1982 during a period of moderate rain, when the reservoir was 80 percent of capacity. At reservoir volumes of 8,000 acre-ft or more, the average value for SC was generally less than 300 µS/cm. Generally, at reservoir volumes of less than 8,000 acre-ft, the SC was 300 µS/cm or greater.

Variations in SC profiles (fig. 6) were minimal between sampling stations, seasons, and depths (U.S. Geological Survey, 1982-84). SC values tended to increase with the season from winter to fall. In summer, SC values generally were greatest in the metalimnion, where biota may have been more abundant. Biota may decrease major ions by uptake or contribute them during decomposition. Fall profiles lacked a hypolimnion, possibly because of bottom-water withdrawal from the reservoir.

Kendall's tau (see Glossary) was used to determine associations of selected water-quality constituents. Statistically significant negative correlations (n=58, where n=number of observations; $P<0.05$, where $P<0.05$ = probability of less than 5 percent that the correlation is not real) were found between SC and turbidity for all stations, except at the dam, where bottom-water withdrawal may raise turbidity levels. Generally, turbidity increased and SC decreased following rainstorms in winter and spring; SC increased in summer and fall, probably because of evaporation and the absence of rainstorms.

SC is closely proportional to concentrations of major ions in a typical bicarbonate-type lake. A significant positive correlation was found between SC and dissolved solids (DS) at the reservoir stations ($P<0.01$). DS concentration was estimated by the regression of DS versus SC, resulting in the following relation:

$$DS = 0.37\ (SC) + 62.$$

SC was 250-366 μS/cm, and DS was 145-212 mg/L, for n = 58 observations in common. The coefficient of determination, r^2, was 0.80 (see Glossary).

The straight-line formula $DS = X \cdot SC$ is often used for calculating approximate DS values from SC determination; X is usually between 0.55 and 0.75 (Hem, 1985). The X value for Calero Reservoir was 0.58.

SC measured in the Almaden-Calero canal ranged from 267 to 367 μS/cm; the mean value was 326 μS/cm. Maximum SC was observed in April 1982 after a light rain. Minimum SC was observed in January 1982 during a period of moderate rain; this was the only SC value less than 320 μS/cm. DS concentration was not estimated from SC measurements because of the scarcity of samples.

Major Ions

The major ions comprise most of the dissolved solids (DS) measured. The primary cations are calcium, magnesium, sodium and potassium; the associated anions are bicarbonate, sulfate and chloride. These are essential plant nutrients and are usually not limiting in most lakes. Under natural conditions, the concentration of major ions in natural water relates to the minerals in rocks found in the drainage basin, but human activities may add significant amounts of these constituents. The buffering action of bicarbonates influences concentrations of phosphorus and other trace constituents (Hem, 1985; Wetzel, 1975).

Percent major-ion concentrations (calculated as milliequivalents per liter, the equivalent weight of chemical dissolved in one liter of water) in Calero Reservoir showed little areal or seasonal variation, although concentrations of the dominant ions were greater in fall, probably as a result of evaporation (U.S. Geological Survey, 1982-84). Relative dominance of major ions is shown in trilinear diagrams in figure 9. Bicarbonate usually accounted for more than 80 percent of the anion balance, and chloride and sulfate generally accounted for the remainder. Bicarbonate concentrations ranged from 160 to 250 mg/L and had a mean of 172 mg/L. Calcium made up 42-50 percent of the cation balance in the reservoir samples; concentrations ranged from 23 to 36 mg/L and had a mean of 28 mg/L. Magnesium made up 36-42 percent of the cation balance in the reservoir; concentrations ranged from 12 to 21 mg/L and had a mean of 16 mg/L. Calcium concentrations in the Almaden-Calero canal ranged from 18 to 37 mg/L, and the mean was 27 mg/L. Percent magnesium content of canal water was generally higher than in reservoir water (fig. 9), the range of magnesium concentrations was 13-38 mg/L, and the mean was 25 mg/L.

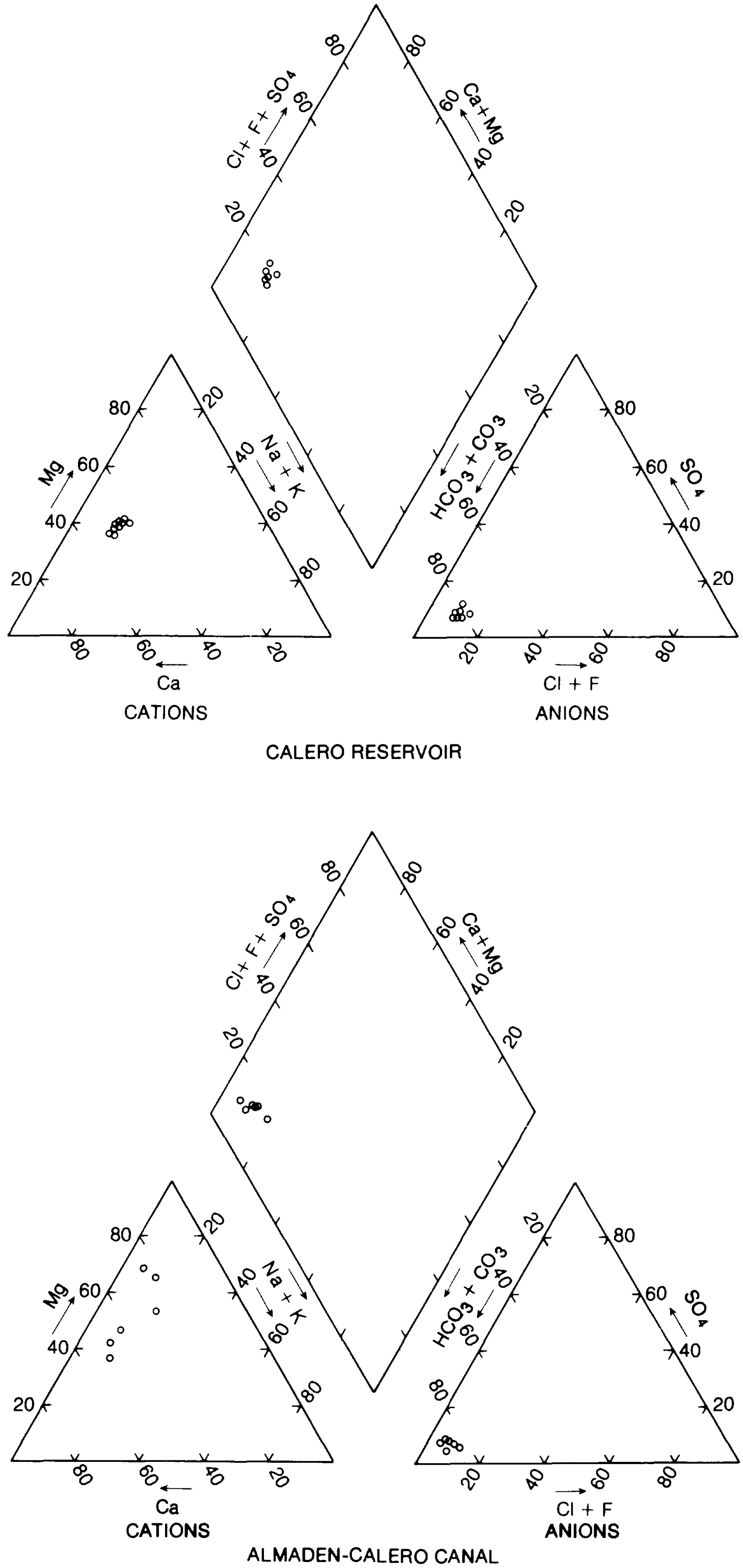


FIGURE 9.–Major-ion composition, in percent, of water in Calero Reservoir and Almaden-Calero canal for 1981-83. (Many data points are hidden in the Calero Reservoir plot).

Calcium and magnesium were the dominant cations, and bicarbonate was the dominant anion in the reservoir. The general character of the reservoir water is "calcium-magnesium bicarbonate," because calcium and magnesium are first and second in order of abundance among the cations, but neither amounts to 50 percent of all cations, and bicarbonate amounts to 50 percent or more of the anions (Piper and Garrett, 1953). Canal water is "magnesium-calcium bicarbonate," because magnesium, in milliequivalents per liter, was more dominant than calcium in the canal samples.

Hardness chiefly results from calcium and magnesium ions in water, although iron, barium, strontium, and manganese can also be important. Hardness characterizes the total dissolved solids in water, and the carbonated fraction measured is chemically equivalent to bicarbonates in water. Moderately hard water has hardness concentrations of 61 to 120 mg/L, and hard water has concentrations of 121 to 180 mg/L (Hem, 1985). Hardness (as $CaCO_3$) in Calero reservoir ranged from 110 to 170 mg/L, and the mean was 139 mg/L. Hardness in the Almaden-Calero canal ranged from 130 mg/L in January 1982 after a period of heavy rain to 210 mg/L in April 1982; the mean for the canal was 171 mg/L.

Alkalinity is the acid-neutralizing (buffering) capacity of water. Commonly occurring materials that increase alkalinity are bicarbonates, carbonates, phosphates, and hydroxides. Alkalinity in municipal water supplies is important because it affects the amounts of chemicals needed for water treatment. Naturally occurring concentrations of alkalinity (as $CaCO_3$) in drinking water up to 400 mg/L are not a health problem (U.S. Environmental Protection Agency, 1976). Alkalinity concentrations in the reservoir ranged from 100 to 210 mg/L, and the mean was 133 mg/L. Almaden-Calero canal alkalinity ranged from 120 to 202 mg/L, and the mean was 168 mg/L.

Dissolved silica, which derives from mineral sources, is moderately abundant in freshwater. The range of concentrations of silica most common in natural water is 1-30 mg/L (Hem, 1985). Silica is a major component of diatom cell structure and a major influence on diatom productivity. Assimilation of dissolved silica by diatoms and the sedimentation of diatoms from the euphotic zone can decrease available silica in the water column and epilimnion. In Calero Reservoir, seasonal maximum mean dissolved-silica concentrations were 12.4 mg/L in winter and 11.5 mg/L in spring; the minimum was 8.8 mg/L in both summer and fall (fig. 8). Dissolved-silica values and reservoir volume were high throughout 1983. Total phytoplankton and chlorophyll-*a* correlated negatively[3] ($P<0.01$) with dissolved silica concentration in winter, summer, and fall samples, but did not correlate for spring samples. A probable explanation is that abundant phytoplankton in summer and fall assimilate available silica; conversely, silica concentrations are higher in winter, when phytoplankton are not abundant. In summer, silica concentrations were lower in the epilimnion and higher in the hypolimnion. Silica concentrations correlated positively ($P<0.05$) with depth in summer and fall at the same time that phytoplankton populations (in summer) and chlorophyll-*a* concentrations (in fall) were negatively correlated with depth ($P<0.05$).

Trace Constituents

The trace constituents measured in this study included aluminum, arsenic, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, vanadium, and zinc. Trace constituents generally occur in low concentrations (<100 μg/L) in water. Many are essential plant nutrients, but some may be toxic even at low concentrations. Trace constituents are usually transported in the dissolved state or

[3]Sample sizes for correlation analyses included from 17 to 25 paired observations.

attached to sediments, which settle to the reservoir bottom. Under anaerobic conditions in the hypolimnion in late summer and fall, many trace constituents in the sediment dissolve and remobilize into the water column, where toxic concentrations may come into contact with biota in the epilimnion during such periods of rapid mixing as fall overturn.

Samples for trace-constituent analysis were collected from the water column at the Calero Reservoir center station once each year in fall (table 5). Most dissolved constituents measured were low in concentration or less than the detection limits. Boron concentrations (90-170 μg/L) were the highest of any trace constituent but were not critical to drinking-water quality (U.S. Environmental Protection Agency, 1976). The dissolved-mercury concentration of 4.7 μg/L measured in 1981 by the U.S. Geological Survey laboratory did not meet the drinking-water criterion of 2 μg/L.

Mercury data collected from Calero Reservoir by several different agencies in 1971 include water samples containing 0.0 and 3.0 μg/L dissolved mercury in March, 2.0 μg/L in May, and 0.0 μg/L in September (Britton and others, 1974).

Although dissolved mercury was generally not detectable in the water column in 1981-83 samples, mercury stored in bottom sediments in Calero Reservoir may dissolve into the water under anaerobic conditions. Hypolimnetic water released from the bottom-outflow structure at the dam might contain dissolved mercury. A clearer picture of seasonal changes in dissolved-mercury concentrations in Calero Reservoir might be obtained from samples collected more than once a year.

Mercury in Bottom Sediments

Evidence of mercury contamination of surface water from abandoned mercury mines led to a large-scale sampling program in 1971 by many agencies to determine mercury concentrations in sediment and fish in Santa Clara Valley reservoirs. Britton and others (1974) reported that in April 1971 samples of largemouth bass, carp, catfish, bluegill, black crappie, and sunfish contained 0.2 to 5.1 mg/kg mercury (mean = 1.2 mg/kg; median = 0.8 mg/kg; n = 12); the authors cited a maximum acceptable limit for mercury in fish tissue of 0.5 mg/kg, as established by the U.S. Food and Drug Administration. Two sediment samples collected in April 1971 contained 1.0 and 3.0 mg/kg mercury, and four water samples contained 0.0 to 0.3 μg/L mercury (Britton and others, 1974). No definitive relation is known, however, between the concentration of toxic substances such as mercury in fish tissues and the actual concentration in water or sediment. In a literature survey of data from U.S. Army Corps of Engineers reservoirs, Khalid and others (1983) found that inorganic-mercury concentration in fish tissue is from 129 to 33,800 times that of water.

Concentrations of total recoverable mercury (an approximation of biologically available mercury) in sediment samples from Calero Reservoir and the Almaden-Calero canal ranged from 0.06 to 0.85 mg/kg. Mean values for mercury in the reservoir were 0.40 mg/kg at the canal, 0.56 mg/kg at the center, 0.53 mg/kg at the dam, and 0.34 mg/kg at the east station. Higher mercury concentrations were observed at the dam and center stations probably because finer-grained sediments are deposited at these locations than at upriver locations; higher concentrations in the winter (mean concentration 0.56 mg/kg) and spring (mean concentration 0.44 mg/kg) samples probably result from storm-related sediment transport. Mean concentration for both summer and fall was 0.37 mg/kg.

Nitrogen and Phosphorus

Nitrogen (N) and phosphorus (P) are important plant nutrients. Sources include soils, rocks, and lake sediment; precipitation; and agricultural, industrial, and domestic wastes. In winter and spring, nutrients are generally

Table 5.--Trace-element concentrations for Calero Reservoir, center station, 1981-83

[USGS = U.S. Geologial Survey; SCVWD = Santa Clara Valley Water District. All constituents are dissolved, and measured in micrograms per liter. --, no data]

Date	Time (hours)	Agency analyzing sample	Sampling depth (m)	Aluminum (as Al)	Arsenic (as As)	Boron (as B)	Cadmium (as Cd)	Chromium (as Cr)	Cobalt (as Co)	Copper (as Cu)
September 24, 1981	1045	USGS	1.0	10	1	110	<1	<10	<10	2
	1046	SCVWD	1.0	50	<10	<200	<1	<5	<10	<10
August 17, 1982[1]	1055	SCVWD	5.0	<5	<10	170	<1	<5	<10	10
September 7, 1983	1100	USGS	14.0	<10	<1	90	<1	<10	<3	2

Date	Iron (as Fe)	Lead (as Pb)	Manganese (as Mn)	Mercury (as Hg)	Molybdenum (as Mo)	Nickel (as Ni)	Selenium (as Se)	Vanadium (as V)	Zinc (as Zn)
September 24, 1981	<10	<1	<10	[2]4.7	2	5	<1	4	10
	30	<10	8	<1.0	<10	<50	<10	<50	<50
August 17, 1982	10	<10	<10	<1.0	<10	<10	<1	<10	30
September 7, 1983	4	<1	--	<.1	<1	6	<1	--	7

[1]Data from original SCVWD lab sheets.
[2]See comments in section, "Mercury in Bottom Sediments."

available to biota throughout the water column, but by summer they are generally tied up in biomass, organic waste products, or sediment. These nutrients again become available to algae during fall overturn. Increased nutrient loading and resulting algal blooms downstream of the reservoir can be caused by withdrawal of nutrient-rich hypolimnetic water from the bottom outflow structure of the reservoir when conditions are optimal for algal growth.

Nitrate is the preferred form of nitrogen used by algae and is produced by the oxidation of ammonia by specialized bacteria. Organic nitrogen may be secreted or released by algae or aquatic plants as they decompose (Wetzel, 1975).

Mean total N concentration in Calero Reservoir was 1.00 mg/L, much of it in dissolved form (mean concentration 0.85 mg/L). This total is within the range for meso-eutrophic water bodies (0.5 to 1.1 mg/L) cited by Wetzel (1975). Organic N concentrations (mean total 0.65 mg/L) were greater than ammonia or nitrate concentrations (mean total 0.10 and 0.21 mg/L); species were mostly in dissolved form (fig. 8). Organic N concentrations were highest in fall, when phytoplankton populations and decomposing organic matter were most abundant, and lowest in summer during thermal stratification. Ammonia concentrations showed little seasonal variability. Nitrate concentrations were highest in winter, when phytoplankton were least abundant; nitrate concentrations decreased throughout the spring and summer as the thermocline developed and as phytoplankton became more abundant.

Phytoplankton correlated[4] positively with dissolved organic nitrogen concentrations in winter and fall ($P<0.01$) and spring ($P<0.10$) and with total organic nitrogen in winter and fall ($P<0.05$). Chlorophyll-*a* and -*b* showed similar correlations. By contrast, phytoplankton correlated negatively with total nitrate in winter and spring ($P<0.05$) and negatively with dissolved nitrate in winter ($P<0.01$) and summer ($P<0.10$). Chlorophyll-*a* was negatively associated with dissolved nitrate during all seasons and with total nitrate in winter and spring ($P<0.05$). Total and dissolved nitrate were positively associated with depth ($P<0.01$) in spring and summer at the same time that chlorophyll-*a* in spring and phytoplankton in summer were negatively correlated with depth ($P<0.05$). Thus, nitrate concentrations were higher where phytoplankton concentrations were lower. These correlations indicate that uptake and incorporation of nitrates into tissues by phytoplankton and bacteria and release of organic N into the water by decomposition of aquatic organisms partially control nitrogen concentrations in Calero Reservoir.

More than 90 percent of phosphorus in lake water is bound in living matter or organic phosphates, or adsorbed to particulate organic materials. The only significant form of inorganic P, soluble orthophosphate, is assimilated rapidly by planktonic algae and bacteria and is commonly the first limiting nutrient in water bodies (Wetzel, 1975).

Mean values for total P and dissolved ortho-P in Calero Reservoir and the canal were 0.05 and 0.019 mg/L, respectively. Total P for meso-eutrophic water bodies is 0.01-0.03 mg/L, and most uncontaminated surface waters are 0.01-0.05 mg/L (Wetzel, 1975). To prevent nuisance algal growth, total phosphates should not exceed 0.025 mg/L within the reservoir and 0.050 mg/L in any stream at the point where the stream enters the reservoir (U.S. Environmental Protection Agency, 1976). Minimum ortho-P concentrations were less than the 0.01 mg/L detection limits, and the maximum was 0.15 mg/L; thus, there is sufficient phosphate at times to support nuisance algal growth.

[4]Sample sizes for correlation analyses included from 8 to 24 paired observations.

Total P and ortho-P correlated negatively[5] with phytoplankton and chlorophyll-*a* and -*b* in winter ($P<0.01$) when phytoplankton and chlorophyll concentrations were lowest (fig. 8). Low chlorophyll-*a* and -*b* concentrations were positively associated with total P in summer ($P<0.01$); low summer phytoplankton counts might be due to unavailable ortho-P in the epilimnion. Total P and ortho-P concentrations increased with depth ($P<0.05$) during summer thermal stratification, when nutrients are restricted to bed sediments or the hypolimnion. Ortho-P and silica were positively correlated at high concentrations in winter, when phytoplankton numbers were low, and during summer thermal stratification ($P<0.05$). In spring and fall, ortho-P and silica concentrations were negatively associated ($P<0.05$); both are essential nutrients, but different mechanisms govern their seasonal availability (fig. 8).

The ratio of nitrogen (N) to phosphorus (P) often shows which constituent potentially is limiting to algal growth; the ratio is 7N:1P by weight in plants. The N:P ratio in Calero Reservoir was consistently 20:1 each season and for all the data, showing that P is potentially limiting to the system.

BIOLOGICAL CHARACTERISTICS

Phytoplankton Composition and Chlorophyll-*a* Concentrations

Phytoplankton are useful indicators of biological conditions in a reservoir because they are primary energy producers and are easily collected. Excess nutrients and high temperatures may result in increased phytoplankton populations or algal blooms, which can cause poor taste and odor, toxicity, and oxygen depletion in reservoirs.

Temperate freshwater phytoplankton populations generally exhibit a seasonal periodicity. Growth is reduced during the winter period of low light and temperature, and numbers increase in spring throughout the water column because of improved light conditions. Summer populations are limited to the epilimnion and the zone of available light; they are also limited by the nutrients present in the epilimnion. By the fall overturn, when temperature and light are decreasing, more nutrients required for algal growth become available, sometimes resulting in large algal blooms (Wetzel, 1975).

The highest total phytoplankton counts in Calero Reservoir were in fall (58,000 cells/mL) and the lowest in winter (43 cells/mL) (tables 2 and 3; fig. 8). Chlorophyll-*a* concentrations at the center and dam stations were greatest in fall 1981-82 when maximum values ranged from 14 to 16 μg/L, and at the east station concentrations were greatest in spring 1982, when the maximum was 18 μg/L (table 1). Chlorophyll-a correlated positively[6] ($P<0.01$) with phytoplankton at the center and dam stations, but no significant correlation was observed at the east station, where chlorophyll values were high in some surface samples. The greater spring productivity in shallow water at east station may result from greater nutrient availability from bottom sediments than stations in deeper water.

Cooler temperatures and higher turbidity due to storm runoff contribute to lower phytoplankton populations in winter and spring. Phytoplankton and turbidity correlated negatively in winter and in spring ($P<0.01$; $n = 14$), and total phytoplankton and temperature correlated positively in winter ($P<0.01$; $n = 23$). Phytoplankton associations with nutrients are discussed in the "Nitrogen and Phosphorus" section.

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[5]Sample sizes for correlation analyses included from 14 to 26 paired observations.
[6]Sample sizes for correlation analyses included from 33 to 36 paired observations.

In addition to the seasonal periodicity of phytoplankton counts, a periodicity in taxonomic composition also occurs in reservoirs. The perennial phytoplankton community succession described by Wetzel (1975) was typical of the Calero phytoplankton community shown for the center station (table 3). Small green algae, such as *Chlamydomonas*, and euglenophyceace, such as *Trachelomonas*, generally overwinter in small numbers. *Pediastrum*, a large green algae, was common during all seasons. The spring maximum was often dominated by larger algae, such as diatoms, which have slower turnover rates than summer algae. At 1-m depth in spring 1983, *Cyclotella* caused major algal blooms of 7,900, 12,000, and 49,000 cells/mL at the dam, center, and east stations, respectively. When *Cyclotella* abundance was low at lower reservoir levels in spring 1981, *Aphanizomenon*, *Pediastrum*, and *Sphaerocystis* were dominant. Many different bluegreen algae and diatoms were dominant in summer, including *Melosira*, *Anacystis*, *Oscillatoria*, and *Lyngbya*, and a green algae, *Schroederia*. *Anacystis* caused major algal blooms in fall 1982 of 33,000 cells/mL at both the center and dam stations at 1-m depth. Other dominant fall bluegreen algae were *Lyngbya* and *Ocillatoria*, which, along with *Anacystis*, tend to form algal mats. Dominant algae at the dam and east stations were generally the same as described at the center station. Other dominant algae at the dam included the green algae *Coelastrum* in 1981 and *Ankistrodesmus* and *Kirchneriella* in 1983; and at east station included *Chroomonas* in 1981, the diatom *Coscinodiscus* in 1982, and two green algae, *Crucigenia* and *Kirchneriella*, in 1983.

Temporal and spatial variation in phytoplankton counts (with depth or station) demonstrate the "patchiness" or heterogeneity of phytoplankton communities described by Hutchinson (1967). This variation makes sampling for a representative population difficult, and four samples per year are insufficient to define the continuous, ongoing changes in the phytoplankton community. However, these phytoplankton samples, along with water-quality samples, do provide information to help determine water-quality conditions in a reservoir. For instance, *Anacystis*, *Aphanizomenon*, and *Melosira* are common in water bodies like Calero Reservoir, which are eutrophic, usually alkaline, and nutrient enriched.

Primary Productivity

Primary productivity generally represents the major synthesis and input of organic matter in a reservoir and follows the annual cycle of incident solar radiation. Primary productivity is generally highest in the epilimnion in the summer, when algal populations are large, and lowest throughout the water column in winter, when light levels are too low for algal growth. Primary productivity rates are often reduced during periods of high runoff, when nonbiotic turbidity can be high. The depth at which the remaining light is 1 percent of the surface level is termed the "light compensation level" and is commonly the depth at which the rate of photosynthesis equals the rate of respiration. The upper part of the water column, the area of primary productivity, is also termed the "euphotic zone." Depth to the euphotic zone ranged from 1.5 to 5.0 m (table 4).

In Calero Reservoir, the depth of the euphotic zone showed both annual and seasonal variations (table 4). Estimates of net primary productivity in Calero Reservoir ranged from -2,000 to 10,000 (mg O_2/m^3)/d, and the median value was 430 (mg O_2/m^3)/d (table 4). When five samples collected below the euphotic zone were eliminated from the computation, the median value for net primary productivity was 930 (mg O_2/m^3)/d.

Production generally exceeded respiration, and net productivity values were generally positive. Gross and net primary-productivity values were greatest in the upper 2 m of the euphotic zone. Samples collected below the euphotic zone in spring and summer showed negative net productivity. Primary productivity was lowest in winter, when light and temperature are limiting, and highest in summer and fall; this is a typical pattern for temperate reservoirs. Respiration was greatest at 3-4 m depths in summer, and little or no respiration was measured in the euphotic zone in fall and winter.

In June 1982, respiration exceeded productivity throughout the euphotic zone, indicating a greater biomass of respiring organisms than of photosynthetic organisms. Conditions were similar in June 1981 below 2 m and June 1983 below 1.2 m. Both chlorophyll-*a* and total phytoplankton concentrations were generally highest in fall, not summer (fig. 8). One exception was a summer 1981 algal bloom, which had low chlorophyll concentrations and featured a diatom (*Melosira*) with dominant golden-brown pigments in addition to chlorophyll-*a* pigments (Wetzel, 1975).

Trophic-State Index

The trophic state of a lake or reservoir indicates the degree of nutrient enrichment. No single criterion for determining trophic state is adequate, because many of the constituents measured are seasonal. The trophic state index (TSI) developed by Carlson (1977 and 1981) is based on the relation of Secchi-disk transparency to chlorophyll-*a* and total-P measurements. The technique assumes that highly productive water bodies have high algal populations and chlorophyll concentrations; abundant nutrients, such as total P, available; and reduced water transparency. Besides chlorophyll, turbidity and color may influence the Secchi-disk reading. Generally, TSI values greater than 50 indicate a eutrophic system, in which nutrient enrichment results in increased algal productivity and deterioration of water quality. TSI formulas developed by Carlson (1977) are described in the glossary.

There was generally less than 10 percent difference between trophic indices for each sampling date at Calero Reservoir based on chlorophyll-*a* (CTSI), transparency (STSI) and total phosphorus (PTSI) indices; mean CTSI was 52, mean STSI was 56, and mean PTSI was 57 (table 1). Most TSI values were greater than 50, indicating a eutrophic state. CTSI values were highest during fall algal blooms (fig. 8) and low reservoir volume (fig. 4) and lowest in winter, when algal productivity (table 4) was lowest. STSI values were most consistent seasonally (seasonal means ranged from 53 to 59); values were high in fall and winter, when turbidity was high, and low in summer. PTSI values were high in winter, spring, and fall; values were lowest in summer during thermal stratification.

Bacteria

Fecal-coliform and fecal-streptococcal bacteria, which indicate contamination by fecal matter of warm-blooded animals, help to identify environmental changes and quantify levels of environmental contamination in bodies of water.

Maximum concentration of fecal-coliform bacteria were 20 col/100 mL (the median was 3 col/100 mL) and fecal-streptoccocal bacteria were 44 col/100 mL (the median was 5 col/100 mL) in Calero Reservoir. The range of values was similar at each station. Higher values were observed in the winter and spring samples, when there was more surface runoff, higher turbidity, and possibly more contamination from the pastures surrounding the reservoir (table 6). High turbidity in fall 1981 might have been from a combination of low reservoir volume, reservoir use, and phytoplankton (populations were 5,300 cells/mL and chlorophyll-*a* was 15.5 µg/L at center station) (tables 1 and 3).

Table 6.--Bacterial concentrations and turbidity in Almaden-Calero canal and Calero Reservoir, 1981-83

[K = non-ideal colony count. NTU = nephelometric turbidity units, <, less than; >, greater than]

Date	Dis-charge (ft^3/s)	Bacteria (surface sample)		Turbidity at surface (NTU)
		Fecal-coliform (col/100 mL)	Fecal-streptococcal (col/100 mL)	
Almaden-Calero Canal Station				
1982				
January 19	59	K39	260	45
April 20	0.02	100	K100	7.5
June 15	<0.01	K15	250	1.3
December 7	--	K19	K18	--
1983				
May 3	<0.10	>200	60	--
June 16	30	K29	230	--
Calero Reservoir Center Station				
1980				
December 9		K7	K12	10
1981				
April 7		K6	K1	3.3
June 16		<1	<1	6.1
September 24		K1	K1	20
1982				
January 19		K10	K20	24
April 20		K5	<5	18
June 15		<1	<1	4.2
August 17		<1	K1	6.7
December 7		K14	K6	--
1983				
May 3		K4	K44	--
June 15		<1	K4	--
September 7		<1	K11	--
Calero Reservoir Dam Station				
1980				
December 9		K5	K7	11
1981				
April 7		K1	K4	3.0
June 16		<1	<1	5.3
September 24		K1	K2	17
1982				
January 19		K5	K13	24
April 20		K20	K5	18
June 15		<1	K2	2.6
August 17		<1	<1	4.8
December 7		K17	K10	--
1983				
May 3		K4	K10	--
June 15		K2	K3	--
September 7		<1	K8	--
Calero Reservoir East Station				
1980				
December 9		K6	K10	10
1981				
April 7		K3	K3	3.8
June 16		K1	K2	11
1982				
January 19		K5	K25	18
April 20		K7	<5	18
June 15		<1	K4	2.7
1983				
May 3		K10	K5	--
June 15		--	K2	--

Total populations of fecal-coliform and fecal-streptococcal bacteria were an order of magnitude greater at the Almaden-Calero canal station than at the reservoir stations; median values were 34 col/100 mL for fecal coliform and 165 col/100 mL for fecal-streptococcal bacteria. Larger populations of fecal-coliform bacteria were observed generally during low streamflows, which indicates a local source of these bacteria, possibly livestock. Large fecal-streptococcal populations, however, were associated generally with high streamflows and probably overland runoff. However, the maximum fecal-coliform bacteria populations (greater than 200 col/100 mL) were observed in May 1983 after 3.4 inches (11.3 mm) of rainfall the preceding week. The large populations probably resulted from runoff from nearby pastures; the canal passes through pasture land between the Almaden and Calero Reservoirs. The maximum populations of fecal-streptococcal bacteria (260 col/100 mL) in the canal were observed in January 1982 during a rainstorm. Concurrent with this maximum was the maximum turbidity value for the period (45 NTU). Mean turbidity values on January 19 were 26, 24, and 18 NTU at the center, dam, and east stations, respectively. The east station is farthest from the canal, and the turbidity measurements may delineate a "plume" of turbidity from the canal through the reservoir. Reduction of population numbers in Calero Reservoir probably results from both dilution of the bacteria populations from the canal and natural die-off.

COMPARISONS OF WATER-QUALITY CONDITIONS WITH WATER-QUALITY CRITERIA

Existing and potential beneficial uses of water in Calero Reservoir are municipal and domestic water supply, water-contact and noncontact recreation, warm-water fish habitat, wildlife habitat, and fish spawning. Water samples from Calero Reservoir and Almaden-Calero canal generally met water-quality criteria for beneficial uses established by the California Regional Water Quality Control Board, San Francisco Bay Region (1982). The number of water samples not in compliance with water-quality criteria is shown in table 7. The dissolved-oxygen criterion of 5.0 mg/L was not met in 22 percent of the samples, particularly in summer, fall, and a few spring samples. Noncompliance was found generally in hypolimnetic water representing one- to two-thirds of reservoir volume in summer (1981-83) and one-third to one-half of volume in fall (1982-83). Two percent of the dissolved-oxygen samples were anaerobic (0.0 mg/L oxygen) near the reservoir bottom. The pH criteria were exceeded in less than 1 percent of the reservoir samples, but in three out of the six canal samples. Criteria for dissolved mercury were not met in one of the four samples.

FUTURE STUDIES

Determining the nutrient budget of the reservoir was beyond the scope of the present study, and the quantity and type of nutrients potentially available from the sediment still are not known. A study to develop a nutrient budget would include (1) determination of sources and states (dissolved or suspended) of major nutrient input to the reservoir, and (2) determination of peak periods of nutrient input. Limiting nutrients could be determined by algal-growth potential tests.

High mercury concentrations have been reported in fish taken from Calero Reservoir (Britton and others, 1974). The relation between total recoverable (biologically available) mercury in sediments and dissolved mercury in the water column has yet to be determined. Sediment transport mechanisms as well as particle-size affinities of mercury still need to be determined because particle flux through the water column is a major factor regulating trace-metal concentrations in natural waters (Santschi, 1984).

Mercury distribution could be mapped throughout the reservoir by determining particle-size distribution of the bottom sediments and by determining flow patterns. Water managers need to know rates of accumulation and magnification of mercury in the biota if significant mercury concentrations are found.

When the reservoir is thermally stratified in late summer or fall, and when the hypolimnion becomes anaerobic, trace metals and nutrients in the bottom sediment can dissolve and remobilize into the water column. Under these conditions, water released from the bottom-outlet release structure in the dam could

Table 7.--Measured properties and constituents not in compliance with water-quality criteria for Calero Reservoir and Almaden-Calero canal, 1981-83

[Water-quality criterion from California Regional Water Quality Control Board, San Francisco Bay Region, 1982]

Station name	Property or constituent	Criterion	Number of times sample was not in compliance	Number of samples
Calero Reservoir, center	pH	Maximum 8.5	1	205
	Dissolved oxygen	Minimum 5.0 mg/L (warmwater fish habitat)	44	205
	Mercury	Maximum 2 μg/L (municipal supply)	1	4
Calero Reservoir, dam	pH	Maximum 8.5	1	253
	Dissolved oxygen	Minimum 5.0 mg/L (warm-water fish habitat)	73	253
Calero Reservoir, east	Dissolved oxygen	Minimum 5.0 mg/L (warm-water fish habitat)	3	97
Almaden-Calero canal	pH	Maximum 8.5	3	6

contain high concentrations of nutrients, which would promote nuisance algal growth, as well as mercury and other trace-constituent concentrations that may not meet criteria for domestic water supply or other beneficial uses. A water-release structure in the dam near the water surface would release water with lower concentrations of nutrients and trace constituents but might release water with high concentrations of nuisance algae in late summer. Measurement of the water temperature profile in the reservoir on a weekly basis would indicate whether the reservoir is thermally stratified and whether it is likely to be anaerobic in the hypolimnion.

SUMMARY

Calero Reservoir volumes at times of sample collection ranged from 13 to 100 percent capacity and often exceeded the monthly mean volumes for the period of record. Calero Reservoir is classified as a warm monomictic reservoir. Water temperature ranged from 8.5 to 23.4°C in the reservoir and from 7.5 to 34.0°C in the canal. Dissolved-oxygen concentrations were less than 5.0 mg/L in 22 percent of the samples; this included primarily summer and fall samples in hypolimnetic water and represented one- to two-thirds of reservoir volume. Water was anaerobic in only 2 percent of the samples, which were taken near the reservoir bottom. Water transparency profiles show a rapid attenuation of light with depth in the water column. Light extinction values were generally high throughout the water column in winter and spring samples collected following rainstorms and in most summer and fall samples collected near the reservoir bottom. The depth of the euphotic zone ranged from 1.5 to 5.0 m.

Median pH values were 7.9 in the reservoir and 8.4 in the canal. Mean specific conductance was 299 μS/cm in the reservoir and 326 μS/cm in the canal. Dominant cations were calcium and magnesium, and the dominant anion was bicarbonate. Boron concentrations ranged from 90 to 170 μg/L.

Dissolved-mercury concentrations were below detection limits, except for a concentration of 4.7 μg/L in a September 1981 sample. Total recoverable (biologically available) mercury in bottom-sediment material ranged from 0.06 to 0.85 mg/kg. Britton and others (1974) reported mercury concentrations of 1.0 and 3.0 mg/kg in two sediment samples, and 0.0-0.3 μg/L mercury in four water samples; in addition, they reported mercury concentrations of 0.2 to 5.1 mg/kg in tissues of fish collected from Calero Reservoir in 1971. Many fish-tissue samples were greater than the minimum acceptable limit of 0.5 mg/kg established by the U.S. Food and Drug Administration.

Mean values for total N, organic N, and nitrate were 1.00, 0.65, and 0.21 mg/L, respectively. Most N was in the dissolved form, and mean dissolved N was 0.85 mg/L. Nitrate was inversely related and organic N was directly related to concentrations of phytoplankton cells or chlorophyll-*a* and -*b*. Mean total phosphorus (P) and dissolved ortho-P concentrations were 0.05 and 0.019 mg/L, respectively. Significant positive correlations were found between total P and chlorophyll-*a* and -*b*.

Summer and fall algal blooms consisted primarily of the blue-green algae *Anacystis*, and spring blooms were composed primarily of the diatom *Cyclotella*. Estimates of net primary productivity in Calero Reservoir ranged from -2,000 to 10,000 (mg O_2/m^3)/d, and the median for the euphotic zone was 930 (mg O_2/m^3)/d. Net primary productivity values in the euphotic zone were generally positive (except in summer), which indicates that production generally exceeded respiration.

Carlson's trophic-state index (TSI), calculated using water transparency, total phosphorus, and chlorophyll-*a* values, indicates that the reservoir is eutrophic. Mean TSI values were 52 for chlorophyll-*a*, 56 for light transparency, and 57 for total P.

Fecal-coliform bacteria concentrations were less than 20 col/100 mL in the reservoir and less than 200 col/100 mL in the canal. Fecal streptococcal bacteria were generally less than 45 col/100 mL in the reservoir and up to 260 col/100 mL in the canal.

Water from Calero Reservoir and Almaden-Calero canal generally met water-quality criteria of the California Regional Water-Quality Control Board, San Francisco Region, for maintaining water suitable for municipal and domestic water supply, water-contact recreation, noncontact water recreation, warmwater fish habitat, wildlife habitat, and fish spawning. The criteria not met were dissolved-oxygen concentration in 22 percent of the samples; pH in less than 1 percent of reservoir samples and in three out of the six canal samples; and dissolved mercury in one of the four reservoir samples.

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GLOSSARY OF SELECTED TERMS

[Note: The following definitions are modified from Slack and others (1973) and U.S. Geological Survey (1982-84), unless otherwise noted]

Aerobic. Having oxygen.

Algal bloom. A large number of a particular algal species, often amounting to 500-1,000 cells/mL of water.

Anaerobic. Devoid of oxygen.

Bacteria. Microscopic, unicellular organisms. Some bacteria cause disease while others perform an essential role in the recycling of materials.

Blue-green algae. A group of algae with a blue pigment in addition to the green chlorophyll. Blue-green algae are the group that usually causes nuisance conditions in water.

Coefficient of determination, r^2. The square of the correlation coefficient, r. The coefficient of determination is used to determine the strength of relation between two variables. Values range from 0 to 1; values approaching 1 indicate a strong relation.

Density. The quantity or mass of a substance per unit volume. Computed as grams per cubic centimeter in the case of water.

Diatom. A unicellular or colonial alga having a siliceous shell.

Dissolved concentration. The amount of a constituent material in a representative water sample that passes through a 0.45-μm membrane filter.

Epilimnion, epilimnetic. The upper relatively warm, circulating zone of water in a thermally stratified lake.

Eutrophication, eutrophic. The natural process of enrichment and aging of a body of water, which may be accelerated by human activities. The terms pertain to water in which primary production is high as a consequence of a large supply of available nutrients.

Genus, genera. The taxonomic category consisting of species and the first part of the scientific name of organisms.

Green algae. Algae that have pigments similar in color to those of higher green plants. Some forms produce floating algal mats in lakes.

Gross primary productivity. The total rate of photosynthesis, including the organic matter used up in respiration during the measurement period.

Hypolimnion, hypolimnetic. The lower, relatively cold, noncirculating water zone in a thermally stratified lake.

Kendall's tau, τ. This nonparametric correlation analysis is based on the order (ranks) of the observations and must be used with independent and continuous variables (Sokal and Rohlf, 1973; Connover, 1980). The formula (if there are no ties in the ranks) is:

$$\text{Kendall's tau} = N/n(n-1)$$

where
- n = the sample size and
- N = a count of ranks.

The quantity N measures how well the second variable corresponds to the order of the first variable. The probability level, $P<0.05$ indicates that the probability is less than 5 percent that the correlation is not real.

Light absorption. The transformation of light energy to heat within a water body (Wetzel, 1975).

Light attenuation, light extinction. The diminishing of light energy with lake depth due to scattering or reflection of light (Wetzel, 1975). The light extinction (attenuation) coefficient eta (η) is calculated from the equation (Wetzel, 1975):

$$\eta = (1/L\ (\ln T))$$

where
- L = the path length in meters,
- T = the fraction of light transmitted,
- $\ln$ = the natural logarithm; and

$$\ln T = \ln I_o - \ln I_z$$

where

I_o = the percent of light at the surface (usually 100 percent)

and

I_z = the percent of light remaining at a given depth.

Limnology. The science or study of inland water.

Metalimnion, metalimnetic. The middle layer of water in a thermally stratified lake, in which temperature decreases rapidly with depth.

Net primary productivity. The effective production of new cell material after respiratory requirements have been met.

Nutrient. Any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes.

Organic. Pertaining or relating to a compound containing carbon (except carbonates).

Oxygen saturation. A dissolved-oxygen concentration in water that is equal to the equilibrium concentration that the water would normally hold at the existing temperature, pressure, and salinity. Water that has a dissolved-oxygen concentration below the equilibrium concentration is undersaturated, and that which has an excess is supersaturated.

Photosynthesis, photosynthetic. A process whereby green plants use light as an energy source and convert chemical compounds to carbohydrates. In the process, carbon dioxide is used and oxygen is released.

Phytoplankton, phytoplanktonic. The plant part of the plankton.

Plankton, planktonic. The community of suspended or floating organisms that drift passively with water currents.

Production, productivity. The total amount of energy or organic matter produced from raw materials in an area per unit time, regardless of the fate of the material.

Reduction. The process by which oxygen is lost from a substance or an element gains electrons.

Respiration. A life process in which carbon compounds are oxidized to carbon dioxide and water and the liberated energy is used in the metabolic processes of living organisms.

Sediment. Fragmental material, both mineral and organic, that is suspended or transported by the water mass or has been deposited on the bottom of the aquatic environment.

Suspended sediment. Fragmental material, both mineral and organic, that is maintained in suspension in water.

Thermal stratification. A temperature distribution in which the lake water is distinctly layered because of thermal-density differences.

Total concentration. The total amount of a given constituent in a representative water-suspended sediment sample, regardless of the constituent's physical or chemical form. This term is used only when the analytical procedure assures measurement of at least 95 percent of the constituent present in both the dissolved and suspended phases of the sample and is determined by the complete dissolution of the sample.

Total recoverable concentration. The amount of a constituent that is in solution after digestion in a dilute acid solution, which results in dissolution of only readily soluble substances. The determination represents less than the "total" amount (less than 95 percent) of the constituent. The operational definition of this concentration depends on the solution used for extraction.

Trophic state index (TSI) calculations (Carlsen, 1977).

Secchi disk (SD)	STSI, in meters = 10{6-[ln (SD/ln 2)]}
Chlorophyll-*a* (Chl-*a*)	CTSI, in micrograms per liter = 10{6-[2.04 - (0.68 ln Chl-*a*/ln 2)]}
Total phosphorus (TP)	PTSI, in milligrams per liter = 10{6-[ln(48/TP)/ln 2]} + 100

Turbidity. A measurement of the reduction of transparency due to the presence of suspended particulate matter, biotic or abiotic.

Water quality. The discipline of hydrology that deals with the kinds and amounts of matter dissolved and suspended in natural water, the physical characteristics of the water, and the ecological relations between aquatic organisms and the environment.

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