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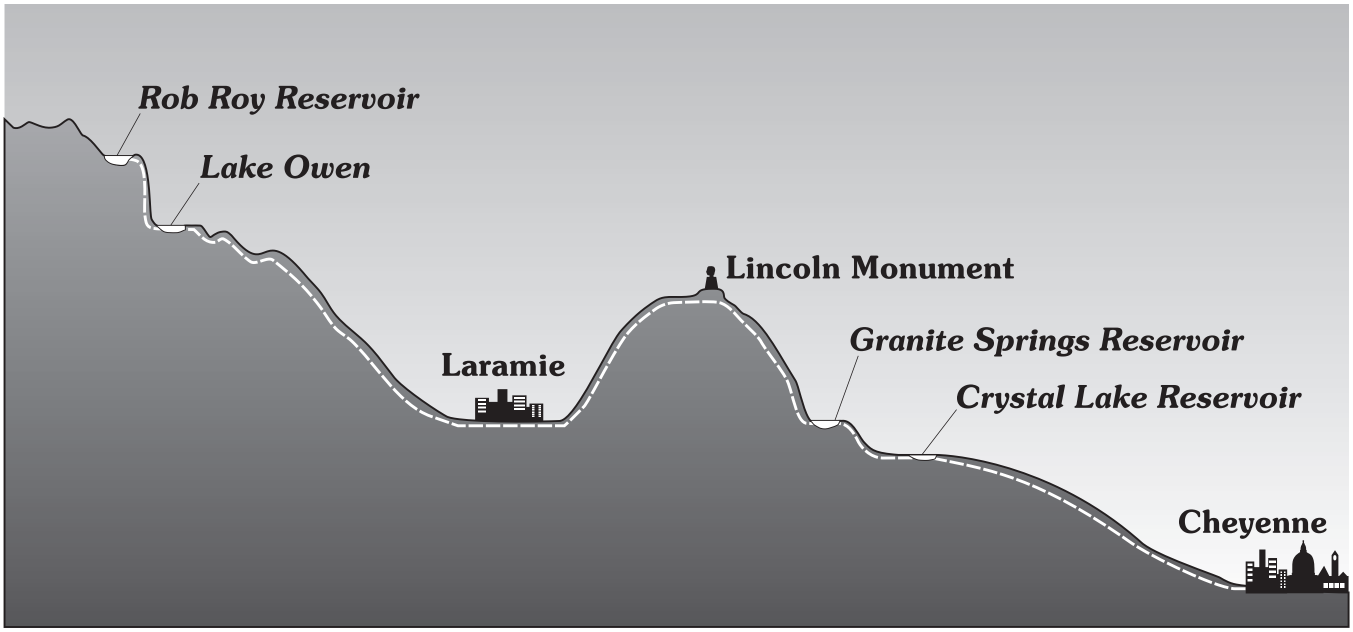
Water Quality of Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming, 1997-98

Water-Resources Investigations Report 99-4220

Prepared in cooperation with the
Cheyenne Board of Public Utilities



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By Kathy Muller Ogle[1], David A. Peterson[1], Bud Spillman[2], and Rosie Padilla[2]

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Cheyenne, Wyoming
1999

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CONVERSION FACTORS

Multiply	By	To obtain
acre	43,560	square foot (ft^2)
	4,047	square meter
	0.001562	square mile
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon per day (gal/d)	3.785	liter per day
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	1.121	thousand acre-feet per year
	0.001547	thousand cubic feet per second
	0.6944	thousand gallons per minute
	0.003785	million cubic meters per day
	1.3815	million cubic meters per year
square mile (mi^2)	2.590	square kilometer
thousand acre-feet per year	0.8921	million gallons per day
	0.001380	thousand cubic feet per second
	0.6195	thousand gallons per minute
	0.003377	million cubic meters per day

Some other water relations in inch-pounds units are listed below:

1 gallon	=	8.34 pounds
1 million gallons	=	3.07 acre-feet
1 cubic foot	=	62.4 pounds
	=	7.48 gallons
1 acre-foot (acre-ft)	=	325,851 gallons
	=	43,560 cubic feet
1 inch of rain	=	17.4 million gallons per square mile
	=	27,200 gallons per acre
	=	100 tons per acre

Temperatures can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by using the following equations:

$$°F = 9/5(°C)+32$$

$$°C = 5/9(°F-32)$$

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

Water Quality of Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming, 1997-98

By **Kathy Muller Ogle, David A. Peterson, Bud Spillman, and Rosie Padilla**

ABSTRACT

The water quality of four reservoirs was assessed during 1997 and 1998 as a cooperative project between the Cheyenne Board of Public Utilities and the U. S. Geological Survey. The four reservoirs, Rob Roy, Lake Owen, Granite Springs, and Crystal Lake, provide approximately 75 percent of the public water supply for Cheyenne, Wyoming. Samples of water and bottom sediment were collected and analyzed for selected physical, chemical, and biological characteristics to provide data about the reservoirs. Water flows between the reservoirs through a series of pipelines and stream channels. The reservoirs differ in physical characteristics such as elevation, volume, and depth.

Profiles of temperature, dissolved oxygen, specific conductance, and pH were examined. Three of the four reservoirs exhibited stratification during the summer. The profiles indicate that stratification develops in all reservoirs except Lake Owen. Stratification developed in Rob Roy, Granite Springs, and Crystal Lake Reservoirs by mid-July in 1998 and continued until September, with the thickness of the epilimnion increasing during that time. Secchi disk readings indicated Rob Roy Reservoir had the clearest water of the four reservoirs studied.

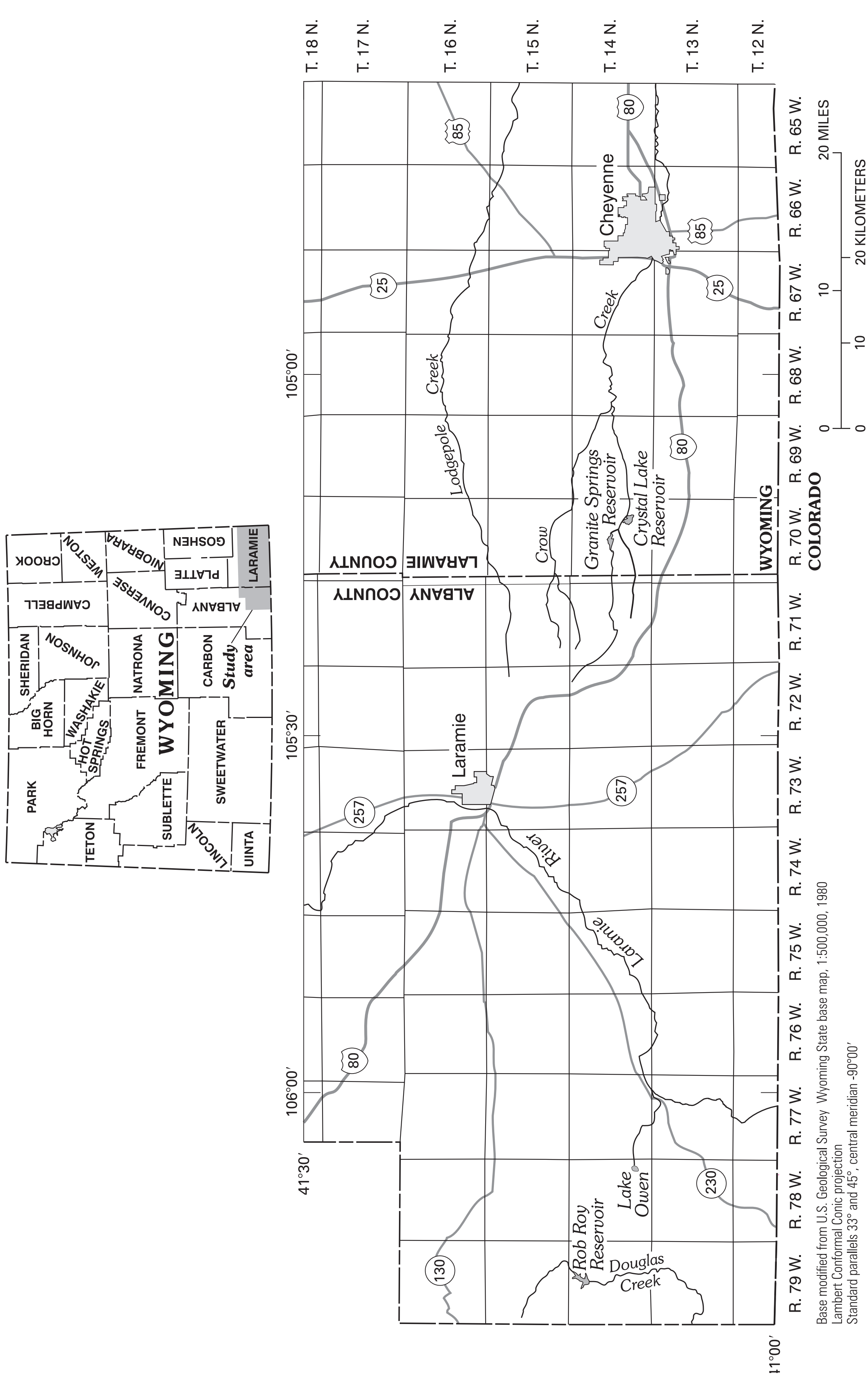
The composition of the phytoplankton community was different in the upper two reservoirs from that in the lower two reservoirs. Many of the species found in Rob Roy Reservoir and Lake Owen are associated with oligotrophic, nutrient-poor conditions. In contrast, many of the species found in Granite Springs and Crystal Lake Reservoirs are associated with mesotrophic or eutrophic conditions. The total number of taxa identified also increased downstream.

The chemical water type in the reservoirs was similar, but dissolved-solids concentrations were greater in the downstream reservoirs. Water in all four reservoirs was a calcium-bicarbonate type. In the fall of 1997, Rob Roy Reservoir had the lowest dissolved-solids concentration (19 milligrams per liter), whereas Crystal Lake Reservoir had the highest concentration (63 milligrams per liter). Relatively little differences in the concentrations of major-ion species were noted between samples collected near the surface and near the bottom of the same reservoir. In contrast, iron and manganese concentrations generally were higher in samples collected near the bottom of a reservoir than in near-surface samples collected from the same reservoir.

Composite bottom-sediment samples from all four reservoirs contained similar concentrations of bulk constituents such as aluminum, iron, phosphorus and titanium, but varied in concentrations of trace elements. Trace-element concentrations in Rob Roy Reservoir and Lake Owen were similar to the crustal average, whereas in Granite Springs and Crystal Lake Reservoirs the concentrations were similar to granitic rocks.

INTRODUCTION

Surface water contributes approximately 75 percent of the City of Cheyenne’s public water supply. The water is collected from the Douglas Creek and Crow Creek drainage areas. Most of the water is stored in four reservoirs located in southeastern Wyoming—Rob Roy, Lake Owen, Granite Springs, and Crystal Lake (fig. 1). Water flows through the reservoir system via a series of pipelines and stream channels. At Crystal Lake Reservoir, the water is diverted into pipelines and routed to the public water-treatment facilities. The entire water collection, treatment, and distribution system is operated by the Cheyenne Board of Public Utilities (BOPU).



Base modified from U.S. Geological Survey Wyoming State base map, 1:500,000, 1980
Lambert Conformal Conic projection
Standard parallels 33° and 45°, central meridian -90°00′

Figure 1. Location of Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

Although extensive water-quality data have been collected for the treated water, relatively limited data are available for the raw-water quality within the storage reservoirs. Data on the water quality in the reservoirs are needed to assist BOPU managers for future planning of the Cheyenne water system. In order to meet those needs, a study was conducted during 1997-98 by the BOPU and the U.S. Geological Survey (USGS). Data on the reservoir water quality collected during the study will assist the BOPU in evaluating reservoir and watershed management options in conjunction with treatment options.

Purpose and Scope

This report provides baseline water-quality data for four reservoirs—Rob Roy, Lake Owen, Granite Springs, and Crystal Lake. Specifically this report summarizes phytoplankton and profile data collected at a selected monitoring site in each reservoir over a summer season, selected physical, chemical and biological constituents for a single sample collected from the water column during the summer of 1997, and selected chemical constituents in composite samples of bottom sediment from each reservoir. The report is limited to the four reservoirs and to a general description of the water quality of the reservoirs. Lake processes are not examined. Due to unexpected opportunities, the project team was able to add winter, spring, and summer profiles for Granite Springs and Crystal Lake Reservoirs.

Description of the Water System

Surface water for the City of Cheyenne's public-water system is collected in reservoirs, two of which—Rob Roy and Lake Owen—are about 80 miles west of Cheyenne (fig. 1). Most diversion facilities and a delivery pipeline were constructed in the 1960s. These facilities were designed and constructed to divert water from the Douglas Creek drainage (fig. 2A) to provide Cheyenne with a long-term surface-water supply. The original construction was referred to as Stage I. Stage II was constructed in 1985 and consisted of improvements to the dams as well as construction of a parallel pipeline from Rob Roy Reservoir to Crystal Lake Reservoir.

The Cheyenne water-treatment facilities receive raw water directly from Crystal Lake Reservoir, located in the Middle Crow Creek drainage (fig. 2D). The average annual yield from Middle Crow Creek drainage, which includes Granite Springs and Crystal Lake, is estimated to be about 1.23 billion gallons. The 1998 annual treated-water demand was approximately 4.5 billion gallons. Of this total, about 1 billion gallons of treated water is supplied by ground water and the remainder is supplied by surface water. To meet the current and future treated-water demands of the community, yield from the Stage I and Stage II projects is required. This will include the average annual divertable flow from the Douglas Creek drainage of about 6.8 billion gallons.

Description of Area

The study area (fig. 1) is the four reservoirs—Rob Roy, Lake Owen, Granite Springs, and Crystal Lake. The reservoir system begins with Rob Roy Reservoir located in the Douglas Creek drainage. Runoff is collected and stored in Rob Roy Reservoir (fig. 2A). BOPU diverts stored water from Rob Roy by a pipeline to Lake Owen (fig. 2B). From Lake Owen, water is transported, again by pipeline to the Middle Crow Creek drainage (fig. 2C).

Within the Middle Crow Creek drainage, water is stored in two reservoirs—Granite Springs and Crystal Lake. Granite Springs provides 1.7 billion gallons of storage and Crystal Lake provides 1.1 billion gallons. Water within the Middle Crow Creek drainage is routed from Granite Springs down Middle Crow Creek and also by pipeline to Crystal Lake. From Crystal Lake, water is transported by pipelines and Middle Crow Creek to the water treatment facilities. Selected characteristics of the four reservoirs are summarized in table 1.

Acknowledgments

The Cheyenne BOPU and many BOPU employees have contributed to making this project a success. The sampling assistance of Kay Knott, Marv Tripp, Jason Haughton, and Deb Streetman is gratefully acknowledged. Tim Wilson's continuing support and Herman Noe's help in collecting information about the reservoirs are appreciated. Jerry Mark and Jack Carroccia were instrumental in initiating the study.

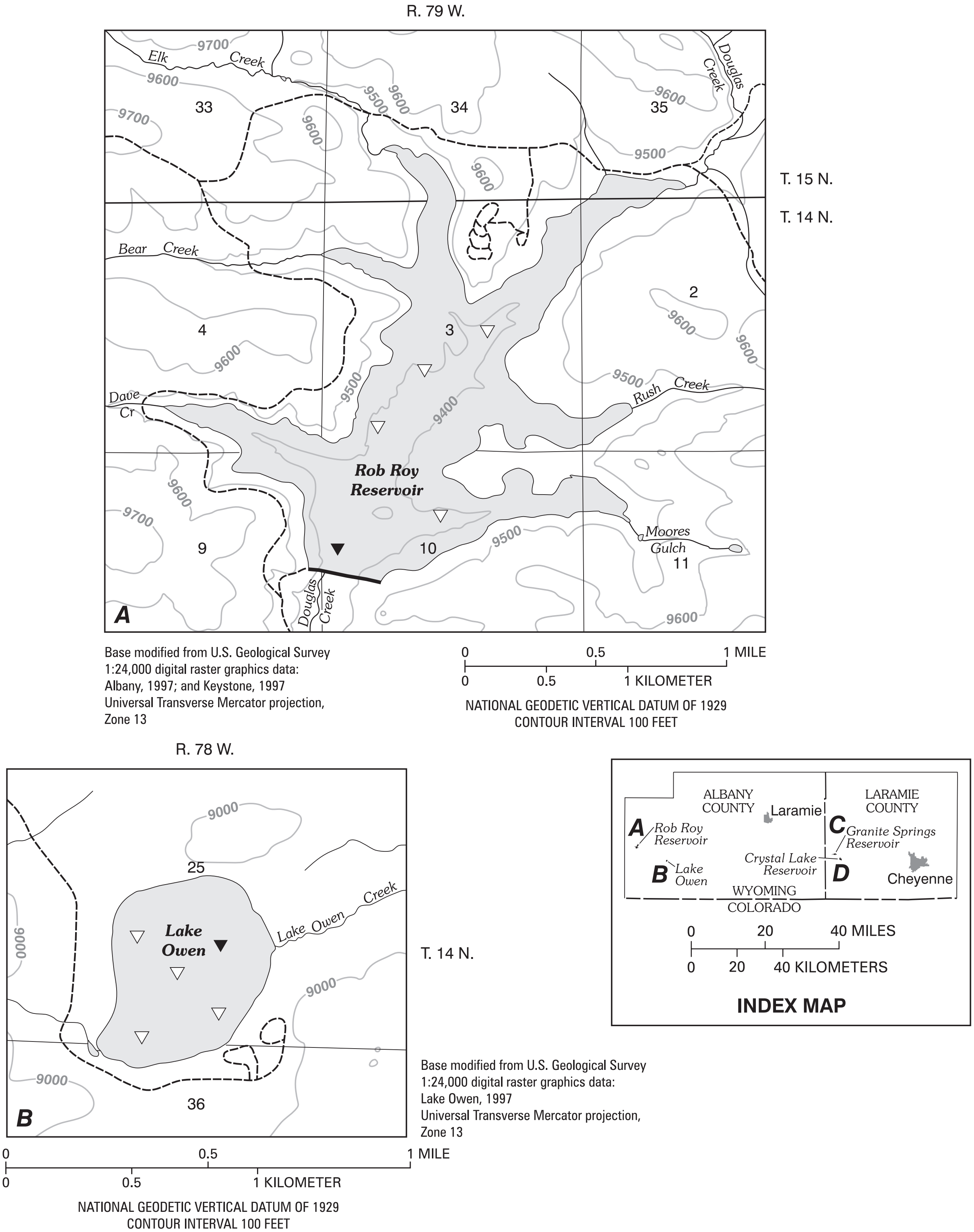
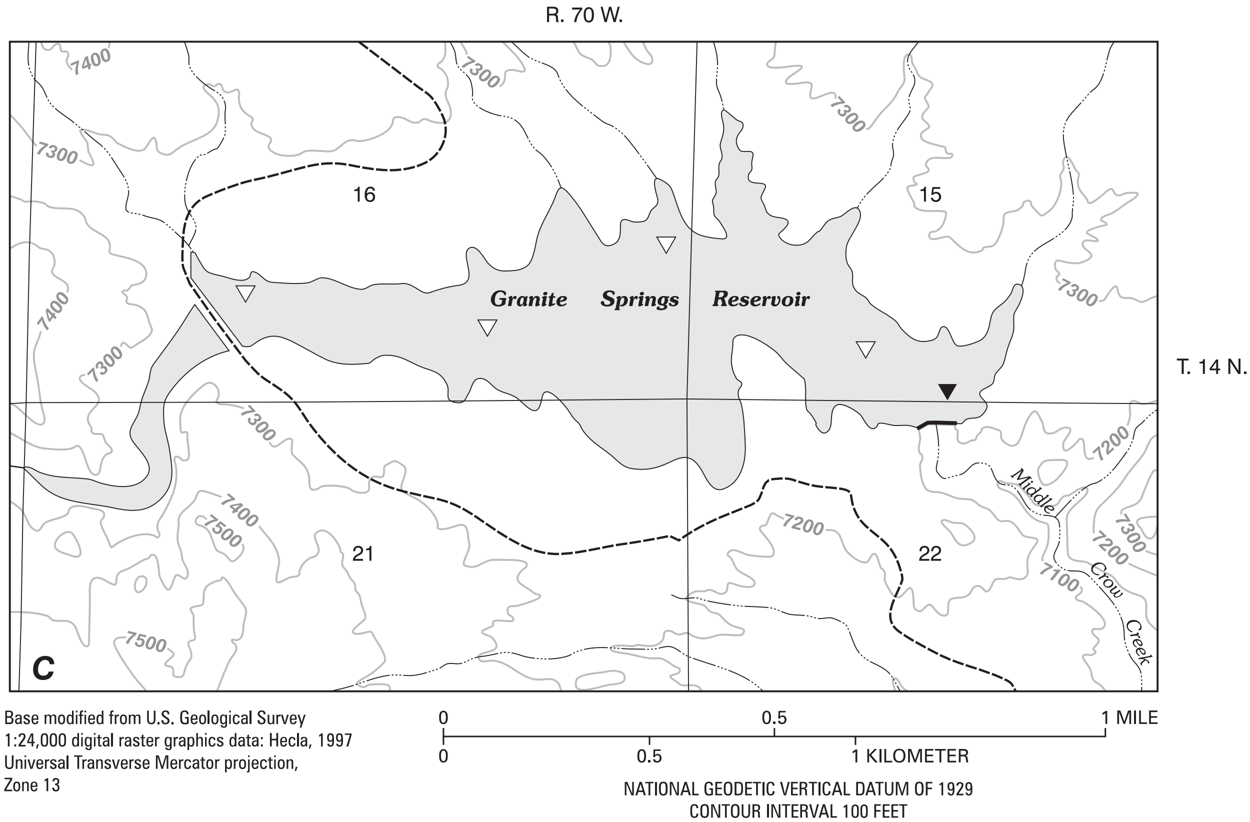
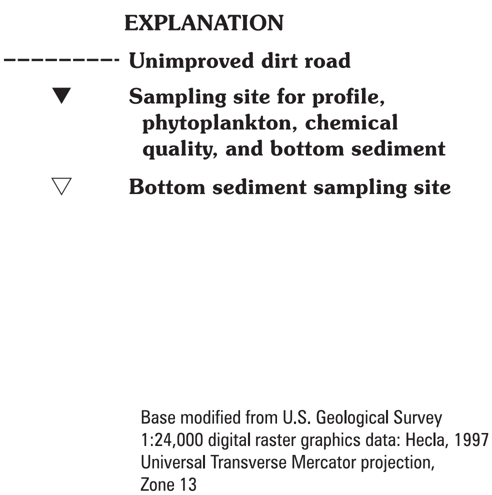


Figure 2. Locations of sampling sites in Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.





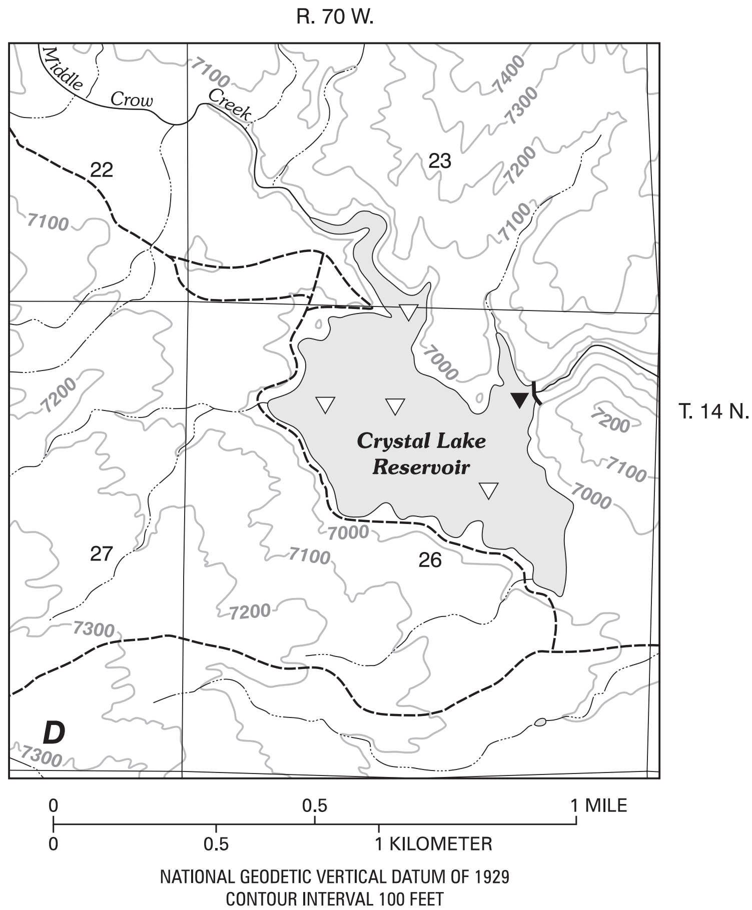


Figure 2. Continued.

Table 1. *Selected reservoir characteristics for Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming*

[Elevation and storage data provided by Cheyenne Board of Public Utilities]

Reservoir	Approximate elevation (feet above sea level)	Approximate storage (billions of gallons)	Approximate depth at profiling site (feet)	Percent of system storage
Rob Roy	9,470	11.4	80	79
Lake Owen	8,955	.2	10	1
Granite Springs	7,210	1.7	60	12
Crystal Lake	6,969	1.1	65	8

DATA COLLECTION

The sampling sites in each reservoir were located at or near the deepest point, to reflect integrated water quality to the extent possible (fig. 2A, B, C, D). Three types of sampling were completed at each reservoir: (1) depth profiles of temperature, dissolved oxygen, specific conductance, and pH, and sampling of phytoplankton, (2) a one-time sampling for chemical quality, and (3) a composite bottom-sediment sample. Profile measurements and phytoplankton samples were collected once in the late summer of 1997 and approximately every two weeks in the summer of 1998 at all four reservoirs.

The reservoirs were vertically profiled from about 1 foot below the water surface to the bottom of the lake in a location estimated to have the greatest depth, based on examination of maps and initial sounding of depths. During late summer of 1997, all four reservoirs were profiled. Granite Springs and Crystal Lake Reservoirs also were profiled in February 1998. Rob Roy Reservoir and Lake Owen were not profiled in the winter due to accessibility problems and dangerous ice conditions. Profile data for Granite Springs and Crystal Lake Reservoirs were collected from mid-May until mid-July of 1998. Beginning in mid-July, profiles were completed at all four reservoirs until late summer of 1998. The data were measured with HydroLab Scout II and YSI 6920 multiparameter probes. Data collected were temperature, dissolved oxygen, specific conductance, and pH. Individual probes were calibrated before profiling, and the two multiparameter-probes were compared to each other in the field at random times. Readings of the two instruments were comparable with temperature differences between 0.1 and 0.15 degrees, dissolved-oxygen differences between 0.02 and 0.5 mg/L (milligrams per liter), and pH differences from 0.06 to 0.2. Specific conductance had the largest differences between probes varying from 2.6 μS/cm (microsiemens per centimeter at 25°C) to 22.5 μS/cm. The same profile pattern was obtained with both instruments. No adjustments were made to the data. Secchi disk transparencies were collected at each reservoir.

At the same time as profiling, a sample was collected at a depth of 1 foot below the water surface (hereafter referred to as the surface sample) at each water sampling site for identification and enumeration of phytoplankton. During the sampling for chemical quality in the late summer of 1997, a bottom sample of phytoplankton also was collected at 3 ft (feet) above the reservoir bottom (hereafter referred to as the bottom sample) at Rob Roy, Granite Springs and Crystal Lake Reservoirs. Due to its shallow depth, only a surface sample was collected at Lake Owen. The same nomenclature for surface and bottom samples is used throughout this report for both phytoplankton and chemical-quality samples.

The four reservoirs were sampled once in the fall of 1997 between August 28 and September 11 for chemical analysis of organic and inorganic constituents. Reservoirs were sampled at the same location where the profiles were measured. At each sampling site, water-quality samples were collected at two depths, using a Kemmerer bottle. As described for phytoplankton sampling, a surface sample was collected at a depth of 1 ft below the water surface in the epilimnion. A bottom sample was collected from about 3 ft above the reservoir bottom. Likewise, at Lake Owen, due to its shallow depth and the lack of variability in the profile data, a single surface sample was collected. A third sample was collected at Crystal Lake at 30 ft below the reservoir surface. This depth was estimated to correlate to the pipeline intake level for the water treatment plant. The constituent list included phytoplankton, nutrients, major ions, trace elements, and microscopic particulate analysis (MPA). Additional analyses for selected radiochemical and pesticide compounds were completed in samples collected from Crystal Lake Reservoir because it is the direct source of the water to the treatment plant. Nutrients, major ions, and trace elements were analyzed at the USGS National Water Quality Laboratory in Arvada, Colorado. The MPA samples were collected by BOPU using the procedure recommended by the U.S. Environmental Protection Agency (1996); the procedure specifies a total collection time of 24 hours from filter installation. The phytoplankton and MPA analyses were performed by CH Diagnostic in Loveland, Colorado. Phytoplankton biomass was calculated from phytoplankton biovolume, assuming a density of one gram per cubic centimeter. Chemical analyses and physical properties of the water samples collected from the four reservoirs are listed in table 2.

Samples of the bottom sediment were collected at five sites in each reservoir (fig. 2) using a Ponar grab sampler. One of the five sites in each reservoir also was the sampling site for profiles, phytoplankton, and chemical quality. Each sample was subsampled to obtain material that had not been in contact with the sides of the sampler. The five samples then were composited into a single sample for each reservoir. If needed, the sample was sieved through a 63-um (micrometer) sieve in preparation for trace-element analysis. Sediment samples were analyzed for trace elements and nutrients at the USGS, Branch of Geochemistry Analytical Services Group Laboratory, Denver, Colorado.

A second sample for replicate phytoplankton analysis was collected from Crystal Lake Reservoir on September 7, 1997. Comparison of the two samples indicated the difference was less than 30 percent for phytoplankton biomass, density, and number of taxa identified. No adjustments were made to the phytoplankton data based on the quality-control sample.

A duplicate sample for chemical analysis was collected when the surface sample was collected at Crystal Lake. Major-ion concentrations agreed closely. Differences in the individual ion concentration between the two samples were less than 0.1 mg/L, except for alkalinity, which varied by 1 mg/L.

WATER QUALITY

Water in reservoirs often becomes stratified. This zonation of lakes is a reflection of the differences in water density with the warmer, less dense water at the top; a cold dense layer at the bottom; and a zone of rapidly changing density between them. The three zones are the epilimnion (the upper, warmer water), the metalimnion (the middle zone where the rate of change in temperature is the greatest—also sometimes called the thermocline), and the hypolimnion (the lower, colder water). Powell (1964, p. 19-20) states that the metalimnion in natural lakes is often observed between 25 to 40 ft below the surface, but may vary from that depth in artificial impoundments.

Profiles of temperature were examined in all four reservoirs for thermal stratification. As is commonly found in temperate lakes (Horne and Goldman, 1994, p. 53-65), three vertical zones were identified in Rob Roy, Granite Springs, and Crystal Lake Reservoirs at selected times during late summer. Lake Owen's shallow depth precluded such stratification. Temperatures in the reservoirs in this study are influenced by both natural lake processes and pipeline inflow and outflow. That stratification impacts the quality of the impounded water (McGauhey, 1968, p. 92).

Surface-water quality in an impoundment is highly variable on both short and long term cycles (Moore, 1989, p. 30). Reservoirs are dynamic and have a complex interaction of chemistry and biology both seasonally and over decades. Samples collected during this study represent the quality of the water in the reservoirs at that point in time.

Sediment can act as sites for ion exchange between aquatic and solid phases. If elements or compounds are in large concentrations in the water, the sediments may remove them by adsorption. Conversely, if the concentrations are low, the elements or compounds may move from the sediment into the water. Thus, a dynamic equilibrium exists between the sediment and the water. Bottom-sediment samples were collected at all four reservoirs. The sediment-analysis results for each reservoir are summarized in table 3.

Sediment in reservoirs is strongly influenced by the geology of the watershed of the lake. Concentrations of selected constituents in sediment from the reservoirs were compared to published values for diabase (diorite), crustal averages, and granitic rocks (Mason, 1966) to give a perspective on the concentration.

Rob Roy Reservoir

Rob Roy Reservoir is the largest, deepest, and highest in the series of the reservoirs (fig. 2A; table 1). It contains 79 percent of the storage capacity of the four-reservoir system. At the profiling site, the reservoir was about 80-ft deep. The spillway elevation is 9,470 ft above sea level (table 1). Rob Roy is located in a mountainous area surrounded by evergreen forest. The lake and surrounding area are the focus of recreational activities, such as boating, fishing and camping. Rob Roy is the only reservoir of the four that receives runoff only from its watershed and receives no inflow from other reservoirs.

Table 1. *Chemical analyses and physical properties of water-quality samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming*

[QA, duplicate sample collected for quality assurance purposes; a, not measured due to the occurrence of a lightning storm; concentrations of copper, lead, boron, aluminum, arsenic, and selenium from Rob Roy Reservoir and Lake Owen should be considered approximate. The initial samples were misplaced at laboratory login. Back-up samples that had been chilled were used for replacements. µS/cm, microsiemen per centimeter at 25°C; °C, degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter]

Site (fig. 2)	Identification number	Date sampled	Time sampled	Specific conduct-ance (µS/cm)	pH	Water tempera-ture (°C)	Color (as platinum-cobalt)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Hardness (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)
Rob Roy Reservoir (top)	411153106154401	9/2/97	10:40	25	6.9	15.4	20	6.0	11	10	3.1	0.6	1.4
Rob Roy Reservoir (bottom)	411153106154402	9/2/97	12:15	24	6.2	6.3	30	6.2	11	10	3.0	0.6	1.3
Lake Owen (top)	410858106060901	9/2/97	15:40	30	7.2	15.6	16	6.7	11	13	3.9	0.7	1.4
Granite Springs Reservoir (top)	411031105132501	8/28/97	13:40	95	8.0	19.9	22	8.0	19	40	13	1.8	2.7
Granite Springs Reservoir (bottom)	411031105132502	8/28/97	15:30	101	6.7	16.0	22	6.7	13	43	14	1.9	2.8
Crystal Lake Reservoir (top)	410928105115201	9/4/97	9:50	108	8.4	18.5	12	6.3	15	46	15	2.3	3.0
Crystal Lake Reservoir (top-QA)	410928105115201	9/4/97	9:55	108	8.4	18.5	13	6.3	16	46	15	2.3	3.0
Crystal Lake Reservoir (middle)	410928105115203	9/11/97	13:00	a	a	a	12	a	15	47	15	2.3	3.0
Crystal Lake Reservoir (bottom)	410928105115202	9/4/97	12:00	114	6.7	16.3	13	<1	<10	48	15	2.3	3.0

Table 2. *Chemical analyses and physical properties of water-quality samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming--Continued*

Site (fig. 2)	Sodium (percent)	Sodium adsorption ratio	Potassium, dissolved (mg/L)	Alkalinity as $CaCO_3$, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica as SiO_2, dissolved (mg/L)	Dissolved solids, sum of constitu-ents (mg/L)	Residual solids (mg/L)	Nitrogen as ammonia, dissolved (mg/L)	Nitrogen, NO_2, dissolved (mg/L)
Rob Roy Reservoir (top)	22	0.2	0.4	13	1.3	0.3	<0.1	4.0	19	39	<0.02	<0.01
Rob Roy Reservoir (bottom)	21	0.2	0.4	12	1.4	0.3	<0.1	6.9	22	45	<0.02	<0.01
Lake Owen (top)	19	0.2	0.3	15	1.1	0.7	<0.1	2.5	20	42	<0.02	<0.01
Granite Springs Reservoir (top)	13	0.2	1.0	40	3.4	2.4	0.3	5.8	55	69	0.15	<0.01
Granite Springs Reservoir (bottom)	13	0.2	1.0	41	3.4	2.5	0.4	8.3	59	79	<0.02	<0.01
Crystal Lake Reservoir (top)	12	0.2	1.1	46	4.5	2.4	0.5	2.1	58	80	<0.02	<0.01
Crystal Lake Reservoir (top-QA)	13	0.2	1.2	46	4.4	2.6	0.5	2.1	58	91	<0.02	<0.01
Crystal Lake Reservoir (middle)	12	0.2	1.3	45	4.3	2.7	0.5	3.9	60	87	0.09	<0.01
Crystal Lake Reservoir (bottom)	12	0.2	1.2	44	4.4	3.4	0.5	6.4	63	90	0.14	<0.01

Table 3. *Chemical analyses and physical properties of water-quality samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming--Continued*

Site (fig. 2)	Nitrogen, $NO_2 + NO_3$, dissolved (mg/L)	Phosphorus Ortho as P, dissolved (mg/L)	Oil & grease (total) (mg/L)	Arsenic, dissolved (μg/L)	Boron, dissolved (μg/L)	Copper, dissolved (μg/L)	Iron, dissolved (μg/L)	Lead, dissolved (μg/L)	Manganese, dissolved (μg/L)	Aluminum, dissolved (μg/L)	Selenium, dissolved (μg/L)
Rob Roy Reservoir (top)	<0.05	<0.01	<1	<1	16	4	51	<1	2	45	<1
Rob Roy Reservoir (bottom)	0.08	<0.01	2	<1	17	4	69	<1	69	123	<1
Lake Owen (top)	<0.05	<0.01	<1	<1	19	4	130	2.3	8	24	<1
Granite Springs Reservoir (top)	<0.05	<0.01	<1	<1	14	4	7	<1	5	18	<1
Granite Springs Reservoir (bottom)	<0.05	<0.01	<1	<1	8.4	4	21	4.1	76	<5	<1
Crystal Lake Reservoir (top)	<0.05	<0.01	2	<1	12	2	10	<1	<1	6.4	<1
Crystal Lake Reservoir (top-QA)	<0.05	<0.01	<1	<1	<16	2	13	<1	<1	14.2	<1
Crystal Lake Reservoir (middle)	<0.05	<0.01	<1	<1	18	2	28	<1	2	8.4	<1
Crystal Lake Reservoir (bottom)	<0.05	<0.01	<1	<1	12	7	24	<1	31	10	<1

Table 4. *Chemical analyses of composite samples of bottom sediment collected in 1998 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming*

[Except for nitrogen, all results are for sediment passing through a 63 µm sieve; µg/g, microgram per gram}

Site (fig. 2)	Date sampled	Nitrogen, as total $NO_2 + NO_3$ (mg/kg as N)	Aluminum (percent)	Arsenic (µg/g)	Barium (µg/g)	Beryllium (µg/g)	Bismuth (µg/g)	Cadmium (percent)	Calcium (percent)	Cerium (µg/g)	Chromium (µg/g)	Cobalt (µg/g)
Rob Roy Reservoir	7/23/98	9	6.9	<10	690	2	<10	<2	1.0	58	53	13
Lake Owen	7/23/98	8	6.9	<10	520	1	<10	<2	2.2	50	120	16
Granite Springs Reservoir	2/5/98	<2	6.2	<10	830	2	<10	<2	.65	130	12	5
Crystal Lake Reservoir	2/3/98	<2	6.8	<10	720	3	<10	<2	.90	200	21	7

Site (fig. 2)	Date	Copper (µg/g)	Europium (µg/g)	Gallium (µg/g)	Gold (µg/g)	Holmium (µg/g)	Iron (percent)	Lanthanum (µg/g)	Lead (µg/g)	Lithium (µg/g)	Magnesium (percent)	Manganese (µg/g)
Rob Roy Reservoir	7/23/98	43	<2	14	<8	<4	3.1	35	19	36	.89	800
Lake Owen	7/23/98	58	<2	13	<8	<4	2.7	30	16	29	1.4	470
Granite Springs Reservoir	2/5/98	77	<2	17	<8	<4	2.2	82	28	15	.34	290
Crystal Lake Reservoir	2/3/98	150	2	20	<8	<4	3.6	120	31	20	.71	460

Table 5. *Chemical analysis of composite samples of bottom sediment collected in 1998 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming--Continued*

Site (fig. 2)	Date	Mercury (μg/g)	Molybdenum (μg/g)	Neodymium (μg/g)	Nickel (μg/g)	Niobium (μg/g)	Phosphorus (percent)	Potassium (percent)	Scandium (μg/g)	Selenium (μg/g)	Silver (μg/g)	Sodium (percent)
Rob Roy Reservoir	7/23/98	.05	<2	27	25	16	.080	1.8	10	0.4	<2	1.1
Lake Owen	7/23/98	.04	<2	26	52	13	.050	1.3	14	0.9	<2	.84
Granite Springs Reservoir	2/5/98	.02	<2	63	8	22	.050	3.3	6	0.4	<2	1.7
Crystal Lake Reservoir	2/3/98	.03	<2	93	14	29	.080	2.7	10	0.6	<2	1.3

Site (fig. 2)	Date	Strontium (μg/g)	Sulfur (μg/g)	Tantalum (μg/g)	Thorium (μg/g)	Tin (μg/g)	Titanium (percent)	Uranium (μg/g)	Vanadium (μg/g)	Yttrium (μg/g)	Ytterbium (μg/g)	Zinc (μg/g)
Rob Roy Reservoir	7/23/98	160	.05	<40	8	<5	.32	<100	87	17	1	96
Lake Owen	7/23/98	220	.24	<40	7	<5	.23	<100	110	16	1	71
Granite Springs Reservoir	2/5/98	130	<.05	<40	21	<5	.19	<100	29	31	3	66
Crystal Lake Reservoir	2/3/98	120	.07	<40	31	<5	.31	<100	46	49	5	99

Profiles

Profile measurements indicated that Rob Roy was stratified from mid-July to late September 1998. Stratification is shown in a profile measured September 2, 1997 (fig. 3A). The temperature, dissolved oxygen, specific conductance, and pH profiles were relatively constant in the epilimnion, from about 1 ft below the surface to about 11 ft. The temperature decreased at a steady rate, from about 15°C (degrees Celsius) at 11 ft, to about 6°C at about 65 ft below the surface. The pH also gradually decreased, from 6.9 at about 8 ft to 6.2 at about 55 ft. The Secchi disk transparency was 9.8 ft, which was the deepest transparency recorded during the summer 1997 sampling trips. In many lakes the Secchi depth is approximately one-third the depth of the euphotic zone (Horne and Goldman, 1994, p. 34); therefore, the euphotic zone was estimated to extend to about 29 ft below the surface, which is also where dissolved-oxygen concentrations decrease about 1 mg/L.

Likewise, the July 23, 1998 profiles of Rob Roy (fig. 3B) show stratification of the water column in the reservoir. The temperature, dissolved oxygen, specific conductance, and pH profiles were relatively constant from the surface to about 13 ft. The temperature decreased with depth at a fairly steady rate, from about 17°C at 13 ft, to about 8.5°C at about 27 ft in the metalimnion. Within about that same interval, dissolved oxygen increased and specific conductance decreased. The Secchi disk transparency on July 21 was 12.5 ft (fig. 4), yielding an estimated euphotic zone of about 38 ft.

The September 3, 1998 profiles of Rob Roy (fig. 3C) were similar to the September 2, 1997 profiles; however, the most noticeable change was the increased thickness of the epilimnion and the decreased thickness of the metalimnion in 1998. The temperature, dissolved oxygen, and specific conductance were relatively constant from the surface to about 24 ft in depth. The temperature ranged from about 15°C to 14°C in the upper 24 ft, then sharply decreased to about 8.2°C at 29 ft. Temperature then gradually decreased from about 8.2 to 6.4°C at 67 ft. The pH increased from 6.9 at the surface to 7.3 at 12 ft and then decreased to 6.5 at 28 ft. The pH remained relatively constant from 28 ft to 67 ft. Dissolved-oxygen concentrations varied from 7.4 mg/L at the surface to 5.9 mg/L at 67 ft. A zone of slightly lower dissolved oxygen was present from 24 to 29 ft. The Secchi disk transparency was 11.6 ft, with the estimated euphotic zone extending to about 35 ft. Additional profiles for 1998 are included in appendix A.

The profiles indicate that the depth of stratification in Rob Roy changed over time in 1998. When the seasonal variations of temperature in the summer and fall of 1998 are examined (fig. 5), two characteristics of Rob Roy are apparent. The first is that a strong stratification developed by mid-July and continued until September; by early October, the reservoir was no longer stratified. The second is that the zone of warming in the reservoir extended deeper into the reservoir from mid-July to late September 1998. The 10°C temperature contour line dropped from about 20 ft in mid-July to about 30 ft by late September. The zone continued to deepen after surface cooling began in early September.

Phytoplankton

Bacillariophyta (diatoms) and Chlorophyta (green algae) dominated the phytoplankton community of Rob Roy. The diatoms, in terms of biomass (mass of the phytoplankton cells), dominated the samples collected during September 1997 and August 1998 (fig. 6). The data shown in figure 6 are from samples collected at a depth of 1 ft below the surface, at a site near the deepest part of the reservoir (fig. 2A). An abrupt shift in the phytoplankton community from diatoms to green algae was evident in the September 1998 samples. Other algae identified in the samples included the Cryptophyta (cryptomonads), the Pyrrophyta (dinoflagellates), and the Chrysophyta (golden-brown algae). Euglenophyta (euglenoids) and Cyanophyta (blue-green algae), which are often associated with organic or nutrient enrichment, were absent from the samples. Phytoplankton taxa are listed in table 4. The complete phytoplankton data set for all four reservoirs are listed in Appendix B; data for Rob Roy are listed in table B1 of Appendix B.

Twenty-nine taxa of algae were identified from the samples (table 4). Two species of diatoms, *Asterionella* and *Fragilaria*, were responsible for the predominance of diatoms in the September 1997 and August 1998 samples. The maximum biomass of *Asterionella* was 3,500 µg/L (micrograms per liter), which constituted 98 percent of the total phytoplankton biomass in the September 1997 sample. The corresponding density of *Asterionella* in that sample was 2,590 cells per milliliter (cells/mL). *Asterionella* and *Fragilaria* were codominant species during August 1998. The maximum concentration of *Fragilaria* was 1,700 µg/L biomass (1,550 cells/mL density) in the August 11 sample.

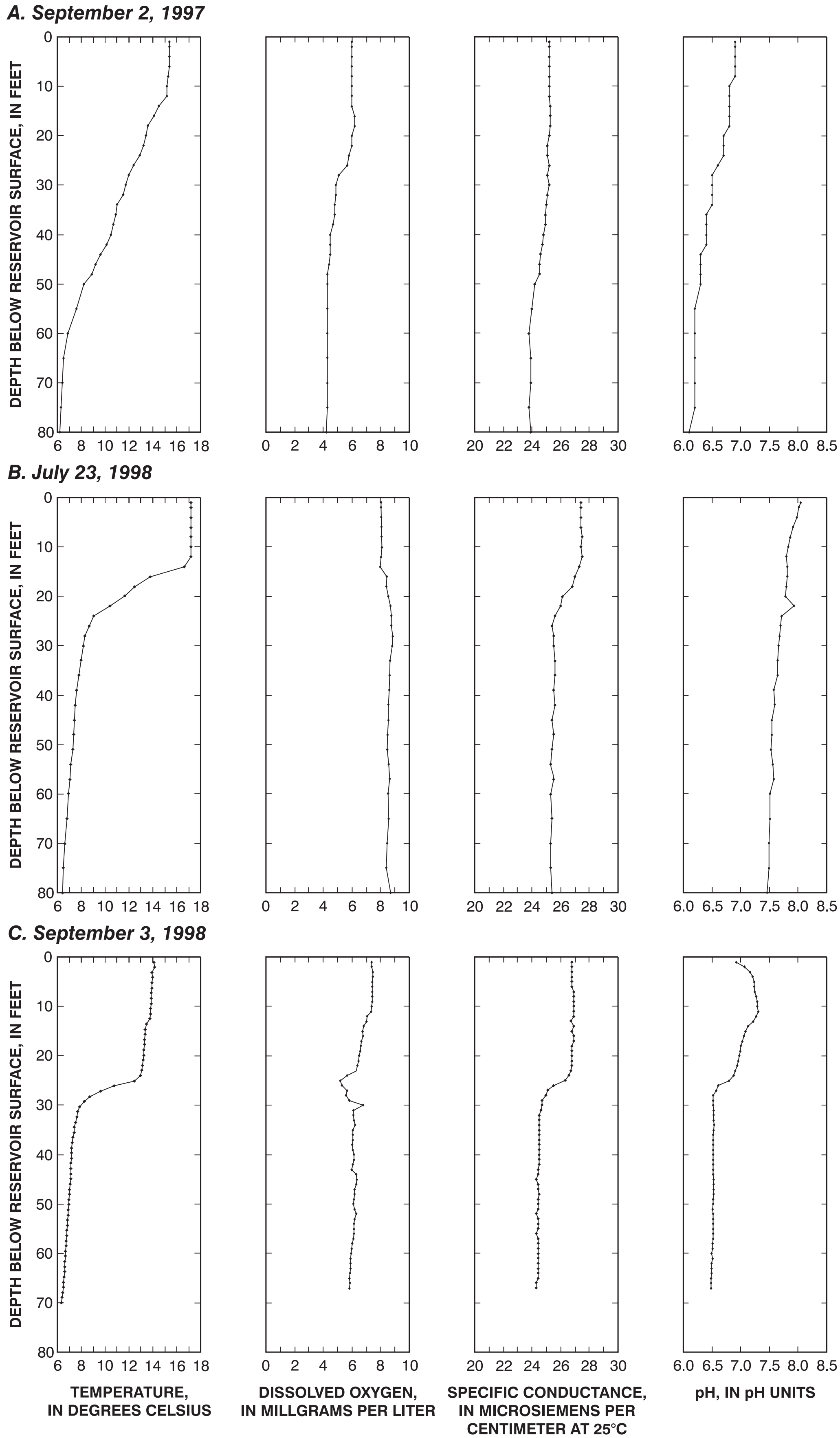


Figure 3. Temperature, dissolved oxygen, specific conductance and pH profiles of Rob Roy Reservoir, Albany County, Wyoming.

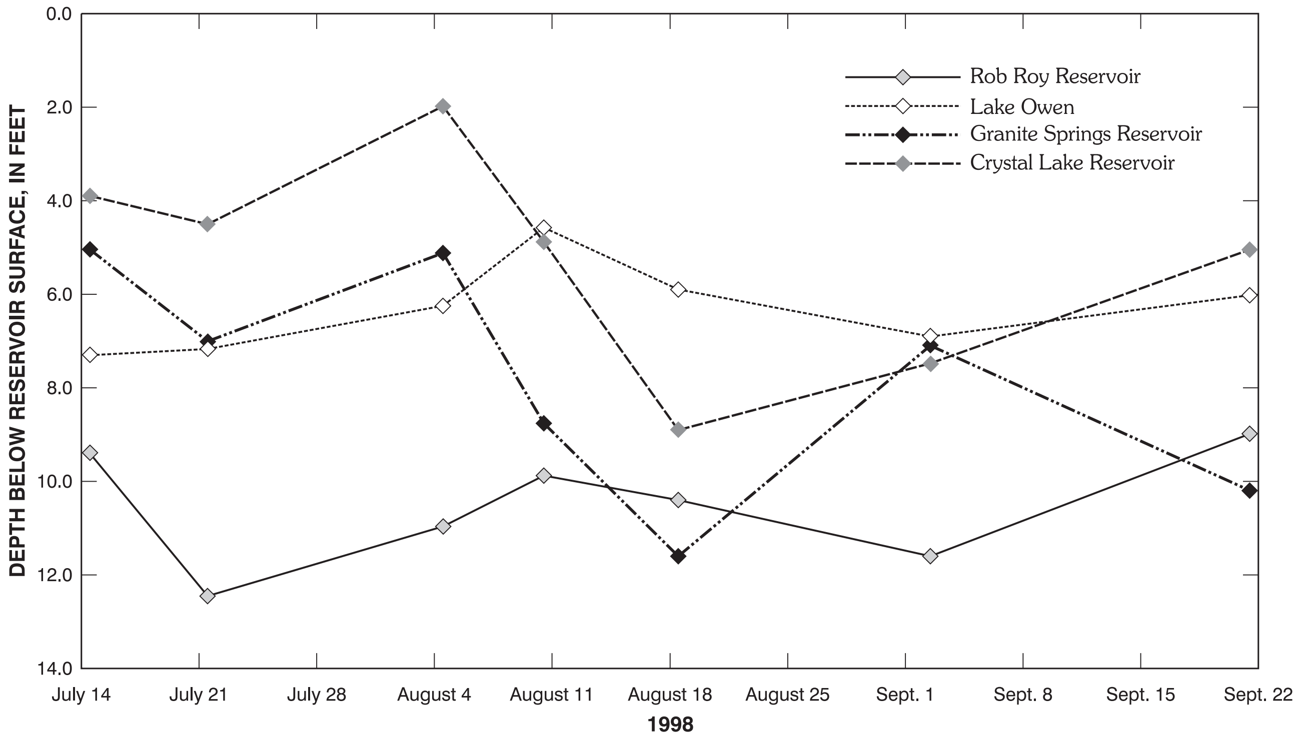


Figure 4. Secchi disk transparency depths in 1998 for Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

Eighteen taxa of green algae were identified. The genus *Cosmarium* was the predominant algae in samples collected on September 3, 17, and 22, 1998. *Staurastrum* dominated the September 10, 1998, sample. *Dictyosphaerium* was a codominant species in the September 3, 1998, sample, and *Spondylosium* was a subdominant species in the September 22, 1998, sample. The maximum biomass of green algae was 740 µg/L of *Cosmarium* in the September 17 sample. The corresponding density of *Cosmarium* was 40 cells/mL, which is a relatively low density but is reflective of the large size of the cells.

One or more species of cryptomonads were present in most of the samples. The crytomonads typically were not dominant, with the exception of the July 23 sample that was dominated by *Campylomonas rostratiformis*. Other species that occurred in Rob Roy include *Gymnodinium* (dinoflagellates) and *Mallomonas* (golden-brown algae).

A phytoplankton sample also was collected during September 1997 about 3 ft above the bottom of the reservoir. That sample contained only *Asterionella*, at a relatively low concentration. The algae likely were cells that had sunk from the euphotic zone. The depth of the euphotic zone, where sufficient light is available for photosynthesis, was estimated to be about 29 ft based on a Secchi disk transparency of 9.8 ft.

The Secchi disk transparencies measured during 1998 in Rob Roy ranged from 9.0 to 12.5 ft; the average transparency was 10.4 ft (fig. 4). The greatest transparencies were in mid-July and early September. Comparison of transparencies to the water profile data indicate the euphotic zone extended below the metalimnion when the reservoir was stratified.

Protozoa (animal kingdom) also were noted in the samples from Rob Roy (Appendix B, table B1). Unidentified flagellates, ciliates, and ameba were present at densities on the order of tens to hundreds per milliliter; the maximum biomass was 53 µg/L. The distinction between protozoa and algae, especially the flagellated forms, can be controversial (Smith, 1950, p. 1-11; Reid and Wood, 1976, p. 320-330). For this report, the algae were distinguished from the protozoa by the presence of chlorophyll and other photosynthetic pigments in the algae.

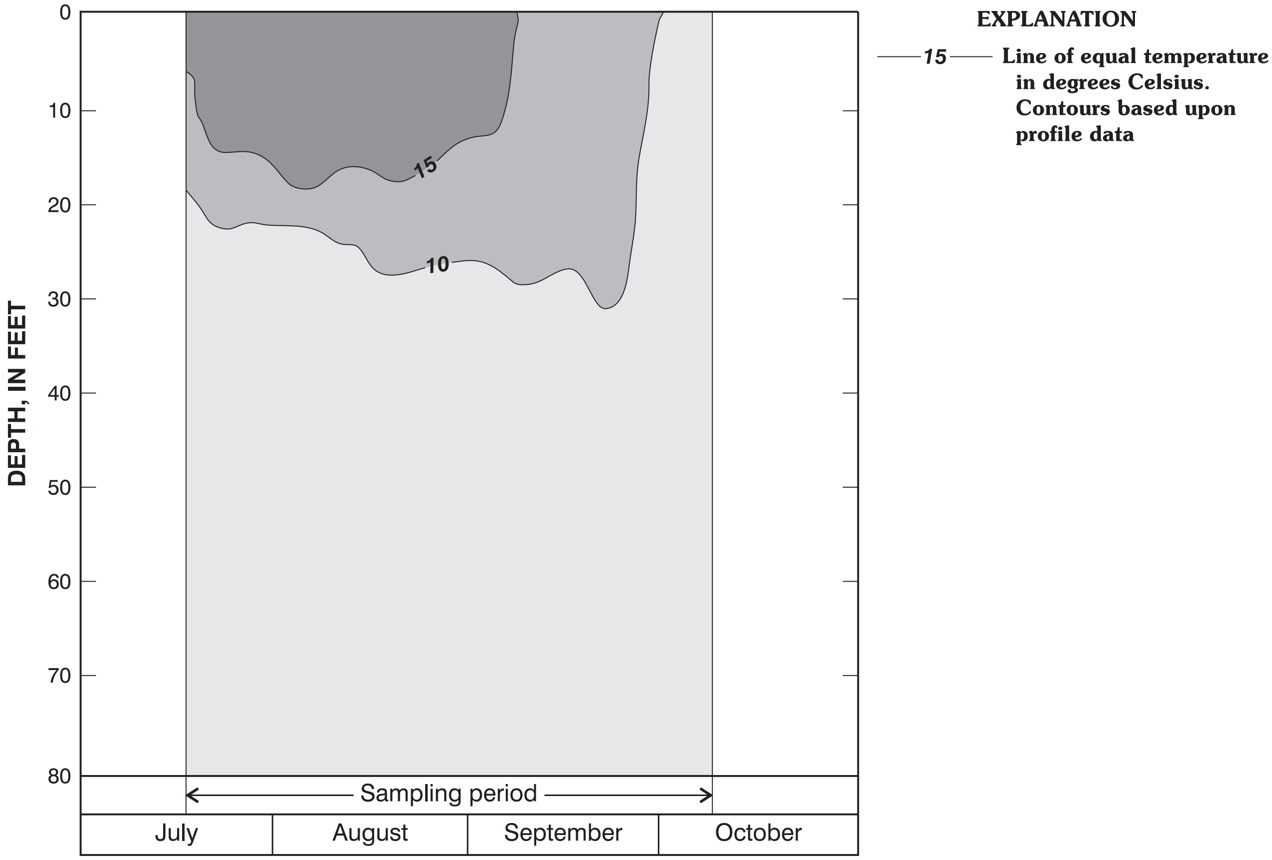


Figure 5. Temporal variation of temperature with depth in Rob Roy Reservoir, Albany County, Wyoming, in summer and fall, 1998.

In Rob Roy in the fall of 1997, MPA was dominated by non-diatomaceous phytoplankton and diatoms. The MPA results are summarized in table 5.

Chemical Quality

Relatively little difference in water chemistry existed between the top and bottom of Rob Roy Reservoir (table 2). The dissolved-solids concentration was 19 mg/L for the surface sample and 22 mg/L for the bottom sample (fig. 7). The water was a calcium bicarbonate type. The concentrations of selected major ions shown on the pie diagrams in figure 8 indicate no differences in the concentration of major ions between surface and bottom water samples. Dissolved fluoride concentrations were less than the detection level of 0.1 mg/L. Silica concentrations, as dissolved SiO_2, increased slightly with depth (table 2; fig. 9). Nutrient concentrations generally were less than the detection level. An exception was dissolved nitrogen, as nitrite plus nitrate, in the bottom sample, which was 0.08 mg/L (table 2).

Some differences were detected in selected trace-element concentrations between the top and bottom samples collected at Rob Roy. Dissolved iron (fig. 10) and dissolved manganese concentrations (fig. 11) were higher in the bottom sample.

Bottom Sediment

On July 23, 1998, bottom sediment samples were collected from five sites (fig. 2A) in Rob Roy and composited into a single sample. The composite sample was analyzed for selected constituents (table 3). The nitrogen concentration, reported as total nitrite plus nitrate, was 9 mg/kg, the highest concentration from all four reservoirs (table 3). Of the constituents analyzed, aluminum was present in the highest percentage (6.9 percent) and iron was next highest (3.1 percent). Most of the

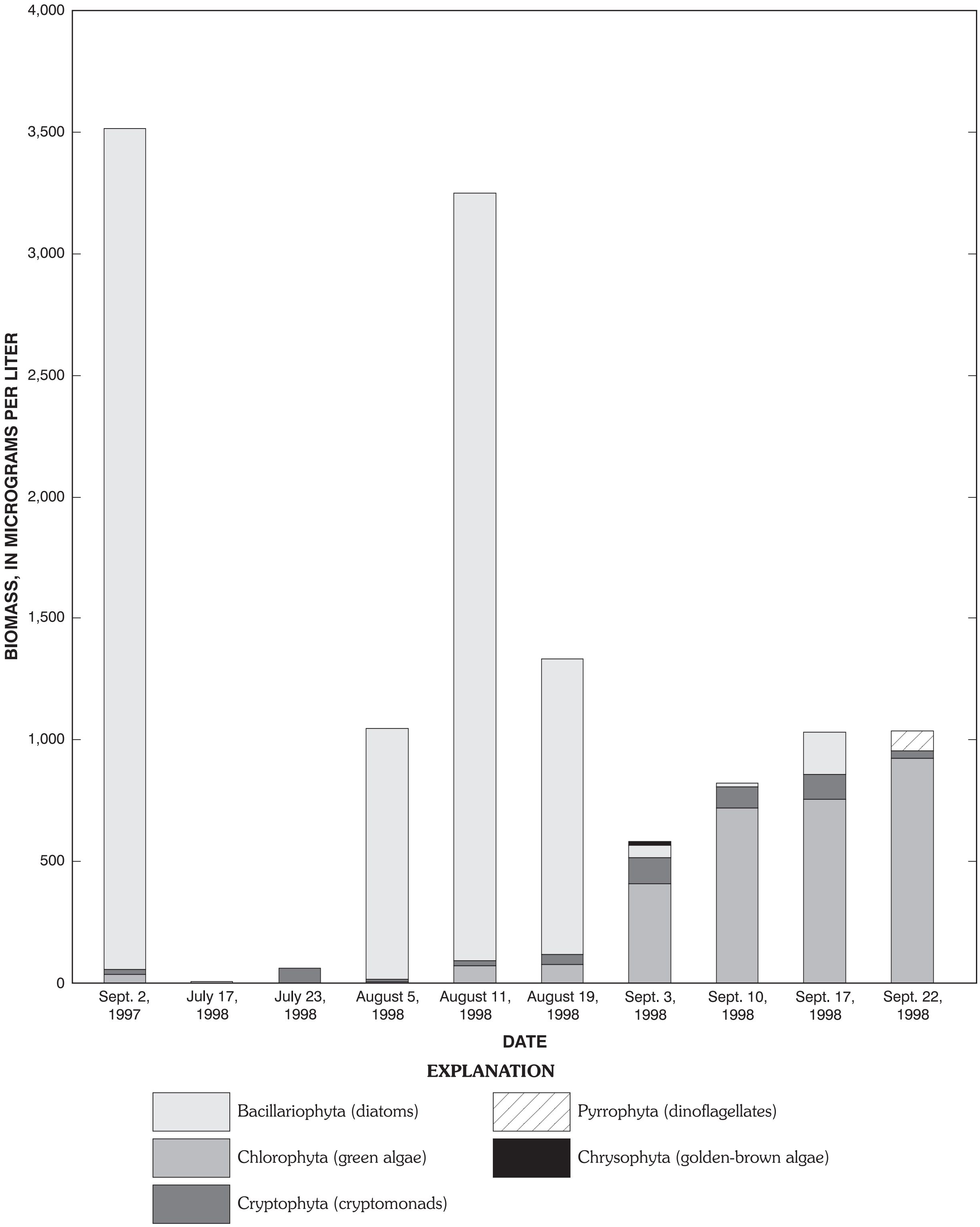


Figure 6. Phytoplankton biomass changes over time in Rob Roy Reservoir, Albany County, Wyoming.

Table 4. *Phytoplankton taxa list for Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming*

[x indicates taxa presence]

Phytoplankton taxa	Reservoir			
	Rob Roy	Lake Owen	Granite Springs	Crystal Lake
BACILLARIOPHYTA (Diatoms)				
Centrales (Centric diatoms)				
Centrales size 1			x	x
Centrales size 2			x	x
Centrales size 3			x	x
Centrales size 4			x	
Cyclotella			x	x
Melosira				x
Melosira size 1			x	
Melosira size 2			x	
Melosira size 3			x	
Stephanodiscus			x	x
Pennales (Pennate diatoms)				
Achnanthes		x		x
Asterionella	x	x	x	
Cymbella			x	
Fragilaria	x	x	x	x
Nitzschia	x			
Pennales size 1			x	
Pennales size 2		x	x	
Pennales size 3		x		x
Synedra		x		
Tabellaria			x	
CHLOROPHYTA (Green algae)				
Actinastrum		x		
Ankistrodesmus	x	x	x	
Chlamydomonas size 1	x			
Chlamydomonas size 2	x			
Chlorella	x	x	x	x
Chlorophyte size 1			x	

Table 4. *Phytoplankton taxa list for Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming--Continued*

Phytoplankton taxa	Reservoir			
	Rob Roy	Lake Owen	Granite Springs	Crystal Lake
Chlorophyte size 2	x	x	x	x
Chlorophyte size 3	x			x
Chlorophyte size 4	x	x	x	x
Chlorophyte size 5	x			
Chlorophyte size 6			x	x
Chlorophyte size 7	x			
Chlorococcales				x
Closterium				x
Coelastrum				x
Cosmarium	x	x		x
Crucigenia		x		
Dictyosphaerium	x			x
Didymocystis			x	
Elakatothrix	x			
Eudorina			x	
Micractinium			x	
Oocystis		x		
Oocystis size 1	x		x	x
Oocystis size 2				x
Pandorina				x
Quadrigula	x	x	x	x
Scenedesmus		x	x	
Schroederia	x			
Sphaerocystis	x	x	x	x
Spondylosium	x	x		x
Staurastrum	x			x
Tetraspora		x		
Zygnematales		x		
CHRYSOPHYTA (Golden-brown algae)				
Chrysophyte size 1		x		
Dinobryon		x	x	

Table 4. *Phytoplankton taxa list for Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming--Continued*

Phytoplankton taxa	Reservoir			
	Rob Roy	Lake Owen	Granite Springs	Crystal Lake
Mallomonas	x	x		
Uroglenopsis		x		
CRYPTOPHYTA (Cryptomonads)				
Campylomonas reflexa	x	x	x	x
Campylomonas rostratiformis	x	x	x	x
Cryptomonas	x	x		x
Cryptophyte size 1		x	x	x
Cryptophyte size 2	x	x		
Cryptophyte size 3		x		x
Cryptophyte size 4				x
Katablepharis	x	x	x	x
Plagioselmis	x	x	x	x
CYANOPHYTA (Blue-green algae)				
Anabaena			x	x
Aphanothece			x	x
Cyanophyte size 1				x
Gomphosphaeria				x
Microcystis				x
Pseudanabaena			x	
EUGLENOPHYTA (Euglenoids)				
Euglena		x		
Euglenophyte size 1		x		
Euglenophyte size 2		x		
Trachelomonas size 1			x	x
Trachelomonas size 2		x	x	x
PYRROPHYTA (Dinoflagellates)				
Ceratium			x	x
Gymnodinium	x	x	x	

Table 5. *Microscopic particulate analyses of water samples collected in the fall of 1997 at Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming*

[ND, none detected; µm, micrometer; L, liter].

Reservoir (fig. 2)	Date sampled	Amorphous clay, silt, and detritus - aggregates (diameter, in µm)	Nondiatomaceous phyto plankton (million counts/100L)	Diatoms (million counts/100L)	Plant Debris	Rotifers (counts/ 100L)	Nematodes	Pollen	Ameba
Rob Roy	9/2/97	1-75	1.00	0.40	ND	ND	ND	ND	ND
Lake Owen	9/2/97	1-100	0.40	0.03	ND	60	ND	ND	ND
Granite Springs	8/28/97	1-50	0.80	8.00	ND	1,000	ND	ND	ND
Crystal Lake	9/4/97	1-50	4.00	7.00	ND	ND	ND	ND	ND

Reservoir (fig. 2)	Date sampled	Ciliates	Colorless Flagellates	Crustaceans	Other arthropods (thousand counts/100L)	Other	Total (million counts/100L)	Volume of water filtered (gallons)	[1]Giardia, total (number/ 100L)	[1]Cryptosporidium (number/ 100L)
Rob Roy	9/2/97	ND	ND	ND	1.00	ND	1.40	905	<11	11
Lake Owen	9/2/97	ND	ND	ND	ND	ND	0.43	791	3	<2
Granite Springs	8/28/97	ND	ND	ND	3.00	ND	8.80	1174	19	<19
Crystal Lake	9/4/97	ND	ND	ND	ND	ND	11.00	798	<14	<14

[1]Analyzed by method outlined by U.S. Environmental Protection Agency (1996b). All limitations stated in the method apply.

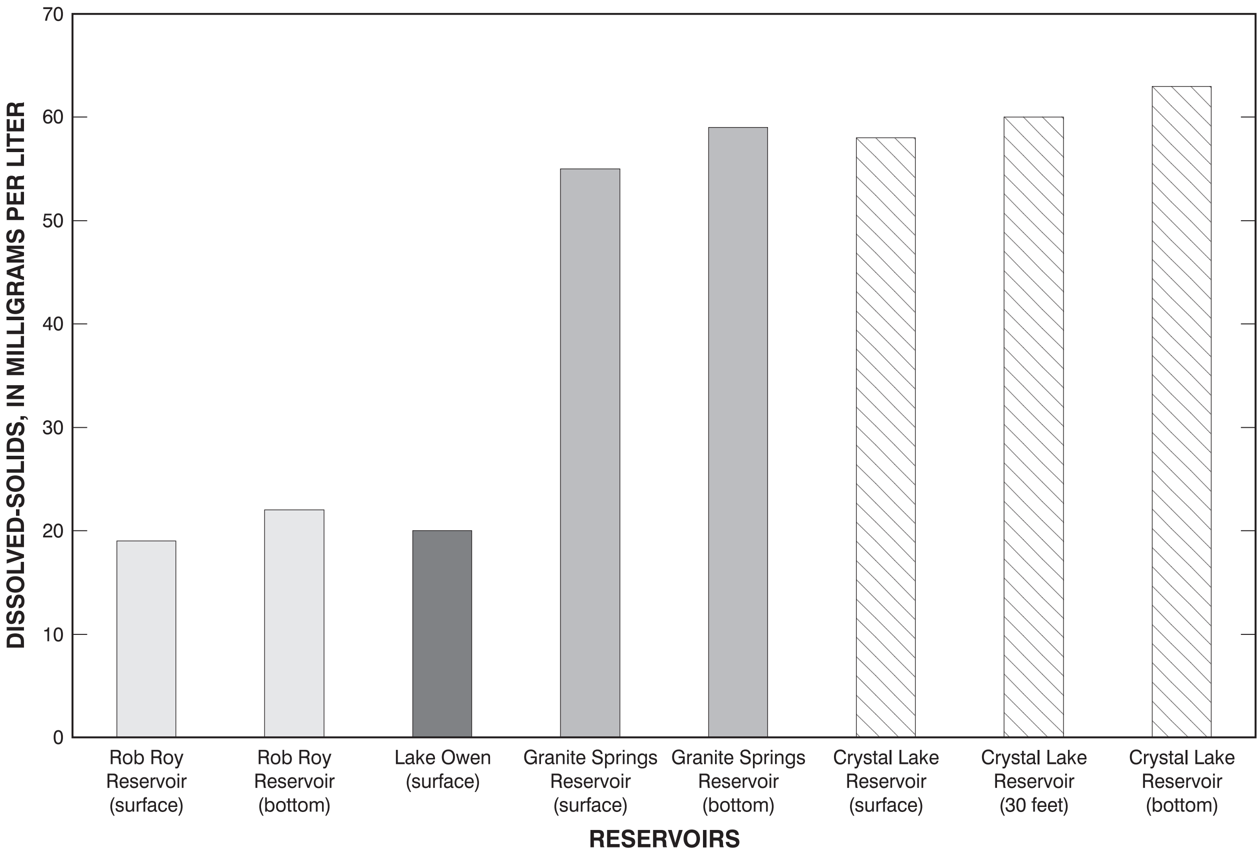


Figure 7. Dissolved-solids concentrations in water samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

trace elements are present in concentrations in the microgram per gram range. Trace-element concentrations of arsenic, bismuth, cadmium, europium, gold, holmium, molybdenum, silver, tantalum, tin, and uranium were less than the detection limit. Cerium, chromium, thorium, and vanadium concentrations fit best with Group 1, the crustal average, rather than diabase or granitic rocks (fig. 12). The similarity is probably a reflection of the surrounding geology which is composed of sedimentary deposits (Tertiary age) and metasedimentary and metavolcanic rocks (Pre-Cambrian) (Love and Christiansen, 1985).

Lake Owen

Lake Owen is the shallowest and smallest in the series of reservoirs (fig. 2B; table 1). Its maximum depth is about 10 ft and it contains only about 1 percent of the storage capacity of the system. Although lower in elevation than Rob Roy Reservoir, Lake Owen is located in a high mountainous area and has a spillway elevation of 8,955 ft above sea level. The vegetation surrounding Lake Owen is composed of mixed evergreen and aspen areas with some open meadow. Lake Owen is used primarily for recreational activities such as boating and fishing.

Profiles

Probably due to its shallow depth, Lake Owen is not stratified. The September 2, 1997 profiles of Lake Owen (fig. 13) did not indicate stratification. The water temperature was about 15°C, the dissolved oxygen was about 6.5 mg/L, the specific conductance was about 30 µS/cm, and the pH was about 7.2. The Secchi disk was still visible when resting on the reservoir bottom. Profile data collected September 16, 1997 indicate a sharp drop in water temperature. The water temperature was just over 11°C on September 16 (Appendix A).

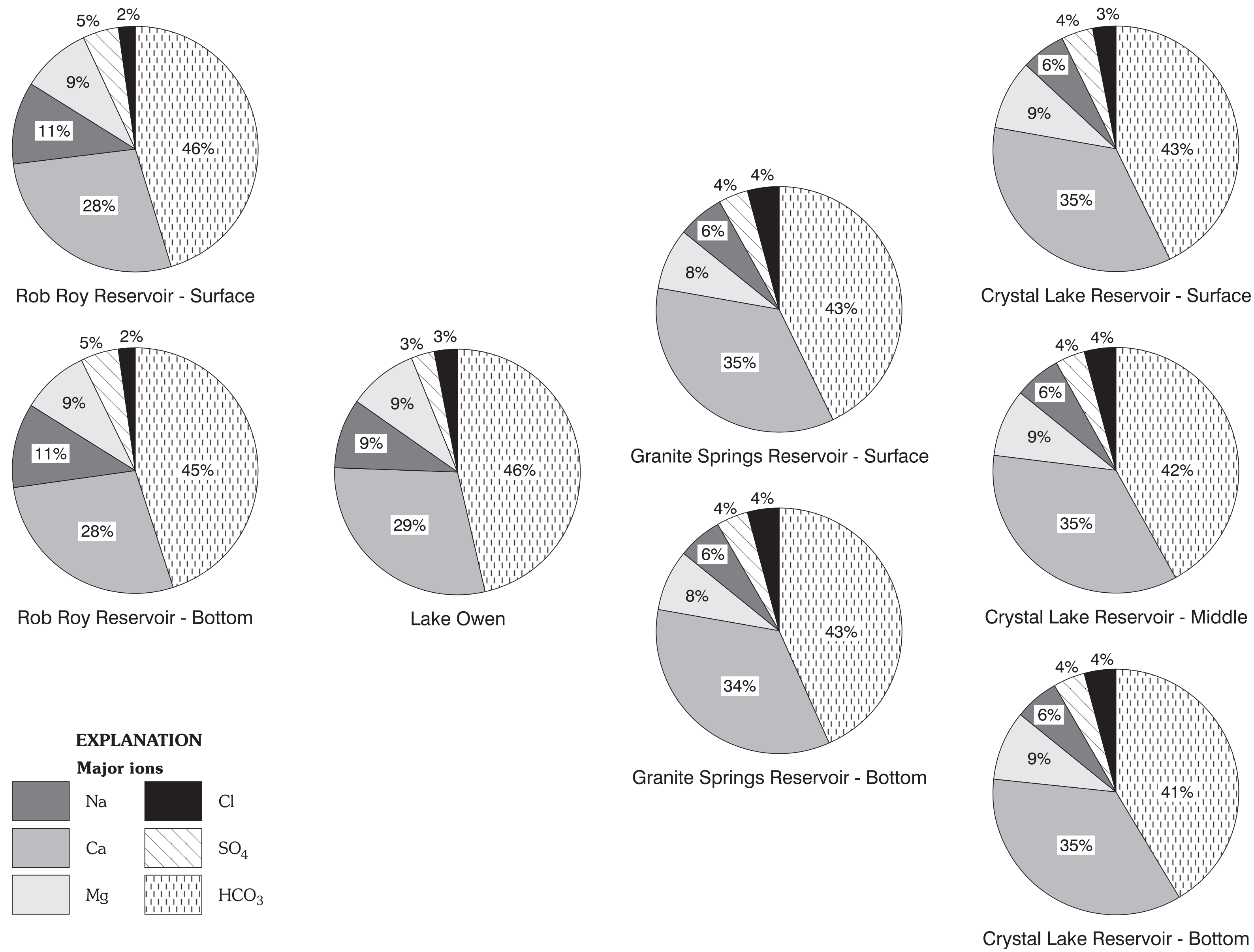


Figure 8. Relative percentage of major ions in water samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming. Percentages calculated from concentrations, measured in milliequivalents per liter.

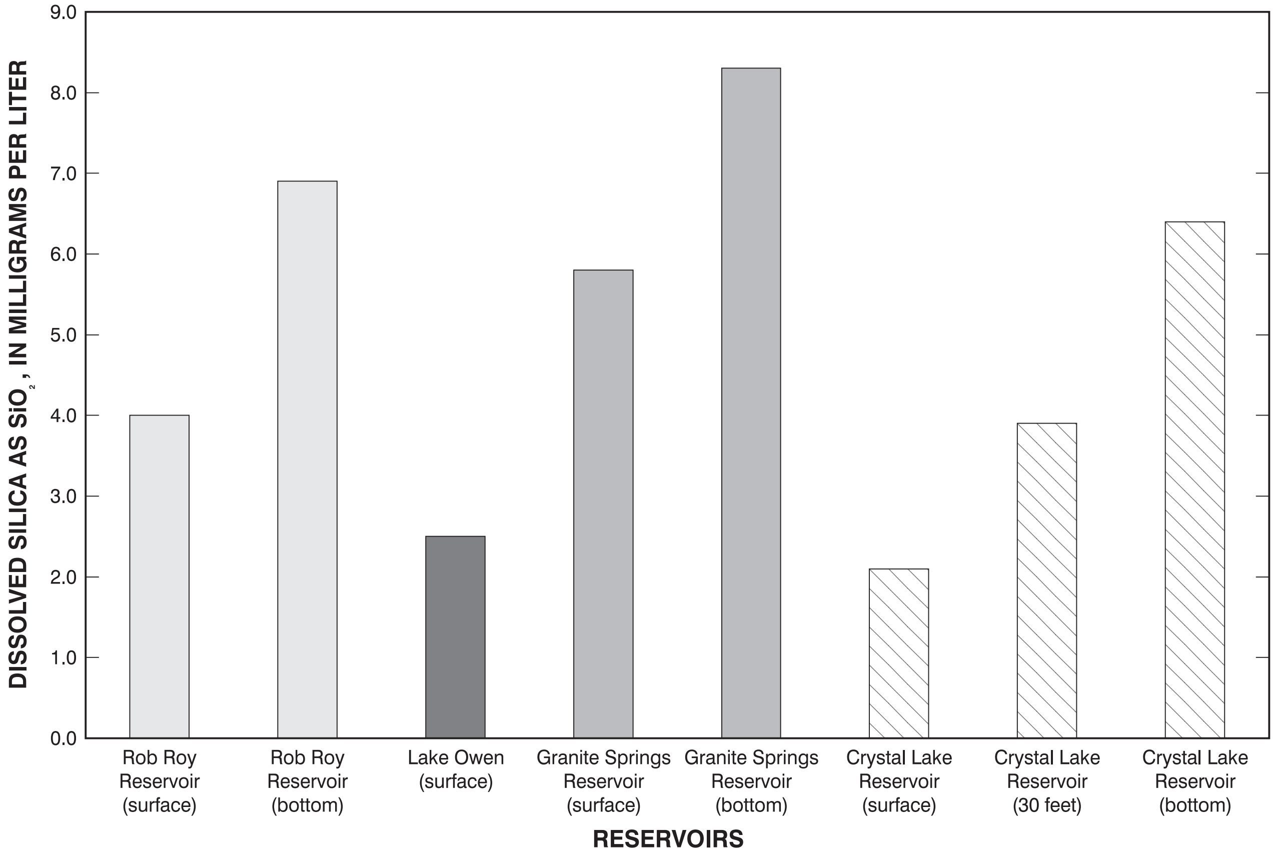


Figure 9. Dissolved-silica concentrations in water samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

Lake Owen also was not stratified in 1998. The July 23, 1998 profile showed a consistent water temperature of 18.2°C, dissolved oxygen decreased from 7.3 to 7.2 mg/L, the specific conductance was about 57 µS/cm, and pH decreased from 7.9 to 7.8. By September 3, 1998 the temperature decreased from 16.6 to 14.6°×C, dissolved oxygen increased from 8.2 to 9.0 mg/L, specific conductance remained around 42 to 43 µS/cm, and pH increased from 8.4 to 8.9.

The temperature changes probably were facilitated by Lake Owen's high elevation, shallow depth, large surface-area exposure, and the seasonal climatic change. Temporal changes indicate that although Lake Owen warms by mid-July, it cools quickly in the fall (fig. 14). Water transparency, as measured by a Secchi disk, ranged from a minimum of 4.6 ft on August 10, 1998 to 7.3 ft on July 17, 1998 (fig. 4).

Phytoplankton

The golden-brown algae (chrysophyta) dominated the phytoplankton community in Lake Owen. The biomass of the golden-brown algae ranged from about 3,500 to 7,1000 µg/L in samples collected on August 11 and during early to mid-September 1998 (fig.15). The cause for the low concentration of phytoplankton on August 19, between 2 weeks of higher concentrations, is unknown. Green algae were present in nearly all of the samples, whereas the dinoflagellates and euglenoids appeared only in the late summer samples (fig.15).

Uroglenopsis was the dominant species of chrysophyte in the samples from Lake Owen. The maximum biomass of *Uroglenopsis* was 7,000 µg/L (30,500 cells/mL) in the September 3, 1998 sample (Appendix B, table B2). Other chrysophytes, such as *Dinobryon* and *Mallomonas,* were present in smaller

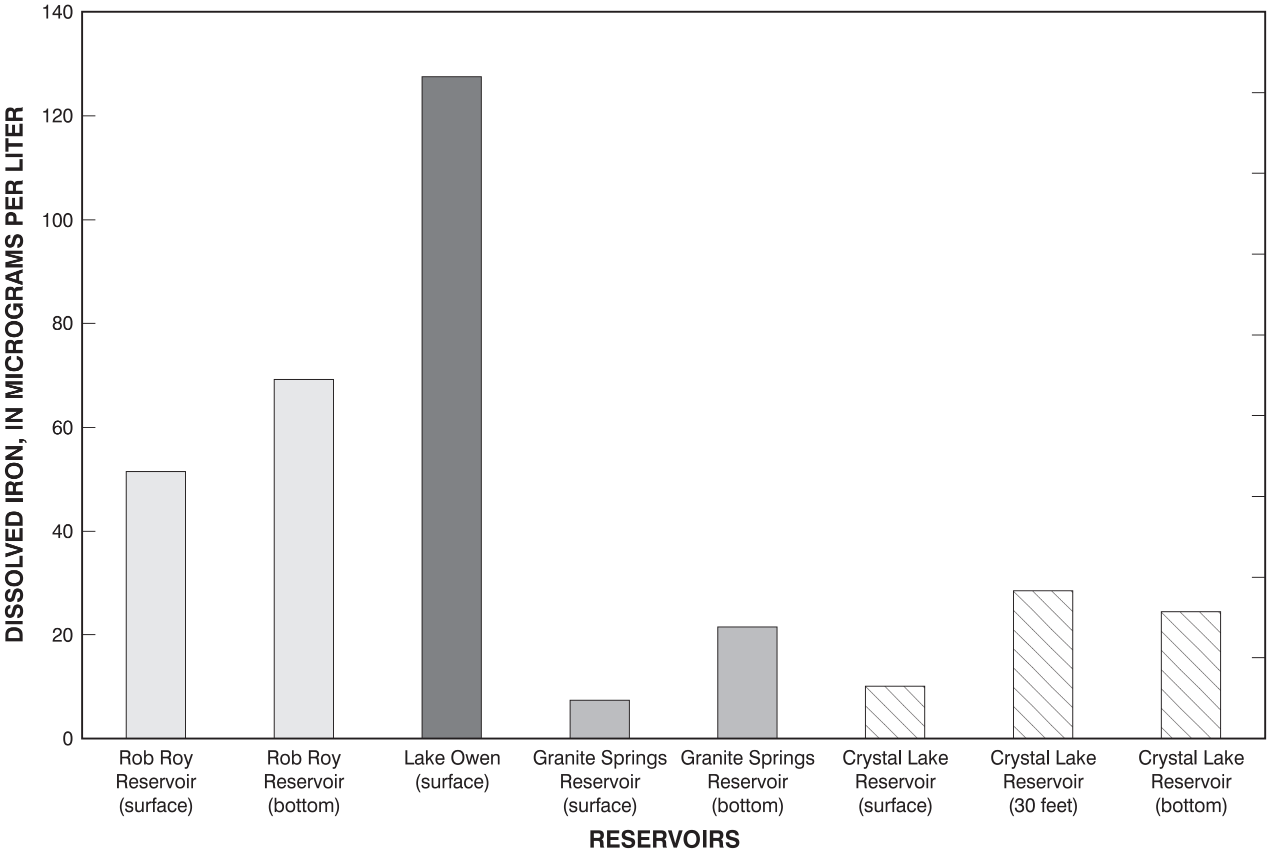


Figure 10. Dissolved-iron concentrations in water samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

quantities in some samples. Green algae were the most diverse group of algae in Lake Owen; of the 37 taxa identified, 14 taxa were green algae. *Cosmarium* was the most common green algae, particularly in the samples collected on July 23 and September 22 (fig. 15). The green algae *Quadrigula* and *Tetraspora* were present at biomasses less than 100 µg/L. Other species of algae identified include the diatoms, *Asterionella* and *Fragilaria*, the euglenoids *Euglena* and *Trachelomonas*, and the dinoflagellate *Gymnodinium*.

Lake Owen is the only reservoir in this study to have extensive macrophyte growth. This may be due in part to the shallow depth of Lake Owen, which allows sunlight to penetrate to the bottom and in turn, allows photosynthesis by rooted plants. On some occasions, the Secchi disk was still visible as it rested on the lake bottom.

Protozoa were present in some samples, mostly at small concentrations. The exception was the September 17 sample, which contained a biomass of 13,000 µg/L of ciliated protozoans. Biomasses of other protozoans in the samples typically were less than 50 µg/L.

In Lake Owen in the fall of 1997, MPA was dominated by non-diatomaceous phytoplankton and diatoms. A few rotifers were detected. This rotifers group are suspension feeders that influence algae species through selective feeding. The MPA results are summarized in table 5.

Chemical Quality

Due to the shallow depth of Lake Owen and lack of variability in the profile data, only a single surface sample was collected for water quality. Dissolved-solids

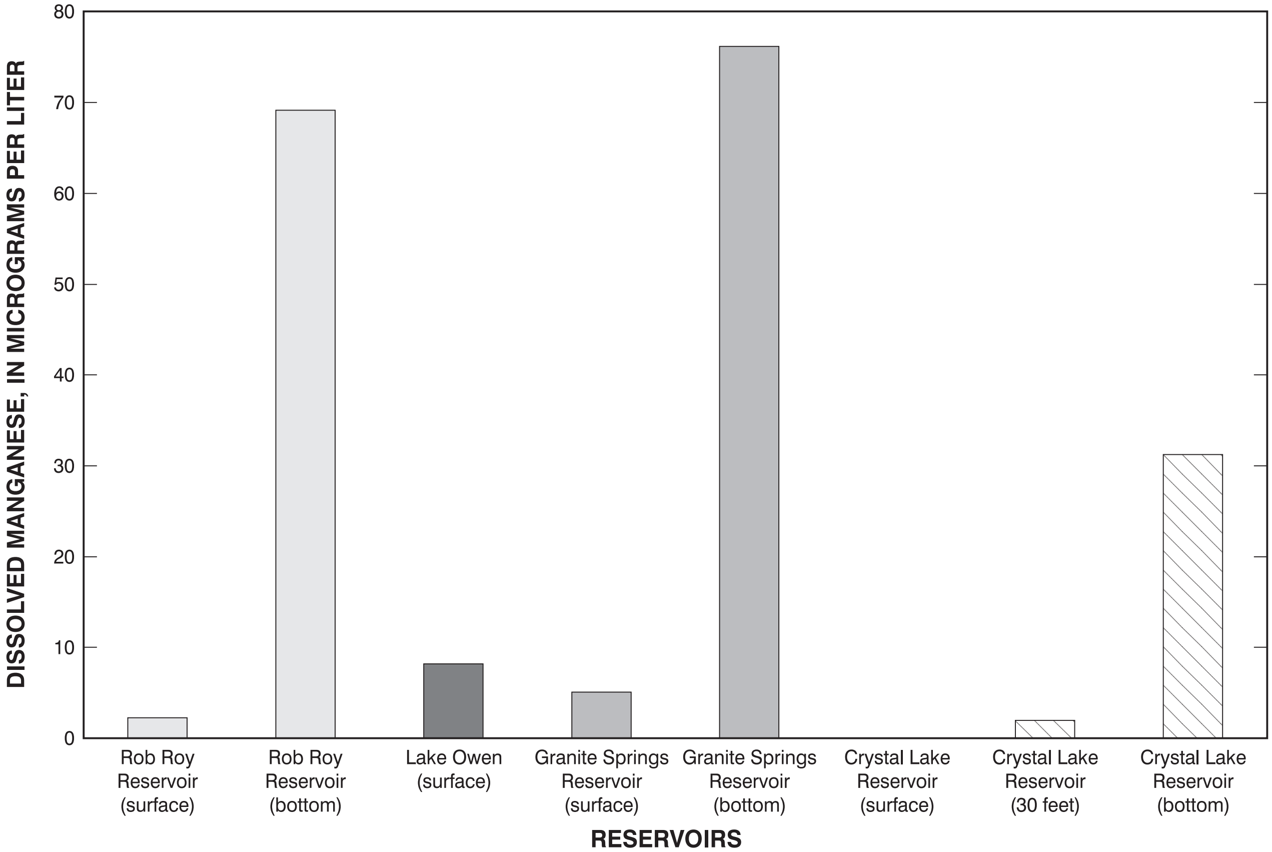


Figure 11. Dissolved-manganese concentrations in water samples collected in 1997 from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

concentration was 20 mg/L (fig. 7). The water was a calcium bicarbonate type. The relative concentrations of major ions are shown on the pie diagram (fig. 8). Dissolved-fluoride concentration was less than the detection level of 0.1 mg/L. Silica concentration, as dissolved SiO_2, was 2.5 mg/L (fig. 9). Nutrient concentrations were less than the detection limit.

Trace-element concentrations in samples were variable (table 2). Dissolved-iron concentration at 130 µg/L was the highest in any sample collected from the four reservoirs (fig. 10). A possible source for this iron might be a magnetite gabboro (Lake Owen mafic complex, Precambrian) which outcrops at the reservoir. Houston and Orback (1976) found that unit to contain more than 10 percent magnetite in the gabbro and sparse layers of massive magnetite several inches thick. Dissolved-manganese concentration was slightly higher than surface samples collected from the other reservoirs.

Bottom Sediment

On July 23, 1998, bottom sediment samples were collected at five sites (fig. 2B) in Lake Owen and composited into a single sample. The composite sample was analyzed for selected constituents (table 3). The nitrogen concentration, reported as total nitrite plus nitrate, was 8 mg/kg. Of the constituents analyzed, aluminum was present at the highest concentration at 6.9 percent, iron was 2.7 percent, and calcium was 2.2 percent. Trace-element concentrations of arsenic, bismuth, cadmium, europium, gold, holmium, molybdenum, silver, tantalum, tin, and uranium were less than the detection limit. When thorium, vanadium, cerium and chromium concentrations are plotted (fig.12), it is apparent that the sediment concentrations are more like the crustal average than either diabase or granitic rocks. The trace-element concentrations are probably similar to crustal averages due to the local geology, which is composed of sedimentary deposits

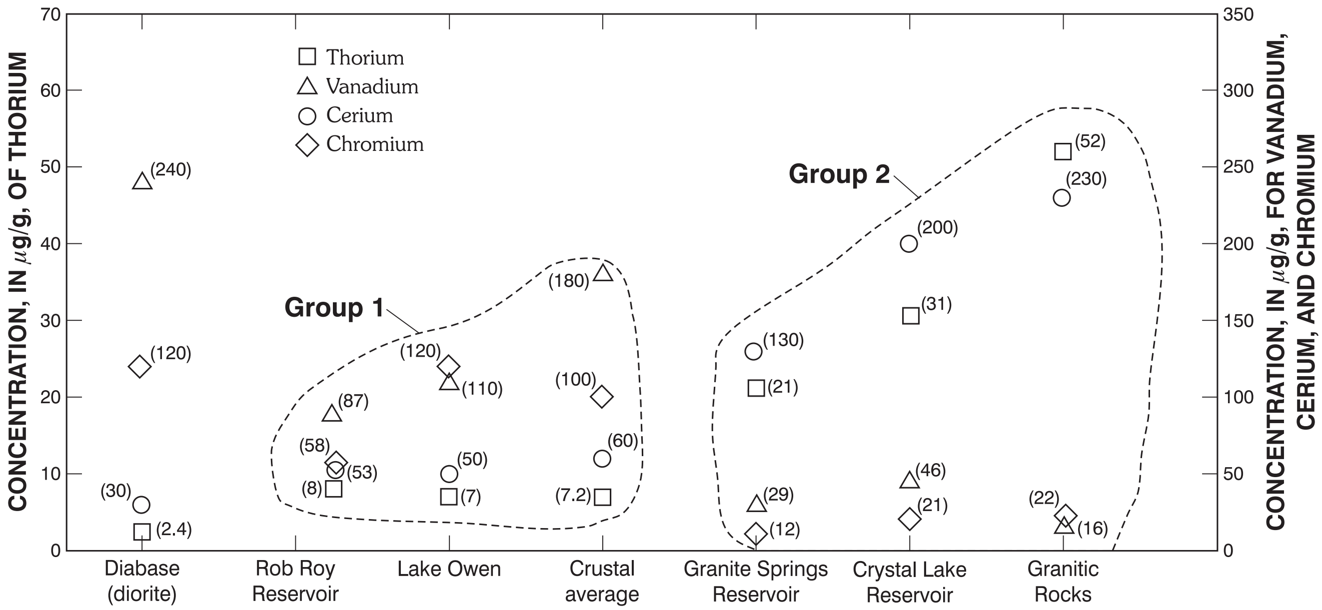


Figure 12. Concentrations of selected constituents in bottom sediment samples collected from Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming (diabase, crustal average, and granitic concentrations are from Mason, 1966, pp. 45-46). Number in parentheses is concentration, in µg/g. Group 1 concentrations are similar to crustal average concentrations, while group 2 concentrations are similar to granitic rock concentrations.

(Tertiary age) and metasedimentary and metavolcanic rocks (Pre-Cambrian age). Near Lake Owen, alluvium, gravel, colluvium, conglomerate sandstones, and shales occur, along with medium to coarse grained gabbros, and other mafic rocks.

Granite Springs Reservoir

Granite Springs Reservoir is the third reservoir in the series (fig. 2C) and receives water through both Stage I and Stage II pipelines from Lake Owen. The reservoir contains about 12 percent of the system storage and has a spillway elevation of 7,210 ft above sea level (table 1). Granite Springs is located in an area of mixed forest and grassland. It is an active recreational site with boating, fishing, and camping being the primary activities. Some houses are present in the area surrounding the reservoir.

Profiles

Profile data were collected for Granite Springs once during summer 1997, from mid-May through the first part of October in 1998, and once during winter 1998. These profiles indicate that Granite Springs was stratified by early to mid-July and was unstratified in the winter.

The August 28, 1997 profiles (fig. 16A) indicate stratification in the reservoir. Changes in the temperature, dissolved oxygen, specific conductance, and pH profiles indicate that the epilimnion extended from the surface to about 19 ft deep. In the epilimnion, the temperature decreased from 20 to 18°C, dissolved-oxygen concentrations were about 7 to 8 mg/L, specific conductance was about 94 to 95 µS/cm, and pH ranged from 8.3 to 8.5. Dissolved-oxygen concentrations in the epilimnion were above saturation, probably due to photosynthetic activity by the phytoplankton. The euphotic zone also extended to about 19 ft, as estimated from a Secchi disk transparency of 6.2 ft. The metalimnion appeared to range from about 19 to 26 ft below the reservoir surface. Water temperature, dissolved oxygen, and pH decreased relatively in the metalimnion, while specific conductance increased slightly. In the hypolimnion, dissolved-oxygen concentrations continued to decrease, and were less than the 5 mg/L level suggested

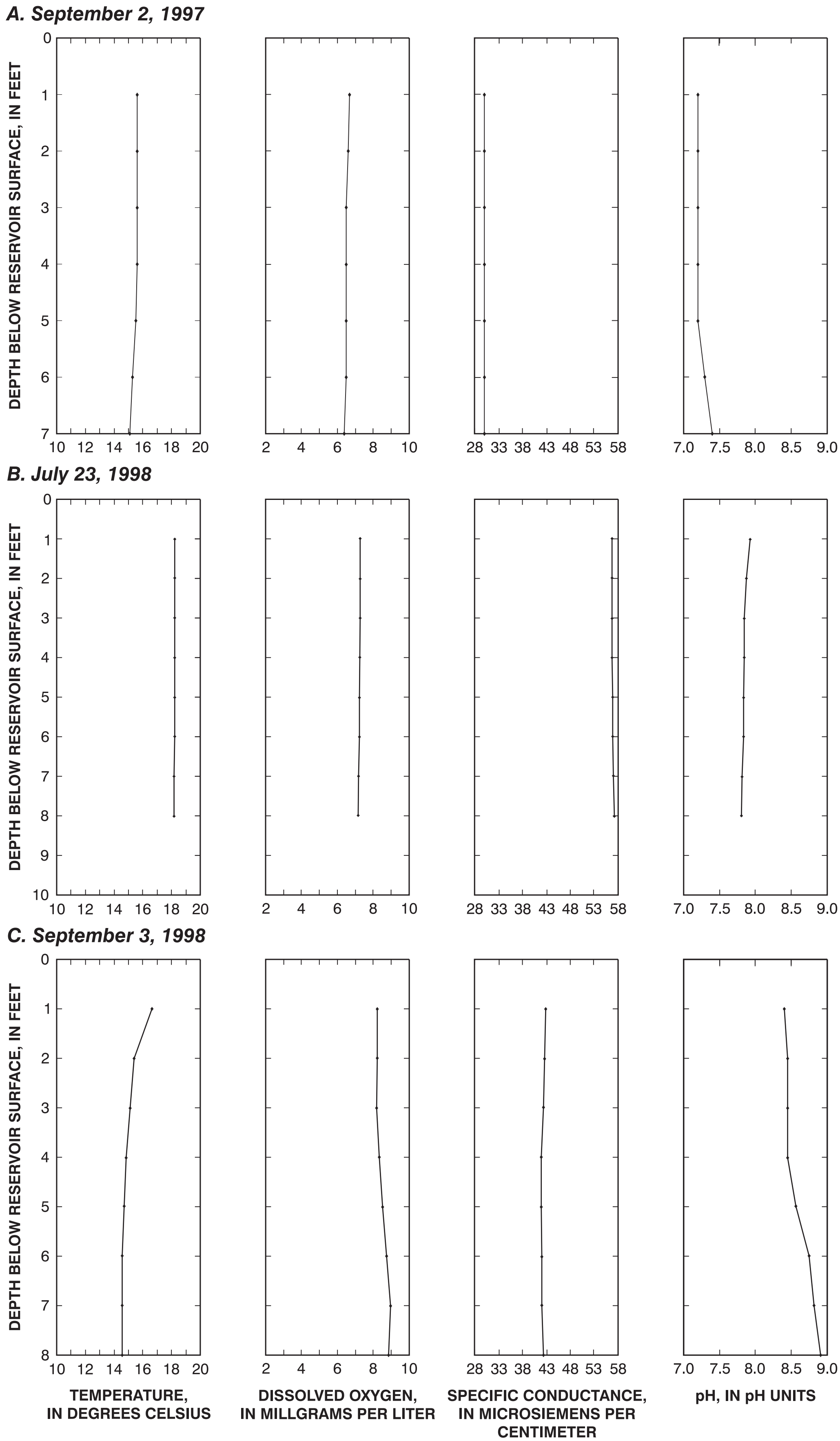


Figure 13. Temperature, dissolved oxygen, specific conductance and pH profiles, Lake Owen, Albany County, Wyoming.

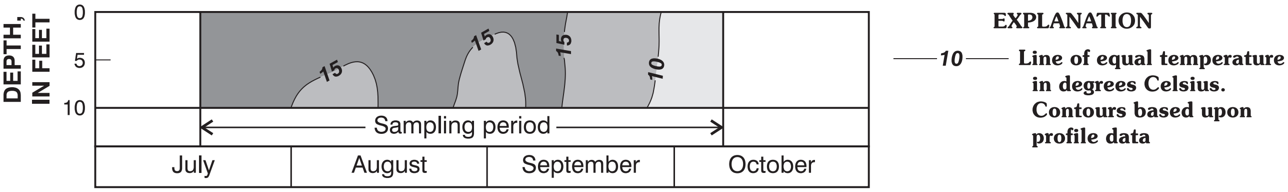


Figure 14. Temporal variation of temperature with depth in Lake Owen, Albany County, Wyoming, in summer and fall, 1998.

for protection of cold-water fish. The dissolved-oxygen concentrations decreased from 73 percent of saturation at 26 ft to 38 percent of saturation at 60 ft.

The February 5, 1998 profiles of Granite Springs (fig. 16B) show a lack of stratification in the water column, with only slight changes in the profiles, mostly below about 50 ft. Water temperature was approximately 4°C. Dissolved-oxygen concentrations decreased from about 11 to about 8 mg/L. Specific conductance generally was less than 115 µS/cm to about 50 ft, below which conductance increased to almost 145 µS/cm. pH decreased from 7.7 to 6.9.

July 21, 1998 profiles again show stratification in Granite Springs (fig.16C). The temperature in the epilimnion was about 22°C, dissolved-oxygen concentrations were about 8.5 mg/L, the specific conductance was about 128 µS/cm, and pH measured about 8.5. Changes in temperature and pH occurred in the metalimnion. Below 30 ft, in the hypolimnion, the temperature decreased from about 15 to about 14°C. Dissolved-oxygen concentrations remained near 4.0 mg/L to about 38 ft, then decreased to less than 1 mg/L near the bottom. Specific conductance was about 122 µS/cm from about 32 ft to about 44 ft, then increased to 127 µS/cm. The pH gradually decreased from 7.7 to 7.4.

The September 1, 1998 profiles (fig. 16D) continue to show strong stratification of dissolved oxygen and pH; both were stable to about 25 ft. The metalimnion also was defined by changes in dissolved oxygen and pH. Dissolved-oxygen concentrations dropped from 7.1 to less than 1 mg/L at 45 ft. Over the same interval, pH decreased from 8.1 to 7.1. Temperature decreased gradually from top to bottom in this profile. In the metalimnion and hypolimnion, specific conductance gradually increased.

Examination of the 1998, Granite Springs temperature profiles (fig. 17) shows a seasonal increase of the water temperature in the reservoir. The reservoir lacked stratification in early May and was a fairly consistent 9°C. By late May into mid June, a nearly linear gradation in temperature developed from about 14°C at the surface to slightly greater than 10°C near the bottom. During this time period, no stratification was present. By July, stratification began to develop in the reservoir (Appendix A). Stratification continued to develop in early August, with the epilimnion expanding down to about 25 ft, and the metalimnion ranged from about 25 to 35 ft. Stratification became less pronounced in mid-August, with the temperature decreasing gradually from about 20 to 14°C with depth. By mid-September, thermostratification had ceased and the profiles indicate little change in water temperature from the reservoir surface to the bottom. In late September and early October, the reservoir cooled quickly compared to its rate of warming (fig. 17). It is interesting to note the persistence of stratification of dissolved oxygen and pH well after temperatures had nearly equalized throughout the water column.

Phytoplankton

Diatoms and blue-green algae dominated the phytoplankton community of Granite Springs. Although five other divisions of algae were present in the samples, their biomasses were small relative to the diatoms and blue-green algae (fig. 18).

Blue-green algae, principally *Anabaena*, dominated the biomass of the algae in the August 28, 1997 and July, 16, 1998 samples. The biomass of *Anabaena* was 59,000 µg/L (69,100 cells/mL density) in the July 14 sample (Appendix B, table B3). Blue green algae, particularly *Anabaena*, are known for producing algal blooms and creating taste and odor problems in temperate-zone lakes. The blooms tend to occur in late

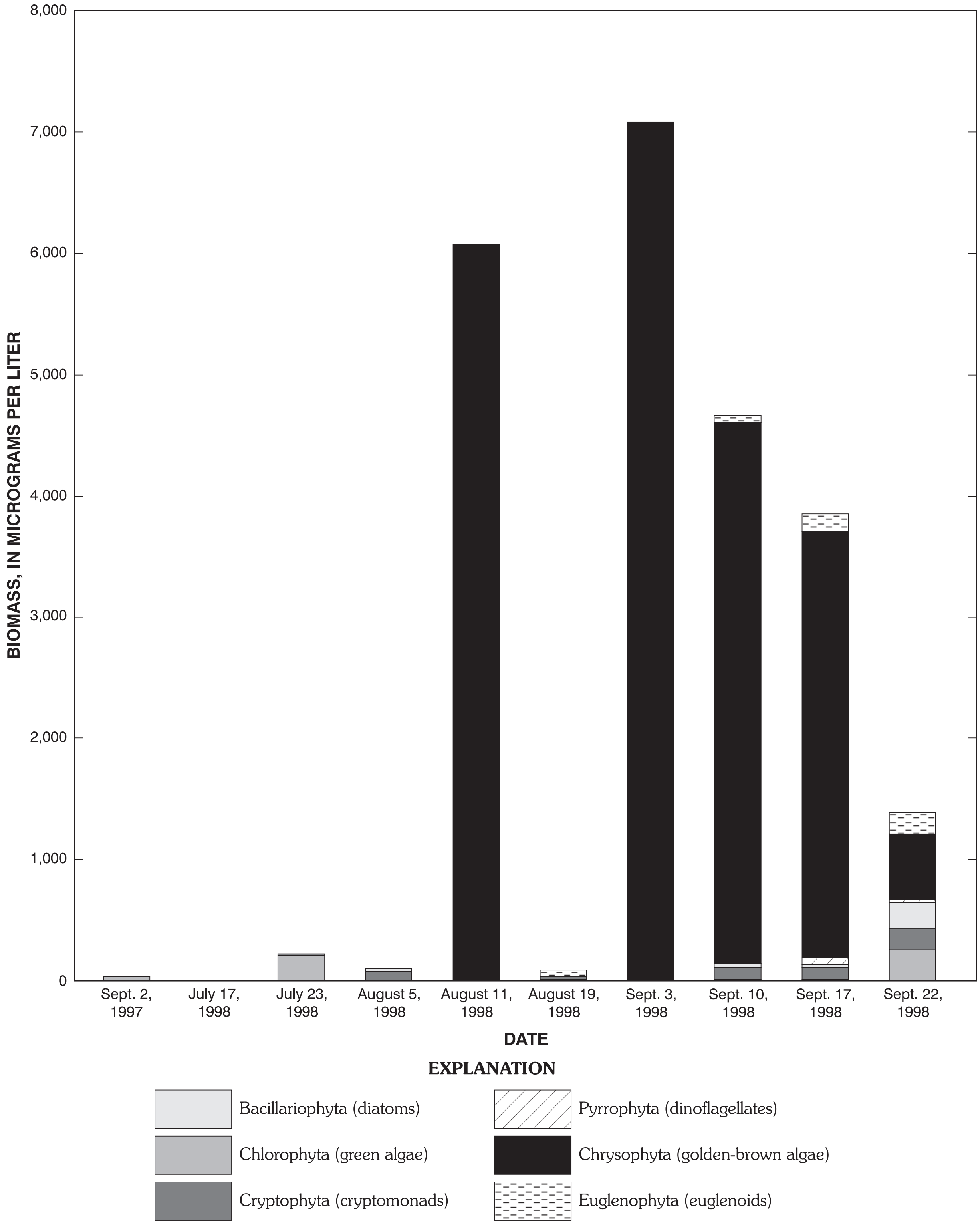


Figure 15. Phytoplankton biomass changes over time in Lake Owen, Albany County, Wyoming.

summer, when water temperatures are warmest and nutrients have been removed from the epilimnion. Many blue-green algae are capable of fixing atmospheric nitrogen, and therefore have a competitive advantage over other algae when nutrient supplies are limited. Somewhat in contrast to this general pattern for temperate-zone lakes, the blue-green algae in Granite Springs peaked in mid-July; diatoms dominated the phytoplankton later in the summer (fig. 18). Peak concentrations of the diatoms were considerably smaller, however, than the peak concentrations of the blue-green algae.

Both orders of diatoms, the Pennales and the Centrales, were represented in the samples. The pennate diatoms typically are elongate; cigar or boat shaped organisms, whereas the centric diatoms are round, pill-box-shaped organisms (Prescott, 1978, p. 241). The pennate diatom *Fragilaria* dominated the July 22 and September 1, 1998 samples and was a subdominant species in some of the other samples from Granite Springs. The peak concentration of *Fragilaria* was 4,200 µg/L (fig. 18) (3,030 cells/mL) in the July 22 sample. The centric diatom *Cyclotella* was a subdominant in the July 22 sample (1,700 µg/L) and the September 1 sample (1,100 µg/L). The centric diatom *Stephanodiscus* dominated the August 4 sample and was a subdominant in the September 9 sample, but was not identified in other samples from Granite Springs. An unidentified centric diatom dominated the samples from August 10 and 18, and September 15 and 21. Of the 41 taxa identified from Granite Springs, 15 taxa were diatoms and 13 taxa were green algae.

A phytoplankton sample, collected on August 28, 1997, at 3 ft above the reservoir bottom at the same site as the near-surface sample, contained mostly diatoms. The biomass of the deep sample was 950 µg/L, considerably less than the 4,400 µg/L of the near-surface sample. The cause for the predominance of the diatoms *Fragilaria* and *Melosira* in the bottom sample may be related to the resistance of their siliceous shells. The relatively soft-bodied blue-green algae that predominated in the near-surface sample on the same date may have decomposed as they sank through the water column.

Secchi disk transparencies from Granite Springs averaged 8.2 ft. A maximum transparency of 12.5 ft was recorded under ice cover in February; a minimum transparency of 5.1 ft was recorded July 14 and August 4, 1998. The low transparencies on July 14 were coincident with the high phytoplankton concentration. In contrast, the phytoplankton concentration on August 4 was relatively low (fig. 18). Inorganic material suspended in the water may have contributed to the low reading on August 4. The depth of the euphotic zone extended below the thermocline when the reservoir was stratified, indicating adequate light for photosynthesis throughout the epilimnion.

Protozoans were present in samples at concentrations of a few hundred micrograms per liter or less, with the exception of the July 14 sample. The concentration of rotifers in the July 14 sample was 5,000 µg/L biomass (10 organisms/mL).

In Granite Springs in the fall of 1997, MPA was dominated by non-diatomaceous phytoplankton and diatoms. A few rotifers were detected. The MPA results are summarized in table 5.

Chemical Quality

Two samples were collected at Granite Springs (surface and bottom). The dissolved-solids concentrations of 55 mg/L for the surface sample and 59 mg/L for the bottom sample (table 2) indicated little difference in the dissolved solids between the two samples. The water was a calcium bicarbonate type. The relative concentrations of major ions shown in pie diagrams in figure 8 indicate no differences between surface and bottom samples. Dissolved-fluoride concentrations were at 0.3 mg/L in the surface sample and 0.4 mg/L in the bottom sample (table 2). Silica concentrations, as dissolved SiO_2, increased slightly with depth (table 2; fig. 9). Nutrient concentrations were less than the detection level in both samples. An exception was dissolved nitrogen as ammonia in the surface sample, which was 0.15 mg/L.

The concentrations of metals indicated some differences between the surface and bottom samples. Iron concentrations increased from 7 µg/L (surface sample) to 21 µg/L (bottom sample) (fig. 10). The increase in manganese concentration from 5 µg/L (surface sample) to 76 µg/L (bottom sample) was even greater (fig. 11).

Bottom Sediment

On February 5, 1998, bottom sediment samples were collected at five sites (fig. 2C) in Granite Springs and composited into a single sample. The composite sample was analyzed for selected constituents (table 3). Nitrogen concentration, reported as total nitrate plus nitrite, was less than the detection limit. Of the constituents analyzed, aluminum concentration was 6.2 percent, iron was 2.2 percent, and potassium was 3.3 percent.

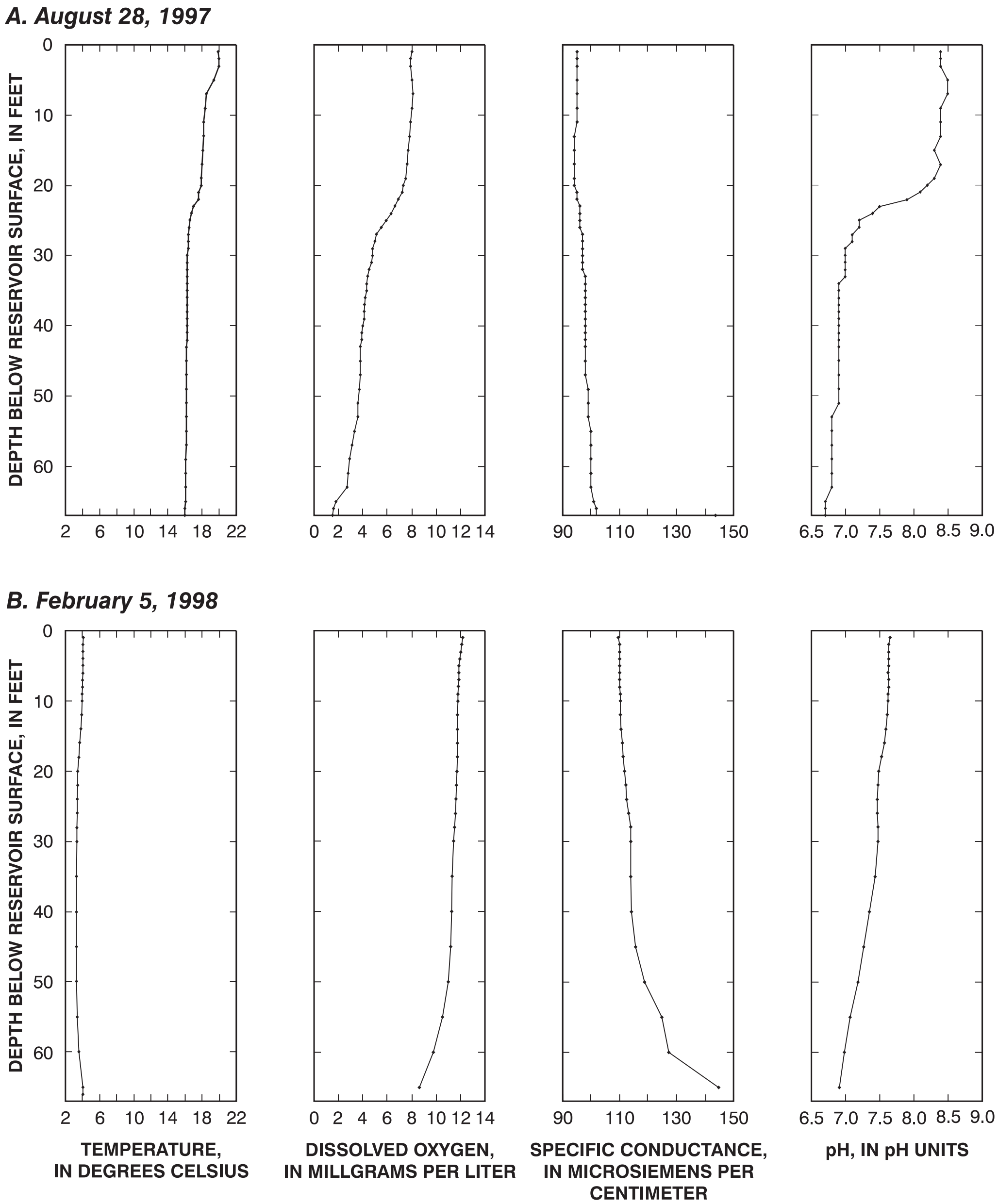


Figure 16. Temperature, dissolved oxygen, specific conductance and pH profiles for Granite Springs Reservoir, Laramie County, Wyoming.

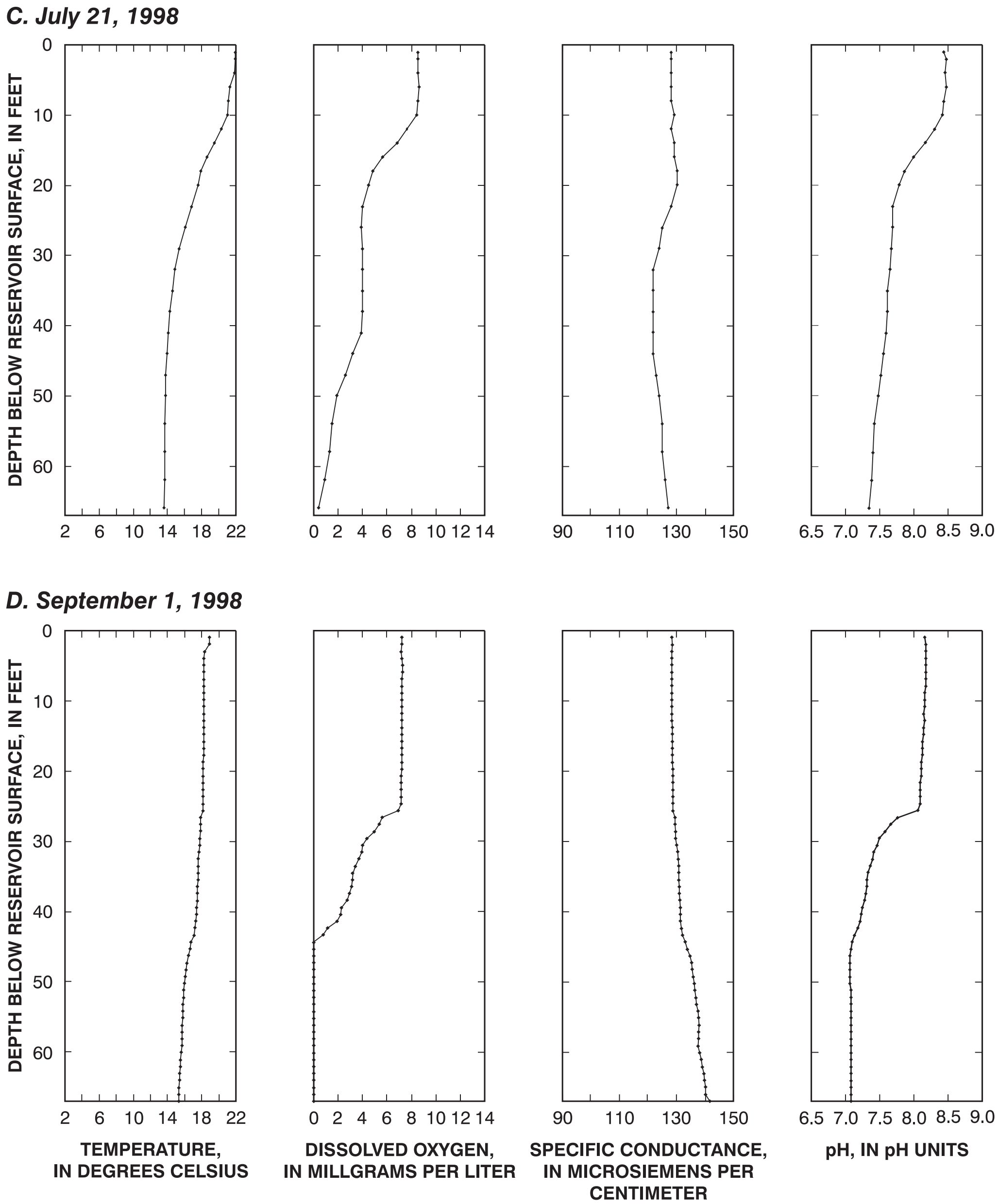


Figure 16. Continued.

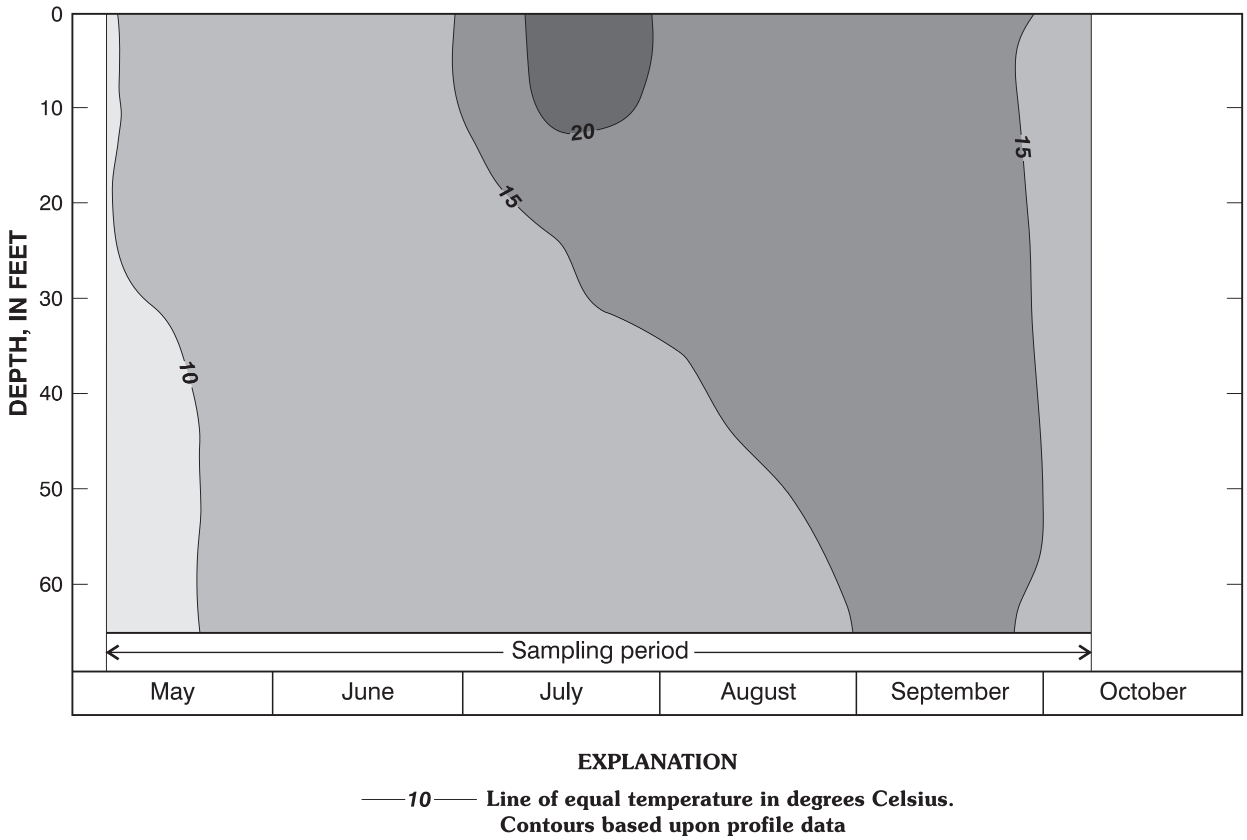


Figure 17. Temporal variation of temperature with depth in Granite Springs Reservoir, Laramie County, Wyoming, 1998.

Most bottom-sediment concentrations were in the microgram-per-gram range. Concentrations of nitrogen, arsenic, bismuth, cadmium, europium, gold, holmium, molybdenum, silver, sulfur, tantalum, tin, and uranium were less than the detection limit (table 3). Concentrations of thorium, vanadium, cerium, and chromium are plotted in figure 12. The trace-element concentrations fit best in Group 2—more like granitic rocks than either diabase or the crustal average. The similarity is most likely due to the sediments having been derived from the surrounding Sherman Granite (Precambrian).

Crystal Lake Reservoir

Crystal Lake Reservoir is the last reservoir in the series (fig. 2D). During the period of this study, water flowed via Middle Crow Creek and a pipeline from Granite Springs Reservoir into Crystal Lake Reservoir. At 6,969 ft, Crystal Lake has the lowest spillway elevation of the four reservoirs. The reservoir contains about 8 percent of the system storage and is about 65 ft deep (table 1). It is located in an open forest and grassland area, and is popular for recreational activities such as boating, fishing, and camping.

Profiles

Profile data indicate that stratification occurs in Crystal Lake during the warmer months. The September 4, 1997 profiles of Crystal Lake (fig. 19A) show stratification of dissolved oxygen and pH in the reservoir. Water temperature, dissolved oxygen, specific conductance, and pH were essentially constant in the epilimnion. Temperature was constant to about 17 ft. The dissolved-oxygen concentration was 6.3 mg/L and 86 percent of saturation at a depth of 1 ft. The dissolved-oxygen concentrations decreased to less than

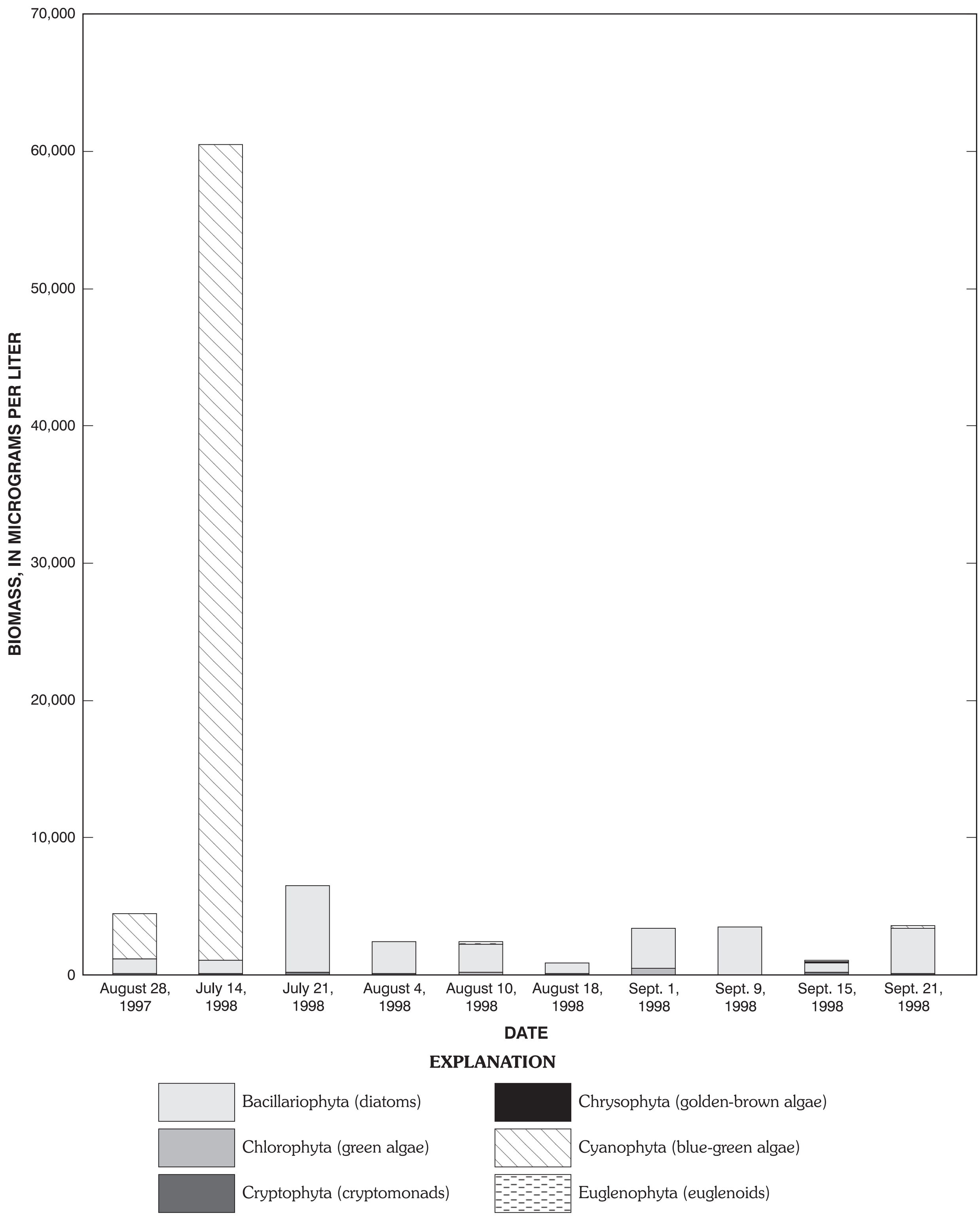


Figure 18. Phytoplankton biomass changes over time in Granite Springs Reservoir, Laramie County, Wyoming.

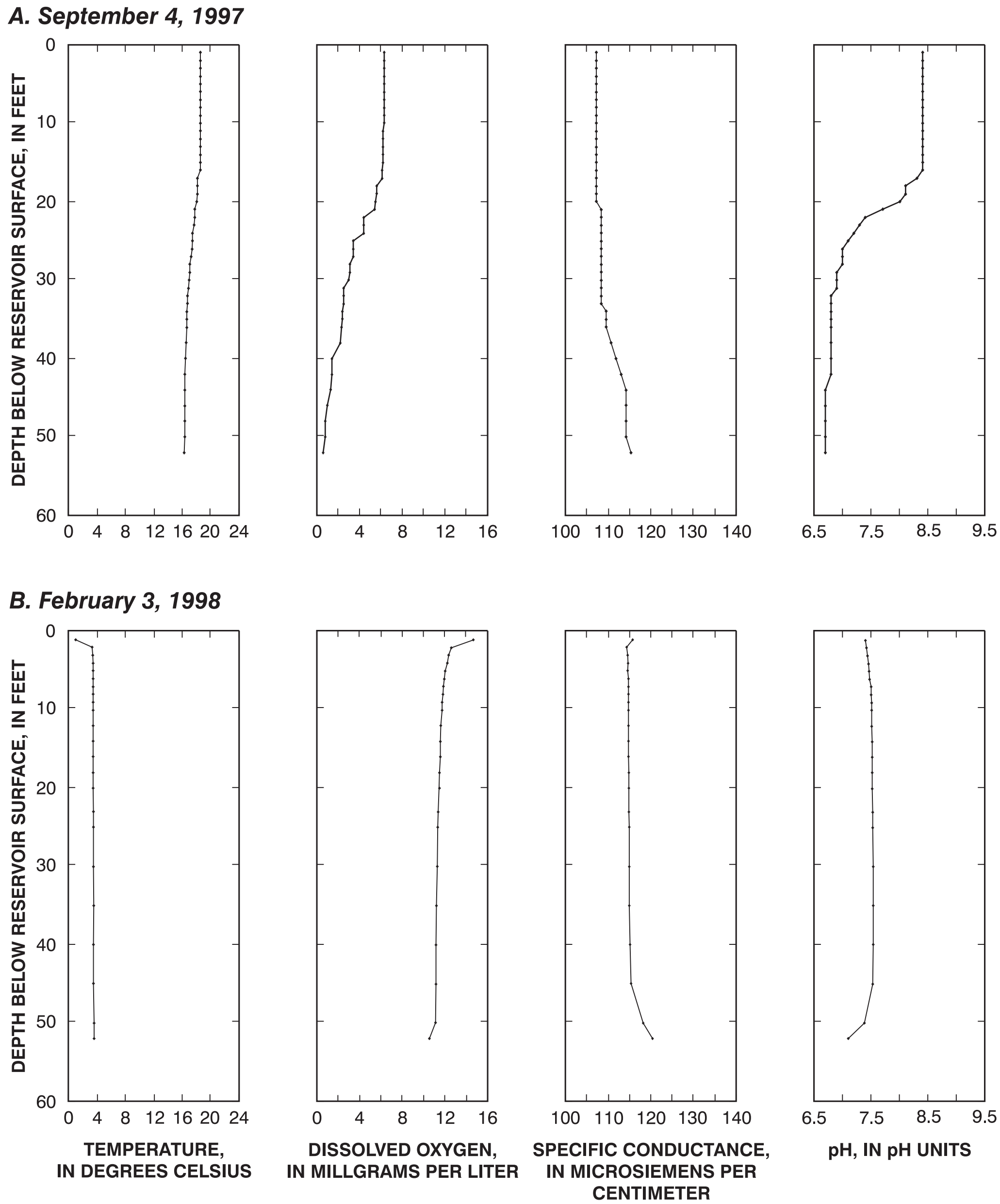


Figure 19. Temperature, dissolved oxygen, specific conductance and pH profiles for Crystal Lake Reservoir, Laramie County, Wyoming.

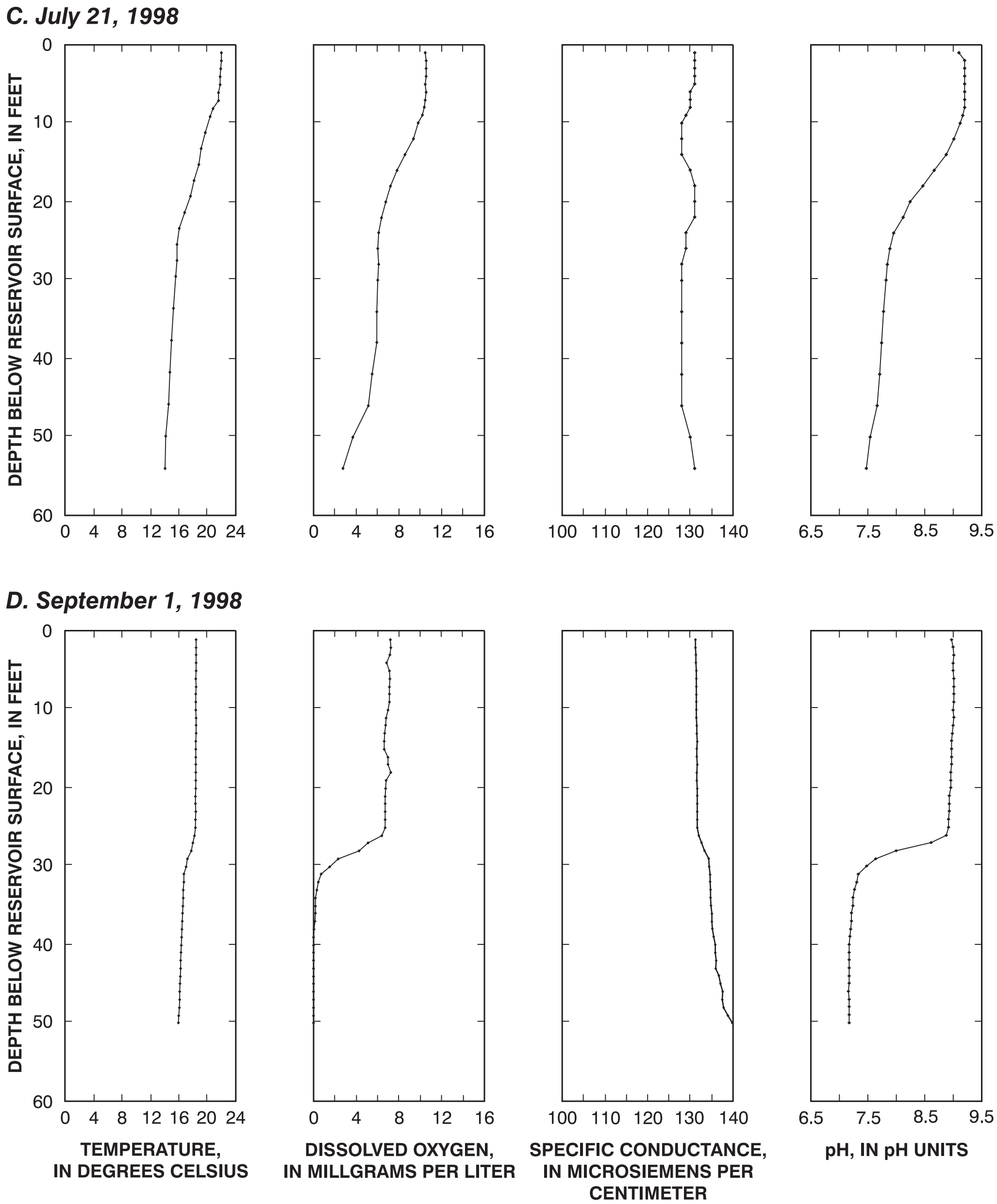


Figure 19. Continued.

5 mg/L in the metalimnion. A minimum dissolved-oxygen concentration of 5 mg/L generally has been suggested for the protection of cold-water fish. Water temperature and pH also decreased in the metalimnion, which extended from about 16 ft to about 26 ft below the surface. The euphotic zone extended to about the bottom of the metalimnion, based on a Secchi disk transparency of 7.7 ft. In the hypolimnion, dissolved-oxygen concentrations continued to decrease (fig. 19A). The dissolved-oxygen concentration was about 1.3 mg/L at about 44 ft and was only 17 percent of saturation. This concentration was less than the concentration generally suggested for the protection of warm-water fish. Specific conductance increased with depth in the hypolimnion, from about 109 to 115 µS/cm.

The February 3, 1998 winter profiles (fig. 19B) show a general lack of stratification of the water in Crystal Lake. On February 3, the reservoir was covered with about 1 ft of very clear ice with virtually no snow cover. The clear ice apparently allowed enough light for photosynthesis by the phytoplankton, as indicated by the dissolved-oxygen concentration of 14.7 mg/L, or 134 percent of saturation, at a depth of 1 ft below the ice. The water temperature at 1 ft beneath the water surface was 1.0°C; below that depth the temperature, ranged between 3 and 4°C. This temperature pattern, typical of temperate lakes, was expected because water at its maximum density is at about 4°C. From 2 ft to about 50 ft below the surface, the profiles show little variation. Below 50 ft, small changes in pH and specific conductance were noted.

The July 21, 1998 profile data indicate weak stratification (fig. 19C). The epilimnion extended to about 10 ft, the metalimnion from about 10 to 24 ft, and the hypolimnion from about 24 ft to the bottom. Temperatures ranged from 22 to 20°C in the epilimnion, decreased from 20 to 16°C through the metalimnion, and ranged from 16 to 14°C in the hypolimnion. Dissolved-oxygen concentrations were near 10 mg/L to a depth of about 9 ft. Concentrations then decreased to 5.6 mg/L at about 24 ft. In the hypolimnion, dissolved-oxygen concentrations were essentially stable to about 42 ft, then decreased to 1.9 mg/L near the bottom.

By September 1, 1998, profiles indicate that stratification had reached much deeper into the reservoir with the epilimnion extending down to nearly 30 feet (fig. 19D). Dissolved-oxygen concentrations and pH showed sharp changes between about 26 ft and 31 ft. Dissolved oxygen ranged from 7.3 to 6.4 mg/L from the surface to 26 ft; concentrations then decreased to less than 1 mg/L by 31 ft and were less than 1 mg/L throughout the hypolimnion. The pH was fairly constant down to about 26 ft, about 9.0. In the metalimnion, the pH decreased from 8.9 to 7.3. The pH remained around 7.2 to 7.3 throughout the hypolimnion. From about 26 ft, specific conductance increased in the metalimnion. Specific conductance continued to gradually increase with depth in the hypolimnion.

Temperature and dissolved oxygen in Crystal Lake were measured between May and October, 1998. In mid-May, the reservoir showed a relatively uniform temperature profile, ranging between 5 and 10°C (fig. 20). Throughout May and June, the reservoir warmed and began to stratify. By mid-July, the reservoir was stratified and the surface-water temperature was slightly higher than 20°C. The water cooled throughout the fall, and by early October 1998 the water was relatively uniform in comparison to the summer profiles. Dissolved-oxygen concentrations (fig. 21) during May and June 1998 ranged from 5 to 10 mg/L. However, in mid-July a zone of dissolved oxygen in the upper 10 ft of the lake was higher than 10 mg/L.

From late-June until mid-September, a dissolved oxygen zone of less than 5 mg/L developed near the bottom of the reservoir. By August, the zone had expanded and concentrations were less than 1 mg/L. The multiparameter probes used in this study do not accurately measure oxygen concentrations below 1 mg/L. By mid-August, dissolved-oxygen concentrations of 1 mg/L or less extended about 30 ft above the bottom of the reservoir. As oxygen concentrations approach zero, many trace elements become more soluble and may move into the water column from the sediment. An increase in manganese concentration is sometimes observed in the raw water at the water treatment facilities. A possible explanation could be anoxic conditions of the lower part of the reservoir, which allows the manganese to become more soluble.

Phytoplankton

Blue-green algae and diatoms dominated the phytoplankton community of Crystal Lake. Other divisions, such as the green algae and the cryptomonads, were present in the samples, but each constituted less than 25 percent of the total biomass (fig. 22).

Of the 42 algal taxa identified, only 5 taxa were blue-green algae. Nonetheless, the blue-green algae *Anabaena* dominated the phytoplankton community in the July 14, July 21, and August 10, 1998 samples

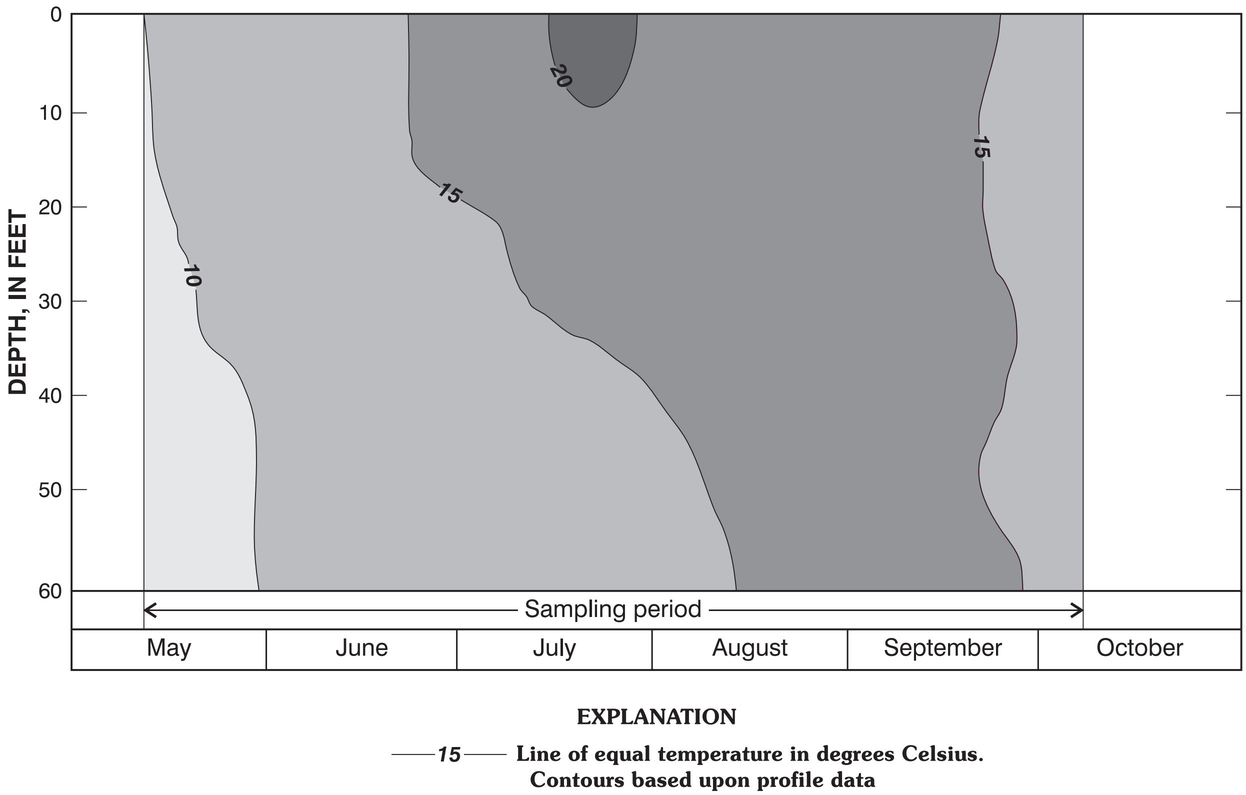


Figure 20. Temporal variation of temperature with depth in Crystal Lake Reservoir, Laramie County, Wyoming, 1998.

(Appendix B, table B4; fig. 22). *Anabaena* reached a maximum concentration of 18,000 µg/L biomass (29,100 cells/mL density) in the July 14 sample. *Anabaena* also was the most common of the blue-green algae present in the samples collected on September 9, 15, and 21, 1998. Diatoms, particularly *Fragilaria*, were the dominant algae in the remainder of the samples (fig. 22). The peak mass of *Fragilaria* was 6,500 µg/L (4,490 cells/mL) in the September 4, 1997 sample. The diatoms *Stephanodiscus* and *Cyclotella* were subdominants in some of the samples; *Stephanodiscus* predominated in the September 9 sample. A total of 17 taxa of green algae were identified, but none was dominant. The most common taxa of green algae were *Staurastrum* and *Cosmarium*.

Samples were collected 1 foot below the surface and 3 ft above the lake bottom on September 4, 1997. The total phytoplankton biomass of the deep sample was 2,000 µg/L, compared to 9,000 in the near- surface sample. The diatom *Fragilaria* was the predominant alga in both samples. A phytoplankton sample was collected at a depth of about 30 ft, within the metalimnion, on September 11, 1997; the diatom *Fragilaria* predominated in the sample. The total phytoplankton mass in the sample collected at 30 ft was 4,900 µg/L.

The concentration of Protozoa in samples from Crystal Lake typically was less than 100 µg/L. Some samples had higher concentrations; for example, September 9 sample had a concentration of ciliates of 670 µs/L.

In Crystal Lake in the fall of 1997, MPA was dominated by non-diatomaceous phytoplankton and diatoms. MPA results are summarized in table 5.

Chemical Quality

Three samples were collected for chemical analysis at Crystal Lake: a surface sample, a sample at 30-ft below the lake surface, (hereafter referred to as the middle sample), and a bottom sample. The depth for the middle sample was selected based on the estimated pipe-

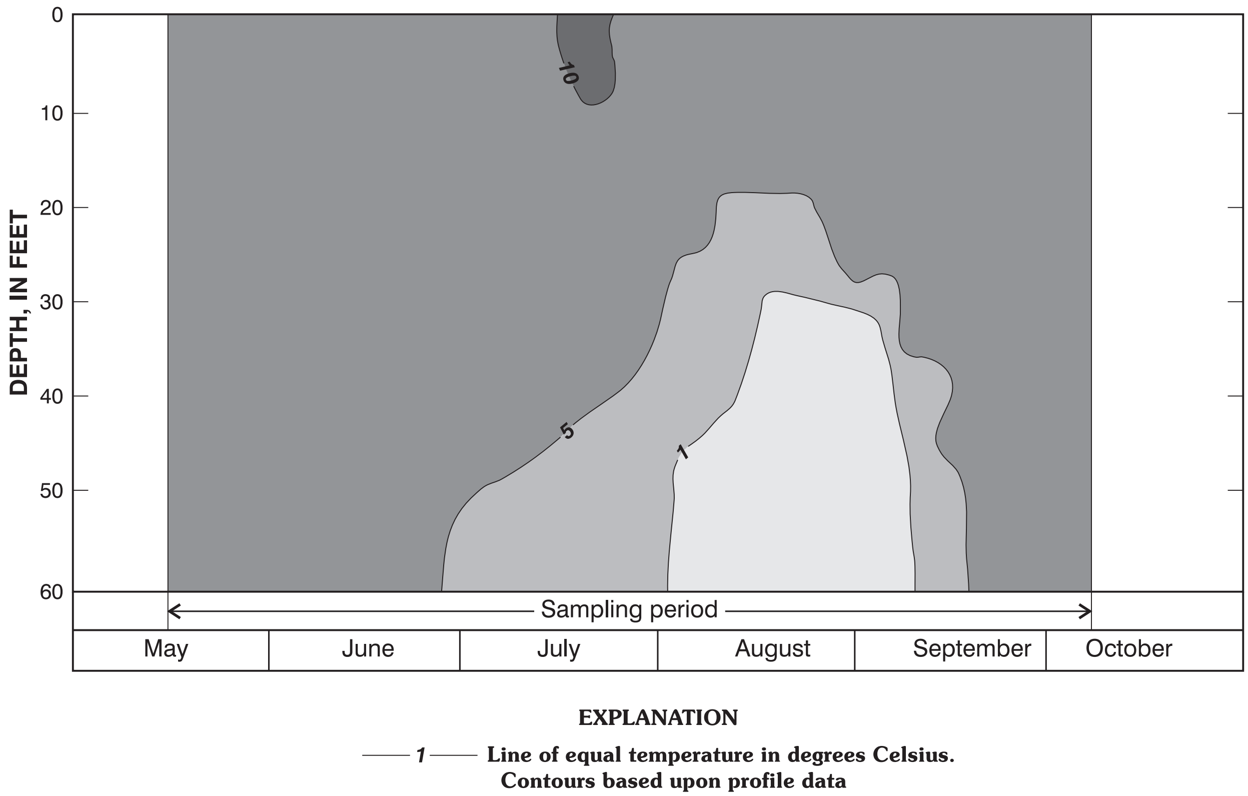


Figure 21. Temporal variation of dissolved oxygen with depth in Crystal Lake Reservoir, Laramie County, Wyoming, 1998.

line intake level for the water treatment plants. The dissolved-solids concentrations of 58 mg/L for the surface sample, 60 mg/L for the middle sample, and 63 mg/L for the bottom sample (table 2; fig. 7) indicate relatively little difference between the three samples, with a possible slight increase toward the reservoir bottom. The water was a calcium-bicarbonate type. No differences were apparent in the percentages of major ions between samples collected from the top, middle, and bottom of the reservoir (fig. 8). Dissolved-fluoride concentrations were 0.5 mg/L in all three samples. Silica concentrations, as dissolved SiO_2, increased from 2.1 to 6.4 mg/L with depth (table 2; fig. 9). Nutrient concentrations were less than the detection level in all samples except two. In the sample at 30 ft, dissolved nitrogen as ammonia was 0.09 mg/L, and in the bottom sample nitrogen as ammonia was 0.14 mg/L. Dissolved-iron concentrations were slightly higher in the middle and bottom samples than in the surface sample (fig. 10). Dissolved-manganese concentrations increased from <1 µg/L in the surface to 31 µg/L in the bottom sample (fig. 11).

Because water is diverted from Crystal Lake to the treatment plants, analyses also were completed for 4 radionuclides and 48 organic compounds. Two radionuclides and two organic compounds were detected; all others were less than the detection limit. Alpha (Th-230 and beta (CS-137) emission were the radionuclides detected. Metolachlor and atrazine were detected, but the low concentrations were estimated. Metholachlor was detected only in the surface sample at a concentration estimated to be slightly greater than the detection limit. Results are summarized in table 6.

Bottom Sediment

On February 3, 1998, bottom-sediment samples were collected at five sites in Crystal Lake (fig. 2D). The samples were composited into a single sample. The concentrations of selected constituents analyzed in

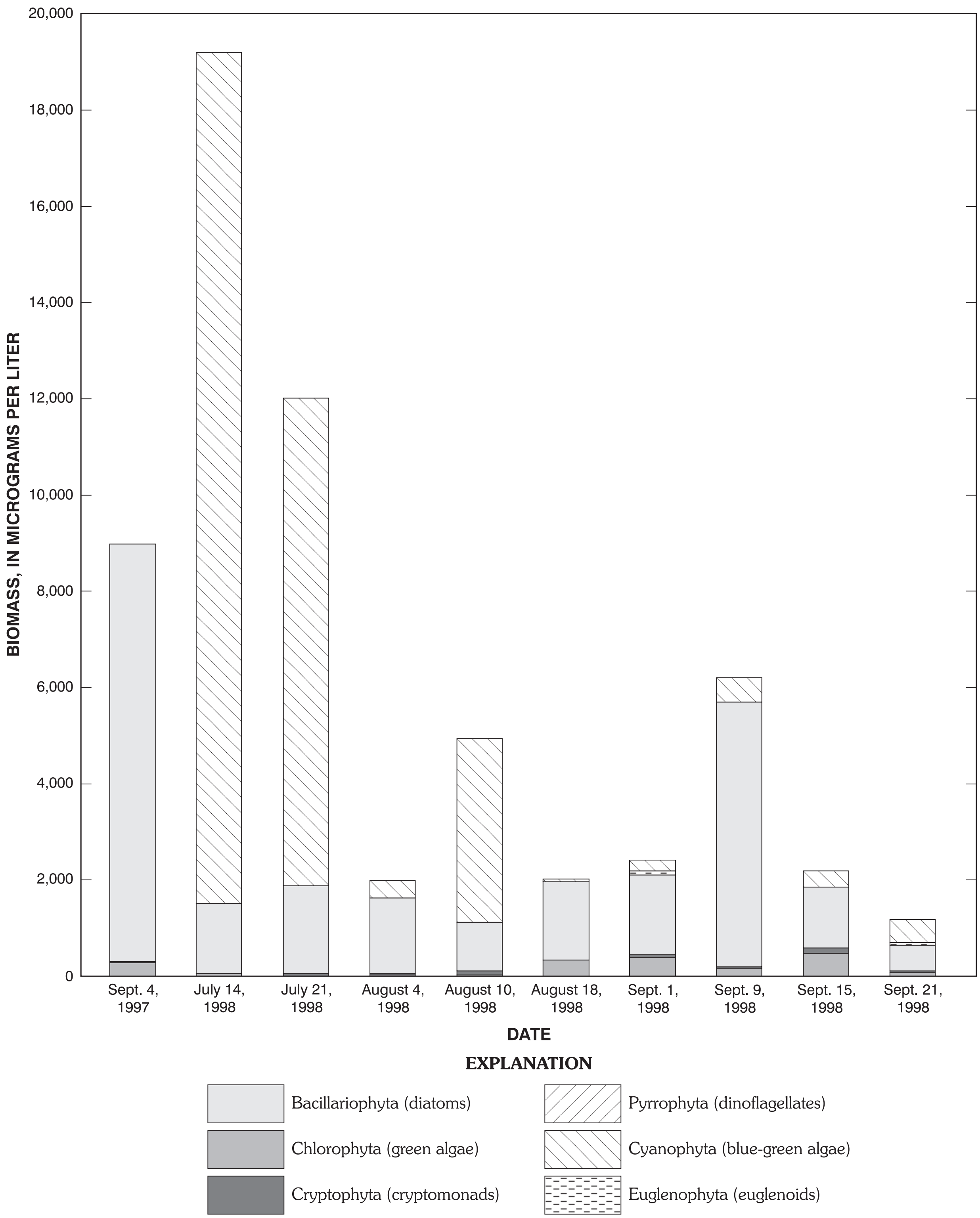


Figure 22. Phytoplankton biomass changes over time in Crystal Lake Reservoir, Laramie County, Wyoming.

Table 6. *Concentrations of selected radionuclide activities and organic compounds in water-quality samples collected September 4, 1997, at Crystal Lake Reservoir, Laramie County, Wyoming*

[Surface sample collected 1 foot below reservoir surface; bottom sample collected 3 feet above reservoir bottom; est., estimated; pCi/L, picoCurries per liter; µg/L, microgram per liter; concentrations are dissolved unless otherwise noted]

Parameter/compound	Surface sample (µg/L except as noted)	Bottom sample (µg/L except as noted)
Gross beta, dissolved as Cs-137	<4.0 pCi/L	<4.0 pCi/L
Propachlor,	<.007	<.007
Butylate	<.002	<.002
Simazine	<.005	<.005
Prometon	<.018	<.018
Des-ethylatrazine,	<.002	<.002
Cyanazine	<.004	<.004
Fonofox	<.003	<.003
Alpha, dissolved as Th-230	<3.0 pCi/L	<3.0 pCi/L
Phenols, total	<1	<1
Alpha BHC	<.002	<.002
p,p’ DDE	<.006	<.006
Chlorpyrifos	<.004	<.004
Lindane	<.004	<.004
Dieldrin	<.001	<.001
Metolachlor	.002 est.	<.002
Malathion	<.005	<.005
Parathion	<.004	<.004
Diazinon	<.002	<.002
Atrazine	.0028 est.	.0029 est.
Alachlor	<.002	<.002
Acetochlor	<.002	<.002
Alpha, pe Th-230	.56 pCi/L	.41 pCi/L
Beta, pe Cs-137	1.95 pCi/L	1.97 pCi/L
Metribuzin	<.004	<.004

Table 6. *Concentrations of selected radionuclide activities and organic compounds in water-quality samples collected September 4, 1997, at Crystal Lake Reservoir, Laramie County, Wyoming--Continued*

Parameter/compound	Surface sample (µg/L except as noted)	Bottom sample (µg/L except as noted)
2,6-Diethylaniline	<0.003	<0.003
Trifluralin	<.002	<.002
Ethalfluralin	<.004	<.004
Phorate	<.002	<.002
Terbacil	<.007	<.007
Linuron	<.002	<.002
Methyl parathion	<.006	<.006
EPTC	<.002	<.002
Pebulate	<.004	<.004
Tebuthiuron	<.01	<.01
Molinate	<.004	<.004
Ethoprop	<.003	<.003
Benfluralin	<.002	<.002
Carbofuran	<.003	<.003
Terbufos	<.013	<.013
Pronamide	<.003	<.003
Disulfoton	<.017	<.017
Triallate	<.001	<.001
Propanil	<.004	<.004
Carbaryl	<.003	<.003
Thiobencarb	<.002	<.002
DCPA	<.002	<.002
Pendimethalin	<.004	<.004
Napropamide	<.003	<.003
Propargite	<.04	<.013
Methyl azinphos	<.001	<.001
cis-Permethrin	<.005	<.005

in that sample are listed in table 3. Of the constituents analyzed, aluminum concentration was highest at 6.8 percent, iron was 3.6 percent, and potassium was 2.7 percent.

Most of the trace-element concentrations are in the microgram-per-gram range. Concentrations of nitrogen, (nitrite plus nitrate), arsenic, bismuth, cadmium, gold, holmium, molybdenum, silver, tantalum, tin, and uranium were less than the detection limit. Concentrations of thorium, vanadium, cerium and chromium are plotted in figure 12. The trace-element concentrations fit best in Group 2—more like granitic rocks than either diabase or the crustal average. This similarity is probably due to the extensive exposures of Sherman Granite (Precambrian) within the drainage area of the reservoir.

Comparison among Reservoirs

All reservoirs have some distinct characteristics, but, in general, Rob Roy Reservoir and Lake Owen are unique, whereas Granite Springs and Crystal Lake Reservoirs are similar. Rob Roy is the highest in elevation, the largest in storage capacity, and the deepest. In contrast, Lake Owen has minimal storage capacity and is the shallowest of the four reservoirs. Both Rob Roy and Lake Owen are located in the Medicine Bow Mountains, Albany County; Granite Springs and Crystal Lake are located in the Laramie Mountains, Laramie County, about 45 miles to the east. Granite Springs and Crystal Lake are close to 7,000 ft above sea level, about 2,000 ft lower than Rob Roy and Lake Owen. Granite Springs and Crystal Lake have comparable storage capacities and similar depths. All four reservoirs are recreational areas.

Profiles

A general comparison can be made among the profiles measured at Rob Roy, Granite Springs, and Crystal Lake. Lake Owen, due to its shallow depth, is not very comparable to the other three reservoirs and will not be discussed further in this section.

Rob Roy, Granite Springs, and Crystal Lake are dimictic reservoirs because they mix or “turn over” twice a year. In 1998, Rob Roy was always cooler, probably due to the high elevation, than either Granite Springs or Crystal Lake Reservoirs. In 1998, temperature in the hypolimnion zone in Rob Roy generally ranged from 5 to 10°C (fig. 5). By September 1998, the temperature in the hypolimnion was about 15°C in both Granite Springs and Crystal Lake. In 1998, the temperature in the epilimnion of Rob Roy reached a maximum of 16.7°C. During 1998 the maximum temperature in the epilimnion was 26.6°C in Granite Springs and 21.1°C in Crystal Lake. Rob Roy retained a stronger stratification in mid-September, 1998, in comparison to Granite Springs or Crystal Lake.

Granite Springs and Crystal Lake showed very similar thermal changes over time (figs. 17 and 20). Both reservoirs were unstratified in May, developed strong thermal stratification by mid-July, and stratification dissipated by early fall. It is most likely that the large volume of water that passes through Granite Springs and Crystal Lake reservoirs disrupts the more classic stratification pattern associated with temperate lakes. Whereas Rob Roy reservoir maintained temperatures below 8°C in the hypolimnion throughout the summer, much warmer temperatures (greater than 10°C) were measured in the hypolimnion of Granite Springs and Crystal Lake reservoirs.

September 1998 profiles (fig. 3C, 16D, 19D) show similar patterns of higher pH in the epilimnion, and lower pH in the hypolimnion. The pH also was greater in the two lower reservoirs than in the upper reservoirs: 6.5 to 7.5 in Rob Roy; 7.0 to above 8.0 in Granite Springs; and 7.0 to 8.5 in Crystal Lake. Dissolved oxygen during the same period was substantially different in Rob Roy (fig. 3C) than in Granite Springs and Crystal Lake (figs. 16D and 19D). Dissolved-oxygen concentrations in Rob Roy decreased from slightly higher than 7 mg/L to about 5 mg/L. In contrast, concentrations in both Granite Springs and Crystal Lake were slightly higher than 7.5 mg/L near the surface to about 26 ft and decreased to less than 1mg/L in the hypolimnion.

Phytoplankton

The phytoplankton community was different in each reservoir. The average biomass and density of phytoplankton were lowest in Rob Roy, and the concentrations generally increased progressively from Lake Owen to Granite Springs and Crystal Lake (fig. 23A). The one exception to the pattern was that the average density was larger in Granite Springs than in Crystal Lake. The average concentrations are slightly skewed by a phytoplankton bloom in Granite Springs and to a lesser degree, blooms in Crystal Lake and Lake Owen

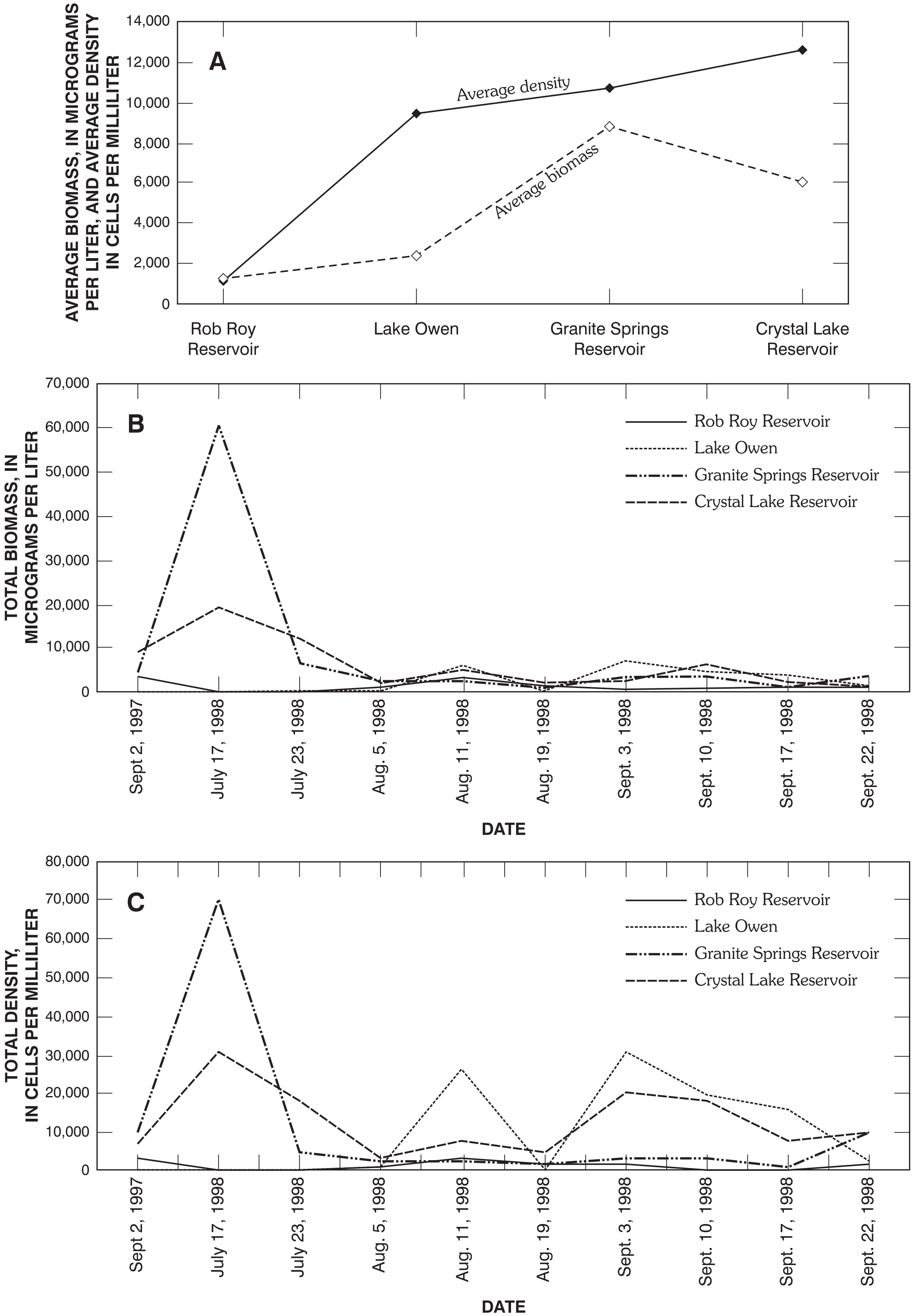


Figure 23. Phytoplankton biomass and density in Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming (**A**, average biomass and average density; **B**, total biomass; and **C**, total density).

(fig. 23B). The phytoplankton density followed the seasonal pattern of the biomass, although large concentrations of relatively small-sized Chrysophyta in Lake Owen caused a spike in density relative to biomass, as did large concentrations of relatively small-sized blue-green algae in Crystal Lake (fig. 23C). The biomass concentrations are considered a more reliable indicator of primary productivity because the size of the algae is not accounted for in the density estimate.

The composition of the phytoplankton community also was different between the upper and lower reservoirs. Many of the species found in Rob Roy and Lake Owen are associated with oligotrophic, nutrient-poor conditions. In contrast, many of the species found in Granite Springs and Crystal Lake are associated with mesotrophic (between poor and rich nutrient conditions) or eutrophic (nutrient-rich) conditions. As an example, blue-green algae were absent from the higher elevation reservoirs, but dominated some of the samples from the lower reservoirs. The species *Anabaena*, which is often associated with algal blooms, was the predominant species of blue-green algae in the lower reservoirs. Green algae, diatoms, and chrysophytes dominated the phytoplankton samples from the higher-elevation reservoirs. An abundance of desmids (a family of green algae) relative to other algae in oligotrophic lakes has been noted by Prescott (1968, p. 293). The desmids *Cosmarium, Staurastrum*, and *Spondylosium* were dominant or subdominant in some of the samples from Rob Roy, as described earlier in this report. Desmids also were present in Lake Owen and Crystal Lake, but at relatively smaller concentrations. Desmids typically are found sparingly in phytoplankton samples, with large numbers of species or individuals usually found only where the pH ranges from 5 to 6 (Smith, 1950, p. 310). The pH values at Rob Roy were the lowest of the four reservoirs studied and generally were less than 7.

Nutrient concentrations could be limiting phytoplankton growth in the reservoirs, based on samples collected in late August and early September 1997 (table 2). All concentrations of dissolved ortho-phosphorus were less than the reporting limit of 0.01 mg/L. For comparison, the U.S. Environmental Protection Agency (1986) recommends ortho-phosphate concentrations in lakes and reservoirs not exceed 0.025 mg/L for protection against aquatic nuisance algal blooms and to control accelerated or cultural eutrophication. Concentrations of dissolved nitrogen species generally were less than the reporting limits, particularly in the near-surface samples. Silica can be a limiting nutrient to diatoms, because they need silica to build their frustules. Concentrations of silica from the one set of surface samples collected in this study, however, were in the range of 2.1 to 5.8 mg/L, indicating adequate supplies of silica. Limiting concentrations of silica for certain diatoms are 0.5-0.8 mg/L (Reid and Wood, 1976, p. 244), and 0.5-1.0 mg/L (Prescott, 1968, p. 338).

The total number of taxa identified also increased downstream in the reservoirs: Rob Roy, 29 taxa; Lake Owen, 37 taxa; Granite Springs, 41 taxa; and Crystal Lake, 42 taxa. The green algae were the most diverse division, with a total of 34 taxa identified in this study. Some green algae, such as *Chlorella*, *Quadrigula*, and *Sphaerocystis* were found in all four reservoirs (table 4). Twenty taxa of green algae, however, were found in only one reservoir. Other taxa of algae found in all four reservoirs include the diatom *Fragilaria*, and the cryptomonads *Campylomonas reflexa, Campylomonas rostratiformis, Katablepharis*, and *Plagioselmis*. A total of 80 taxa were identified in the samples from this study.

The phytoplankton communities and water chemistry of Rob Roy and Lake Owen appear to be somewhat similar to those of Fremont and New Fork Lakes, two oligotrophic lakes in western Wyoming. The dissolved solids and nutrient concentrations in all four water bodies were similar to each other, except for silica, which was lower in Fremont Lake (median concentration 1.4 mg/L) (Peterson and others, 1987, p. 36-43). The average phytoplankton density was 4,840 cells/mL in Fremont Lake and 1,710 cells/mL in New Fork Lakes (Peterson and others, 1987, p. 26-29); this range is similar in Rob Roy and Lake Owen. Diatoms, green algae, golden-brown algae, and blue-green algae were common components of the phytoplankton community at Fremont and New Fork Lakes. In contrast, blue-green algae were not identified in Rob Roy or Lake Owen.

During 1983-84 and 1989, a total of 146 species were identified in samples from Fremont Lake (Averett and others, 1993). The larger number of species identified in Fremont Lake, compared to Rob Roy and Lake Owen, is due, at least in part, to two factors: (1) the wider scope of seasons, years, and depths sampled from Fremont Lake, and (2) the species-level identifications, as opposed to the mostly genus-level identifications from this study. Many of the same genera of algae were identified from all three-water bodies.

Secchi disk transparencies indicate that Rob Roy had the clearest water of the four reservoirs studied (fig. 4). The average transparency in each reservoir was:

Reservoir	Secchi disk transparency (feet)	Approximate euphotic zone thickness (feet)
Rob Roy	10.4	31
Lake Owen	6.6	20
Granite Springs	8.2	25
Crystal Lake	6.1	18

The euphotic zone is the upper layer of the lake where sufficient sunlight penetrates for photosynthesis. The depth of the euphotic zone typically extended below the metalimnion when the reservoirs were stratified, indicating adequate light for photosynthesis throughout the epilimnion. For comparison, Secchi disk readings from Fremont and New Fork Lakes ranged from 10.5 to 49 ft (Peterson and others, 1987, p. 18-19).

The phytoplankton counts in the MPA are lower in Rob Roy then in Granite Springs and Crystal Lake. Rob Roy is at an elevation of 9,470 ft. The surface of the reservoir is frozen and snow-covered for most of the year, thereby, restricting sunlight and phytoplankton growth. Water flows from Rob Roy to Lake Owen where the MPA indicated less algae. Several factors at Lake Owen could influence it's phytoplankton counts. Lake Owen is shallow and vegetation is abundant. Also, Lake Owen contains some rotifers that may be consuming algae. Lake Owen may be acting as a wetland with the vegetation consuming the nutrients, thereby limiting the algal cell growth. The elevation of Crystal Lake Reservoir is 6,969 ft, allowing even more favorable conditions for algal growth.

Higher phytoplankton counts in the MPA are seen in both Granite Springs and Crystal Lake. Granite Springs is dominated by diatoms, whereas Crystal Lake had both non-diatomaceous phytoplankton and diatoms in the MPA. The warmer climate associated with the lower elevation of these two reservoirs, and the wind, which often keeps the ice from being covered by snow, are possible reasons for the higher phytoplankton counts. Investigation of the reasons for these differences is beyond the scope of this study.

Chemical Quality

Dissolved-solids (fig. 7) concentrations were slightly greater with depth within Rob Roy, Granite Springs, and Crystal Lake Reservoirs. The pattern was consistent in all three reservoirs although the amount of increase was small. Silica, as dissolved SO_2, showed a consistent pattern of increasing with depth in Rob Roy, Granite Springs, and Crystal Lake (fig. 9), as did iron (fig. 10) and manganese (fig. 11).

Dissolved-solids concentrations in Granite Springs and Crystal Lake were about double those of the upper two reservoirs, Rob Roy and Lake Owen (fig. 24). The concentrations of individual major ions were larger in the lower two reservoirs, but the percentages of major ions were similar (fig. 8). Thus, although the concentrations of individual dissolved constituents were larger in the two lower reservoirs, the major-ion concentrations occurred in about the same proportions.

Bottom Sediment

Composite sediment samples were collected and analyzed from all four reservoirs (table 3). The major constituents analyzed were present in similar concentrations in all four reservoirs, except for nitrogen. Rob Roy and Lake Owen were similar with 9 and 8 mg/kg of nitrogen, reported as total nitrite plus nitrate. Granite Springs and Crystal Lake both had nitrogen concentrations less than the detection limit. In all four reservoirs, aluminum was 6.2 to 6.9 percent of the sediment. Iron concentrations in samples from all four reservoirs ranged from 2.2 percent to 3.6 percent. Phosphorus and titanium were present in similar concentrations in all four reservoirs.

Differences in bottom-sediment samples from the reservoirs were most apparent in the concentrations of trace elements. When thorium, vanadium, cerium and chromium concentrations were plotted (fig. 12), the samples fell into two groups. Sediment concentrations from Rob Roy and Lake Owen (Group l) are more like the crustal average than either diabase or granitic rocks. In contrast, the concentrations from Granite Springs and Crystal Lake Reservoirs (Group 2) are closer to concentrations present in granitic rocks.

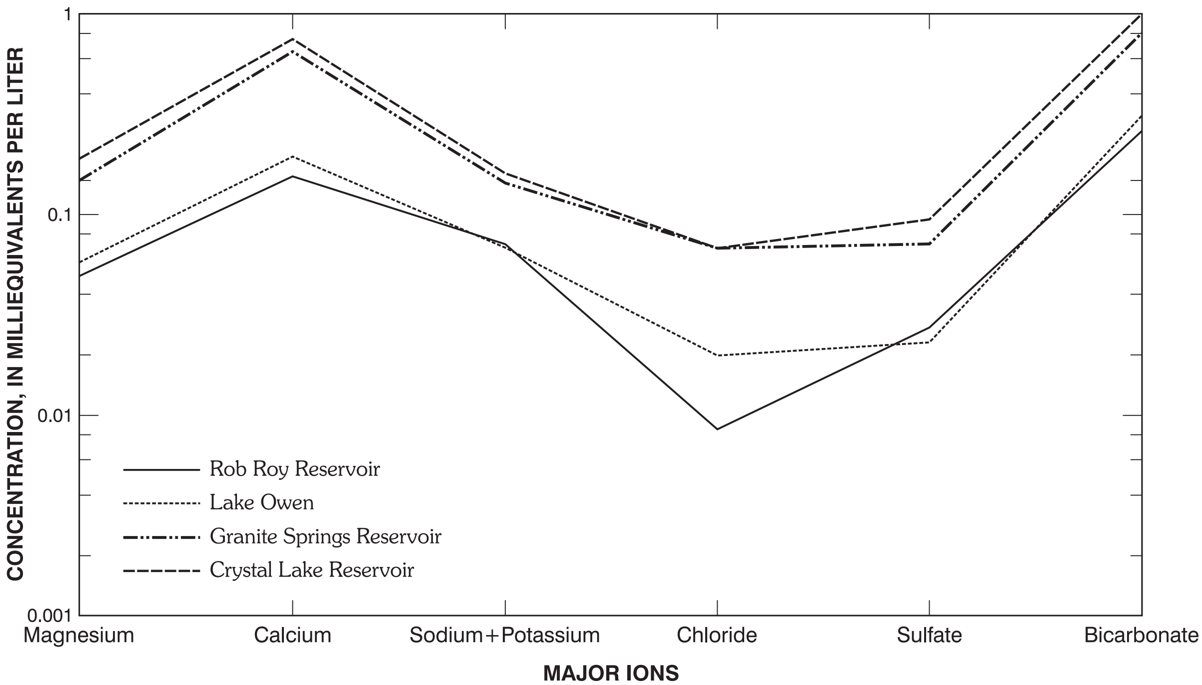


Figure 24. Comparison of the concentration of major ions in the surface samples collected in the fall of 1997 at Rob Roy Reservoir and Lake Owen, Albany County, and Granite Springs and Crystal Lake Reservoirs, Laramie County, Wyoming.

SUMMARY

Surface water contributes approximately 75 percent of the City of Cheyenne's drinking-water supply. Most of that surface water is provided by four reservoirs: Rob Roy, Lake Owen, Granite Springs, and Crystal Lake. Although extensive water-quality data are collected for the treated water, limited data were available on the raw-water quality within the storage reservoirs.

Rob Roy Reservoir is the largest, deepest, and highest in the series of the reservoirs. Profile measurements indicate that in 1998 Rob Roy was strongly stratified from mid-July into late September and by early October was no longer stratified. The zone of warming in Rob Roy extended progressively deeper into the reservoir from mid-July into September. Bacillariophyta (diatoms) and Chlorophyta (green algae) dominated the phytoplankton community of Rob Roy. Twenty-nine taxa of algae were identified from the samples, including eighteen taxa of green algae. In Rob Roy, the microscopic particulate analysis (MPA) was dominated by non-diatomaceous phytoplankton and diatoms. The water was a calcium-bicarbonate type with the lowest dissolved solids of the four reservoirs. Dissolved-solids and major-ion concentrations indicated little difference between the top and bottom samples of Rob Roy. Iron and manganese concentrations, however, were higher in the bottom sample. Concentrations of selected trace elements in bottom sediment from Rob Roy resemble the crustal average rock more than either diabase or granitic rocks.

Lake Owen is the shallowest and smallest of the series of reservoirs. It showed little stratification, probably due to its shallow depth and large surface area to volume ratio. Lake Owen warmed by mid-July in 1998 and cooled quickly in the fall. The golden-brown algae Chrysophyte dominated the phytoplankton community; *Uroglenopsis* was the most common species in the samples. Lake Owen is the only one of the four reservoirs in this study to have extensive macrophyte growths. In the fall of 1997, MPA was dominated by non-diatomaceous phytoplankton and diatoms, with a few rotifers being detected. Analysis of a single water sample, collected 1 foot below the reservoir surface, indicated the water quality was similar to that of Rob Roy, with a dissolved-solids concentration of 20 mg/L and of a calcium-bicarbonate type. Lake Owen had the largest concentration of dissolved iron of the four reservoirs. Like Rob Roy, bottom sediment from Lake Owen resembled crustal averages.

Granite Springs Reservoir is the third reservoir in the series and receives water through both Stage I and Stage II pipelines from Lake Owen. Profiles indicate that Granite Springs developed stratification by early-to-mid July; the reservoir was unstratified in the winter. The 1998 temperature profiles in Granite Springs indicate a seasonal progression of the water temperature in the reservoir from a uniform profile, to linear warming, to stratification, to a uniform profile. Diatoms and blue-green algae dominated the phytoplankton community. Blue-green algae, principally *Anabaena*, dominated the biomass of the algae in the August 1997 and July 14, 1998 samples. The two samples collected for chemical analysis indicated that the water was a calcium-bicarbonate type. Dissolved-solids concentration increased slightly with depth. Likewise, dissolved-iron and -manganese concentrations increased with depth. The MPA was dominated by non-diatomaceous phytoplankton and diatoms. A few rotifers were detected. Trace-element concentrations in bottom sediment in Granite Springs resemble concentrations found in granitic rocks.

Crystal Lake Reservoir is the last reservoir in the series. Water flows down Middle Crow Creek and through a pipeline from Granite Springs into Crystal Lake. Profile data indicate that stratification occurred during the warmer months. Throughout the May and June period of 1998 the reservoir warmed and stratification developed. By mid-July, the reservoir was stratified and surface water temperature was slightly greater than 20°C. Blue-green algae and diatom biomass dominated the phytoplankton community. Of the 42 algal taxa identified, only 5 taxa were blue-green algae. The MPA was dominated by non-diatomaceous phytoplankton and diatoms. The three samples collected for chemical analysis at Crystal Lake indicated the water was a calcium-carbonate type with dissolved-solids concentrations varying from 58 mg/L at the surface to 63 mg/L at the bottom. Concentrations of dissolved iron and manganese increased with depth in Crystal Lake. Selected trace-element concentrations in bottom sediment were more like granitic rocks than either diabase or the crustal average.

A general comparison was made between the 1998 profiles measured at Rob Roy, Granite Springs, and Crystal Lake Reservoirs. Rob Roy was always cooler, probably due to it's higher elevation. In Rob Roy, the temperature in the epilimnion reached a maximum of 16.7°C. In Granite Springs and Crystal Lake, the maximum temperature in the epilimnion was several degrees warmer—26.6°C in Granite Springs and 21.1°C in Crystal Lake. The hypolimnion in Rob Roy remained between 5 to 10°C. By September 1998, the temperature in the hypolimnion was greater than 15°C in both Granite Springs and Crystal Lake. This difference may be a result of the large inflow and outflow in Granite Springs and Crystal Lake caused by water-supply withdrawals. Granite Springs and Crystal Lake showed similar thermal changes over time. Both were unstratified in May, developed strong stratification by mid-July, and the stratification dissipated by early fall.

The phytoplankton community changed progressively downstream in the four reservoirs. The average biomass and density of phytoplankton were smallest in Rob Roy, and the concentrations generally were progressively larger in Lake Owen, Granite Springs, and Crystal Lake. The composition of the phytoplankton community also changed downstream. Many of the species found in Rob Roy and Lake Owen are associated with oligotrophic, nutrient-poor conditions. In contrast, many of the species found in Granite Springs and Crystal Lake are associated with mesotrophic or eutrophic conditions. The total number of taxa identified also changed progressively downstream: Rob Roy, 29 taxa; Lake Owen, 37 taxa; Granite Springs, 41 taxa; and Crystal Lake, 42 taxa.

The reservoirs showed increases in concentrations of dissolved solids in the direction of water flow between the reservoirs. Dissolved-solids concentrations in the two lower reservoirs, Granite Springs and Crystal Lake, were more than twice the dissolved-solids concentrations in the upper two reservoirs, Rob Roy and Lake Owen. The water type in all four reservoirs was calcium bicarbonate. Silica, as dissolved SiO_2, increased with depth in all four reservoirs. Major-ion concentrations were present in about the same proportion in all four reservoirs. Concentrations of dissolved iron and manganese were elevated in the bottom samples as compared to the surface samples in all three reservoirs (figs. 10 and 11).

Bottom sediment was examined because sediment particles can act as sites for ion exchange between aquatic and solid phases. Differences in the reservoir sediment samples were most apparent when concentrations of trace elements were examined. Concentrations of selected trace elements from Rob Roy and Lake Owen are more like the crustal average than concentrations in either diabase or granitic rocks. In contrast, the concentrations from Granite Springs and Crystal Lake more closely resemble concentrations present in granitic rocks.

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APPENDIX A—PROFILE DATA

Explanation of figure numbers. Letter indicates reservoir.

R	Rob Roy Reservoir
L	Lake Owen
G	Granite Springs Reservoir
C	Crystal Lake Reservoir

Numerals respresent date of profile. Example:

R9-2-97 Profile measured in Rob Roy Reservoir on September 2, 1997

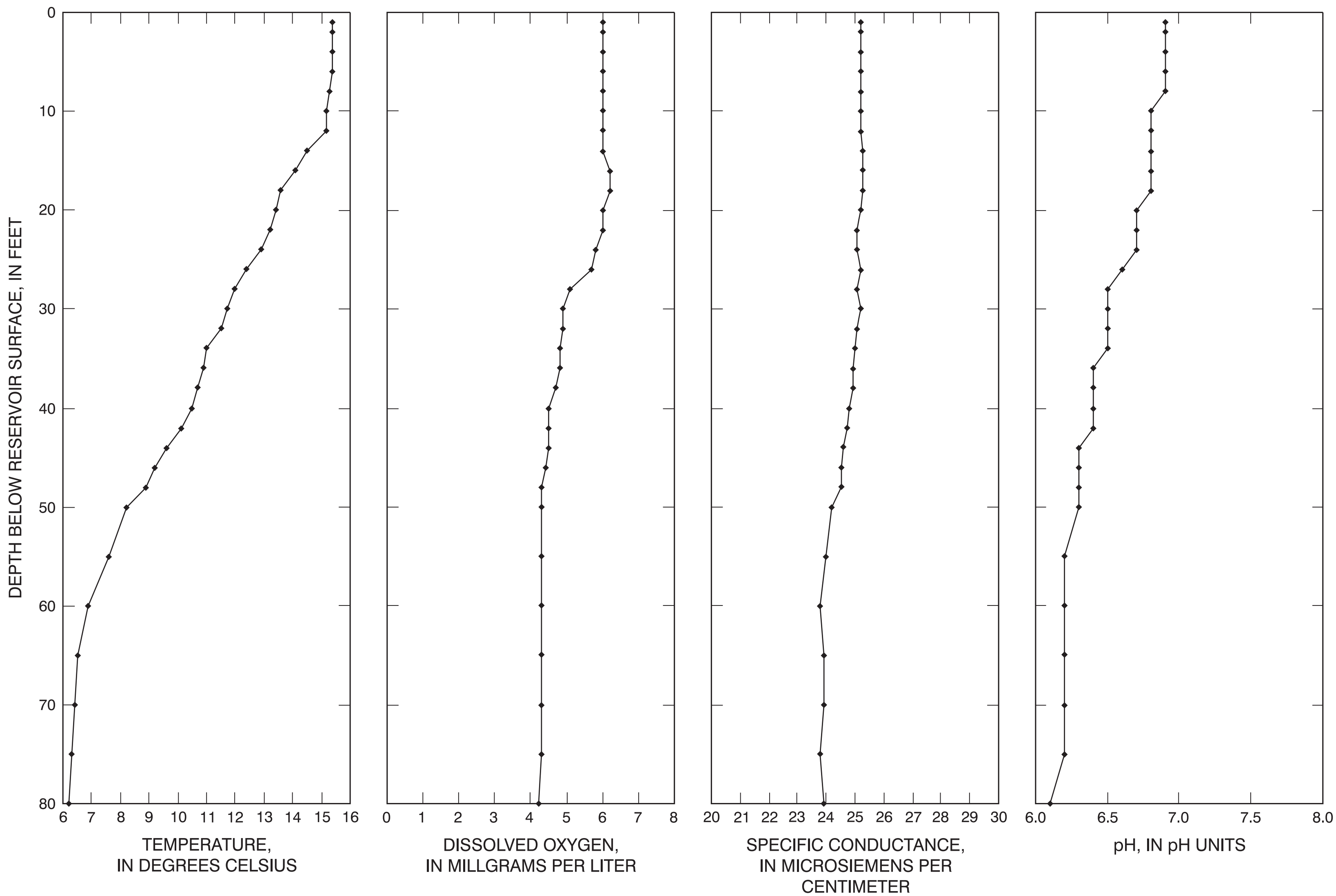

Figure R9-2-97. Temperature, dissolved oxygen, specific conductance and pH profiles on September 2, 1997, Rob Roy Reservoir, Albany County, Wyoming.

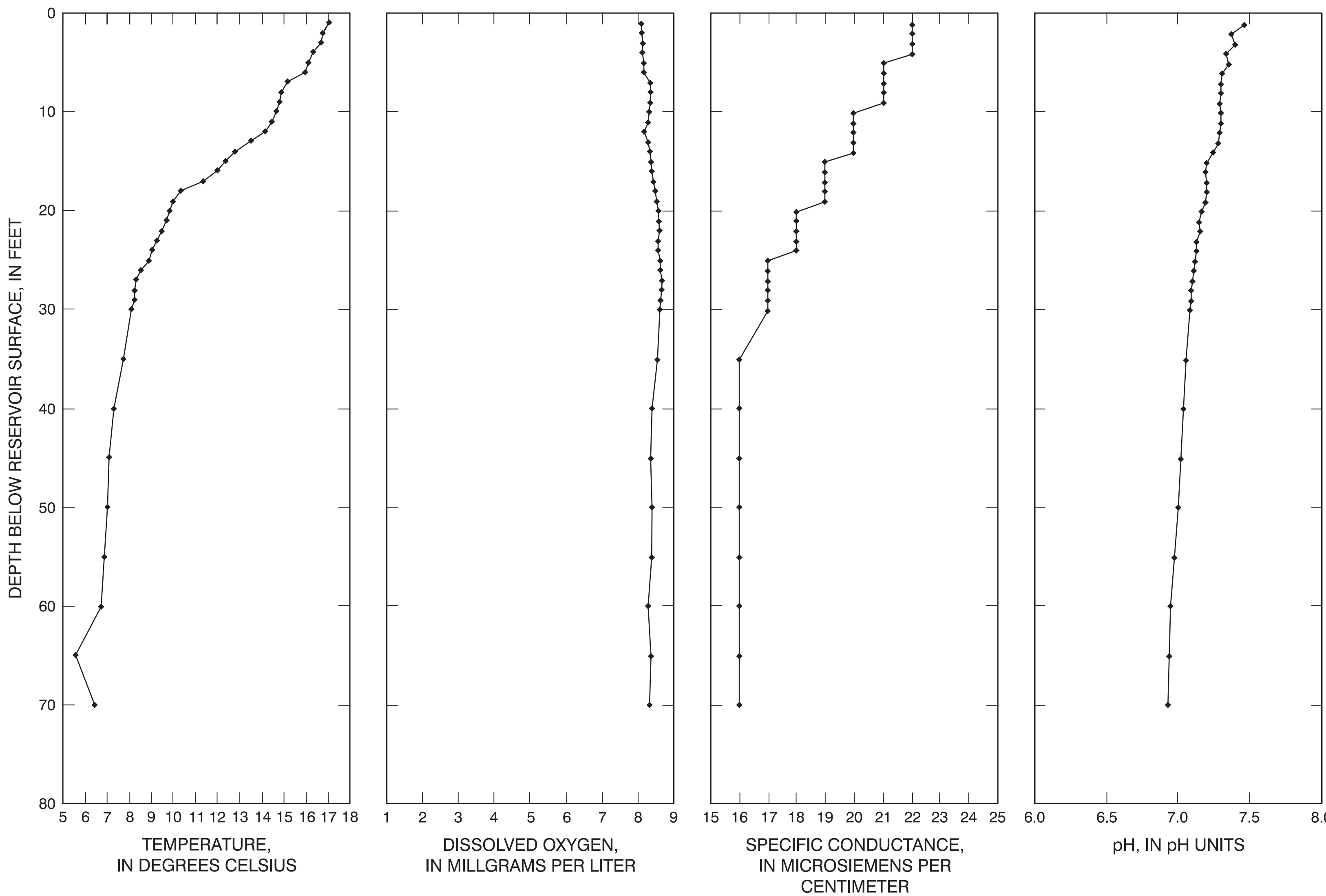

Figure R7-17-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 17, 1998, Rob Roy Reservoir, Albany County, Wyoming.

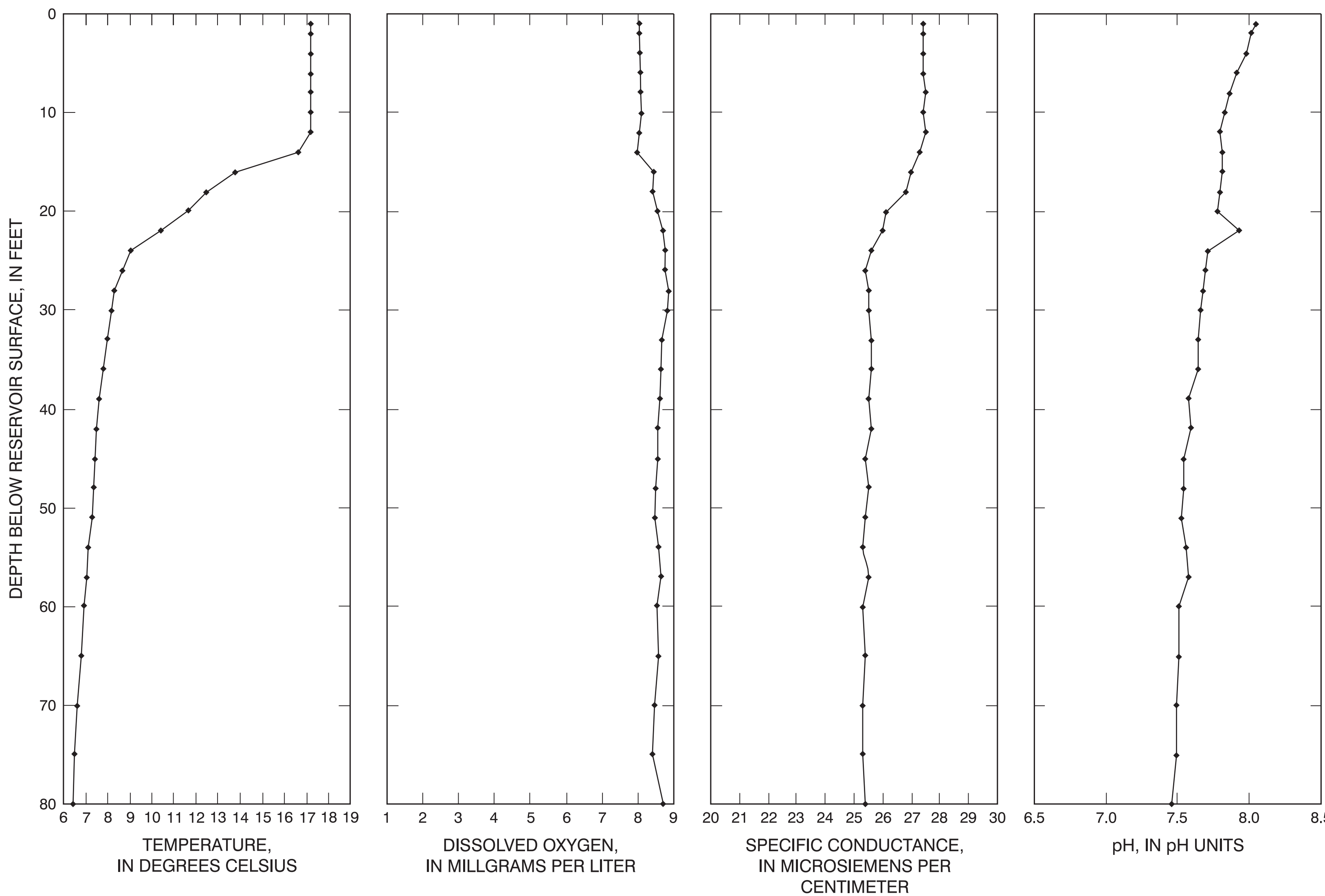

Figure R7-23-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 23, 1998, Rob Roy Reservoir, Albany County, Wyoming.

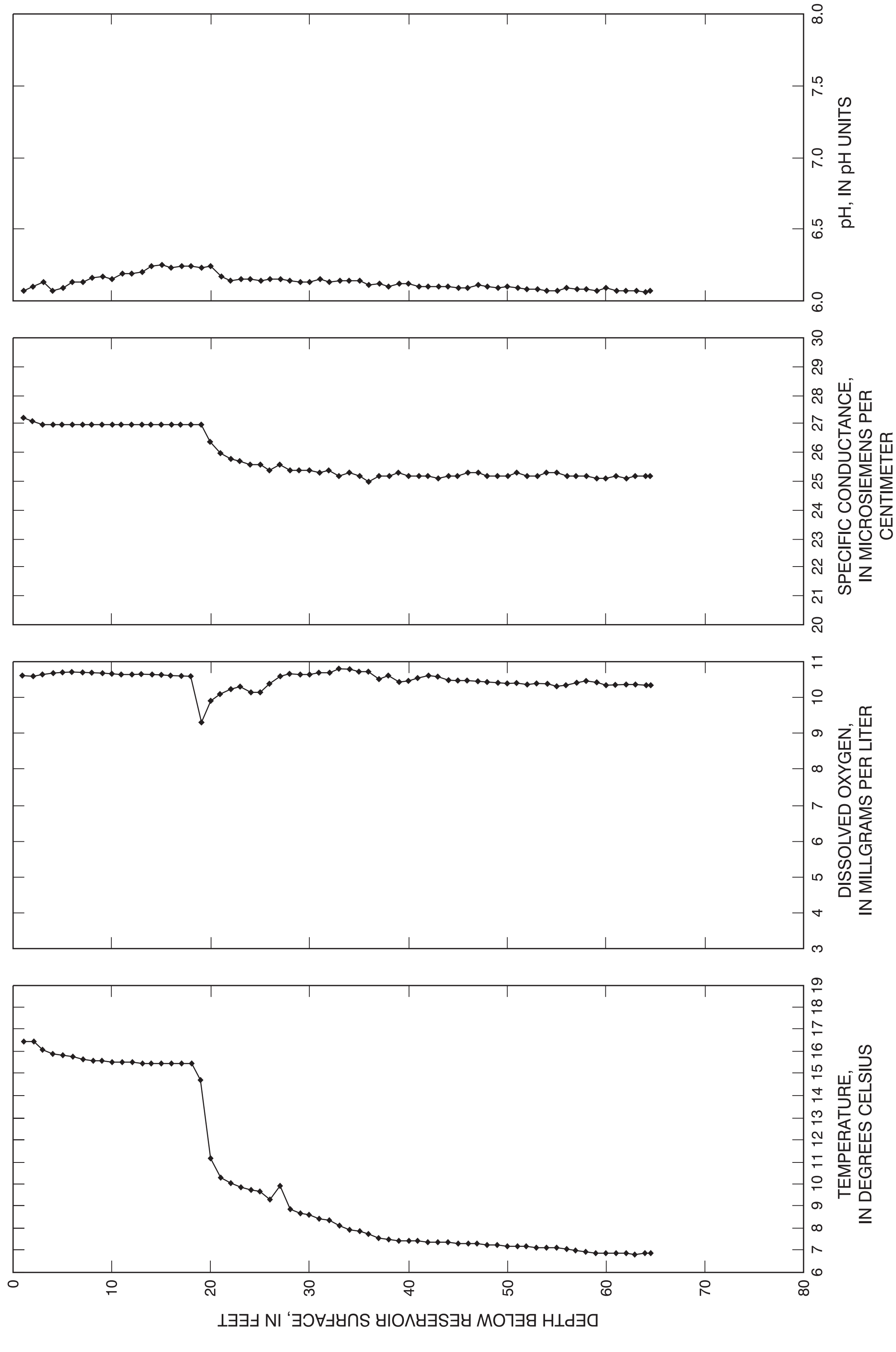

Figure R8-5-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 5, 1998, Rob Roy Reservoir, Albany County, Wyoming.

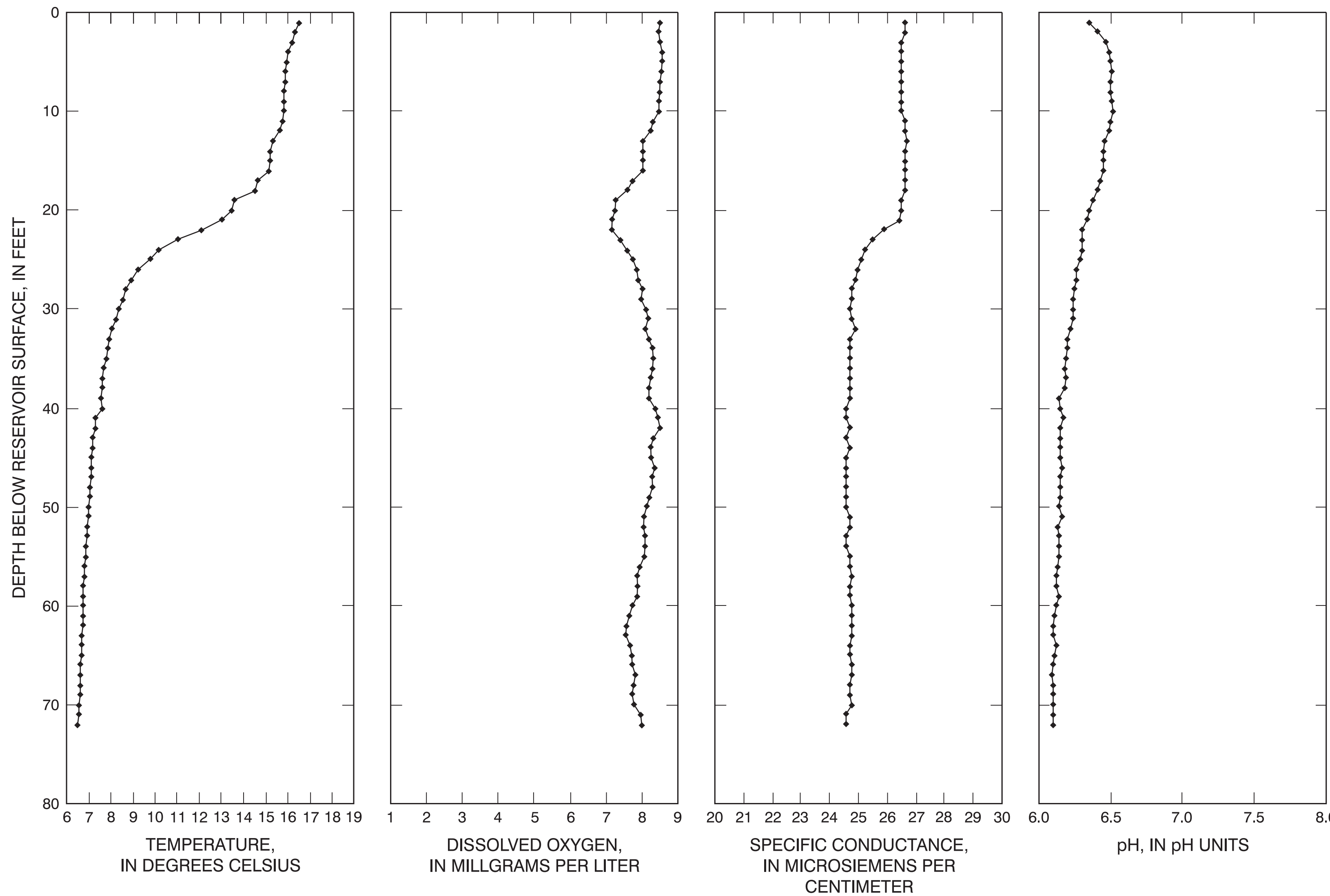

Figure R8-11-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 11, 1998, Rob Roy Reservoir, Albany County, Wyoming.

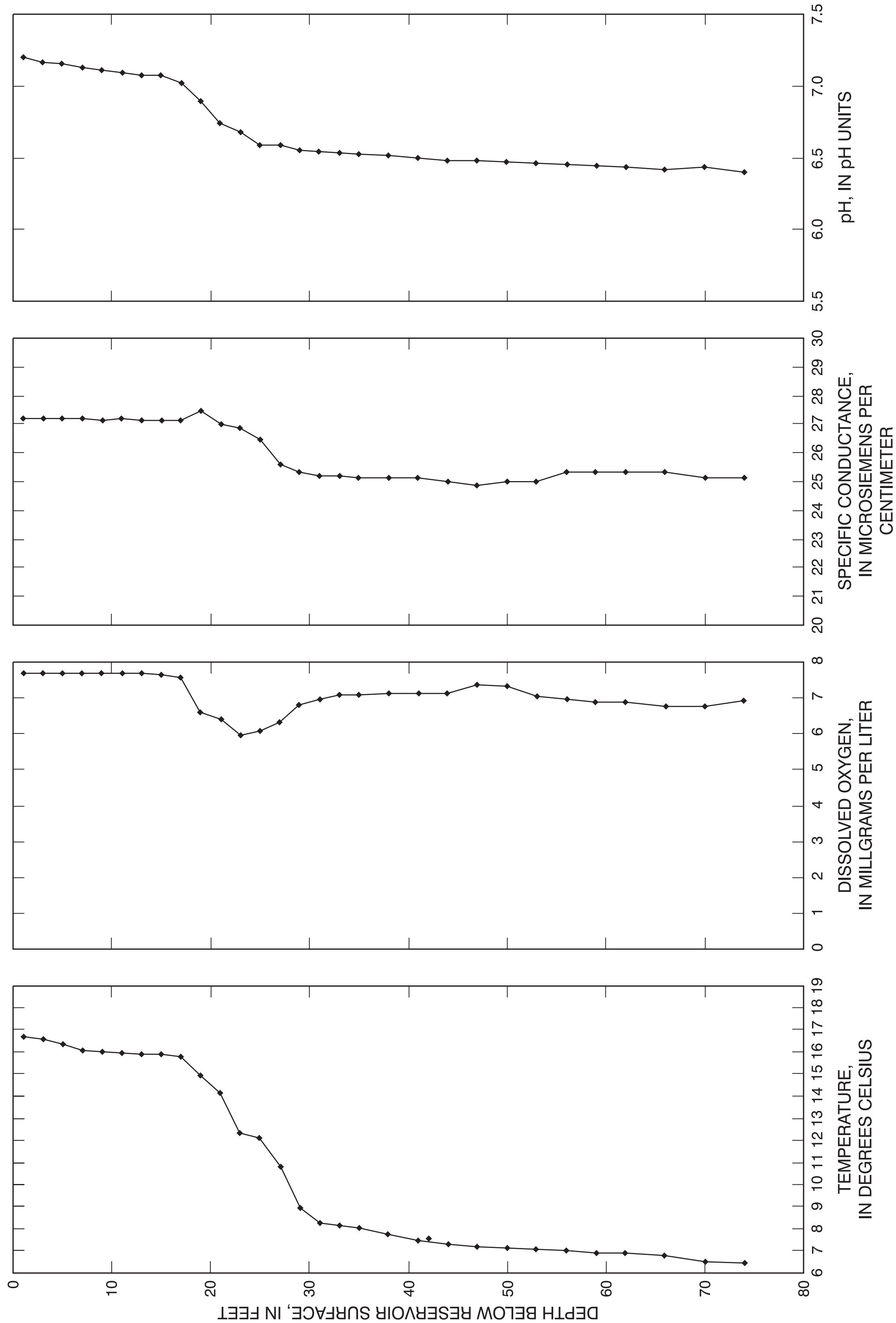

Figure R8-19-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 19, 1998, Rob Roy Reservoir, Albany County, Wyoming.

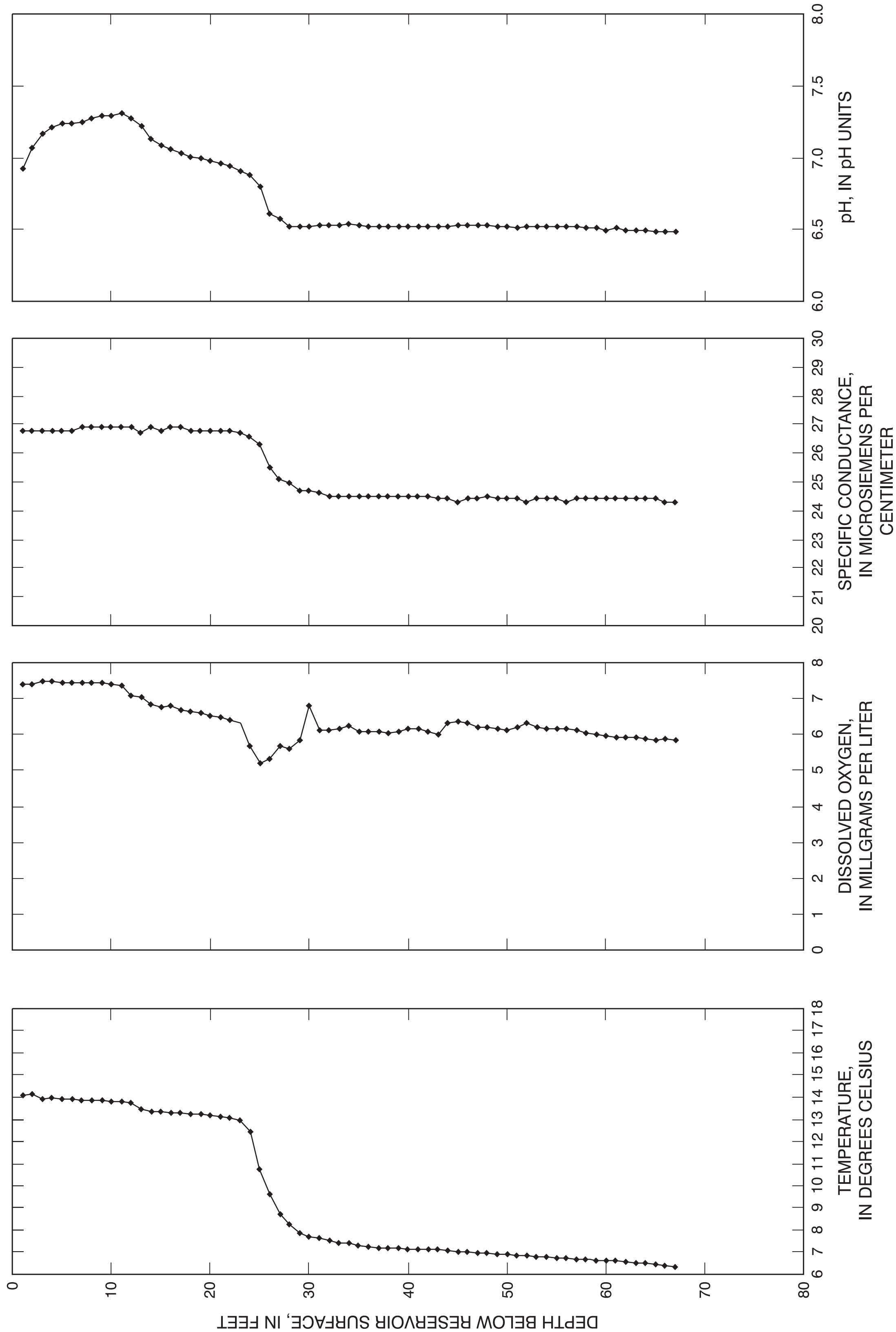

Figure R9-3-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 3, 1998, Rob Roy Reservoir, Albany County, Wyoming.

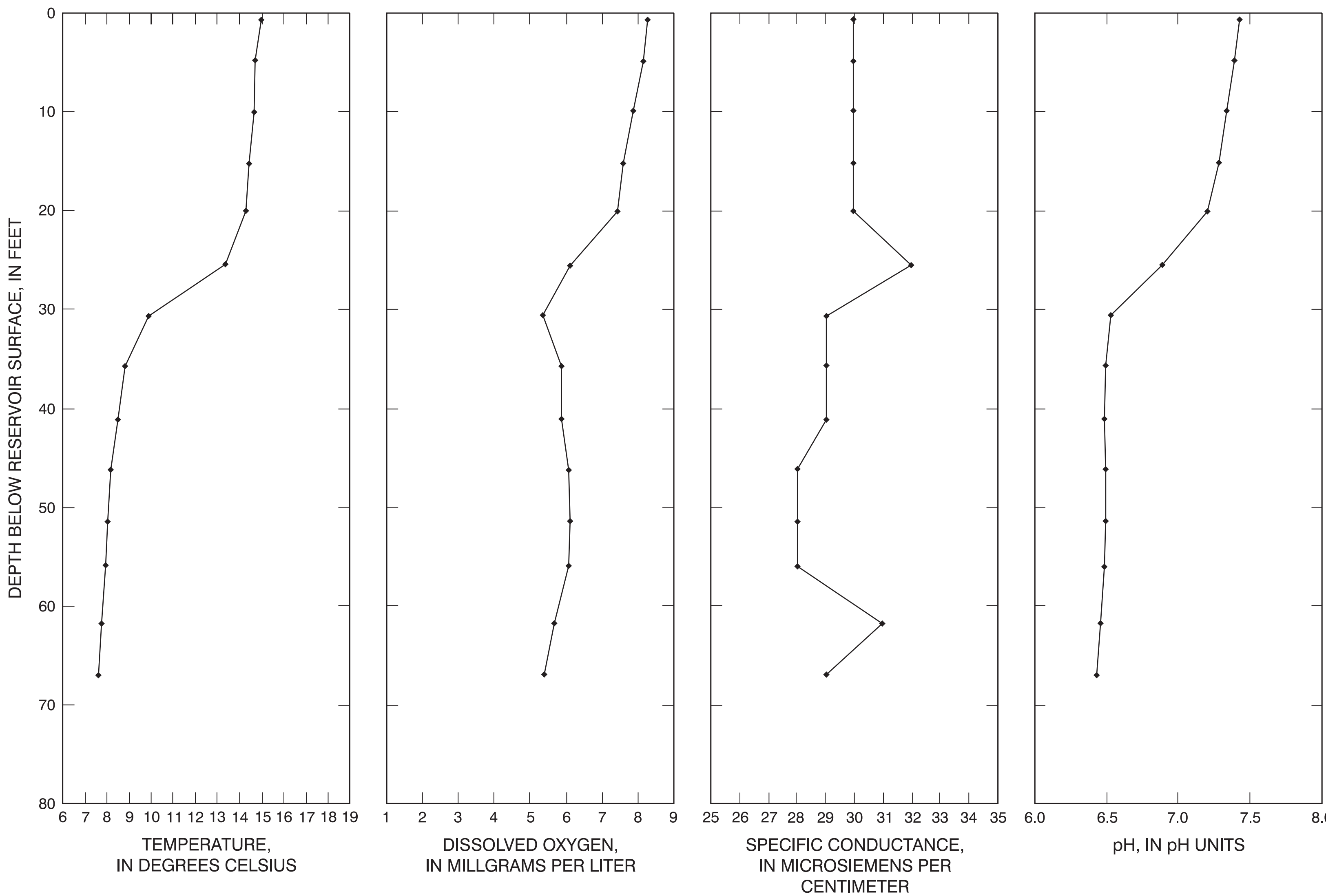

Figure R9-10-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 10, 1998, Rob Roy Reservoir, Albany County, Wyoming.

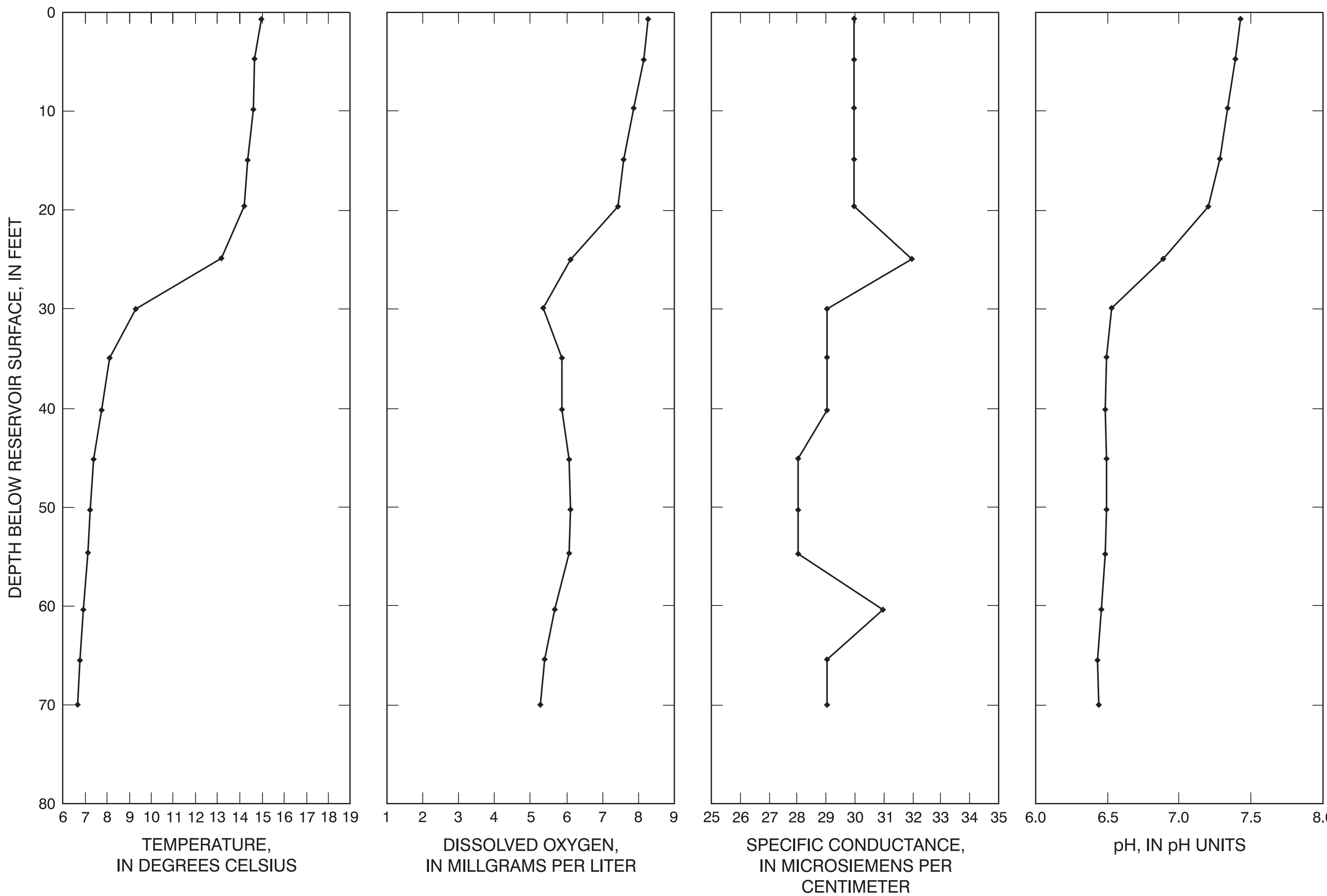

Figure R9-17-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 17, 1998, Rob Roy Reservoir, Albany County, Wyoming.

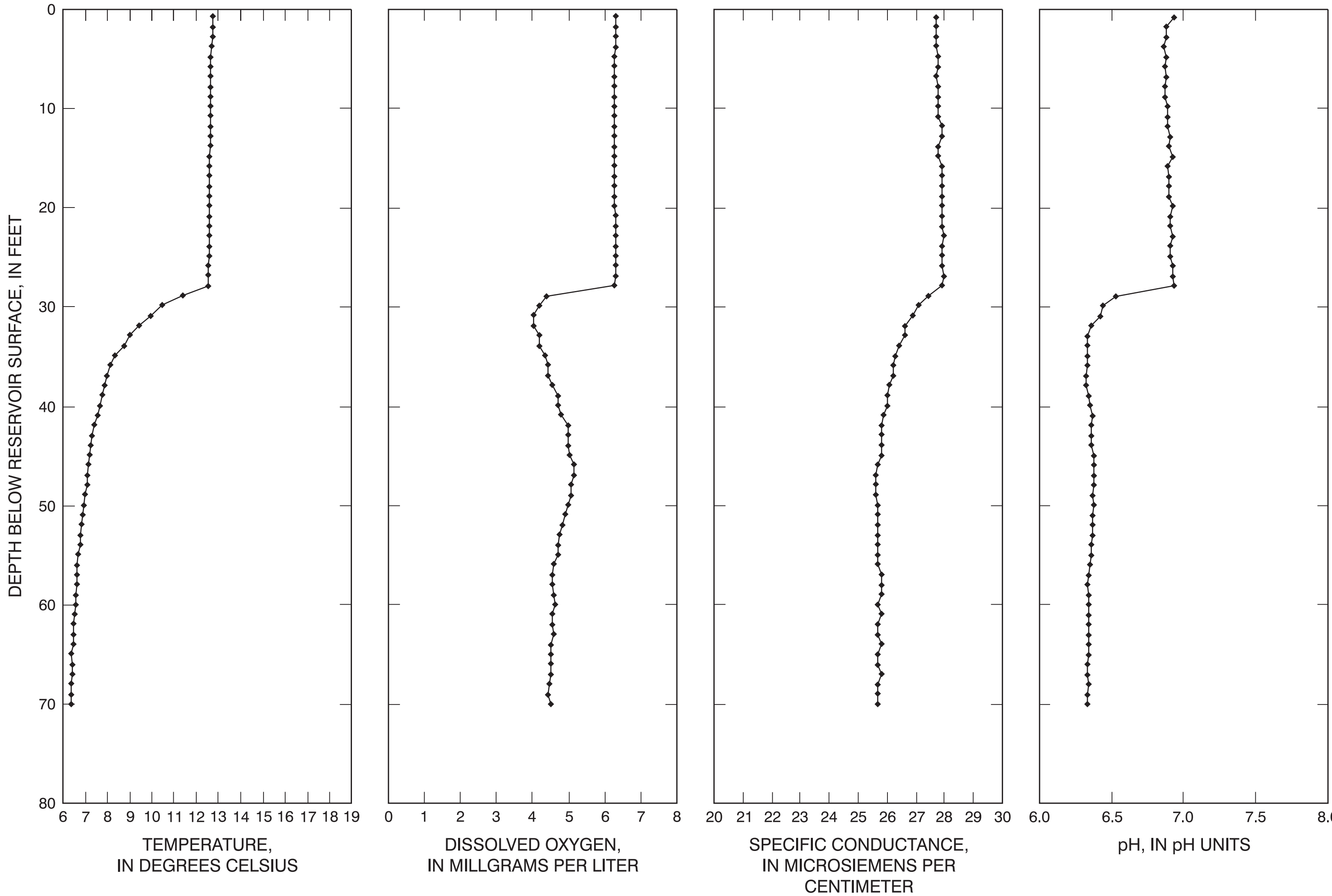

Figure R9-22-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 22, 1998, Rob Roy Reservoir, Albany County, Wyoming.

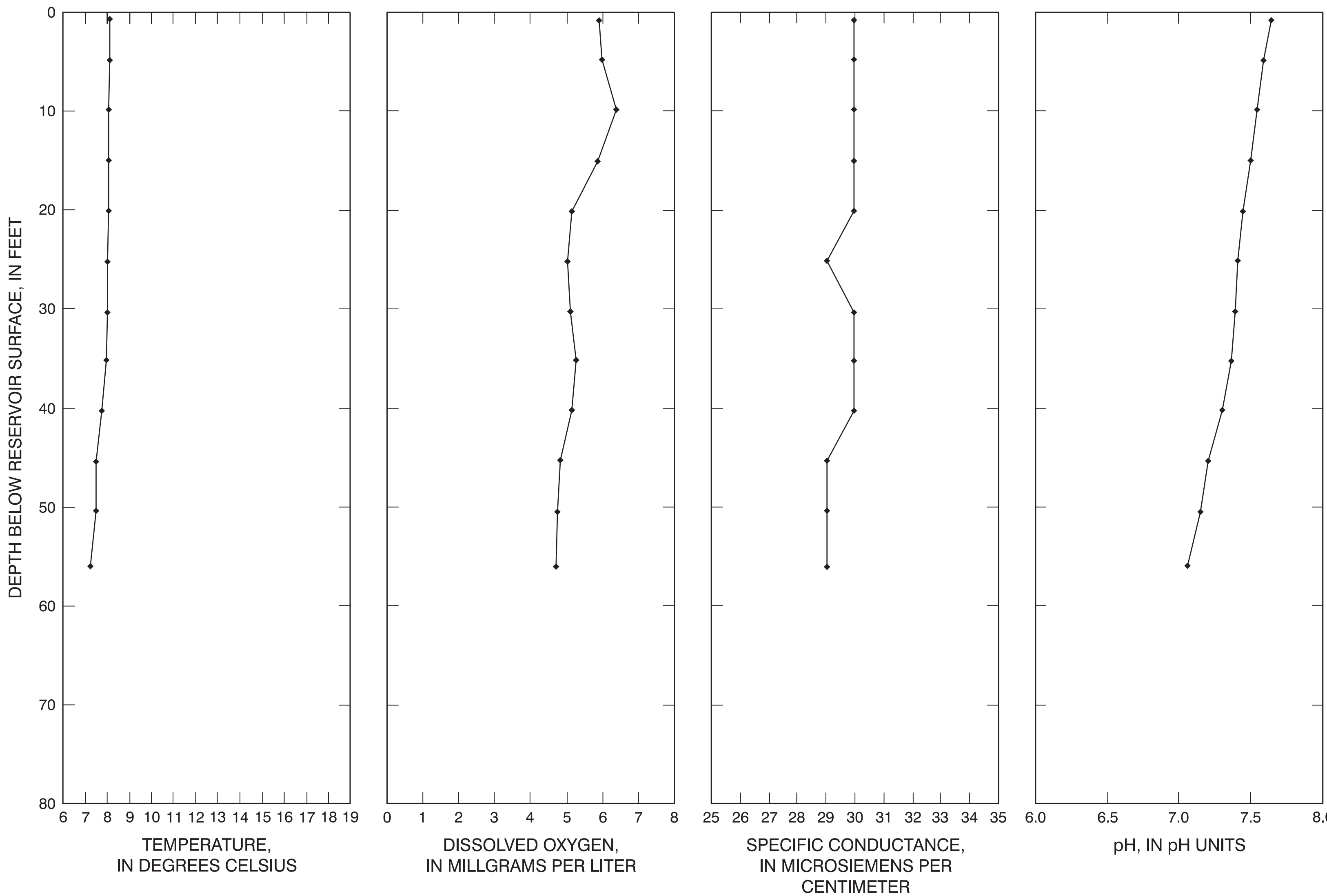

Figure R10-8-98. Temperature, dissolved oxygen, specific conductance and pH profiles on October 8, 1998, Rob Roy Reservoir, Albany County, Wyoming.

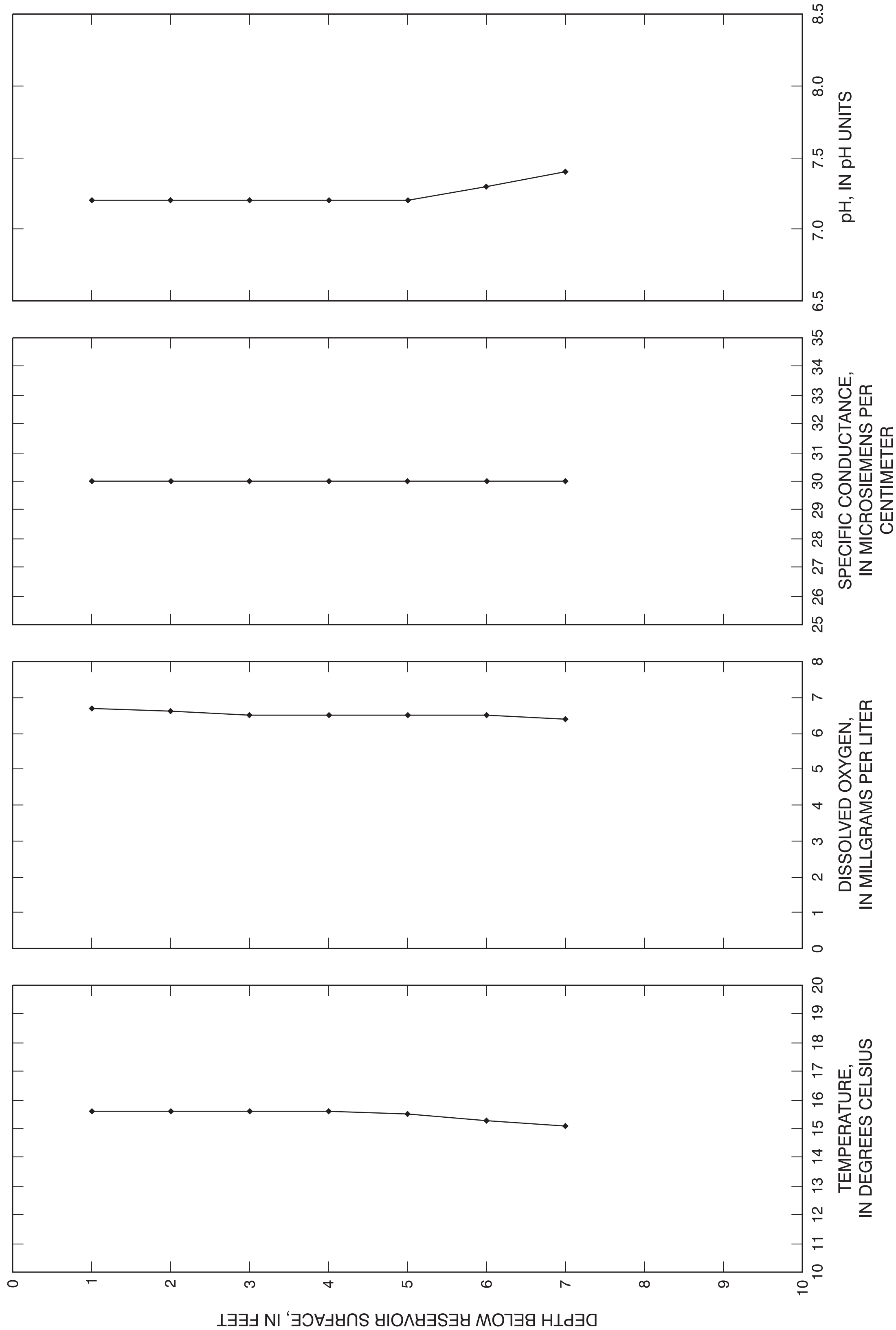

Figure L9-2-97. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 2, 1997, Lake Owen, Albany County, Wyoming.

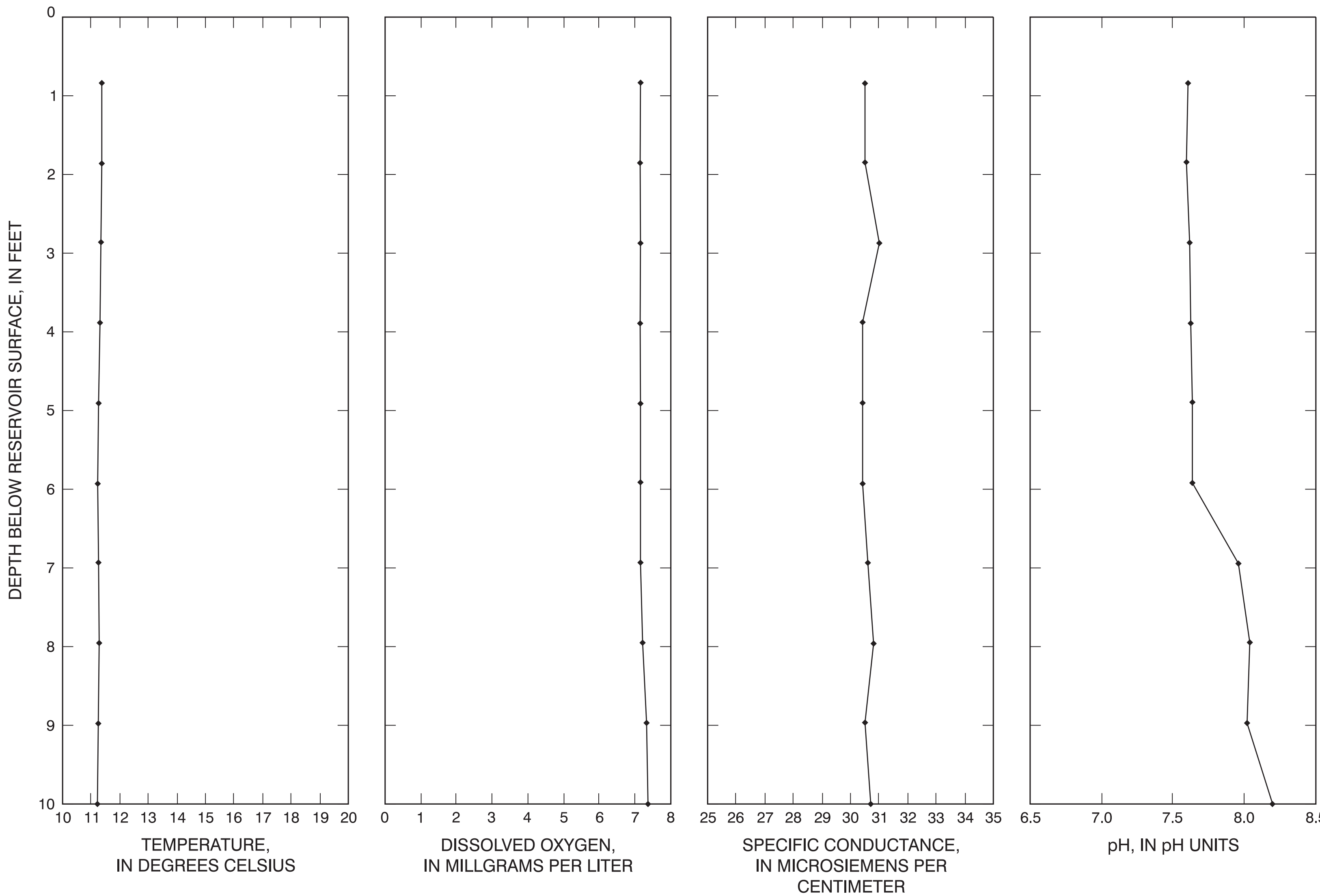

Figure L9-16-97. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 16, 1997, Lake Owen, Albany County, Wyoming.

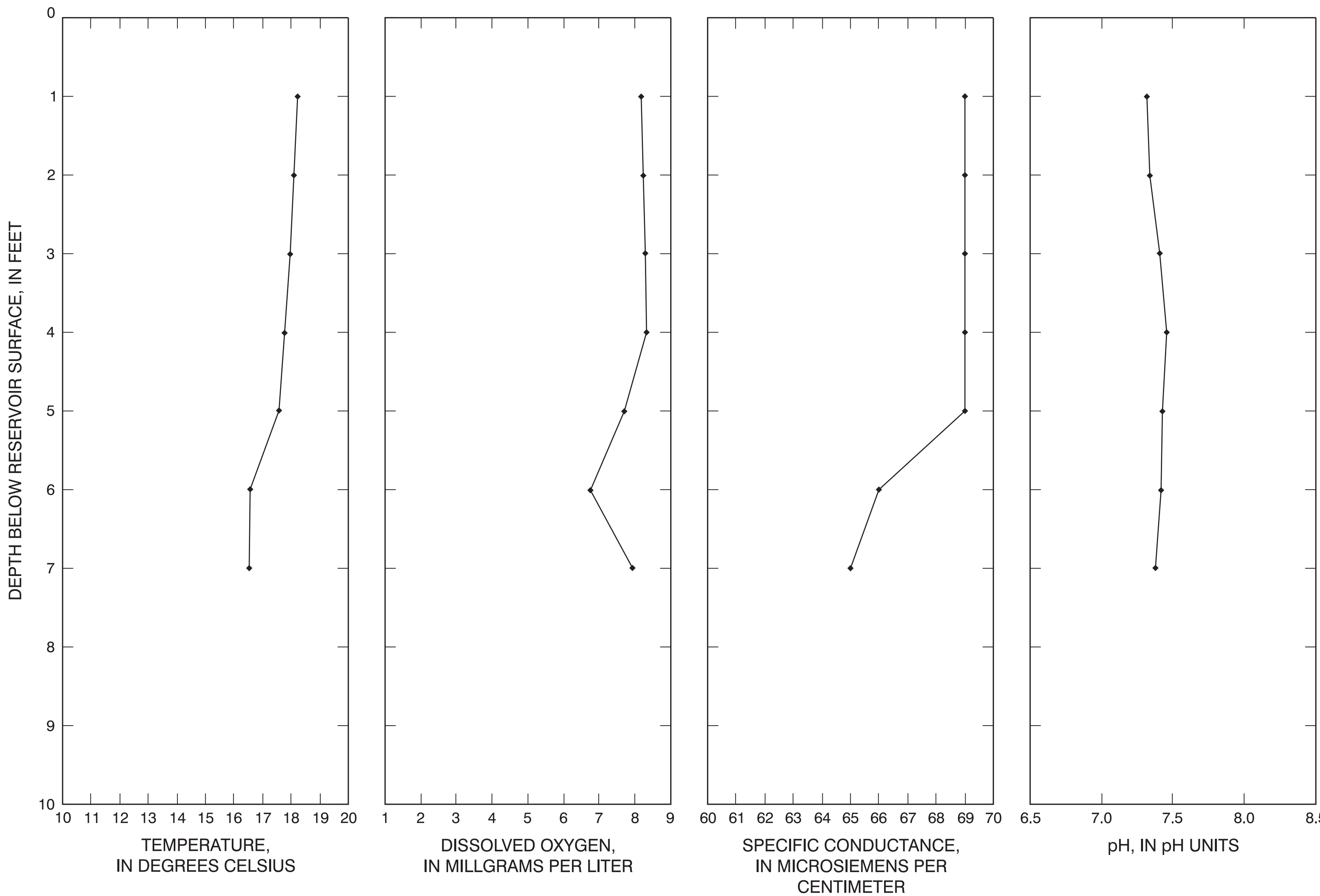

Figure L7-17-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on July 17, 1998, Lake Owen, Albany County, Wyoming.

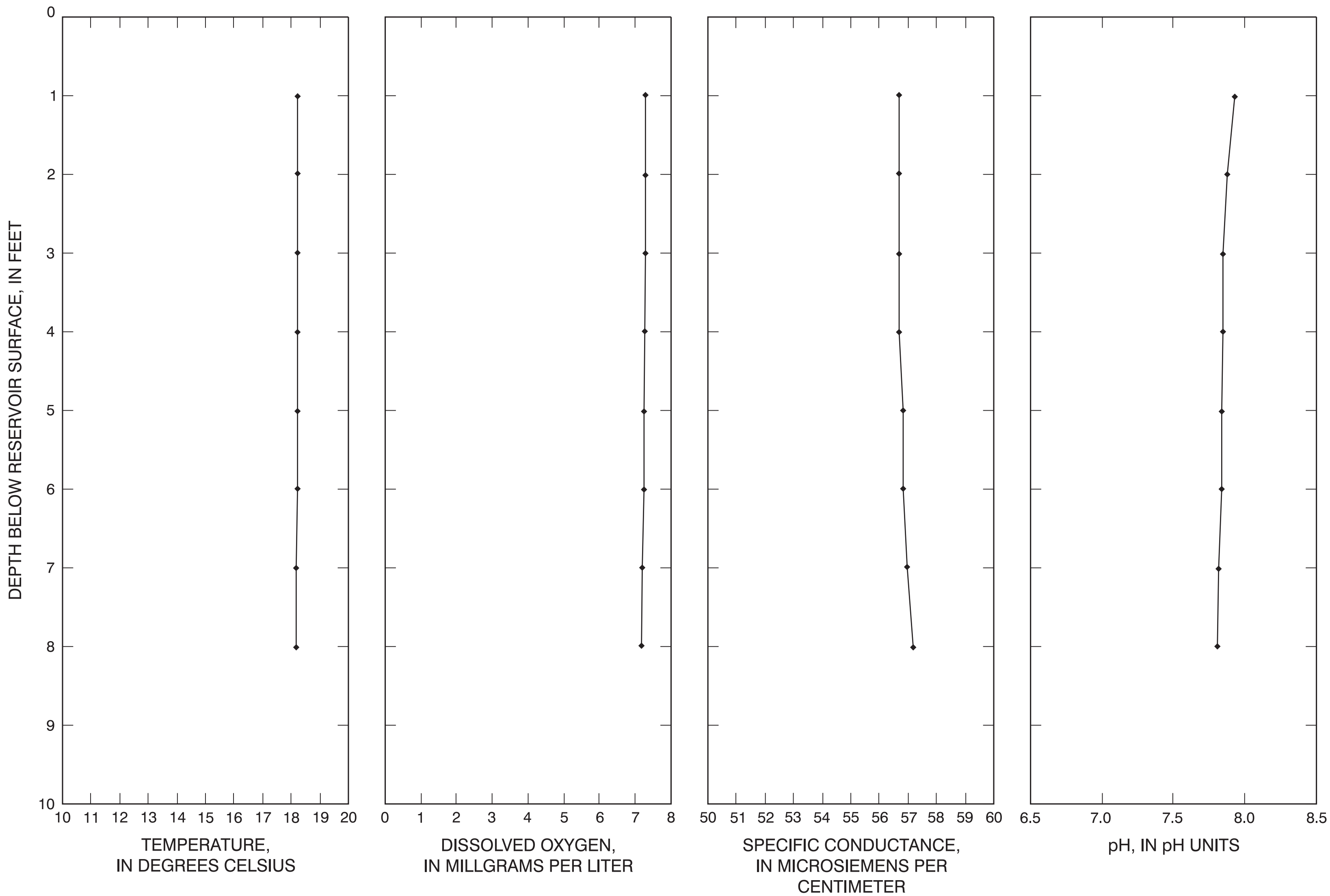

Figure L7-23-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on July 23, 1998, Lake Owen, Albany County, Wyoming.

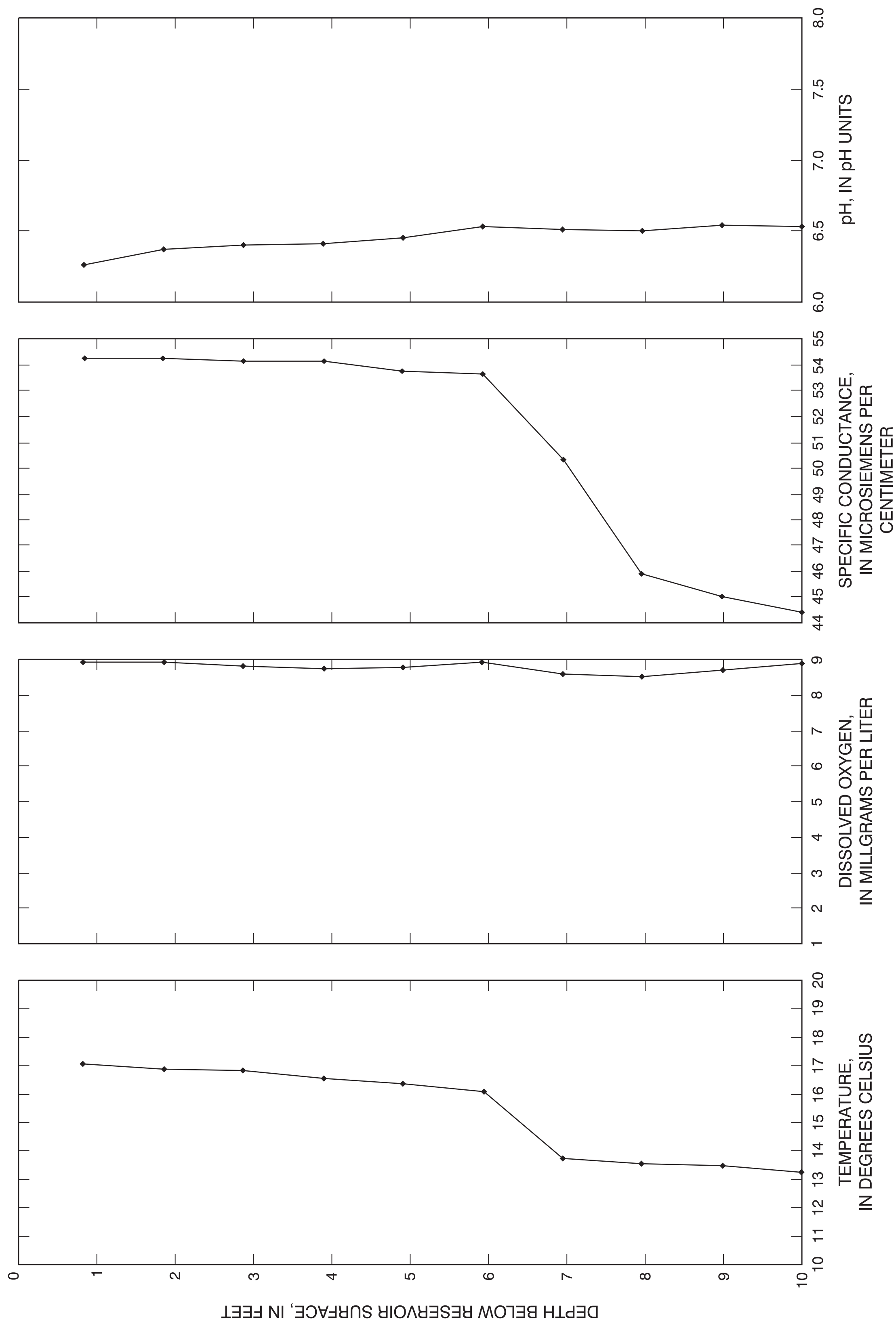

Figure L8-5-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on August 5, 1998, Lake Owen, Albany County, Wyoming.

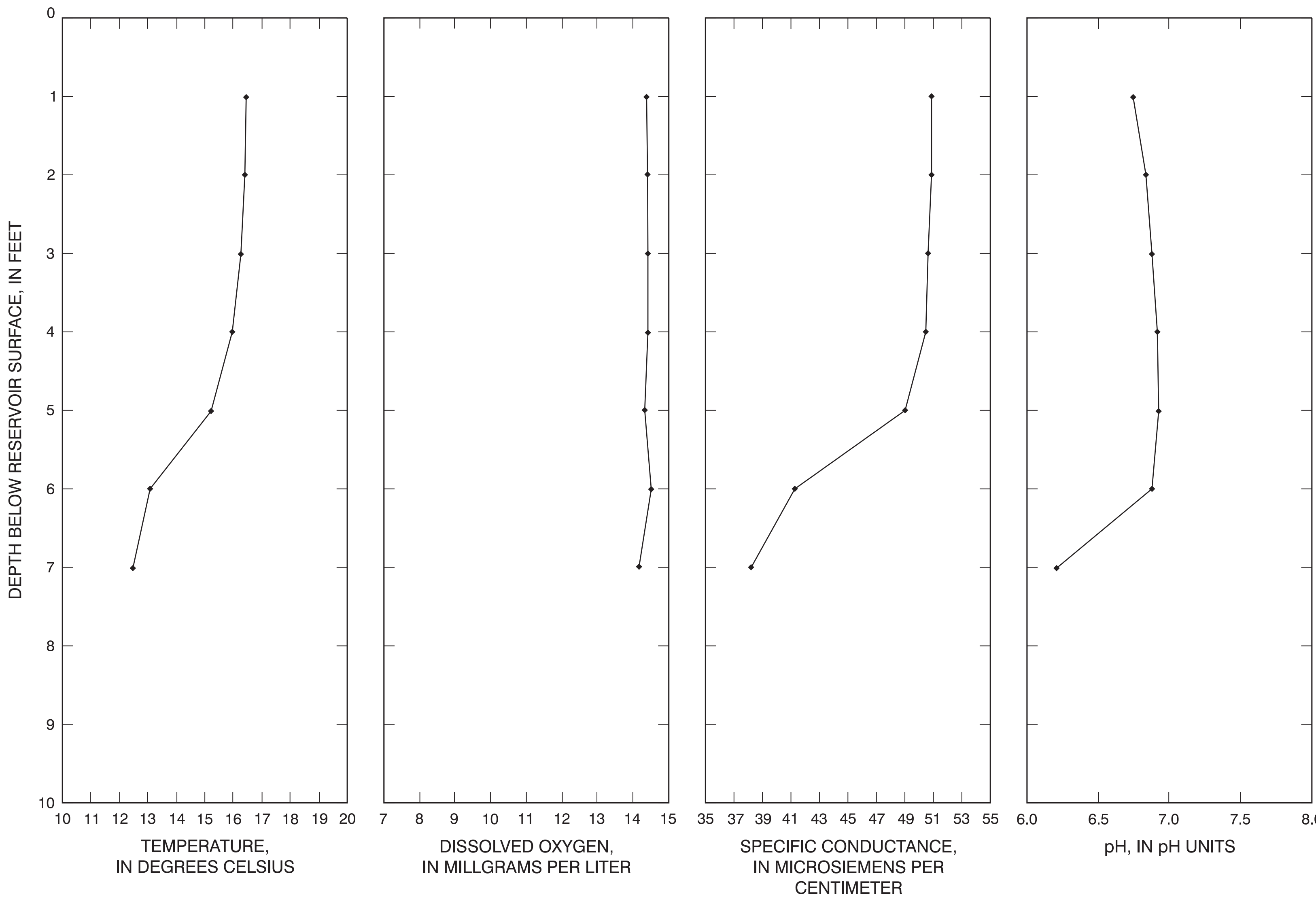

Figure L8-11-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on August 11, 1998, Lake Owen, Albany County, Wyoming.

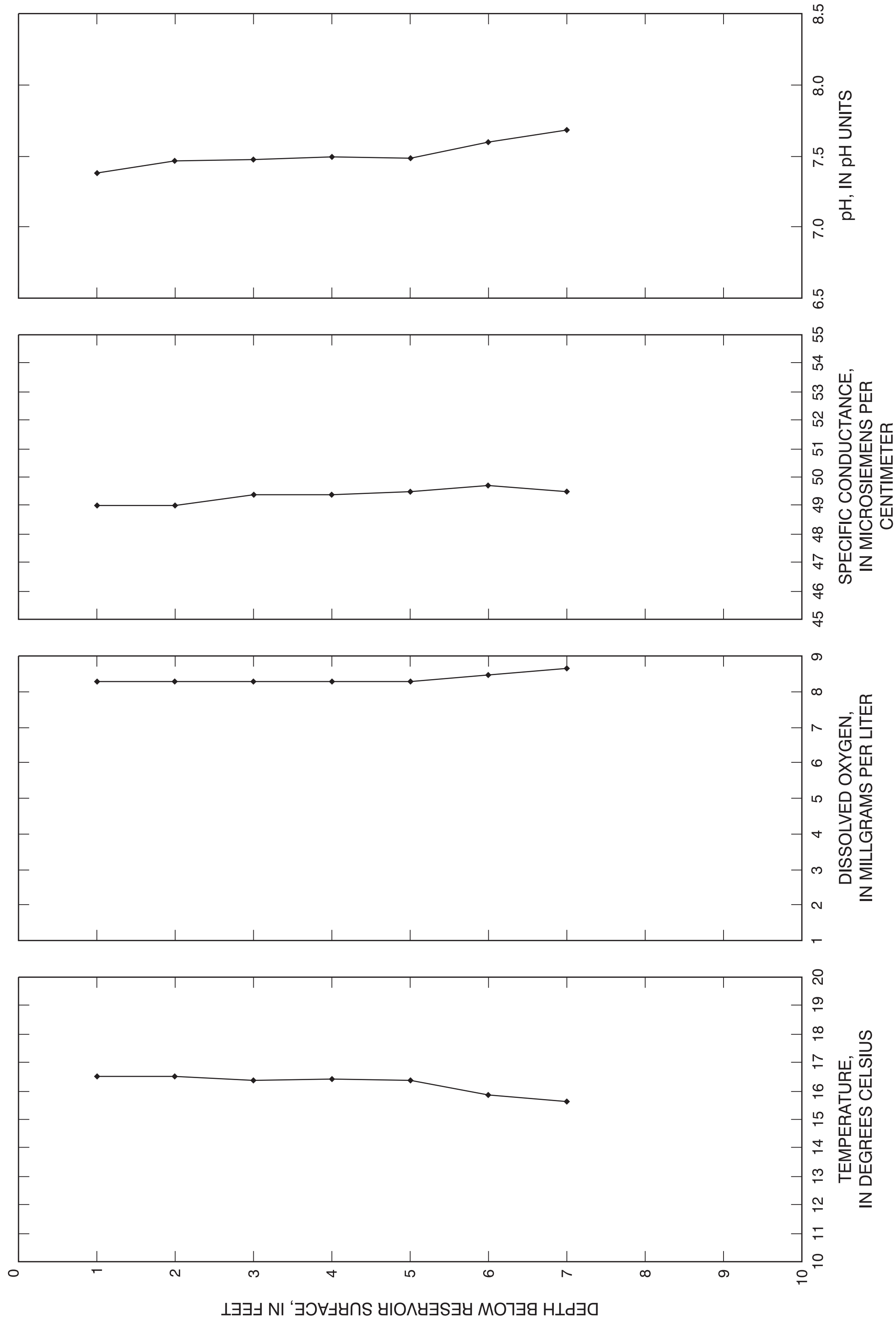

Figure L8-19-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on August 19, 1998, Lake Owen, Albany County, Wyoming.

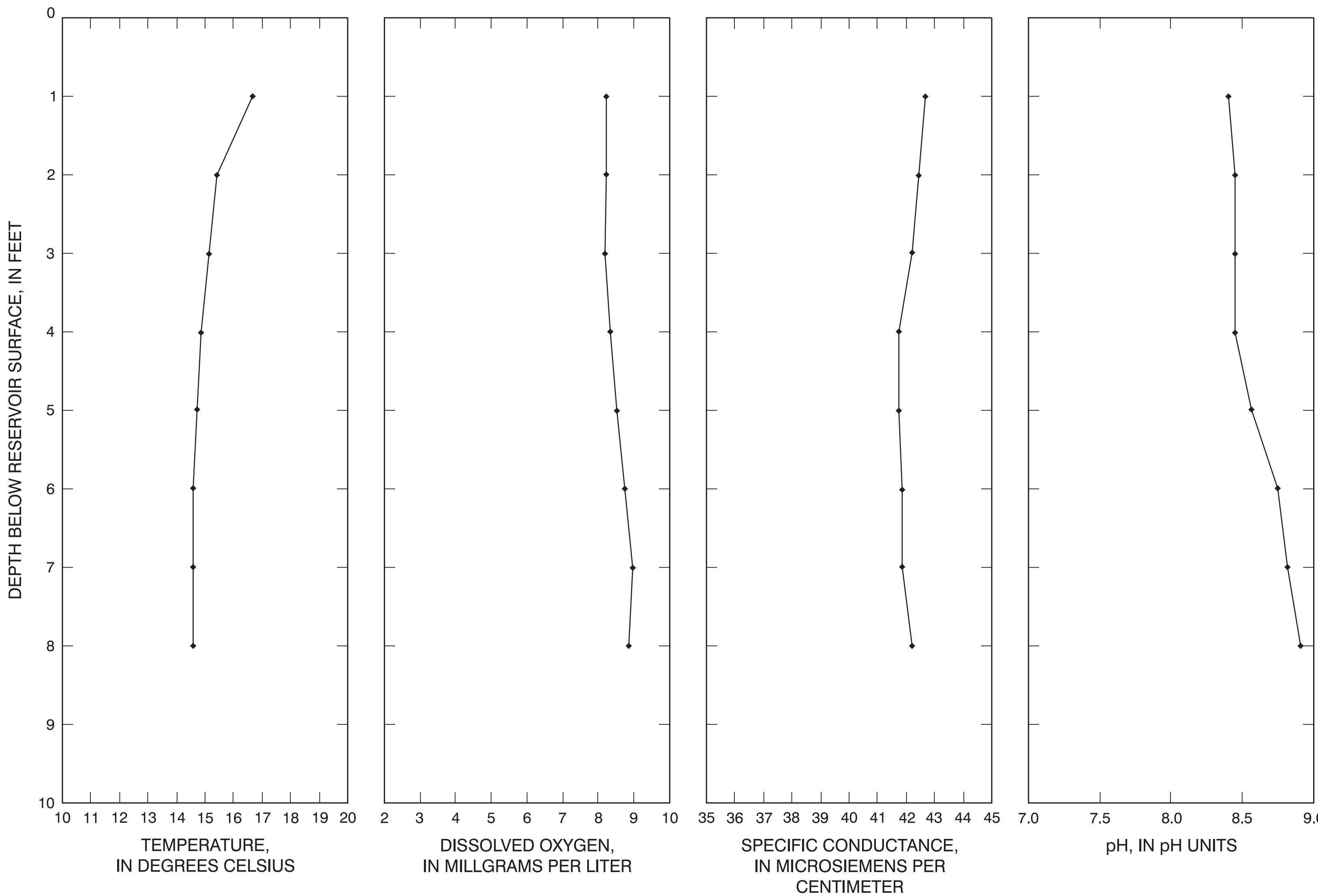

Figure L9-3-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 3, 1998, Lake Owen, Albany County, Wyoming.

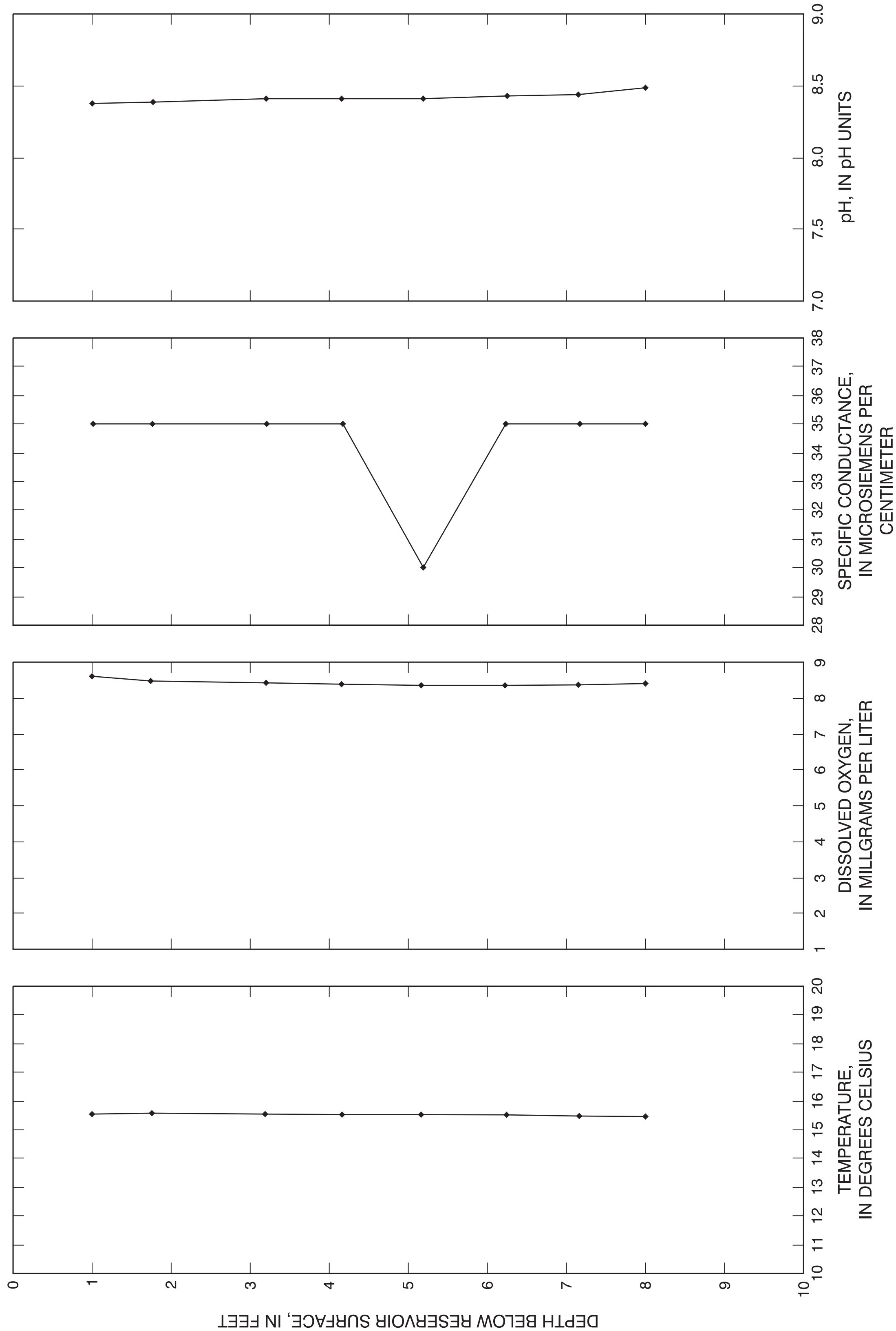

Figure L9-10-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 10, 1998, Lake Owen, Albany County, Wyoming.

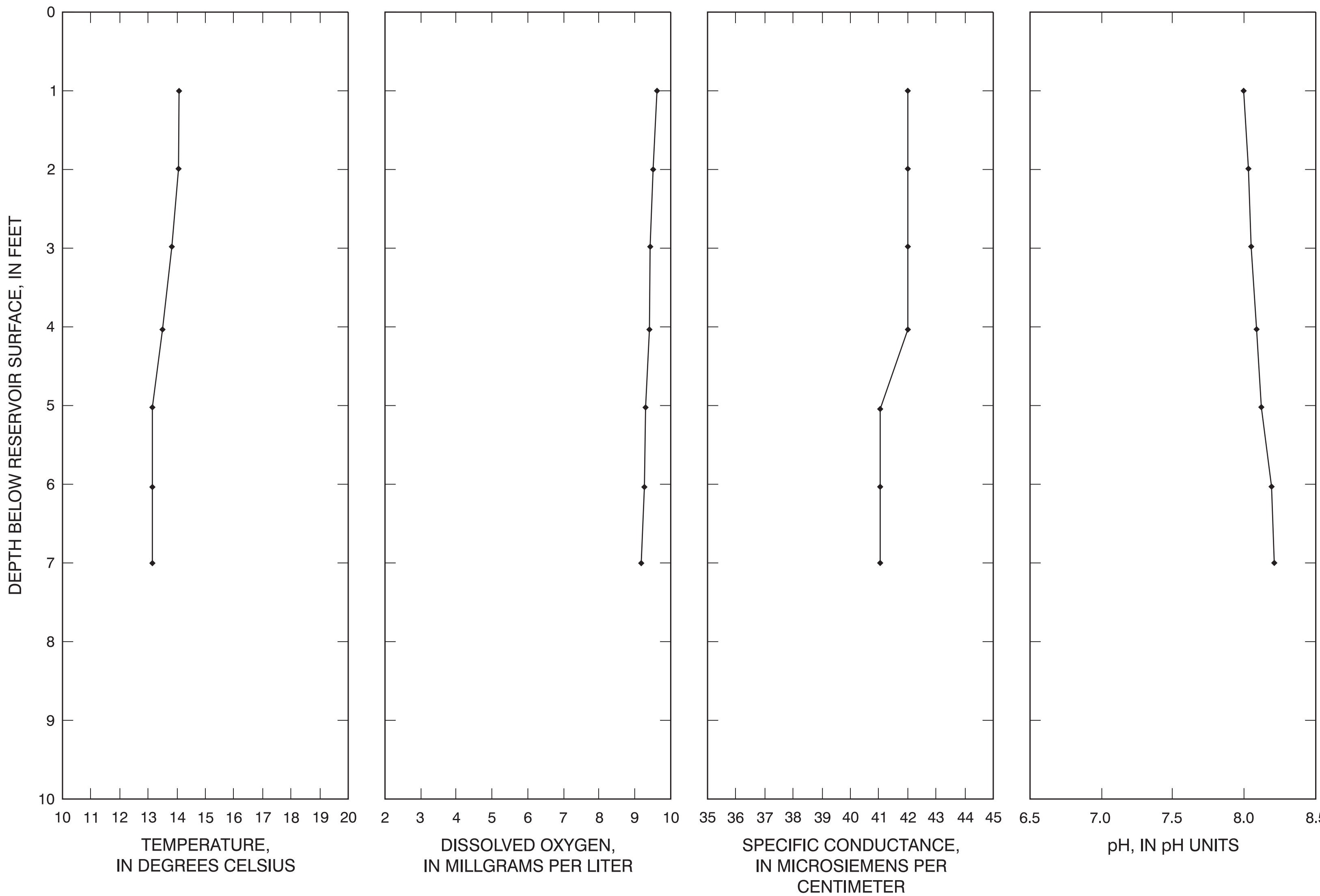

Figure L9-17-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 17, 1998, Lake Owen, Albany County, Wyoming.

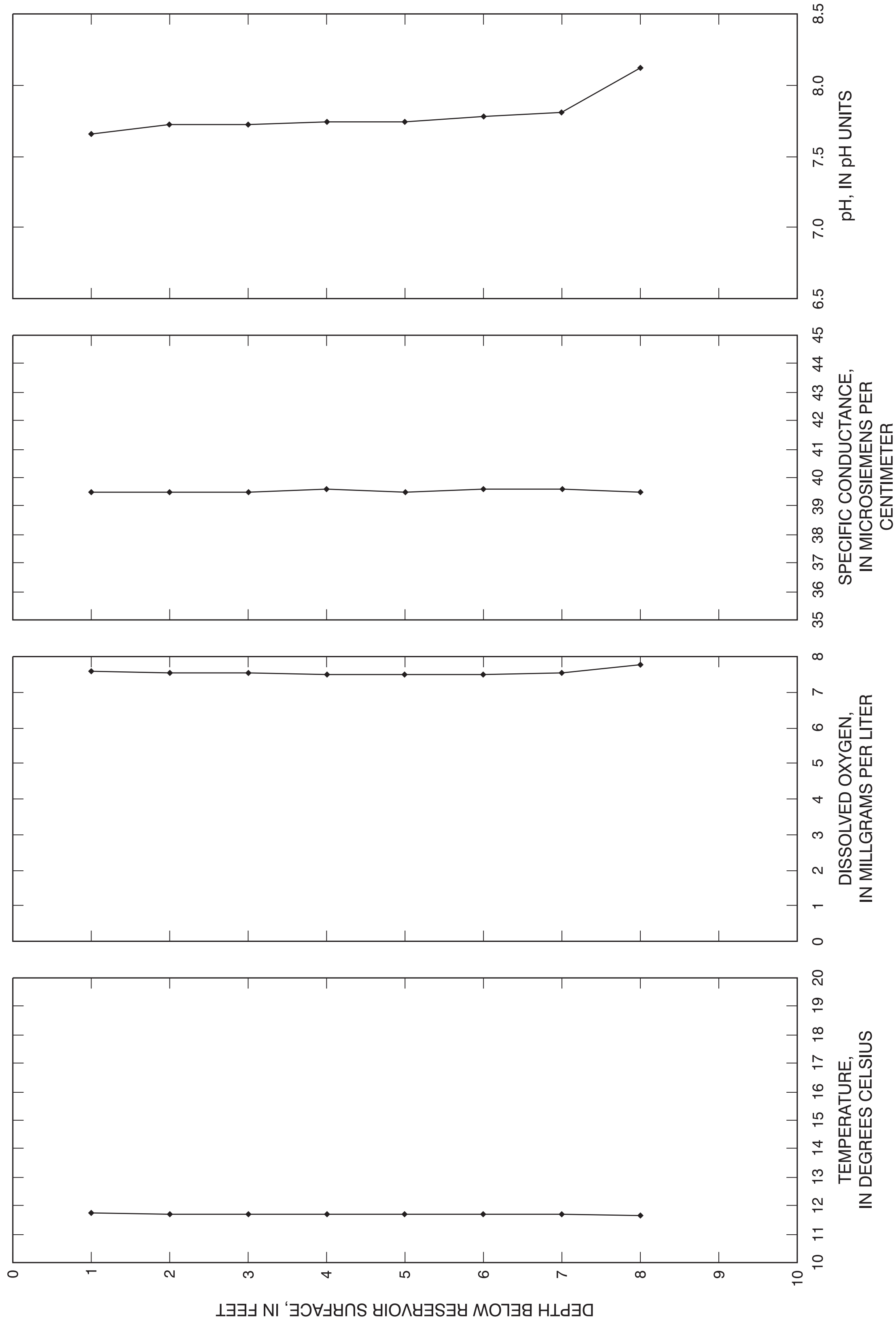

Figure L9-22-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on September 22, 1998, Lake Owen, Albany County, Wyoming.

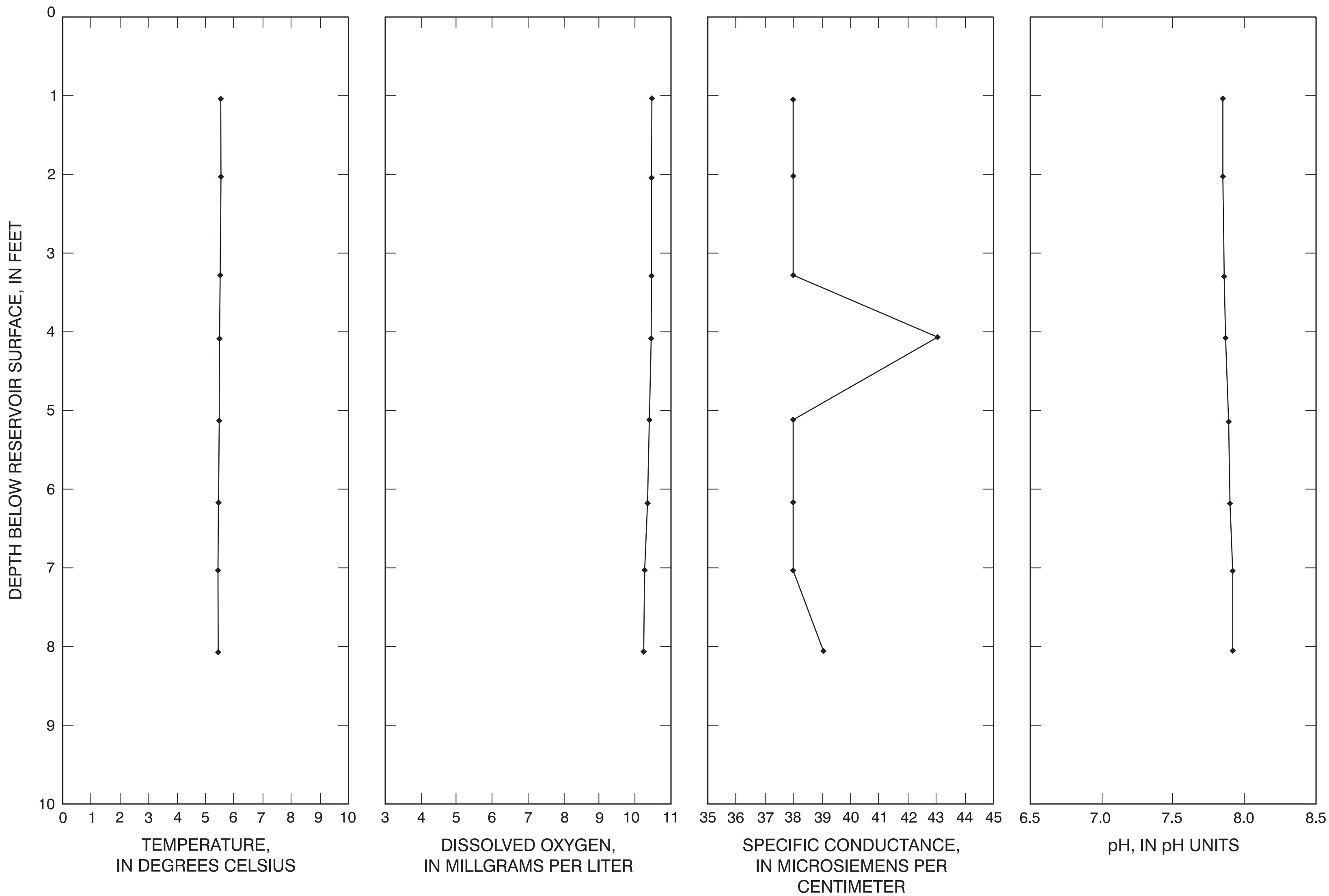

Figure L10-8-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on October 8, 1998, Lake Owen, Albany County, Wyoming.

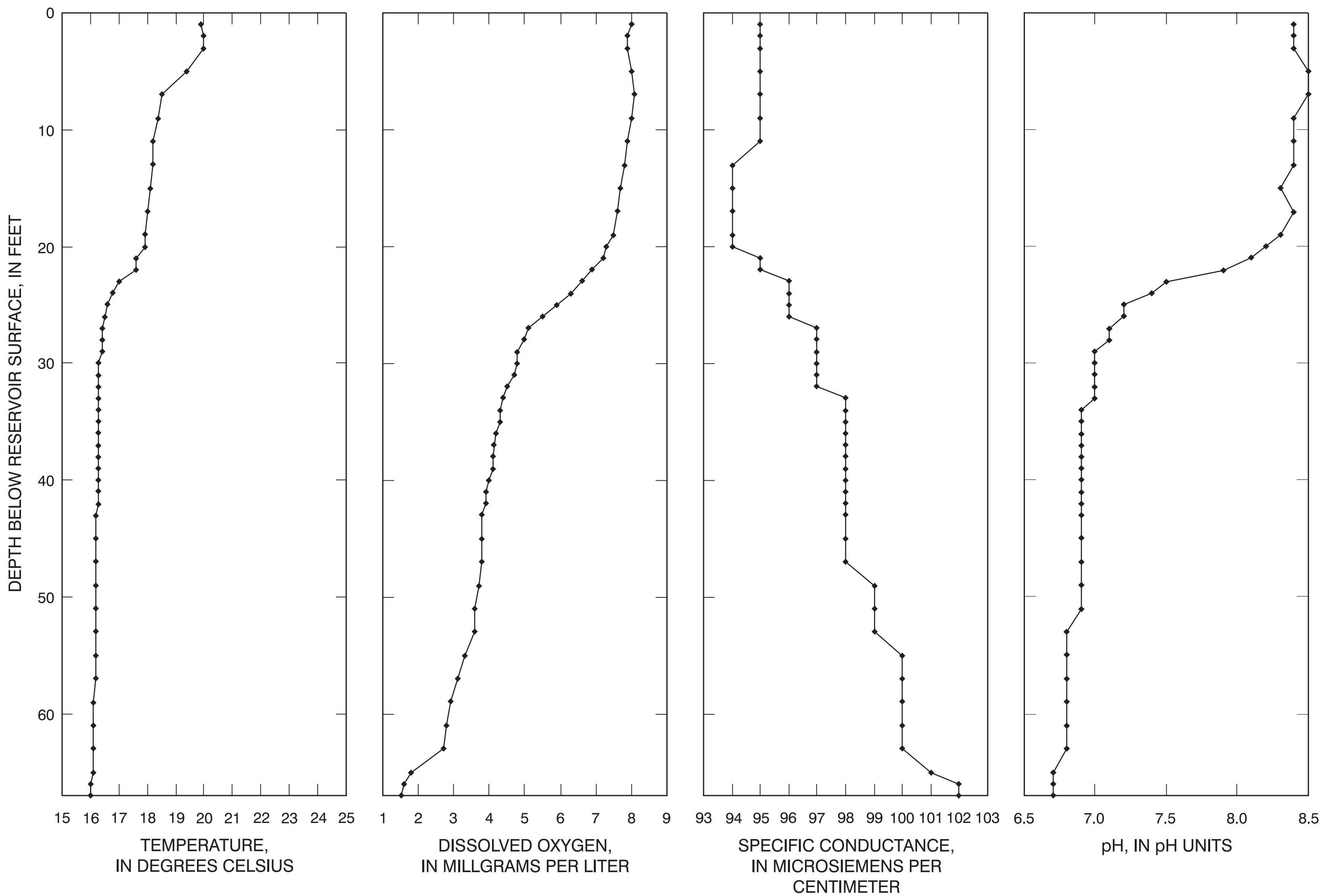

Figure G8-28-97. Temperature, dissolved oxygen, specific conductance and pH profiles on August 28, 1997, Granite Springs Reservoir, Laramie County, Wyoming.

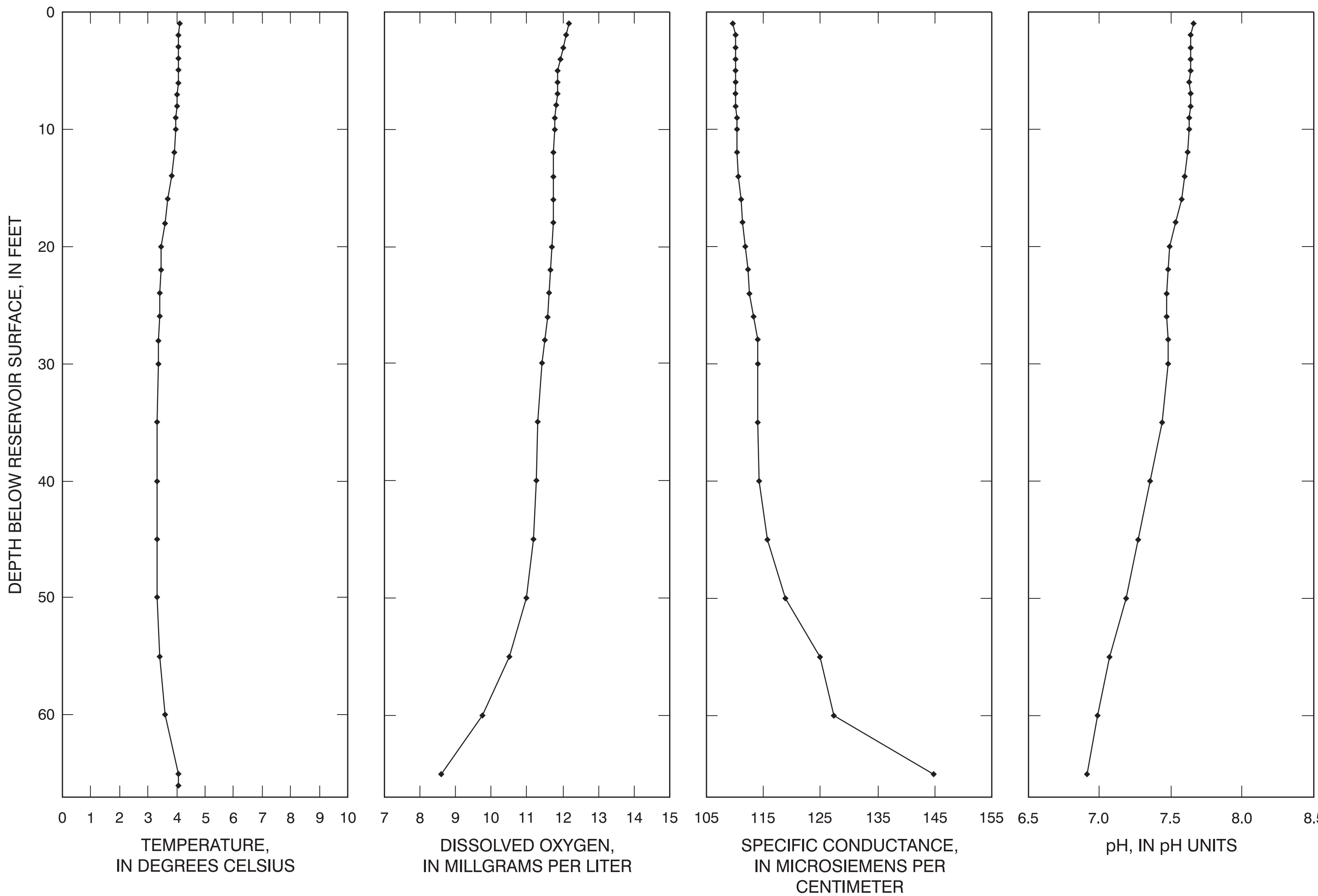

Figure G2-5-98. Temperature, dissolved oxygen, specific conductance and pH profiles on February 5, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

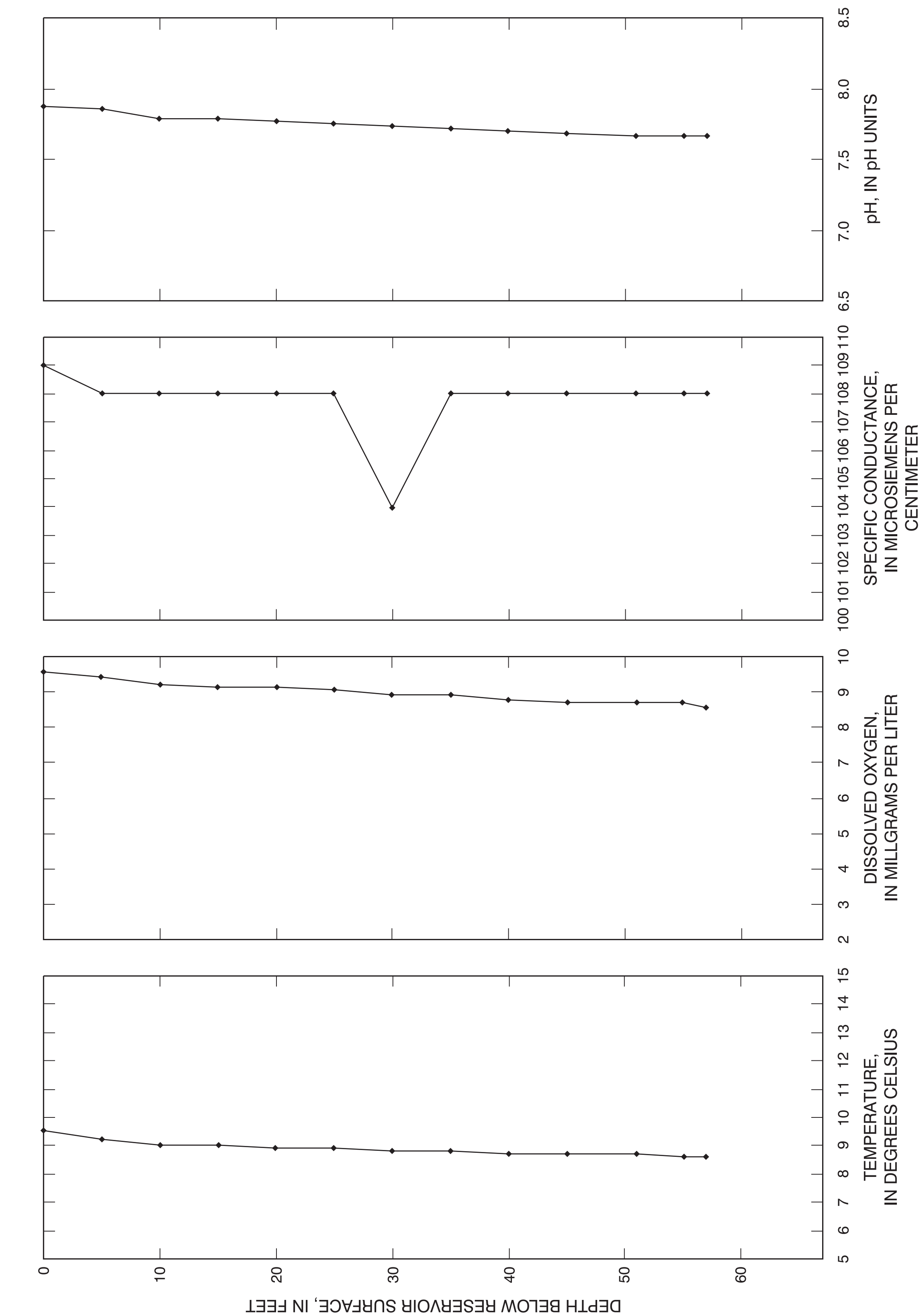

Figure G5-12-98. Temperature, dissolved oxygen, specific conductance and pH profiles on May 12, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

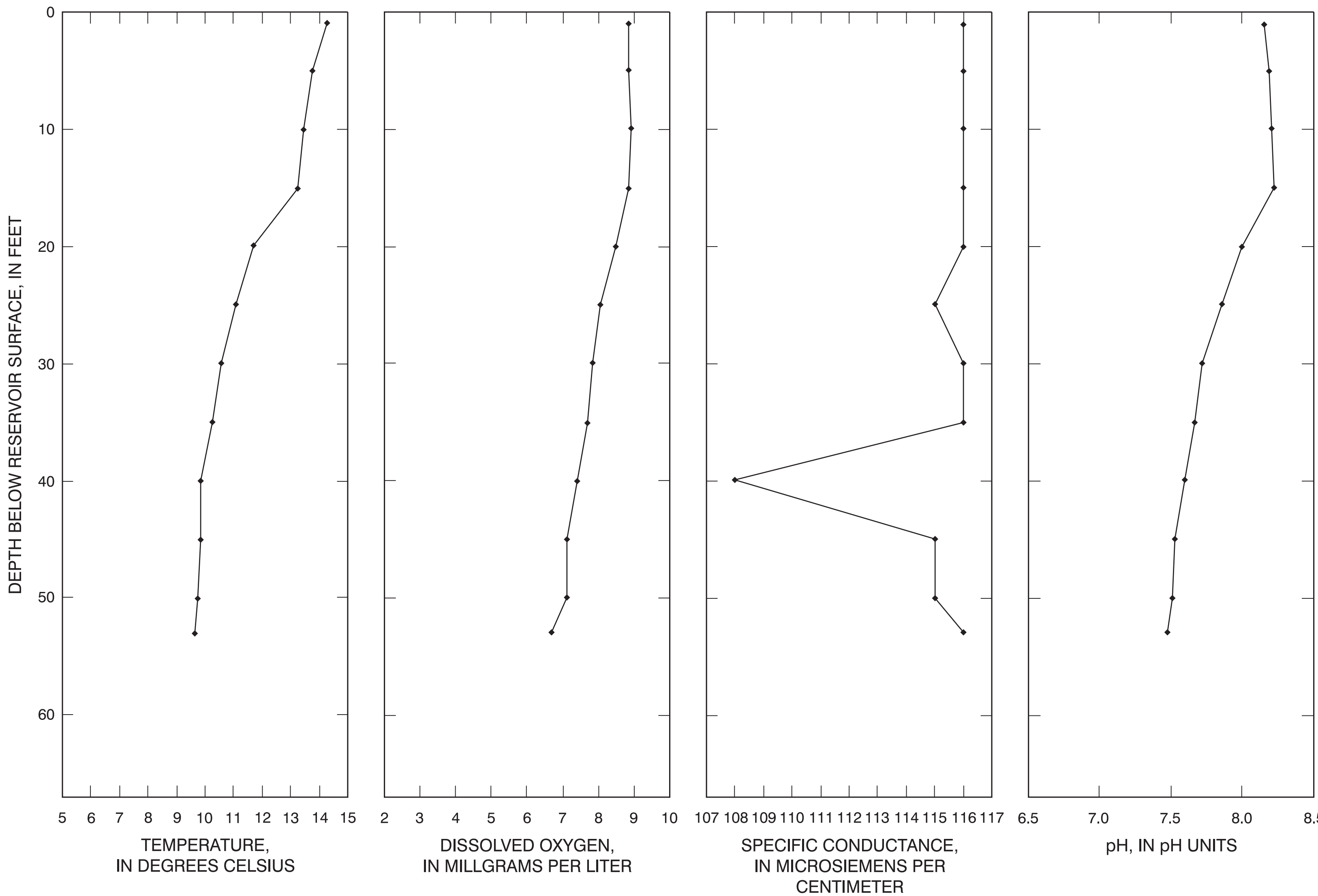

Figure G5-27-98. Temperature, dissolved oxygen, specific conductance and pH profiles on May 27, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

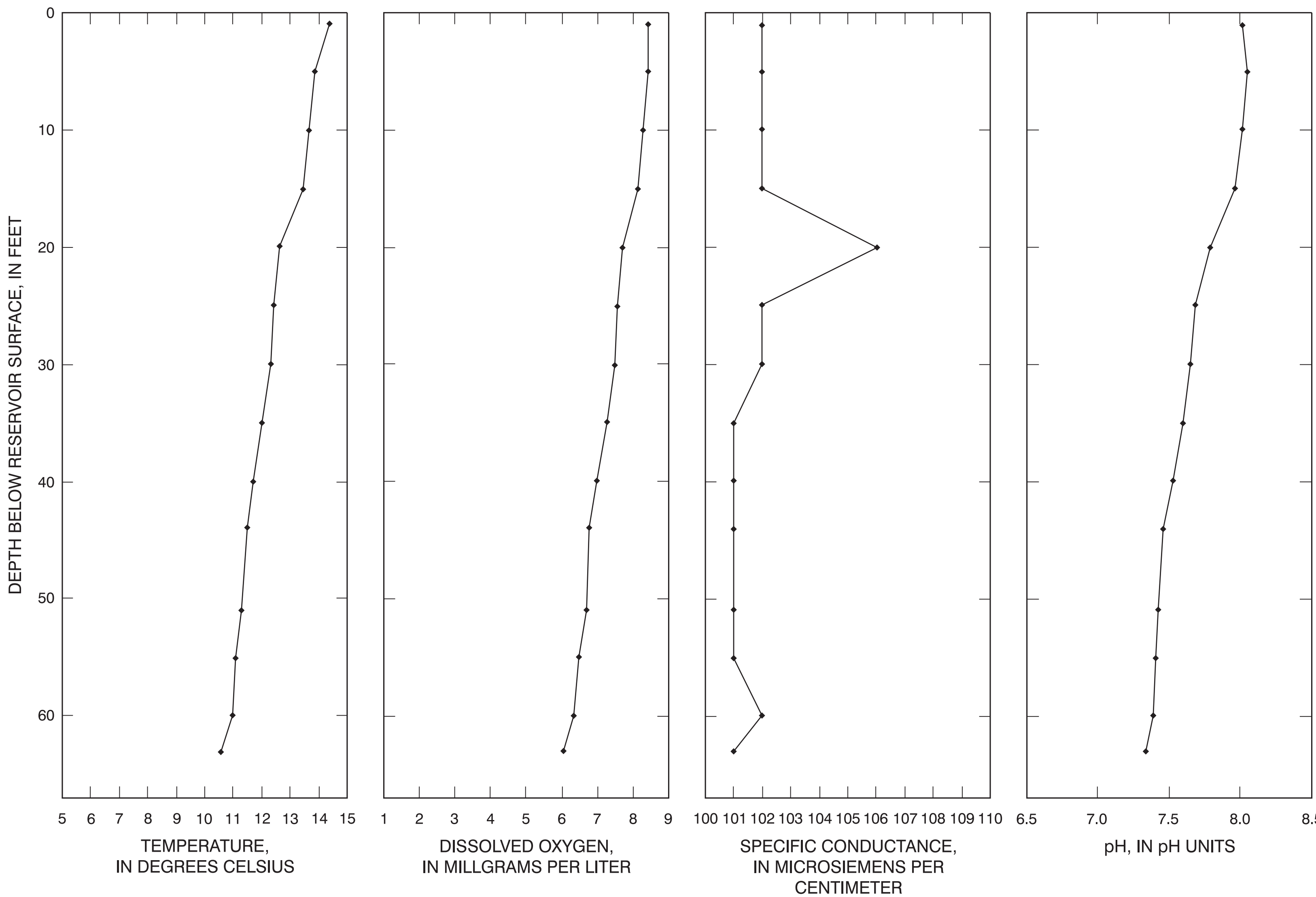

Figure G6-2-98. Temperature, dissolved oxygen, specific conductance and pH profiles on June 2, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

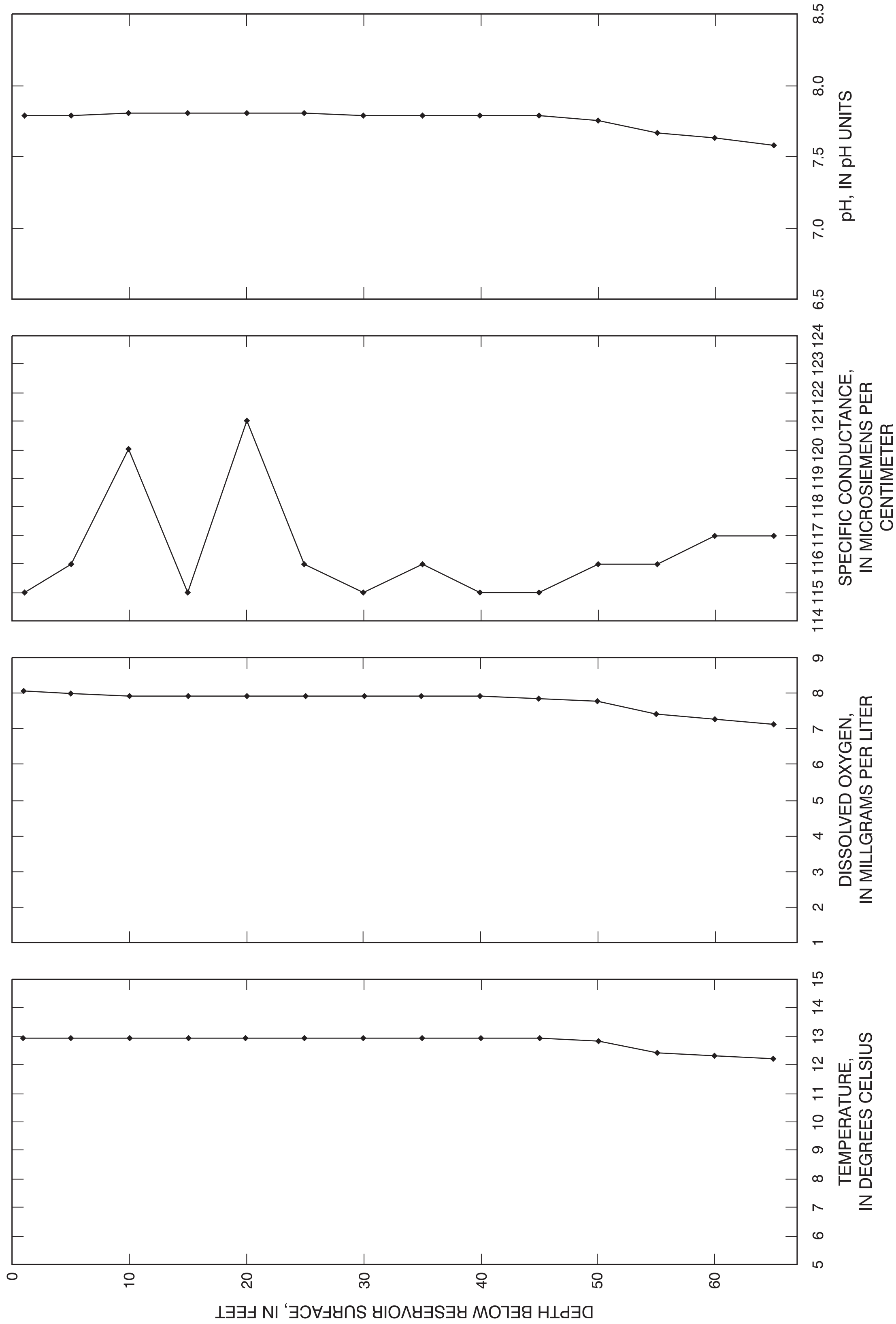

Figure G6-16-98. Temperature, dissolved oxygen, specific conductance and pH profiles on June 16, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

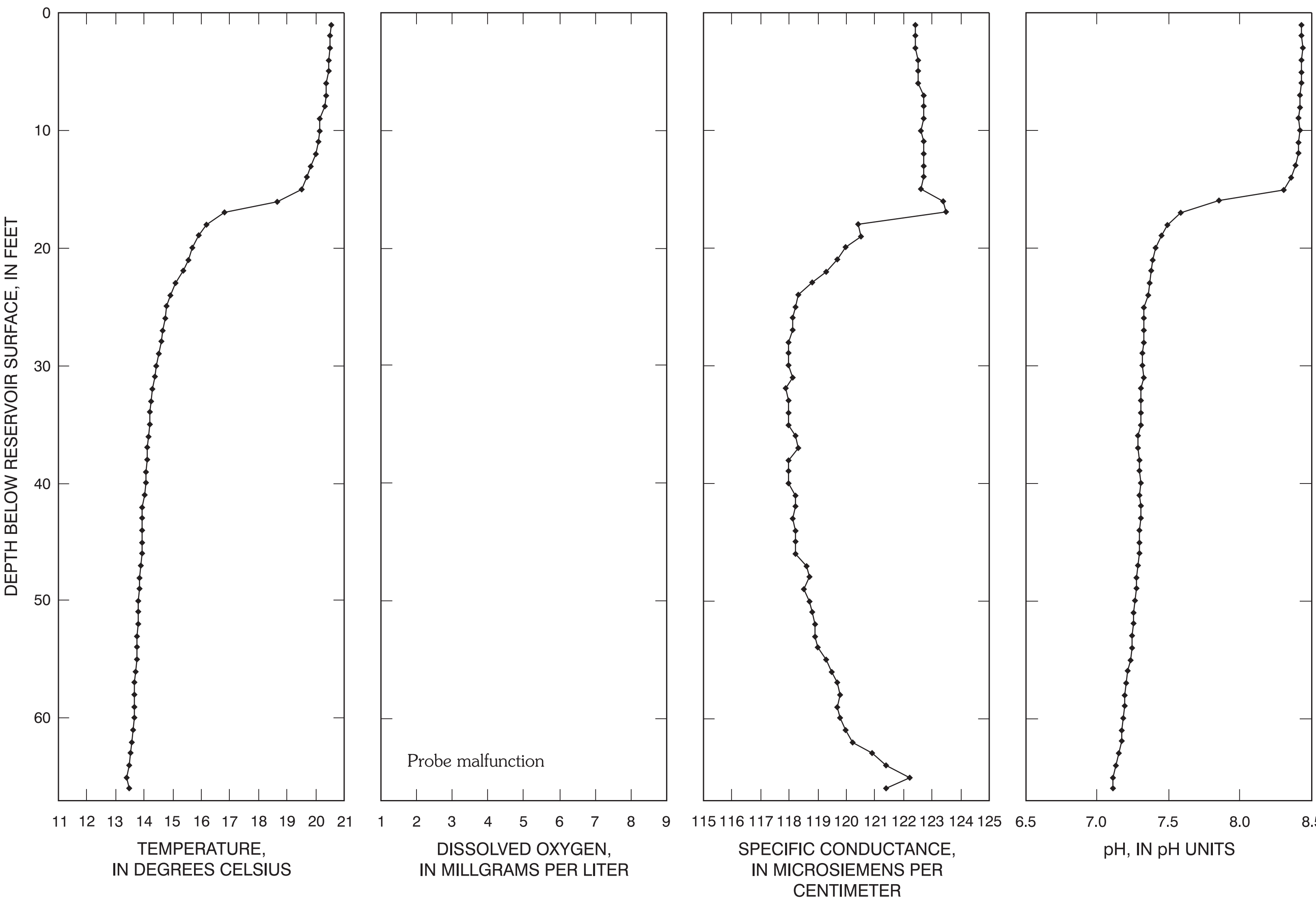

Figure G7-14-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 14, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

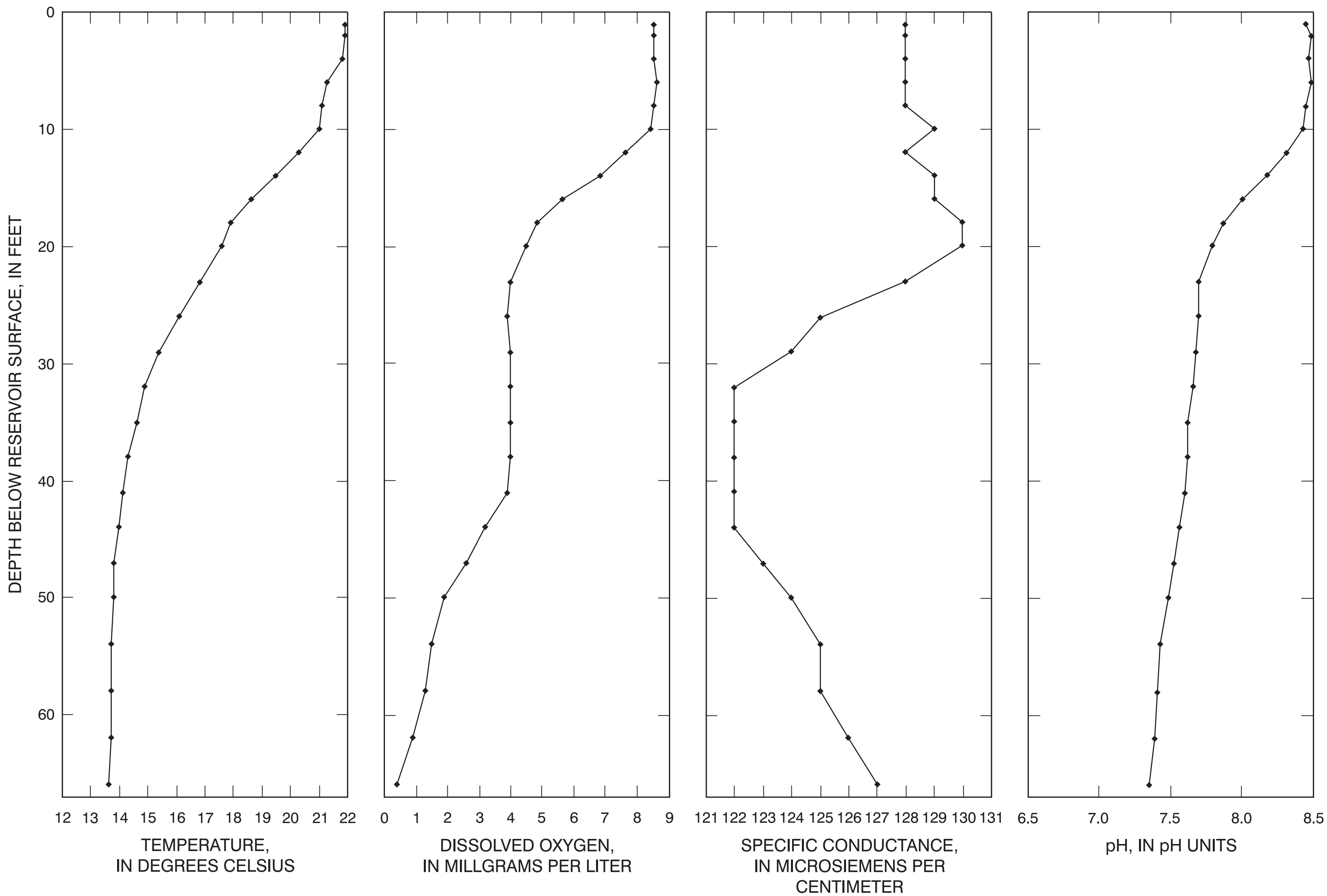

Figure G7-21-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 21, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

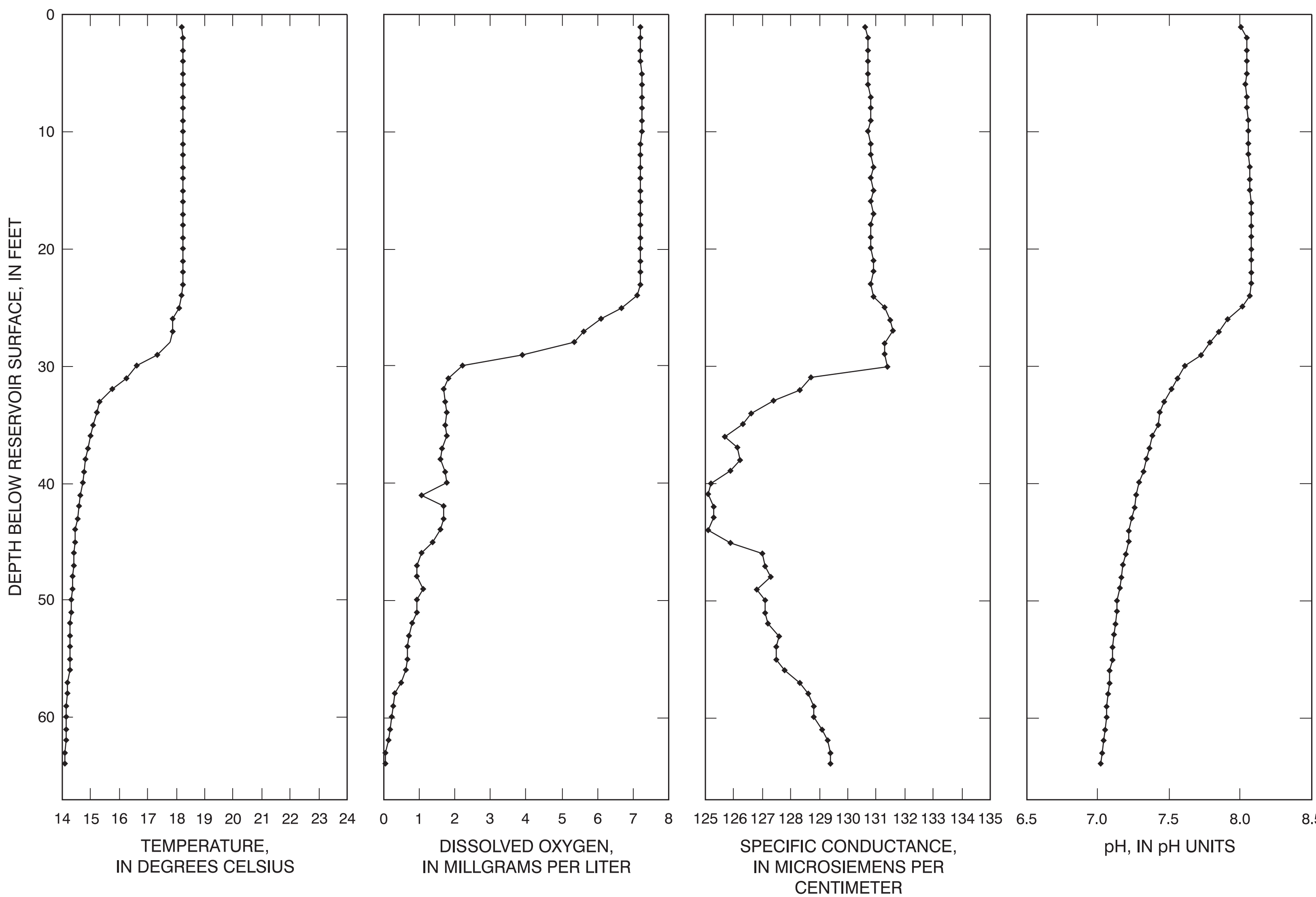

Figure G8-4-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 4, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

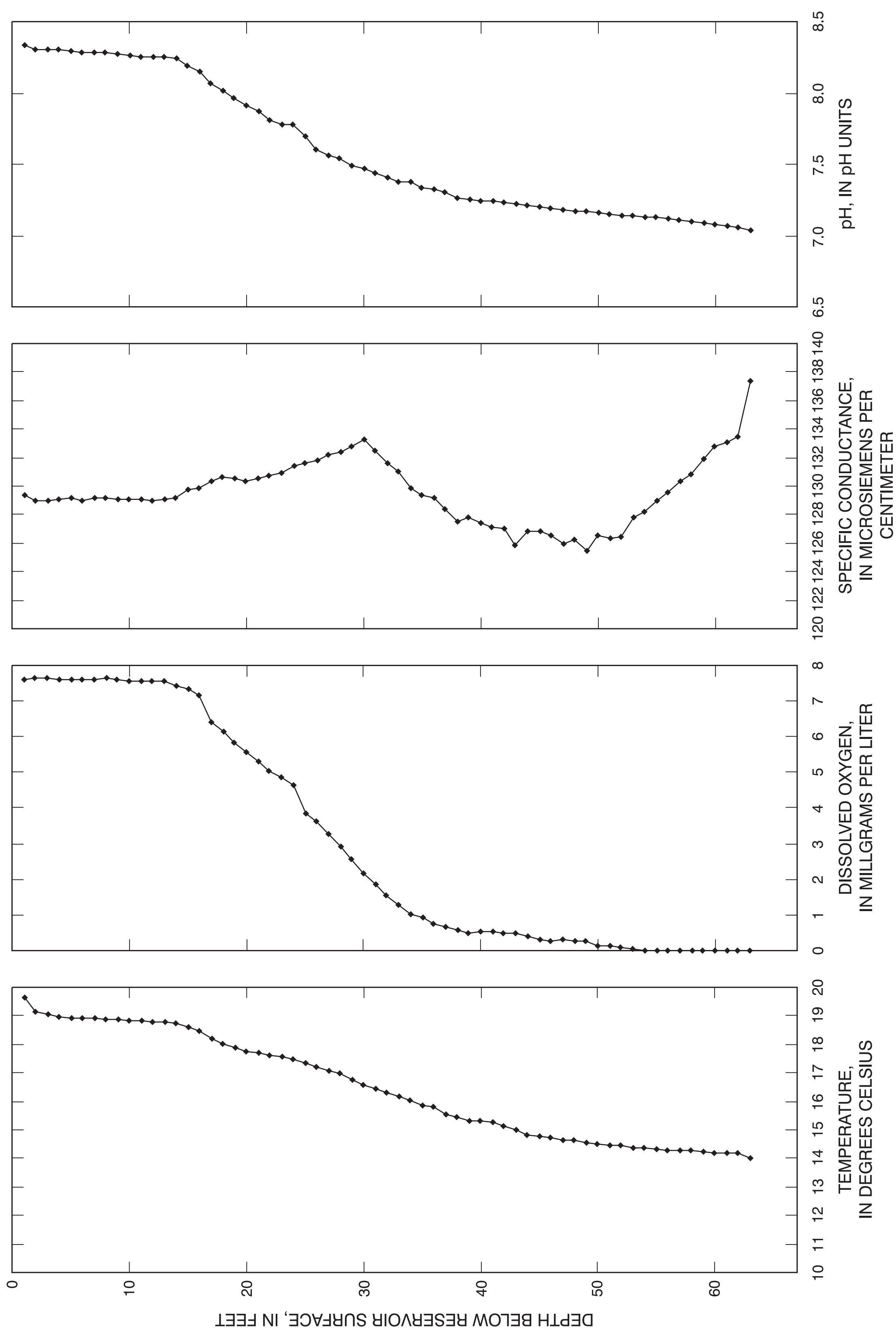

Figure G8-10-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 10, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

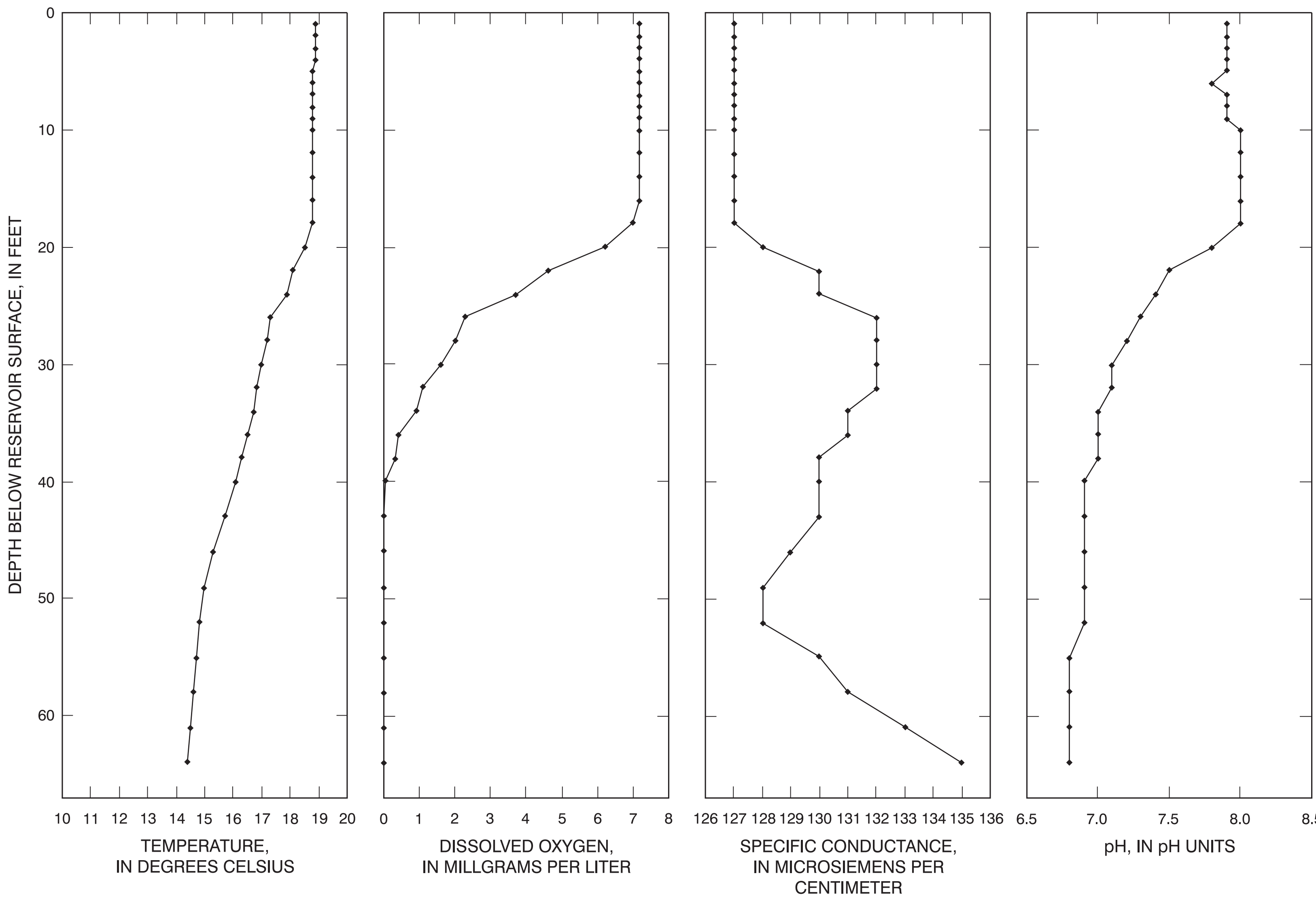

Figure G8-18-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 18, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

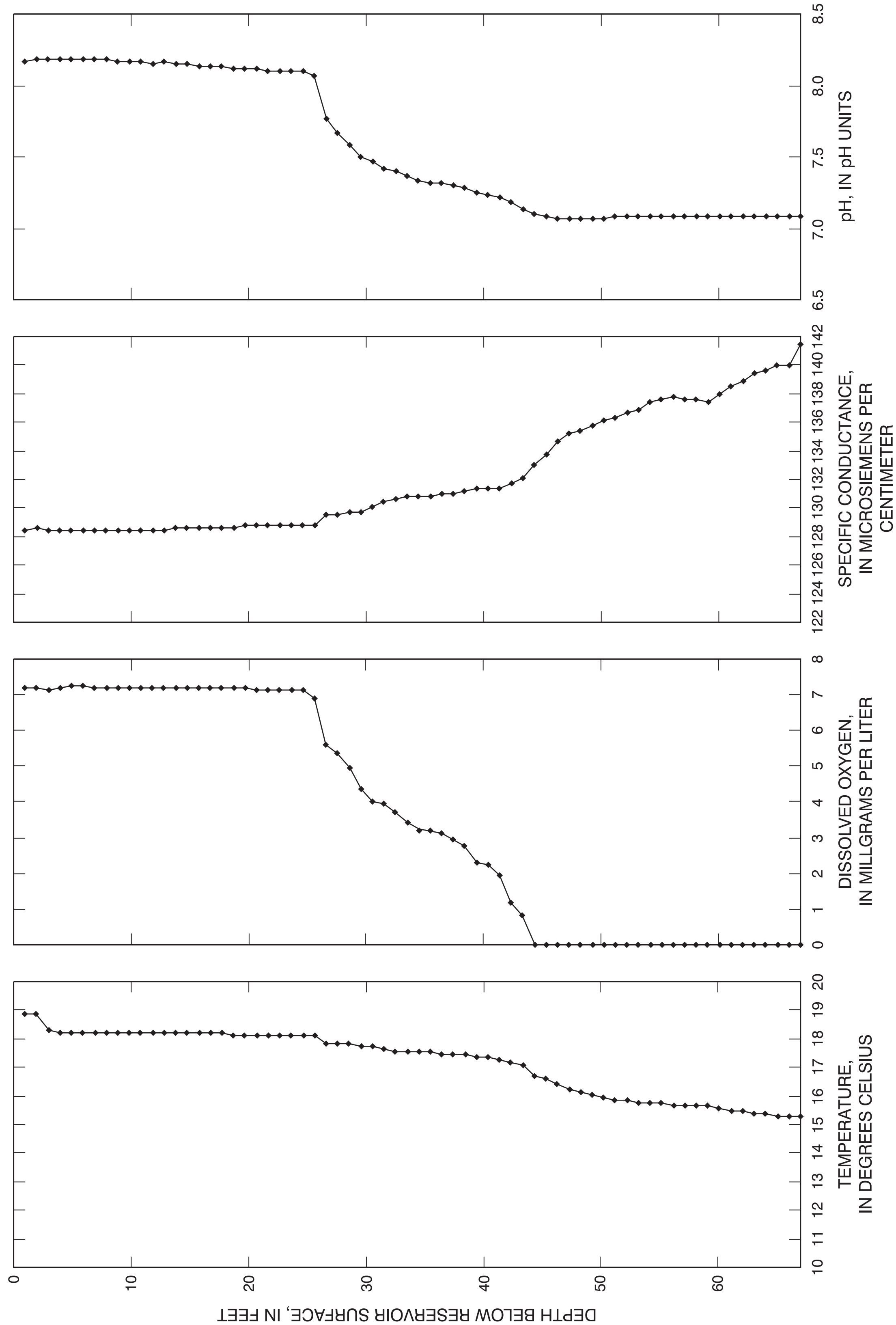

Figure G9-1-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 1, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

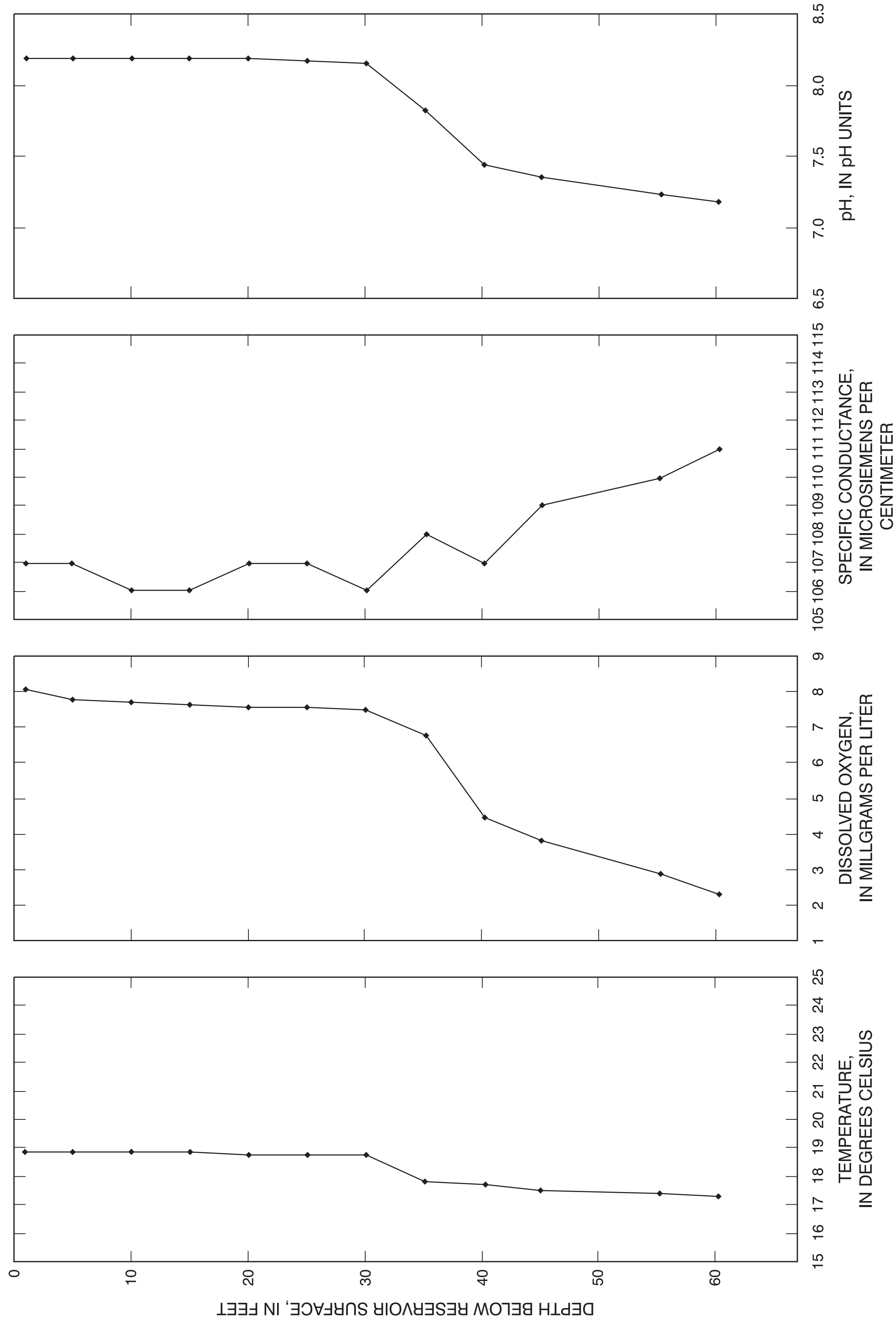

Figure G9-9-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 9, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

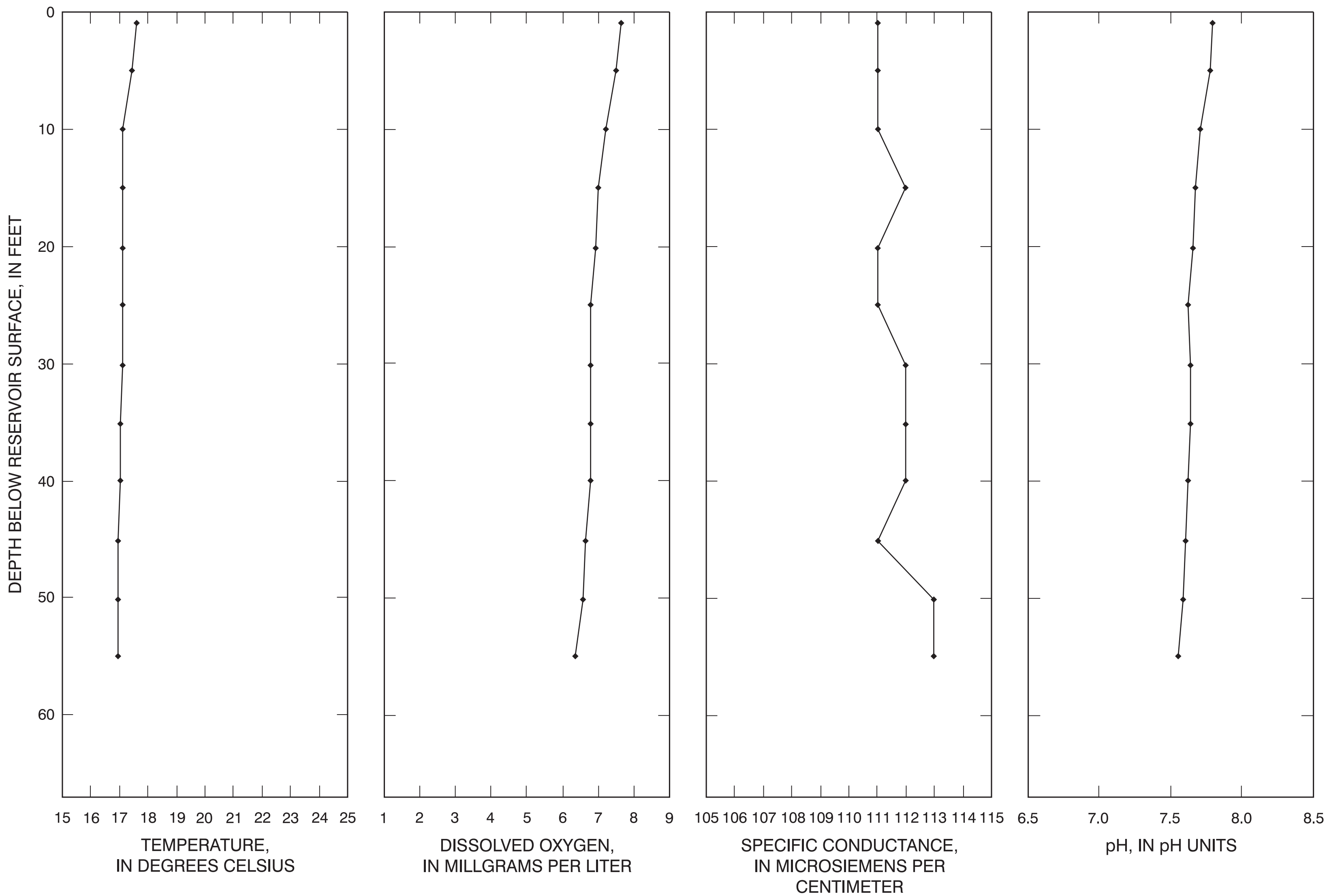

Figure G9-15-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 15, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

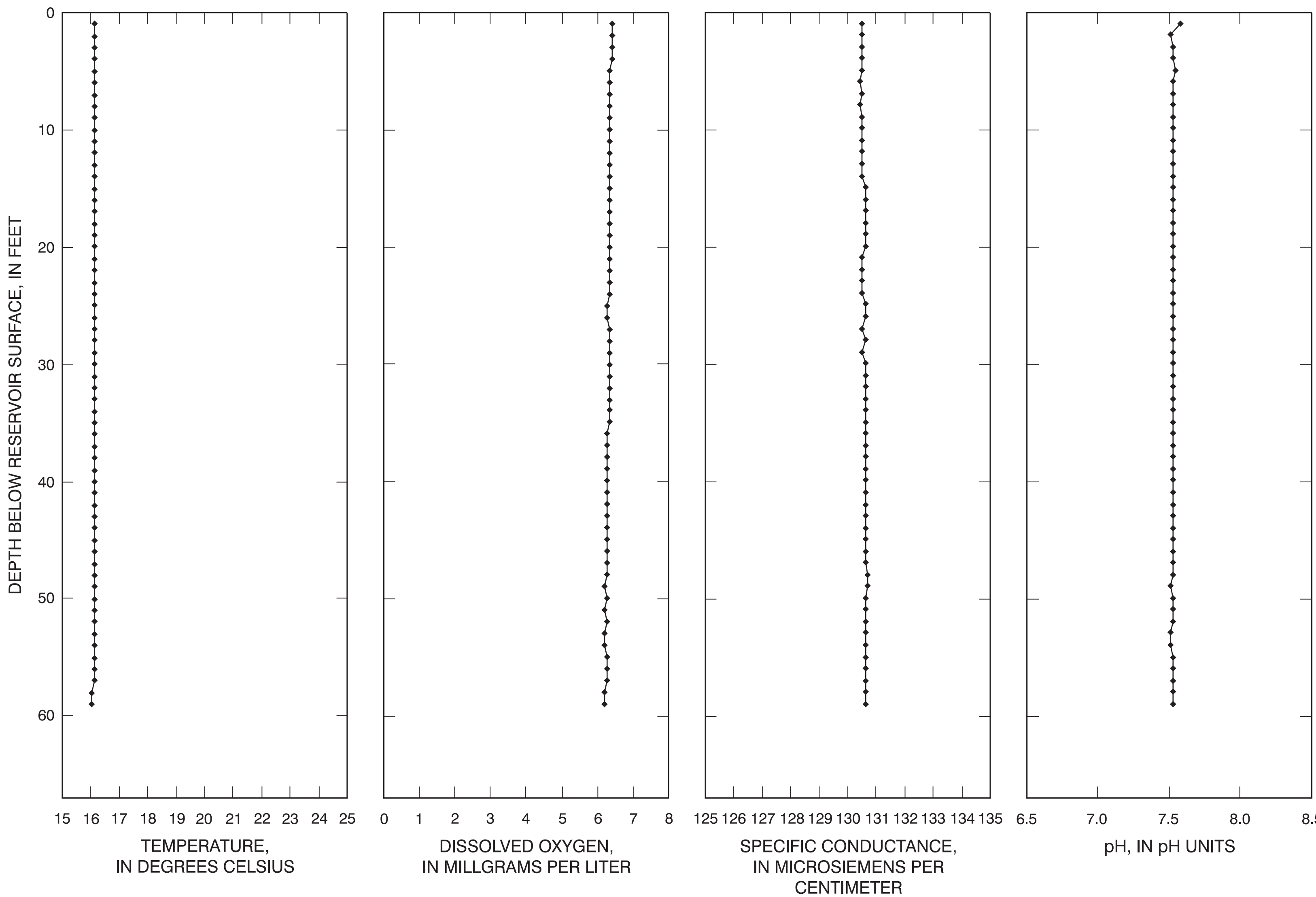

Figure G9-21-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 21, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

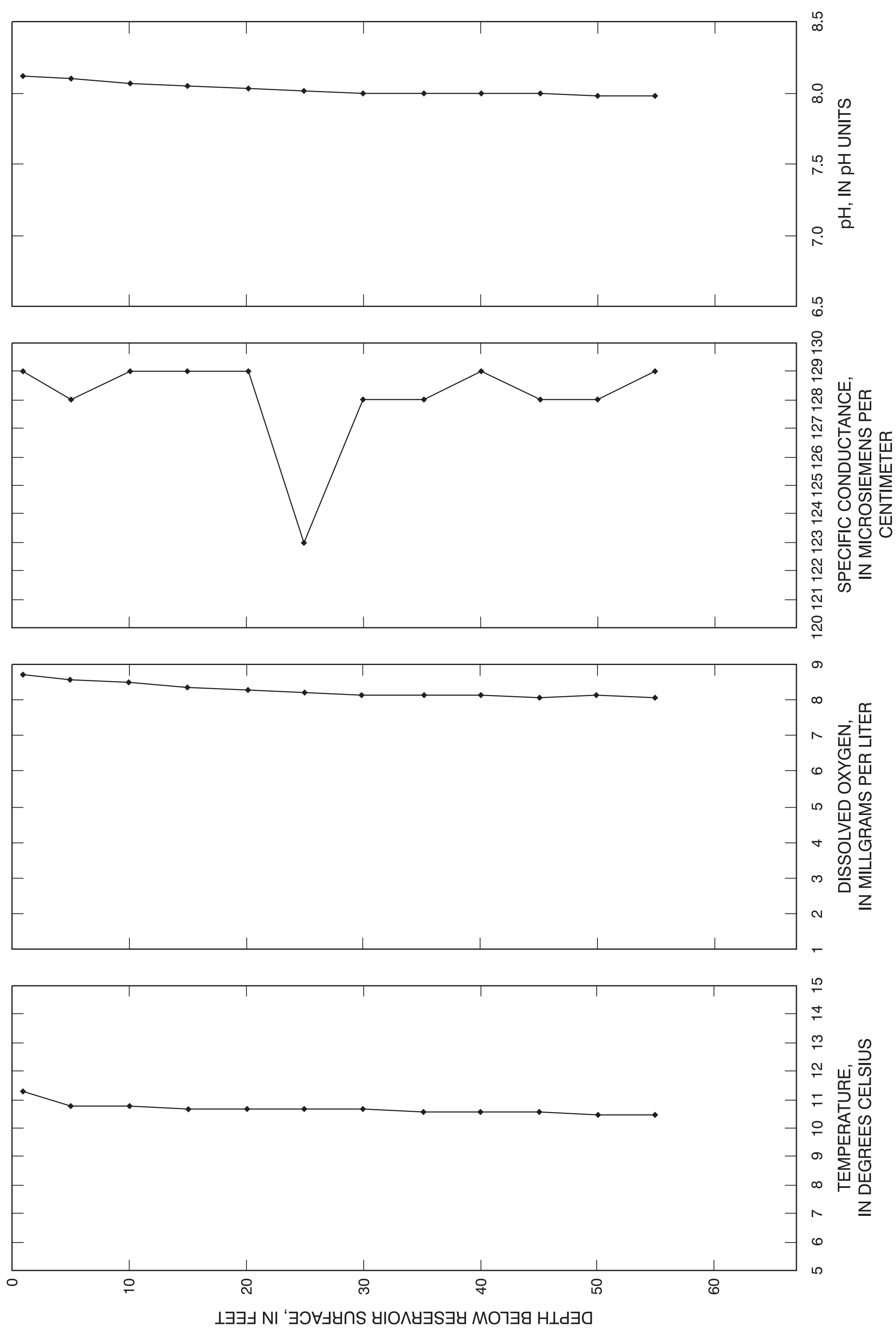

Figure G10-7-98. Temperature, dissolved oxygen, specific conductance and pH profiles on October 7, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

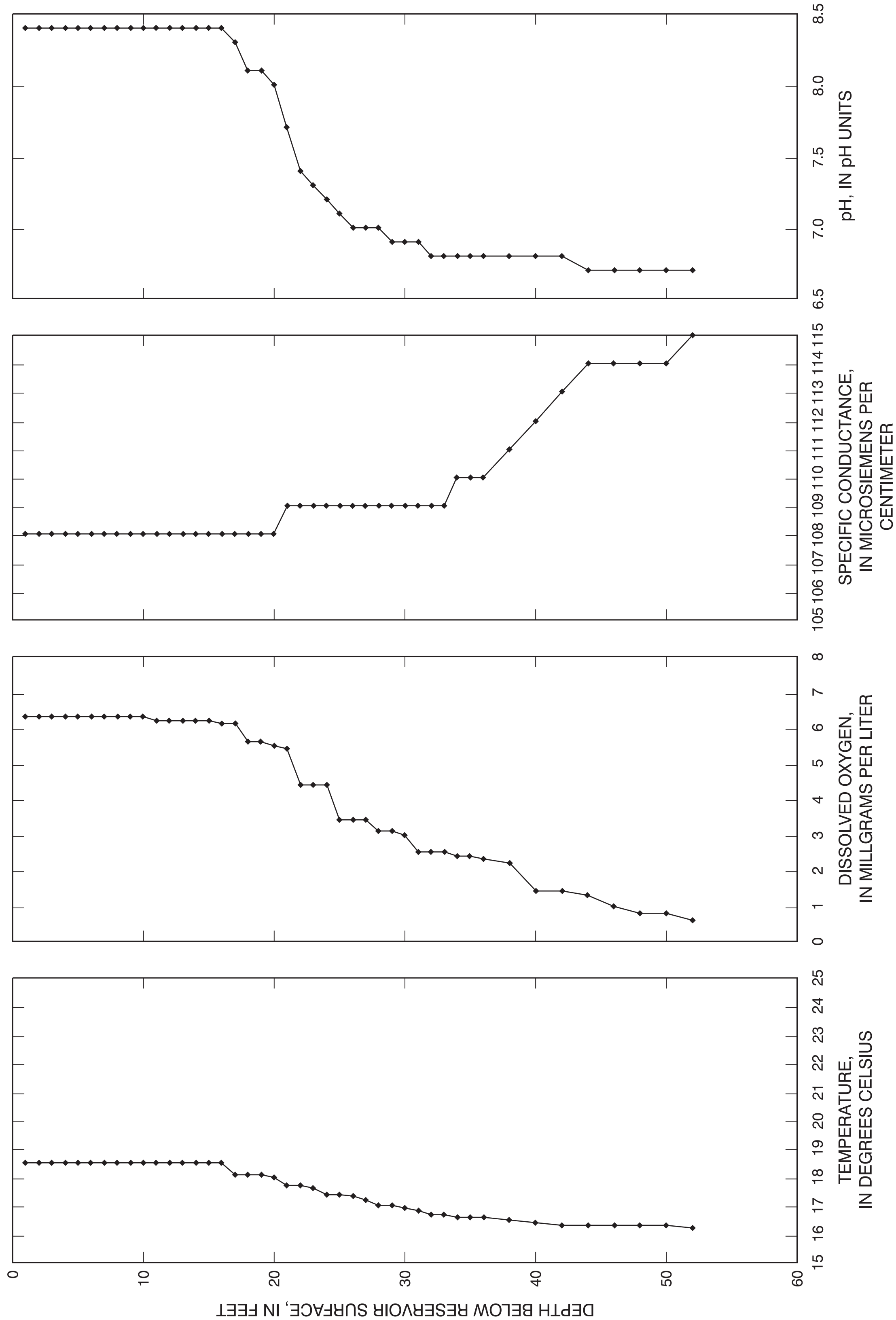

Figure C9-4-97. Temperature, dissolved oxygen, specific conductance and pH profiles on September 4, 1997, Crystal Lake Reservoir, Laramie County, Wyoming.

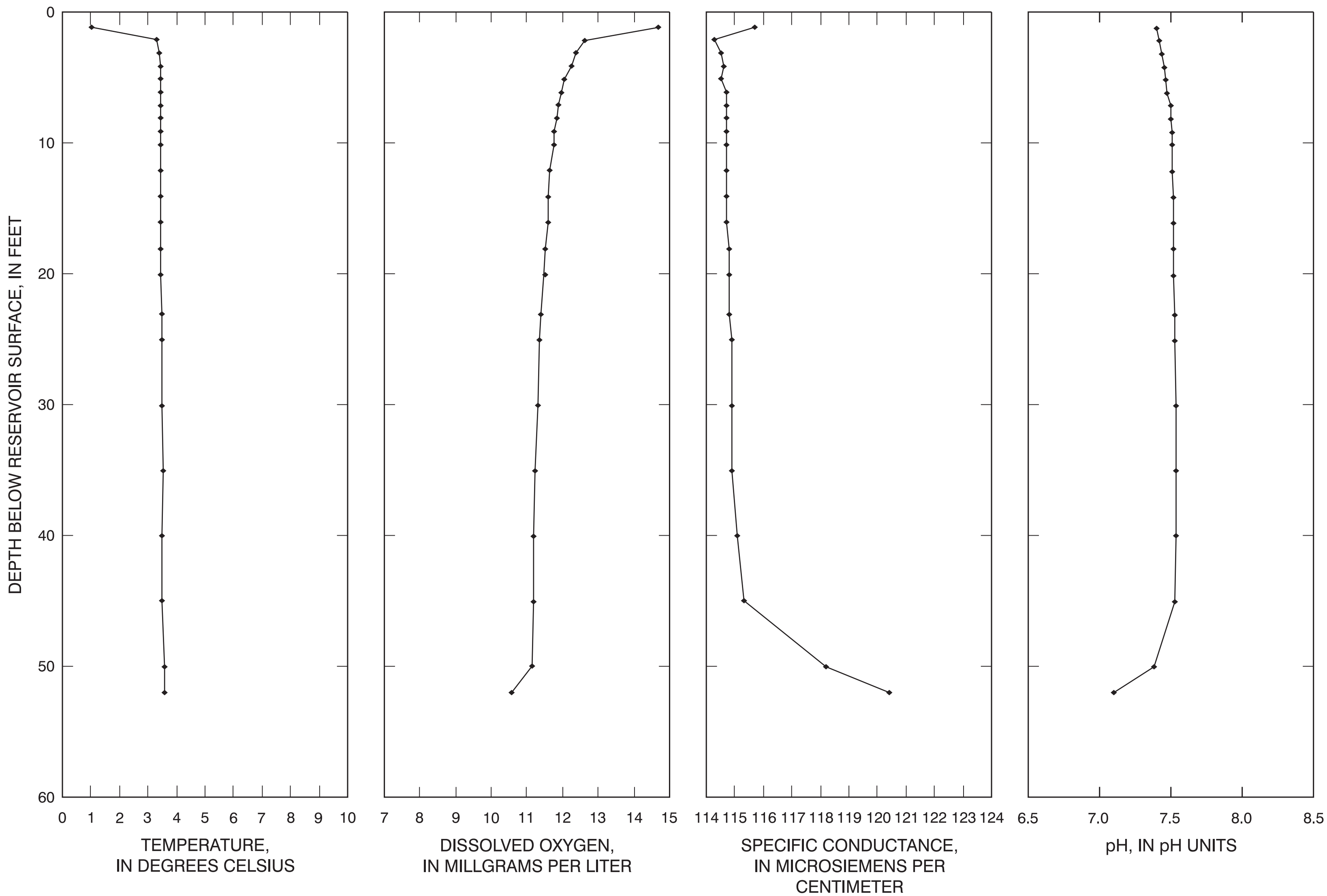

Figure C2-3-98. Temperature, dissolved oxygen, specific conductance and pH profiles on February 3, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

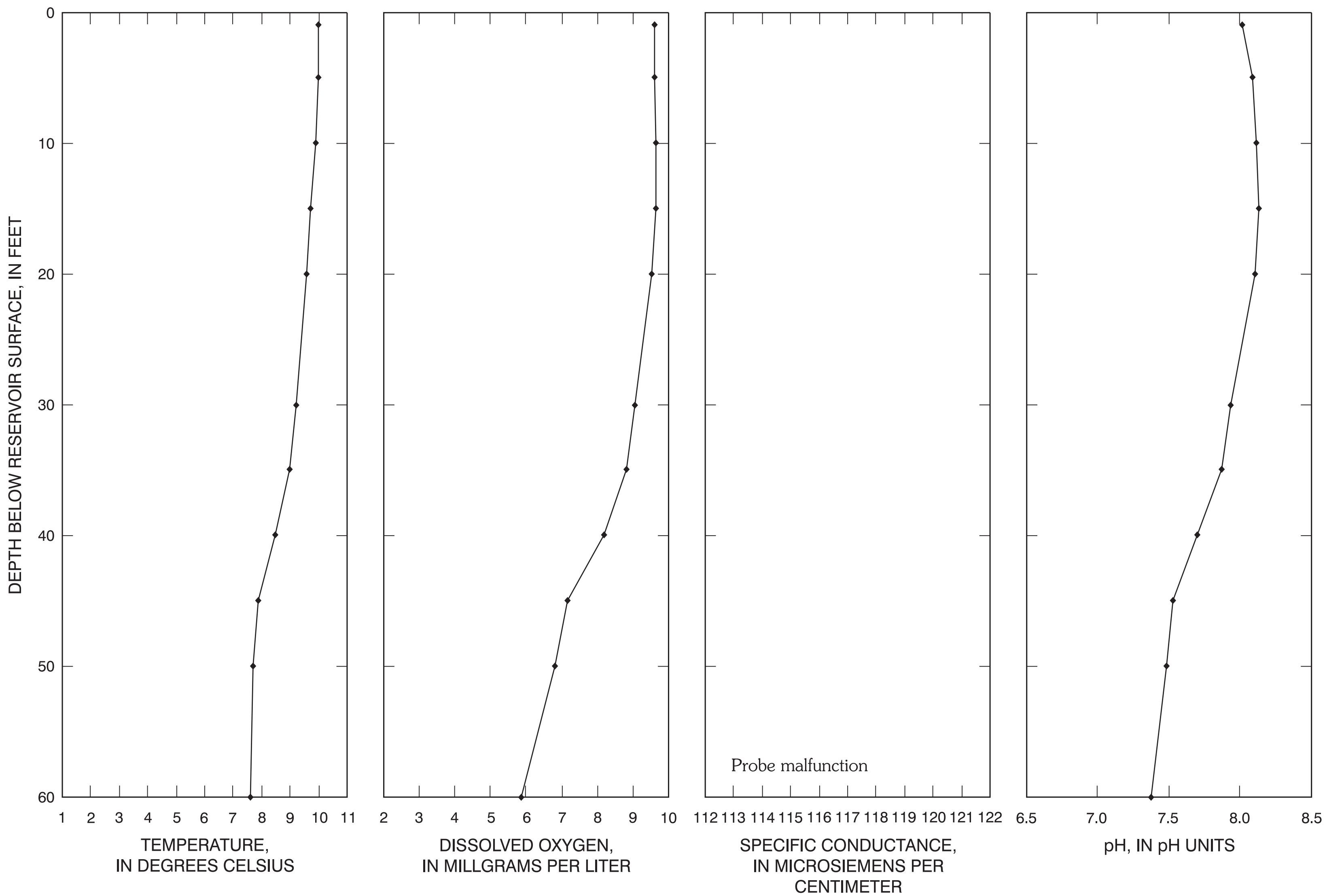

Figure C5-12-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on May 12, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

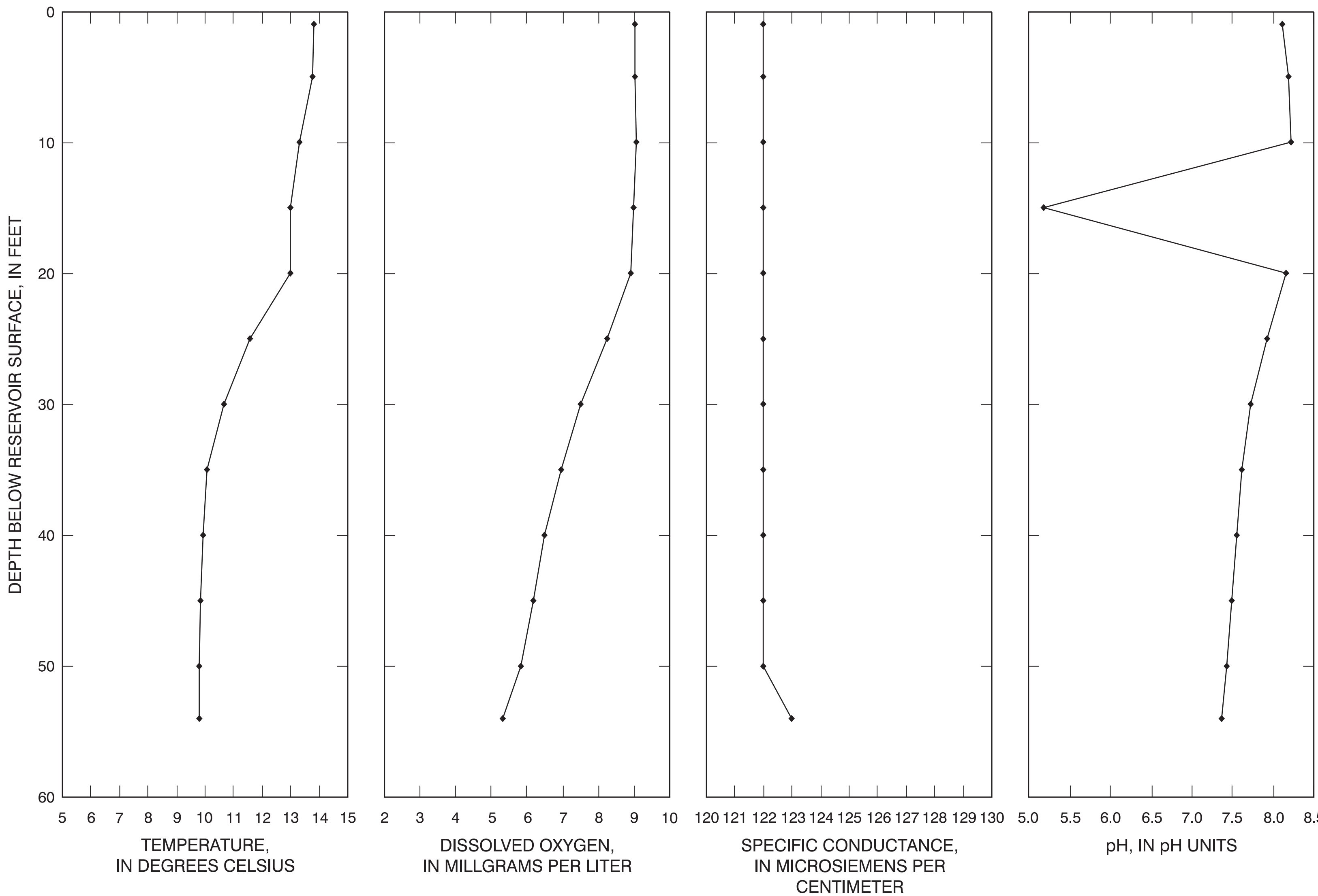

Figure C5-27-98. Temperature, dissolved oxygen, specific conductance and pH profiles on May 27, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

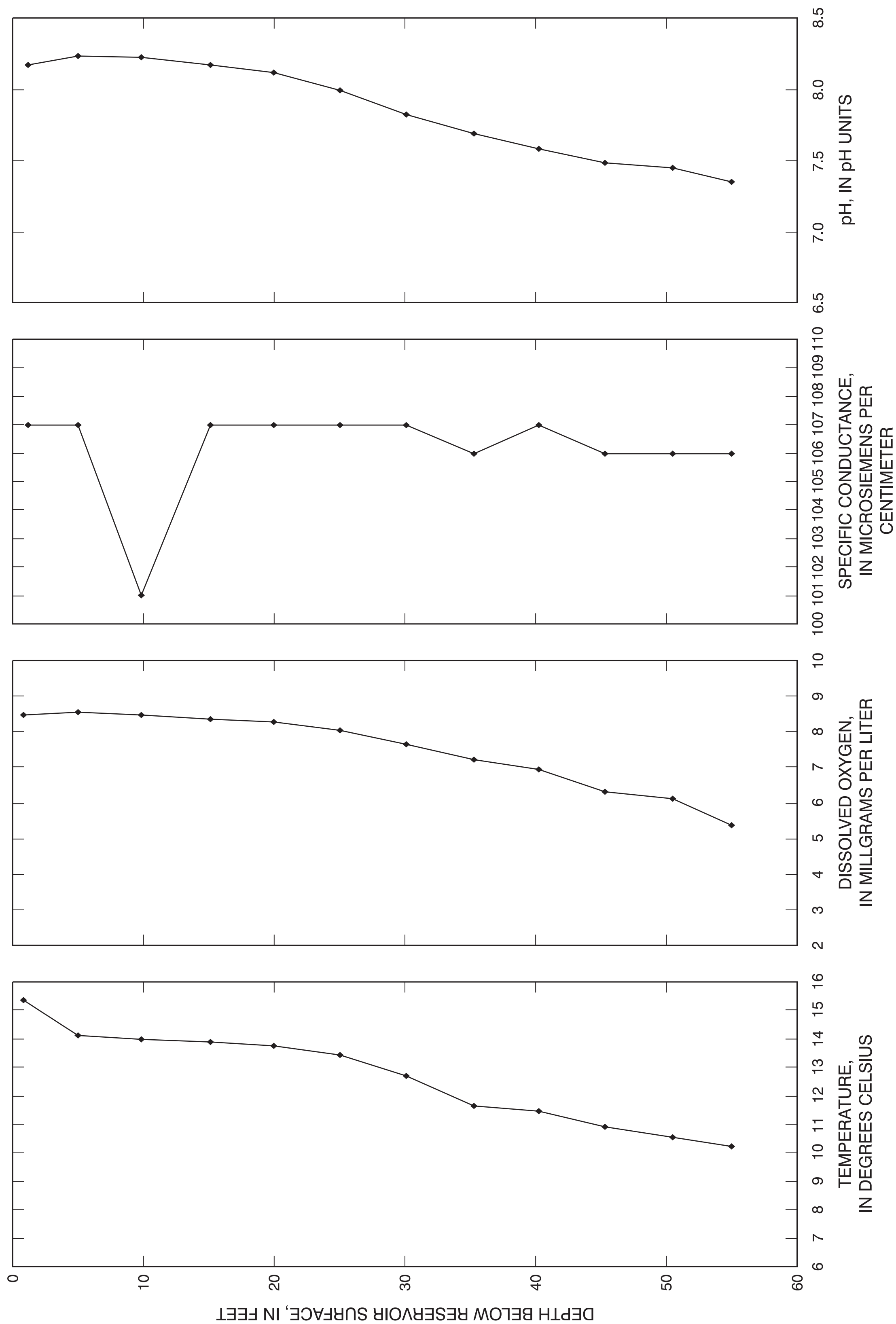

Figure C6-2-98. Temperature, dissolved oxygen, specific conductance, and pH profiles on June 2, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

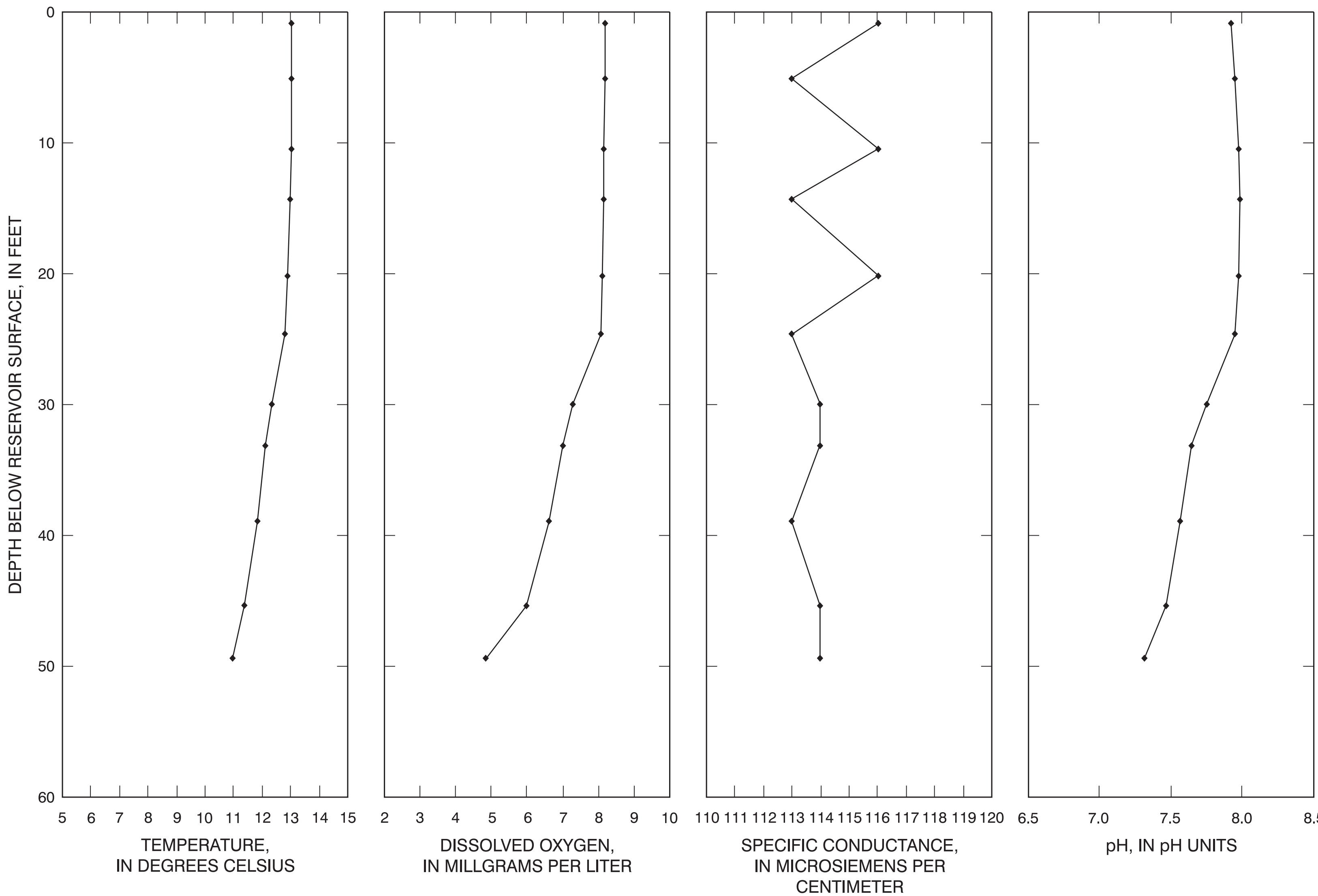

Figure C6-10-98. Temperature, dissolved oxygen, specific conductance and pH profiles on June 10, 1998, Granite Springs Reservoir, Laramie County, Wyoming.

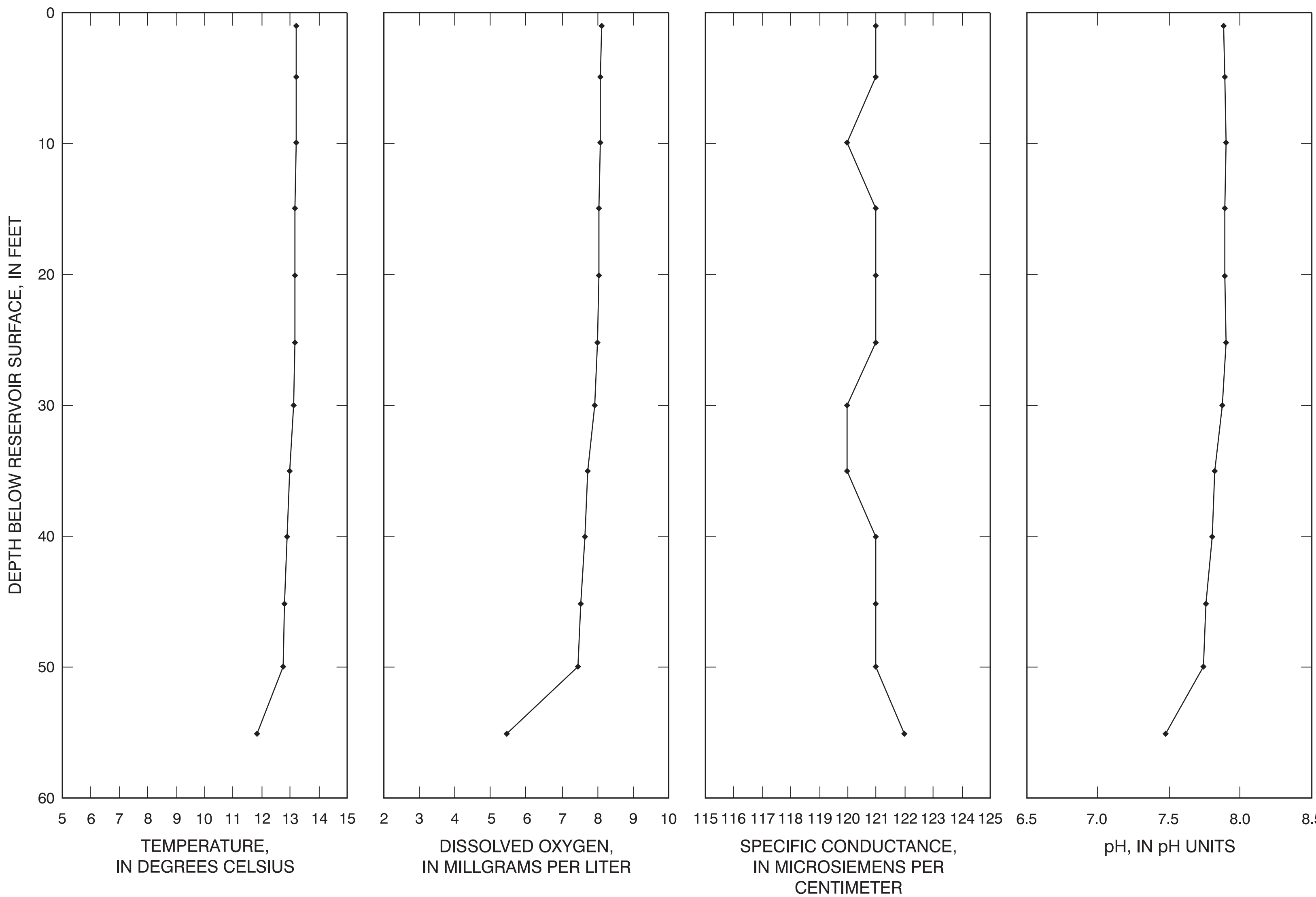

Figure C6-16-98. Temperature, dissolved oxygen, specific conductance and pH profiles on June 16, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

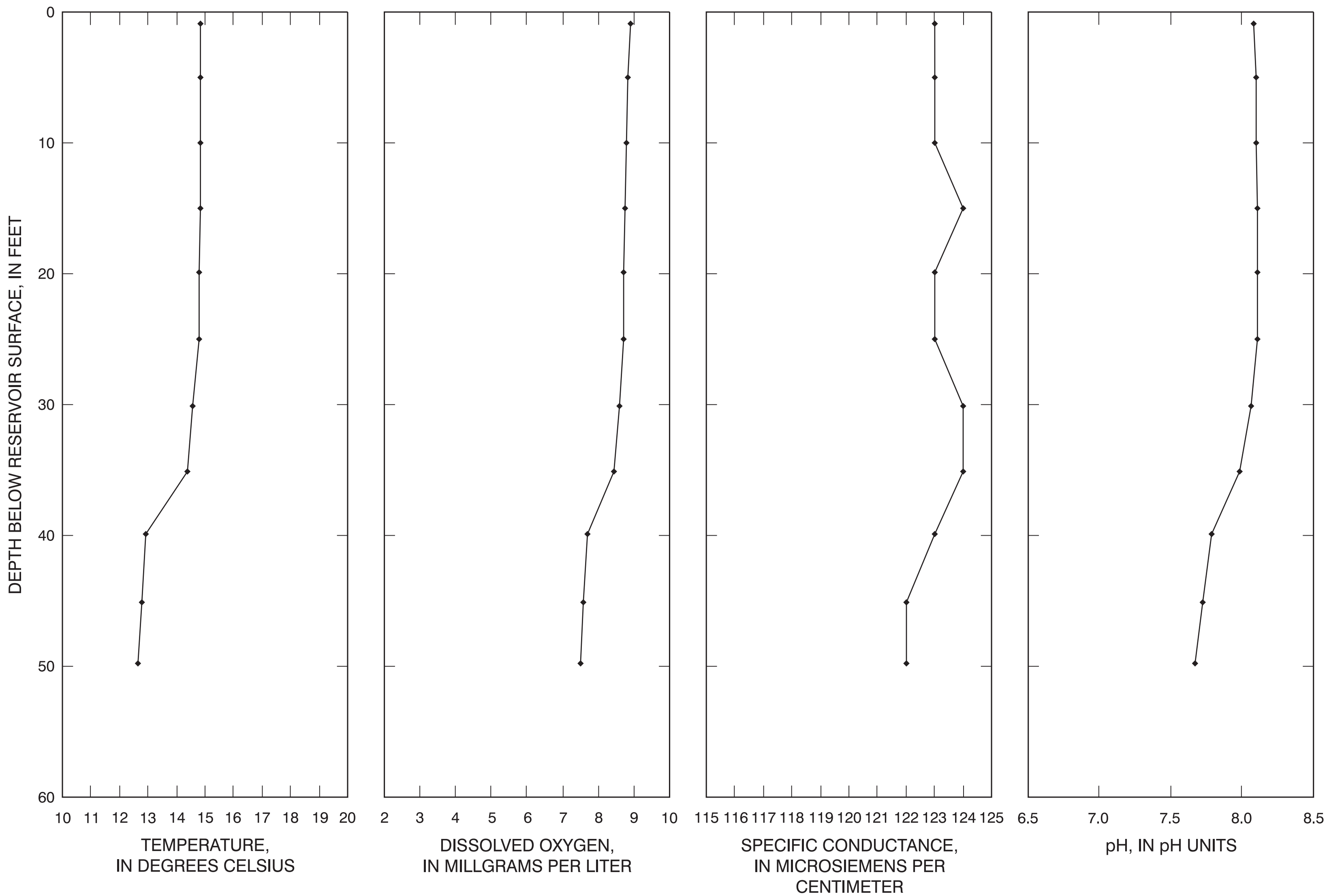

Figure C6-23-98. Temperature, dissolved oxygen, specific conductance and pH profiles on June 23, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

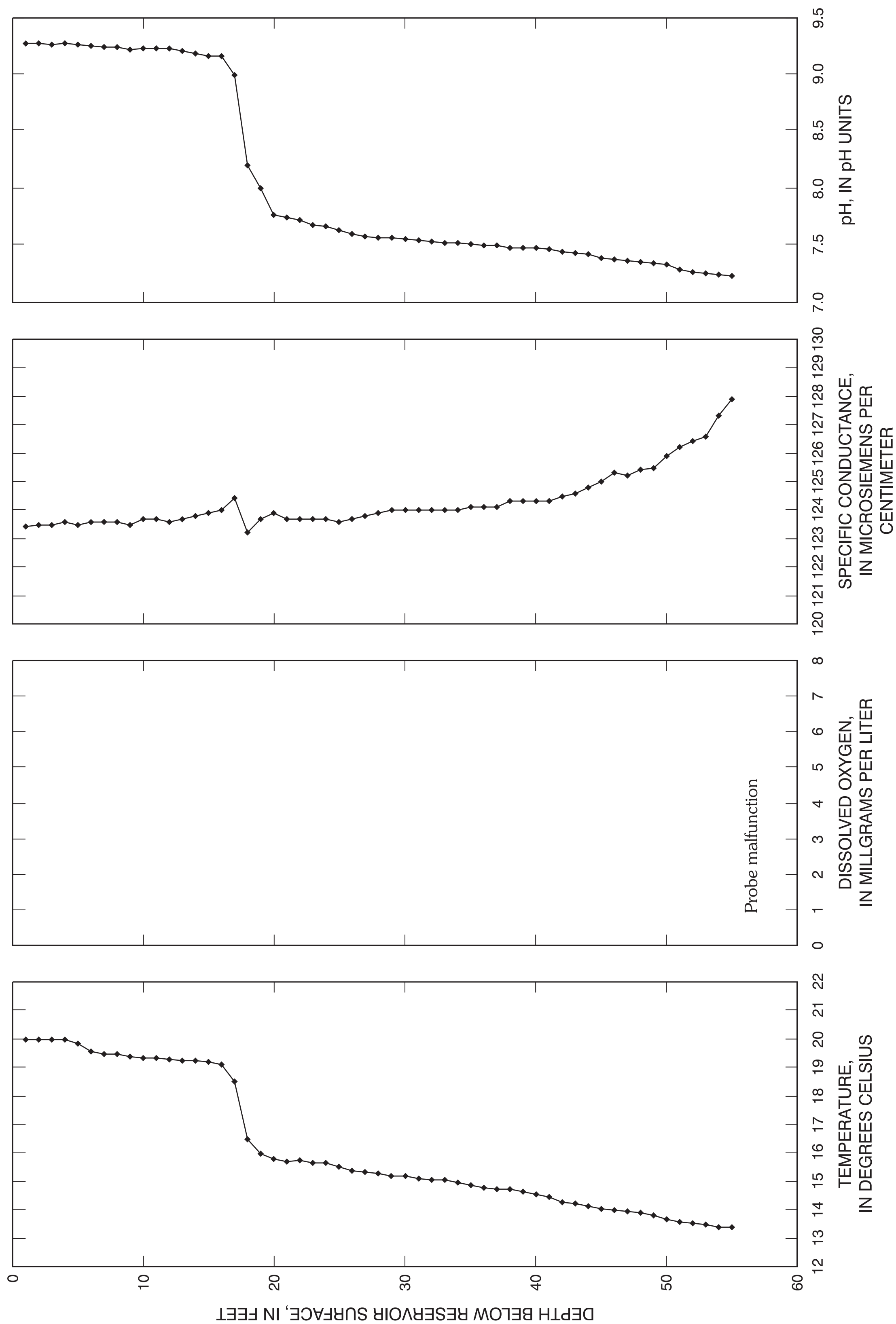

Figure C7-14-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 14, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

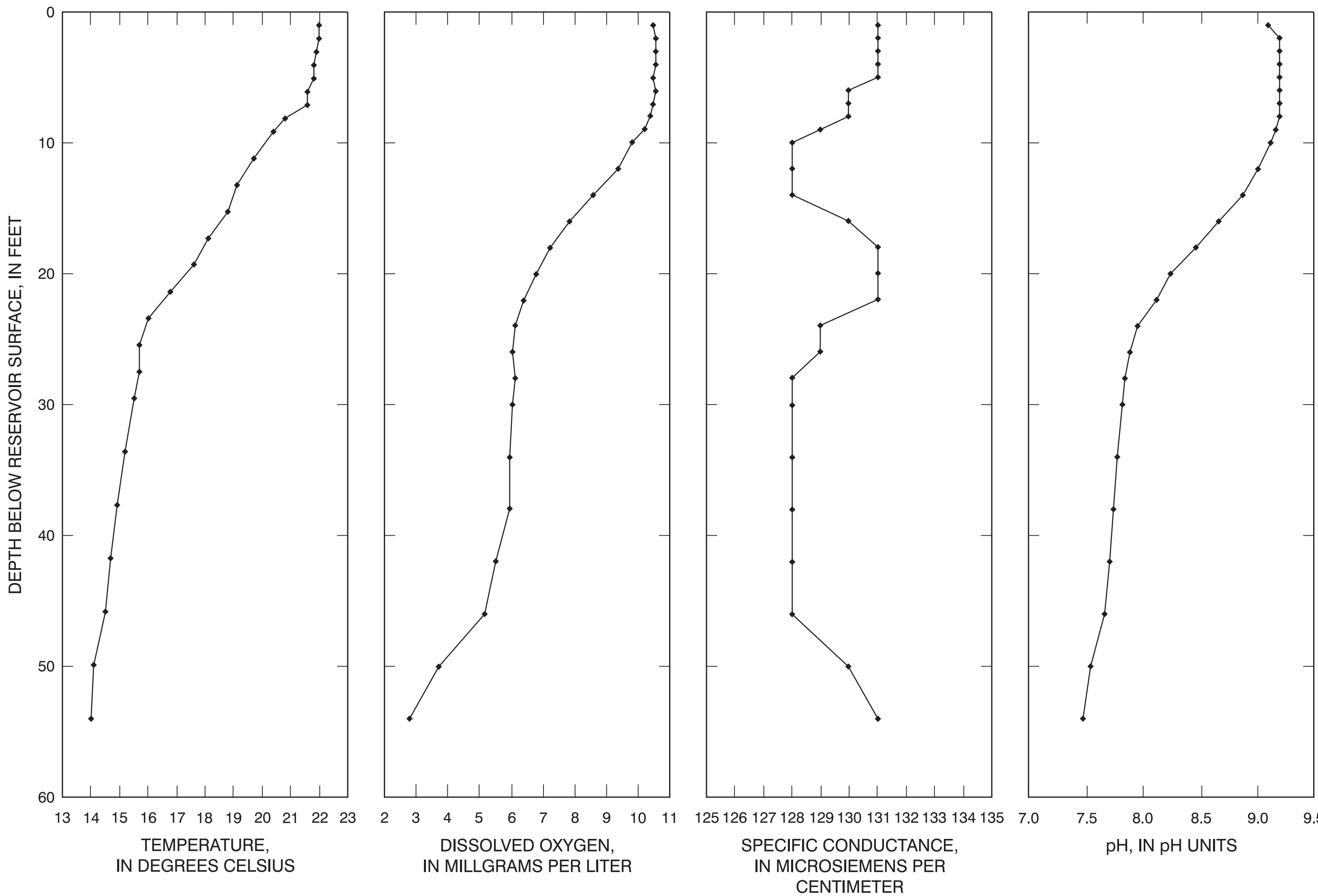

Figure C7-21-98. Temperature, dissolved oxygen, specific conductance and pH profiles on July 21, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

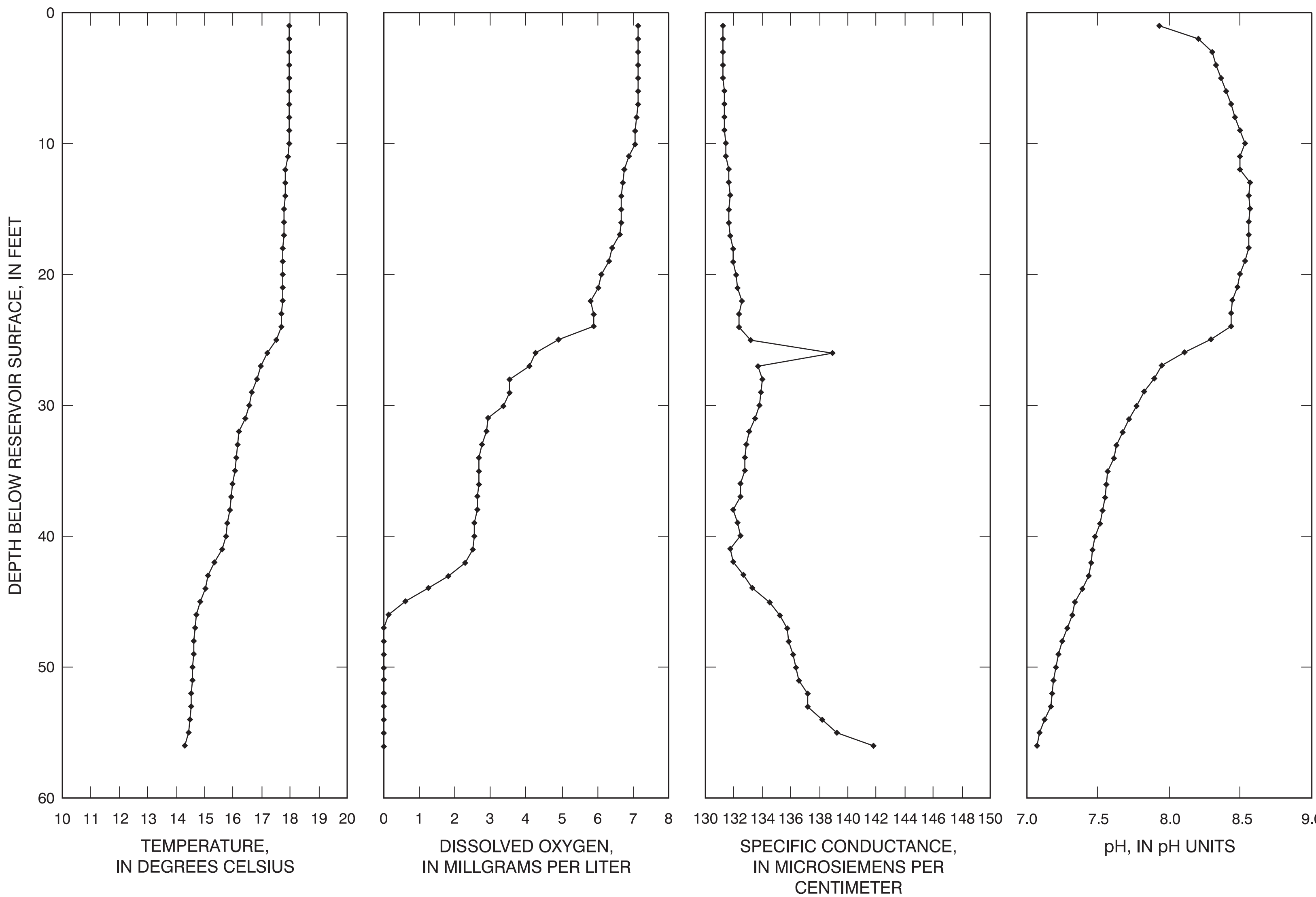

Figure C8-4-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 4, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

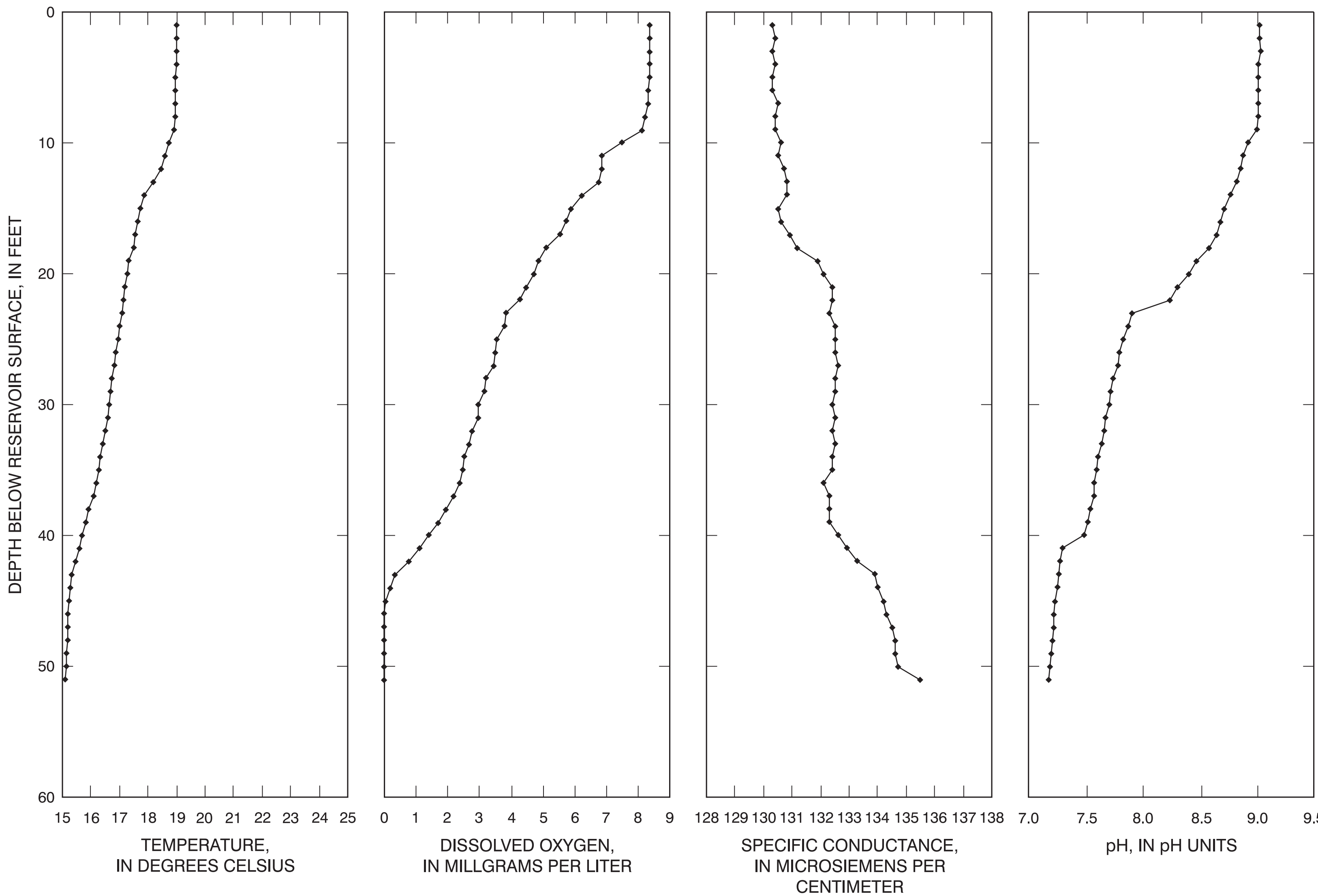

Figure C8-10-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 10, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

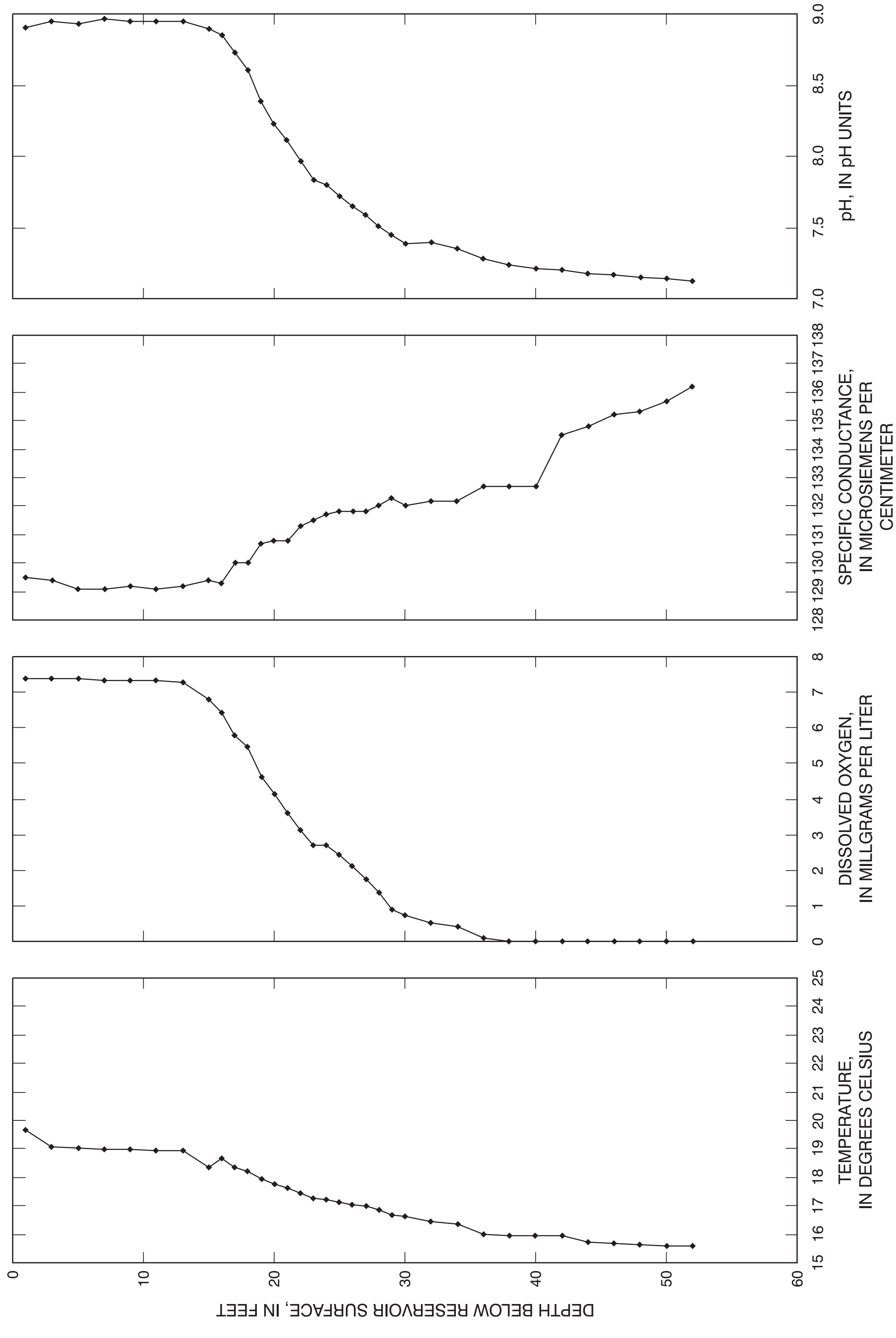

Figure C8-18-98. Temperature, dissolved oxygen, specific conductance and pH profiles on August 18, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

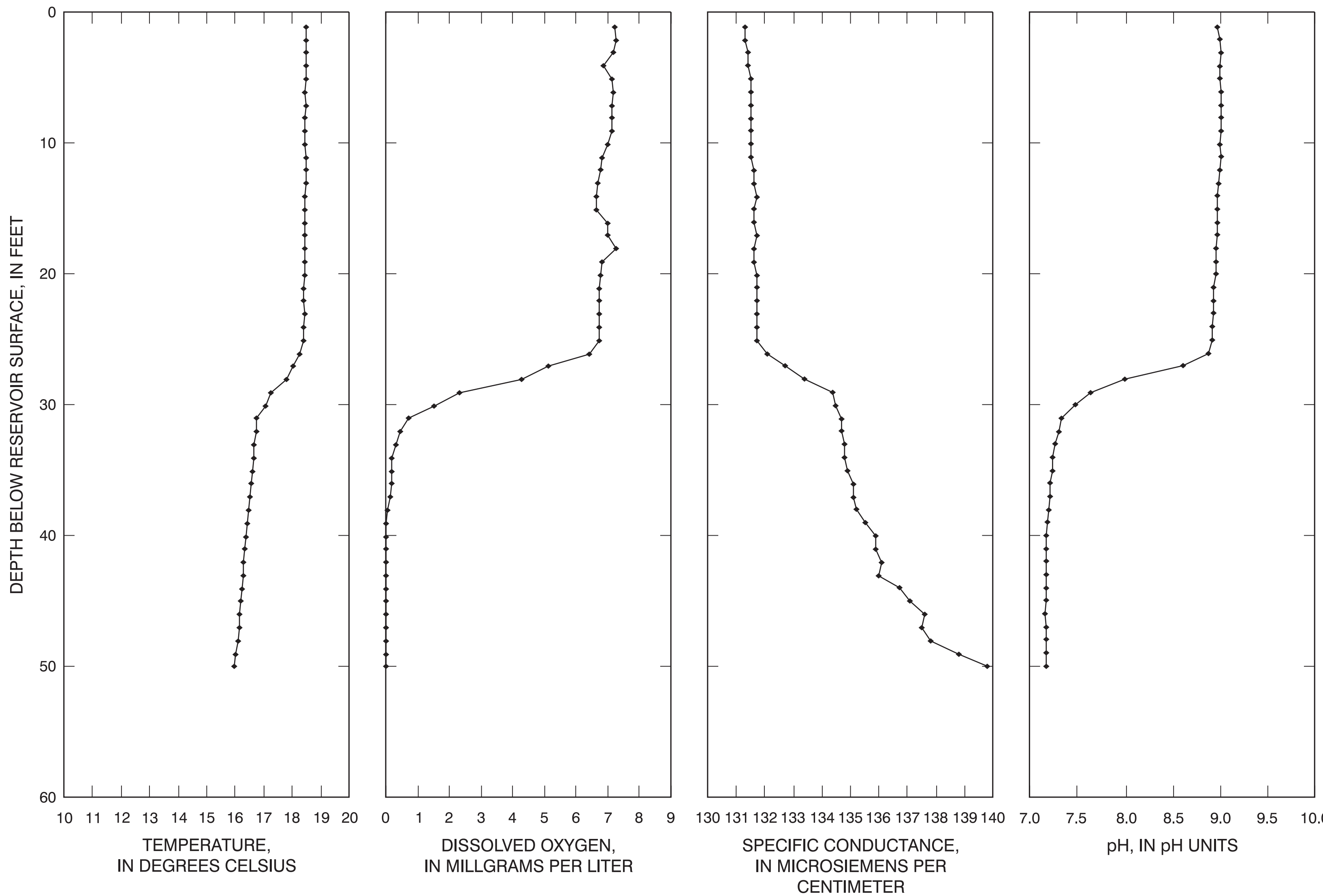

Figure C9-1-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 1, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

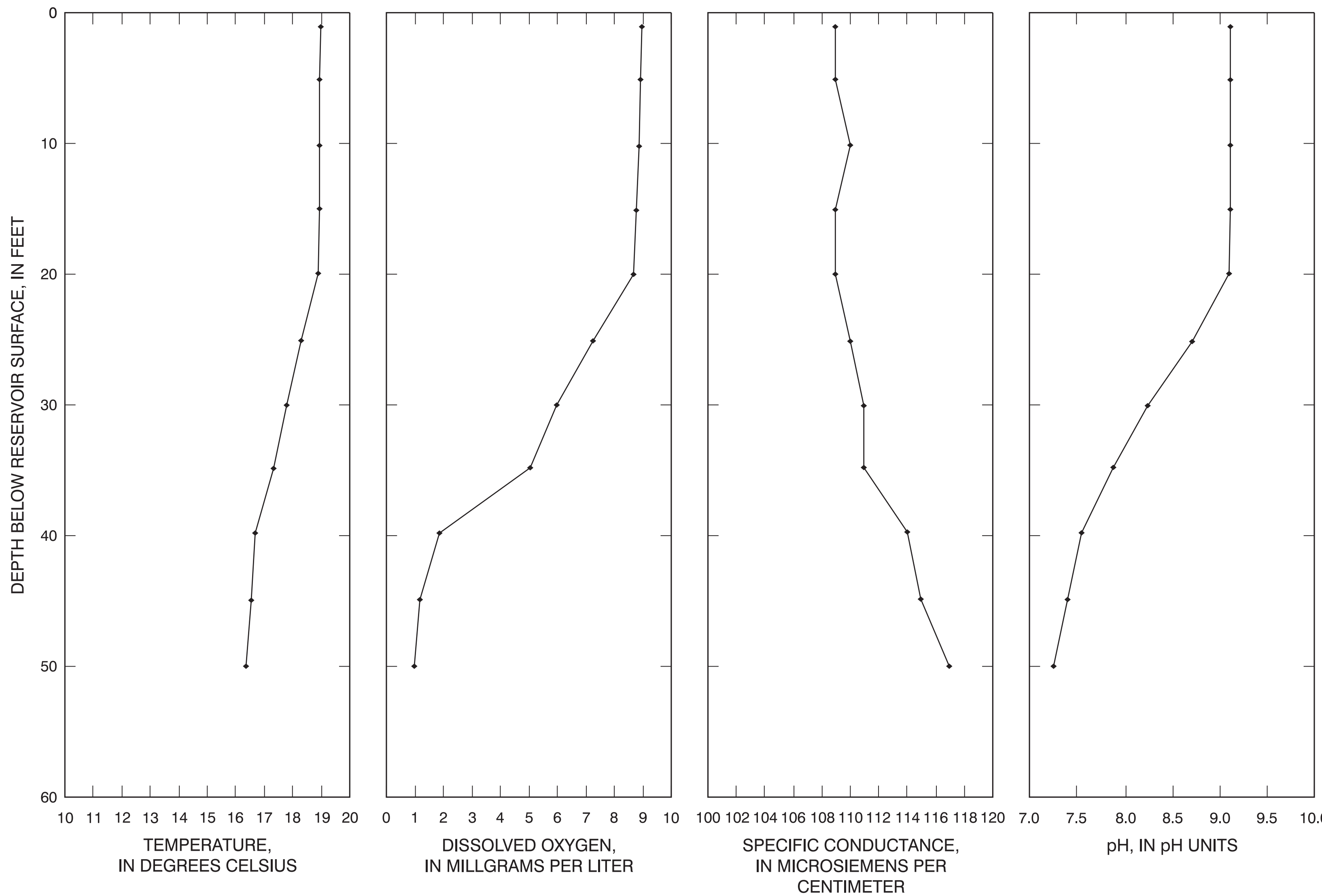

Figure C9-9-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 9, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

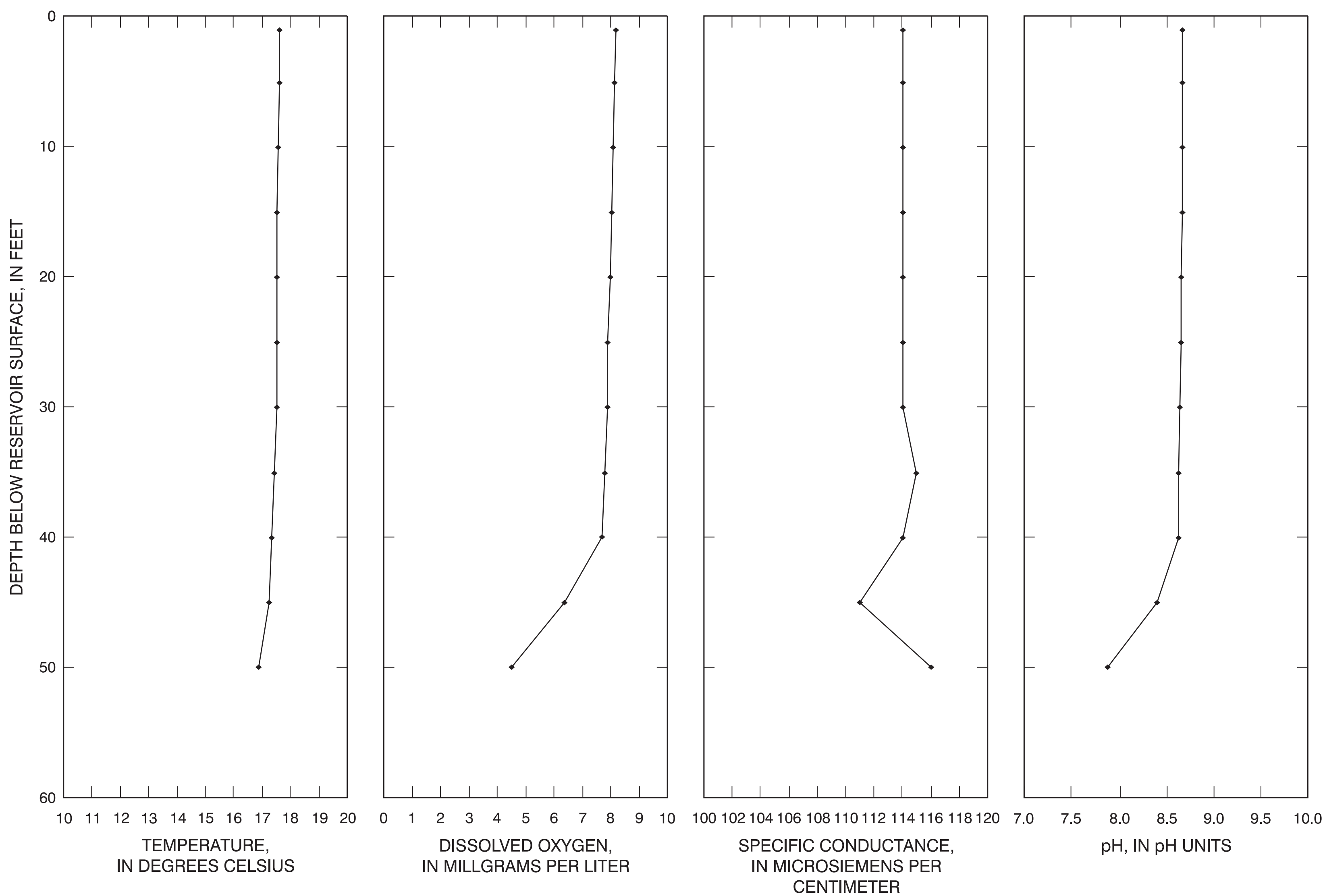

Figure C9-15-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 15, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

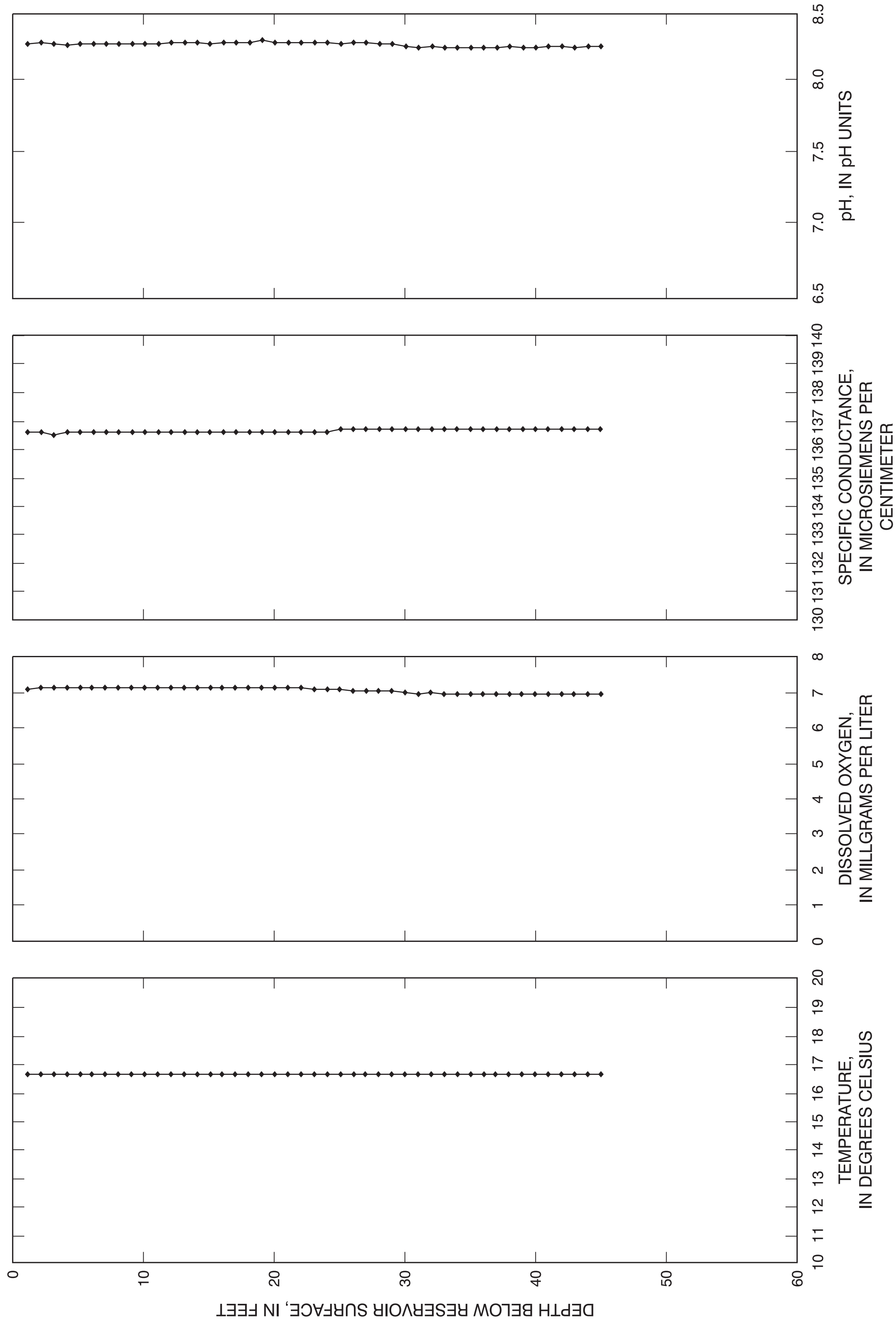

Figure C9-21-98. Temperature, dissolved oxygen, specific conductance and pH profiles on September 21, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

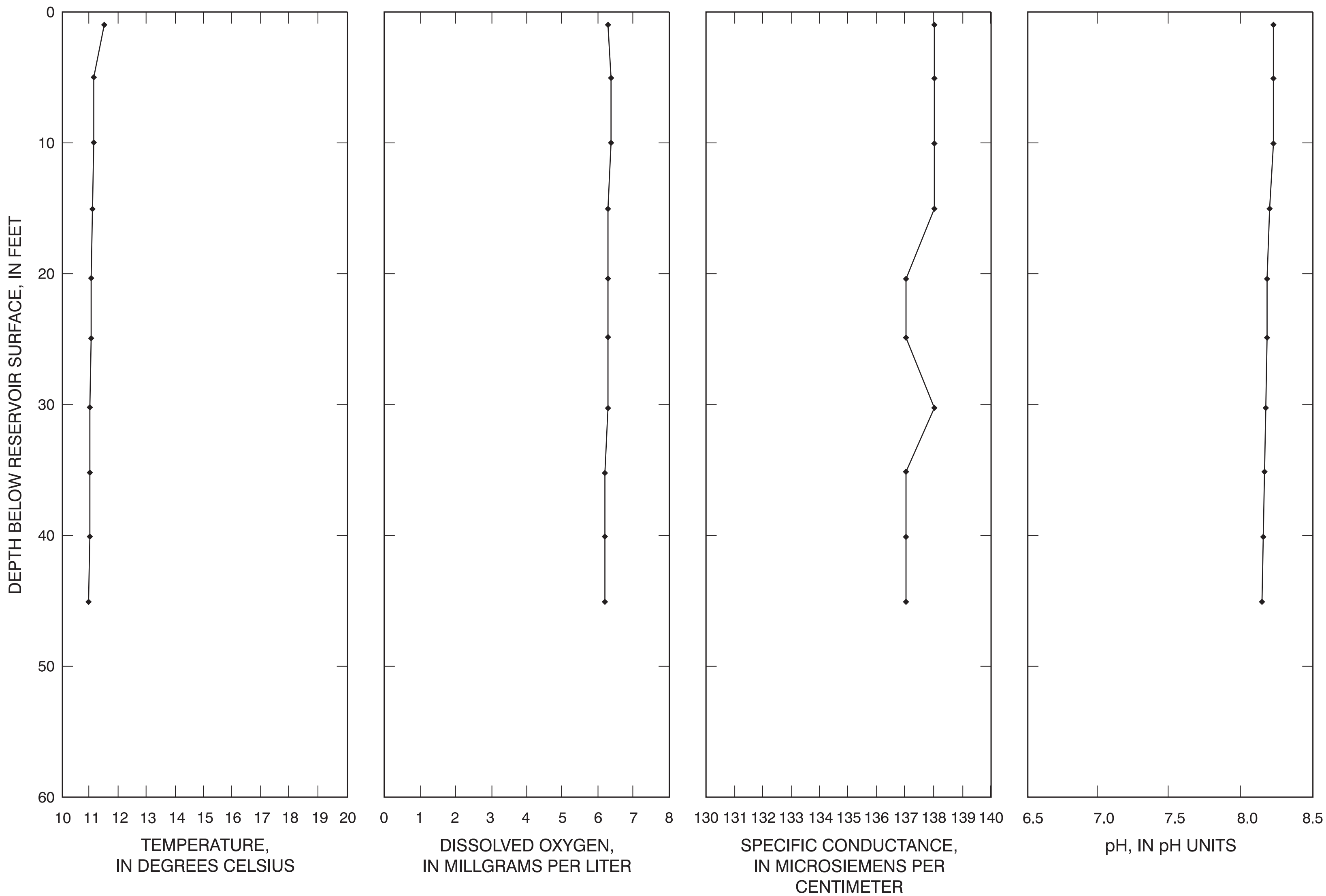

Figure C10-7-98. Temperature, dissolved oxygen, specific conductance and pH profiles on October 7, 1998, Crystal Lake Reservoir, Laramie County, Wyoming.

APPENDIX B—PHYTOPLANKTON DATA

Tables of phytoplankton density and biomass.

Table B1. *Phytoplankton density and biomass, Rob Roy Reservoir*

[Density in cells per liter, biomass in micrograms per liter]

	Date										
	9-2-97	**9-2-97**	**7-17-98**	**7-23-98**	**8-5-98**	**8-11-98**	**8-19-98**	**9-3-98**	**9-10-98**	**9-17-98**	**9-22-98**
	3' above bottom	**1' below surface**									
Chlorophyta											
Ankistrodesmus density	0	20,000	0	0	10,000	0	0	0	0	0	0
Ankistrodesmus biomass	0	5.0	0	0	2.5	0	0	0	0	0	0
Chlamydomonas size 1 density	0	0	0	0	10,000	0	0	0	0	0	0
Chlamydomonas size 1 biomass	0	0	0	0	1.1	0	0	0	0	0	0
Chlamydomonas size 2 density	0	0	0	0	0	0	0	0	0	0	10,000
Chlamydomonas size 2 biomass	0	0	0	0	0	0	0	0	0	0	8.9
Chlorella density	0	0	10,000	0	0	0	0	0	0	0	0
Chlorella biomass	0	0	2.7	0	0	0	0	0	0	0	0
Chlorophyte size 2 density	0	0	0	0	0	0	20,000	0	20,000	0	0
Chlorophyte size 2 biomass	0	0	0	0	0	0	16	0	16	0	0
Chlorophyte size 3 density	0	10,000	0	0	0	10,000	20,000	0	0	0	0
Chlorophyte size 3 biomass	0	26	0	0	0	26	51	0	0	0	0
Chlorophyte size 4 density	0	10,000	0	10,000	0	0	0	20,000	0	0	0
Chlorophyte size 4 biomass	0	2.1	0	2 .1	0	0	0	4.1	0	0	0
Chlorophyte size 5 density	0	60,000	0	0	0	0	0	0	0	0	0
Chlorophyte size 5 biomass	0	0.9	0	0	0	0	0	0	0	0	0
Chlorophyte size 7 density	0	0	0	0	0	0	0	0	0	0	10,000
Chlorophyte size 7 biomass	0	0	0	0	0	0	0	0	0	0	56
Cosmarium density	0	0	0	0	0	0	0	10,000	0	40,000	30,000
Cosmarium biomass	0	0	0	0	0	0	0	190	0	740	560
Dictyosphaerium density	0	0	0	0	0	0	0	1,250,000	0	0	840,000
Dictyosphaerium biomass	0	0	0	0	0	0	0	140	0	0	95
Elakatothrix density	0	0	0	0	0	0	0	100,000	0	80,000	0
Elakatothrix biomass	0	0	0	0	0	0	0	15	0	12	0
Oocystis size 1 density	0	0	0	0	0	0	0	120,000	30,000	0	0
Oocystis size 1 biomass	0	0	0	0	0	0	0	17	4.3	0	0
Quadrigula density	0	0	0	0	0	0	0	0	160,000	0	0
Quadrigula biomass	0	0	0	0	0	0	0	0	69	0	0

Table B1. *Phytoplankton density and biomass, Rob Roy Reservoir--Continued*

	Date										
	9-2-97	**9-2-97**	**7-17-98**	**7-23-98**	**8-5-98**	**8-11-98**	**8-19-98**	**9-3-98**	**9-10-98**	**9-17-98**	**9-22-98**
	3' above bottom	**1' below surface**									
Schroederia density	0	0	0	0	0	0	0	0	0	10,000	0
Schroederia biomass	0	0	0	0	0	0	0	0	0	0.8	0
Sphaerocystis density	0	0	0	0	0	160,000	40,000	160,000	0	0	140,000
Sphaerocystis biomass	0	0	0	0	0	47	12	47	0	0	41
Spondylosium density	0	0	0	0	0	0	0	0	0	0	130,000
Spondylosium biomass	0	0	0	0	0	0	0	0	0	0	167.12
Staurastrum density	0	0	0	0	0	0	0	0	50,000	0	0
Staurastrum biomass	0	0	0	0	0	0	0	0	630	0	0
Chrysophyta											
Mallomonas density	0	0	0	0	0	0	0	10,000	0	0	0
Mallomonas biomass	0	0	0	0	0	0	0	13	0	0	0
Cryptophyta											
Campylomonas reflexa density	0	0	0	10,000	0	10,000	0	10,000	60,000	0	20,000
Campylomonas reflexa biomass	0	0	0	14	0	14	0	14	85	0	28
Campylomonas rostratiformis density	0	0	0	10,000	0	0	0	20,000	0	30,000	0
Campylomonas rostratiformis biomass	0	0	0	32	0	0	0	64	0	96	0
Cryptophyte size 2 density	0	20,000	0	0	0	0	0	0	0	0	0
Cryptophyte size 2 biomass	0	21	0	0	0	0	0	0	0	0	0
Cryptomonas density	0	0	0	0	0	0	10,000	10,000	0	0	0
Cryptomonas biomass	0	0	0	0	0	0	23	23	0	0	0
Katablepharis density	0	0	0	80,000	60,000	20,000	80,000	20,000	10,000	40,000	20,000
Katablepharis biomass	0	0	0	14	11	3.6	14	3.6	1.8	7.1	3.6
Plagioselmis density	0	0	0	0	10,000	10,000	10,000	0	0	0	10,000
Plagioselmis biomass	0	0	0	0	1.5	1.5	1.5	0	0	0	1.5
Bacillariophyta											
Asterionella density	140,000	2,590,000	0	0	270,000	1,090,000	590,000	40,000	10,000	130,000	0
Asterionella biomass	190	3,500	0	0	360	1,500	790	53	13	170	0
Fragilaria density	0	0	0	0	610,000	1,550,000	390,000	0	0	0	0
Fragilaria biomass	0	0	0	0	670	1,700	430	0	0	0	0
Nitzschia density	0	0	0	0	0	10,000	0	0	0	0	0
Nitzschia biomass	0	0	0	0	0	1.0	0	0	0	0	0

Table B1. *Phytoplankton density and biomass, Rob Roy Reservoir--Continued*

	Date										
	9-2-97	9-2-97	7-17-98	7-23-98	8-5-98	8-11-98	8-19-98	9-3-98	9-10-98	9-17-98	9-22-98
	3' above bottom	1' below surface									
Pyrrophyta											
Gymnodinium density	0	0	0	0	0	0	0	0	0	0	10,000
Gymnodinium biomass	0	0	0	0	0	0	0	0	0	0	80
Colorless Flagellates											
Flagellate size 3 density	0	370,000	0	20,000	0	0	0	10,000	0	30,000	0
Flagellate size 3 biomass	0	53	0	2.9	0	0	0	1.4	0	4.3	0
Flagellate size 5 density	0	0	10,000	0	0	0	0	0	0	0	0
Flagellate size 5 biomass	0	0	7.0	0	0	0	0	0	0	0	0
Ciliate size 2 density	0	0	0	0	0	0	0	0	30,000	0	0
Ciliate size 2 biomass	0	0	0	0	0	0	0	0	25	0	0
Ameba											
Ameba density	0	0	0	10,000	0	0	0	0	0	0	0
Ameba biomass	0	0	0	26	0	0	0	0	0	0	0

Table B2. *Phytoplankton density and biomass, Lake Owen Reservoir*

[Density in cells per liter, biomass in micrograms per liter]

	Date										
	9-2-97	**9-16-97**	**7-17-98**	**7-23-98**	**8-5-98**	**8-11-98**	**8-19-98**	**9-3-98**	**9-10-98**	**9-17-98**	**9-22-98**
Chlorophyta											
Actinastrum density	0	0	5,000	0	0	0	0	0	0	0	0
Actinastrum biomass	0	0	1.1	0	0	0	0	0	0	0	0
Ankistrodesmus density	0	0	0	0	10,000	0	0	0	0	0	0
Ankistrodesmus biomass	0	0	0	0	2.8	0	0	0	0	0	0
Chlorella density	0	2,314,000	0	10,000	0	0	0	0	0	0	0
Chlorella biomass	0	78	0	0.3	0	0	0	0	0	0	0
Chlorophyte size 2 density	70,000	0	0	10,000	0	0	0	0	0	0	0
Chlorophyte size 2 biomass	42	0	0	6.1	0	0	0	0	0	0	0
Chlorophyte size 4 density	0	0	0	0	10,000	10,000	50,000	0	0	0	40,000
Chlorophyte size 4 biomass	0	0	0	0	1.6	1.6	8.1	0	0	0	6.4
Cosmarium density	0	0	0	10,000	0	0	0	0	0	0	10,000
Cosmarium biomass	0	0	0	200	0	0	0	0	0	0	200
Crucigenia density	0	0	0	0	0	0	0	0	0	10,000	0
Crucigenia biomass	0	0	0	0	0	0	0	0	0	6.9	0
Oocystis density	0	0	0	10,000	0	0	0	0	0	0	40,000
Oocystis biomass	0	0	0	1.0	0	0	0	0	0	0	4.0
Quadrigula density	0	90,000	0	0	0	0	0	0	20,000	0	0
Quadrigula biomass	0	53	0	0	0	0	0	0	12	0	0
Scenedesmus density	0	0	0	0	0	0	80,000	0	0	0	40,000
Scenedesmus biomass	0	0	0	0	0	0	4.1	0	0	0	2.1
Sphaerocystis density	0	0	0	0	0	80,000	0	0	0	0	0
Sphaerocystis biomass	0	0	0	0	0	9.0	0	0	0	0	0
Spondylosium density	0	0	0	0	0	0	0	0	0	10,000	0
Spondylosium biomass	0	0	0	0	0	0	0	0	0	7.2	0
Tetraspora density	0	170,000	0	0	0	0	0	0	0	0	0
Tetraspora biomass	0	89	0	0	0	0	0	0	0	0	0
Zygnematales density	0	0	0	0	0	0	0	0	0	0	10,000
Zygnematales biomass	0	0	0	0	0	0	0	0	0	0	39

Table B2. *Phytoplankton density and biomass, Lake Owen Reservoir--Continued*

	Date										
	9-2-97	9-16-97	7-17-98	7-23-98	8-5-98	8-11-98	8-19-98	9-3-98	9-10-98	9-17-98	9-22-98
Chrysophyta											
Chrysophyte size 1 density	0	0	0	0	0	0	0	0	0	10,000	40,000
Chrysophyte size 1 biomass	0	0	0	0	0	0	0	0	0	13	51
Dinobryon density	0	0	0	0	0	50,000	0	0	0	0	0
Dinobryon biomass	0	0	0	0	0	5.4	0	0	0	0	0
Mallomonas density	0	0	0	0	0	0	0	40,000	50,000	0	0
Mallomonas biomass	0	0	0	0	0	0	0	23	29	0	0
Uroglenopsis density	0	0	0	0	0	26,236,000	0	30,503,000	19,175,000	15,170,000	2,104,000
Uroglenopsis biomass	0	0	0	0	0	6,100	0	7,000	4,400	3,500	490
Cryptophyta											
Campylomonas reflexa density	0	0	0	0	20,000	0	0	0	0	0	0
Campylomonas reflexa biomass	0	0	0	0	16	0	0	0	0	0	0
Campylomonas rostratiformis density	0	0	0	0	0	0	0	0	10,000	10,000	30,000
Campylomonas rostratiformis biomass	0	0	0	0	0	0	0	0	51	51	150
Cryptophyte size 1 density	0	10,000	0	0	0	0	0	0	0	0	0
Cryptophyte size 1 biomass	0	5.0	0	0	0	0	0	0	0	0	0
Cryptophyte size 2 density	0	0	0	0	0	0	0	0	0	10,000	10,000
Cryptophyte size 2 biomass	0	0	0	0	0	0	0	0	0	19	19
Cryptophyte size 3 density	0	10,000	0	0	0	0	0	0	0	0	0
Cryptophyte size 3 biomass	0	2.3	0	0	0	0	0	0	0	0	0
Cryptomonas density	0	0	0	0	0	0	0	0	20,000	10,000	0
Cryptomonas biomass	0	0	0	0	0	0	0	0	41	21	0
Katablepharis density	0	0	0	40,000	330,000	40,000	140,000	20,000	60,000	40,000	40,000
Katablepharis biomass	0	0	0	7.3	60	7.3	26	3.7	11	7.3	7.3
Plagioselmis density	0	0	0	30,000	0	0	0	0	0	0	10,000
Plagioselmis biomass	0	0	0	3.5	0	0	0	0	0	0	1.2
Bacillariophyta											
Achnanthes density	0	0	0	0	0	0	0	0	0	10,000	0
Achnanthes biomass	0	0	0	0	0	0	0	0	0	1.5	0
Asterionella density	0	0	0	0	0	0	0	0	30,000	20,000	0
Asterionella biomass	0	0	0	0	0	0	0	0	34	23	0
Fragilaria density	0	0	0	0	0	0	0	0	0	0	60,000

Table B2. *Phytoplankton density and biomass, Lake Owen Reservoir--Continued*

	Date										
	9-2-97	**9-16-97**	**7-17-98**	**7-23-98**	**8-5-98**	**8-11-98**	**8-19-98**	**9-3-98**	**9-10-98**	**9-17-98**	**9-22-98**
Fragilaria biomass	0	0	0	0	0	0	0	0	0	0	117
Pennales size 2 density	0	0	0	0	0	0	0	0	0	0	10,000
Pennales size 2 biomass	0	0	0	0	0	0	0	0	0	0	99.73
Pennales size 3 density	0	0	0	0	0	0	0	10,000	0	0	0
Pennales size 3 biomass	0	0	0	0	0	0	0	14	0	0	0
Synedra density	0	0	0	0	10,000	0	0	0	0	0	0
Synedra biomass	0	0	0	0	25	0	0	0	0	0	0
Pyrrophyta											
Gymnodinium density	0	0	0	0	0	0	0	0	0	30,000	10,000
Gymnodinium biomass	0	0	0	0	0	0	0	0	0	61	20
Euglenophyta											
Euglena density	0	0	0	0	0	0	0	0	0	0	10,000
Euglena biomass	0	0	0	0	0	0	0	0	0	0	180
Euglenophyte size 1 density	0	0	0	0	0	0	0	0	0	10,000	0
Euglenophyte size 1 biomass	0	0	0	0	0	0	0	0	0	26	0
Euglenophyte size 2 density	0	0	0	0	0	0	0	0	0	10,000	0
Euglenophyte size 2 biomass	0	0	0	0	0	0	0	0	0	115	0
Trachelomonas size 2 density	0	0	0	0	0	0	10,000	0	10,000	0	0
Trachelomonas size 2 biomass	0	0	0	0	0	0	58	0	58	0	0
Colorless Flagellates											
Flagellate size 3 density	0	0	5,000	40,000	0	0	80,000	30,000	0	0	0
Flagellate size 3 biomass	0	0	0.7	5.8	0	0	12	4.3	0	0	0
Salpingoeca density	0	0	0	0	0	0	0	0	60,000	0	0
Salpingoeca biomass	0	0	0	0	0	0	0	0	180	0	0
Ciliates											
Ciliate size 1 density	0	0	0	0	0	0	0	0	10,000	0	0
Ciliate size 1 biomass	0	0	0	0	0	0	0	0	14	0	0
Ciliate size 2 density	0	0	0	0	0	0	10,000	0	0	0	10,000
Ciliate size 2 biomass	0	0	0	0	0	0	42	0	0	0	42
Ciliate size 3 density	0	0	0	0	0	0	0	0	0	20,000	0
Ciliate size 3 biomass	0	0	0	0	0	0	0	0	0	110	0
Ciliate size 5 density	0	0	0	0	0	0	0	0	0	10,000	0

Table B2. *Phytoplankton density and biomass, Lake Owen Reservoir--Continued*

	Date										
	9-2-97	9-16-97	7-17-98	7-23-98	8-5-98	8-11-98	8-19-98	9-3-98	9-10-98	9-17-98	9-22-98
Ciliate size 5 biomass	0	0	0	0	0	0	0	0	0	13,000	0
Ciliate size 6 density	0	0	0	20,000	0	0	0	0	0	0	0
Ciliate size 6 biomass	0	0	0	9.4	0	0	0	0	0	0	0
Rotifers	0	0	0	0	0	0	0	0	0	0	0
Ameba density	0	0	0	0	0	0	0	0	0	0	10,000
Ameba biomass	0	0	0	0	0	0	0	0	0	0	14

Table B3. *Phytoplankton density and biomass, Granite Springs Reservoir*

[Density in cells per liter, biomass in micrograms per liter]

	Date										
	8-28-97	8-28-97	7-14-98	7-22-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	3' above bottom	1' below surface									
Chlorophyta											
Ankistrodesmus density	0	30,000	0	0	0	0	0	0	0	0	0
Ankistrodesmus biomass	0	5.0	0	0	0	0	0	0	0	0	0
Chlorella density	0	0	0	10,000	0	0	0	0	0	0	0
Chlorella biomass	0	0	0	2.7	0	0	0	0	0	0	0
Chlorophyte size 1 density	0	20,000	0	0	0	0	0	0	0	0	0
Chlorophyte size 1 biomass	0	71	0	0	0	0	0	0	0	0	0
Chlorophyte size 2 density	20,000	0	10,000	0	10,000	0	0	500,000	0	0	10,000
Chlorophyte size 2 biomass	18	0	9.0	0	9.0	0	0	450	0	0	9.0
Chlorophyte size 4 density	0	0	0	0	0	0	0	140,000	50,000	0	0
Chlorophyte size 4 biomass	0	0	0	0	0	0	0	25	9.0	0	0
Chlorophyte size 6 density	0	0	0	0	20,000	0	0	0	0	0	0
Chlorophyte size 6 biomass	0	0	0	0	3.0	0	0	0	0	0	0
Didymocystis density	0	0	0	0	0	0	0	0	0	0	10,000
Didymocystis biomass	0	0	0	0	0	0	0	0	0	0	2.3
Eudorina density	0	0	0	0	0	240,000	0	0	0	0	0
Eudorina biomass	0	0	0	0	0	170	0	0	0	0	0
Micractinium density	0	0	0	0	0	0	0	0	0	0	120,000
Micractinium biomass	0	0	0	0	0	0	0	0	0	0	1.7
Oocystis size 1 density	0	0	0	130,000	0	0	0	0	0	0	0
Oocystis size 1 biomass	0	0	0	20	0	0	0	0	0	0	0
Quadrigula density	0	0	0	20,000	0	0	0	0	0	0	0
Quadrigula biomass	0	0	0	15	0	0	0	0	0	0	0
Scenedesmus density	0	0	40,000	0	0	0	0	0	40,000	0	0
Scenedesmus biomass	0	0	12	0	0	0	0	0	12	0	0
Sphaerocystis density	0	0	110,000	59,000	0	0	0	0	0	0	0
Sphaerocystis biomass	0	0	16	8.5	0	0	0	0	0	0	0

Table B3. *Phytoplankton density and biomass, Granite Springs Reservoir--Continued*

	Date										
	8-28-97	8-28-97	7-14-98	7-22-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	3' above bottom	1' below surface									
Chrysophyta											
Dinobryon density	0	0	0	0	0	0	0	0	10,000	0	0
Dinobryon biomass	0	0	0	0	0	0	0	0	9.16	0	0
Cryptophyta											
Campylomonas reflexa density	0	0	30,000	30,000	20,000	10,000	0	0	0	40,000	20,000
Campylomonas reflexa biomass	0	0	24	24	16	8.0	0	0	0	32	16
Campylomonas rostratiformis density	0	0	0	10,000	0	0	0	0	0	20,000	10,000
Campylomonas rostratiformis biomass	0	0	0	36	0	0	0	0	0	72	36
Cryptophyte size 1 density	0	0	0	0	0	0	0	10,000	0	0	0
Cryptophyte size 1 biomass	0	0	0	0	0	0	0	11	0	0	0
Katablepharis density	0	0	0	0	60,000	130,000	480,000	10,000	0	270,000	160,000
Katablepharis biomass	0	0	0	0	9	20	72	1.5	0	41	24
Plagioselmis density	0	0	0	280,000	120,000	60,000	0	30,000	0	30,000	10,000
Plagioselmis biomass	0	0	0	41	17	8.7	0	4.4	0	4.4	1.5
Cyanophyta											
Anabaena density	0	3,830,000	69,127,000	0	0	0	0	40,000	0	120,000	210,000
Anabaena biomass	0	3,300	59,000	0	0	0	0	34	0	100	180
Aphanothece density	0	4,750,000	0	0	0	0	0	0	1,140,000	0	8,000,000
Aphanothece biomass	0	8.1	0	0	0	0	0	0	1.9	0	14
Pseudanabaena density	0	0	0	0	0	0	0	0	0	0	140,000
Pseudanabaena biomass	0	0	0	0	0	0	0	0	0	0	5.9
Bacillariophyta											
Asterionella density	0	0	0	0	0	40,000	0	0	0	0	0
Asterionella biomass	0	0	0	0	0	19	0	0	0	0	0
Centrales size 1 density	0	70,000	150,000	0	0	1,270,000	700,000	0	0	410,000	0
Centrales size 1 biomass	0	67	140	0	0	1,200	670	0	0	400	0
Centrales size 2 density	0	0	0	0	0	0	0	0	0	100,000	0
Centrales size 2 biomass	0	0	0	0	0	0	0	0	0	210	0
Centrales size 3 density	0	0	0	30,000	0	0	0	0	0	0	0
Centrales size 3 biomass	0	0	0	410	0	0	0	0	0	0	0

Table B3. *Phytoplankton density and biomass, Granite Springs Reservoir--Continued*

	Date										
	8-28-97	**8-28-97**	**7-14-98**	**7-22-98**	**8-4-98**	**8-10-98**	**8-18-98**	**9-1-98**	**9-9-98**	**9-15-98**	**9-21-98**
	3' above bottom	**1' below surface**									
Centrales size 4 density	0	0	0	0	10,000	0	0	0	0	0	450,000
Centrales size 4 biomass	0	0	0	0	60	0	0	0	0	0	2,700
Cyclotella density	0	0	0	1,170,000	0	0	0	790,000	0	0	0
Cyclotella biomass	0	0	0	1,700	0	0	0	1,100	0	0	0
Cymbella density	0	0	0	10,000	0	0	0	0	0	0	0
Cymbella biomass	0	0	0	4.2	0	0	0	0	0	0	0
Fragilaria density	140,000	660,000	630,000	3,030,000	580,000	500,000	80,000	1,230,000	720,000	0	110,000
Fragilaria biomass	200	930	880	4,200	810	700	110	1,700	1,000	0	150
Melosira size 1 density	560,000	50,000	0	0	240,000	120,000	0	0	0	0	260,000
Melosira size 1 biomass	600	53	0	0	260	130	0	0	0	0	280
Melosira size 2 density	0	0	0	0	0	0	0	0	0	50,000	0
Melosira size 2 biomass	0	0	0	0	0	0	0	0	0	2.8	0
Melosira size 3 density	0	0	0	0	0	0	0	0	90,000	0	0
Melosira size 3 biomass	0	0	0	0	0	0	0	0	1,600	0	0
Pennales size 1 density	10,000	0	0	0	0	0	0	0	0	0	0
Pennales size 1 biomass	2.8	0	0	0	0	0	0	0	0	0	0
Pennales size 2 density	110,000	0	0	0	0	0	0	0	0	0	0
Pennales size 2 biomass	140	0	0	0	0	0	0	0	0	0	0
Stephanodiscus density	0	0	0	0	1,360,000	0	0	0	960,000	0	0
Stephanodiscus biomass	0	0	0	0	1,100	0	0	0	800	0	0
Tabellaria density	0	0	0	0	50,000	0	0	0	0	40,000	60,000
Tabellaria biomass	0	0	0	0	140	0	0	0	0	110	170
Pyrrophyta											
Ceratium density	0	10,000	0	0	0	0	0	0	0	0	0
Ceratium biomass	0	0.4	0	0	0	0	0	0	0	0	0
Trachelomonas size density	0	0	0	10,000	0	0	10,000	0	0	20,000	0
Trachelomonas size 1 biomass	0	0	0	31	0	0	31	0	0	61	0
Trachelomonas size 2 density	0	0	0	0	0	30,000	0	0	10,000	10,000	10,000
Trachelomonas size 2 biomass	0	0	0	0	0	110	0	0	36	36	36

Table B3. *Phytoplankton density and biomass, Granite Springs Reservoir--Continued*

	Date										
	8-28-97	**8-28-97**	**7-14-98**	**7-22-98**	**8-4-98**	**8-10-98**	**8-18-98**	**9-1-98**	**9-9-98**	**9-15-98**	**9-21-98**
	3' above bottom	**1' below surface**									
Colorless Flagellates											
Flagellate size 2 density	0	170,000	0	0	0	0	0	0	0	0	0
Flagellate size 2 biomass	0	38	0	0	0	0	0	0	0	0	0
Flagellate size 3 density	0	0	0	50,000	0	0	0	0	60,000	0	0
Flagellate size 3 biomass	0	0	0	5.7	0	0	0	0	6.8	0	0
Flagellate size 5 density	0	0	0	0	0	0	0	0	0	0	10,000
Flagellate size 5 biomass	0	0	0	0	0	0	0	0	0	0	7.0
Ciliates											
Ciliate size 1 density	0	0	0	0	0	0	0	0	0	0	10,000
Ciliate size 1 biomass	0	0	0	0	0	0	0	0	0	0	7.0
Ciliate size 3 density	0	0	0	0	0	10,000	0	0	0	0	0
Ciliate size 3 biomass	0	0	0	0	0	82	0	0	0	0	0
Ciliate size 4 density	0	0	0	0	20,000	0	0	10,000	0	10,000	10,000
Ciliate size 4 biomass	0	0	0	0	560	0	0	280	0	280	280
Rotifers											
Rotifer size 2 density	0	0	10,000	0	0	0	0	0	0	0	0
Rotifer size 2 biomass	0	0	5,000	0	0	0	0	0	0	0	0
Ameba											
Ameba size 1 density	0	0	0	0	0	0	40,000	10,000	0	0	10,000
Ameba size 1 biomass	0	0	0	0	0	0	28	7.0	0	0	7.0
Ameba size 2 density	0	0	0	0	0	0	0	0	0	10,000	0
Ameba size 2 biomass	0	0	0	0	0	0	0	0	0	190	0

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir*

[Density in cells per liter, biomass in micrograms per liter]

	Date												
	9-4-97	9-4-97	9-4-97	9-11-97	7-14-98	7-21-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	1’ below surface		3’ above bottom	At 30’	1' below surface								
Chlorophyta													
Chlorella density	330,000	375,000	0	1,322,000	0	0	0	0	0	0	0	0	0
Chlorella biomass	4.7	5.3	0	19	0	0	0	0	0	0	0	0	0
Chlorophyte size 2 density	0	0	0	20,000	0	0	30,000	0	0	0	0	0	0
Chlorophyte size 2 biomass	0	0	0	20	0	0	31	0	0	0	0	0	0
Chlorophyte size 3 density	0	40,000	0	0	0	0	0	10,000	10,000	0	40,000	0	0
Chlorophyte size 3 biomass	0	100	0	0	0	0	0	26	26	0	100	0	0
Chlorophyte size 4 density	350,000	300,000	0	310,000	0	0	0	0	0	0	0	0	0
Chlorophyte size 4 biomass	120	100	0	110	0	0	0	0	0	0	0	0	0
Chlorophyte size 6 density	0	0	0	0	0	0	0	0	0	0	130,000	0	0
Chlorophyte size 6 biomass	0	0	0	0	0	0	0	0	0	0	20	0	0
Chlorococcales density	0	0	0	0	0	0	0	0	0	0	0	110,000	0
Chlorococcales biomass	0	0	0	0	0	0	0	0	0	0	0	29	0
Closterium density	0	0	0	0	0	0	0	0	0	0	0	10,000	0
Closterium biomass	0	0	0	0	0	0	0	0	0	0	0	60	0
Coelastrum density	0	0	0	0	0	0	0	0	0	0	70,000	0	0
Coelastrum biomass	0	0	0	0	0	0	0	0	0	0	4.6	0	0
Cosmarium density	0	10,000	0	0	0	0	0	0	20,000	0	0	0	0
Cosmarium biomass	0	150	0	0	0	0	0	0	290	0	0	0	0
Dictyosphaerium density	0	0	0	0	0	0	0	0	0	0	70,000	0	0
Dictyopshaerium biomass	0	0	0	0	0	0	0	0	0	0	19	0	0

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir--Continued*

	Date												
	9-4-97	9-4-97	9-4-97	9-11-97	7-14-98	7-21-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	1' below surface		3' above bottom	At 30'	1' below surface								
Oocystis size 1 density	40,000	0	0	0	90,000	0	0	0	80,000	0	0	0	0
Oocystis size 1 biomass	4.6	0	0	0	10	0	0	0	9.1	0	0	0	0
Oocystis size 2 density	0	0	0	0	20,000	0	0	0	0	0	0	0	40,000
Oocystis size 2 biomass	0	0	0	0	40	0	0	0	0	0	0	0	80
Pandorina density	0	0	0	0	0	120,000	0	0	0	0	0	0	0
Pandorina biomass	0	0	0	0	0	14	0	0	0	0	0	0	0
Quadrigula density	0	0	0	0	0	0	0	0	0	0	50,000	0	0
Quadrigula biomass	0	0	0	0	0	0	0	0	0	0	34	0	0
Sphaerocystis density	0	0	0	0	0	0	80,000	0	80,000	0	0	0	0
Sphaerocystis biomass	0	0	0	0	0	0	5.2	0	5.2	0	0	0	0
Spondylosium density	80,000	0	0	0	0	0	0	0	0	0	0	0	0
Spondylosium biomass	170	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum density	0	0	0	0	0	0	0	0	0	10,000	0	10,000	0
Staurastrum biomass	0	0	0	0	0	0	0	0	0	390	0	390	0
Cryptophyta	0	0	0	0	0	0	0	0	0	0	0	0	0
Campylomonas reflexa density	0	0	0	0	0	20,000	20,000	50,000	0	10,000	20,000	10,000	0
Campylomonas reflexa biomass	0	0	0	0	0	19	19	48	0	9.5	19	9.5	0
Campylomonas rostratiformis density	0	0	0	0	0	0	0	0	0	0	0	40,000	0
Campylomonas rostratiformis biomass	0	0	0	0	0	0	0	0	0	0	0	76	0
Cryptophyte size 1 density	20,000	0	0	0	0	0	0	0	0	0	0	0	0

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir--Continued*

	Date												
	9-4-97	9-4-97	9-4-97	9-11-97	7-14-98	7-21-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	1' below surface		3' above bottom	At 30'	1' below surface								
Cryptophyte size 1 biomass	13	0	0	0	0	0	0	0	0	0	0	0	0
Cryptophyte size 3 density	0	0	0	0	0	0	0	0	0	0	0	0	10,000
Cryptophyte size 3 biomass	0	0	0	0	0	0	0	0	0	0	0	0	2.1
Cryptophyte size 4 density	0	0	0	10,000	0	0	0	0	0	0	0	0	0
Cryptophyte size 4 biomass	0	0	0	2.7	0	0	0	0	0	0	0	0	0
Cryptomonas density	0	0	0	0	0	0	0	0	0	30,000	0	0	10,000
Cryptomonas biomass	0	0	0	0	0	0	0	0	0	50	0	0	17
Katablepharis density	0	0	0	0	0	50,000	50,000	220,000	40,000	20,000	60,000	90,000	10,000
Katablepharis biomass	0	0	0	0	0	8.6	8.6	38	6.9	3.4	10	15	1.7
Plagioselmis density	0	0	0	0	0	180,000	60,000	20,000	0	10,000	10,000	40,000	20,000
Plagioselmis biomass	0	0	0	0	0	28	9.4	3.1	0	1.6	1.6	6.3	3.1
Cyanophyta													
Anabaena density	0	0	0	0	29,127,000	16,706,000	550,000	6,300,000	0	12,000	620,000	480,000	630,000
Anabaena biomass	0	0	0	0	18,000	10,000	330	3,800	0	7.3	380	290	380
Aphanothece density	0	0	0	0	0	0	0	0	0	3,780,000	480,000	3,250,000	500,000
Aphanothece biomass	0	0	0	0	0	0	0	0	0	5.9	0.8	5.1	0.8
Cyanophyte size 1 density	0	0	0	0	0	0	0	0	0	0	4,500,000	0	0
Cyanophyte size 1 biomass	0	0	0	0	0	0	0	0	0	0	8.0	0	0
Gomphosphaeria density	0	0	0	0	0	0	1,500,000	0	0	15,020,000	9,800,000	2,500,000	8,000,000
Gomphosphaeria biomass	0	0	0	0	0	0	21	0	0	210	140	35	110
Microcystis density	0	0	0	0	0	0	0	0	3,313,000	0	0	0	0

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir--Continued*

	Date												
	9-4-97	**9-4-97**	**9-4-97**	**9-11-97**	**7-14-98**	**7-21-98**	**8-4-98**	**8-10-98**	**8-18-98**	**9-1-98**	**9-9-98**	**9-15-98**	**9-21-98**
	1’ below surface		**3’ above bottom**	**At 30’**	**1' below surface**								
Microcystis biomass	0	0	0	0	0	0	0	0	47	0	0	0	0
Bacillariophyta													
Achnanthes density	160,000	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes biomass	64	0	0	0	0	0	0	0	0	0	0	0	0
Centrales size 1 density	0	0	0	0	0	0	0	80,000	0	0	0	400,000	0
Centrales size 1 biomass	0	0	0	0	0	0	0	92	0	0	0	460	0
Centrales size 2 density	1,060,000	650,000	80,000	600,000	0	0	0	0	0	0	0	0	0
Centrales size 2 biomass	2,100	1,300	160	1,200	0	0	0	0	0	0	0	0	0
Centrales size 3 density	0	0	10,000	0	0	0	0	0	0	0	0	0	0
Centrales size 3 biomass	0	0	170	0	0	0	0	0	0	0	0	0	0
Cyclotella density	0	0	0	0	230,000	0	0	0	120,000	550,000	0	0	270,000
Cyclotella biomass	0	0	0	0	270	0	0	0	140	650	0	0	320
Fragilaria density	4,490,000	3,630,000	1,130,000	2,490,000	810,000	710,000	830,000	590,000	1,030,000	690,000	1,230,000	550,000	150,000
Fragilaria biomass	6,500	5,300	1,600	3,600	1,200	1,000	1,200	860	1,500	1,000	1,800	800	220
Melosira density	0	0	0	0	40,000	0	110,000	0	0	0	0	0	0
Melosira biomass	0	0	0	0	33	0	90	0	0	0	0	0	0
Pennales size 3 density	0	0	10,000	0	0	0	0	0	0	0	0	0	0
Pennales size 3 biomass	0	0	9.8	0	0	0	0	0	0	0	0	0	0
Stephanodiscus density	0	0	0	0	0	240,000	80,000	20,000	0	0	1,120,000	0	0
Stephanodiscus biomass	0	0	0	0	0	790	260	66	0	0	3,700	0	0
Pyrrophyta													
Ceratium density	0	0	0	0	0	0	0	20,000	0	0	0	0	10,000
Ceratium biomass	0	0	0	0	0	0	0	0.8	0	0	0	0	0.4
Euglenophyta													

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir--Continued*

	Date												
	9-4-97	9-4-97	9-4-97	9-11-97	7-14-98	7-21-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	1' below surface		3' above bottom	At 30'	1' below surface								
Trachelomonas size 1 density	0	0	0	0	0	0	0	0	0	0	0	0	20,000
Trachelomonas size 1 biomass	0	0	0	0	0	0	0	0	0	0	0	0	51
Trachelomonas size 2 density	0	0	0	0	0	0	0	0	0	20,000	0	0	0
Trachelomonas size 2 biomass	0	0	0	0	0	0	0	0	0	83	0	0	0
Colorless Flagellates													
Flagellate size 1 density	0	0	0	0	0	60,000	0	0	0	0	0	0	0
Flagellate size 1 biomass	0	0	0	0	0	9.0	0	0	0	0	0	0	0
Flagellate size 2 density	0	0	0	0	0	10,000	20,000	0	0	0	0	0	0
Flagellate size 2 biomass	0	0	0	0	0	4.2	8.4	0	0	0	0	0	0
Flagellate size 3 density	0	0	0	0	10,000	0	0	0	1,270,000	0	0	20,000	20,000
Flagellate size 3 biomass	0	0	0	0	1.1	0	0	0	140	0	0	2.3	2.3
Flagellate size 4 density	0	0	0	0	0	0	0	0	0	0	0	30,000	0
Flagellate size 4 biomass	0	0	0	0	0	0	0	0	0	0	0	0.03	0
Flagellate size 5 density	0	0	0	0	0	0	0	0	0	0	0	0	40,000
Flagellate size 5 biomass	0	0	0	0	0	0	0	0	0	0	0	0	28
Ciliates													
Ciliate size 2 density	0	0	0	0	0	0	0	10,000	0	0	10,000	0	0
Ciliate size 2 biomass	0	0	0	0	0	0	0	42	0	0	42	0	0
Ciliate size 4 density	0	0	0	0	0	0	0	0	0	10,000	30,000	0	0
Ciliate size 4 biomass	0	0	0	0	0	0	0	0	0	210	630	0	0
Ciliate size 7 density	0	0	0	0	0	0	0	0	0	0	0	0	20,000

Table B4. *Phytoplankton density and biomass, Crystal Lake Reservoir--Continued*

	Date												
	9-4-97	9-4-97	9-4-97	9-11-97	7-14-98	7-21-98	8-4-98	8-10-98	8-18-98	9-1-98	9-9-98	9-15-98	9-21-98
	1' below surface		3' above bottom	At 30'	1' below surface								
Ciliate size 7 biomass	0	0	0	0	0	0	0	0	0	0	0	0	450
Rotifers													
rotifer size 1 density	0	0	0	0	10,000	0	0	0	0	0	0	0	0
rotifer size 1 biomass	0	0	0	0	230	0	0	0	0	0	0	0	0
Ameba													
Ameba density	0	0	0	0	0	10,000	10,000	0	0	0	0	0	0
Ameba biomass	0	0	0	0	0	3.8	3.8	0	0	0	0	0	0