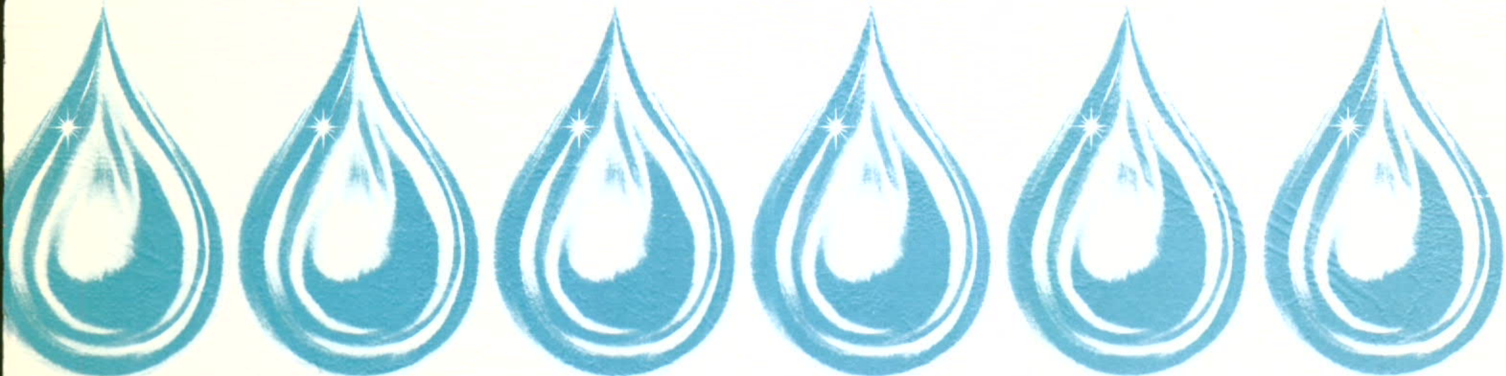

Water-Supply Bulletin 42

DATA ON SELECTED LAKES IN WASHINGTON

Part 2

WASHINGTON STATE DEPARTMENT OF ECOLOGY • June, 1974
Prepared in Cooperation with
United States Department of the Interior
Geological Survey

STATE OF WASHINGTON
Daniel J. Evans, Governor

DEPARTMENT OF ECOLOGY
John A. Biggs, Director

WATER-SUPPLY BULLETIN 42

Data on Selected Lakes in Washington Part II

By
G. C. BORTLESON, G. T. HIGGINS, and G. W. HILL

Prepared in cooperation with
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3

CONTENTS

ILLUSTRATIONS

TABLES

DATA ON SELECTED LAKES IN WASHINGTON, PART II

By G. C. Bortleson, G.T. Higgins, and G. W. Hill

ABSTRACT

Twenty-three lakes in Washington were investigated to determine their present trophic status and evaluate their potential for nutrient enrichment from cultural and natural sources. The lake basins vary from relatively undisturbed forest land to urban and suburban land, with lakeshore homes numbering from none to more than 50 homes per mile of shoreline. The mean depth—probably the most significant morphometric parameter affecting lake productivity—was rather shallow (12-25 ft) in about two-thirds of the lakes investigated.

The midsummer dissolved-oxygen profiles of most lakes show saturation or slight supersaturation in the epilimnion, and low oxygen content (often depleted) in the hypolimnion. The observed specific-conductance values during winter mixing ranged from 10 to 145 micromhos per centimeter. The specific conductance for about 40 percent of the lakes was fairly low (10-50 micromhos per centimeter). The mean total-phosphorus concentration in the photic zone throughout the year ranged from 3 to 108 micrograms per liter; the median value was 16 micrograms per liter. The mean inorganic nitrogen (ammonia plus nitrate) concentration in the photic zone throughout the year ranged from 50 to 980 micrograms per liter; the median value was 180 micrograms per liter.

Algal blooms were observed at least once on nine lakes; persistent algal blooms were observed on three lakes. The bottom area occupied by submergent rooted aquatic plants ranged from 0.2 to 34 percent of the total bottom area, and the water surface occupied by emergent and (or) floating rooted aquatic plants ranged from less than 0.01 to 9.4 percent of the lake surface area. The lakes with the more abundant macrophyte growth contained a higher percentage of muck in the littoral zone, while lakes with less abundant macrophyte growth contained a higher percentage of coarse sand, gravel and cobbles in the littoral zone.

INTRODUCTION

Washington has a vast and valuable resource of several thousand fresh-water lakes. Lakes are used for recreational and esthetic purposes as well as for water supply, power, irrigation, flood control, and wildlife. As the State's population increases, there are ever-increasing demands placed on lakes and their basins, creating potential nutrient-supply increases, hydrologic changes, and water-quality deterioration. Therefore, a continuing appraisal and evaluation of the lacustrine resource is most important to the welfare and economy of the State.

Various human activities contribute to accelerated enrichment (cultural eutrophication) of lake waters. Among the symptoms of cultural eutrophication are nuisance blooms of algae, increased nutrient levels, depletion of hypolimnetic oxygen, increased turbidity, and changes in the populations and species of phytoplankton, invertebrates, and fishes. In order to detect any present or anticipated impairment, it is essential that existing conditions in Washington's lakes be investigated and defined. (See Glossary for definition of limnological and hydrologic terms used throughout the report.)

Purpose and Scope

The trophic status of lakes are difficult to document, being controlled by the interaction of many factors both natural and man induced. Although lakes are widely recognized for their importance as a many-faceted resource, the data now available on most of Washington's lakes are not adequate to provide the understanding needed for wise water-management decisions. Therefore, this study was designed to help define the aquatic ecosystems of the lakes in Washington. The study consists of collecting physical, hydrologic, chemical, biologic, and environmental information needed to (1) document the present status of lakes and their basins, (2) establish a base of reference to allow periodic appraisals of future lake conditions, and (3) identify severe limnetic conditions in order to guide more detailed study.

This is the second of a planned series of reports on selected lakes in Washington. The first report by Collings (1973) presented data on 22 lakes studied in 1970. The present report contains data on 23 lakes, shown in figure 1, and includes additional data collected on 13 of the 22 lakes studied by Collings.

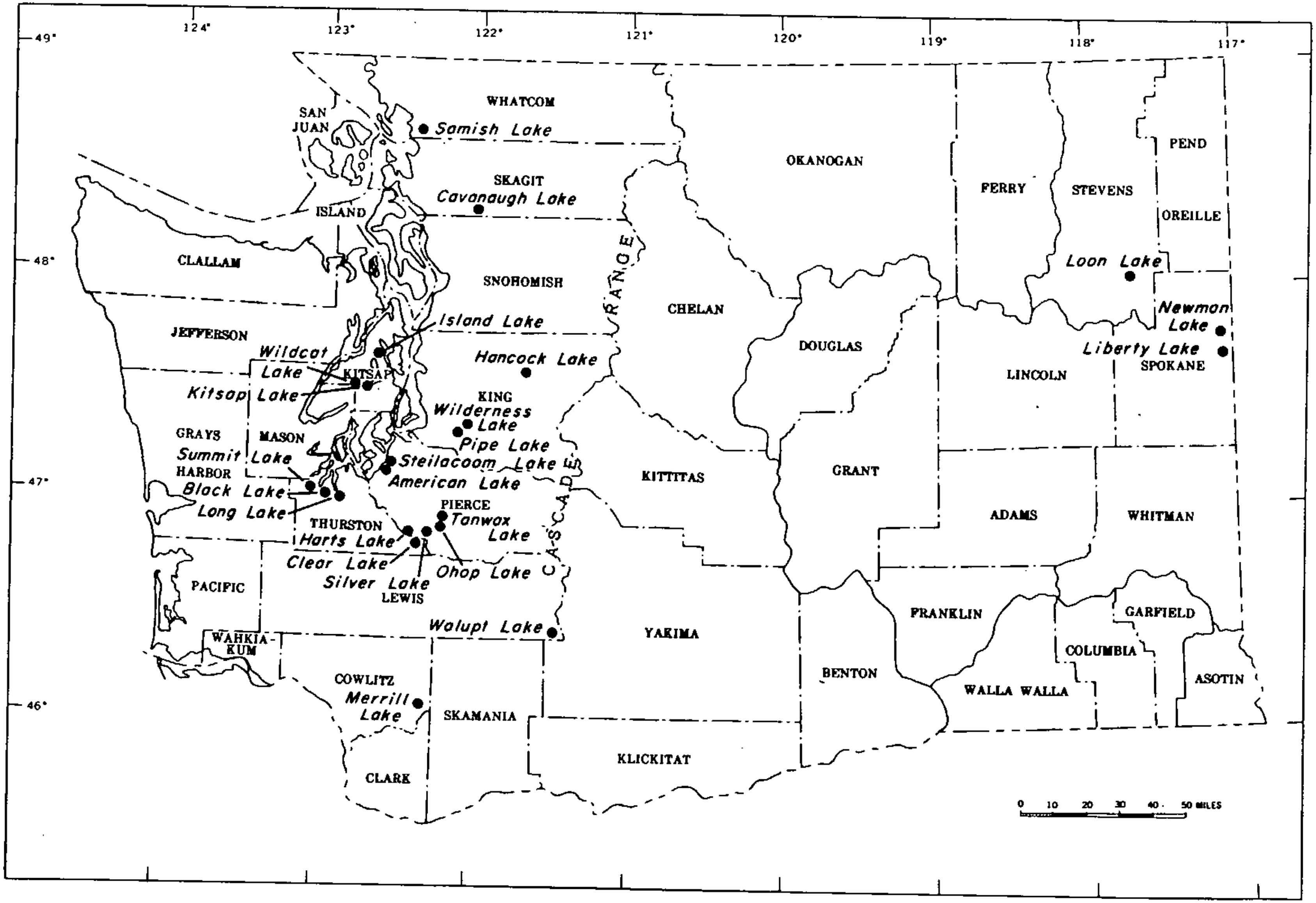

FIGURE 1.—Locations of lakes studied in Washington during 1971.

Acknowledgments

This study was made by the U.S. Geological Survey as part of a program of water-resources investigations carried out in cooperation with the State of Washington Department of Ecology. The authors gratefully acknowledge the assistance of the State of Washington Department of Game which furnished many of the lake bathymetric maps and granted permission to reproduce the maps. Appreciation also is expressed to R. W. Beck and Associates who furnished the bathymetric map of Merrill Lake. Special appreciation is expressed to several lake residents who volunteered to read gage heights to determine lake levels. Critical review of the manuscript by J. D. Stoner of the U.S. Geological Survey and Dr. E. B. Welch of the University of Washington Department of Civil Engineering is gratefully acknowledged.

Data Collection

In 1971, 20 lakes were studied in western Washington and three lakes were studied in eastern Washington. Each lake is listed in the basic-data section of the report by name and by a unique number as a means of identification. An explanation of the lake-numbering system is given by Collings (1973). Sixteen of the 23 lakes studied are lowland lakes in western Washington. Harts, American, Island, and Wilderness Lakes were selected for more detailed data collection (for example, chlorophyll *a*, biomass, algal identification, and total coliform bacteria) as well as for sampling at a frequency of six times annually.

The frequency of lake sampling was governed by the cycles of water mixing and stratification. The most critical sampling periods are during the maximal summer thermal stratification and winter mixing. Sampling during and between these periods facilitates the assessment of duration and rate of DO (dissolved-oxygen) depletion, degree of temperature stratification, biologic productivity, chemical-quality changes induced by stratification and mixing, and mean temperatures in the photic zone. Therefore, data were collected during (1) the winter mixing period; (2) spring, shortly after thermal stratification begins; (3) summer, during thermal stratification; and (4) late summer, at maximum thermal stratification.

Field Methods

Water-Quality Data

Vertical profiles of temperature, DO concentration, and specific conductance were determined in situ in the deepest part of the lake. Water samples for mineral, nutrient, pH, and color analyses were collected at depths of 3 feet below the water surface and 4 to 5 feet above the lake bottom. Measurements of pH and color, as well as the filtration of nutrient samples, were performed in the field. Samples for orthophosphate P (orthophosphate phosphorus) and nitrite plus nitrate N (nitrogen) were filtered immediately through a 0.45-μ (micrometer) millipore filter. The nutrient samples were iced in the field and later refrigerated at 4°C (Celsius). Reactive iron also was determined immediately on selected samples which were unfiltered and unacidified.

Biological data

A visual assessment of phytoplankton density and algal blooms was made during each lake visit. Samples for chlorophyll *a* were filtered immediately in the field (0.5-2 liters) using a 0.45-μ millipore filter. The filtered samples were stored immediately in a dessicator and iced in the field and later stored in a dessicator at -20°C. Analyses were performed on samples from 1 to 20 days after collection. Samples for net phytoplankton identification and biomass (dry-weight phytoplankton, zooplankton and seston) were collected using a Clarke-Bumpus sampler with a 140-μ mess nylon net. Samples collected for biomass were oven dried at 105° for 16 to 20 hours (Vollenweider, 1969). The final values were expressed as milligrams of dry weight per liter. The algae collected for identification were preserved with Lugol's solution according to Standard Methods (American Public Health Association and others, 1971). The rooted aquatic-plant (macrophyte) growth was assessed according to the percentage of the water surface occupied by emergent and (or) floating plants and the percentage of the lake bottom occupied by submergent plants. The plants were identified according to Steward, Dennis, and Gilkey (1963) or Fassett (1969). The water-surface area occupied by emergent and (or) floating plants was categorized as very heavy (>20 percent), heavy (6-20 percent), moderate (2-5 percent), light (0.1-1 percent), and sparse (<0.1 percent). The bottom area occupied by submergent rooted aquatic plants was categorized as very heavy (>50 percent), heavy (26-50 percent), moderate (5-25 percent), light (1-4 percent), and sparse (<1 percent).

Hydrologic data

The seasonal fluctuations in lake stage were obtained from a staff as well as from a crest-stage gage. Instantaneous measurements of surface-water inflow and outflow were made at all lakes. Surface-water outflow from Steilacoom and Hancock Lakes have been or are continuously monitored at Geological Survey gaging stations.

Environmental data

The nearshore dwellings were counted in a field survey and compared to the nearshore structures shown on U.S. Geological Survey topographic maps for previous years. Nearshore homes are defined in this study as riparian homes or those generally within 500 feet of the shoreline. The number of homes per mile of shoreline was calculated and grouped into six categories. The categories were very dense (>45 homes/mi), dense (36-45 homes/mi), moderately dense (21-35 homes/mi), moderately light (11-29 homes/mi), and sparse (0-10 homes/mi).

The amount of forest cover of the lake-drainage area—for example, heavily forested (>90 percent), moderately heavy forest (76-90 percent), moderately forested (51-75 percent), scattered forest (25-50 percent), and sparsely forested (<25 percent)—and the type of land use—for example, agricultural, residential, commercial, and recreational—were estimated with the aid of topographic maps, aerial photographs of lake environs, and field reconnaissance.

The land use categories are defined in the glossary. Vertical, black and white aerial photographs were taken of each lake. The photographs which show sufficient, page-size detail are included in the report. The remaining photographs of the larger lakes are on file with the State Department of Ecology in Olympia and with the U.S. Geological Survey in Tacoma.

Bathymetric maps

Nineteen maps shown in the report were obtained from Wolcott (1964, 1965) or from the files of the Washington Department of Game. Maps of Long and Merrill Lakes were obtained from the U.S. Department of Agriculture, Soil Conservation Service, and R.W. Beck and Associates (consulting engineers), respectively. The maps of Black and Walupt Lakes were made by the U.S. Geological Survey, using plane-table methods for location and a recording fathometer for development of cross-section profiles. The Hancock Lake map was surveyed in 1953 by the U.S. Geological Survey. The majority of the bathymetric maps presented by Wolcott (1964, 1965) were made by the Washington Department of Game using plane-table methods and soundings.

Mean sea-level (msl) datum is established for Loon, Merrill, and Hancock Lakes bathymetric maps, and an arbitrary datum is established for the Walupt, Black, and Kitsap Lake maps. The water-surface altitude for the other 17 lakes was not referenced to any datum at the time the bathymetric maps were surveyed.

Laboratory Methods

Water-quality data

The mineral and nutrient analyses were performed by U.S. Geological Survey laboratories using procedures outlined by Brown, Skougstad, and Fishman (1970). Orthophosphate P and nitrite plus nitrate N analyses were performed on filtered samples (0.45 μ), and total P and ammonia N analyses were performed on unfiltered samples. The samples were preserved on ice or refrigerated until commencement of the analysis.

Biological data

Chlorophyll *a* was determined by the method of Richards and Thompson (1952) as modified by Creitz and Richards (1955) and Strickland and Parsons (1968). The specific absorption coefficients reported by Strickland and Parsons (1968) were used to calculate chlorophyll *a* concentrations.

CONDITIONS AFFECTING TROPHIC STATUS OF LAKES

The change in biota and physiochemical conditions in many lakes has been attributed to eutrophication. Of major concern is the rate of eutrophication or the rate of change in the manifestations of nutrient enrichment. There are no well-defined units or quantitative measures of trophic state. The trophic state of a lake is usually defined by a variety of physical, chemical, and biological indicators. For example, some commonly used chemical indicators are sediment type, hypolimnetic DO deficit, and concentrations of dissolved solids, nutrients, and chlorophyll *a*.

Limnologists have long recognized that lake productivity is affected by factors other than the concentration of nutrients in a body of water. Rawson (1939, 1955) suggested many interrelationships among factors affecting the trophic status of a lake as outlined in figure 2. The nutrient and mineral load imposed on a lake is a function of the geochemistry of its drainage basin, climate, the hydrology of the region, and other natural conditions. Superimposed on these natural factors is a variety of human effects, such as runoff from urban and agricultural areas and the amount of domestic sewage discharging or seeping to a lake. Physical factors influence lake productivity primarily by affecting the distribution, availability, and the utilization of nutrients. Such modifying factors include mean depth, littoral area, bottom conformation, insolation, temperature, circulation, flushing rate, and shoreline irregularity.

Natural Changes

As a lake ages, it goes through a succession of biological, physical, and chemical conditions and events. Most of the lakes in the north temperate regions were formed as a result of glaciation during the Pleistocene "Ice Age" roughly prior to 10,000 or 12,000 years ago. For example, the 13,650-year radiocarbon age of basal peat in Lake Washington establishes this as a minimum date for withdrawal of the Vashon ice sheet from west-central Washington (Crandell and others, 1958). Under natural conditions, lakes proceed toward geological extinction at varying rates of eutrophication or bog formation (Hasler, 1969). Hutchinson (1941) states that three distinct factors are involved in lake eutrophication: (1) the edaphic factor, representing the potential nutrient supply in the surrounding drainage basin; (2) the age of the lake at any stage, indicating the degree of utilization of the nutrient supply; and (3) the morphometric character of any stage, which is dependent on both the original morphometry of the lake basin and the age of the lake, and which presumably influences the oxygen concentration. Hutchinson maintains that true eutrophication takes place only in regions well supplied with nutrients. There are many points of view on the question of natural eutrophication and the trophic-dynamic aspect in succession.

The developmental history of lakes can be called ageing, but all ageing cannot be called eutrophication. Beeton (1966) and Brezonik and others (1969) proposed several possible lines of change for new lakes formed from glacial origin. The classical scheme of lakes inevitably passing through the evolutionary series of oligotrophy, mesotrophy, and eutrophy has been questioned during several recent studies (Goulden, 1964; Mackereth, 1965). Mackereth (1965) theorized that lakes may be more productive in their earlier stages (shortly after glaciation in this case) than in their later stages. Lindeman (1942) and Hutchinson and Wollack (1940) also suggested that the initial period of oligotrophy is relatively short after glacial scour. Lindeman (1942) considered that, after glacial scour, the early eutrophication period levels off and a long period of relatively constant production ensues in a lake. This stable period is termed stage equilibrium, during which the sediments act as a nutrient reservoir or trophic buffer to maintain high production. During the stage equilibrium, sediments continue to accumulate and the lake approaches extinction. From the foregoing, it appears that it has not yet been possible to estimate accurately the basic natural rate of eutrophication.

Cultural Eutrophication

The influence of man on a lake's watershed can result in an increased rate of nutrient influx to the lake which will usually bring about an accelerated rate of undesirable chemical, physical, and biological effects. This process of artificial lake fertilization has often been distinguished from natural eutrophication.

Over the past 50 years it has been determined that large-scale human use of certain lakes has accelerated eutrophication. Much of the enrichment of lakes and streams has been caused by the improperly treated discharge of sewage, Cultural eutrophication has been noted in the lakes near Madison, Wisconsin, Lake Washington in Seattle, Lake Erie, Lake Tahoe, and others. The reader is referred to Stewart and Rohlich (1967) for case histories of lakes that have recently undergone changes. However, Hasler (1969) has cited several cases, including Lake Washington, in which cultural eutrophication has been reversed by corrective measures such as the diversion of effluents from lakes.

According to Edmondson (1968), most lakes appear responsive to fertilization most of the time. Edmondson recognized that because of the interaction of physical and hydrological factors—such as size, shape, depth, exposure to wind, and rate of replenishment of water—on the ability of a lake to produce a crop of organisms with a given supply of nutrients, different lakes will have different sensitivities to enrichment. It would appear from the case histories of culturally eutrophic lakes and the deliberate fertilization of lakes that increased input of nutrients often causes measurable changes in biota and physiochemical conditions. However, indicators of trophic state are only qualitative; it is still impossible, when using certain criteria of trophic status, to state specifically how much more eutrophic one lake is than another or to express the rate of cultural eutrophication of a lake as related to the amount of nutrients.

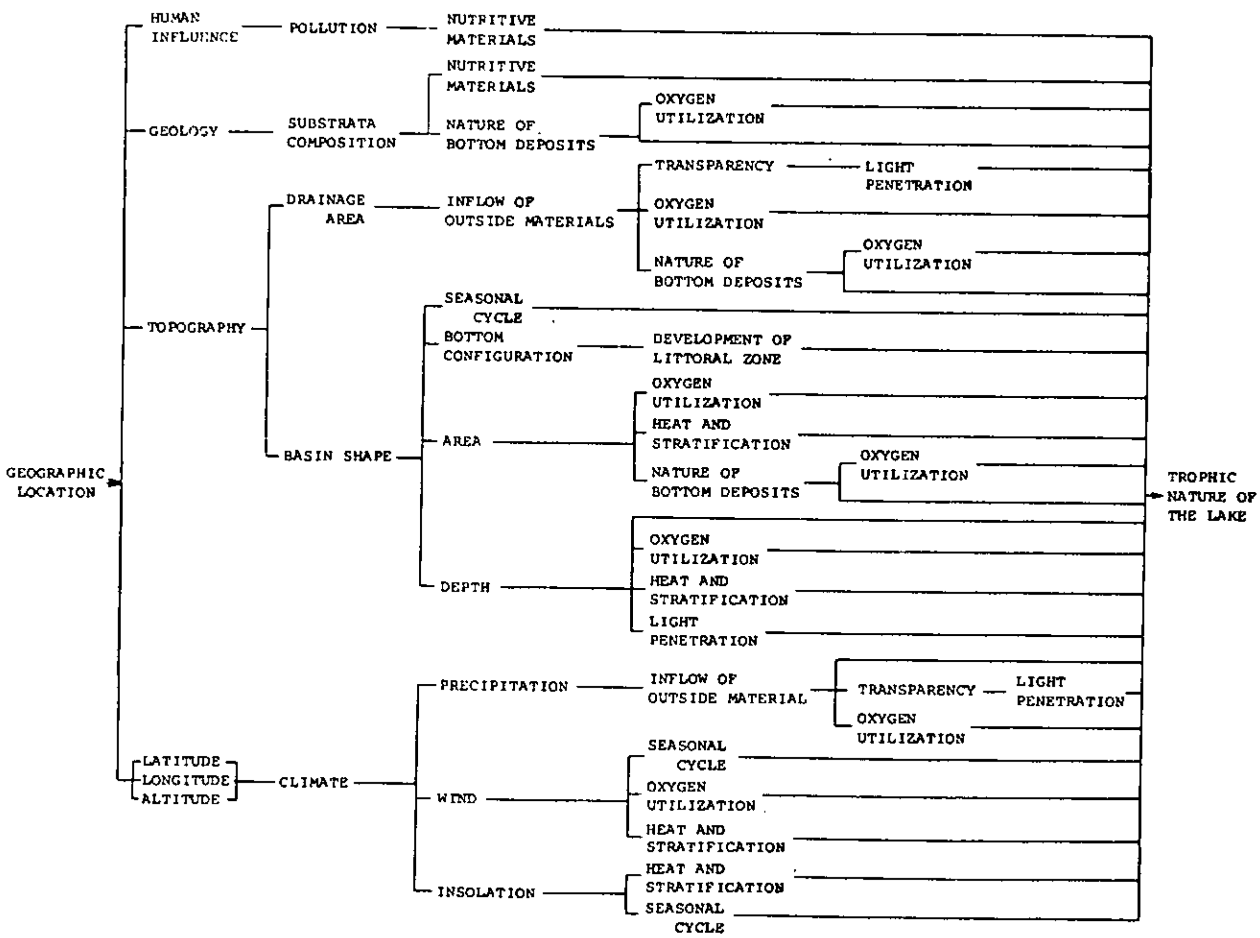

FIGURE 2.—Relations of selected parameters which determine the condition and "age" of a lake (modified from Rawson, 1939).

CHARACTERISTICS OF WASHINGTON LAKES

The basic data for each lake investigated is presented separately in the lake-data section. Despite the individuality of lakes, it is beneficial to discuss the common characteristics of the lakes investigated.

Origin

The origin of many lakes in Washington rests with the area's history of continental and alpine glaciation. Many lakes occupy kettle basins (formed by the melting of masses of buried ice), several occupy glacial-drainage channels, and most of the remaining lakes occupy glacier-cut valleys dammed by glaciofluvial materials or by volcanic rock and mudflow deposits.

Basin Characteristics

Geology

With the exception of nutrient and mineral transport from residential, agricultural, and urban sources, the concentrations of major ions in lake waters are largely influenced by basin characteristics such as bedrock geology, glacial geology, and soil type. If a lake basin is formed in igneous or metamorphic rocks, which are hard and highly insoluble, the water remains low in dissolved constituents. If the lake is created in a region that contains sedimentary rock, the lake reflects the fact by containing more dissolved mineral matter.

Soils

Soil type, as glacial and bedrock geology, exerts a major influence on the ionic composition of lake waters. Diverse parent materials, relief, drainage, and climate in the various lake basins have produced exceedingly dissimilar soils. Most of the soils have developed from weathered bedrock, old valley fillings, recent alluvium, and organic accumulation.

Five lakes (Summit, Hancock, Cavanaugh, Merrill, and Walupt) are in basins with rough, mountainous soils which are infertile, stony, and shallow. About one-half of the lake basins contain some gravelly sandy loam soil developed on glacial till and outwash plains. The gravelly sandy loam is of low fertility, and the surface runoff from this soil is very low because of its high permeability. Poorly drained, local peat and muck deposits are found in about one-third of the lake basins. Inflow streams draining peat and muck deposits are primarily responsible for the high color of Black, Silver, Harts, Tanwax, and Ohop Lakes.

Altitude

The altitude of the lake basin affects leaching processes which release soluble solids and nutrients to the water. In an alpine basin, for example, the water from rain and melted snow may pass through the drainage basin rapidly and is in contact with the surface rocks for only a short time. The higher altitude lakes generally receive a greater amount of runoff from precipitation annually. As such water passes to lower altitudes through additional lakes and streams, it dissolves more and more organic matter, nutrients, carbonates, and soluble salts.

The altitudes above mean sea level of the lakes studied range from 131 feet (Black Lake) to 3,927 feet (Walupt Lake), although about 85 percent of the lakes investigated in western Washington are lowland lakes less than 1,000 feet in altitude. Comparison of the altitudes of eastern and western Washington lakes is not significant because of differences in climate and topography.

Drainage Area

The net flux of nutrients and dissolved salts to a lake is a complex function of environmental factors, but a small ratio of surface area and (or) volume of water to drainage area would tend to produce increased nutrient loading which is often expressed on a basis of unit surface area or volume in order to predict lake response. Thus, in basins with similar inflows, drainage areas, and geologic character, the potential for a high nutrient loading rate is greater for a small lake than for a large lake.

The ratio of volume of water to drainage area, expressed in sq mi (square miles), ranged from 39 acre-ft/sq mi (Steilacoom Lake) to 9,940 acre-ft/sq mi (Summit Lake). About 40 percent of the lakes had ratios ranging from 500 to 2,000 acre-ft/sq mi.

Land Use and Cover

Although the nutrient and mineral load imposed on a lake is a function of the geochemistry of its drainage basin and other natural conditions, superimposed on these natural factors is a variety of land-use and population effects such as pollution from urban and residential runoff. Under natural conditions, well-stocked forest stands—which originally characterized most of the lands in this area—have been found to make very small contributions to eutrophication of natural waters (Cooper, 1969). Deteriorating lake quality occurs when a greater input of nutrient and other substances to lake waters results from increases in the number and concentration of people, commercial and industrial activities, land fertilization, concentration of livestock, and disturbance of natural cover.

Lake basins vary in character from relatively undisturbed forest to sparse forest cover, and from rural to suburban and urban land. Most of the basins described in this report, except the urban and suburban basins of Kitsap, Long, Black, American, and Steilacoom Lakes, are moderately forested to moderately heavy forested.

Population

An assessment was made of the lakeshore residential population at each lake. The shoreline population (homes per mile of shoreline) varied from sparse to very dense, with most lakes catagorized as moderately dense (21-35 homes per mi). The number of homes ranged from none (Walupt Lake) to more than 50 homes (Summit, Cavanaugh, Loon Lakes) per mile of shoreline. At many places the shorelines remaining undeveloped are not suitable for building because of adjacent wetlands. The lakes which have little or no remaining undeveloped land near the shoreline are Summit, Long, Steilacoom, and Cavanaugh Lakes, and the western arm of Samish Lake. The lakes with some scattered undeveloped land are Wildcat, Black, Pipe, Loon, and Liberty. The remaining lakes have open space and (or) wetlands near their shorelines.

The percentage of shoreline occupied by residential development was determined. The residential development did not include church grounds, scout camps, recreational lodges, and other quasi-public and institutional lands.

The capacity of a lake to dilute concentrations of nutrients, silt, and other organic and inorganic materials may be represented by the volume of water (acre-ft) per shoreline home. The dilution capacity of the lakes ranged from 62,300 acre-ft with no shoreline residential homes (Walupt Lake) to 12.4 acre-ft/home (Steilacoom Lake), with about 65 percent of the lakes ranging from 12.4 to 97 acre-ft/home.

A summary of cultural and geomorphic characteristics of the lakes studied are presented in table 1.

Physical Characteristics of a Lake

Since there is a delicate interplay among the factors influencing lake productivity (Rawson, 1939), the net result can hardly be ascribed to the influence of each factor acting alone. However, important generalizations can be made by assessing the individual parameters involved. The morphometric parameters discussed below are often considered as some of the most important of the various physical factors affecting the ability of a lake to produce a standing crop of organisms. A summary of the physical characteristics of 23 Washington lakes is shown in table 2.

Mean Depth

Depth is probably the most significant physical feature affecting a lake's productivity and ability to assimilate nutrients. Water in a small shallow lake may be subject to a greater increase in nutrient enrichment than that in a large deep lake. In shallow, more mature lake basins the ratio of water volume to lake bottom is less than in a deep lake, and thus the potential amount of nutrient material that can diffuse from the mud to water is greater in shallow than in deep lakes. In deeper lakes the total water mass is circulated less than in shallow lakes; this allows the nutrients in the hypolimnion (or region of decomposition) to remain there rather than being brought back into the photosynthetic zone. The mean depths of the lakes studied range from 11 feet (Steilacoom Lake) to 176 feet (Walupt Lake). However, mean depths for about two-thirds of the lakes are rather shallow (12-25 ft).

Mean Slope

The extent of shallow water in a lake is important relative to the total biological activity. Rooted aquatic plants usually grow more profusely in a lake with a gradually sloping basin than in a deep lake with steep sides, where decreasing light intensity becomes a limiting factor. A steep lake-bottom slope also is accompanied by a smaller littoral area and tends to result in poorer recirculation of bottom nutrients.

TABLE 1. Cultural and geomorphic characteristics of lakes studied

Lake	Lake volume (acre-ft) per square mile of lake drainage area	Lake area (acres) per square mile of lake drainage area	Number of homes per mile of shoreline	Volume of lake (acre-ft) per home	Percentage of shoreline undeveloped	Percentage of shoreline containing muck
Island	1,130	66	17	32	58	90
Wildcat	900	48	33	30	19	10
Kitsap	1,640	91	34	50	27	60
Summit	9,930	190	52	97	7	40
Black	1,060	56	29	62	16	20
Long	470	40	29	19	11	40
Ohop	220	13	35	24	49	70
Silver	980	81	19	54	70	90
Tanwax	820	42	25	48	30	30
Clear	1,220	64	3	350	84	5
Harts	880	34	4	520	90	100
American	2,370	45	21	240	47	0
Steilacoom	39	3.5	50	12	0	5
Wilderness	2,150	100	28	28	57	20
Pipe	2,320	87	35	24	17	30
Hancock	820	32	8	270	85	45
Cavanaugh	4,860	110	49	95	8	15
Samish (West Arm)	2,460	35	28	180	38	15
Samish (East Arm)	3,600	74	27	140	9	5
Loon	3,650	80	60	110	15	30
Newman	790	43	32	72	33	40
Liberty	1,230	54	41	83	17	10
Merrill	2,070	54	1	2,350	96	20
Walupt	4,550	26	0	6,230	100	5
Average	2,090	61	28	460	41	--
Median	1,220	54	28	72	30	--

TABLE 2. Physical characteristics of lakes studied

Lake	Surface area (acres)	Mean depth (ft)	Maximum depth (ft)	Shoreline configuration	Development of volume	Mean slope (percent)
Island	47	17	35	1.55	0.49	8.6
Wildcat	121	18	32	1.45	.58	4.7
Kitsap	248	18	29	1.22	.62	2.7
Summit	528	53	100	1.74	.53	9.1
Black	567	19	29	1.80	.65	2.8
Long	328	12	21	2.79	.57	3.8
Ohop	230	17	25	2.15	.66	4.5
Silver	149	12	25	1.01	.54	2.1
Tanwax	170	20	30	1.51	.65	5.1
Clear	168	19	25	1.50	.75	4.0
Harts	121	26	50	1.04	.52	5.5
American	1,135	53	90	2.49	.59	8.2
Steilacoom	317	11	20	2.28	.56	2.8
Wilderness	69	21	38	1.53	.54	7.7
Pipe	55	27	65	1.64	.41	13
Hancock	246	25	36	1.25	.70	3.3
Cavanaugh	804	44	80	1.91	.56	6.0
Samish (West Arm)	130	71	145	1.14	.49	16
Samish (East Arm)	680	31	75	1.71	.42	5.1
Loon	1,127	46	100	1.68	.46	5.4
Newman	1,220	19	30	2.00	.62	2.0
Liberty	713	23	30	1.27	.76	1.9
Merrill	488	39	77	2.04	.50	8.1
Walupt	354	176	295	1.29	.60	24
Average	--	34	--	1.67	0.57	6.4
Median	--	21	--	1.55	.56	5.1

Shoreline Configuration

Shoreline configuration—used in the report instead of the accepted but sometimes confusing limnological term "development of shoreline"—is the relation of the shoreline length to the circumference of a circle having the same area as the lake. Shoreline configuration (D_L) may be calculated from the formula:

$$D_L = L/2\sqrt{\pi A}$$

in which L is the length of the shoreline and A is the area of the lake. Since the ratio is related to a circle, a perfectly round lake would result in an index of 1.0. Increasing irregularity of shoreline, in the form of embayments and projections from shore, is reflected in the ratio by values greater than 1.0. Increased shoreline irregularity results in greater contact of water and land, increased areas of protected bays and areas of shallow water, and increased opportunity for close superposition of the photosynthetic zone on the decomposition zone, resulting in rapid turnover of nutrients.

The shoreline-configuration ratio of the lakes studied ranged from 1.04 (Harts Lake) to 2.79 (Long Lake) with about 40 percent of the lakes investigated being in the range of 1.51 to 2.00.

Development of Volume

The development of volume is defined as the ratio of the mean depth to the maximum depth and provides a measure of the shape of the lake basin. The majority of lake basins in this study have a ratio greater than 0.33, the value that would be given by a conical depression. Thus, lakes with a high development of volume are generally shallow lakes with flat bottoms. The larger the development of volume the greater is the opportunity for exposure of bottom sediments to overlying water and for circulation of bottom nutrients.

The development of volume ranged from 0.41 (Pipe Lake) to 0.76 (Liberty Lake) with about 40 percent of the lakes investigated being in the range of 0.51 to 0.60.

Water-Quality Characteristics

The present water-quality characteristics of the lakes were evaluated in order to (1) determine basic limnological features of the lakes, (2) provide foundation data for future studies, and (3) study the relationships of lake watershed conditions to lake-water quality.

Chemical Quality

A summary of the chemical-quality data from the 23 study lakes is shown in table 3. A more comprehensive listing of water-quality data is published by the U.S. Geological Survey (1970-71).

Specific conductance

In natural waters the specific conductance is related to dissolved solids. Lakes with higher dissolved solids tend to be more productive than lakes with very dilute waters. The specific-conductance values depend mainly on the quantity in solution of ions of Ca (calcium), Na (sodium), K (potassium), Mg (magnesium), SO_4 (sulfate), HCO_3 (bicarbonate), and Cl (chloride). Water analysis during the winter mixing period gave mean values of Ca, Na, Mg, and K of 6.3, 3.4, 2.1, and 0.7 mg/l, (milligram per liter), respectively, with Ca>Na>Mg>K on a molar basis. The mean values of HCO_3, SO_4, Cl, and F (fluoride) were 31, 3.8, 2.8, and 0.1 mg/l, respectively. The major buffering system in natural waters is the CO_2-bicarbonate-carbonate system. This system not only neutralizes acids and bases so as to reduce the fluctuations in pH, but forms a reservoir of carbon for photosynthesis. HCO_3 concentrations ranged from 9 mg/l (Hancock Lake) to 92 mg/l (Loon Lake).

The vertical distribution of specific conductance was followed seasonally in each lake, and at winter mixing the average specific conductance in the vertical column ranged from 10 µmhos/cm (micromhos per centimeter) in Hancock Lake to 145 µmhos/cm in Loon Lake. The specific conductance increased appreciably in the hypolimnion in about one-half of the lakes during summer stagnation. In Clear, Long, Black, and Ohop Lakes, the specific conductance increased slightly (5-20 µmhos/cm) in the epilimnion as well as in the hypolimnion during the summer, apparently due to a buildup of solutes in the bottom waters and their subsequent transfer to the upper waters.

The progressive decline in DO concentration in the hypolimnion is often concurrent with the mobilization and transfer of ionized solutes and organic materials from the bottom sediments. The liberation of solutes from the bottom sediment may have potential biological consequences when the waters become mixed.

TABLE 3. Average chemical characteristics of lakes studied, 1970-71.
[Number of samples varies between lakes and items sampled, usually from three to seven samples]

Lake	Silica (SiO_2) in epilimnion (mg/l)	Dissolved iron (Fe) in epilimnion (μg/l)	Dissolved iron (Fe) in hypolimnion (μg/l)	Bicarbonate (HCO_3) in epilimnion (mg/l)	Color (Co-Pt) units in epilimnion	Specific conductance (μmhos/cm) at 25°C in epilimnion	Specific conductance (μmhos/cm) at 25°C in hypolimnion
Island[a]	3.5	70	190	16	20	41-43	40-72
Wildcat[a]	1.9	70	160	23	10	43-44	40-75
Kitsap[a]	2.8	150	220	42	15	77-85	80-132
Summit	1.6	70	450	21	15	47-49	47-51
Black	2.6	190	250	26	55	53-58	53-68
Long	6.6	310	320	42	25	82-92	82-130
Ohop[a]	8.4	270	430	20	40	53-73	54-103
Silver[a]	4.2	210	290	36	55	79-82	78-148
Tanwax[a]	2.4	240	960	33	50	63-68	63-160
Clear	1.3	60	70	40	5	66-77	67-100
Harts[a]	4.6	460	4,300	62	40	122-129	120-176
American[a]	7.4	20	130	50	5	96-105	105-116
Steilacoom[a]	7.5	20	360[b]	48	10	108-120	108-140
Wilderness[a]	3.9	50	400	36	5	65-70	65-162
Pipe[a]	4.2	90	270	20	10	48-53	52-56
Hancock[a]	.7	50	50[b]	9	10	10-18	13-16
Cavanaugh	2.1	50	5	13	10[b]	28	26-36
Samish (West Arm)	7.9	60	990	18	5[b]	62-65	65-75
Samish (East Arm)	5.4	50	540[b]	22	10	63-69	63-75
Loon	3.4	40	1,400	92	5	128-145	145-160
Newman	3.6	140	160	28	15	45-50	45-65
Liberty	3.0	110	150[b]	24	15	42-47	44-47
Merrill[a]	1.3	80	20[b]	15	5	23	22-24
Walupt	.4	20	10	17	0	25-27	27-28

[a]Execpt for specific conductance, average value in epilimnion includes data for winter 1970 sampling period.

[b]One sample only.

Color

The lakes can be grouped into four general categories which include high specific conductance and high color (Harts Lake), high specific conductance and low color (Loon, American, and Steilacoom Lakes), low specific conductance and high color (Black, Ohop, Silver, and Tanwax Lakes), and low specific conductance and low color (15 lakes). High specific conductance was designated as greater than 100 μmhos/cm and high color greater than 35 Co-Pt (cobalt-platinum) units. With the exception of Black Lake, the high-color lakes are all located in the Nisqually River basin in south-central Pierce County.

Iron and hydrogen sulfide

The lakes that contain high color were generally high in iron. Iron is often present with organic compounds. The average dissolved iron concentration in the epilimnion ranged from 20 μg/l (micrograms per liter; Walupt, Steilacoom, American Lakes) to 310 μg/l (Long Lake), and averaged 120 μg/l. During the summer stratification period, the bottom waters often become enriched in iron because of low DO conditions. The dissolved-iron concentrations in the hypolimnion increased at least tenfold during the summer in Summit, Harts, American, Steilacoom, Samish, and Loon Lakes. With the exception of Steilacoom, all the lakes are deep, well-stratified lakes.

In a sustained low-DO environment, the "rotten-egg" odor, or H_2S (hydrogen sulfide) gas, is distinctive. The bottom waters of Loon, American, and Harts Lake had maximum H_2S concentrations of 0.5, 3.0, and 1.5 mg/l, respectively, during the summer.

Silica

Silica (SiO_2) forms the basis of the skeletal structure of the most important group of algae in the water, the diatoms. A major decrease in dissolved silica is often found in the epilimnion after a bloom of diatoms. Silica concentrations ranged from 0.7 mg/l (American Lake) to 18 mg/l (Liberty Lake) and averaged 8.5 mg/l.

Transparency, Temperature, and Dissolved Oxygen

A summary of the transparency, temperature, DO, and pH conditions is presented in table 4.

Secchi-disc visibility

Because changes in biological productivity can cause changes in the color and turbidity of a lake, observations of the transparency—or amount of natural light penetrating the upper layers of a lake—are used to describe changes in trophic state. The transparency of lake water is commonly related to the depth of visibility of a Secchi disc. The average Secchi-disc visibility taken over the year ranged from 6 feet (Ohop, Silver, and Harts Lakes) to 26 feet (Walupt Lake); the median Secchi-disc visibility was 12 feet. Pronounced changes in Secchi-disc readings during the year occurred for Clear (4.5 to 22.0 ft), Harts (3.0 to 11.0 ft), Steilacoom (4.5 to 10.5 ft), and Merrill (11 to 33 ft) Lakes.

Water temperature

Typically, in winter and early spring, the temperature of water is uniform from the surface to the bottom. During the summer, however, the vertical distribution of temperature may vary according to light absorption, density phenomena, and wind action. The mean temperature in the photic zone during the summer ranged from 9.1°C (Hancock Lake) to 18.5°C (Tanwax Lake). The mean temperature ranged from 15.0 to 16.9°C in about one-half of the lakes. The degree of temperature stratification varied considerably. Water in the weakly stratified lakes—such as Kitsap, Long, and Clear Lakes—circulates readily from top to bottom, even during part of the summer. Water in the well-stratified lakes—such as Harts, American, Pipe, and Loon Lakes—circulates poorly during the summer and much of the spring and fall. The lowland lakes investigated in western Washington are monomictic—that is, the lakes mix only once a year, which is during the winter.

Water temperature may affect lake productivity in several ways. High temperatures may increase the severity of algal blooms by stimulating metabolic rates. The algal-species distribution also may change with temperature, with the possibility that production of more noxious species—such as blue-green algae—may be favored in warmer waters. Finally, temperature may influence lake productivity more subtly by metabolic changes in algal cells and by limiting circulation, thereby rendering nutrients in the hypolimnion unavailable for primary production.

TABLE 4. Transparency, temperature, and dissolved-oxygen conditions of lakes studied in 1971

Lake	Secchi-disc visibility depth Mean (ft)	Secchi-disc visibility depth Range (ft)	Temperature stratification (degree)	Mean temperature in photic zone May-October (°C)	Dissolved oxygen (DO)* depletion in summer hypolimnion (percent)	pH in epilimnion (units)
Island	10	9-12	Moderate	16.7	25	7.1-7.8
Wildcat	15	14-16	Strong	16.3	11	7.2-7.6
Kitsap	12	7-16	Weak	17.0	5	7.7-8.2
Summit	17	9-25	Strong	14.9	38	7.1-8.2
Black	8	8-9	Weak	16.5	11	7.3-8.0
Long	8	6-11	Weak	16.8	7	7.5-8.1
Ohop	6	6-9	Moderate	17.8	33	6.8-7.8
Silver	6	6-7	Weak	17.1	15	7.4-8.4
Tanwax	7	5-8	Moderate	18.5	35	7.5-8.9
Clear	12	5-22	Weak	16.8	17	7.6-8.2
Harts	6	3-11	Strong	17.8	54	7.6-10.2
American	20	13-25	Strong	15.6	32	7.9-8.8
Steilacoom	8	5-11	Weak	16.5	1.2	7.5-9.2
Wilderness	12	5-18	Strong	15.8	24	7.6-8.9
Pipe	16	15-19	Strong	16.3	18	7.4-7.6
Hancock	17	15-22	Weak	9.1	.5	7.0-7.2
Cavanaugh	15	12-18	Strong	14.3	12	7.2-8.1
Samish (West Arm)	13	12-17	Strong	14.0	14	7.2-8.8
Samish (East Arm)	11	10-17	Strong	16.2	20	7.4-8.1
Loon	23	22-25	Strong	15.6	20	8.3-8.6
Newman	9	6-14	Moderate	17.1	9	7.8-8.6
Liberty	12	10-17	Weak	17.9	9	7.2-8.4
Merrill	22	11-33	Weak	11.0	0	7.0-7.6
Walupt	26	20-32	Strong	9.5	1.5	7.2-7.9

*DO depletion in hypolimnion as a percentage of total volume of lake which contains 4.0 mg/l DO or less.

Dissolved oxygen

Oxygen plays an important role in regulating chemical, biological, and physical processes in water and, in turn, the concentration of oxygen is regulated by these processes. The vertical distribution of DO was followed seasonally in each lake. The feature of special significance is the amount of DO in deep water during midsummer. The organisms in the upper layers of water produce organic matter which settles into the hypolimnion, and thereby the oxygen content in the hypolimnion is then reduced as the organisms degrade the organic materials. Thus, the hypolimnetic-oxygen deficit is frequently related to either the productivity or the biomass of phytoplankton in the epilimnion.

The DO profiles at midsummer show saturation or slight supersaturation in the epilimnion, and low DO content, often depleted, in the hypolimnion. However, in Merrill Lake the DO remained near saturation in the hypolimnion, and in Walupt Lake the DO remained near saturation throughout most of the hypolimnion but decreased near the bottom. In 11 lakes, during the spring and summer stratification, supersaturated (often 120-170 percent of saturation) DO concentrations occurred in and below the epilimnion. The DO supersaturation in or near the metalimnion were observed in Harts, American, Wilderness, Samish (western arm), and Loon Lakes. The supersaturated conditions in the epilimnion also were indicated by the corresponding high pH values. The rate of DO depletion and the duration of low DO concentration in the hypolimnion varied considerably from lake to lake. The summer hypolimnetic water containing less than 4.0 mg/l of DO accounted for 54 percent of the entire volume of Harts Lake. Although the hypolimnetic-DO loss in Harts Lake was the most severe, the hypolimnetic water in 15 other lakes containing less than 4.0 mg/l DO accounted for 10 to 38 percent of the lakes' volumes. A DO concentration of 4.0 to 5.0 mg/l is often considered a minimum quantity needed to sustain those fish and fishfood organisms intolerant of low DO values. For good growth and general health of trout, salmon, and other species of cold-water biota, the DO concentrations should not be below 6.0 mg/l (U.S. Department of Interior, 1968).

Nutrients

Many elements and compounds act as nutrients to supply the food for aquatic plants and phytoplankton. However, nitrogen and phosphorus usually are considered the limiting nutrients and as such received the most emphasis in this study. Whatever nutrient is limiting primary production, the concentrations of nitrogen and phosphorus are useful in evaluating the trophic conditions of a particular lake. Experimental work on Wisconsin lakes led Sawyer (1947) to the conclusion that nuisance algal growths are likely to develop in lakes during the summer when both the concentrations of inorganic nitrogen as N (nitrate plus ammonia) and orthophosphate phosphorus as P exceed 300 μg/l and 10 μg/l, respectively, during the homothermal period. As a general rule, waters with a total P and inorganic N concentrations in excess of 20μg/l and 300μg/l, respectively, may be regarded as critical to likely development of nuisance plant growths (Vollenweider, 1968).

The mean concentrations of orthophosphate P, total P, and inorganic N are shown in table 5. The nutritional status for the lakes was established according to the tentative scale below, as modified from that of Vollenweider (1968) for total P and inorganic N.

Trophic characteristics	Total P (μg/l)	Orthophosphate P (μg/10	Inorganic N (μg/l)
Oligotrophic	<5	<1	<200
Oligo-mesotrophic	5-10	1-5	200-300
Meso-eutrophic	10-30	5-20	300-650
Eutrophic	>30	>20	>650

The mean concentration of total P in the photic zone throughout the year ranged from 3μg/l (Samish Lake, eastern arm) to 108 μg/l (Harts Lake). The median value was 16 μg/l. The mean concentration of inorganic N in the photic zone throughout the year ranged from 50 μg/l (Merrill Lake) to 980 μg/l (Harts Lake). The median value was 180 μg/l. At winter-turnover time, Tanwax, Black. Ohop, Silver, Samish (western arm), and Harts Lakes had water with both the average total P and inorganic N concentrations equal to or greater than 20 μg/l and 300 μg/l, respectively, which is regarded as critical to likely development of nuisance algal growth.

High concentrations of inorganic N were observed in Steilacoom and Samish (eastern arm) Lakes, but the total P concentrations were not in excess of 20 μg/l. High concentrations of total P were observed in Wilderness, Liberty, and Newman Lakes, but the inorganic N concentrations were not in excess of 300 μg/l.

TABLE 5. Average phosphorus and nitrogen concentrations in lakes studied, 1970-71
[Sampled 3 feet below lake surface]

Lake	Number of Samples	Inorganic nitrogen (N), in µg/l	Otho-phosphate (as P), in µg/l	Total phosphorus (P), in µg/l	Number of Samples	Inorganic nitrogen (N), in µg/l	Ortho-phosphate (as P), in µg/l	Total phosphorus (P), in µg/l
	Average (February-May)				Average (February-November)			
Island[a]	3	180	7	13	7	120	7	13
Wildcat[a]	3	180	7	7	5	140	4	6
Kitsap[a]	3	210	3	13	5	300	8	20
Summit	2	40	0	0	4	60	8	8
Black	2	1,350	20	25	4	500	18	35
Long	2	190	10	15	4	260	12	22
Ohop[a]	3	390	17	27	5	320	18	30
Silver[a]	3	520	17	30	5	410	16	34
Tanwax[a]	3	610	7	27	5	450	8	26
Clear	2	240	15	25	4	280	32	45
Harts[a]	3	1,350	123	190	7	680	66	108
American[a]	3	300	3	13	7	170	6	16
Steilacoom[a]	3	1,220	7	17	5	980	8	22
Wilderness[a]	3	210	3	20	7	180	10	31
Pipe[a]	3	220	0	7	5	170	4	10
Hancock[a]	3	130	3	7	5	100	4	6
Cavanaugh	2	300	5	15	4	190	5	10
Samish (West Arm)	2	770	0	20	4	470	3	12
Samish (East Arm)	1	660	0	0	3	400	3	3
Loon	1	50	0	0	3	60	3	7
Newman	2	140	20	30	4	170	15	22
Liberty	2	100	25	30	4	100	18	25
Merrill[a]	3	50	5	10	5	50	7	10
Walupt	1	80	0	0	3	140	3	7

[a]Average value includes data for winter 1970 sampling period.

Hydrologic Characteristics

The average annual precipitation, estimated residence time of the lake water, and observed lake-stage range are presented in table 6.

Surface-Water Inflow and Outflow

Basically, plankton growth—most often used to indicate lake productivity relative to the amounts of nutrients and dissolved salts in the water—is influenced hydrologically by the residence time of water in the lake, or the relation of various sources of inflow to, and outflow from, the lake. The two main sources of water for lakes are surface and ground water. The effect of water replenishment depends primarily on the proportion of the volume of the lake to the volume of water leaving the basin within a year. The seasonal variations of water renewal are also of great importance. The question of whether or not replenishment by water in large quantity diminishes the productivity of a lake also depends on such factors as the time of displacement seasonally, the quality of the inflow, the proximity of inflow to the outflow, and the amount of short circuiting in the lake basin due to thermal stratification or water-density differences. If the residence time of water in the lake is long and the influx of nutrients is high, the lake will likely become enriched to a greater degree. On the other hand, if the residence time is short and the influx of nutrients low (or high), the lake will likely become enriched to a lesser degree.

During four sampling dates in 1971, no outflow was observed at Island, Loon, and Merrill Lakes, whereas no inflow was observed at Island, Silver, Wilderness, Pipe, and Loon Lakes. American and Loon Lakes appear to be seepage lakes and have appreciable exchange of ground-water inflow and outflow, whereas Merrill Lake has only appreciable ground-water outflow.

The estimated residence times ranged from 0.06 year (Steilacoom Lake) to 2.2 years (Harts Lake), and the median value was 1.3 years. The residence time, which was based on the average volume of the lake divided by the average annual surface-water outflow, was calculated for the lakes with an unregulated surface-water outflow.

Lake Stages

From the standpoint of the lakeshore resident, it is generally desirable to keep the lake stage—as recorded by gage height—at about the same level the year around. At high lake stages, water submerges piers and floods yards, basements, and septic-tank drainfields. To maintain a lake at a constant stage requires an outlet structure that permits both the discharge of excess quantities of water and the retention of water during dry periods. The range in stage of an uncontrolled lake primarily depends upon the quantity of water flowing into the lake, the geometry of the lake, and the capacity of the outlet to discharge excess water. Thus, a small lake with a large inflow will have a much greater range in stage than a large lake with the same or smaller inflow, provided the outflow channel capacities are the same. For lakes with small drainage areas the problem of maintaining a suitable level during the dry periods is frequently more difficult than that of trying to dispose of the excess water during wet periods.

water during wet periods.

Data are given for each lake on the type and altitude datum of gage used, frequency of the readings, and historical lake-level records. Most of the gage heights are referenced to an arbitrary local datum, but the lake stages of Merrill, American, Loon, and Liberty Lakes are referenced to mean sea level. Although it is difficult to make comparisons between lakes because of their differing lengths of record and frequency of observations, the average annual variation in gage height, with the exception of that for Merrill Lake, ranged from 1.2 to 3.1 ft for 11 lakes. The stage range was determined only for the lakes with observation frequencies at least once a week. The stage variation of Merrill Lake was 33.8 ft during the 1971 water year, the high inflow rate and corresponding loss to ground water being responsible for the large variation.

Biologic Characteristics

Plankton

One of the more subjective measurements used to assess the biological state of a lake is the number of objectionable blooms of algae. Although there is no general agreement on the exact number of organisms that constitute an algal bloom, frequently 0.5 to 1 million cells per liter is used as a definition. An algal-bloom condition usually results in a "pea soup" appearance. The biomass is used as a measure of the zooplankton and

TABLE 6. Precipitation, water residence time, and maximum variation of lake state

Lake	Average annual precipitation (inches)	Estimated residence time of lake water (years)	Maximum variation of observed lake stage (ft)
Island	40	--	--
Wildcat	55	1.1	[a]2.8
Kitsap	50	1.1	--
Summit	55	--	1.2
Black	45	.5	--
Long	50	.4	--
Ohop	45	.2	3.1
Silver	45	2.0	2.0
Tanwax	45	.8	1.7
Clear	50	1.6	--
Harts	45	2.2	--
American	40	--	--
Steilacoom	40	.06	--
Wilderness	50	1.3	1.3
Pipe	50	1.6	--
Hancock	100	.2	--
Cavanaugh	70	1.3	1.3
Samish (West Arm)	40	.5	2.4
Samish (East Arm)	40	1.2	2.4
Loon	20	--	1.9
Newman	20	1.7	2.1
Liberty	25	--	2.4
Merrill	130	--	34
Walupt	70	1.7	--

[a]Includes crest-stage measurement for observed maximum height.

phytophankton populations, but its determination does not allow a distinction between living and nonliving material. The extraction of chlorophyll *a* (plant pigment) from a sample is a method more commonly used to assess the phytoplankton biomass.

Visual observations showed that algal density and blooms varied considerably from lake to lake. Algal blooms with their "pea soup" appearance were observed at least once on each of nine lakes, with the most persistent blooms being noted on Silver, Harts, and Kitsap Lakes. However, a high algal density (not algal-bloom proportions) was observed at least once on each of 16 lakes. Biomass and chlorophyll *a* were determined on four lakes. The average biomass concentrations determined for four sample-collection dates were 0.14, 1.1, 0.11, and 6.9 mg/l, respectively, for Island, Wilderness, American, and Harts Lakes. Although the increasing net plankton biomass values generally correspond to increasing trophic state of these lakes, there is not necessarily a correlation between trophic state and net plankton biomass. Findenegg (1965) notes that nannoplankton, which are not included in net plankton make up a larger part of the algal biomass. The average chlorophyll *a* concentrations, representing two sample-collection dates ranged from 2.3 μg/l for American Lake to 28 μg/l for Harts Lake.

Macrophytes

Changes in both abundance and type of macrophyte vegetation in a lake have been regarded as indicative of enriched conditions and thus a measure of eutrophication. In general, dominance by any one type of rooted aquatic plant is considered indicative of enriched conditions. Dense growths of rooted aquatic plants near the shoreline often present a nuisance problem for swimming and boating activities. Although the presence of aquatic plants is common, little is known about their adverse and (or) beneficial effects on water quality. During growth, detrimental effects are few because the DO is increased and inorganic nutrients are absorbed from the water. At the end of the growing season, or when the plants are killed, their decomposition may exert heavy demands on the DO content of the water, and, in addition, nutrients may be released from the decaying mass. The factors that trigger the development of dense macrophyte growth instead of dense algal populations (and conversely) are presently unknown, although the competition between phytoplankton and macrophytes has been discussed by Fitzgerald (1968).

The percentage of the bottom area occupied by submergent rooted aquatic plants and of the water surface occupied by emergent and (or) floating rooted aquatic plants varied considerably between lakes. The lakes with more abundant macrophyte growth (either emergent or submergent plants) are Island, Long, Harts, Silver, Pipe, Loon, and Newman Lakes; these lakes contain a greater percentage of muck in the littoral zone. The lakes with the least abundant macrophyte growth are Clear, American, Steilacoom, Wilderness, Walupt, and Samish Lakes. The lakes that appear to develop dense macrophyte growth instead of dense algal populations are Island, Pipe, and Loon Lakes. Conversely, Clear Lake develops a dense algal population and a less dense macrophyte growth.

CONCLUSIONS

The geomorphic, hydrologic, and cultural characteristics of the lakes and their drainage basin were investigated to determine the nutrient-enrichment potential from natural and cultural sources. A summary of the factors that may enhance the distribution and availability of nutrients are listed below.

1. Shallow mean depth.
2. Low altitude.
3. Low mean slope.
4. Small ratio of volume of water to drainage area.
5. Small ratio of lake surface area to drainage area.
6. High value for shoreline configuration.
7. High value for development of volume.
8. Small volume of water to number of nearshore homes.
9. High percentage of the shoreline or watershed developed.
10. High percentage of the shore containing muck deposits.
11. Low flushing rate.
12. Inflow drainage through peat and muck deposits.
13. High mean temperature in the photic zone.
14. High nutrient content in inflow waters.

The nutrient-enrichment potential for eight lakes was rated as medium-high or high as shown in table 7. Only Hancock, Samish (western arm), Merrill, and Walupt Lakes were rated as having either a low or medium-low enrichment potential.

The biological, physical, and chemical parameters used to indicate the trophic state of the lakes are summarized below.

1. Nutrient concentrations in the lake water.
2. Dissolved solids (specific conductance) in the epilimnion and hypolimnion.
3. Color.
4. Bicarbonate concentration.
5. Silica concentration.
6. Frequency of algal blooms.
7. Abundance of rooted aquatic plants.
8. DO depletion in the hypolimnion.

The overall trophic classification of each lake is presented in table 7. The eutrophic lakes included Silver, Harts, and Steilacoom Lakes and the oligotrophic or oligo-mesotrophic lakes included Wildcat, Summit, Pipe, Hancock, Merrill, and Walupt Lakes. Seven lakes were categorized as meso-eutrophic lakes, and the remaining lakes were categorized as mesotrophic.

TABLE 7. Trophic classification of lakes studied

Lake	Nutrient enrichment potential	Phosphorus concentration	Indicators of trophic state[a]	Overall trophic classification
Island	Medium	Meso-eutrophic	Medium	Mesotrophic
Wildcat	Medium	Oligo-mesotrophic	Medium	Oligo-mesotrophic
Kitsap	Medium-high	Meso-eutrophic	Medium	Meso-eutrophic
Summit	Medium	Oligo-mesotrophic	Medium	Oligo-mesotrophic
Black	Medium-high	Meso-eutrophic	Medium	Meso-eutrophic
Long	High	Meso-eutrophic	Medium-high	Meso-eutrophic
Ohop	High	Meso-eutrophic	Medium-high	Meso-eutrophic
Silver	Medium	Meso-eutrophic	Medium-high	Eutrophic
Tanwax	Medium-high	Meso-eutrophic	Medium-high	Meso-eutrophic
Clear	Medium	Meso-eutrophic	Medium	Mesotrophic
Harts	Medium	Eutrophic	High	Eutrophic
American	Medium	Meso-eutrophic	Medium	Mesotrophic
Steilacoom	High	Eutrophic	Medium	Eutrophic
Wilderness	Medium	Meso-eutrophic	Medium	Mesotrophic
Pipe	Medium	Oligo-mesotrophic	Medium-low	Oligo-mesotrophic
Hancock	Medium-low	Oligo-mesotrophic	Medium-low	Oligo-mesotrophic
Cavanaugh	Medium	Meso-eutrophic	Medium-low	Mesotrophic
Samish (West Arm)	Medium-low	Meso-eutrophic	Medium	Meso-eutrophic
Samish (East Arm)	Medium	Oligotrophic (?)	Medium	Mesotrophic
Loon	Medium	Oligo-mesotrophic	Medium	Mesotrophic
Newman	Medium-high	Meso-eutrophic	Medium	Meso-eutrophic
Liberty	Medium-high	Meso-eutrophic	Medium	Meso-eutrophic
Merrill	Low	Oligo-mesotrophic	Medium-low	Oligo-mesotrophic
Walupt	Low	Oligo-mesotrophic	Low	Oligotrophic

[a]Nutrients not included in assessment.

LAKE DATA

12070455. Island Lake near Keyport

Location

Kitsap County, 2.2 miles southwest of Keyport (fig. 1).

Origin

Kettle lake formed in glacial recessional moraine.

Basin geology

Glacial drift and some volcanic rocks (Sceva, 1957).

Soils

Fine sandy loam and loamy sand (Wildermuth and others, 1939).

Land use and cover

Heavily forested, with residential clearings. Forest cover is mostly second-growth Douglas fir and cedar interspersed with alder and madrona.

Population

Lakeshore development moderately light, with 25 homes and a resort in August 1971, compared to 18 lakeshore dwellings in 1953 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 42 percent of lakeshore.

Physical characteristics of lake

A bathymetric map of lake is shown in figure 3 and an aerial photograph of lake and surrounding basin is shown in figure 4. The map was surveyed on July 19, 1955, using an arbitrary datum.

Some morphometric parameters of lake, based on the bathymetric map, are listed below:

Drainage area	0.71 sq mi
Altitude (from topographic map)	217 ft
Surface area	47 acres
Lake volume	805 acre-ft
Mean depth	17 ft
Maximum depth	35 ft
Length of shoreline	7,820 ft
Length of lake	2,520 ft
Mean breadth of lake	805 ft
Shoreline configuration	1.55
Development of volume	0.49
Mean slope	8.6 percent

Hydrologic characteristics

Lake stages

Miscellaneous observations of gage height are presented below. The altitude of gage is 217 ft (from topographic map); datum of gage is arbitrary.

Date (1970)	Gage Height (ft)
Feb 9	12.36
Jun 23	11.80
Oct 8	10.41
Oct 27	10.62
Dec 15	11.94

Date (1971)	Gage Height (ft)
Feb 10	12.64
May 11	12.58
Jun 28	12.30
Aug 12	11.54
Sept 16	11.37
Nov 2	11.35

Regulation of lake stage is achieved by an earth dam and a valved 12-inch vertical pipe. The lake spills over the pipe at about the 12.5-ft gage height or from a lower valve in the pipe at about the 10.1-ft gage height. The high-water mark observed on a crest-stage gage is 12.9 ft.

Surface-water inflow and outflow

Several ephemeral streams contribute minor inflow. During 11 visits, the estimated inflow ranged from 0 to 0.05 cfs (cubic feet per second), and the outflow channel was dry.

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figures 5 and 6.

Biological characteristics

Rooted emergent aquatic-plant growth was heavy, whereas submergent plant growth was moderate. On August 12, 1971, approximately 9 percent of the lake surface and 9 percent of the lake bottom were occupied by macrophytes. The dominant aquatic plant was watershield (*Brasenia* sp.), followed by waterlily (*Nymphaea* sp.), sedge (*Cyperaceae*), and watercelery (*Vallisneria* sp.).

No algal blooms were observed, but a high algal density was recorded on May 11, 1971. The chlorophyll *a* determinations were 2.8 and 4.4 μg/l on May 11 and August 12, respectively. The mean biomass value was 0.14 mg/l, from a range of 0.04 to 0.28 mg/l; the values would be considered low to medium. With the exception of dominance by *Dinobryon* sp. on June 28, most samples were characterized by a diverse species composition. Infrequent algal blooms and a wide variety of phytoplankton species have often been taken as partial evidence of a low trophic condition (Rawson, 1956).

Sampling for total coliform bacteria was performed at four shoreline stations on May 11 and November 2, 1971. None of the samples had a colony density exceeding 240 per 100 ml (milliliters), the recommended bathing-beach standard for the State of Washington. The mean value was 9, from a range of 0 to 30 colonies per 100 ml.

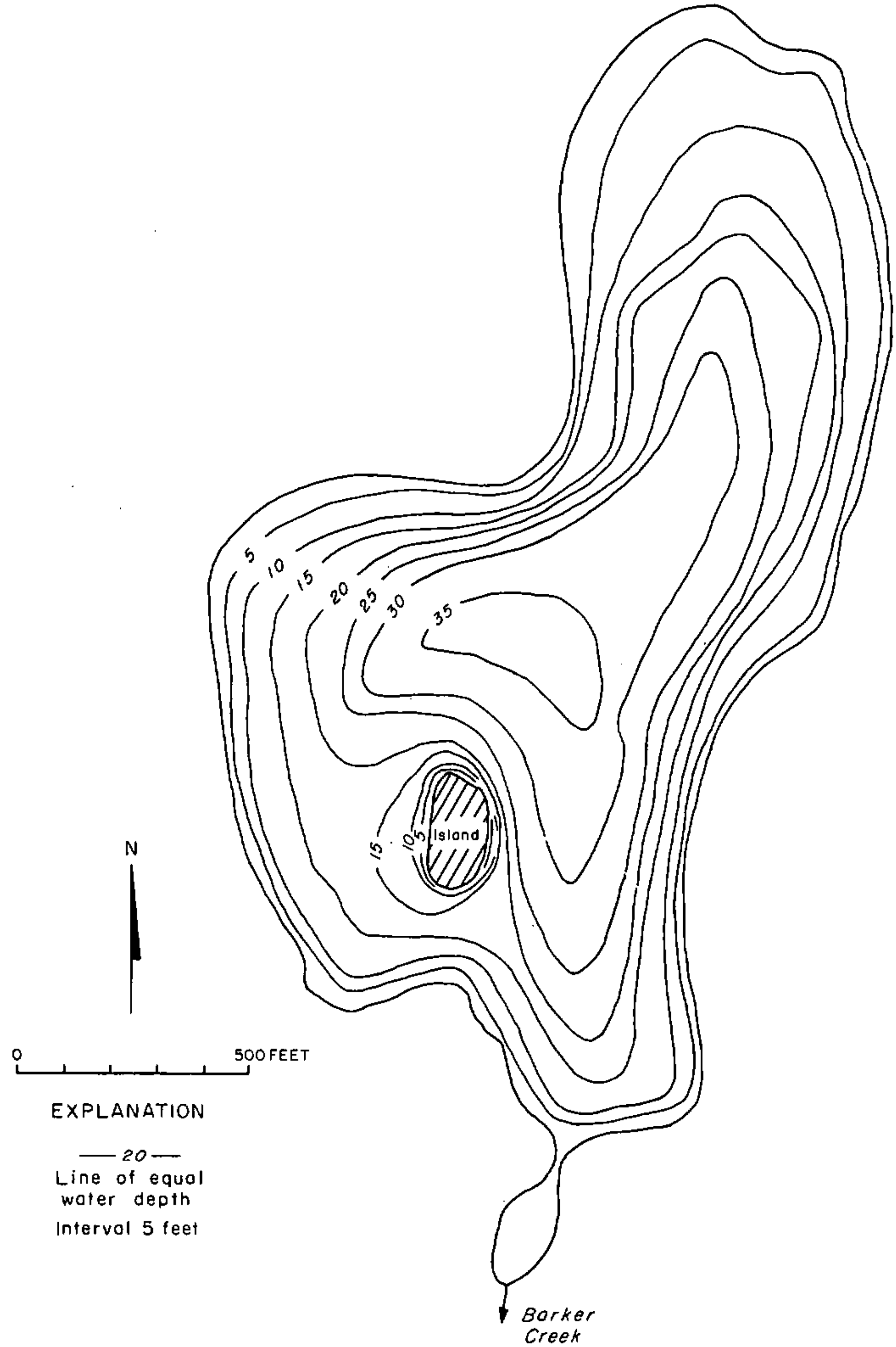

FIGURE 3.–Bathymetric map of Island Lake near Keyport. From Washington Department of Game survey, July 19, 1958.

FIGURE 4.—Aerial photograph of Island Lake near Keyport, August 9, 1972. Scale, 1:6,000.

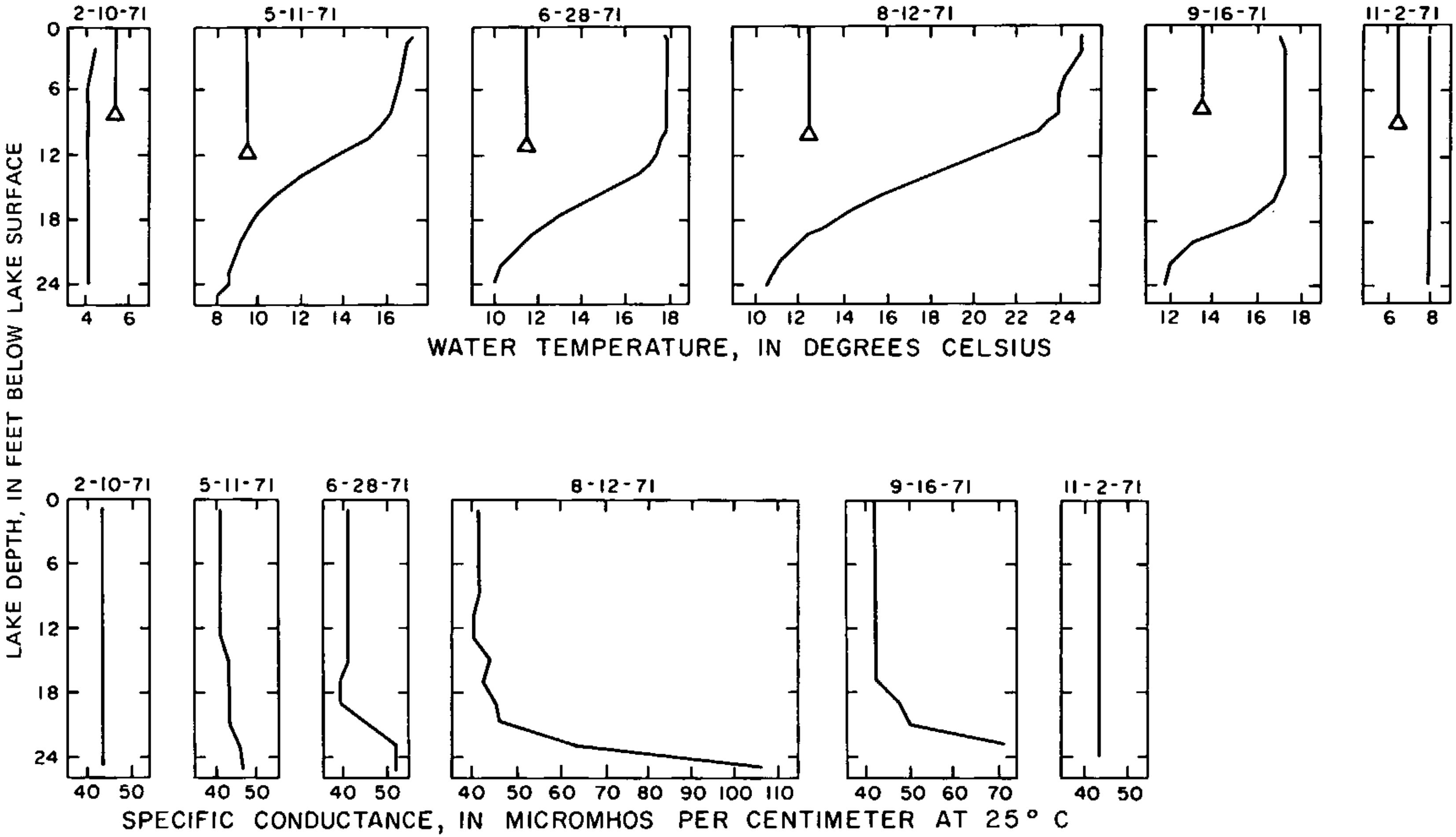

FIGURE 5.—Selected 1971 seasonal profiles of lake temperature and specific conductance, Island Lake near Keyport. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

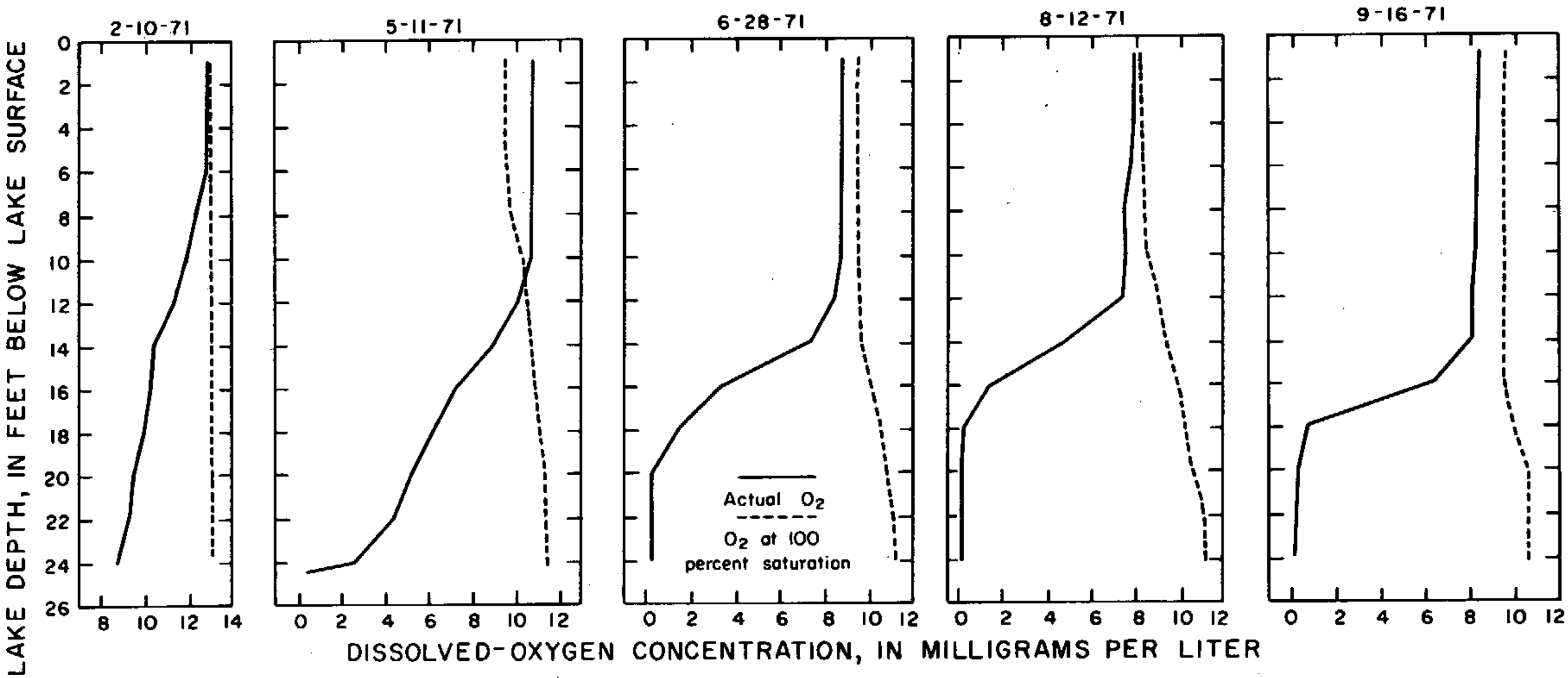

FIGURE 6.–Selected 1971 seasonal profiles of DO concentration, Island Lake near Keyport.

12071000. Wildcat Lake near Bremerton

Location

Kitsap County, 5.5 miles northwest of Bremerton (fig. 1).

Origin

Kettle lake formed in glacial recessional moraine.

Basin geology

Glacial drift, with some volcanic rocks in southwestern part of basin (Sceva, 1957).

Soils

Loam, gravelly sandy loam, and steeply sloping phases of gravelly loamy sand (Wildermuth and others, 1939).

Land use and cover

Moderately heavy forest with residential clearings. The forest cover is predominantly second-growth Douglas fir and cedar, but cascara, alder, big-leaf maple, willow, and dogwood also form part of the riparian vegetation.

Population

Lakeshore development moderately dense with 75 lakeshore or nearshore homes in September 1971, as compared to about 60 lakeshore homes in 1953 (estimated from U.S. Geological Survey topographic maps). Residential development occupies approximately 81 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 7. The map was surveyed on June 11, 1946, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	2.50 sq mi
Altitude (from topographic map)	377 ft
Surface area	121 acres
Lake volume	2,240 acre-ft
Mean depth	18 ft
Maximum depth	32 ft
Length of shoreline	11,890 ft
Length of lake	4,240 ft
Mean breadth of lake	1,240 ft
Shoreline configuration	1.45
Development of volume	0.58
Mean slope	4.7 percent

Hydrologic characteristics

Lake stages

The lake stage, or gage height, was observed on the average, twice weekly from June 1947 to October 1950. The gage height varied 1.82, 3.08, and 2.94 ft during 1948, 1949, and 1950, respectively. The altitude of the gage is 377 ft (from topographic map); datum of gage is arbitrary.

Using the same arbitrary datum as that for 1947-50, the following gage-height observations were obtained during the study period:

Date (1970)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 10	4.23	Feb 10	4.17
Jun 23	3.81	May 10	4.03
Oct 7	3.74	June 28	3.98
Oct 26	4.07	Sep 8	2.98

The reference marks established in 1947 were obscured, so the datum tie may be subject to question. The high-water marks on the crest-stage gage were 4.8 ft in February 1971 and 5.8 ft in May 1971.

Surface-water inflow and outflow

The inflow is from two small streams (sites 1 and 2 on bathymetric map) draining the hills south of the lake. The outflow, which is controlled by natural conditions, is via Wildcat Creek. Miscellaneous measurements of the inflow and outflow are given below:

Date	Inflow at site 1 (cfs)	Inflow at site 2 (cfs)	Outflow via Wildcat Creek (cfs)
1970			
Feb 10	*0.2	2.00	6.99
Jun 23	--	.24	.38
Oct 7	.11	0	0
1971			
Feb 10	1.88	.69	5.41
May 10	.80	* .3	2.47
June 28	* .5	* .05	1.60
Sep 8	.4	.2	1.51

*Estimated

Miscellaneous discharge measurements on Wildcat Creek were made 9 to 10 times annually from 1947-50 (Washington State Department of Conservation, 1964). The mean annual outflow was 9.47, 4.93, and 5.59 cfs in 1948, 1949, and 1950, respectively.

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 8. In September 1951, the DO concentration was 8.2 mg/l at the 25-ft depth and 3.8 mg/l at the 30-ft depth (Washington Department of Game, written commun., 1970) on September 8, 1971, the DO concentration was 0.9 mg/l at the 25-ft depth and zero at the 30-ft depth.

Biological characteristics

Growth of rooted emergent and submergent aquatic plants was light. On September 8, 1971, approximately 1 percent of the lake surface and 1 percent of the lake bottom were occupied by macrophytes.

The lake contained a mixture of waterlily (*Nuphar* sp. and *Nymphaea* sp.), watershield (*Brasenia* sp.), sedge (*Cyperaceae*), cattail (*Typha* sp.), waterweed (*Elodea* sp.), and three varieties of pondweed (*Potamogeton* spp.).

No algal blooms were observed, but a high algal density was recorded on May 10 and June 28, 1971.

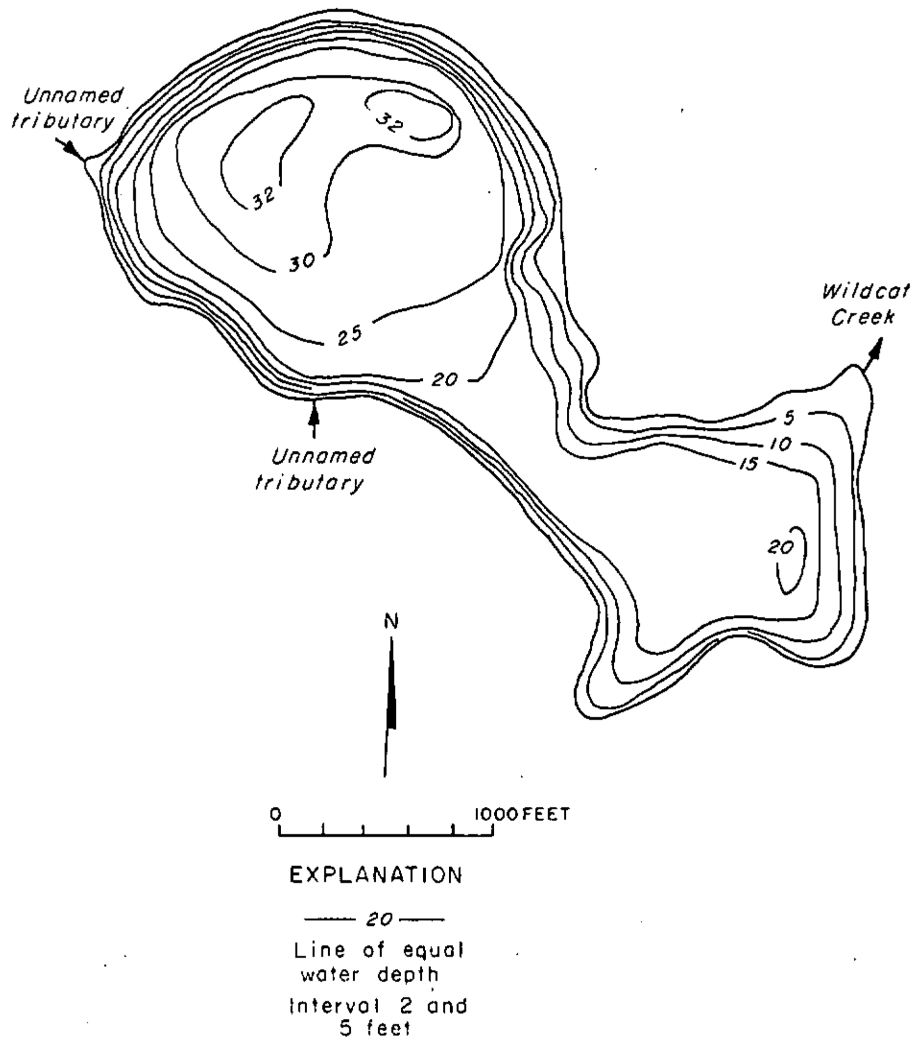

FIGURE 7.—Bathymetric map of Wildcat Lake near Bremerton. From Washington Department of Game survey, June, 11, 1946.

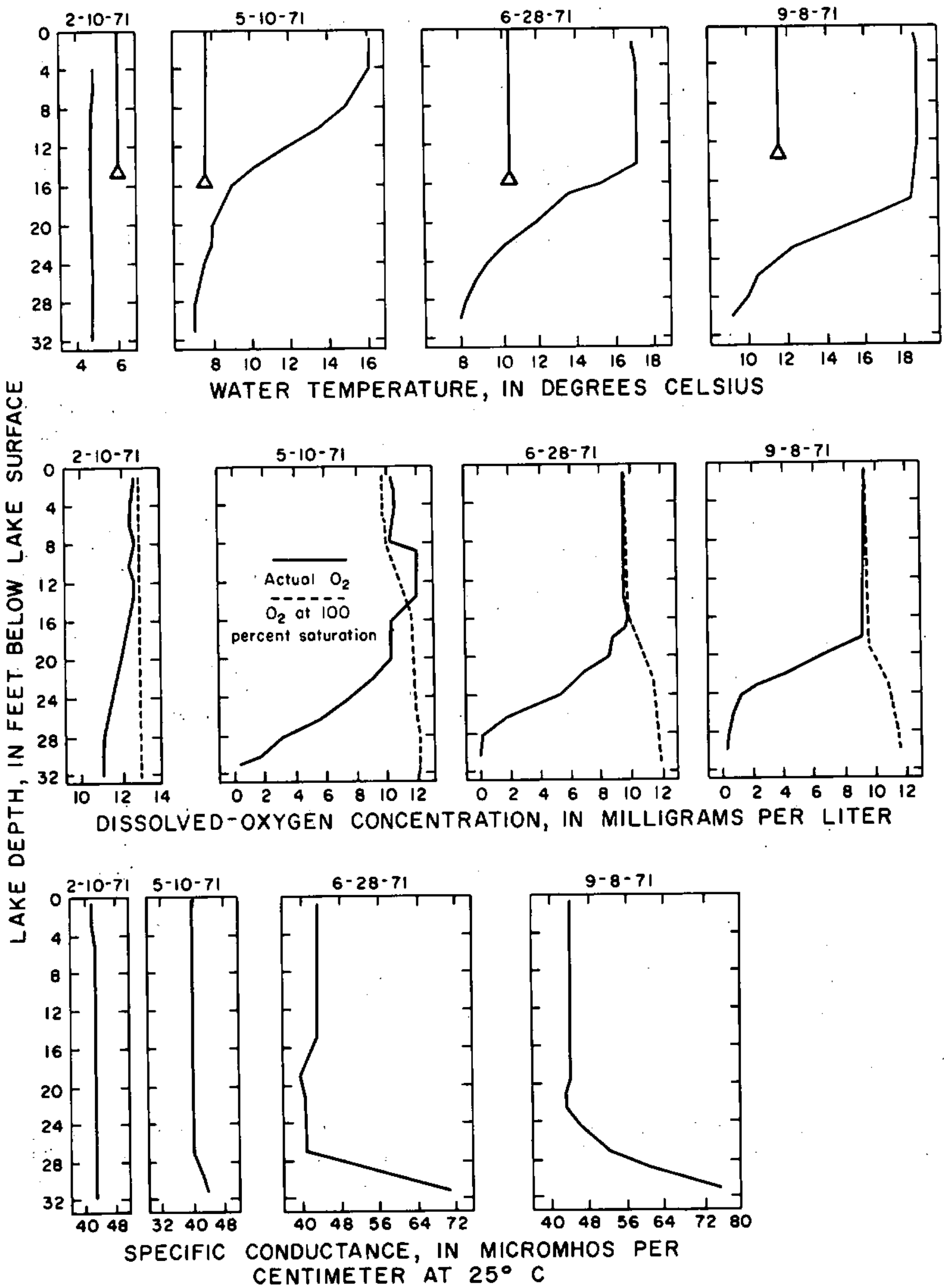

FIGURE 8.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Wildcat Lake near Bremerton. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12071500. Kitsap Lake near Bremerton

Location

Kitsap County, 3 miles west of Bremerton (fig. 1).

Origin

Kettle lake formed in a preglacial drainage channel.

Basin geology

Glacial drift, with volcanic rocks in the southern and southwestern parts of basin (Sceva, 1957).

Soils

Loam and silt loam nearest shore areas. A gravelly sandy loam lies in upper till hills west of the lake (Wildermuth and others, 1939).

Land use and cover

Moderately forested, with residential and commercial clearings. About one-half of the basin is suburban development. A mixture of coniferous (Douglas fir and cedar) and deciduous trees (alder, willow, and big-leaf maple) compose the nearshore cover.

Population

Lakeshore development moderately dense with more than 90 lakeshore dwellings in October 1970, compared to about 55 lakeshore residences in 1953 (estimated from U.S. Geological Survey topographic map). The southern and southwestern shoreline of the lake adjoins wetland, making it less desirable for homesites. Residential development occupies approximately 70 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 9. The map was surveyed on June 7, 1950 and referenced to an arbitrary gage datum. The lake stage during the survey was 1.08 ft.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	2.73 sq mi
Altitude (from topographic map)	156 ft
Surface area	248 acres
Lake volume	4,480 acre-ft
Mean depth	18 ft
Maximum depth	29 ft
Length of shoreline	14,200 ft
Length of lake	5,370 ft
Mean breadth of lake	2,010 ft
Shoreline configuration	1.22
Development of volume	0.62
Mean slope	2.7 percent

Hydrologic characteristics

Lake stages

The gage height was observed about twice weekly from June 1947 to October 1950. The gage height varied 1.05, 1.97, and 1.41 ft during 1958, 1959, and 1950, respectively. The altitude of the gage is 156 ft (from topographic map); the datum of gage is arbitrary.

Using the same datum as that for 1947-50, the following gage-height observations were obtained during the investigation period:

Date (1970)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 9	1.87	Feb 22	1.89
Jun 23	.96	May 10	1.60
Oct 7	.95	Jun 30	1.90
Oct 26	1.46	Sep 9	1.90
Dec 15	2.24		

The high-water mark observed on a crest-stage gage was 2.5 ft in December 1970.

Surface-water inflow and outflow

The inflow is from a small stream on the south end of the lake, and the outflow, which is regulated by a concrete weir, is via Kitsap Creek on the north end of the lake. Miscellaneous measurements of inflow and outflow are given below:

Date	Inflow (cfs)	Outflow via Kitsap Creek (cfs)
1970		
Feb 9	4.62	12.1
June 23	1.34	1.89
Oct 7	1.16	2.14
1971		
Feb 22	5.26	10.8
May 10	3.20	6.18
Jun 30	1.88	3.39
Sep 9	1.26	3.01

Miscellaneous discharge measurements were made 9 to 10 times each year on Kitsap Creek from 1947-50 at the same site as the current measurements (Washington State Department of Conservation, 1964). The mean annual outflow was 9.96, 7.34, and 6.27 cfs for 1948, 1949, and 1950, respectively.

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 10.

In September 1951, the DO concentration was 7.2 mg/l at the 25-ft depth and 4.0 mg/l at the 29-ft depth (Washington Department of Game, written commun., 1970). On September 8, 1971, the DO concentration was zero at the 25-ft depth.

Biological characteristics

Rooted submergent and emergent aquatic-plant growth was moderate. On September 8, 1972, approximately 3 percent of the lake surface and 13 percent of the lake bottom were occupied by macrophytes. The dominant submergent plants were waterweed (*Elodea* sp.), hornwort (*Ceratophyllum* sp.), and four varieties of pondweed (*Potamogeton* spp.). The emergent aquatic plants were dominated by yellow waterlily (*Nuphar* sp.), followed by white waterlily (*Nymphaea* sp.), cattails (*Typha* sp.), and sedge (*Cyperaceae*).

Algal blooms were observed on February 22, June 30, and September 8, 1971. A high algal density was recorded on May 10, 1971. The dominant algae September 8, 1971 were *Gleotrichia* sp. and *Coelosphaerium* sp.

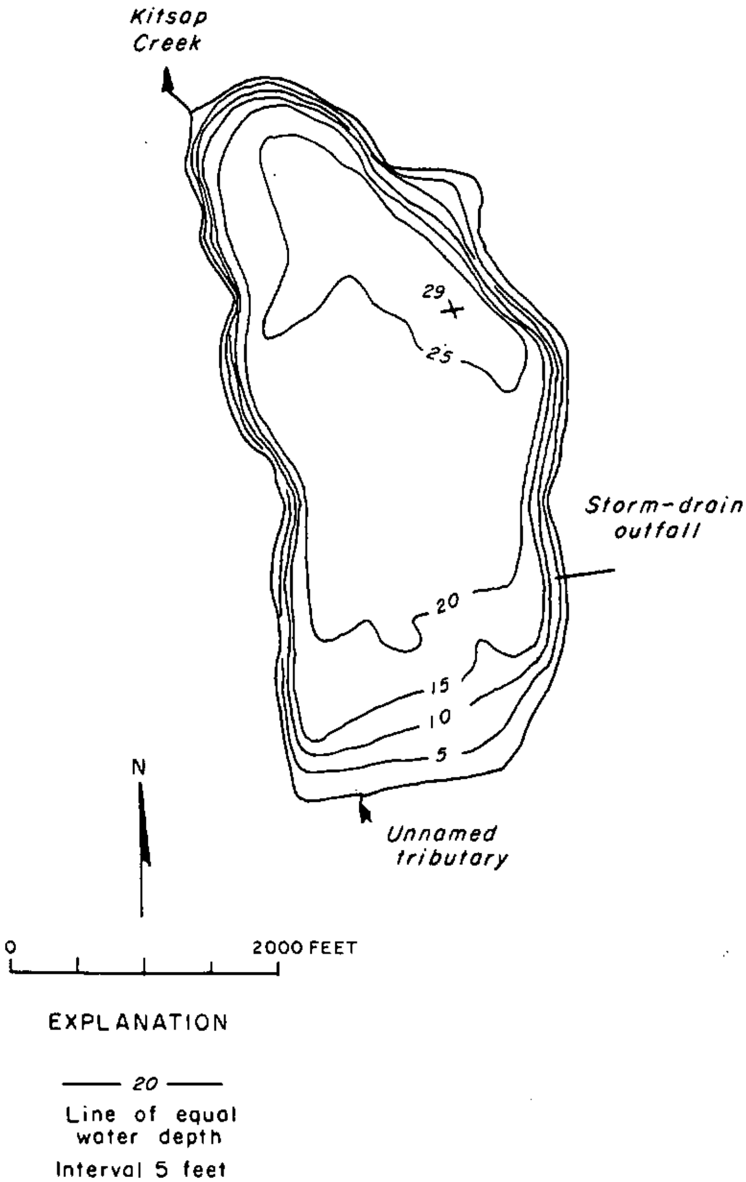

FIGURE 9.—Bathymetric map of Kitsap Lake near Bremerton. From Washington Department of Game survey, June 7, 1950.

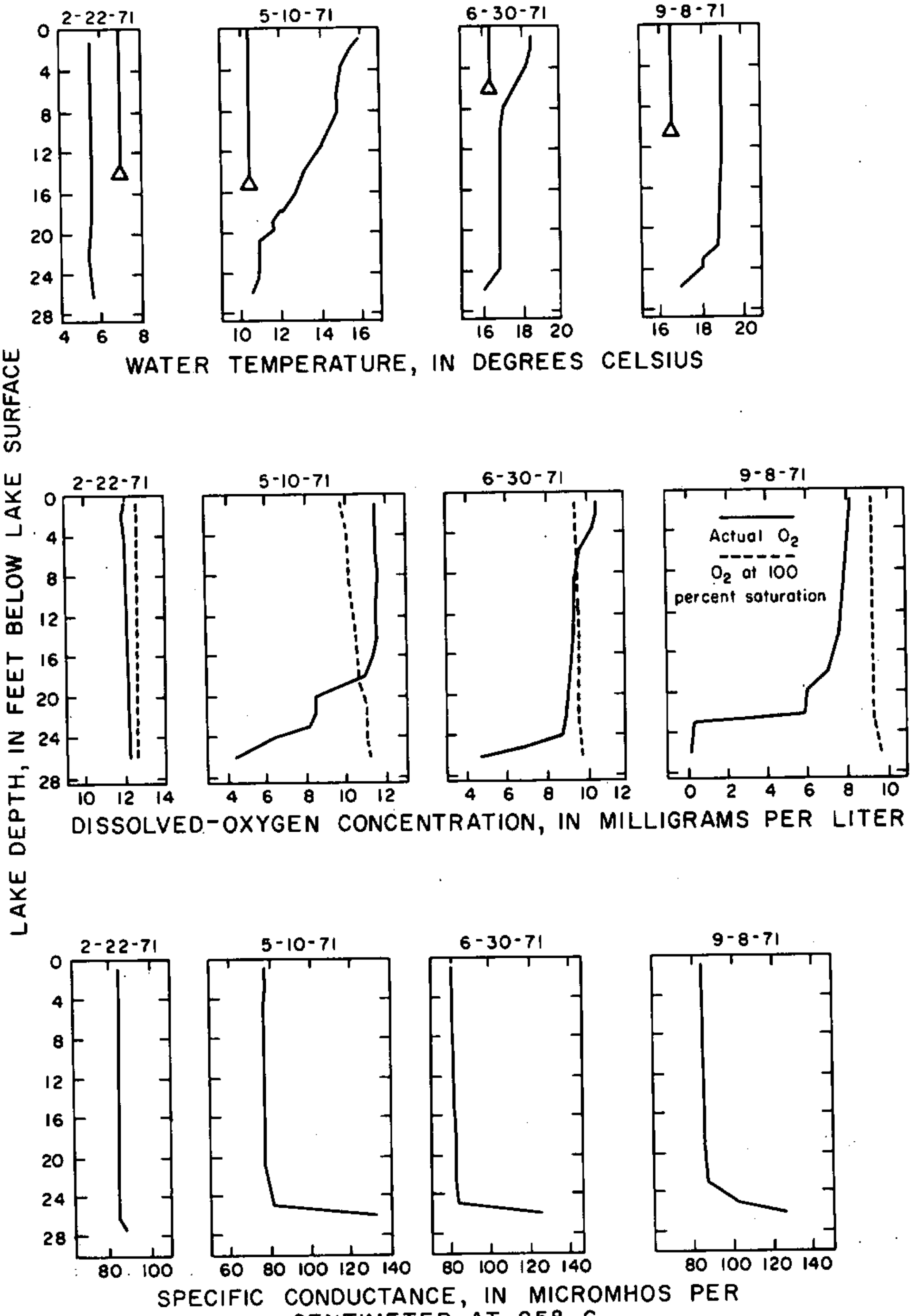

FIGURE 10.–Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Kitsap Lake near Bremerton. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12078200. Summit Lake near Kamilche

Location

Thurston County, 5.5 miles southwest of Kamilche (fig. 1).

Origin

Steep valley dammed by terrace deposits of fluvial and glaciofluvial origin.

Basin geology

Deeply weathered basalt (Noble and Wallace, 1966).

Soils

Soils normally shallow and stony with portion of basin on the northwest and east side composed of gravelly loam (Ness, 1958).

Land use and cover

Heavily forested, with residential clearings. The south shore cover is mostly coniferous trees, and the north shore is mixture of deciduous and coniferous trees.

Population

Lakeshore development very dense with 290 residences (mostly seasonal) surrounding the lake, compared to about 51 lakeshore homes in 1953 (estimated from U.S. Geological Survey topographic map). The shoreline on the west side of the lake adjoins marsh or poorly drained wetland, making it less desirable for building. Residential development occupies approximately 93 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 11. The map was surveyed on June 23, 1952, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	2.82 sq mi
Altitude (from topographic map)	500 ft
Surface area	528 acres
Lake volume	28,000 acre-ft
Mean depth	53 ft
Maximum depth (in 1971 the maximum depth observed was 85 ft)	100 ft
Length of shoreline	29,600 ft
Length of lake*	11,700 ft
Mean breadth of lake	1,960 ft
Shoreline configuration	1.74
Development of volume	0.53
Mean slope	9.1 percent

*Two lines intersecting used to determine length of L-shaped lake.

Hydrologic characteristics

Lake stages

The observed gage heights during 1971 are shown in figure 12. The altitude of the gage is 500 ft (from topographic map); datum of gage is arbitrary. The lake elevation is regulated by flashboards at fish screen near outlet. The observed gage height varied 1.2 ft in 1971. The high-water mark on a crest-stage gage was 4.02 ft on March 6, 1972.

Surface-water inflow and outflow

The inflow is from several small intermittent and ephemeral streams originating in the surrounding mountainous terrain, in addition to seeps and springs. The outflow, which is regulated by flashboards, is via Kennedy Creek. Miscellaneous measurements of inflow and outflow are given below.

Date	Inflow, Total Miscellaneous (cfs)	Outflow via Kennedy Creek (cfs)
1971		
Feb 22	*1.2	21.7
May 20	* .5	.31
Jul 7	* .05	* .1
Sep 21	0	* .2

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 13.

In October 1953, the DO concentration was 4.9, 2.4, and 1.6 mg/l at 40, 60, and 75 ft, respectively, below the water surface (Washington Department of Game, written commun., 1970). On September 21, 1971, the DO concentration was 4.0, 0.7, and 0.2 mg/l at 40, 60, and 75 ft, respectively, below the water surface.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was moderate. On September 21, 1971, approximately 2 percent of the lake surface and 9 percent of the lake bottom were occupied by macrophytes.

The dominant emergent aquatic plant was watershield (*Brasenia* sp.) followed by waterlily (*Nuphar* sp. and *Nymphaea* sp.), sedge (*Cyperaceae*), and cattail (*Typha* sp.). The dominant submergent plant was pondweed (*Potamogeton amplifolius*). Other submergent plants were waterweed (*Elodea* sp.) and two additional pondweed varieties. The muck substrate for rooted plant growth in the littoral zone is moderate accounting for about 38 percent of the shoreline.

No algal blooms were observed, but a high algal density was recorded on September 21, 1971.

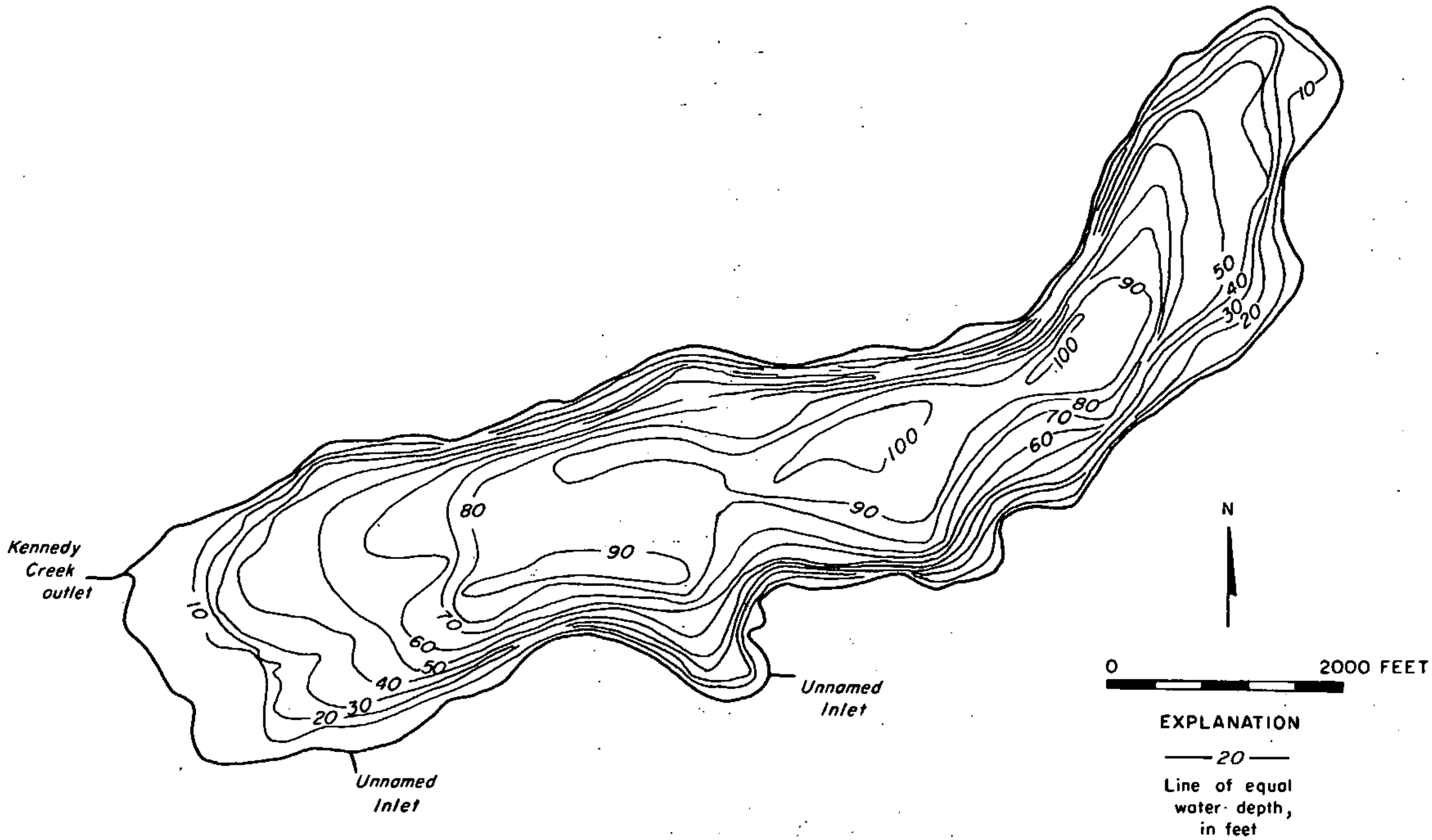

FIGURE 11.—Bathymetric map of Summit Lake near Kamilche. From Washington Department of Game, June 1952.

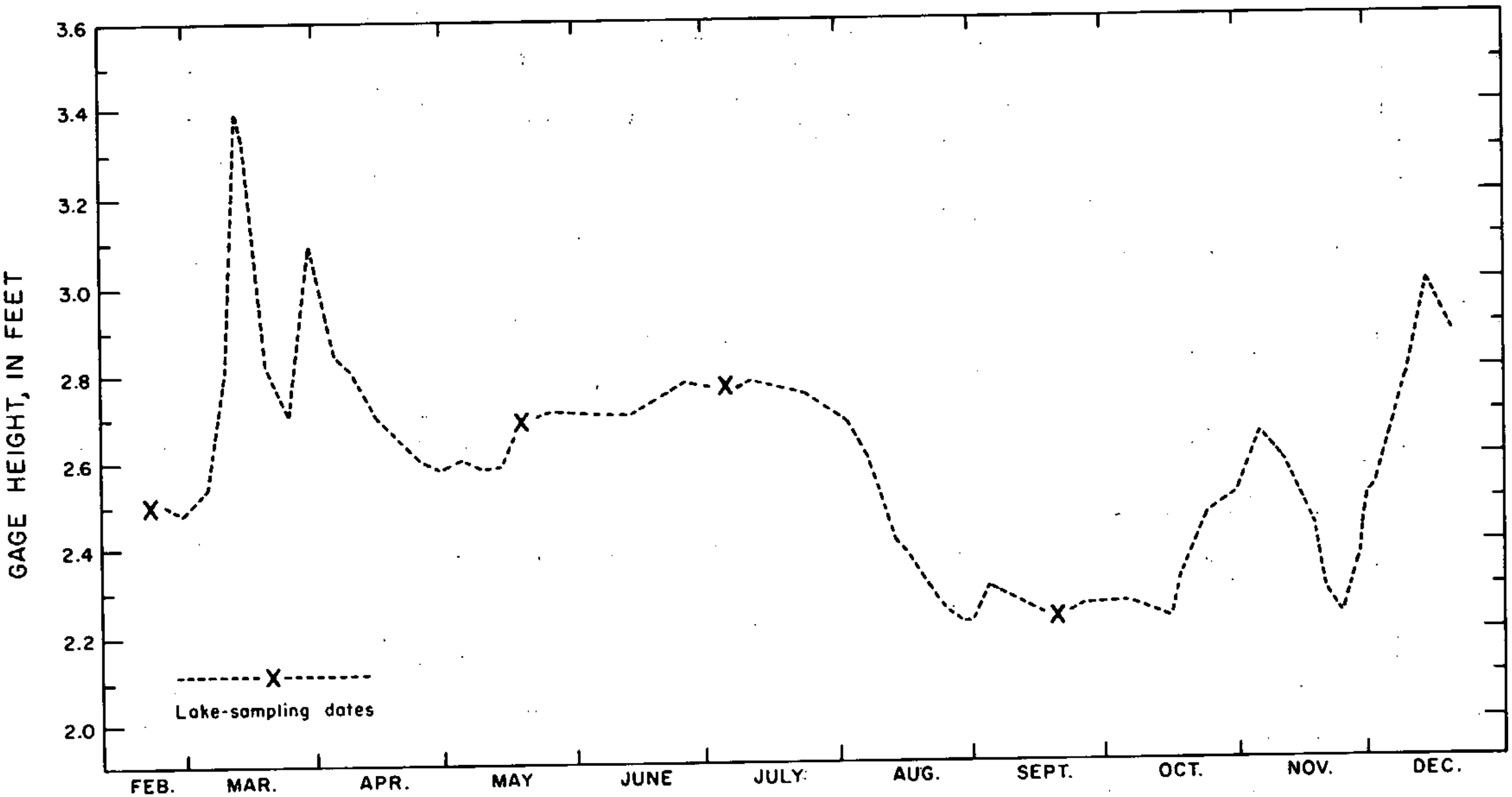

FIGURE 12.–Observed gage heights in 1971, Summit Lake near Kamilche.

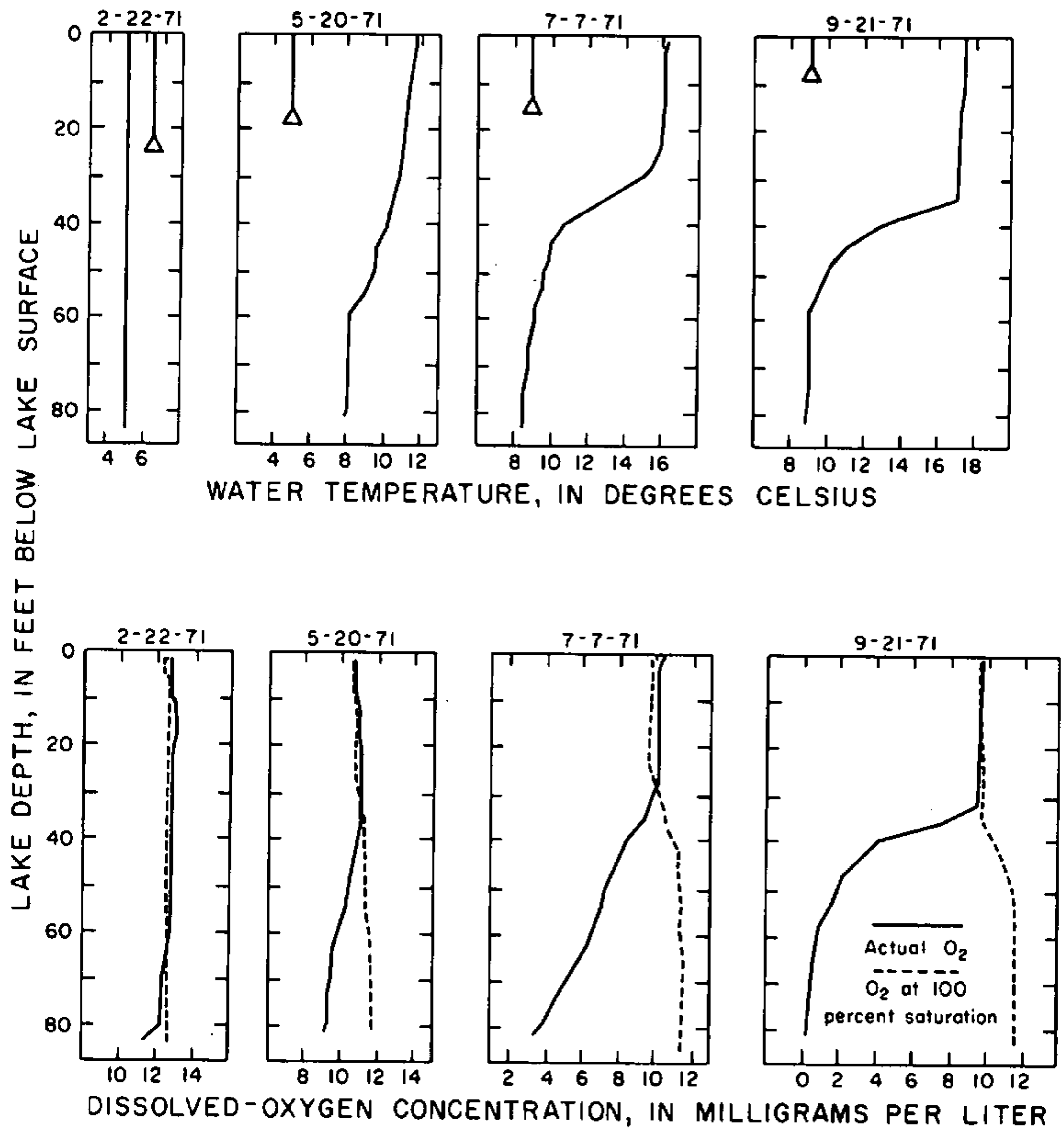

FIGURE 13.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Summit Lake near Kamilche. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12078700. Black Lake near Tumwater

Location
Thurston County, 2.8 miles west of Tumwater (fig. 1).

Origin
Damming of preglacial Black River valley by glacial deposits.

Basin geology
Glacial recessional outwash consisting of sand and silt with lenses of gravel. Weathered basalt underlies the Black Hills to the west of the lake (Noble and Wallace, 1966).

Soils
Intricate patterns of fine sandy loam, gravelly sandy loam, loamy fine sand, and peat deposits. The main surface-water inflows drain through peat deposits on the southeast side of the lake (Ness, 1958).

Land use and cover
Scattered forest, with residential and agricultural clearings. The shore environs support scattered stands of Douglar fir, Oregon ash, alder, and willow.

Population
Lakeshore development moderately dense with 145 lakeshore or nearshore homes, a trailer court (with 27 mobile homes) and a private beach club in September 1971, compared to about 89 lakeshore dwellings in 1959 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 84 percent of the lakeshore.

Physical characteristics of lake
A bathymetric map of the lake is shown in figure 14. The map was surveyed on August 23, 1971 and referenced to an arbitrary gage datum. The lake stage during the survey was 11.50 ft.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below:

Drainage area	10.1 sq mi
Altitude (from topographic map)	131 ft
Surface area	567 acres
Lake volume	10,700 acre-ft
Mean depth	19 ft
Maximum depth	29 ft
Length of shoreline	31,600 ft
Length of lake	12,730 ft
Mean breadth of lake	1,940 ft
Shoreline configuration	1.80
Development of volume	0.65
Mean slope	2.8 percent

Hydrologic characteristics
Lake stages

The gage heights observed periodically in 1971 are shown below.

Date (1971)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 23	13.30	Jul 7	11.75
Feb 27	13.30	Jul 11	11.66
Mar 3	13.30	Jul 18	11.60
Mar 6	13.30	Jul 25	11.50
Mar 11	13.70	Aug 1	11.40
Mar 19	13.60	Aug 8	11.30
Mar 30	13.80	Aug 23	11.50
Apr 26	12.70	Sep 5	11.50
May 20	12.18	Sep 12	11.47
		Sep 21	11.38

The altitude of gage is 131 ft (from topographic map); the datum of gage is arbitrary. The high-water mark on crest-stage gage was 16.07 ft on March 3, 1972.

Surface-water inflow and outflow

The main inflows are from three unnamed tributaries. The outflow, controlled by natural conditions, is via a canal which flows into Percival Creek. The former Black River outlet on the south end of the lake is obstructed by vegetation and beaver dams. Miscellaneous measurements of inflow (sites 1 and 2 on bathymetric map) and outflow are listed below.

Date	Inflow at Site 1 (cfs)	Inflow at Site 2 (cfs)	Outflow, Canal into Percival Creek (cfs)
1970			
May 7	--	--	25.0
Aug 14	--	--	4.93
Sep 14	--	--	7.98
1971			
Feb 23	6.96	9.22	62.6
May 12	--	--	29.2
May 20	3.95	6.21	28.9
Jul 7	* .05	4.34	19.5
Sep 21	1.70	2.12	6.90

*Estimated

Additional miscellaneous discharge measurements at Black Lake outlet (12078665) have been published (Washington State Department of Conservation, 1964; U.S. Geological Survey, 1963-64, 1965-70.).

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 15.

Biological characteristics

Rooted submergent aquatic-plant growth was moderate but the emergent plant growth was light. On September 21, 1971, approximately 0.8 percent of the lake surface and 7 percent of the lake bottom were occupied by macrophytes.

The emergent aquatic plants were dominated by waterlily (*Nuphar* sp. and *Nymphaea* sp.), followed by sedge (*Cyperaceae*) and cattail (*Typha* sp.). The dominant submergent plant was waterweed (*Elodea* sp.), but other plants included hornwort (*Ceratophyllum* sp.) and four varieties of pondweed (*Potamogeton* spp.).

No algal blooms were observed, but a high algal density was noted September 21, 1971.

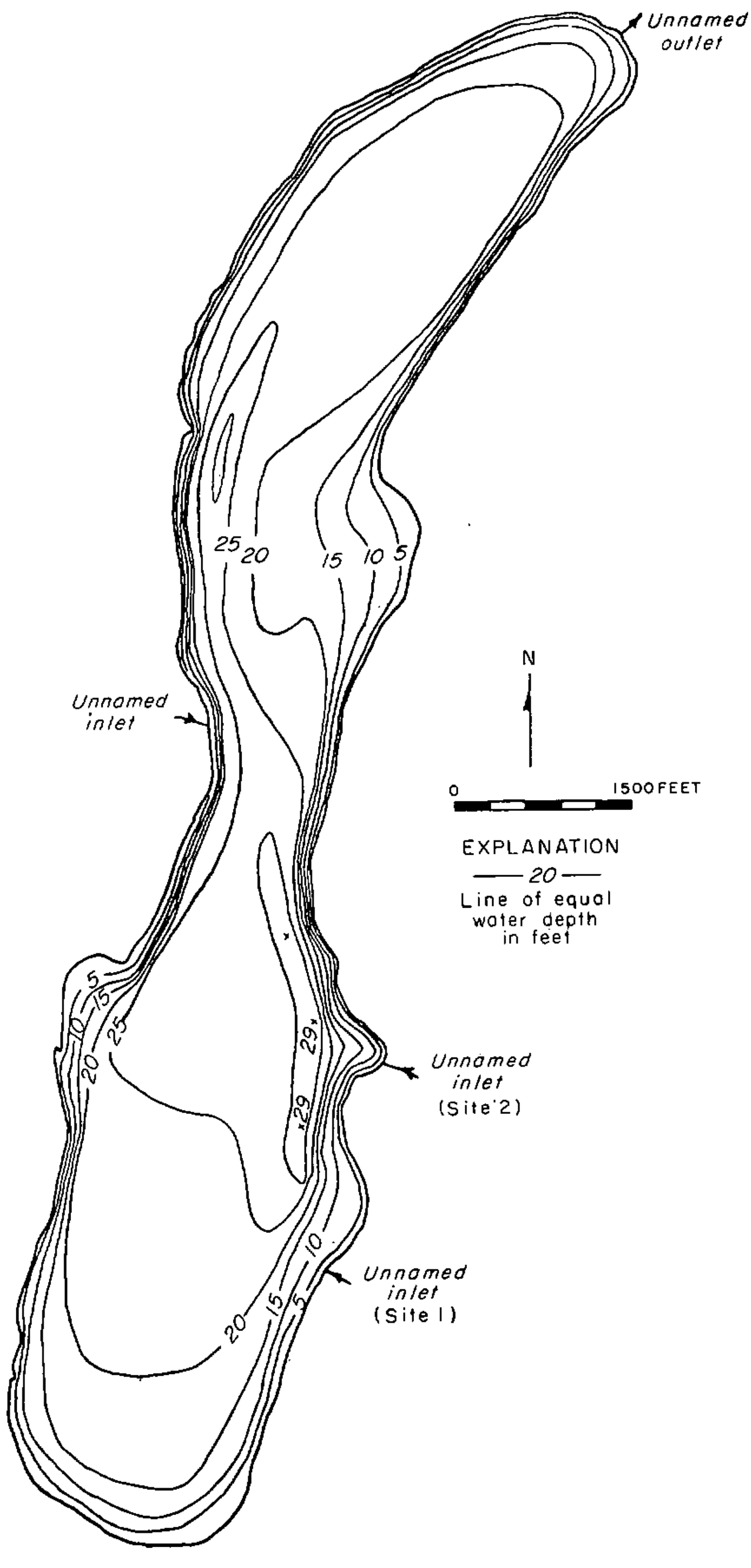

FIGURE 14.—Bathymetric map of Black Lake near Tumwater. From U.S. Geological Survey August 23, 1971.

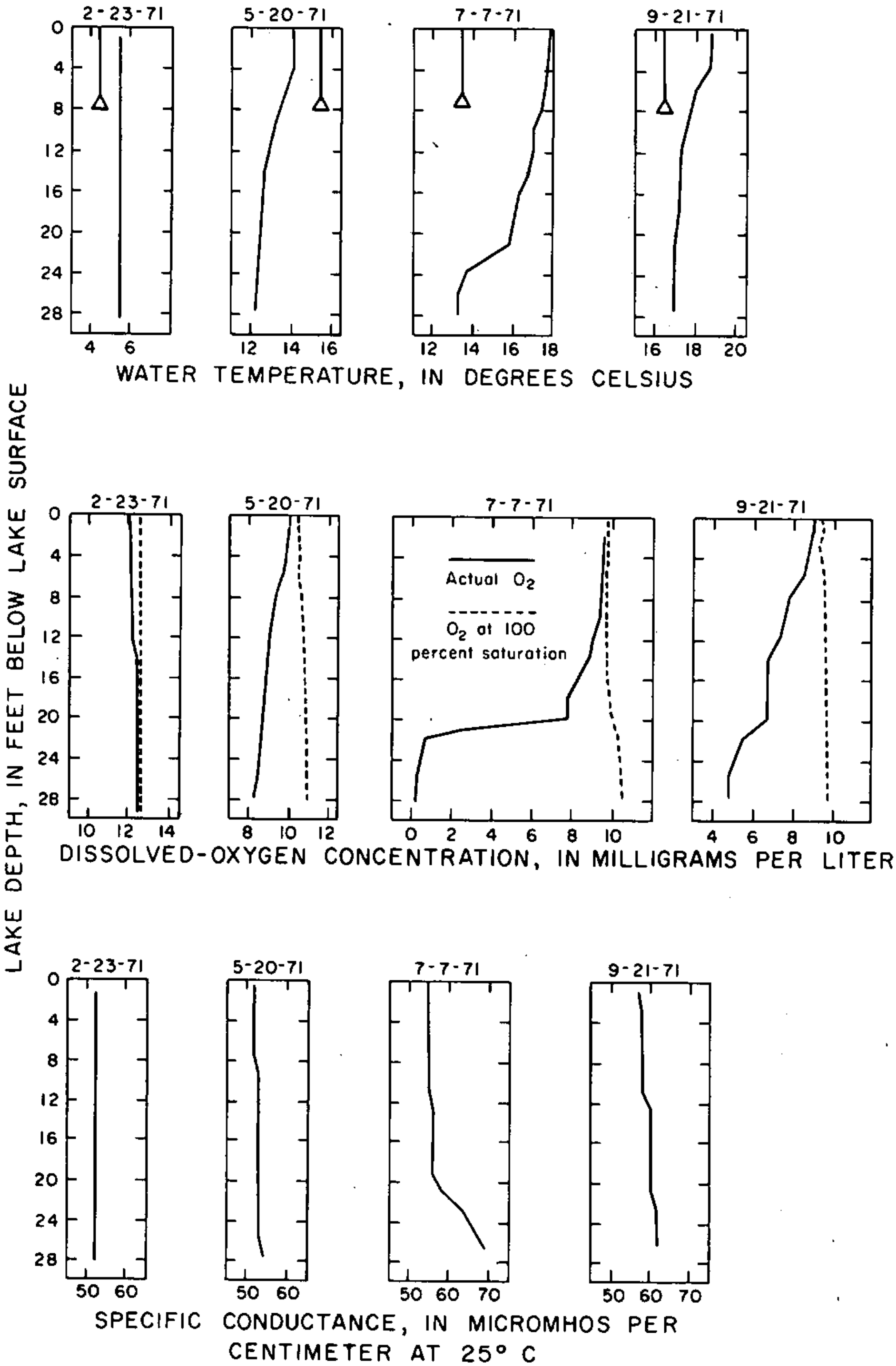

FIGURE 15.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Black Lake near Tumwater. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12080600. Long Lake near Lacey

Location

Thurston County, 2.0 miles east of Lacey (fig. 1).

Origin

Kettle lake.

Basin geology

Glacial drift consisting of recessional outwash of poorly sorted gravel and sand with some alluvium on south shore of lake (Noble and Wallace, 1966).

Soils

Intricate patterns of gravelly sandy loam, loamy fine sand, and loamy sand. The main surface-water inflow drains through peat deposits (Ness, 1958).

Land use and cover

Scattered forest, with residential and agricultural clearings. The nearshore cover is mixture of Douglas fir, cedar, alder, Oregon ash, black cottonwood, madrona, and willow.

Population

Lakeshore development moderately dense with 205 homes surrounding lake, compared to about 117 homes in 1959 (estimated from U.S. Geological Survey topographic map). Approximately 11 percent of shoreline adjoins marsh or wetland, making it less desirable for homesites.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 16. The map was surveyed during spring of 1971 using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	8.25 sq mi
Altitude (from topographic map)	158 ft
Surface area	328 acres
Lake volume	3,910 acre-ft
Mean depth	12 ft
Maximum depth	21 ft
Length of shoreline	37,400 ft
Length of lake	10,000 ft
Mean breadth of lake	1,430 ft
Shoreline configuration	2.79
Development of volume	0.57
Mean slope	3.8 percent

Hydrologic characteristics

Lake stages

The gage heights observed periodically in 1971 are shown below. The altitude of gage is 158 ft (from topographic map); the datum of gage is arbitrary. The high-water mark on crest-stage gage was 9.70 ft on March 1, 1972.

Date (1970)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 25	9.06	Apr 11	9.20
Feb 28	9.02	Apr 17	9.18
Mar 3	9.02	Apr 21	9.14
Mar 10	9.12	Apr 28	9.07
Mar 14	9.20	May 1	9.02
Mar 17	9.20	May 8	8.89
Mar 24	9.15	May 12	8.80
Mar 31	9.30	May 18	8.80
Apr 1	9.25	Jul 12	8.64
Apr 7	9.19	Sep 20	8.12

During the period 1930-48, the average annual variation in lake stage was 1.2 ft (Washington Department of Game, written commun., 1971).

Surface-water inflow and outflow

The inflow is mainly from a stream which drains two upstream lakes. The outflow, which is controlled by natural conditions, is via Woodland Creek. Miscellaneous inflow and outflow measurements are given below:

Date	Inflow (cfs)	Outflow via Woodland Creek (cfs)
Feb 25	20.9	26.1
May 18	17.2	19.0
Jul 12	12.5	11.9
Sep 20	6.75	3.67

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 17.

Nutrient data for inflow to Long Lake near Lacey is shown below.

Item	Nutrient Values in Milligrams Per Liter
Date of sample	July 12, 1971
Orthophosphate (as P)	0.01
Total phosphorus (as P)	.02
Nitrate nitrogen (as N)	.34
Ammonia nitrogen (as N)	.24

Biological characteristics

Rooted submergent aquatic-plant growth was heavy but the emergent and floating plant growth was light, on September 20, 1971. Approximately 0.9 percent of the lake surface and 32 percent of the lake bottom were occupied by macrophytes.

The emergent aquatic plants were dominated by waterlily (*Nuphar* sp. and *Nymphaea* sp.), followed by watershield (*Brasenia* sp.), cattails (*Typha* sp.), and sedge (*Cyperaceae*). The dominant submergent plants were waterweed (*Elodea* sp.), hornwort (*Ceratophyllum* sp.), watercelery (*Vallisneria* sp.), watermilfoil (*Myriophyllum* sp.), and four varieties of pondweed (*Potamogeton* spp.). The muck substrate for rooted plant growth in the littoral zone is moderate, accounting for 40 percent of shoreline.

Algal blooms were observed on May 18, July 12, and September 20, 1971, and a high algal density was noted on February 25, 1971.

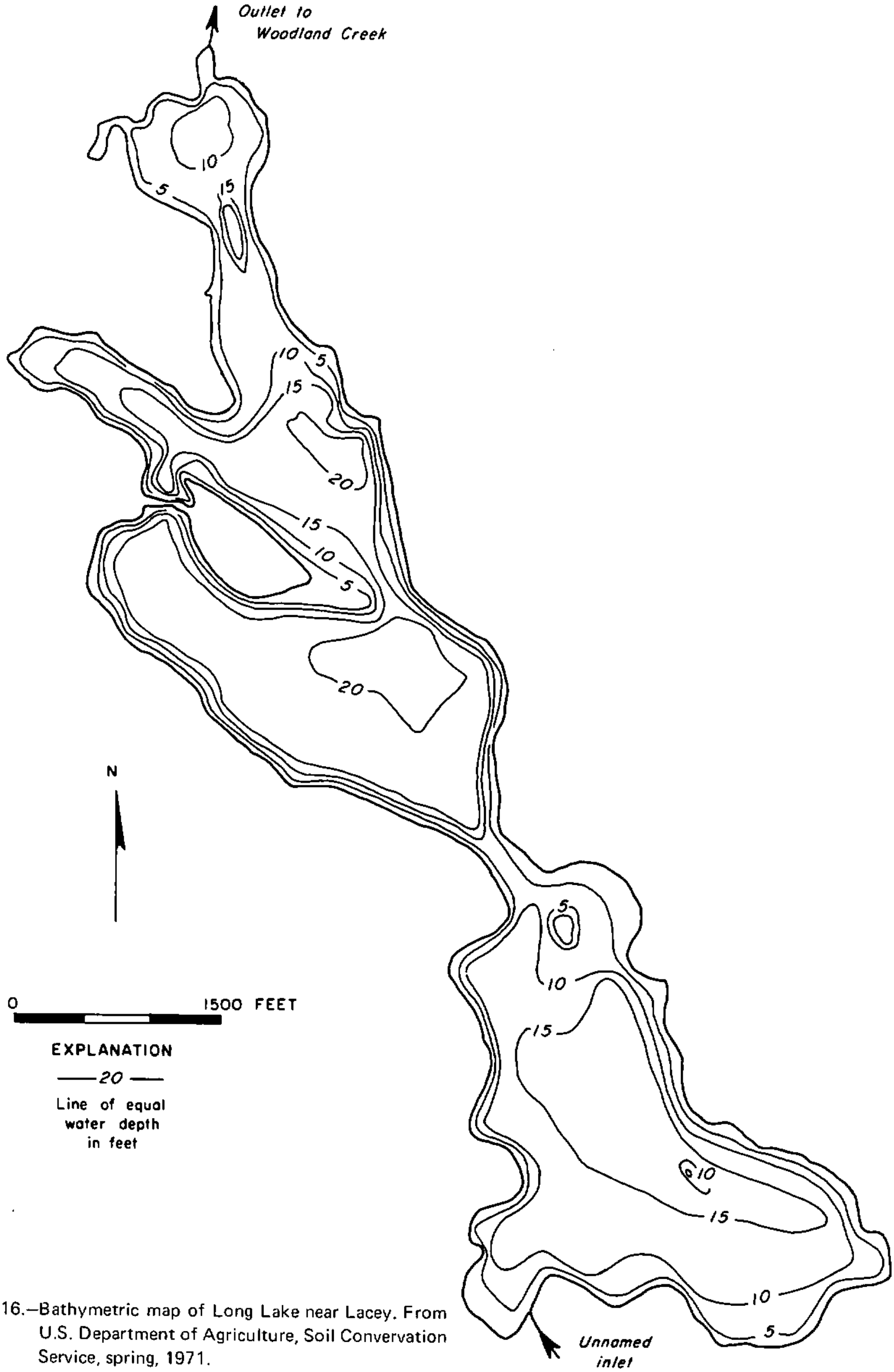

FIGURE 16.—Bathymetric map of Long Lake near Lacey. From U.S. Department of Agriculture, Soil Conservation Service, spring, 1971.

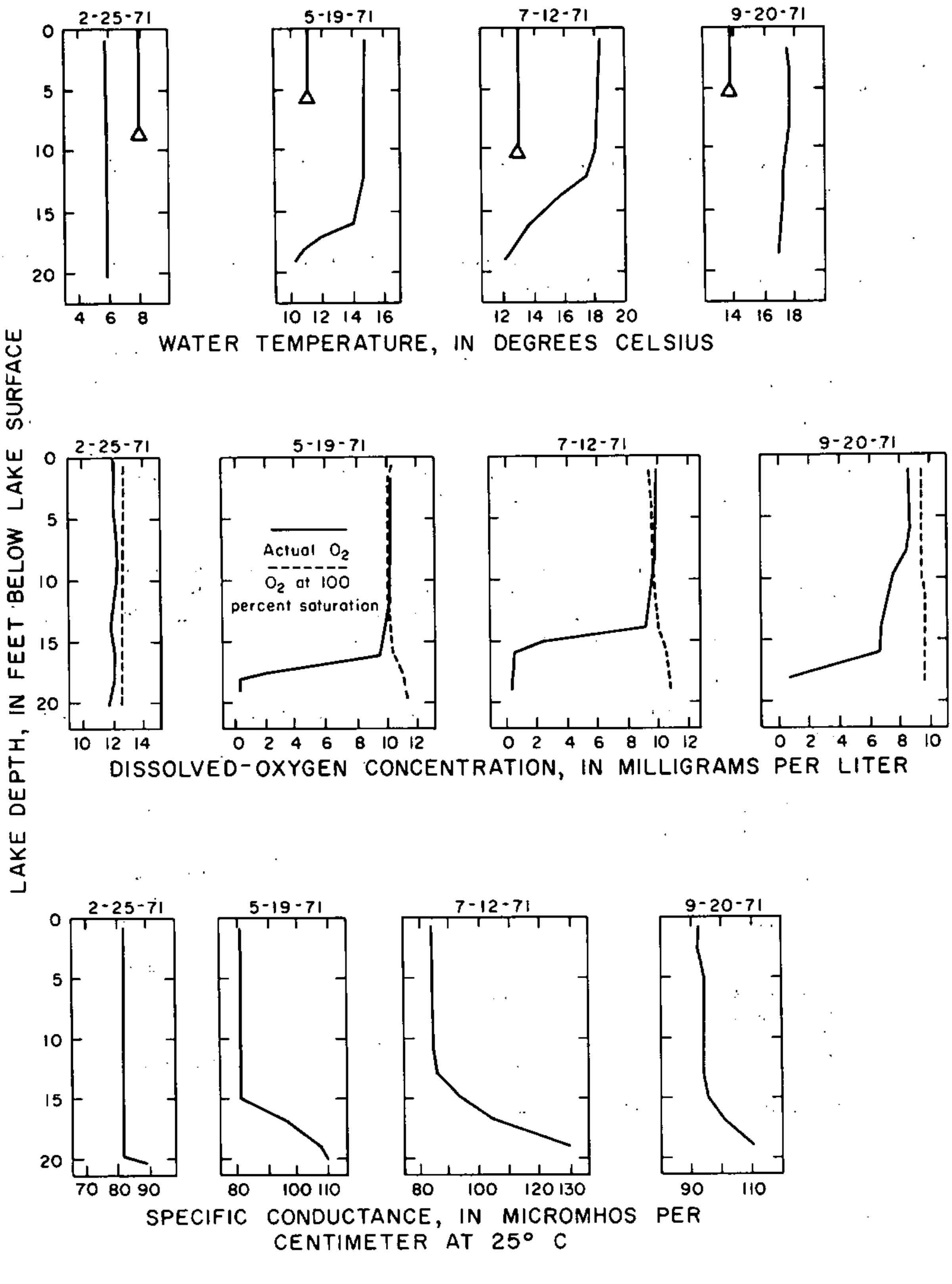

FIGURE 17.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Long Lake near Lacey. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12087400. Ohop Lake near Eatonville

Location

Pierce County, 0.8 mile north of Eatonville (fig. 1).

Origin

Ohop valley cut by large glacial stream; lake formed by dam of deltaic deposits from Lynch Creek, a tributary to Ohop Creek.

Basin geology

Alluvium in valley floor and glacial drift underlying adjacent uplands, with consolidated bedrock underlying hills to east (Walters and Kimmel, 1968).

Soils

Gravelly sandy loam on west valley slope and gravelly loamy sand on east valley slope. The main inflow drains through peat, poorly drained clay loam, silt loam, and muck (Anderson and others, 1955).

Land use and cover

Moderately heavy forest, with agricultural and residential clearings. Ohop valley is mostly farmland while the residential density is greatest at the lake periphery. The shore cover is primarily deciduous trees of alder, black cottonwood, dogwood, big-leaf maple, and Oregon ash.

Population

Lakeshore development moderately dense with 160 homes within 200 ft of shoreline, compared to 19 lakeshore homes in 1949 (estimated from U.S. Geological Survey topographic map). Both the inflow (north end) and the outflow (south end) cross low marshy land, making part of the shoreline undesirable for building. Residential development occupies approximately 51 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 18. The map was surveyed on June 14, 1954, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	17.3 sq mi
Altitude (from topographic map)	524 ft
Surface area	230 acres
Lake volume	3,810 acre-ft
Mean depth	17 ft
Maximum depth	25 ft
Length of shoreline	24,100 ft
Length of lake*	11,700 ft
Mean breadth of lake	880 ft
Shoreline configuration	2.15
Development of volume	0.66
Mean slope	4.5 percent

*Two intersecting lines used to determine length of L-shaped lake.

Hydrologic characteristics

Lake stages

A hydrograph of monthly maximum and minimum observed gage heights during 1962-70 is shown in figure 19. The altitude of gage is 525 ft (from topographic map); the datum of gage is arbitrary. The average annual variation in gage height was 3.6 ft during 1961-70. The gage height was observed daily in 1971 by U.S. Geological Survey (1971). The variation in gage height observed between October 1, 1970 and September 30, 1971 was 3.08 ft.

Surface-water inflow and outflow

The inflow is from Ohop Creek as well as from numerous seeps and springs. However, the main tributary to Ohop Creek is Twenty-five Mile Creek which joins Ohop Creek about 1 mile upstream from Ohop Lake. The outflow, which is controlled by a concrete weir, is via Ohop Creek. Miscellaneous measurements of inflow and outflow are given below.

Date	Inflow via Twenty-five Mile Creek (cfs)	Inflow via Ohop Creek* (cfs)	Outflow via Ohop Creek (cfs)
1970			
Feb 18	56.1	10.3	89.2
June 29	1.20	0	1.23
Oct 12	4.51	0	10.5
1971			
Feb 18	25.3	6.44	58.8
May 12	5.36	0	11.1
Jul 6	19.2	0	14.8
Sep 10	3.01	0	6.78

*Ohop Creek above Twenty-five Mile Creek

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 20.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was moderate. On September 10, 1972, approximately 2 percent of the lake surface and 10 percent of the lake bottom were occupied by macrophytes.

The dominant emergent aquatic plant was white waterlily (Nymphaea sp.), followed by yellow waterlily (*Nuphar* sp.), watershield (*Brasenia* sp.), cattails (*Typha* sp.), and sedge (*Cyperaceae*). The dominant submergent plant was pondweed (*Potamogeton robbinsii*), but other submergent plants included waterweed (*Elodea* sp.), muskgrass (*Chara* sp.), hornwort (*Ceratophyllum* sp.), and three other pondweed varieties.

No algal blooms or high algal densities were observed.

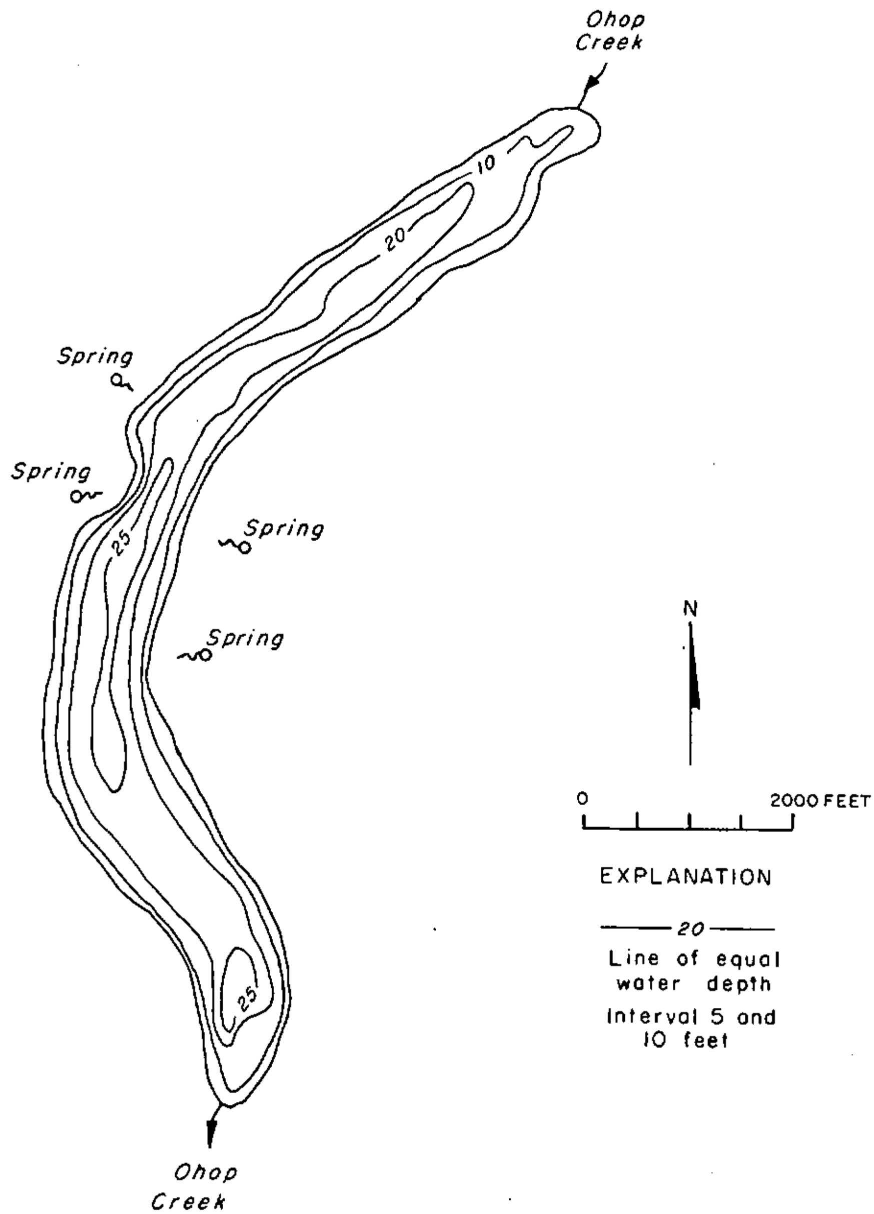

FIGURE 18.—Bathymetric map of Ohop Lake near Eatonville. From Washington Department of Game survey, June 14, 1954.

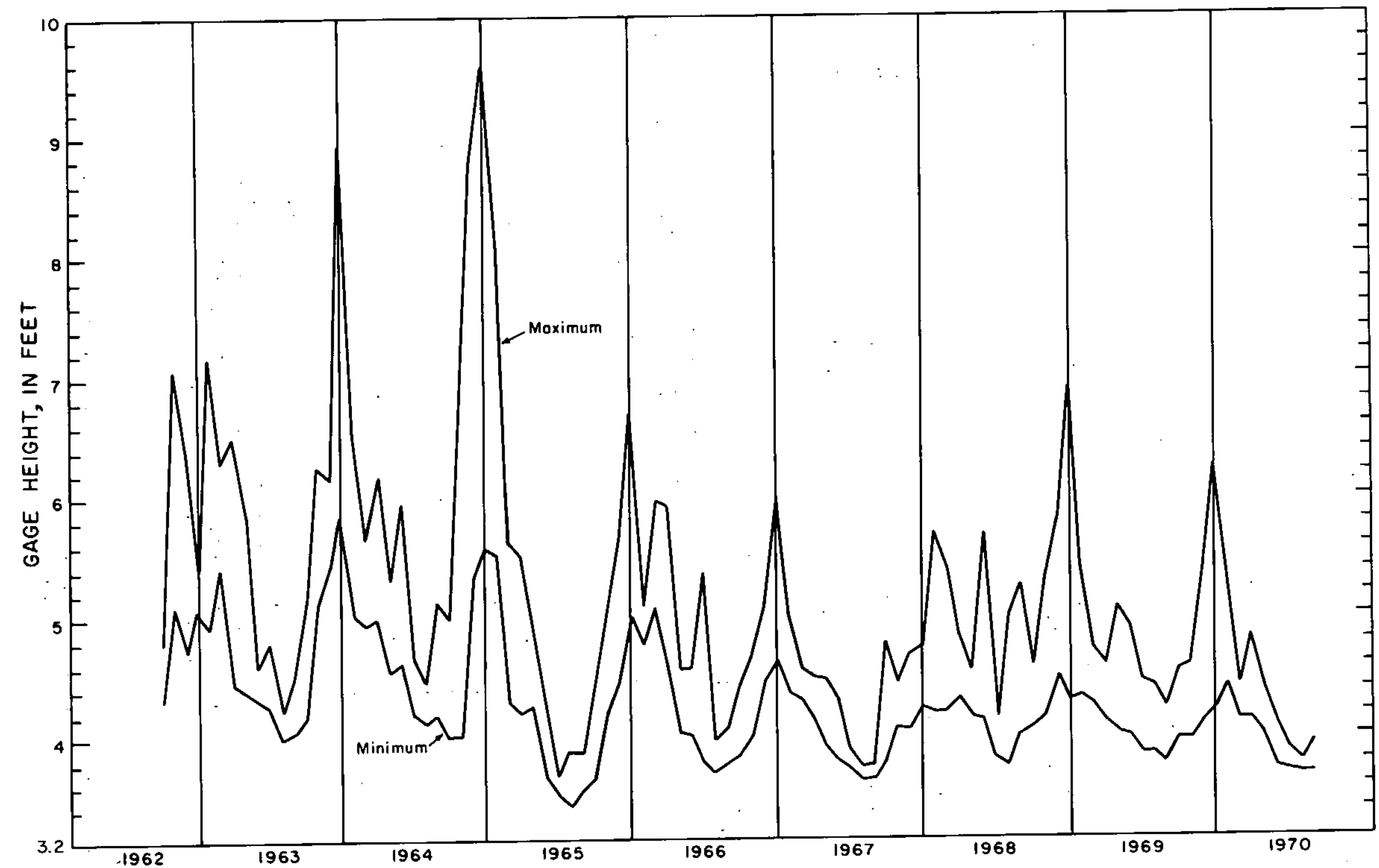

FIGURE 19.—Observed monthly maximum and minimum gage heights, Ohop Lake near Eatonville, 1962-70.

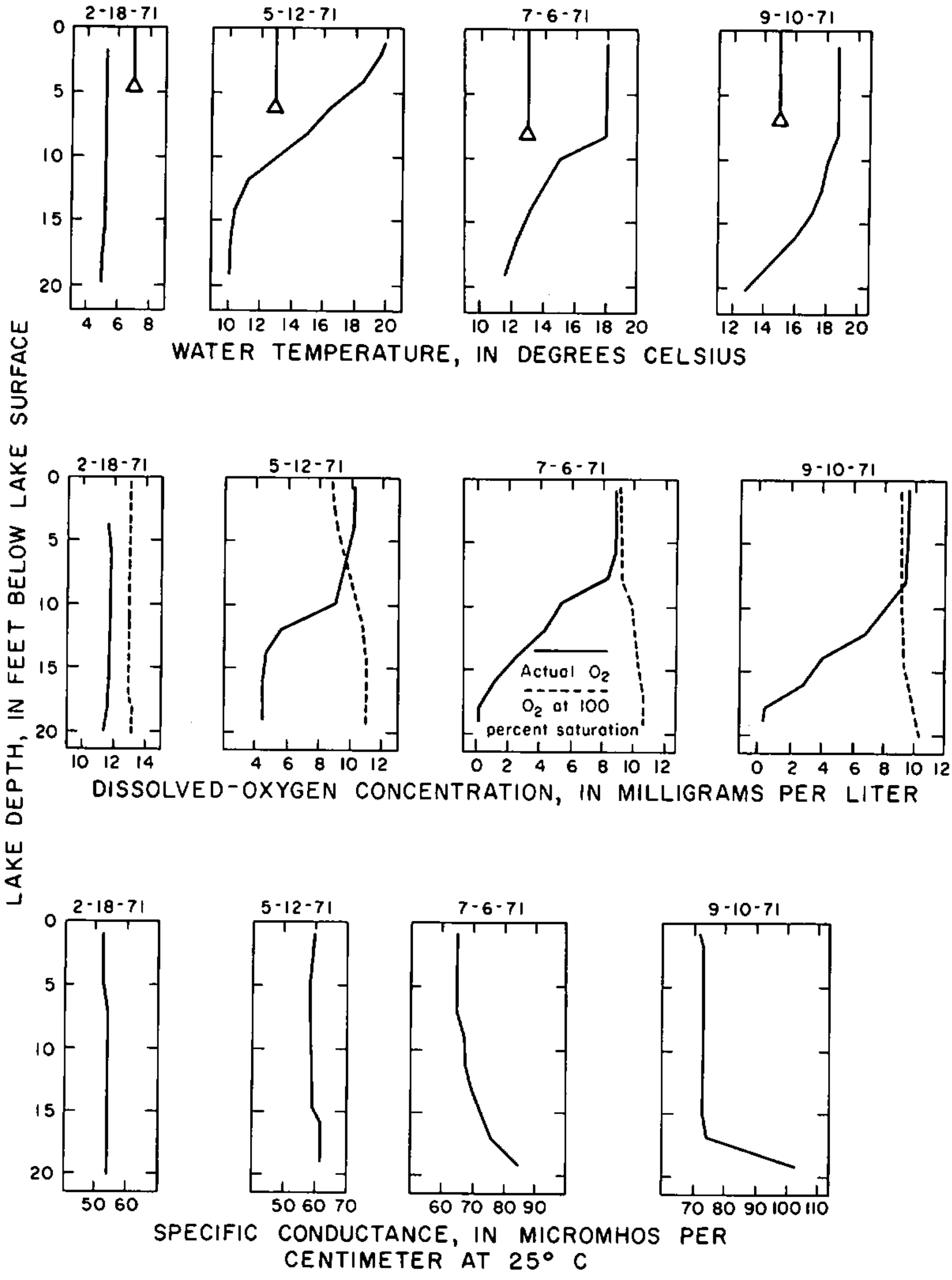

FIGURE 20.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Ohop Lake near Eatonville. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12088300. Silver Lake near La Grande

Location

Pierce County, 3.8 miles northwest of La Grande (fig. 1).

Origin

Kettle lake, part of a northeast trending chain of kettle lakes in area of low relief.

Basin geology

Glacial drift (Walters and Kimmel, 1968).

Soils

Gravelly loam and gravelly sandy loam on moderately sloping bottom land. Poorly drained organic soil encircles most of the lake (Anderson and others, 1955).

Land use and cover

Moderately forested, with agricultural and residential clearings. Residential and recreational development is limited to the east and north side of the lake. Sparse stands of cottonwood and willow dominate the nearshore cover.

Population

Lakeshore development moderately light with 33 dwellings and one resort (five cottages associated) on north shore in September 1971, compared to about seven buildings in 1949 (estimated from U.S. Geological Survey topographic map). Approximately 70 percent of the shoreline borders wetland or marsh, and the closest structure to the lake is about 600 ft from shore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 21 and an aerial photograph of the lake and surrounding basin is shown in figure 22. The map was surveyed on July 15, 1960, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	1.83 sq mi
Altitude (from topographic map)	604 ft
Surface area	149 acres
Lake volume	1,790 acre-ft
Mean depth	12 ft
Maximum depth	25 ft
Length of shoreline	9,120 ft
Length of lake	3,220 ft
Mean breadth of lake	2,020 ft
Shoreline configuration	1.01
Development of volume	0.54
Mean slope	2.1 percent

Hydrologic characteristics

Lake stages

Gage-height observations in 1970-71 are shown in figure 23. The altitude of the gage is 604 ft (from topographic map); the datum of gage is arbitrary. The observed gage height varied 2.0 ft in 1971. The high-water mark on crest-stage gage was 13.20 ft on March 10, 1972.

Surface-water inflow and outflow

No surface inflow is visible. The outflow, which is controlled by natural conditions, is through a small channel that is obstructed by vegetation during the summer. Miscellaneous outflow measurements are given below.

Date (1970)	Outflow (cfs)
Feb 17	3.20
Jun 29	0
Oct 12	0

Date (1971)	Outflow (cfs)
Feb 11	4.27
May 18	*.4
Jul 1	*.3
Sep 13	0

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 24.

Biological characteristics

Submergent rooted aquatic-plant growth was heavy, whereas emergent plant growth was light. On August 12, 1972, approximately 1 percent of lake-surface and 34 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was yellow waterlily (*Nuphar* sp.), followed by cattails (*Typha* sp.) and white waterlily (*Nymphaea* sp.). The principal submergent plants were pondweed (*Potamogeton* sp.), waterweed (*Elodea* sp.), and watercelery (*Vallisneria* sp.).

Algal blooms were observed on July 1 and September 13, 1971 and on October 12, 1970, and a high algal density was recorded on February 11 and May 18, 1971. The dominant species on July 1 was a blue-green alga, *Aphanizomenon* sp.

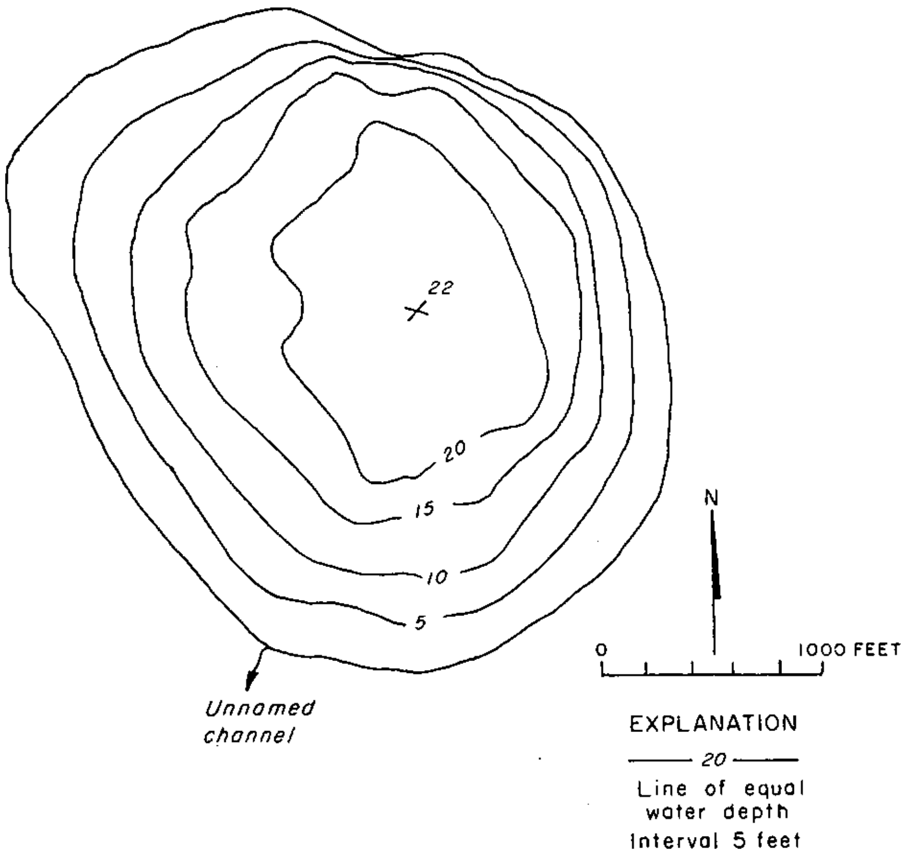

FIGURE 21.—Bathymetric map of Silver Lake near La Grande. From Washington Department of Game survey, July 15,1960.

FIGURE 22.—Aerial photograph of Silver Lake near La Grande, July 14, 1971. Scale, 1:6,600.

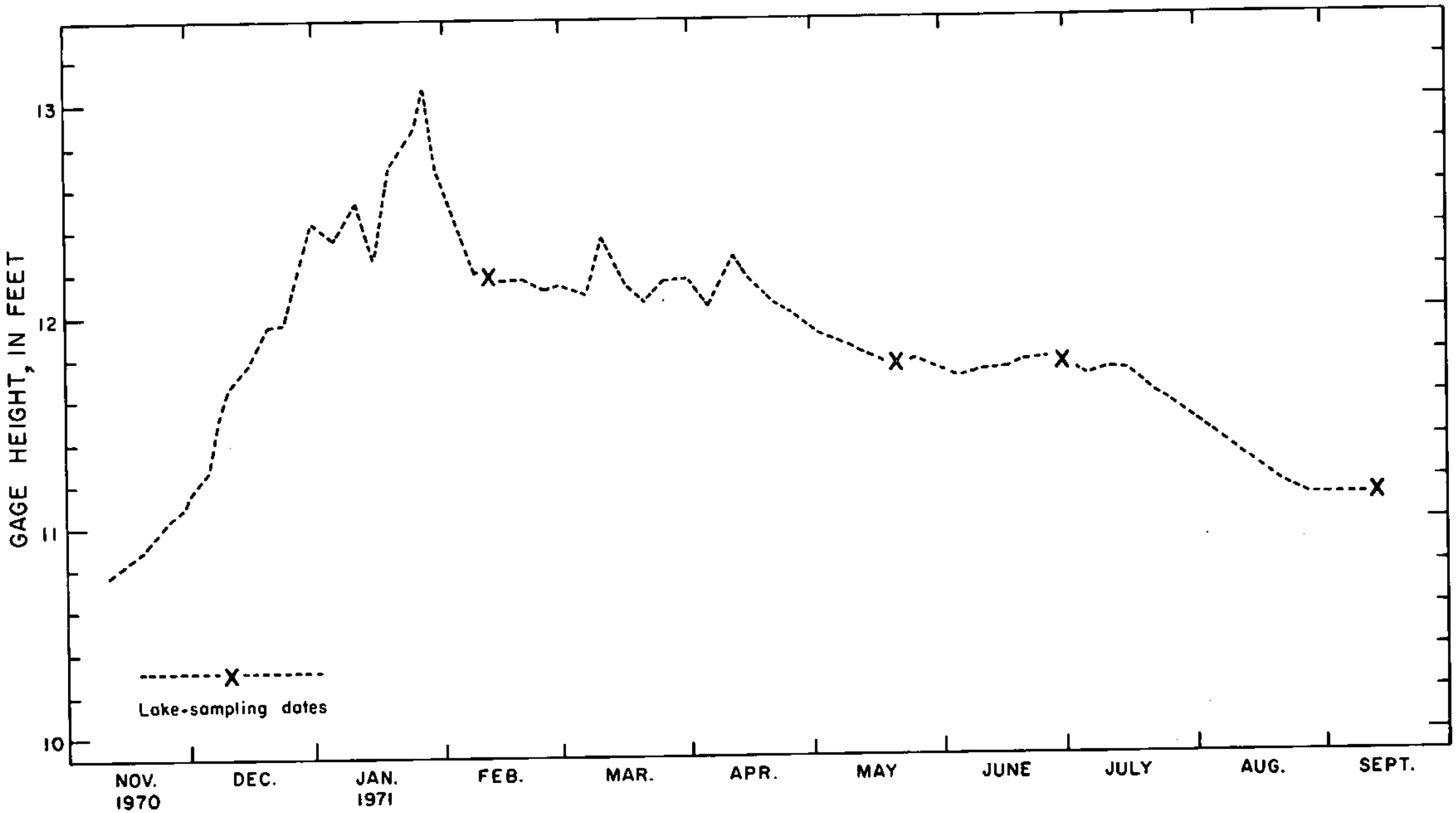

FIGURE 23.—Observed gage heights, Silver Lake near La Grande, 1970-71.

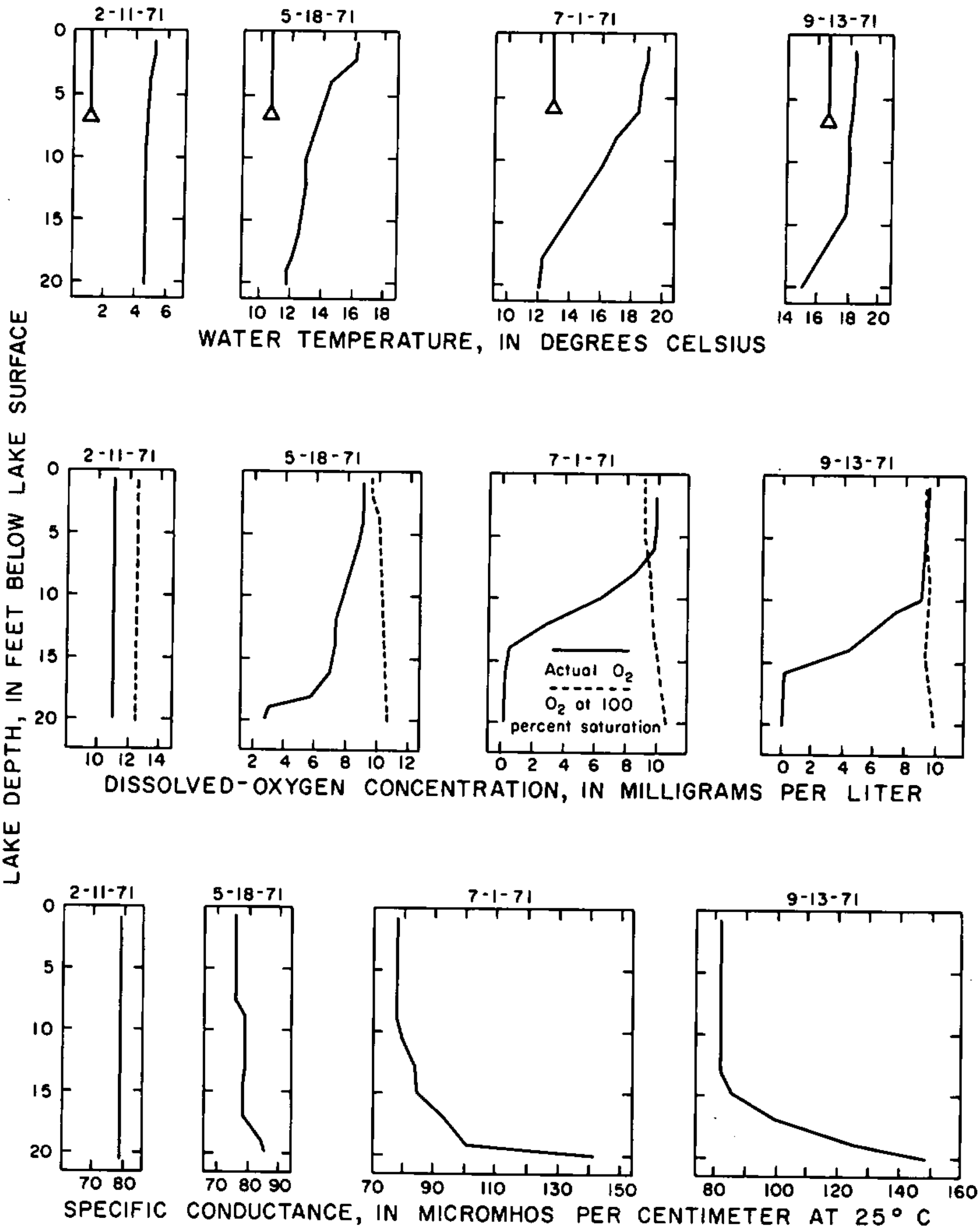

FIGURE 24.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Silver Lake near La Grande. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12088900. Tanwax Lake near Kapowsin

Location

Pierce County, 4.5 miles southwest of Kapowsin (fig. 1).

Origin

Kettle lake, part of a northeast trending kettle-lake chain formed along preglacial drainage lines in moderately sloping terrain.

Basin geology

Glacial recessional outwash and some peat deposits in valley, with compact glacial till underlying adjacent uplands (Walters and Kimmel, 1968).

Soils

Gravelly sandy loam. A smaller portion of basin lies in loamy sand, muck, peat, and rough broken land of mixed soils (Anderson and others, 1955).

Land use and cover

Moderately heavy forest, with residential and agricultural clearing. Some upland area is occupied by farms. The shore environs are primarily covered with deciduous trees of alder, big-leaf maple, Oregon ash, cottonwood, dogwood, and cascara.

Population

Lakeshore development is moderately dense with 70 residences in September 1971, compared to about 63 dwellings in 1959 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 70 percent of lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 25 and an aerial photograph of the lake and surrounding basin is shown in figure 26. The map was surveyed on June 26, 1952, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	4.08 sq mi
Altitude (from topographic map)	600 ft
Surface area	170 acres
Lake volume	3,340 acre-ft
Mean depth	20 ft
Maximum depth	30 ft
Length of shoreline	14,600 ft
Length of lake	6,060 ft
Mean breadth of lake	1,220 ft
Shoreline configuration	1.51
Development of volume	0.65
Mean slope	5.1 percent

Hydrologic characteristics

Lake stages

A hydrograph of monthly maximum and minimum observed gage heights for the period 1965-70 is shown in figure 27. The altitude of gage is 600 ft (from topographic map); the datum of gage is arbitrary. The average annual variation in gage height was 1.6 ft for 1965-70. The gage height was observed two to three times weekly during the 1971 water year (U.S. Geological Survey, 1971). The gage-height variation from October 1, 1970 to September 30, 1971 was 1.74 ft.

Surface-water inflow and outflow

Main inflows are from two unnamed tributaries as well as from seeps and springs. The outflow, which is controlled by a concrete dam, is via Tanwax Creek. Some water is diverted from lake for domestic use. Miscellaneous measurements of inflow (sites 1 and 2 on bathymetric map) and outflow are given below.

Date	Inflow at Site 1 (cfs)	Inflow at Site 2 (cfs)	Outflow via Tanwax Creek (cfs)
1970			
Feb 18	7.35	10.8	22.1
Jun 16	*.3	*.1	*1
Oct 13	.19	.05	0
1971			
Feb 18	4.66	6.29	19.8
May 12	*1	*.7	2.74
Jul 7	.76	.66	*.2
Sep 10	*.5	0	0

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 28.

Biological characteristics

The rooted submergent aquatic-plant growth was moderate, whereas the emergent plant growth was light. On October 12, 1972, approximately 1 percent of the lake surface and 8 percent of the lake bottom were occupied by macrophytes. The dominant submergent plants were muskgrass (*Chara* sp.) and four varieties of pondweed (*Potamogeton* spp.). The emergent plants consisted of waterlily (*Nuphar* sp. and *Nymphaea* sp.), watershield (*Brasenia* sp.), watercelery (*Vallisneria* sp.), cattails (*Typha* sp.), and sedge (*Cyperaceae*).

An algal bloom was observed on October 13, 1970, and a high algal density was recorded on February 18 and September 10, 1971.

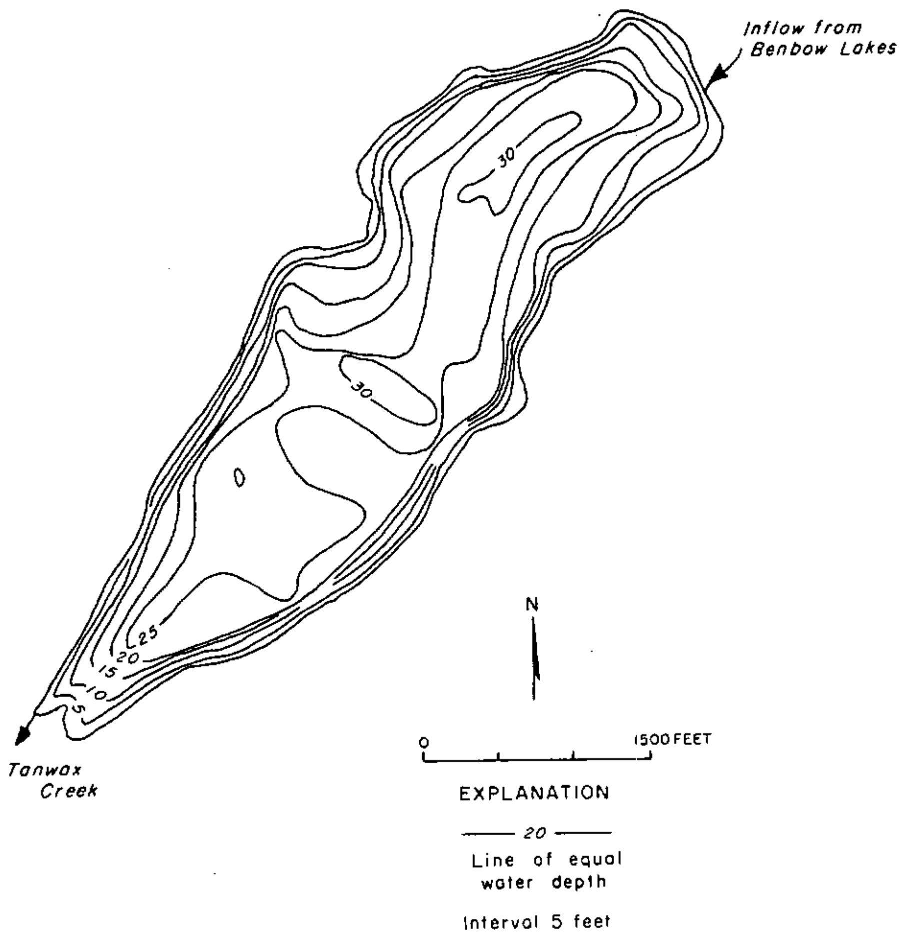

FIGURE 25.—Bathymetric map of Tanwax Lake near Kapowsin. From Washington Department of Game survey, June 26, 1952.

FIGURE 26.—Aerial photograph of Tanwax Lake near Kapowsin, July 14, 1971. Scale, 1:12,000.

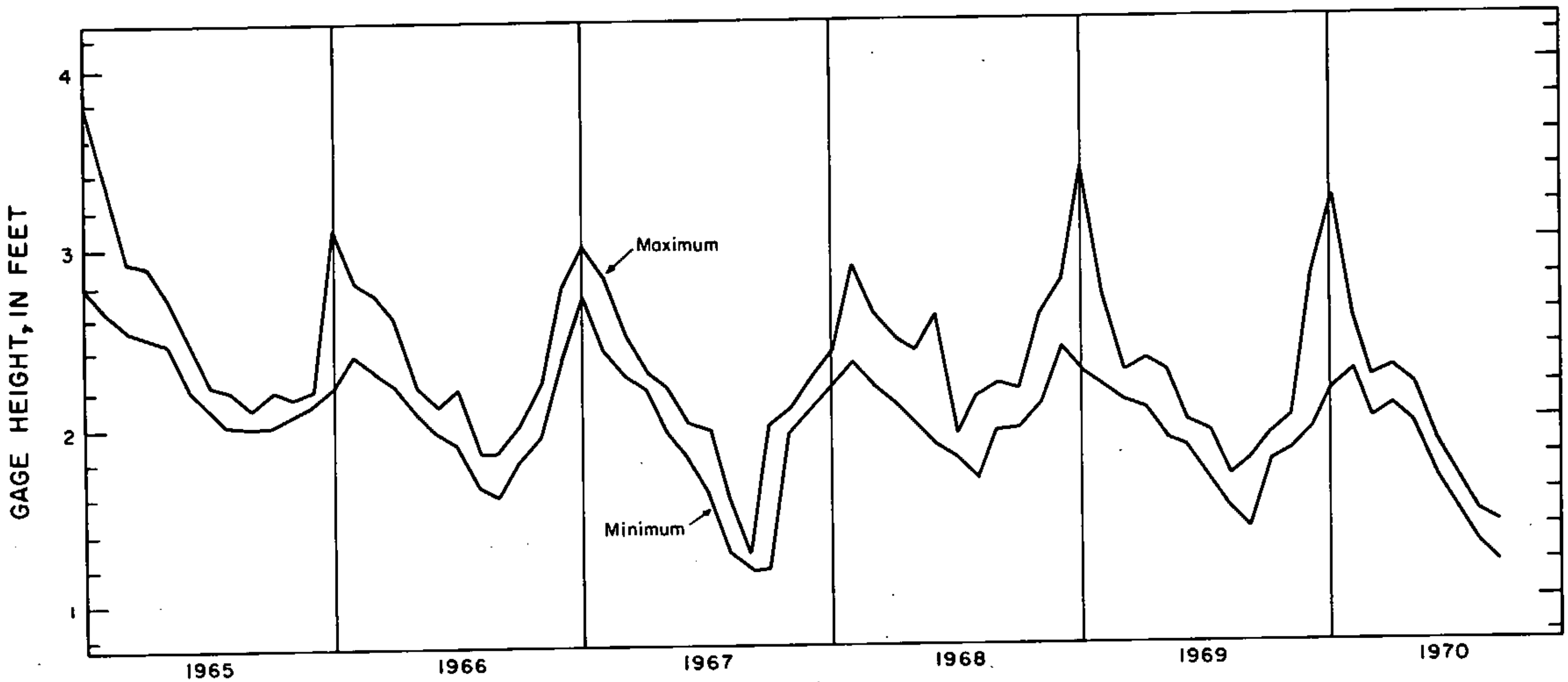

FIGURE 27.—Observed monthly maximum and minimum gage heights, Tanwax Lake near Kapowsin, 1965-70.

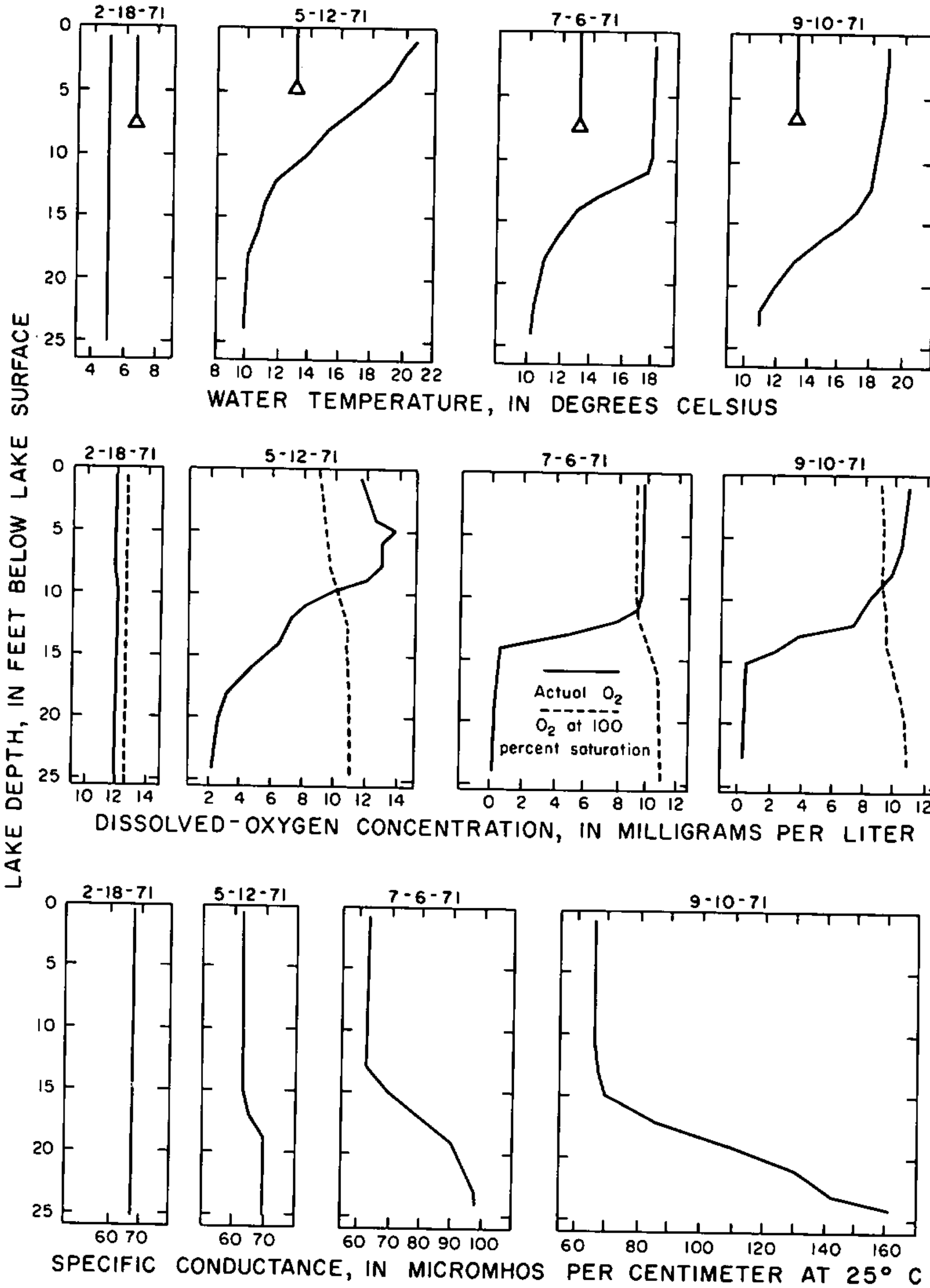

FIGURE 28.–Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Tanwax Lake near Kapowsin. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12089020. Clear Lake near McKenna

Location

Thurston County, 8.5 miles southeast of McKenna (fig. 1).

Origin

Kettle lake in hummocky terrain.

Basin geology

Glacial drift consisting of unstratified sand and gravel deposited along ice margin (Noble and Wallace, 1966).

Soils

Soil of stony sandy loam (Ness, 1958).

Land use and cover

Moderately heavy forest, with recreational and residential clearings. A commercial timber company owns a planned housing development surrounding most of lake. Cover on shore periphery is a mixture of Douglas fir, cedar, alder, madrona, and Oregon ash.

Population

Lakeshore development sparse with nine dwellings (includes four trailer houses) and a resort in September 1971, compared to eight lakeshore homes in 1959 (estimated from U.S. Geological Survey topographic map). Homesites in housing development are located beyond a forest buffer zone of several hundred feet. Residential development occupies approximately 16 percent of lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 29 and an aerial photograph of the lake and surrounding basin is shown in figure 30. The map was surveyed on February 19, 1952, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	2.61 sq mi
Altitude (from topographic map)	516 ft
Surface area	168 acres
Lake volume	3,180 acre-ft
Mean depth	19 ft
Maximum depth	25 ft
Length of shoreline	14,400 ft
Length of lake	4,820 ft
Mean breadth of lake	1,520 ft
Shoreline configuration	1.50
Development of volume	.75
Mean slope	4.0 percent

Hydrologic characteristics

Lake stages

Gage heights observed periodically in 1971 are listed below. The altitude of the gage is 516 ft (from topographic map); datum of gage is arbitrary.

Date (1971)	Gage Height (ft)
Feb 25	12.46
May 19	12.04
Jul 12	11.96
Sep 22	11.49

Surface-water inflow and outflow

The main inflow is a small stream on the south end of the lake. The outflow, which is controlled by natural conditions, is via a well-developed channel. Miscellaneous inflow and outflow measurements are given below.

Date 1971	Inflow (cfs)	Outflow (cfs)
Feb 25	5.67	5.74
May 19	1.81	3.21
Jul 12	1.26	2.13
Sep 22	* .3	* .08

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 31.

Biological characteristics

Rooted aquatic-plant growth was sparse. Less than 0.01 percent of the lake surface and approximately 0.2 percent of the lake bottom were occupied by macrophytes on September 22, 1971. Widely scattered patches of aquatic plants included pondweed (*Potamogeton* sp.), watermilfoil (*Myriophyllum* sp.), cattails (*Typha* sp.), and sedges (*Cyperaceae*).

An algal bloom was observed May 19, 1971, and a high algal density was recorded on July 12, 1971.

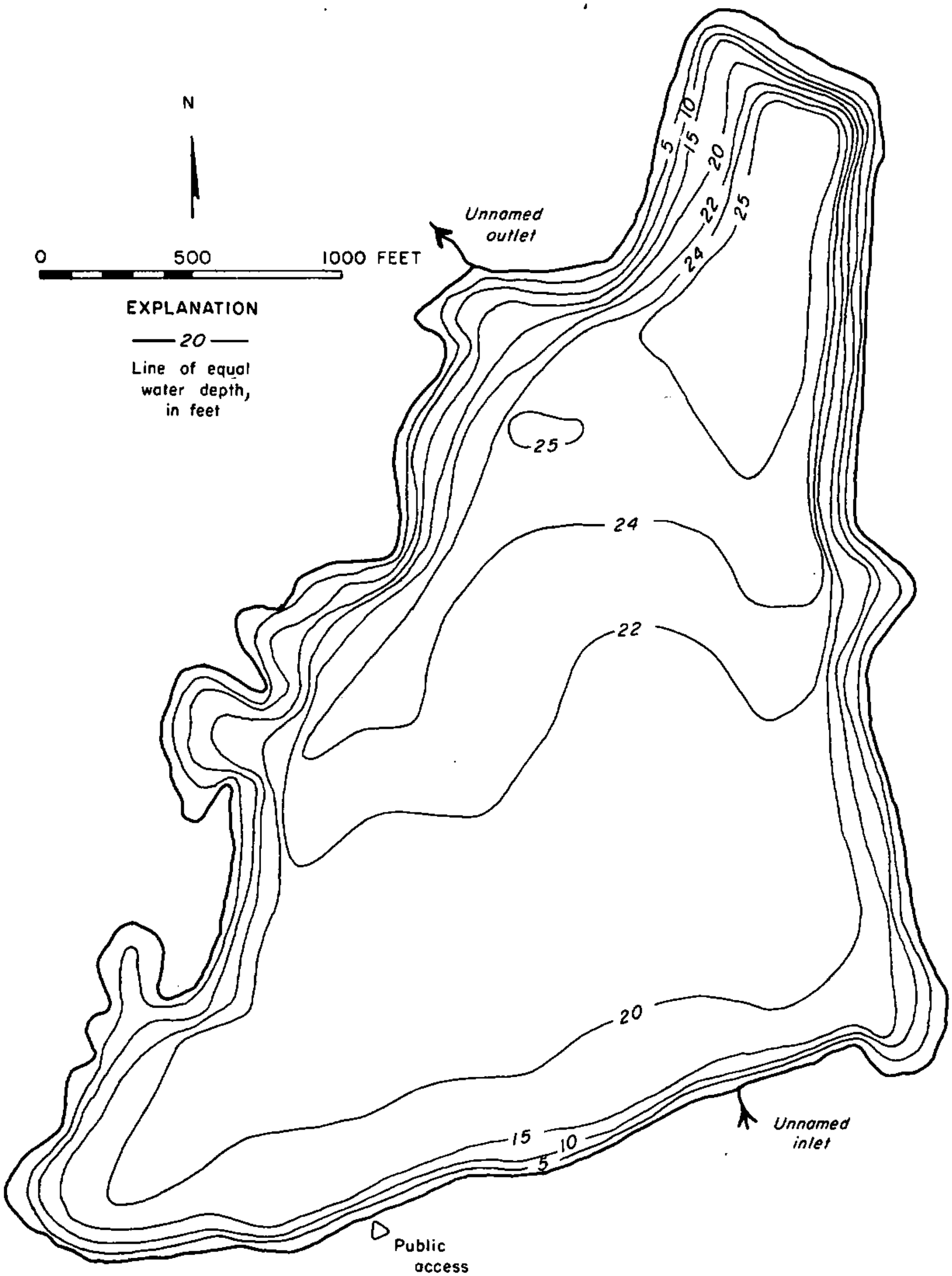

FIGURE 29.—Bathymetric map of Clear Lake near McKenna. From Washington Department of Game, Feb. 19-20, 1952.

FIGURE 30.—Aerial photograph of Clear Lake near McKenna, July 14, 1971. Scale, 1:8900.

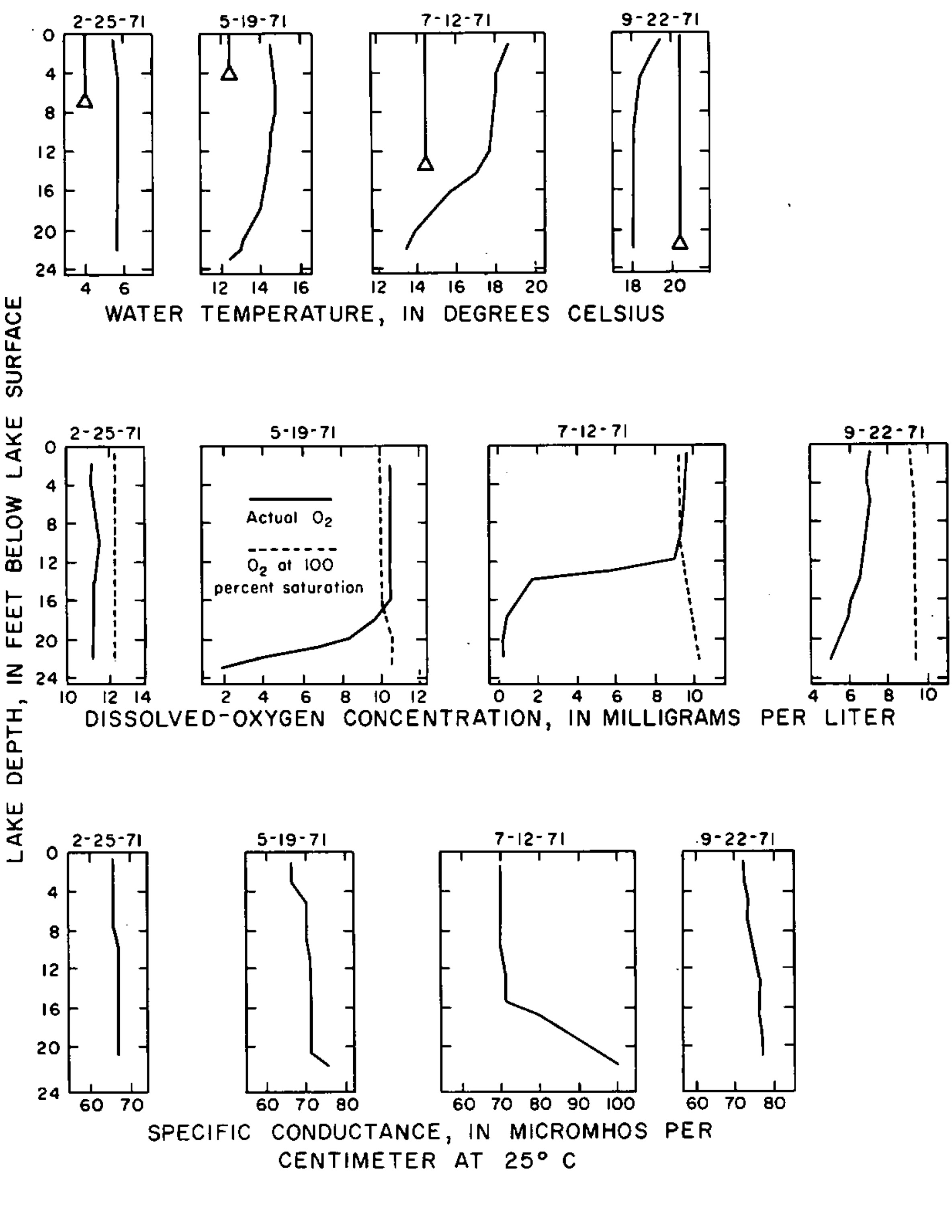

FIGURE 31.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Clear Lake near McKenna. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12089200. Harts Lake near McKenna

Location

Pierce County, 4.8 miles southeast of McKenna (fig. 1).

Origin

Kettle lake.

Basin geology

Recessional outwash plain with till hills in upper basin. Alluvium deposits from the Nisqually River lie along the southern lakeshore (Walters and Kimmel, 1968).

Soils

Mostly peat, gravelly loam, and rough broken land of mixed soil material and some gravelly sandy loam and silt loam (Anderson and others, 1955).

Land use and cover

Moderately heavy forest, with residential and agricultural clearing. Approximately one-half of the lakeshore is adjacent to grazing land. Willow and alder dominate the nearshore cover.

Population

Lakeshore development is sparse with six residences (three seasonal) and a resort in September 1971, compared to 11 lakeshore dwellings in 1959 (estimated from U.S. Geological Survey topographic map). Approximately 20 percent of lake adjoins wet bottom land. Residential development occupies about 10 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 32 and an aerial photograph of the lake and surrounding basin is shown in figure 33. The map was surveyed on June 1, 1953, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	3.57 sq mi
Altitude (from topographic map)	347 ft
Surface area	121 acres
Lake volume	3,130 acre-ft
Mean depth	26 ft
Maximum depth	50 ft
Length of shoreline	8,480 ft
Length of lake	2,870 ft
Mean breadth of lake	1,840 ft
Shoreline configuration	1.04
Development of volume	0.52
Mean slope	5.5 percent

Hydrologic characteristics

Lake stages

Periodic gage heights observed in 1970-71 are shown below. The altitude of the gage is 347 ft (from topographic map); the datum of the gage is arbitrary.

Date	Gage Height (ft)	Date	Gage Height (ft)
1970		*1971*	
Feb 17	8.93	Jan 14	8.16
Jun 29	8.17	Jan 19	8.50
Oct 13	7.46	Jan 26	9.50
Dec 5	7.78	Feb 11	7.98
Dec 10	7.89	Feb 19	7.98
Dec 15	7.90	Feb 26	7.99
Dec 20	7.90	Mar 5	8.09
Dec 24	7.91	Mar 10	8.18
Dec 31	7.92	Mar 15	8.04
		Mar 19	8.08
1971		May 13	8.46
		Jul 1	8.10
Jan 1	7.93	Aug 13	7.50
Jan 10	7.99	Sep 13	7.56
		Nov 1	7.63

The maximum height on the crest-stage gage was 9.50 ft, on January 26, 1971.

Surface-water inflow and outflow

The inflow is from two intermittent streams. The outflow, which is controlled by natural conditions, is via a small channel that is plant-obstructed in summer. Miscellaneous measurements of the inflow and outflow are given below.

Date	Inflow, Total Miscellaneous (cfs)	Outflow (cfs)
1970		
Feb 17	6.34	14.3
Jun 29	0	.49
Oct 13	0	.88
1971		
Feb 11	1.01	6.21
May 13	.17	2.69
July 1	* .2	.84
Aug 13	––	1.08
Sep 13	––	0
Nov 1	* .2	1.20

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of specific conductance and water temperature are shown in figure 34. Profiles of DO concentration and shown in figure 35.

Nutrient data for inflow to Harts Lake near McKenna (Date of sample—February 11, 1971) is shown below.

Item	Nutrient values in milligrams per liter
Orthophosphate (as P)	0.00
Total phosphorus (as P)	.03
Nitrate nitrogen (as N)	.11
Ammonia nitrogen (as N)	.08

Biological characteristics

Rooted aquatic-plant growth was moderate. On August 13, 1971, approximately 4 percent of the lake surface and 9 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was yellow waterlilly (*Nuphar* sp.), followed by white waterlilly (*Nymphaea* sp.), watershield (*Brasenia* sp.), and cattails (*Typha* sp.). The dominant submergent plants were pondweed (*Potamogeton amplifolius*) and waterweed (*Elodea* sp.).

Algal blooms were observed February 11, May 13, July 1, and September 13, 1971. The chlorophyll *a* concentrations were 48 and 9.2 µg/l on May 13 and August 13, respectively. The mean biomass concentration was 6.8 mg/l and the range was 0.28 to 16 mg/l.

The greatest concentration of biomass (16 mg/l) occurred on July 1 when a blue-green algal bloom of *Aphanizomenon* sp. and *Anabaena* sp. composed about 70 percent of the total net phytoplankton. Biomass and chlorophyll *a* determinations indicate medium to high values. In three of four sample periods the phytoplankton population was dominated by a single algal specie. Frequent algal blooms dominated by a few species has often been taken as partial evidence of eutrophic conditions (Rawson, 1956).

Sampling for total coliform bacteria was performed at four shore stations on May 13 and on November 1, 1971. The sample of May 13 had a colony density that exceeded 240 per 100 ml, the recommended bathing-beach standard for the State of Washington. The sample with highest coliform counts probably resulted from contamination by runoff from a dairy farm. Excluding the high coliform sample (250 colonies per 100 ml), the mean value was 5 with a range of 0 to 15 colonies per 100 ml.

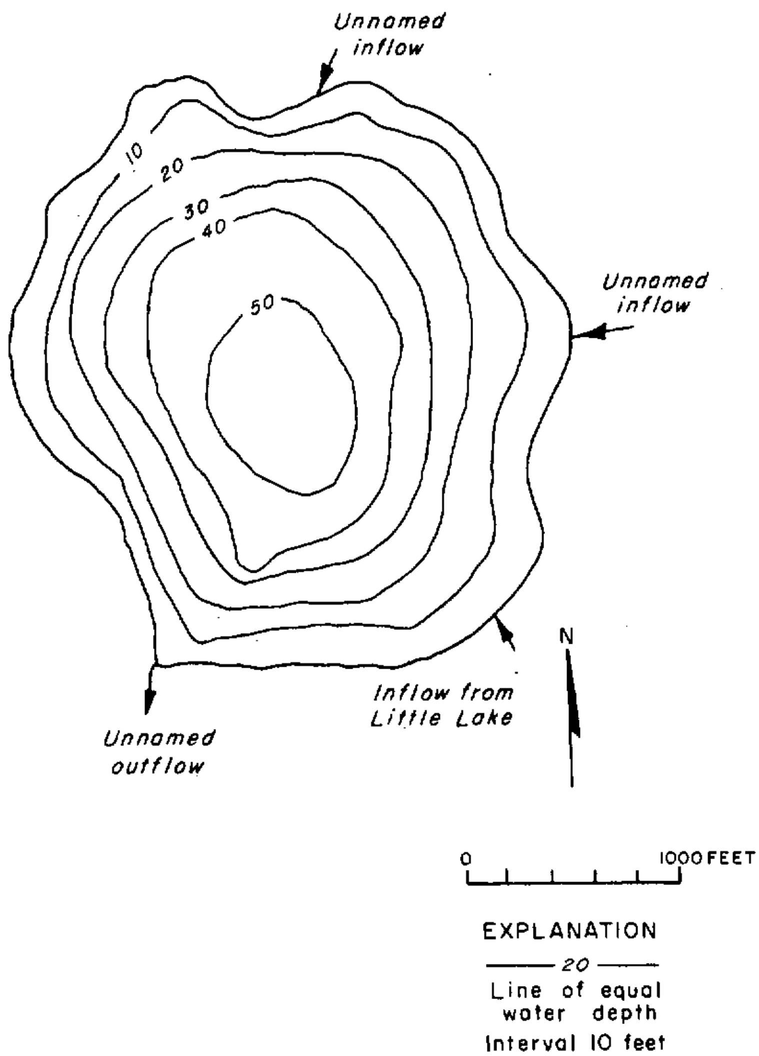

FIGURE 32.–Bathymetric map of Harts Lake near McKenna. From Washington Department of Game survey, June 1, 1953.

FIGURE 33.—Aerial photograph of Harts Lake near McKenna, July 14, 1971. Scale, 1:7550.

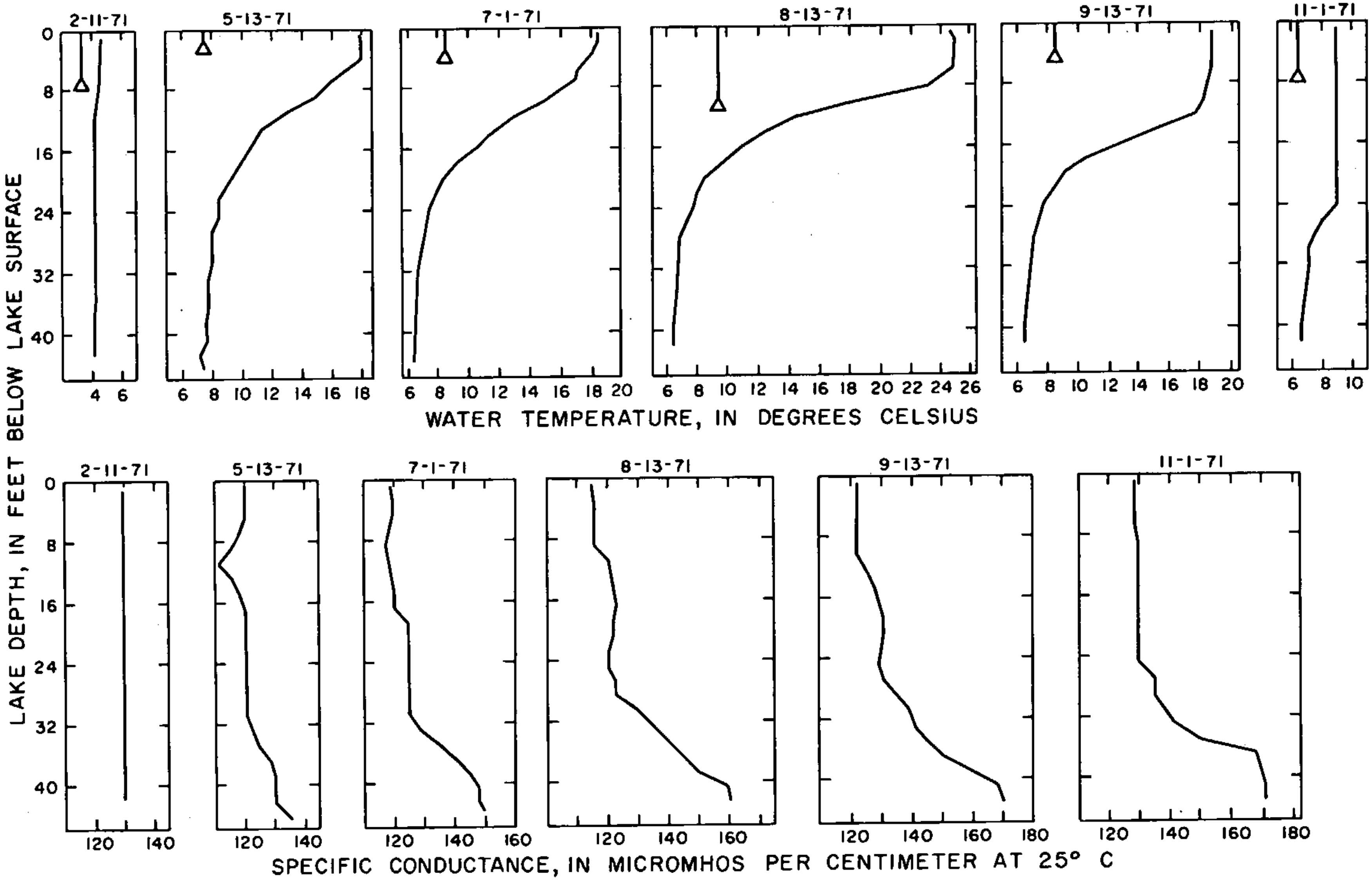

FIGURE 34.—Selected 1971 seasonal profiles of lake temperature and specific conductance, Harts Lake near McKenna. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

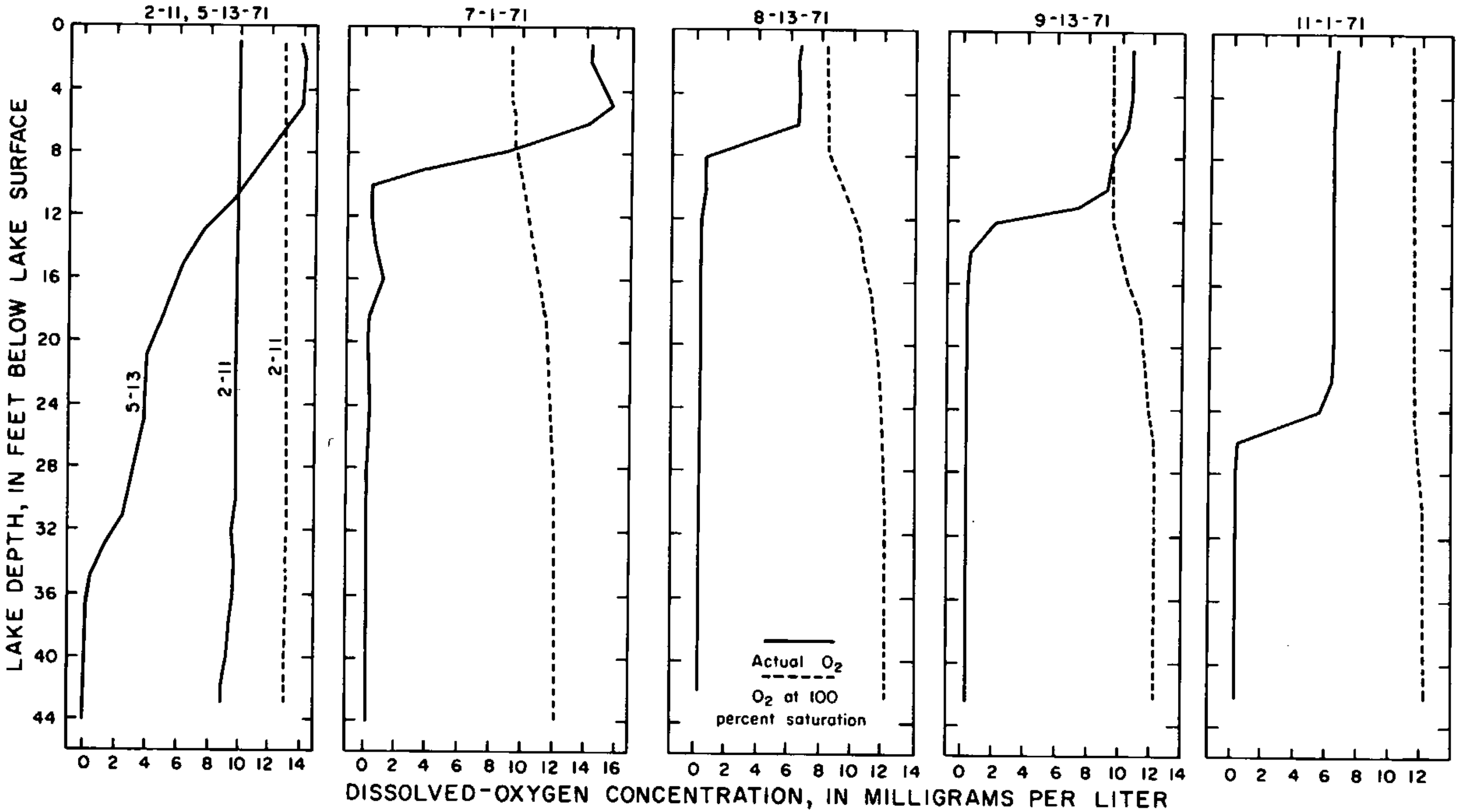

FIGURE 35.—Selected 1971 seasonal profiles of DO concentration, Harts Lake near McKenna.

12090300. American Lake near Tillicum

Location

Pierce County, 1.7 miles southwest of Tillicum (fig. 1).

Origin

Kettle lake formed on glacial outwash plain.

Basin geology

Glacial outwash plain underlain by chiefly pebble to cobble gravel and boulders (Walters and Kimmel, 1968).

Soils

Gravelly sandy loam on gently undulating slope (Anderson and others, 1955).

Land use and cover

Scattered forest, with residential, commercial, and recreational clearings. The nearshore cover includes scattered stands of deciduous and coniferous trees mostly on lawns.

Population

Lakeshore development moderately dense with 250 structures within 300 ft of water's edge in August 1971. Approximately 53 percent of the lakeshore is occupied by residential development, and the remaining 47 percent of the shore environs is occupied by beaches, country-club resorts, and military housing.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 36. The map was surveyed on May 24, 1953, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	25.4 sq mi
Altitude (from topographic map)*	235 ft
Surface area	1,135 acres
Lake volume	60,200 acre-ft
Mean depth	53 ft
Maximum depth	90 ft
Length of shoreline	62,200 ft
Length of lake	17,000 ft
Mean breadth of lake	2,900 ft
Shoreline configuration	2.49
Development of volume	0.59
Mean slope	8.2 percent

*Mean lake stage is 232 ft (msl).

Hydrologic characteristics

Lake stages

Miscellaneous lake-stage observations in 1970-71 are shown below. The datum of gage is mean sea level.

Date (1970)	Lake Stage (ft above msl)	Date (1971)	Lake Stage (ft above msl)
Feb 19	232.19	Feb 12	232.01
Jun 30	231.39	Mar 23	233.41
Oct 19	229.12	May 3	233.56
Nov 19	229.06	May 18	233.41
		June 30	232.85
		Jul 11	231.59
		Sep 16	230.76
		Nov 2	230.03

The observed lake stage varied 3.53 ft in 1971. The lake is controlled by means of a drop-entrance box culvert, altitude 233 ft (msl), which was installed May 14, 1956. A hydrograph of the monthly maximum and minimum lake stages during 1956-60 is presented by Collings (1973). The lake stage varied 2.9, 2.7, and 3.6 ft for 1957, 1958, and 1959, respectively.

Surface-water inflow and outflow

The main inflow is via Murray Creek. No natural outlet existed, but in 1956 a culvert outlet was installed to Sequalitchew Creek to insure against flooding of the lake. Miscellaneous measurements of inflow and outflow are given below.

Date	Inflow via Murray Creek (cfs)	Outflow Sequalitchew Creek (cfs)
1970		
Feb 19	10.6	0
Jun 30	2.53	0
Oct 19	1.33	0
1971		
Feb 12	10.4	0
May 18	10.4	2.61
Jun 30	7.13	0
Jul 11	5.17	0
Sep 16	3.37	0
Nov 2	2.62	0

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 37. In September 1957, the DO concentration at 40 and 80 feet below the water surface was 0.0 mg/l (Washington Department of Game, written commun., 1970). On September 16, 1971, the DO concentration was 1.5 and 0.2 mg/l at the 40- and 80-foot depths, respectively.

Nutrient data for Murray Creek, tributary to American Lake near Tillicum is shown below.

	Nutrient values in milligrams per liter			
Date of sample (1971)	Orthophosphate (as P)	Total Phosphate (as P)	Nitrate Nitrogen (as N)	Ammonia Nitrogen (as N)
Feb 26	0.00	0.02	0.31	0.32
May 18	0.02	0.02	0.40	0.02
Jun 30	0.01	0.01	0.16	0.19
Aug 11	0.01	0.01	0.18	0.07
Sep 9	0.02	0.03	0.07	0.08
Nov 2	0.01	0.03	0.00	0.02

Biological characteristics

Rooted aquatic-plant growth was sparse. On September 13, 1972, approximately 0.02 percent of the lake surface and 0.3 percent of the lake bottom were occupied by macrophytes. The lake contained waterlily (*Nuphar* sp. and *Nymphaea* sp.), sedge (*Scripus* sp. and *Eleocharis* sp.), smartweed (*Polygonum* sp.), waterweed (*Elodea* sp.), watercelery (*Vallisneria* sp.), and five varieties of pondweed (*Potamogeton* spp.).

No algae blooms or high algal densities were noted. The chlorophyll *a* concentrations were 2.6 μg/l and 1.1 μg/l on May 18 and August 11, respectively. The mean biomass concentration was 0.11 mg/l, and the range was 0.03 to 0.15 mg/l. Biomass and chlorophyll *a* concentrations indicate low to medium values. The phytoplankton population was dominated by *Dinobryon* sp., *Fragilaria* sp., and *Anabaena* sp., on May 18, June 30, and August 11, 1971, respectively. Even though single specie dominance existed, nuisance bloom conditions did not develop.

Sampling for total coliform bacteria was performed at five shore stations on May 18 and November 2. None of the samples had a colony density exceeding 240 per 100 ml, the recommended bathing-beach standard for the State of Washington. The mean value was 2 and ranged from 0 to 8 colonies per 100 ml.

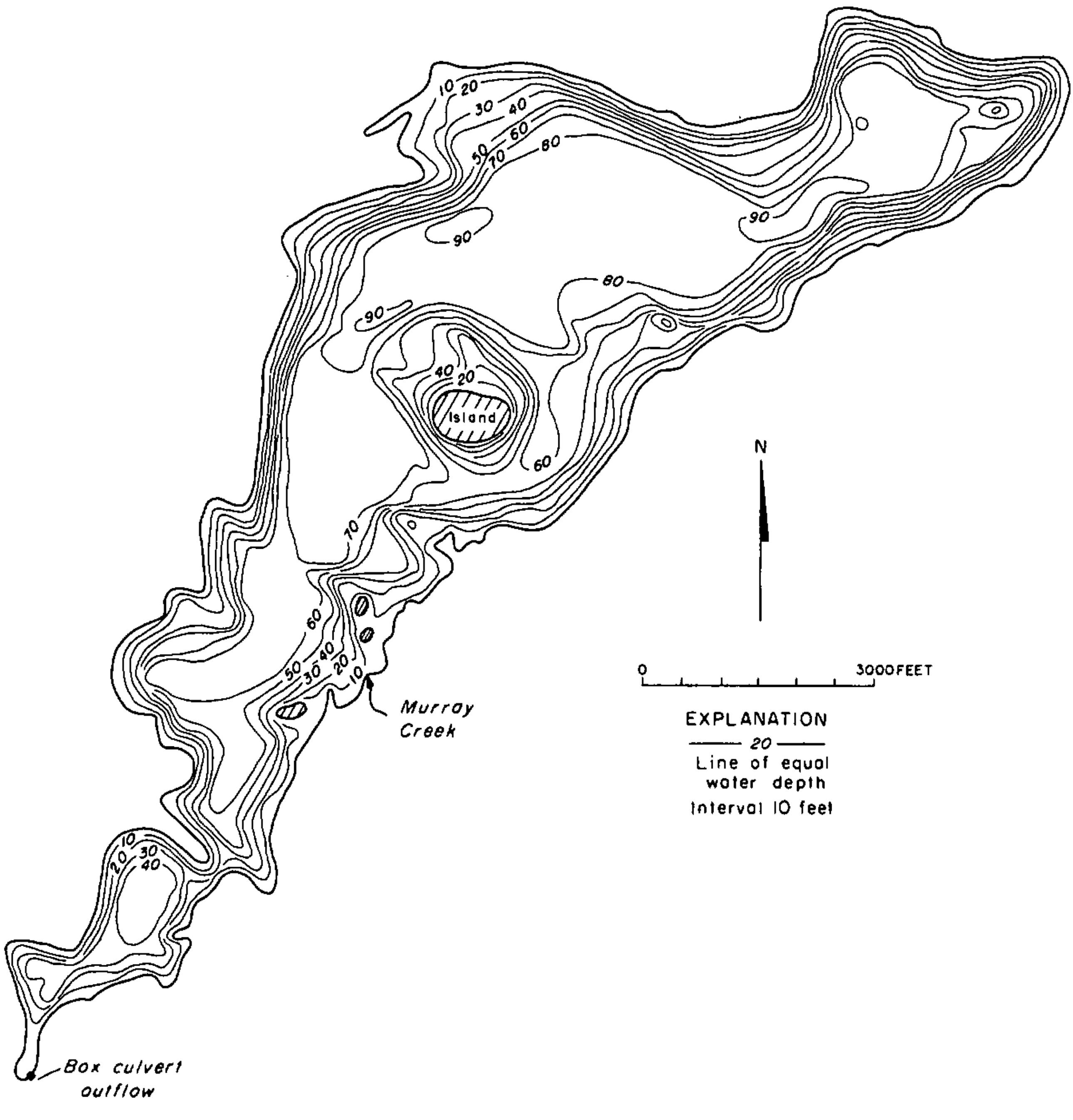

FIGURE 36.—Bathymetric map of American Lake near Tillicum. From Washington Department of Game survey, May 24, 1953.

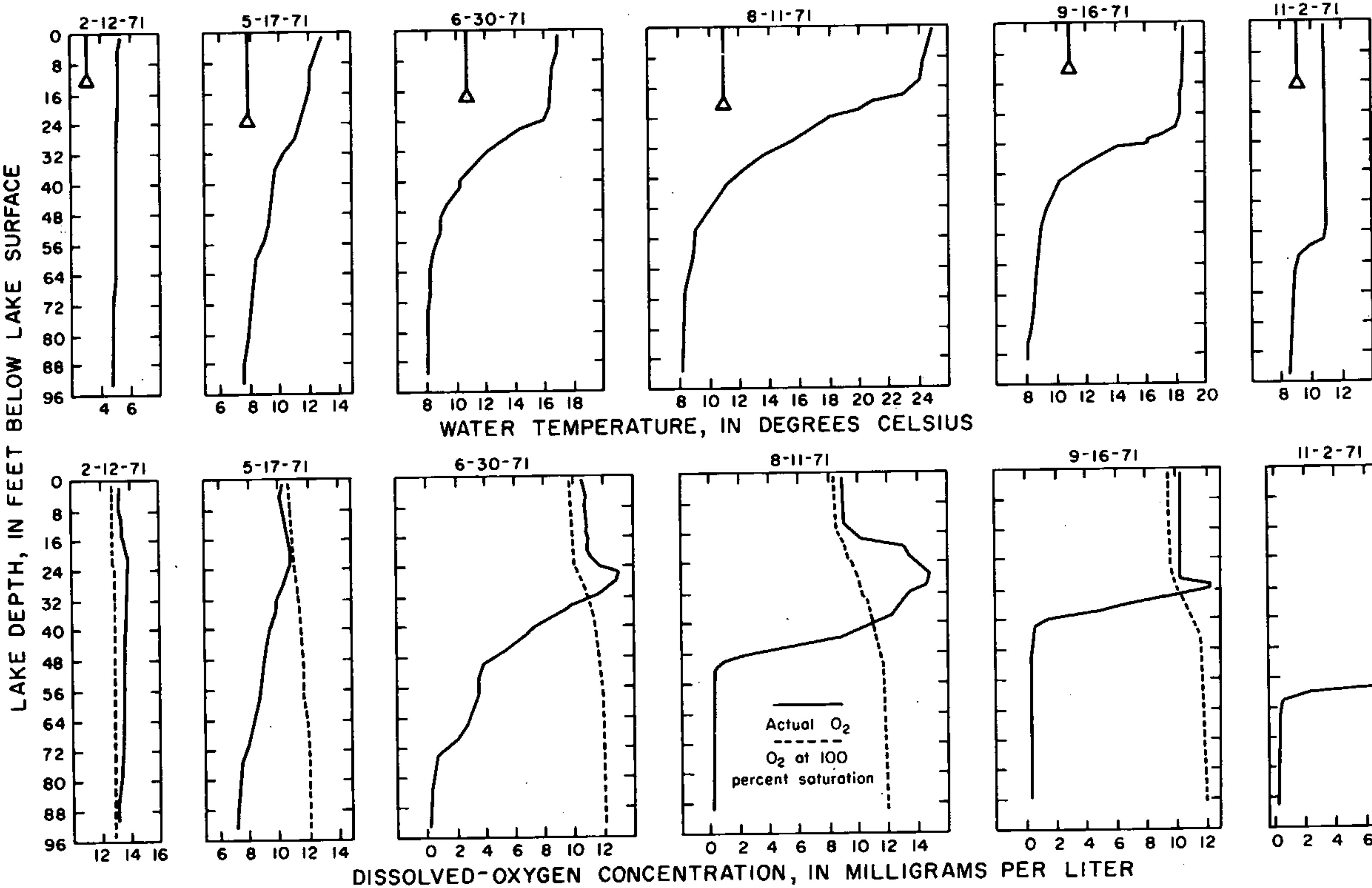

FIGURE 37.—Selected 1971 seasonal profiles of lake temperature and DO concentration, American Lake near Tillicum. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12090990. Steilacoom Lake near Steilacoom

Location

Pierce County, 2.5 miles east of Steilacoom (fig. 1).

Origin

Kettle lake formed on glacial-outwash plain.

Basin geology

Glacial-outwash plain underlain chiefly by pebble to cobble gravel and boulders (Walters and Kimmel, 1968).

Soils

Gravelly sandy loam on gently undulating slope (Anderson and others, 1955).

Land use and cover

Sparsely forested, with commercial and residential clearings. The lake lies in an urban environment. The nearshore cover includes scattered stands of deciduous and coniferous trees mostly on lawns.

Population

Lakeshore development is very dense with 285 nearshore homes in September 1971. Residential development occupies virtually the entire lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 38. The map was surveyed on February 3, 4, and June 2, 1950, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	89.4 sq mi
Altitude (from topographic map)	210 ft
Surface area	317 acres
Lake volume	3,530 acre-ft
Mean depth	11 ft
Maximum depth	20 ft
Length of shoreline	30,100 ft
Length of lake	6,000 ft
Mean breadth of lake	2,300 ft
Shoreline configuration	2.28
Development of volume	0.56
Mean slope	2.8 percent

Hydrologic characteristics

Lake stages

Miscellaneous gage height observations in 1970-71 are shown below. The altitude of the gage is 210 ft (from topographic map); the datum of gage is arbitrary. The lake altitude is regulated by gates at a weir structure near the outlet.

Date 1970	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 19	5.76	Feb 26	5.78
May 11	5.51	Mar 20	6.20
June 30	5.53	May 18	5.88
Oct 22	5.13	Jul 23	5.70
Nov 10	4.47	Sep 15	5.29

The high-water mark on the crest-stage gage was 6.6 ft in February 1971 and 6.5 ft in May 1971.

Surface-water inflow and outflow

The main inflows are from Ponce de Leon and Clover Creeks. The outflow, which is controlled by gages at the weir structure, is via Chambers Creek. Some water is pumped from the lake for domestic use. Miscellaneous measurements of the inflow and outflow are given below.

Date	Inflow via Ponce de Leon Creek (cfs)	Inflow via Clover Creek (cfs)	Outflow via Chambers Creek* (cfs)
1970			
Feb 19	26.7	114	203
Jun 30	10.2	--	53
Oct 22	7.79	0	20
1971			
Feb 26	27.2	--	170
May 18	17.0	51.4	50
Jul 23	11.3	6.34	30
Sep 15	8.02	.56	21

*From rating of recording gage on Chambers Creek (12091040. Chambers Creek above Flett Creek)

The average discharge for 1966-71 was 81.9 cfs at Chambers Creek above Fleet Creek.

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 39.

Nutrient data for Ponce de Leon and Clover Creeks, tributaries to Steilacoom Lake, is shown below.

Date of Sample (1971)	Nutrient values in milligrams per liter			
	Orthophosphate (as P)	Total Phosphorus (as P)	Nitrate Nitrogen (as N)	Ammonia Nitrogen (as N)
Ponce de Leon Creek				
Feb 26	0.04	0.05	1.44	0.00
May 18	0.06	0.06	2.1	0.00
Sep 15	0.05	0.08	1.6	0.03
Clover Creek				
Feb 23	0.00	0.02	1.3	0.02
May 18	0.03	0.03	1.5	0.00
Sep 15	0.02	0.03	0.67	0.07

Biological characteristics

Submergent rooted-aquatic plant growth was light, whereas emergent plant growth was sparse. On September 15, 1971, approximately 0.02 percent of the lake surface and 4 percent of the lake bottom were occupied by macrophytes.

Sedge (*Cyperaceae*) was the only emergent plant observed. Rooted submergent plants were waternymph (*Najas* sp.), waterweed (*Elodea* sp.), and two varieties of pondweed (*Potamogeton* spp.). The most abundant plant growth was in the small circular bay on southwest side of the lake. The muck substrate for rooted plant growth in the littoral zone is low (5 percent of the shoreline), and the lake is treated with herbicides and algaecides to control plant growth.

No algal blooms were observed, but a high algal density was recorded on February 26, May 18, and September 15, 1971.

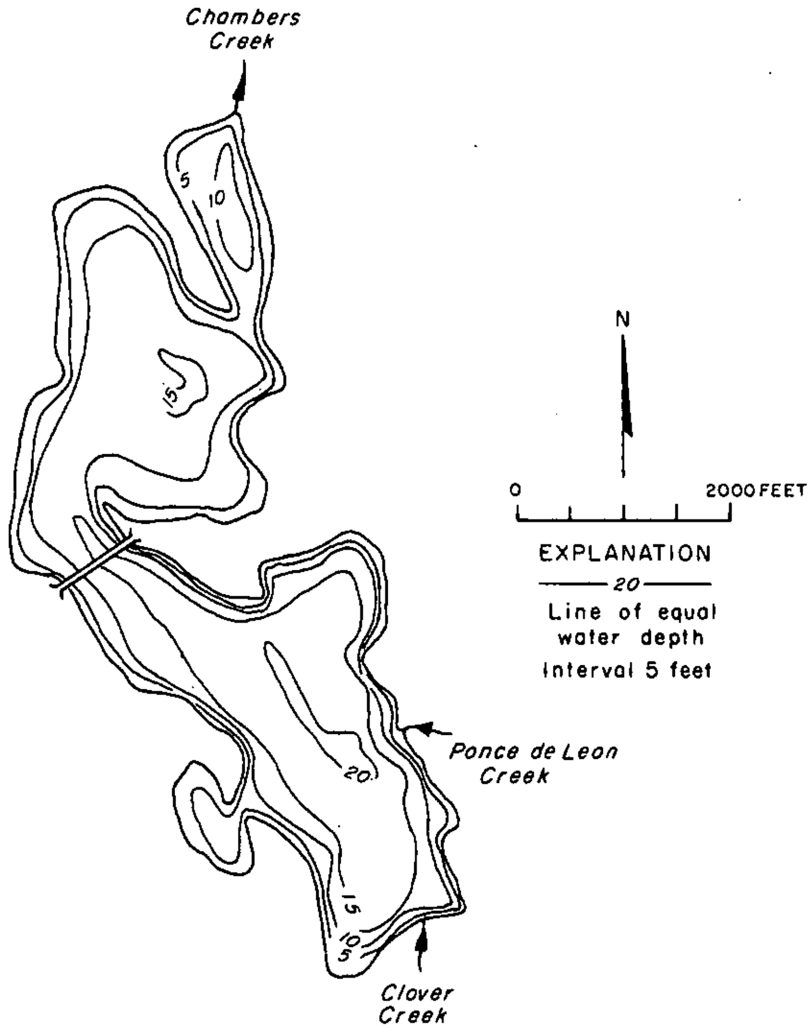

FIGURE 38.—Bathymetric map of Steilacoom Lake near Steilacoom. From Washington Department of Game survey, 1950.

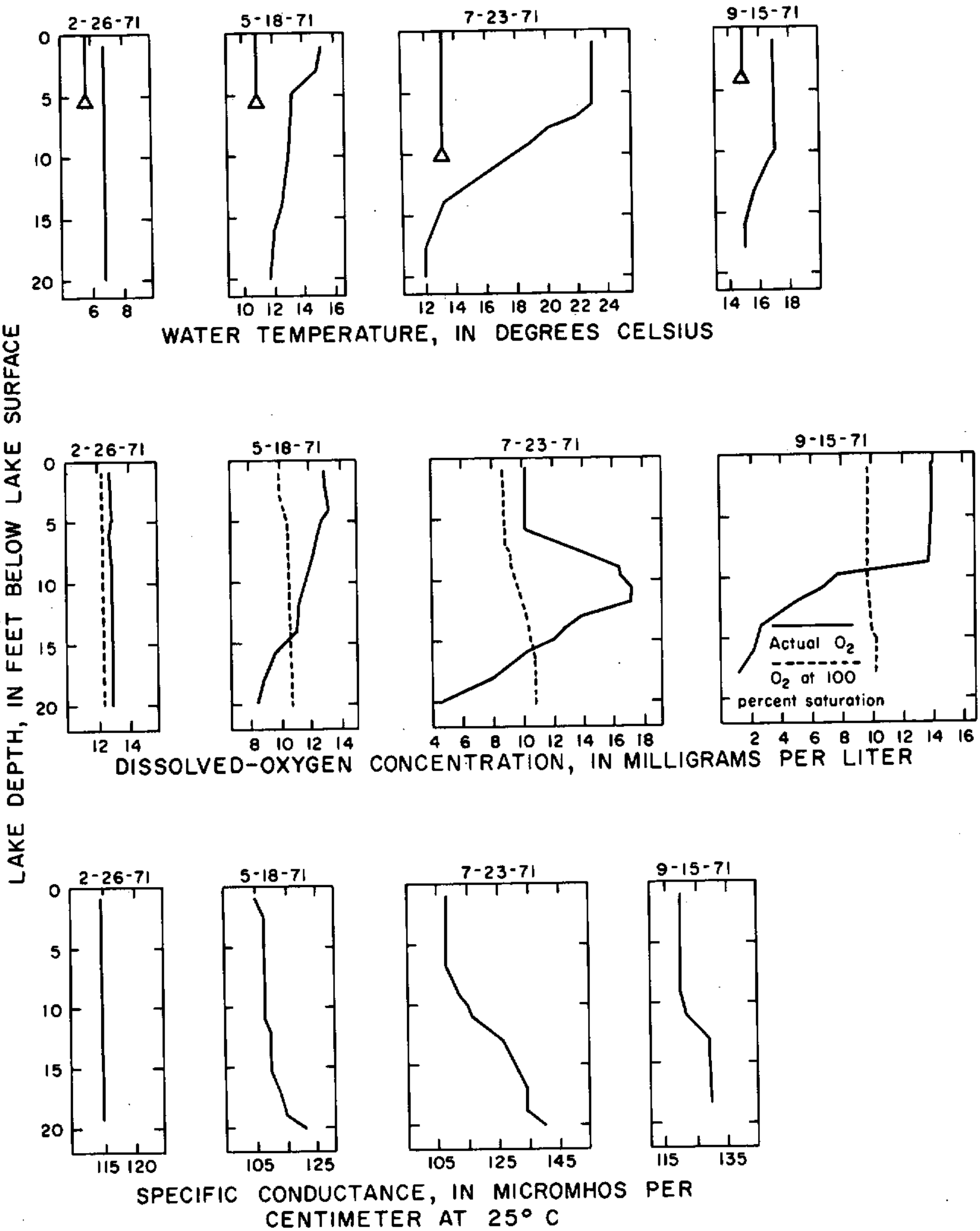

FIGURE 39.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Steilacoom Lake near Tillicum. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12110002. Wilderness Lake near Maple Valley

Location

King County, 2.5 miles south of Maple Valley (fig. 1).

Origin

Kettle lake.

Basin geology

Glacial-outwash plain between hills of glacial till. West side of the lake includes some peat deposits (Luzier, 1969).

Soils

Gravelly fine sandy loam and gravelly sandy loam and some peat deposits (Poulson and others, 1952).

Land use and cover

Moderately heavy forest, with residential clearings. Nearshore cover includes a mixture of Douglas fir, alder, willow, vine maple, and black cottonwood.

Population

Lakeshore development is moderately dense with 50 dwellings, a resort and a park in September 1971, compared to 41 lakeshore homes in 1949 (estimated from U.S. Geological topographic map, but 1949 map also shows over 30 park- and resort-associated buildings no longer in existence). Residential development occupies approximately 48 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 40 and an aerial photograph of the lake and surrounding basin is shown in figure 41. The map was surveyed on July 25, 1952, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	0.66 sq mi
Altitude (from topographic map)	470 ft
Surface area	69 acres
Lake volume	1,420 acre-ft
Mean depth	21 ft
Maximum depth	38 ft
Length of shoreline	9,400 ft
Length of lake	3,480 ft
Mean breadth of lake	860 ft
Shoreline configuration	1.53
Development of volume	0.54
Mean slope	7.7 percent

Hydrologic characteristics

Lake stages

The observed gage heights in 1971 are shown in figure 42. The altitude of the gage is 470 ft (from topographic map) and the gage datum is arbitrary. The lake altitude is regulated by flashboards at the outlet. The observed gage height varied 1.26 ft from November 9, 1970 to August 10, 1971. The high-water mark on the crest-stage gage was 2.2 ft in February 1971.

Surface-water inflow and outflow

No surface inflow was observed. The outflow, which is controlled by flashboards, is through a small well-defined channel. Miscellaneous measurements of the outflow are given below.

Date (1970)	Outflow (cfs)	Date (1971)	Outflow (cfs)
Feb 16	4.40	Feb 9	4.70
Jun 24	.83	Mar 14	.51
Oct 20	.0	Jun 29	.90
		Aug 10	.52
		Sep 14	* .2
		Nov 1	.36

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths, profiles of specific conductance, and water temperature are shown in figure 43. Profiles of DO concentration are shown in figure 44. In September 1952, the DO concentration was 3.2 mg/l at the 30-ft depth (Washington Department of Game, written commun., 1970). On September 14, 1971, the DO concentration was 0.2 mg/l at the 30-ft depth.

Biological characteristics

Emergent rooted aquatic-plant growth was light, and the submergent plant growth was sparse. On August 10, 1971, approximately 0.1 percent of the lake surface and 0.9 percent of the lake bottom were occupied by macrophytes. The lake contained patches of waterlily (*Nuphar* sp. and *Nymphaea* sp.), cattail (*Typha* sp.), waterweed (*Elodea* sp.), and three varieties of pondweed (*Potamogeton* spp.).

Algal blooms were observed on February 9 and October 20, 1971, and a high algal density was recorded on September 14, 1971.

The chlorophyll *a* concentrations were 2.6 and 2.9 μg/l on May 14 and August 10, respectively. The mean biomass concentration was 1.0 mg/l, and the range was 0.08 to 3.8 mg/l. The greatest quantity of biomass (3.8 mg/l) occurred on Febraury 9, 1971, when a blue-green algal bloom of *Aphanizomenon* sp. comprised over 99 percent of the net phytoplankton. The dominant phytoplankton were diatoms on May 19 and green algae on June 29, 1971. Present conditions in the lake are marked by a tendency for dominance by a few species of algae, especially early in the year.

Sampling for total coliform organisms was performed at four shore stations on May 14 and on November 1, 1971. None of the samples had a colony density exceeding 240 per 100 ml, the recommended bathing-beach standard for the State of Washington. The mean value was 29 and ranged from 3 to 88 colonies per 100 ml.

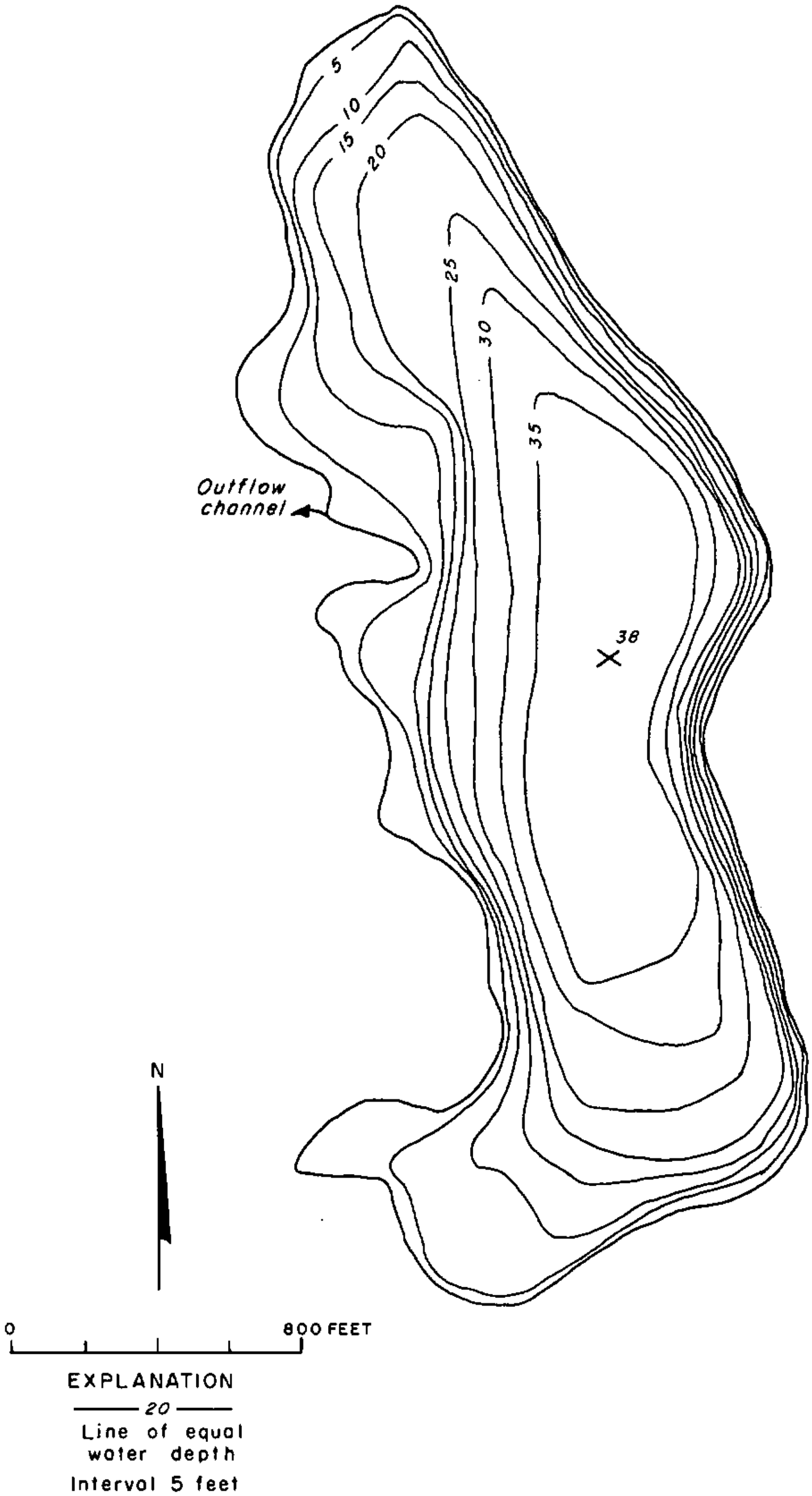

FIGURE 40.—Bathymetric map of Wilderness Lake near Maple Valley. From Washington Department of Game survey, July 25, 1952.

FIGURE 41.—Aerial photograph of Wilderness Lake near Maple Valley. July 14, 1971. Scale, 1:7,700.

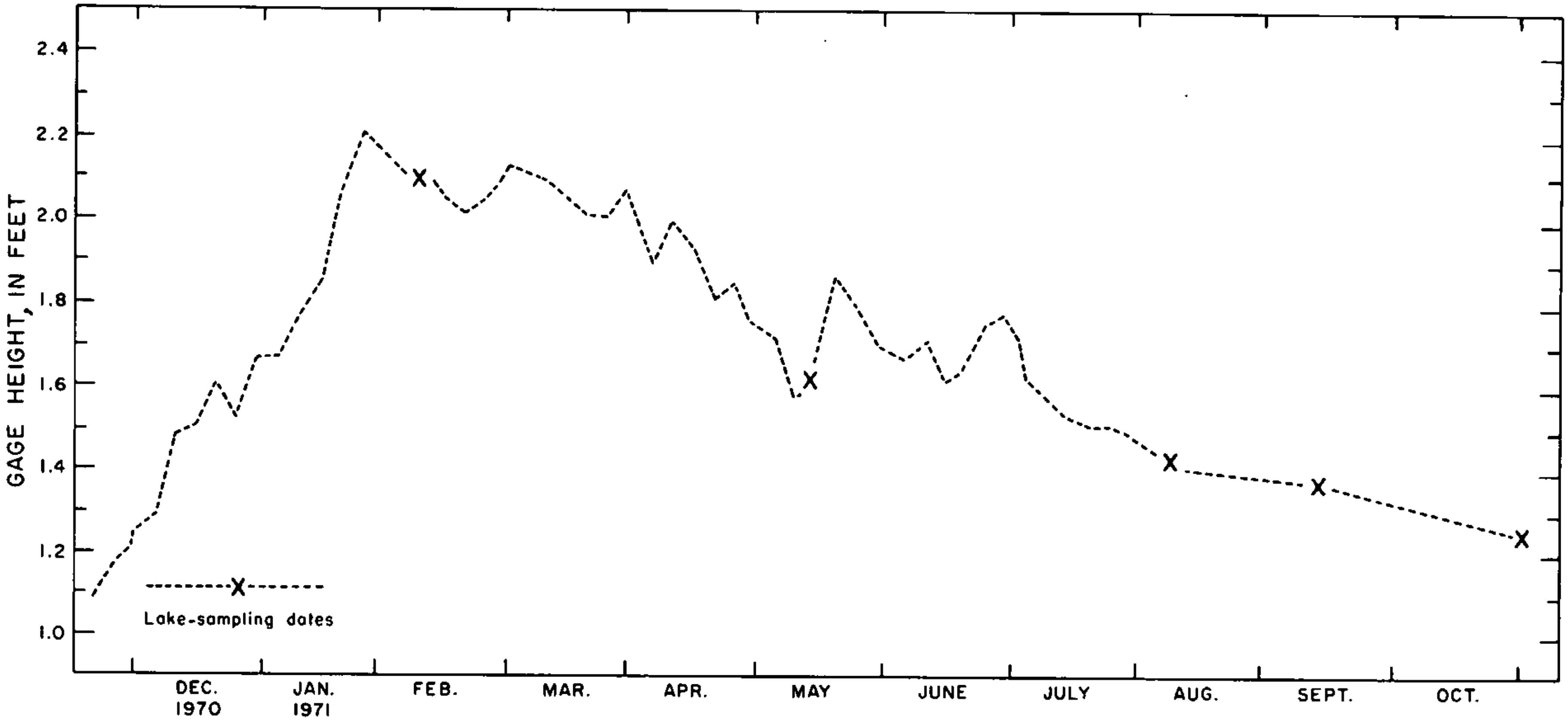

FIGURE 42.—Observed gage heights in 1970-71, Wilderness Lake near Maple Valley.

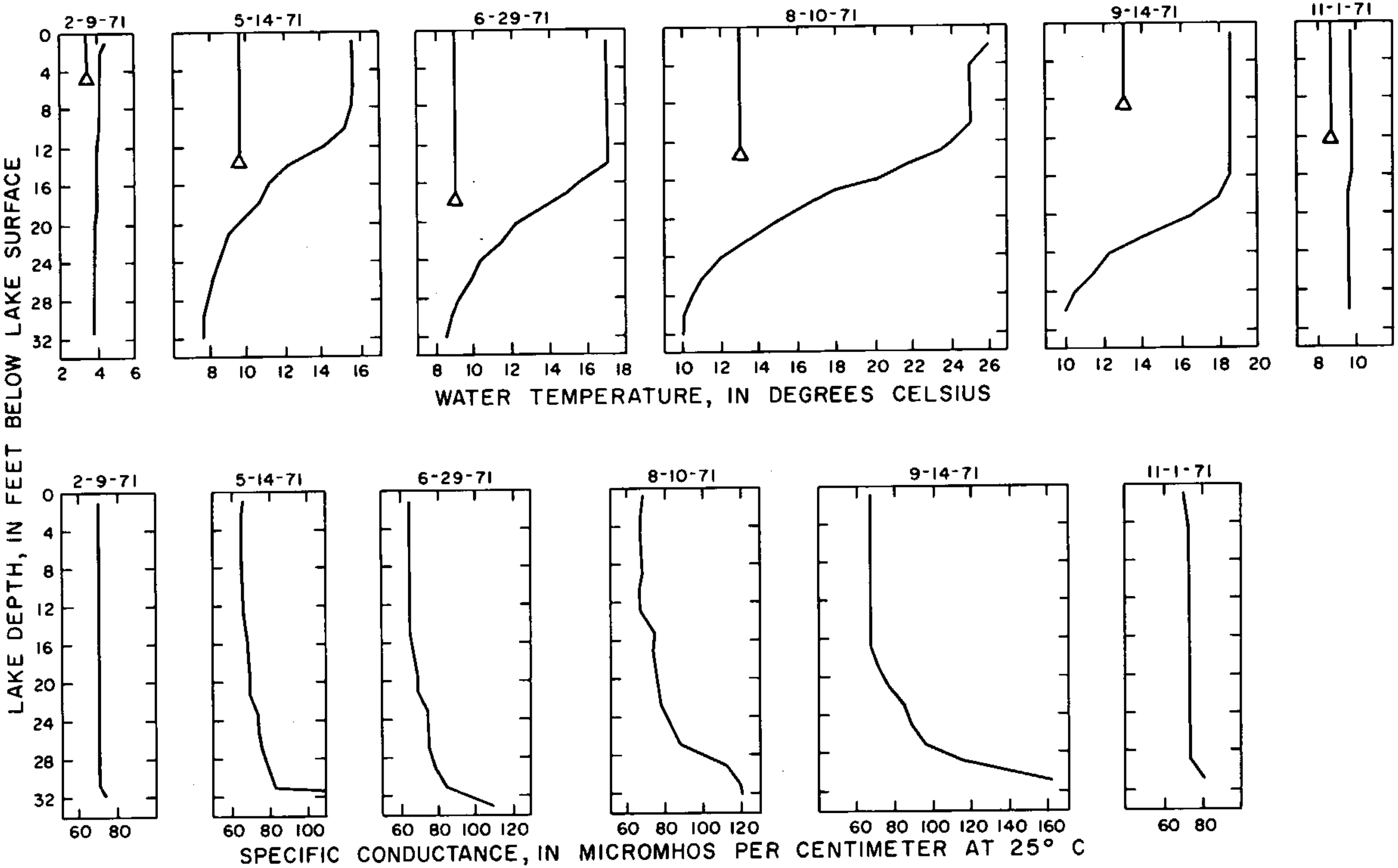

FIGURE 43.—Selected 1971 seasonal profiles of lake temperature and specific conductance, Wilderness Lake near Maple Valley. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

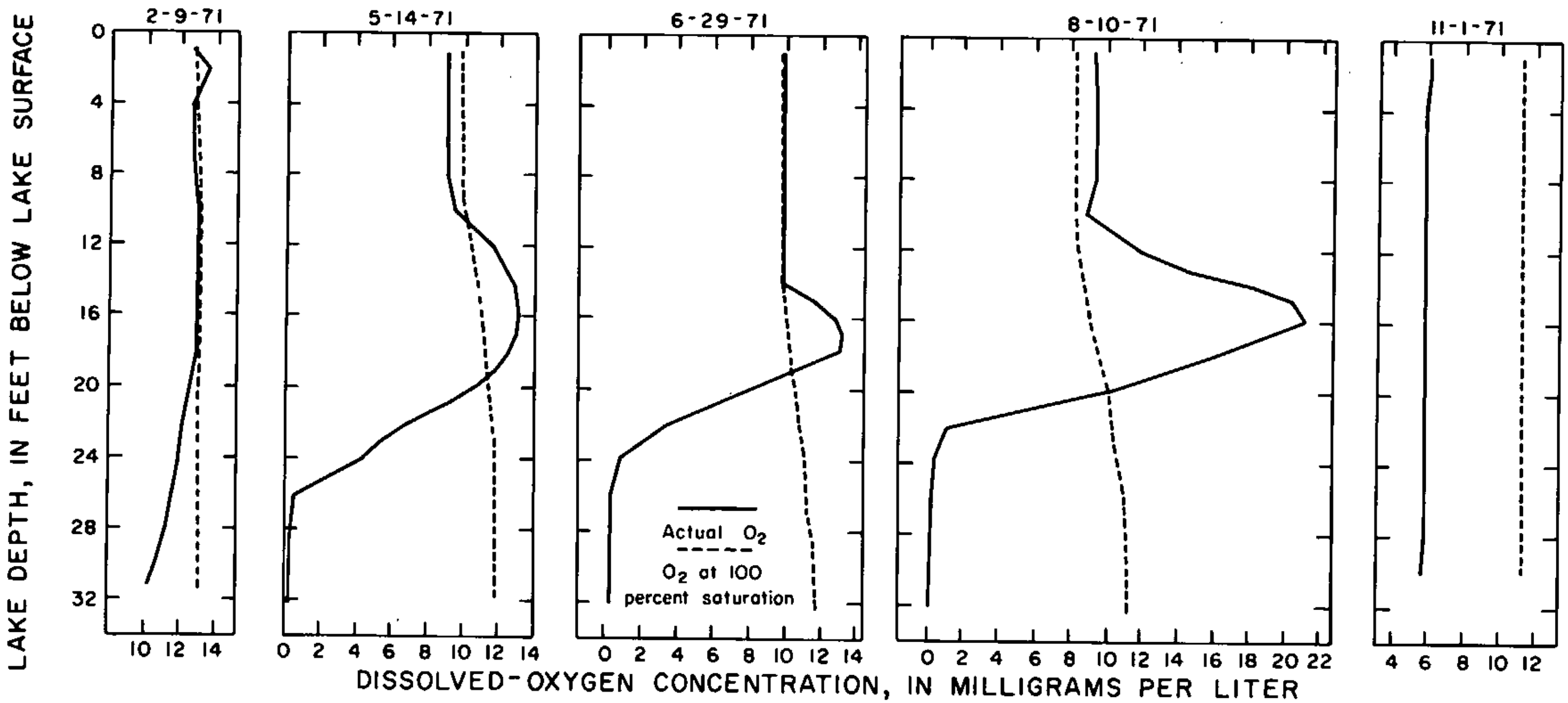

FIGURE 44.—Selected 1971 seasonal profiles of DO concentration, Wilderness Lake near Maple Valley.

12110004. Pipe Lake near Maple Valley

Location

King County, 3.0 miles southwest of Maple Valley (fig. 1).

Origin

Kettle lake.

Basin geology

Glacial drift consisting mostly of compact till (Luzier, 1969).

Soils

Gravelly sandy loam on rolling terrain (Poulson and others, 1952).

Land use and cover

Moderately heavy forest, with residential clearings. Cedar and Douglas fir dominate the nearshore cover.

Population

Lakeshore development moderately dense with 60 dwellings, a church camp, and a country club in September 1971, compared to 42 structures on the lakeshore in 1949 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 83 percent of the shoreline.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 45 and an aerial photograph of the lake and surrounding basin is shown in figure 46. The map was surveyed on February 3, 1955, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	0.63 sq mi
Altitude (from topographic map)	530 ft
Surface area	55 acres
Lake volume	1,460 acre-ft
Mean depth	27 ft
Maximum depth	65 ft
Length of shoreline	9,000 ft
Length of lake	2,560 ft
Mean breadth of lake	930 ft
Shoreline configuration	1.64
Development of volume	0.41
Mean slope	13 percent

Hydrologic characteristics

Lake stages

Miscellaneous gage-height observations in 1970-71 are shown below. The altitude of the gage is 530 ft (from topographic map); the datum of the gage is arbitrary.

Date (1970)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Feb 16	2.03	Feb 17	2.41
May 30	1.59	May 27	1.80
Jun 24	1.37	Jun 29	1.87
Oct 21	.92	Sep 14	1.48

The maximum height on the crest-stage gage was 2.4 ft, in February 1971. Sometime prior to 1934, the original lake level was raised by construction of a road across the outlet of Lucerne Lake. Pipe and Lucerne Lakes are connected by an 80-ft-wide, 5-ft-deep channel.

Surface-water inflow and outflow

No surface inflow was observed. The outflow, which is controlled by natural conditions, is a small channel at Lucerne Lake. Miscellaneous outflow measurements are given below:

Date (1970)	Outflow (cfs)	Date (1971)	Outflow (cfs)
Feb 16	1.97	Feb 17	3.62
Jun 24	0	May 27	* .6
Oct 21	0	Jun 29	.84
		Sep 14	* .02

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 47.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was moderate. On September 14, 1971 approximately 4 percent of the lake surface and 8 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was white waterlily (*Nymphaea* sp.), followed by minor patches of sedge (*Cyperaceae*) and cattail (*Typha* sp.). Submergent plants were waterweed (*Elodea* sp.) and two varieties of pondweed (*Potamogeton* spp.).

No algal blooms or high algal densities were recorded.

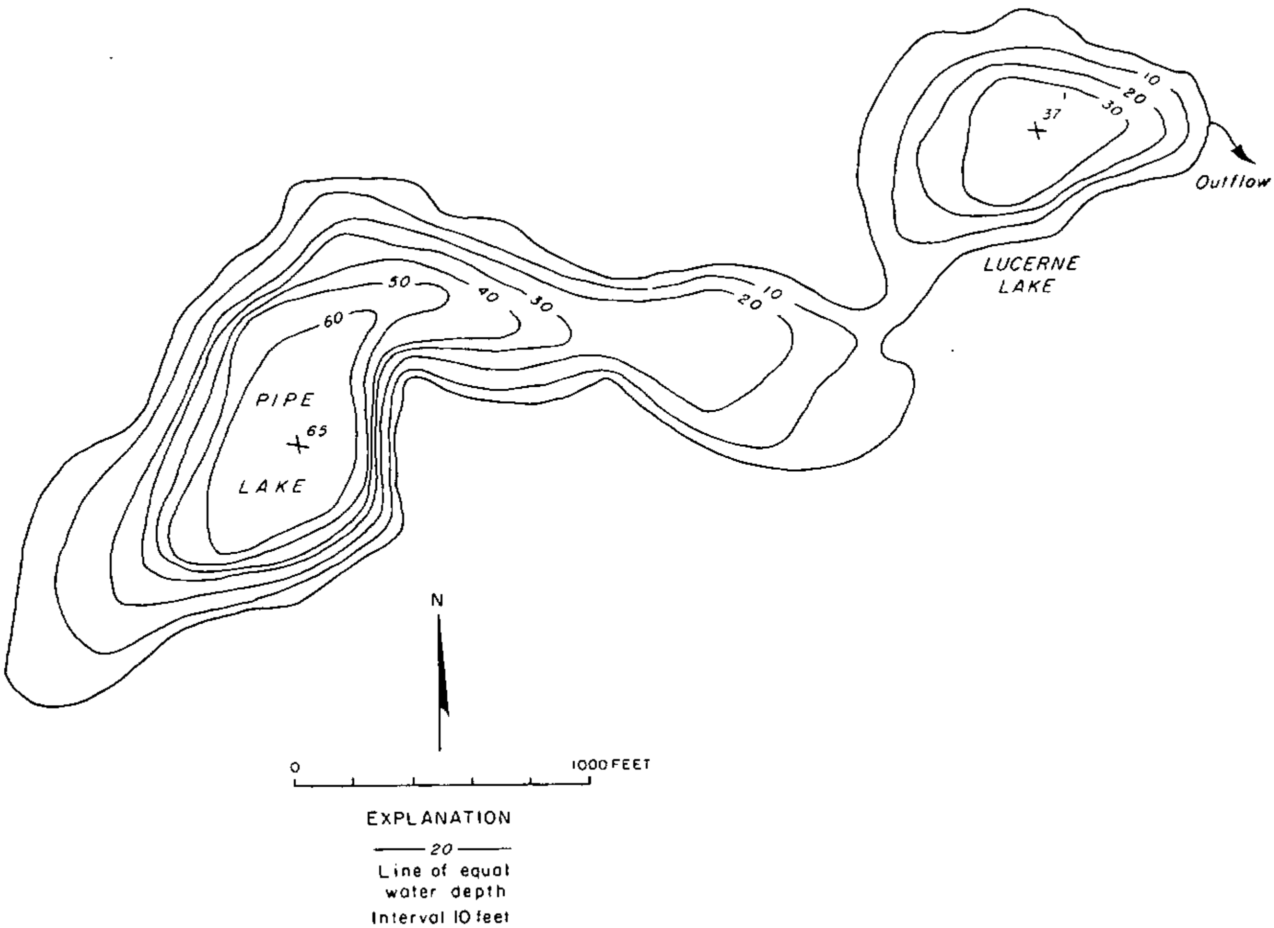

FIGURE 45.—Bathymetric map of Pipe Lake near Maple Valley. From Washington Department of Game survey, February 3, 1955.

FIGURE 46.—Aerial photograph of Pipe Lake near Maple Valley. July 14, 1971. Scale, 1:6,500.

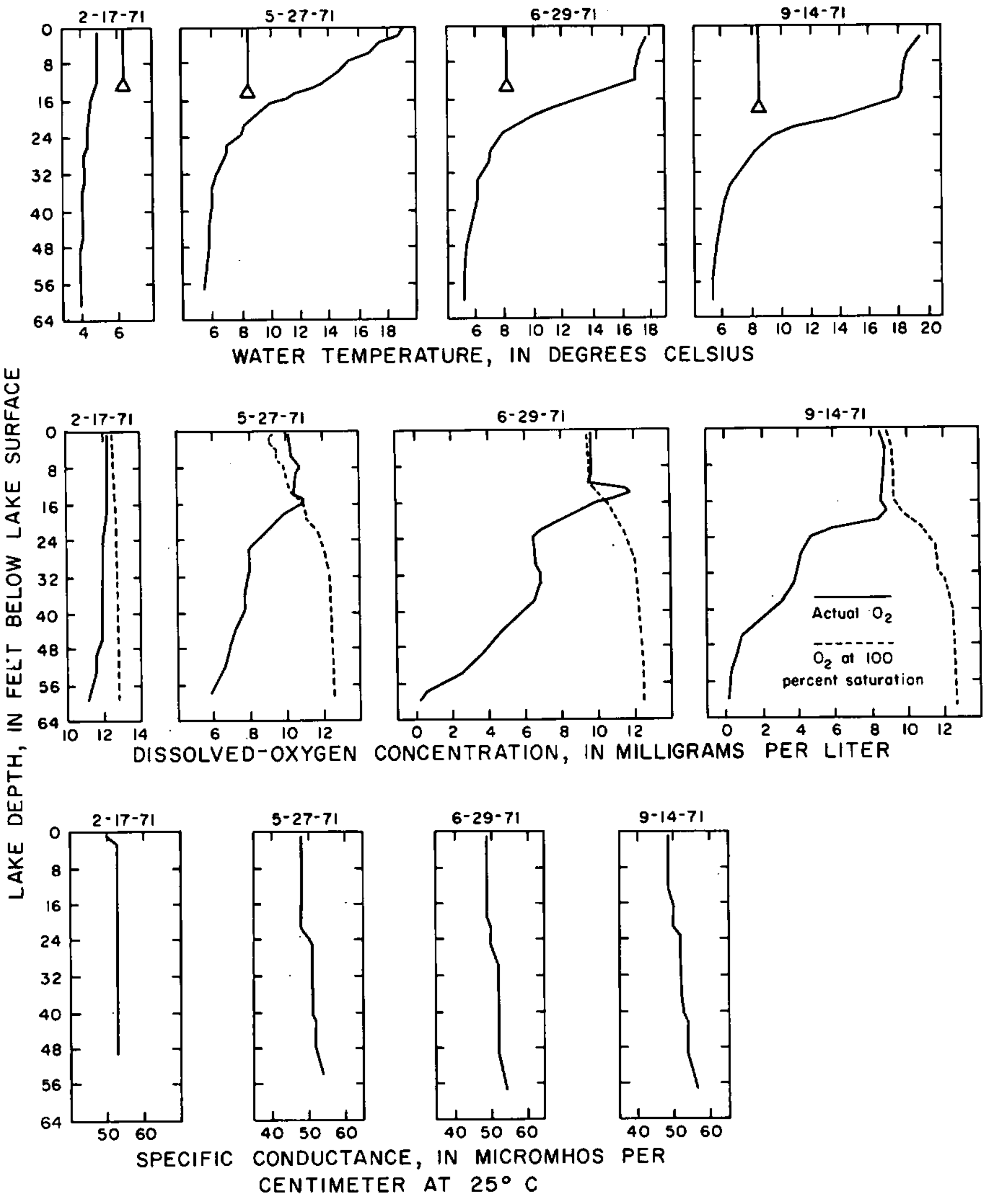

FIGURE 47.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Pipe Lake near Maple Valley. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12142295. Hancock Lake near Snoqualmie

Location

King County, 7.4 miles northeast of Snoqualmie (fig. 1).

Origin

Damming of steep valley by glacial lateral moraine.

Basin geology

Consolidated sedimentary and volcanic rocks, with granitic rock in upper part of basin (Huntting and others, 1961).

Soils

Rough, mountainous land of thin soil containing mostly gravel, stone, and boulders. Gravelly loam lies on the outlet side of the lake (Poulson and others, 1952).

Land use and cover

Heavily forested, with residential and logging clearings. The watershed supports stands of old-growth and second-growth Douglas fir, hemlock, and cedar. The west side of the lake basin has been logged recently, which reduced the forest cover of basin by about 20 percent as of September 1971.

Population

Lakeshore development sparse with 23 seasonal homes in September 1971, compared to 15 seasonal lakeshore dwellings in 1960 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 15 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 48. The map was surveyed on October 7, 1953, and referenced to mean sea level datum. The lake altitude for the survey was 2,173.1 ft.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	7.67 sq mi
Altitude (from topographic map)	2,172 ft
Surface area	246 acres
Lake volume	6,250 acre-ft
Mean depth	25 ft
Maximum depth	36 ft
Length of shoreline	14,500 ft
Length of lake	5,690 ft
Mean breadth of lake	1,880 ft
Shoreline configuration	1.25
Development of volume	0.70
Mean slope	3.3 percent

Hydrologic characteristics

Lake stages

Miscellaneous gage-height observations for 1970-71 are shown below. The altitude of the gage is 2,172 ft (from topographic map); the datum of the gage is arbitrary. The lake staff gage is set at the same datum as the outlet gage (12142300. Hancock Creek near Snoqualmie). The high-water mark on the crest-stage gage was 4.3 ft in February 1971.

Date (1970)	Gage Height (ft)	Date (1971)	Gage Height (ft)
Mar 10	2.31	Jan 7	1.55
Jun 26	1.86	Feb 19	2.18
Oct 16	2.02	Apr 19	2.22
Oct 28	2.10	May 21	2.55
Nov 20	3.00	Jul 13	2.48
Dec 8	3.12	Sep 30	1.82

Surface-water inflow and outflow

A major tributary and five smaller unnamed streams comprise the inflow. The outflow, which is controlled by natural conditions, is via Hancock Creek on the west end of the lake. Miscellaneous discharge measurements of the major inflow tributary (site 1), total inflow from the smaller streams and the outflow are given below.

Date	Inflow at Site 1 (cfs)	Inflow, Total Miscellaneous (cfs)	Outflow via Hancock Creek** (cfs)
1970			
Mar 10	14.9	3.02	42
June 26	13.1	1.02	24
Oct 16	10.1	*3	35
1971			
Feb 19	20.2	Ice	68
May 21	40.6	6.89	101
Jul 13	36.2	22.0	88
Sep 30	12.1	3.16	35

*Estimated

**From rating curve (12142300. Hancock Creek)

The average discharge of Hancock Creek for 6 years of record (1964-70) was 51.3 cfs (12142300. Hancock Creek near Snoqualmie).

Water-quality characteristics

Seasonal Secchi-disc visibility depth and profiles of DO concentration and water temperature are shown in figure 49.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was moderate. On September 30, 1971, approximately 2 percent of the lake surface and 8 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was horsetail (*Equisetum* sp.), followed by sedge (*Cyperaceae*), yellow waterlily (*Nuphar* sp.), buckbean (*Menyanthes* sp.), and rush (*Juncus* sp.). Submergent plants included quillwort (*Isoetes* sp.), waterlobelia (*Lobelia* sp.), and pondweed (*Potamogeton* sp.). The muck substrate for rooted aquatic-plant growth in the littoral zone is moderate accounting for approximately 44 percent of the shoreline.

No algal blooms or high algal densities were observed.

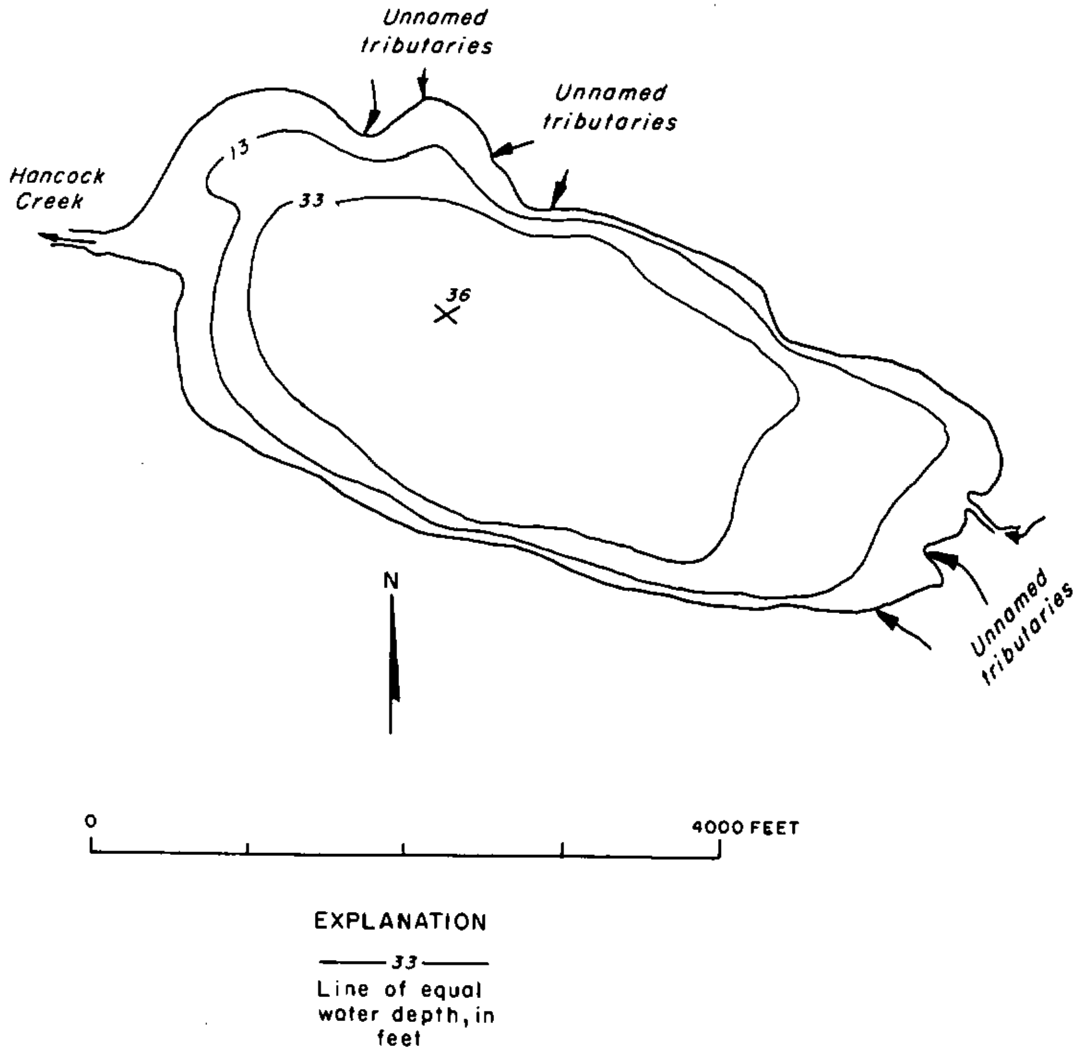

FIGURE 48.—Bathymetric map of Hancock Lake near Snoqualmie. Lake elevation 2,173 ft above mean sea level during survey by U.S. Geological Survey, October 17, 1953.

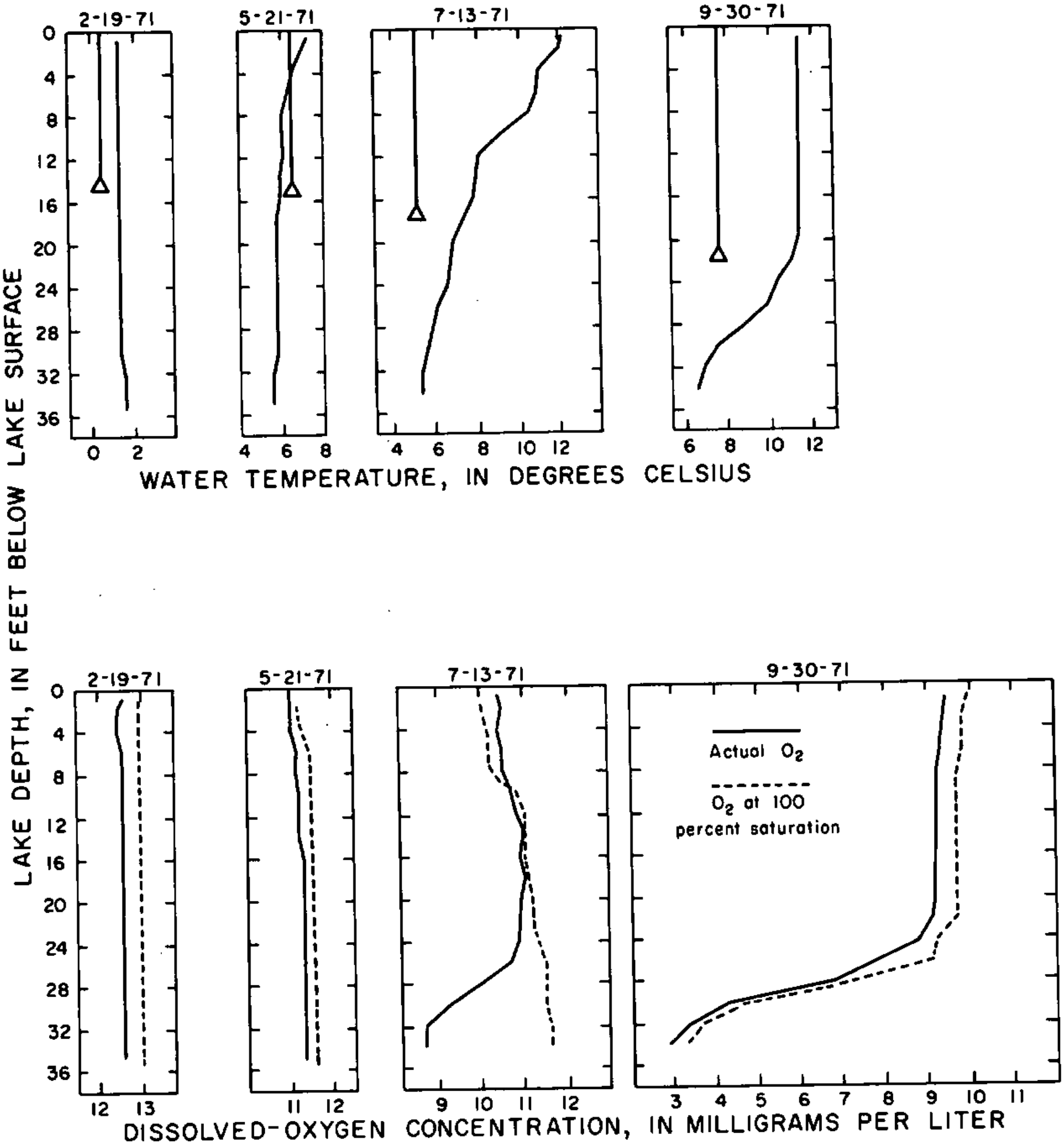

FIGURE 49.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Hancock Lake near Snoqualmie. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12168000. Cavanaugh Lake near Oso

Location

Skagit County, 5.9 miles northwest of Oso (fig. 1).

Origin

Damming of steep glaciated valley by alluvium.

Basin geology

Consolidated sedimentary, metamorphic, and volcanic rocks underlying basin hills, and alluvium in valley bottom (Huntting and others, 1961).

Soils

Variable rough mountainous soil with a mantle of glacial material at lower altitudes. Rock outcrops are prevalent at higher altitudes. Some inflow streams drain through local peat deposits (Ness and others, 1960).

Land use and cover

Heavily forested, with residential clearings. Douglas fir, hemlock, sitka spruce, and cedar dominate the forest cover. Alder, willow, and big-leaf maple appear near the shore.

Population

Lakeshore development is very dense with 376 residences (mostly seasonal) surrounding the lake in September 1971, compared to 145 lakeshore homes in 1956 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 92 percent of the lakeshore. The road is too close to the water's edge for suitable building on part of the north shore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 50. The map was surveyed on August 25-29, 1953, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	7.36 sq mi
Altitude (from topographic map)	1,008 ft
Surface area	804 acres
Lake volume	35,800 acre-ft
Mean depth	44 ft
Maximum depth	80 ft
Length of shoreline	40,100 ft
Length of lake	14,000 ft
Mean breadth of lake	2,490 ft
Shoreline configuration	1.91
Development of volume	0.56
Mean slope	6.0 percent

Hydrologic characteristics

Lake stages

The gage height was observed at least weekly during the 1951 water year. From January 1 to September 30, 1951, the variation in gage height was 4.28 ft. The altitude of the gage is 1,010 ft (from topographic map); the datum of gage is arbitrary.

Using the same datum as that for 1950-51, the following gage-height observations were obtained during the investigation period:

Date (1971)	Gage Height (ft)
Mar 16	2.95
May 25	2.11
July 15	2.04
Sep 24	1.64

Surface-water inflow and outflow

The inflow is from numerous intermittent and ephemeral streams, as well as from seeps and springs draining the mountainous terrain. The outflow, which is controlled at medium and low stages by a concrete weir, is via Lake Creek. Miscellaneous measurements of the main inflow, seasonal streams, and outflow are shown below (see bathymetric map for location of inflows).

Date (1971)	Inflow at Site 1 (cfs)	Inflow at Site 2 (cfs)	Inflow, Total Miscellaneous (cfs)	Outflow via Lake Creek (cfs)
Mar 16	4.06	9.82	*3.5	103
May 11	––	––	––	14.8
May 25	1.46	3.67	*1	32.7
Jul 15	1.95	2.31	* .6	22.6
Sep 24	.46	.67	* .02	9.17

*Estimated

One to five miscellaneous discharge measurements were made annually in 1929-31, 1950-51, 1967, and 1969-70 at Lake Creek, station 12168200 (Washington State Department of Conservation, 1964; U.S. Geological Survey, 1967-70).

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 51.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was light. On September 24, 1971 approximately 0.4 percent of the lake surface and 2 percent of the lake bottom were occupied by macrophytes. The dominant emergent plant was watershield (*Brasenia* sp.) with minor patches of yellow waterlily (*Nuphar* sp.) and sedge (*Cyperaceae*). Submergent plants were quillwort (*Isoetes* sp.), waterweed (*Elodea* sp.), waterlobelia (*Lobelia* sp.), muskgrass (*Chara* sp. and *Nitella* sp.), and two varieties of pondweed (*Potamogeton* spp.).

No algal blooms or high algal densities were recorded.

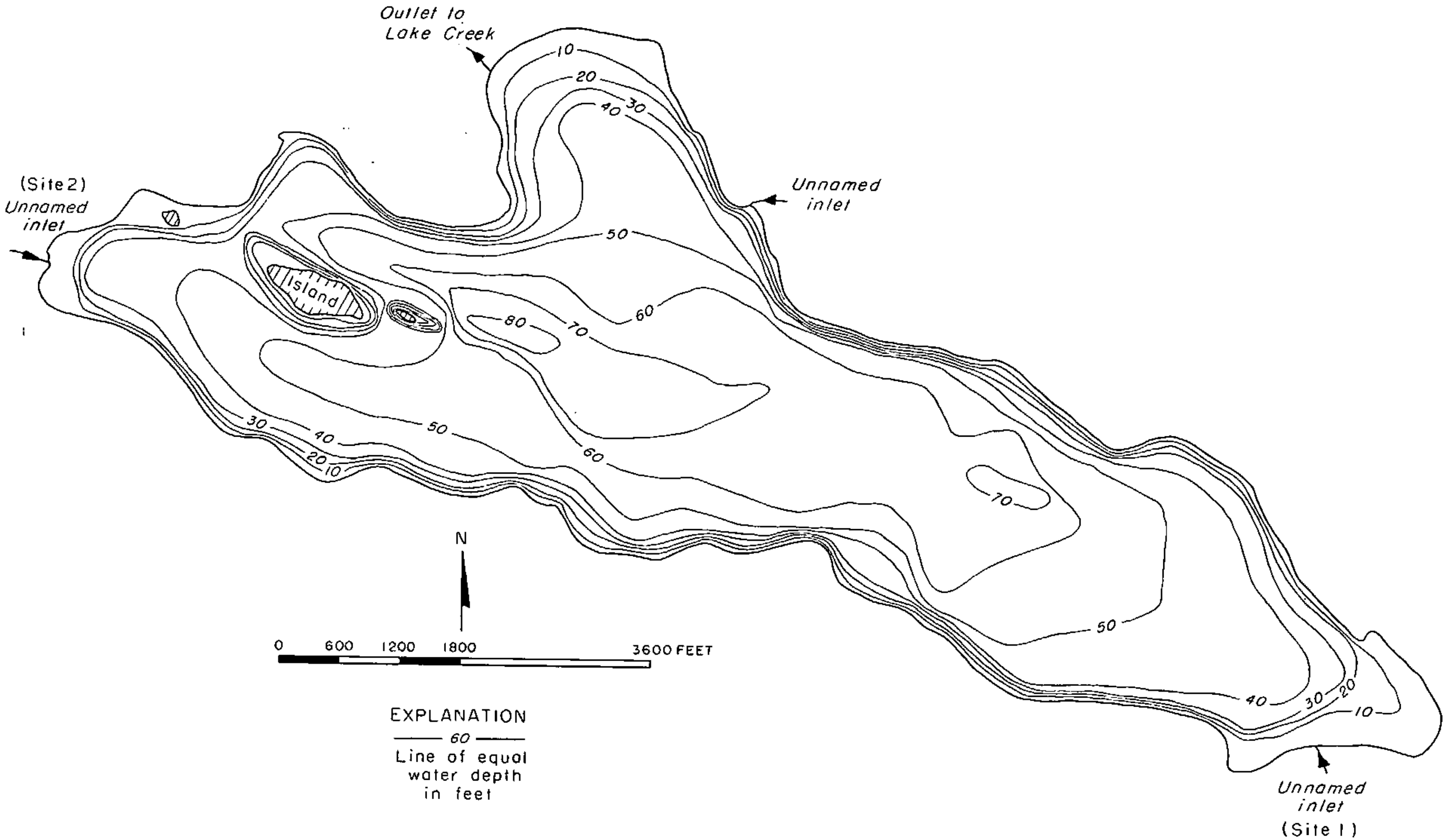

FIGURE 50.—Bathymetric map of Cavanaugh Lake near Oso. From Washington Department of Game survey, August 25-29, 1953.

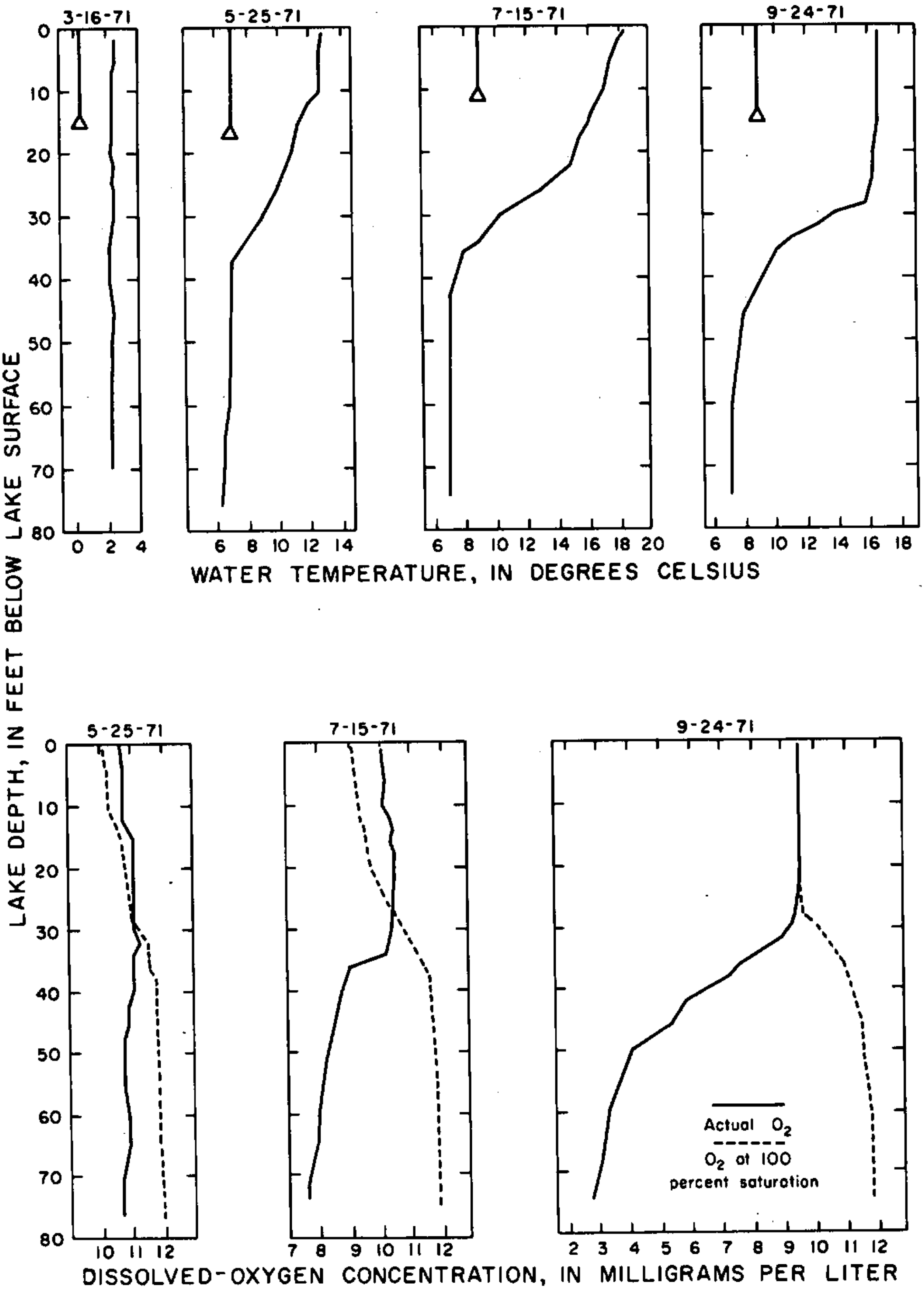

FIGURE 51.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Cavanaugh Lake near Oso. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12200850. Samish Lake near Bellingham

Location

Whatcom County, 8.5 miles southeast of Bellingham (fig. 1).

Origin

Glaciated valley dammed by slide deposits from north.

Basin geology

Consolidated sedimentary rock with thin mantle of glacial drift (Huntting and others, 1961).

Soils

Rough mountainous soil normally shallow and stony. Intricate patterns of silt loam, stony silt loam, and loam occupy the lower area of south slope (Poulson, 1953).

Land use and cover

Moderately heavy forest, with residential and commercial clearings. Nearshore area supports a mixture of deciduous and coniferous trees. Nearly 2 miles of interstate highway parallel within a quarter mile of the northeast shore.

Population

Lakeshore development moderately dense with 221 lakeshore homes (50 homes on west arm and 171 homes on east arm), a large trailer court, and a church camp in September 1971, compared to 142 lakeshore dwellings (34 on west arm and 108 on east arm) in 1954 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 62 and 91 percent of the lakeshore for the west and east arms, respectively.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 52. The map was surveyed on July 16, 1956, using an arbitrary datum. Samish Lake was considered as two bodies of water, the small deep bay being the west arm, and the larger shallow bay being the east arm.

Some morphometric parameters of the west arm, based on the bathymetric map, are listed below.

Drainage area	3.7 sq mi
Altitude (from topographic map)	273 ft
Surface area	130 acres
Lake volume	9,100 acre-ft
Mean depth	71 ft
Maximum depth	145 ft
Length of shoreline	9,500 ft
Length of lake	3,800 ft
Mean breadth of lake	1,500 ft
Shoreline configuration	1.14
Development of volume	0.49
Mean slope	16 percent

Some morphometric parameters of the east arm, based on the bathymetric map, are listed below.

Drainage area	9.2 sq mi
Altitude (from topographic map)	273 ft
Surface area	680 acres
Lake volume	23,800 acre-ft
Mean depth	31 ft
Maximum depth	75 ft
Length of shoreline	33,100 ft
Length of lake	3,780 ft
Mean breadth of lake	7,800 ft
Shoreline configuration	1.71
Development of volume	0.42
Mean slope	5.1 percent

Hydrologic characteristics

Lake stages

Miscellaneous gage-height observations in 1971 are shown in figure 53. The altitude of the gage is 273 ft (from topographic map); the datum of the gage is arbitrary. The observed gage height from March 3 to December 16, 1971 varied 2.40 ft.

Surface-water inflow and outflow

In addition to the main inflow, Lake Creek, at least seven ephemeral or intermittent inflow streams drain from the surrounding mountainous terrain. The outflow, which is controlled by natural conditions, is via Friday Creek. Miscellaneous measurements of the main inflow, total inflow from seasonal streams, and outflow are given below.

Date (1971)	Inflow via Lake Creek (cfs)	Inflow, Total Miscellaneous (cfs)	Outflow via Friday Creek (cfs)
Mar 3	9.01	*9	79.8
May 24	.81	*2	7.98
Jul 14	1.23	*5	19.8
Sep 23	* .1	* .4	0

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature at the two sites are shown in figures 54 and 55.

Biological characteristics (west arm)

Submergent rooted aquatic-plant growth was light and emergent plant growth was sparse. On September 23, 1971, less than 0.01 percent of the lake surface and 1 percent of the lake bottom were occupied by macrophytes. The dominant submergent plants were pondweed (*Potamogeton robbinsii*) and watercelery (*Vallisneria* sp.). Also present were *Potamogeton richardsonii* and waterweed (*Elodea* sp.).

Biological characteristics (east arm)

Rooted aquatic-plant growth was light. On September 23, 1971, approximately 0.5 and 2.9 percent of the lake surface and lake bottom, respectively, were occupied by macrophytes. The dominant emergent plant was watershield (*Brasenia* sp.), followed by smaller patches of waterlily (*Nuphar* sp. and *Nymphaea* sp.) and sedge (*Cyperaceae*). The dominant submergent plants were pondweed (*Potamogeton robbinsii*) and watercelery (*Vallisneria* sp.) followed by waterweed (*Elodea* sp.) and three other varieties of pondweed.

No algal blooms were observed, but a high algal density was recorded for both arms on July 14, 1971.

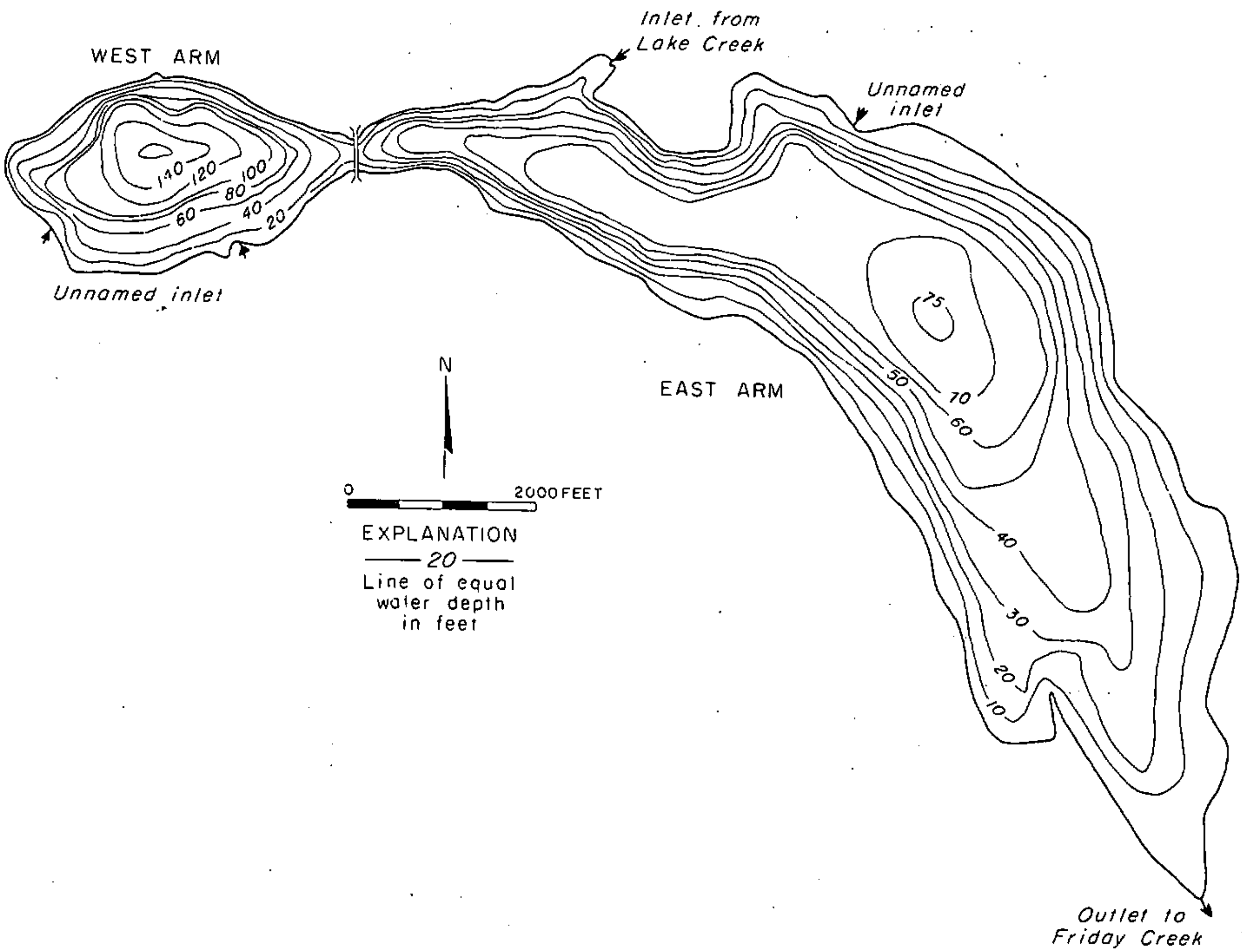

FIGURE 52.—Bathymetric map of Samish Lake near Bellingham. From Washington Department of Game survey, July 16, 1956.

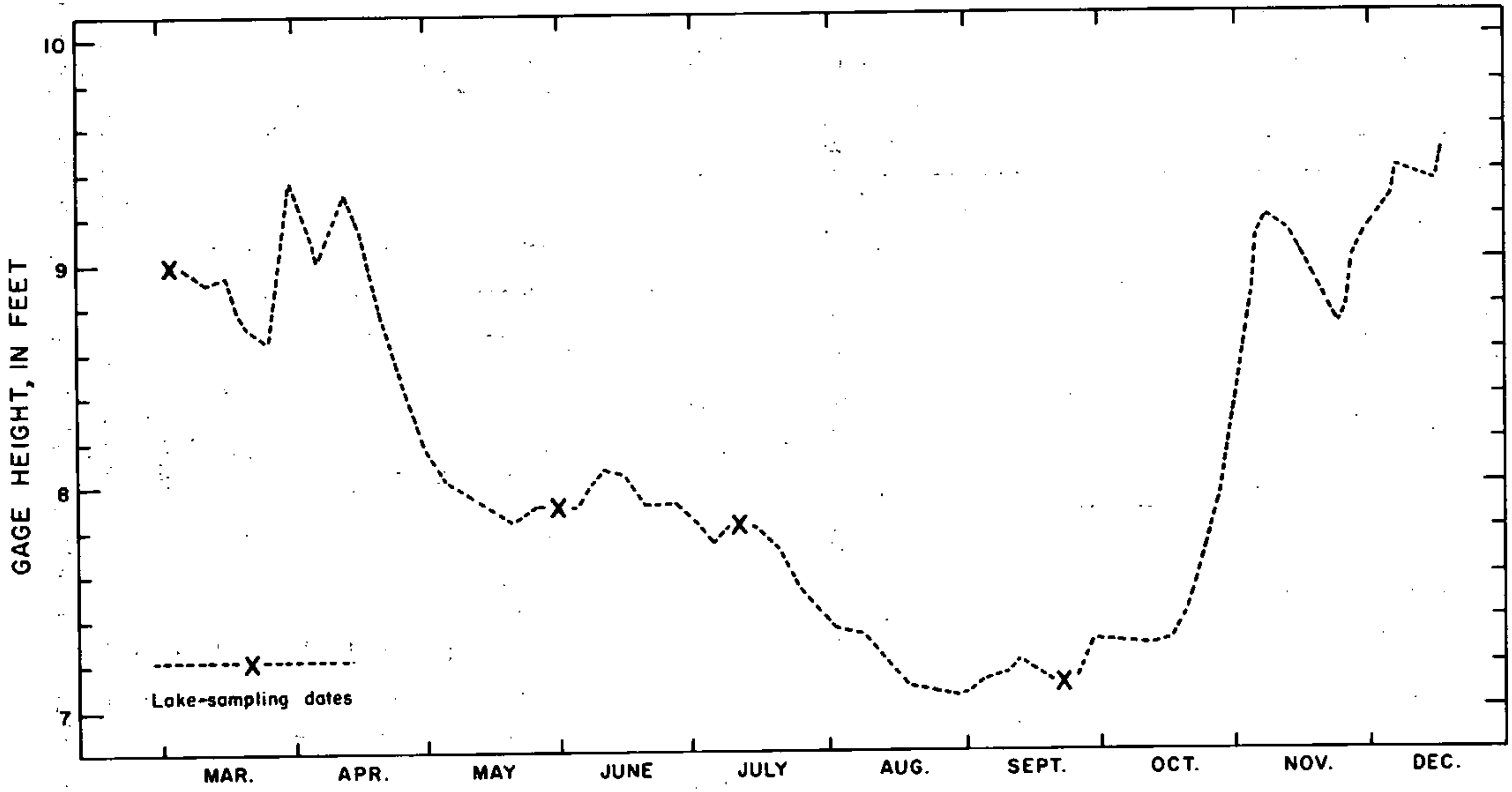

FIGURE 53.—Observed gage heights in 1971, Samish Lake near Bellingham.

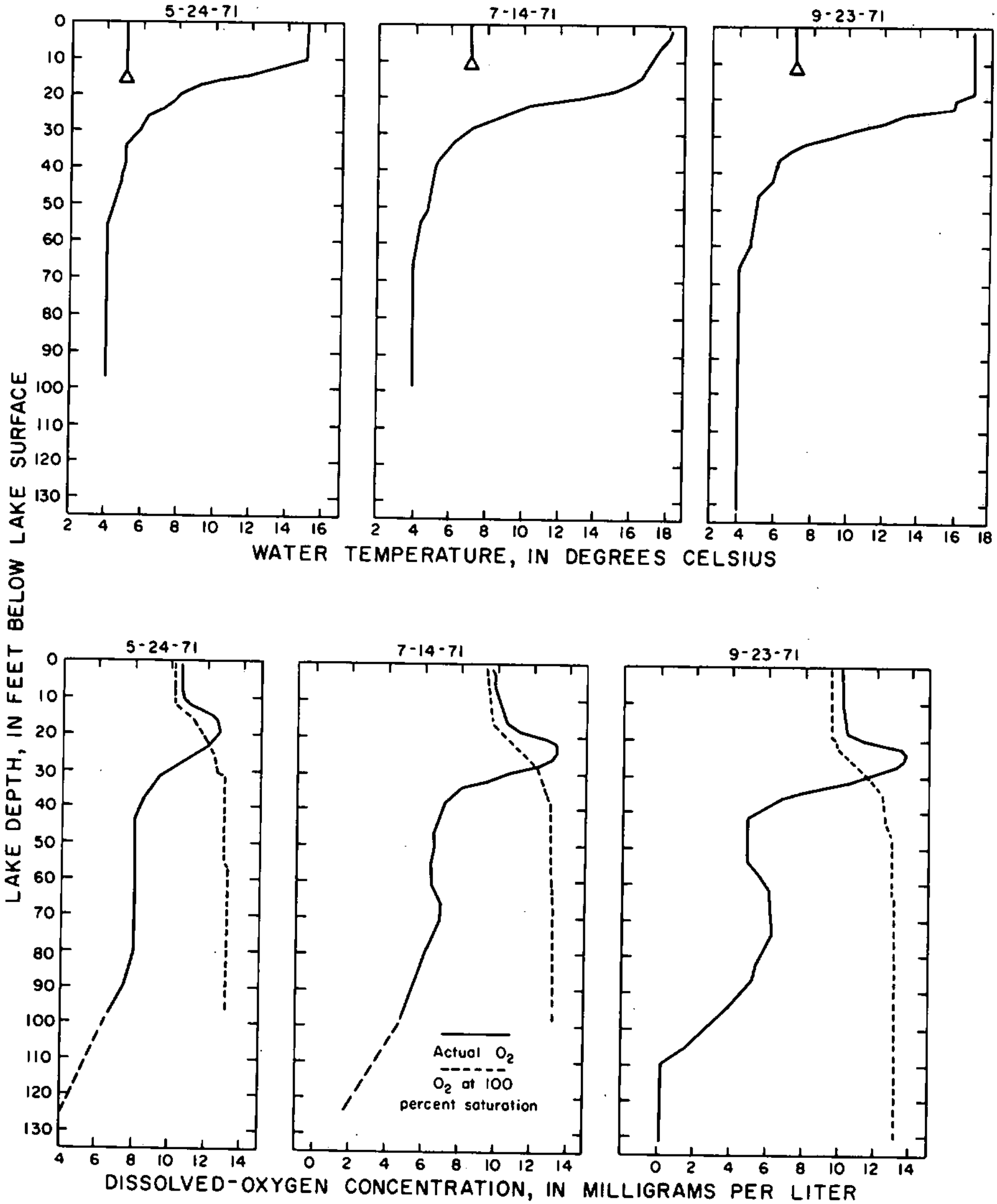

FIGURE 54.—Selected 1971 seasonal profiles of lake temperature and DO concentration in west arm of Samish Lake near Bellingham. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

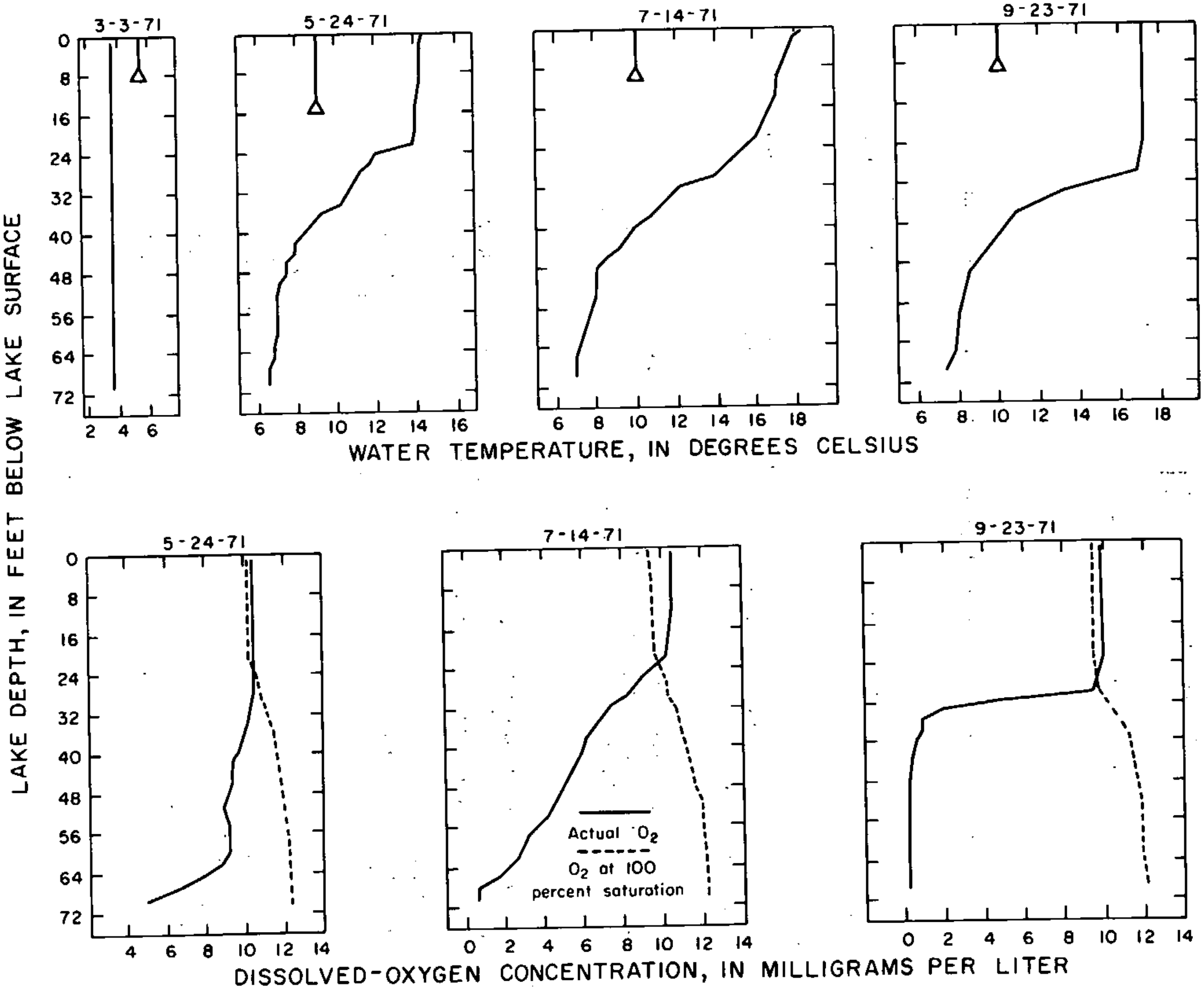

FIGURE 55.—Selected 1971 seasonal profiles of lake temperature and DO concentration in east arm of Samish Lake near Bellingham. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12406500. Loon Lake near Loon Lake

Location

Stevens County, 0.8 mile southwest of the town of Loon Lake (fig. 1).

Origin

Kettle lake.

Basin geology

Glacial drift in valley, with granitic and metamorphic rocks underlying adjacent hills (Huntting and others, 1961).

Soils

Loam, sandy loam, fine sandy loam, gravelly silt loam, stony land. Local muck and peat deposits lie near lake (Van Duyne and Ashton, 1915).

Land use and cover

Moderately forested, with residential, agricultural, and commercial clearings. Several gravel pits lie north of the lake. The main forest cover is mixed stands of ponderosa pine and Douglas fir. The riparian cover includes black cottonwood, bitter cherry, and willow.

Population

Lakeshore development very dense, with 450 homes (mostly seasonal), two resorts, two marinas, and a trailer court (about 22 mobile homes) in September 1971, compared to 367 lakeshore dwellings in 1965 (estimated from U.S. Geological Survey topographic map). Residential development occupies approximately 85 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 56. The map was surveyed on February 14, 1955 and referenced to mean sea level, datum of 1929, unadjusted. Lake altitude for the survey was 2,380.60 ft.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	14.1 sq mi
Altitude (from topographic map)	2,381 ft
Surface area	1,130 acres
Lake volume	51,500 acre-ft
Mean depth	46 ft
Maximum depth	100 ft
Length of shoreline	41,800 ft
Length of lake	14,200 ft
Mean breadth of lake	3,460 ft
Shoreline configuration	1.68
Development of volume	.46
Mean slope	5.4 percent

Hydrologic characteristics

Lake stages

A hydrograph of monthly maximum and minimum lake stages during 1964-70 is shown in figure 57. The datum of the gage is mean sea level, datum of 1929, unadjusted. The lake altitude is regulated by gates at a weir structure near the outlet. The average annual variation in lake stage was 1.7 ft for 1950-70. A continuous recorder monitored lake stage during 1971. The variation in gage height from October 1, 1970 to September 30, 1971, was 1.89 ft (U.S. Geological Survey, 1971).

Surface-water inflow and outflow

The inflow from intermittent streams was estimated at 0.3 cfs in May 1971. In subsequent visits there was no observable inflow. The outflow channel, controlled by gages at a weir, was dry during three visits. Some water is pumped from the lake for domestic uses.

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 58.

Biological characteristics

Submergent and emergent rooted aquatic-plant growth was moderate. On September 28, 1971, approximately 3 percent of the lake surface and 18 percent of the lake bottom were occupied by macrophytes. The dominant emergent plant was watershield (*Brasenia* sp.) followed by sedge (*Cyperaceae*), yellow waterlily (*Nuphar* sp.), and white waterlily (*Nymphaea* sp.). The dominant submergent plant was pondweed (*Potamogeton amplifolius*); other submergents were waterweed (*Elodea* sp.), quillwort (*Isoetes* sp.), watermilfoil (*Myriophyllum* sp.), and five other varieties of pondweed.

No algal blooms or high algal densities were observed.

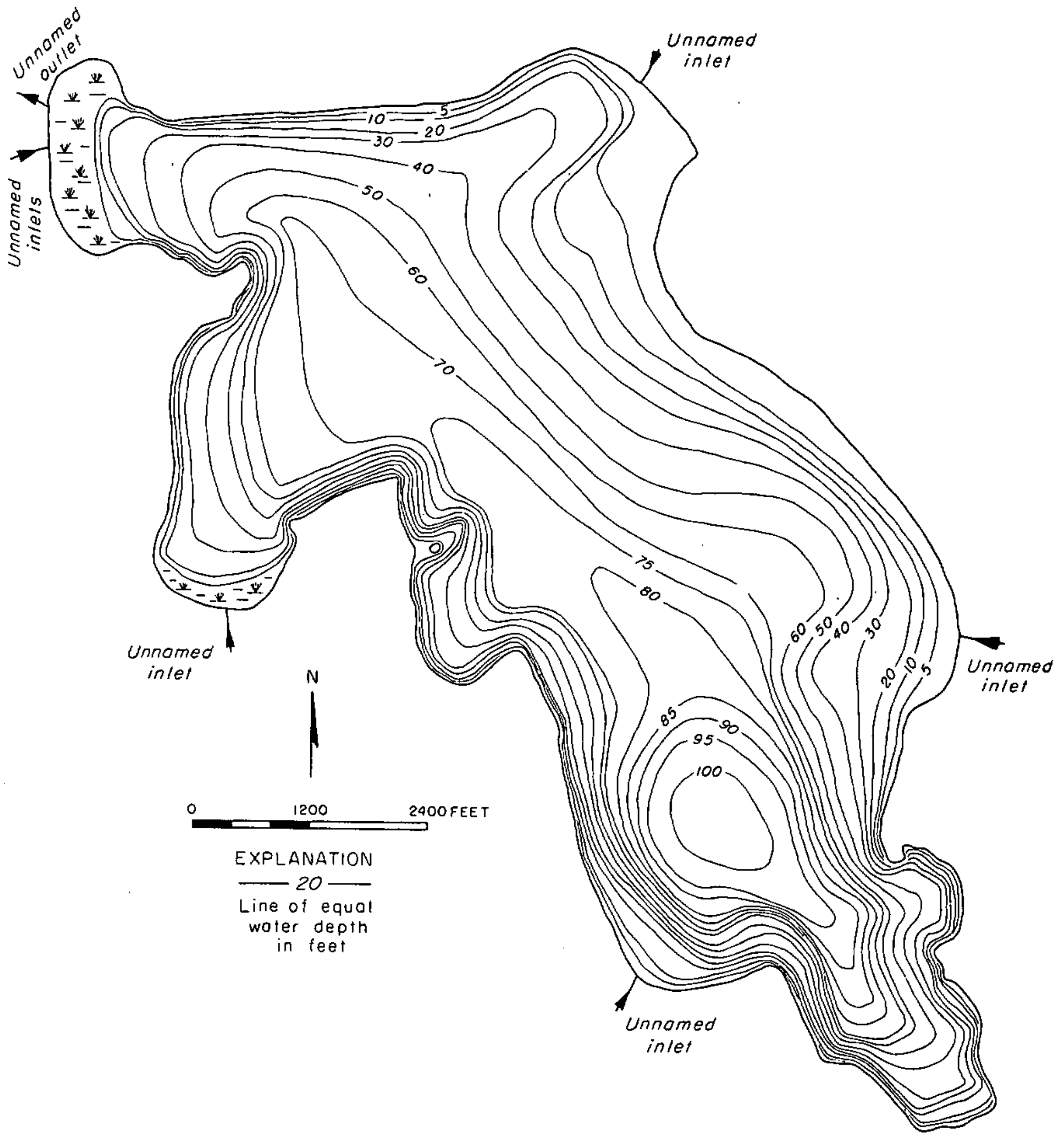

FIGURE 56.—Bathymetric map of Loon Lake near Loon Lake. Lake altitude during survey was 2,380.60 feet above mean sea level. From Washington Department of Game survey, February 14, 1955.

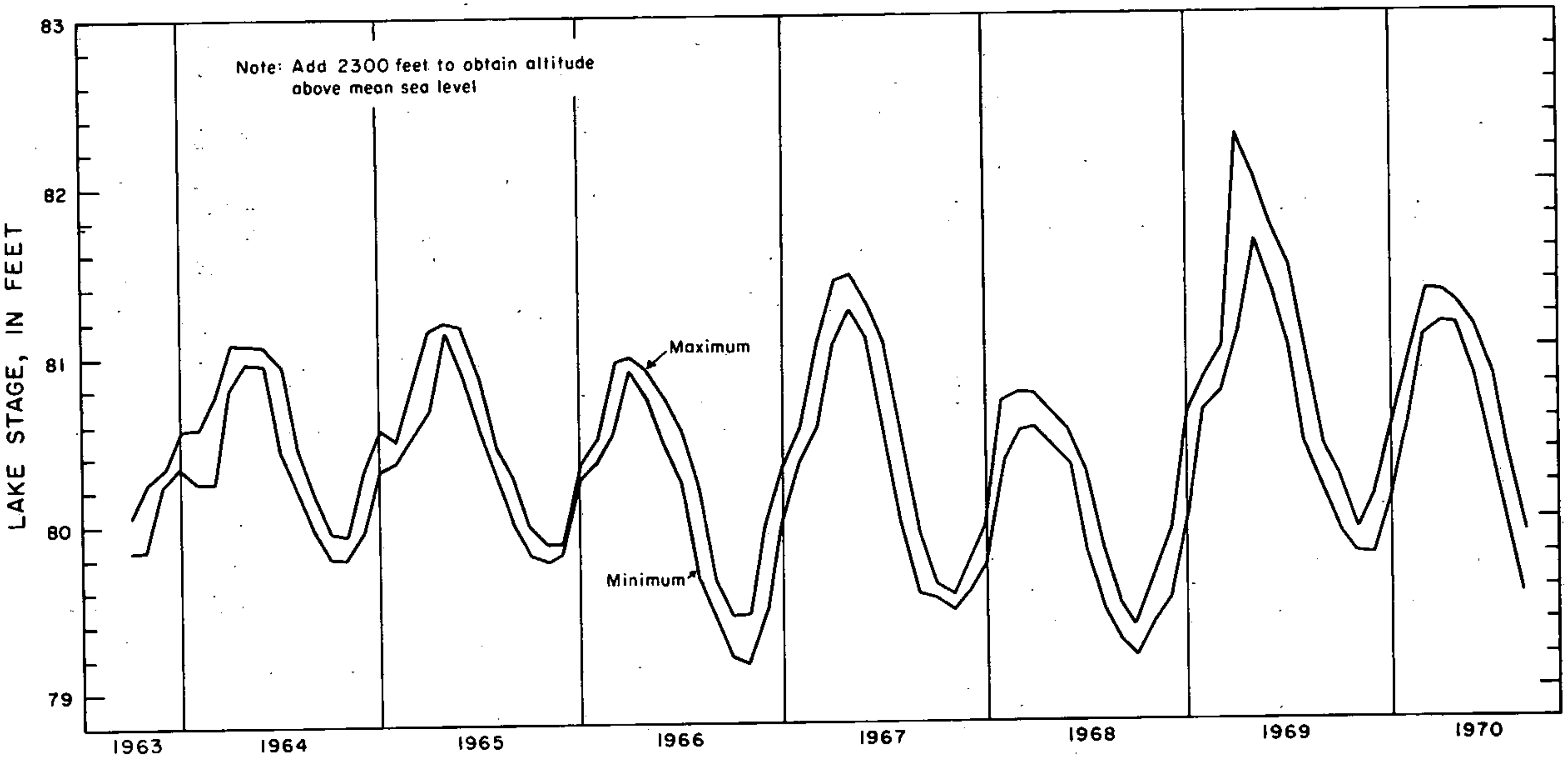

FIGURE 57.—Recorded monthly maximum and minimum lake stages, Loon Lake near Loon Lake, 1963-70.

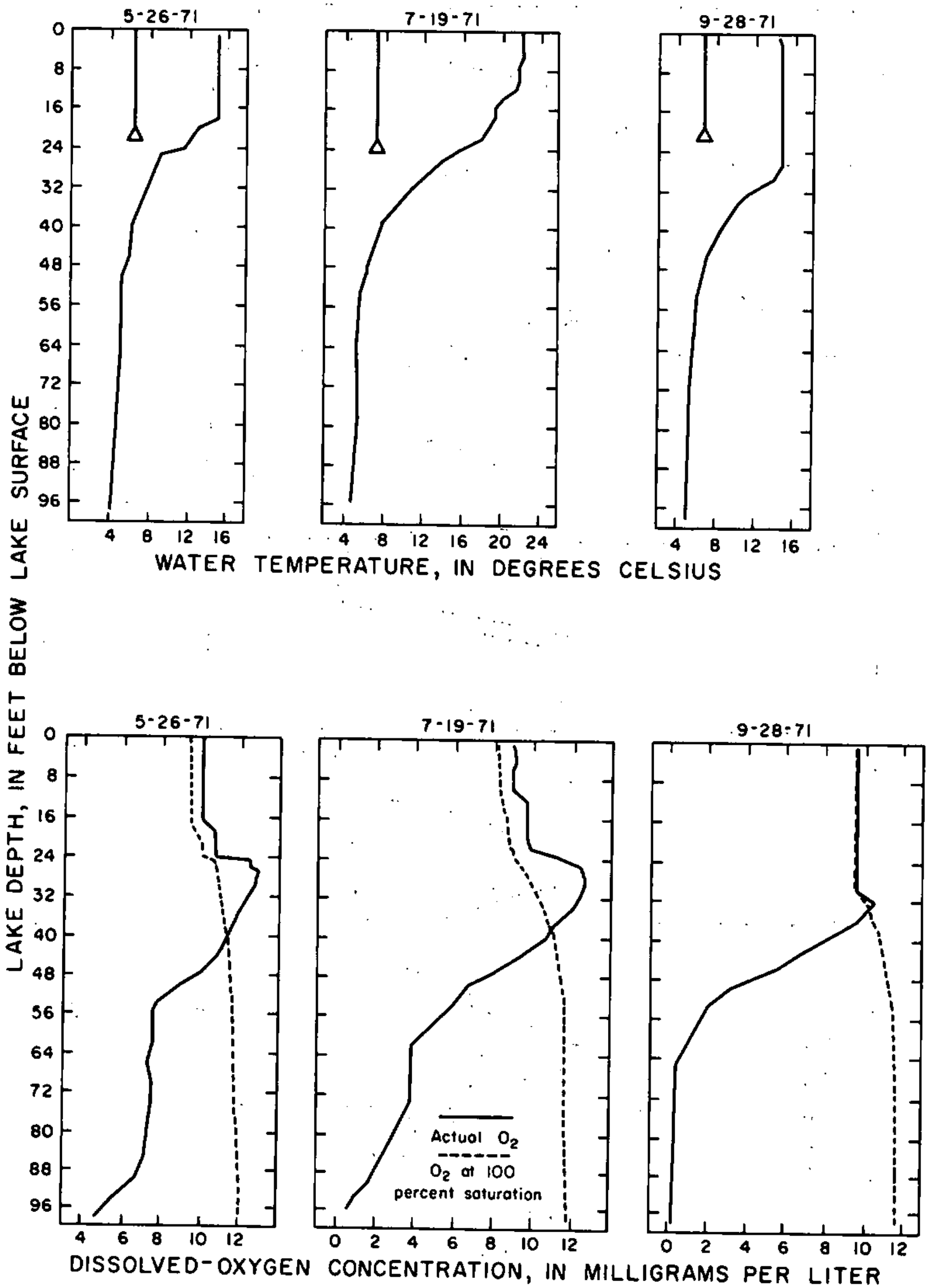

FIGURE 58.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Loon Lake near Loon Lake. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12419800. Newman Lake near Newman Lake

Location

Spokane County, 3 miles north of the town of Newman Lake (fig. 1).

Origin

Damming of glaciated valley by glaciofluvial materials.

Basin geology

Glacial outwash plain with granitic and metamorphic rocks in hills (Huntting and others, 1961).

Soils

Silt loam dominant on mountainous uplands and intricate patterns of silty clay loam, loam, silt loam, rocky complex, marsh, and muck on outwash plain (Donaldson and Giese, 1968).

Land use and cover

Moderately forested, with residential, agricultural, and recreational clearings. Lowlands support crops and pasture while uplands are forest-covered. The main forest is mixed stands of ponderosa pine and Douglas fir with nearshore patches of locust, cottonwood, lodgepole pine, bitter cherry, alder, and willow.

Population

Lakeshore development moderately dense with 316 homes (mostly seasonal) and four resorts in September 1971, compared to 235 lakeshore dwellings in 1950 (estimated from U.S. Geological Survey topographic map). Approximately one-third of shoreline adjoins marsh, and the remaining two-thirds of the lakeshore is residentially developed.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 59. The map was surveyed on February 18, 1951, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	28.6 sq mi
Altitude (from topographic map)	2,120 ft
Surface area	1,220 acres
Lake volume	22,600 acre-ft
Mean depth	19 ft
Maximum depth	30 ft
Length of shoreline	51,500 ft
Length of lake	13,800 ft
Mean breadth of lake	3,840 ft
Shoreline configuration	2.00
Development of volume	0.62
Mean slope	2.0 percent

Hydrologic characteristics

Lake stages

A hydrograph of monthly maximum and minimum observed gage heights during 1965-70 is shown in figure 60. The altitude of the gage is 2,120 ft (from topographic map); the datum of gage is arbitrary. The lake altitude is regulated by gates at concrete headworks near the outlet. The average annual variation in gage height was 3.2 ft for 1959-70. The gage height was observed at least twice weekly during 1971. The variations in observed gage height from October 1, 1970 to September 30, 1971 was 2.06 ft (U.S. Geological Survey, 1971).

Surface-water inflow and outflow

The main inflow is via Thompson Creek. Other smaller seasonal streams drain the hills on the north end of the lake. The outflow, which is controlled by gates at a concrete headworks, is via an irrigation canal. Some water is diverted from the lake for domestic use. Miscellaneous measurements of inflow and outflow are given below.

Date (1971)	Inflow via Thompson Creek (cfs)	Inflow, Total Miscellaneous (cfs)	Outflow (cfs)
Mar 29	16.5	14.7	*34
May 26	21.2	* .8	23.9
Jul 19	6.82	* .2	7.91
Sep 29	4.07	* .2	6.38

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 61.

Biological characteristics

Emergent rooted aquatic-plant growth was heavy, and submergent plant growth was moderate. On September 29, 1971, approximately 6 percent of the lake surface and 20 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was yellow waterlily (*Nuphar* sp.) accounting for 5 percent of the lake surface. The dominant submergent plant was pondweed (*Potamogeton robbinsii*). Other plants were white waterlily (*Nymphaea* sp.), sedge (*Cyperaceae*), cattail (*Typha* sp.), and pondweed (*Potamogeton amplifolius*). The muck substrate for rooted aquatic-plant growth in the littoral zone accounted for 42 percent of the shoreline.

An algal bloom was observed September 29, 1971, and a high algal density was recorded July 14, 1971.

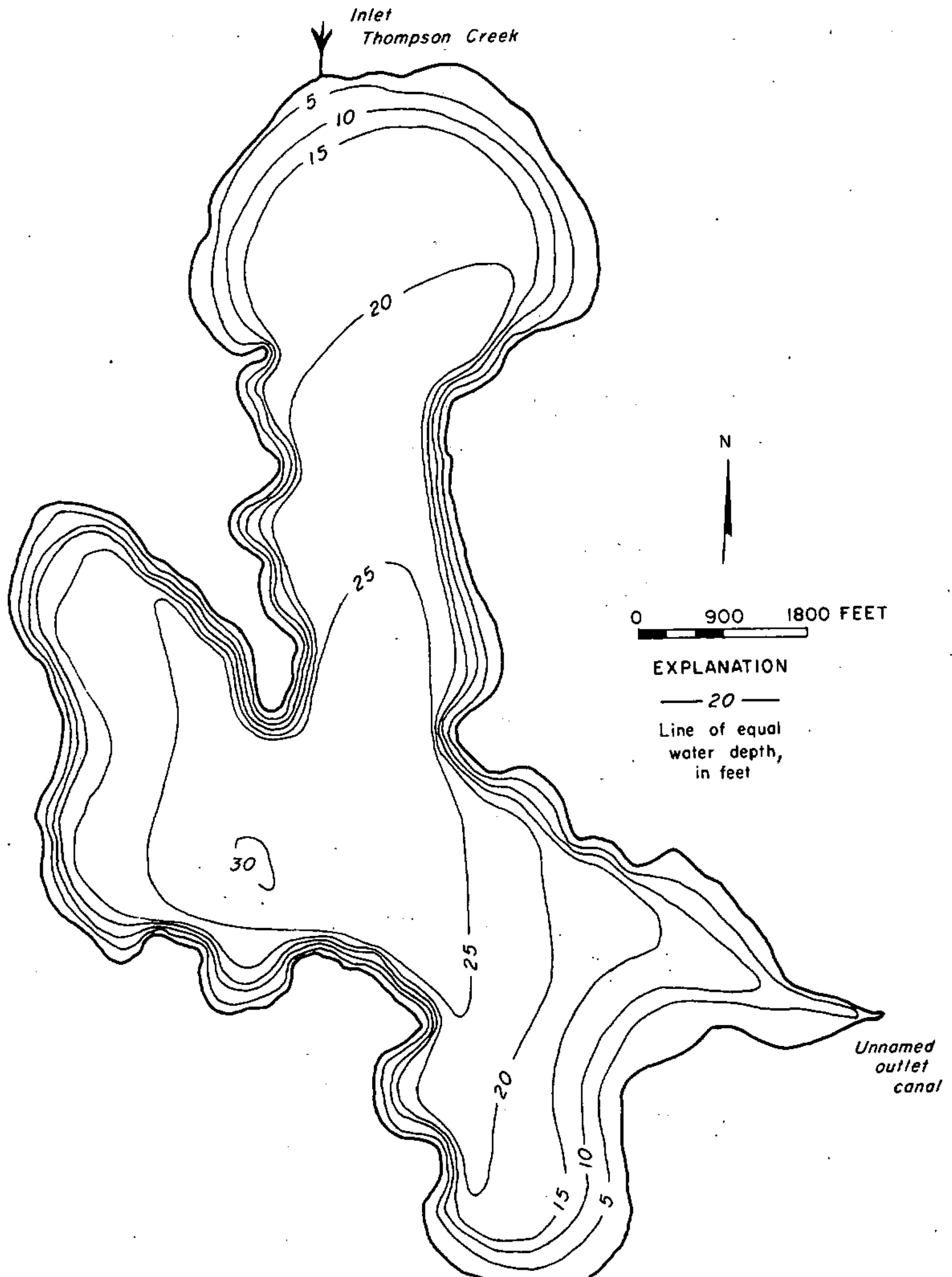

FIGURE 59.—Bathymetric map of Newman Lake near Newman Lake. From Washington Department of Game, Feb. 18, 1951.

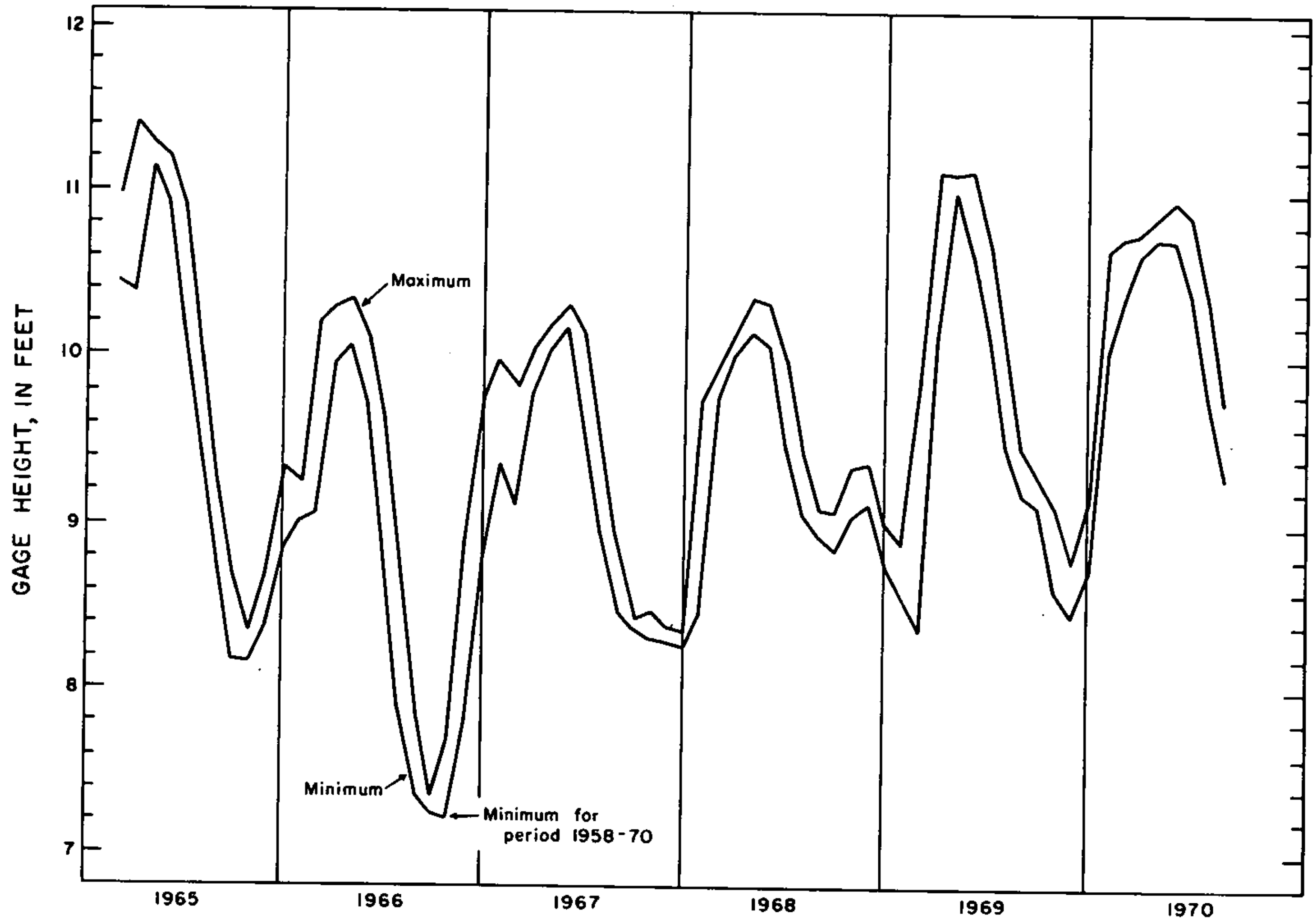

FIGURE 60.—Observed monthly maximum and minimum gage heights, Newman Lake near Newman Lake, 1965-70.

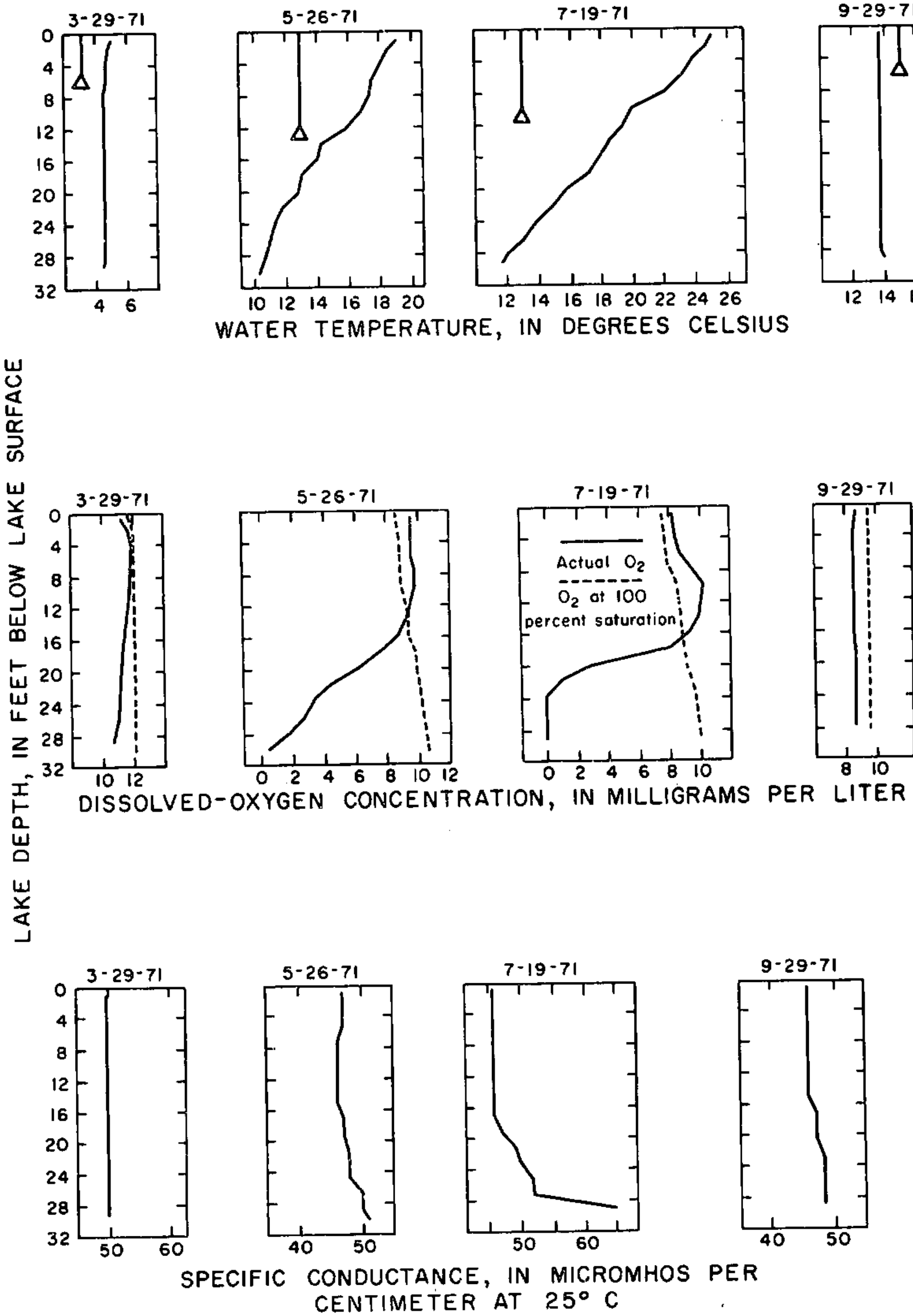

FIGURE 61.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Newman Lake near Newman Lake. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

12420000. Liberty Lake at Liberty Lake

Location

Spokane County, at town of Liberty Lake (fig. 1).

Origin

Damming of glaciated valley by glaciofluvial deposits.

Basin geology

Recessional outwash and alluvium in valley, and granitic and metamorphic rocks in hills (Huntting and others, 1961).

Soils

Intricate patterns of silt loam, loamy sand, loam, rocky complex, stony silt loam, and gravelly sand loam. The main inflow drains through a large muck deposit on south side of the lake (Donaldson and Giese, 1968).

Land use and cover

Scattered forest, with residential and recreational clearings. Nearshore cover includes Douglas fir, ponderosa pine, cottonwood, and locust.

Population

Lakeshore development dense with 196 residences and two resorts in September 1971, compared to 106 dwellings in 1949 (estimated from U.S. Geological Survey topographic map). Approximately 10 percent of shoreline adjoins marsh. Residential development occupies approximately 83 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 62. The map was surveyed on January 14, 1948, using an arbitrary datum.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	13.3 sq mi
Altitude (from topographic map)	2,053 ft
Surface area	713 acres
Lake volume	16,300 acre-ft
Mean depth	23 ft
Maximum depth	30 ft
Length of shoreline	25,200 ft
Length of lake	9,150 ft
Mean breadth of lake	3,390 ft
Shoreline configuration	1.27
Development of volume	0.76
Mean slope	1.9 percent

Hydrologic characteristics

Lake stages

A hydrograph of monthly maximum and minimum lake stages during 1963-70 is shown in figure 63. The datum of the gage is at mean sea level. In 1952 a court decision set the maximum level of the lake at 2,049.5 ft above mean sea level (Rigg, 1958). The lake altitude is regulated by gates at a headworks structure near the outlet. The average annual variation in the lake stage was 2.6 ft for 1956-70. The gage height was observed two to three times weekly during the water year 1971 and showed a variation of 2.34 ft (U.S. Geological Survey, 1971).

Surface-water inflow and outflow

The main inflow is via Liberty Creek draining the hills on the south end of the lake. The outflow, which is controlled by gates, is via an irrigation canal. Some water is pumped from the lake for domestic use. Miscellaneous measurements of inflow and outflow are given below:

Date (1971)	Inflow via Liberty Creek (cfs)	Outflow (cfs)
Mar 30	16.6	--
May 26	*10	* .8
Jul 19	2.41	0
Sep 27	1.81	0

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration, specific conductance, and water temperature are shown in figure 64.

Biological characteristics

Submergent rooted aquatic-plant growth was moderate, and the emergent plant growth was sparse. On September 27, 1971, approximately 0.05 percent of the lake surface and 5 percent of the lake bottom were occupied by macrophytes. The lake contained waterweed (*Elodea* sp.), muskgrass (*Chara* sp. and *Nitella* sp.), hornwort (*Ceratophyllum* sp.), quillwort (*Isoetes* sp.), two varieties of pondweed (*Potamogeton* spp.), waterlily (*Nuphar* sp. and *Nymphaea* sp.), and sedge (*Cyperaceae*).

An algal bloom was observed September 27, 1971, and a high algal density was recorded on July 19, 1971.

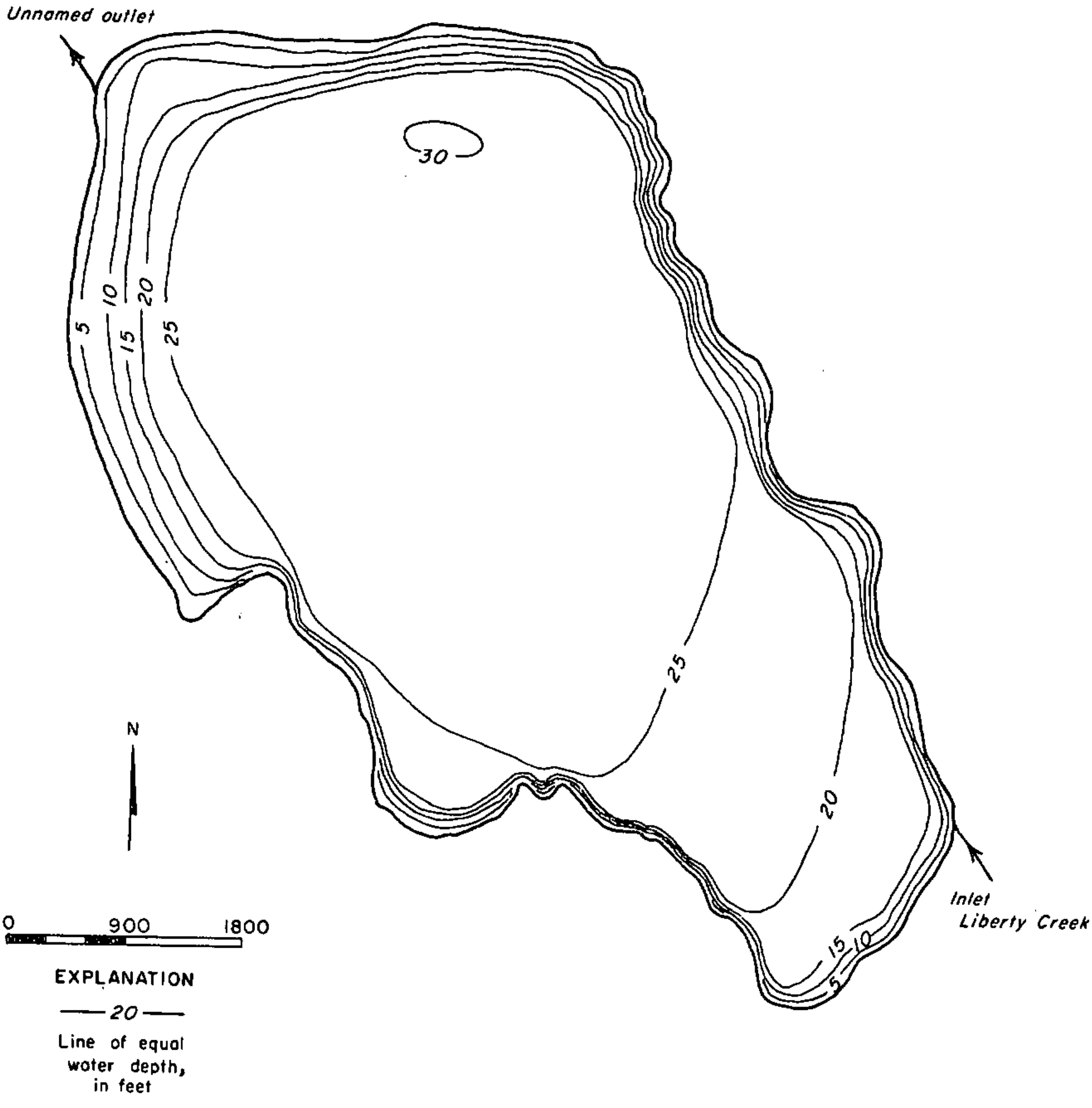

FIGURE 62.–Bathymetric map of Liberty Lake at Liberty Lake. From Washington Department of Game, Jan. 14, 1948.

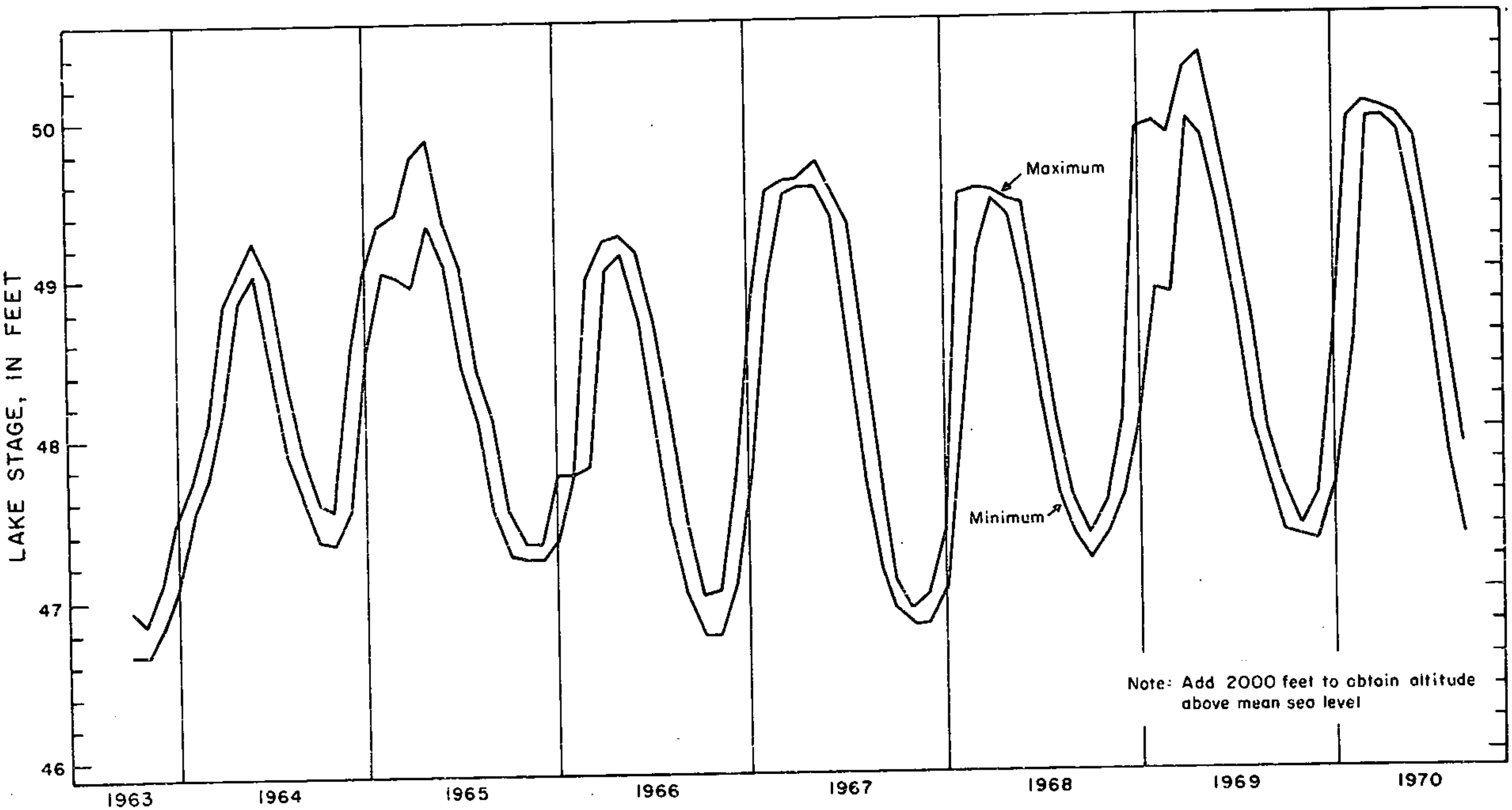

FIGURE 63.–Observed monthly maximum and minimum lake stages, Liberty Lake at Liberty Lake.

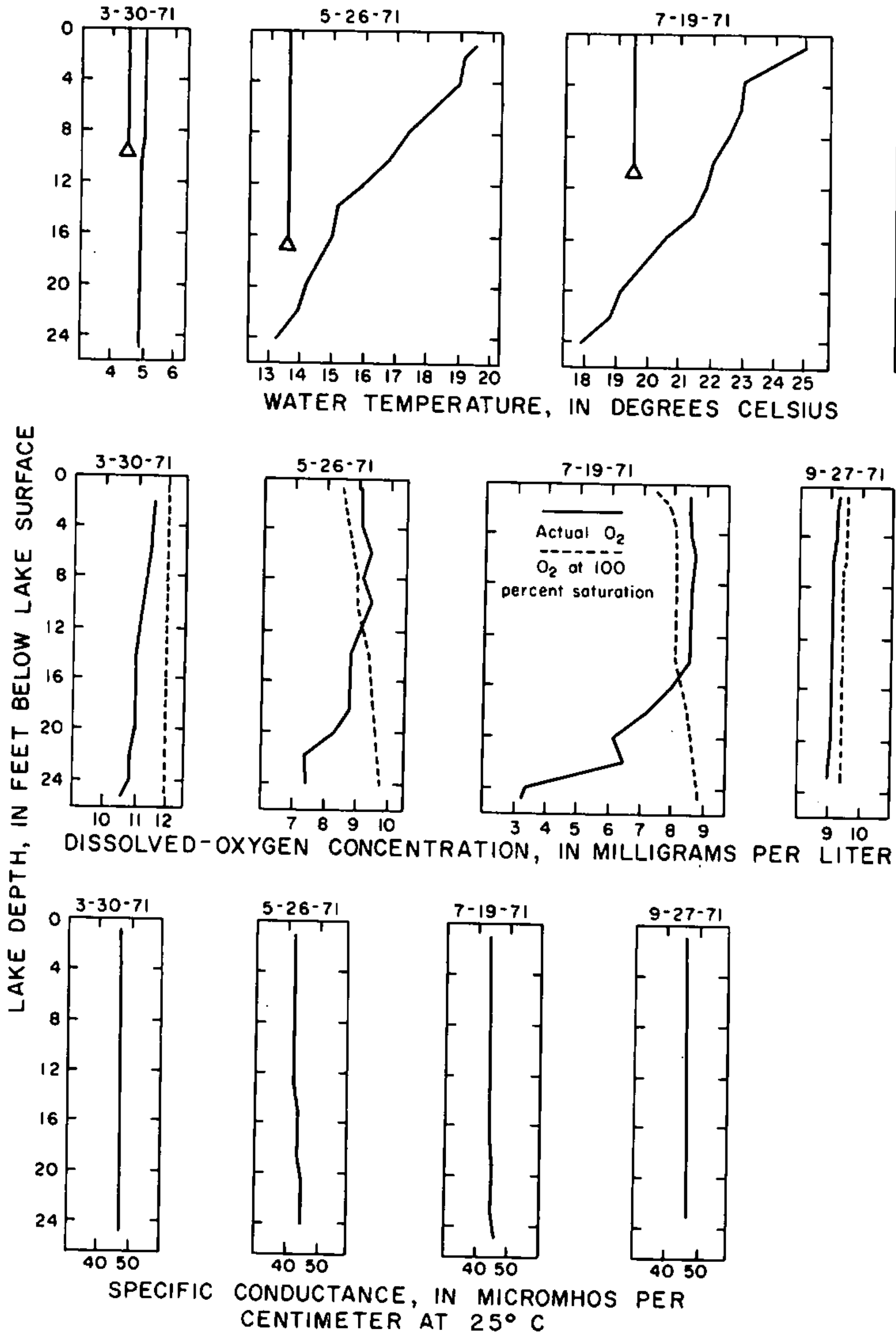

FIGURE 64.—Selected 1971 seasonal profiles of lake temperature, DO concentration, and specific conductance, Liberty Lake at Liberty Lake. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

14222960. Merrill Lake near Cougar

Location

Cowlitz County, 2.1 miles north of Cougar (fig. 1).

Origin

Damming of valley by lava and mudflow deposits from Mount St. Helens.

Basin geology

Volcanic rocks consisting of andesite, basalt, mudflows, and tuff beds (Hyde, 1970).

Soils

Rough mountainous land with shallow stony soils (U.S. Soil Conservation Service, 1968).

Land use and cover

Heavily forested, with logging as well as recreational and residential clearings. Commercial forest is presently being logged, and a State-operated camping area and a boat access are located on the lake. Douglas fir, hemlock, and cedar dominate the hillside cover. Alder, willow, dogwood, black cottonwood, vine maple, and spiraea dominate the riparian cover.

Population

Southwest corner of lake supports eight summer homes which occupy about 4 percent of the lakeshore.

Physical characteristics of lake

A bathymetric map of the lake is shown in figure 65. The map was surveyed on August 25, 1969, and is referenced to mean sea level. A lake altitude of 1,570 ft was assumed for the map.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	9.08 sq mi
Altitude (from topographic map)*	1,541 ft
Surface area	488 acres
Lake volume	18,800 acre-ft
Mean depth	39 ft
Maximum depth**	77 ft
Length of shoreline	33,400 ft
Length of lake	12,050 ft
Mean breadth of lake	1,760 ft
Shoreline configuration	2.04
Development of volume	0.50
Mean slope	8.1 percent

*Lake level can fluctuate widely.

**During 1970-71, the maximum depth observed was 70.7 ft (at a lake altitude of 1,563.71 ft).

Hydrologic characteristics

Lake stages

Miscellaneous lake-stage observations for 1970-71 are shown in figure 66. The datum of the gage is at mean sea level. Between October 1, 1970 and September 30, 1971, the observed lake stage varied 33.8 ft. The high-water mark obtained March 30, 1972 was 60.73 ft. Severe rainstorms in late January 1972 caused slides carrying mud, logs, and debris into the lake from the logged hillsides.

Surface-water inflow and outflow

The inflow is from three main tributaries as well as from smaller intermittent streams. No surface outlet exists; the outflow is by loss to ground water. The following surface-water inflows were measured at inflow sites 1, 2, and 3 shown on the bathymetric map.

Date	Inflow at Site 1 (cfs)	Inflow at Site 2 (cfs)	Inflow at Site 3 (cfs)	Inflow, Total Miscellaneous (cfs)
1970				
Feb 24	2.20	4.04	6.13	*3.0
Jul 5	* .3	.50	.98	* .3
Oct 14	.16	.60	.72	0
1971				
May 5	3.01	--	--	*3.0
Jul 9	.71	2.98	4.33	--
Oct 4	.56	3.45	4.27	.58

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 67.

Biological characteristics

Emergent rooted aquatic-plant growth was moderate and submergent plant growth was light. On October 14, 1971, approximately 2 percent of the lake surface and 2 percent of the lake bottom were occupied by macrophytes. The dominant emergent aquatic plant was sedge (*Cyperaceae*), followed by smartweed (*Polygonum* sp.) and *Spiraea* sp. The dominant submergent plant was muskgrass (*Nitella* sp.).

No algal blooms were observed, but a high algal density was recorded on October 14, 1970 and October 4, 1971.

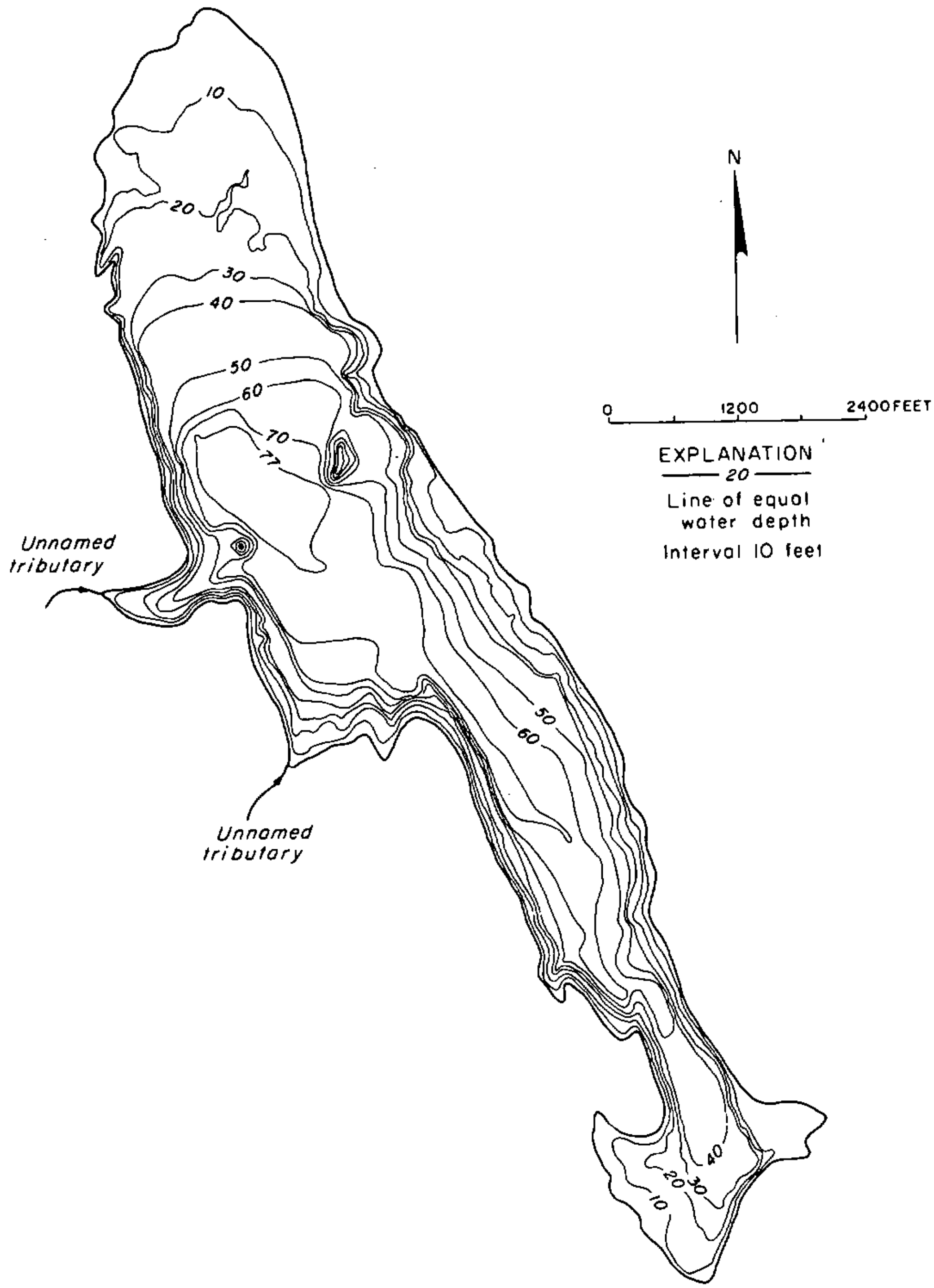

FIGURE 65.—Bathymetric map of Merrill Lake near Cougar. Datum is mean sea level. Based on 27 cross-sectional depth profiles. Adapted from unpublished map by R.W. Beck and Associates. Zero-depth contour is 1,570 feet above mean sea level.

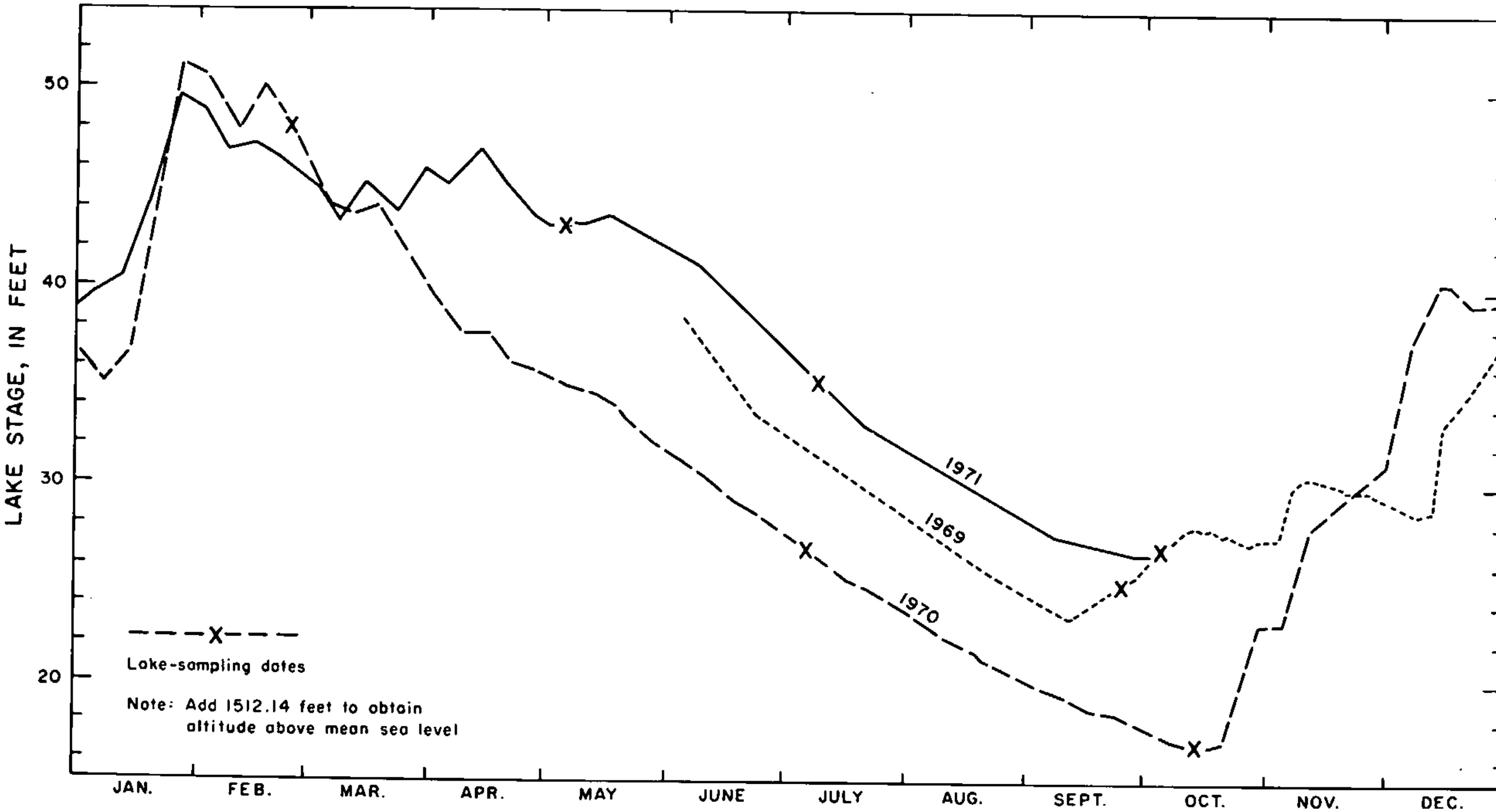

FIGURE 66.—Observed lake stages for 1969-71, Merrill Lake near Cougar.

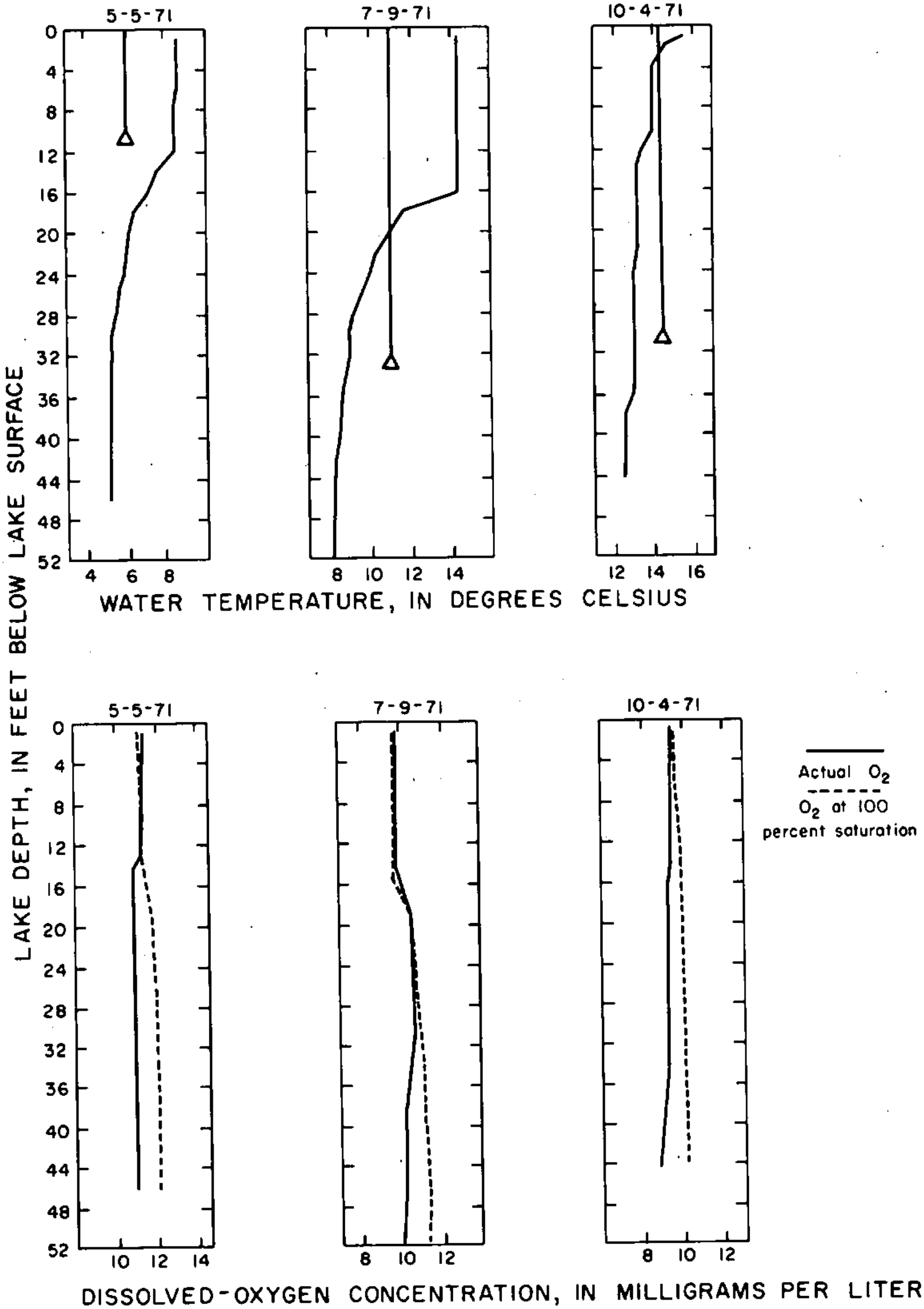

FIGURE 67.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Merrill Lake near Cougar. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

14231670. Walupt Lake near Packwood

Location
Lewis County, 16 miles southeast of Packwood (fig. 1).

Origin
Damming of glaciated valley by lava flow from Mount Adams.

Basin geology
Volcanic rocks consisting of andesite breccia with interbedded andesite and basalt flows, mudflows, and tuff beds (Huntting and others, 1961).

Soils
Rough mountainous land with shallow and stony soils. Bare rock outcrops common (U.S. Soil Conservation Service, 1968).

Land use and cover
Heavily forested, with small recreational clearings. Forest is mixed coniferous stands of fir, cedar, and hemlock. Nearshore cover mainly fir, hemlock, cedar, vine maple, alder, mountain ash, serviceberry, and devils club.

Population
Lakeshore development sparse (campground only). No seasonal or permanent residents inhabit the watershed.

Physical characteristics of lake
A bathymetric map of the lake is shown in figure 68. The map was surveyed on August 18, 1971 and referenced to an arbitrary gage datum. The lake stage during the survey was 96.08 ft.

Some morphometric parameters of the lake, based on the bathymetric map, are listed below.

Drainage area	13.7 sq mi
Altitude (from topographic map)	3,927 ft
Surface area	354 acres
Lake volume	62,300 acre-ft
Mean depth	176 ft
Maximum depth	295 ft
Length of shoreline	18,000 ft
Length of lake	6,330 ft
Mean breadth of lake	2,430 ft
Shoreline configuration	1.29
Development of volume	0.60
Mean slope	24 percent

Hydrologic characteristics

Lake stages
Observed gage heights for 1971 were 7.42, 6.08, and 6.06 ft for July 8, August 18, and October 5, respectively. The altitude of the gage is 3,927 ft; the datum of the gage is arbitrary.

Surface-water inflow and outflow

The inflow is from Walupt Creek, as well as from intermittent and ephemeral streams. The outflow, which is controlled by natural conditions, is via Walupt Creek. Miscellaneous inflow and outflow measurements are given below.

Date (1971)	Inflow Walupt Creek (cfs)	Inflow, Total Miscellaneous (cfs)	Outflow via Walupt Creek (cfs)
Jul 8	102	*6	138
Aug 18	7.46	* .2	17.0
Oct 5	3.53	* .5	0

*Estimated

Water-quality characteristics

Seasonal Secchi-disc visibility depths and profiles of DO concentration and water temperature are shown in figure 69.

Biological characteristics

Emergent rooted aquatic-plant growth was light and submergent plant growth was sparse. On October 4, 1971, approximately 0.2 percent of the lake surface and 0.3 percent of the lake bottom were occupied by macrophytes. The lake contains horsetail (*Equisetum* sp.), sedge (*Cyperaceae*), quillwort (*Isoetes* sp.), muskgrass (*Nitella* sp.), and pondweed (*Potamogeton* sp.).

No algal blooms or high algal densities were observed.

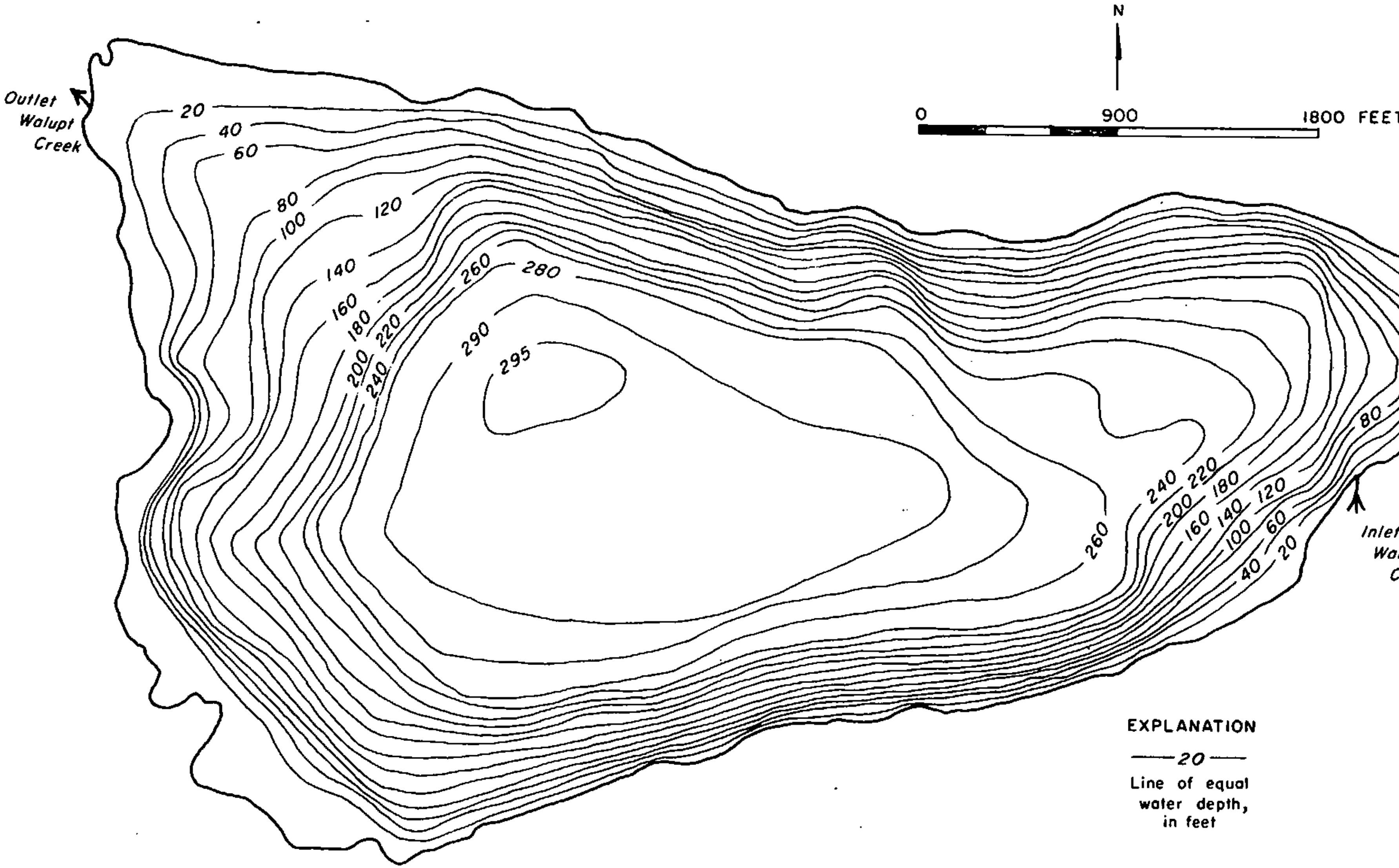

FIGURE 68.—Bathymetric map of Walupt Lake near Packwood. From U.S. Geological Survey, July 18-20, 1971.

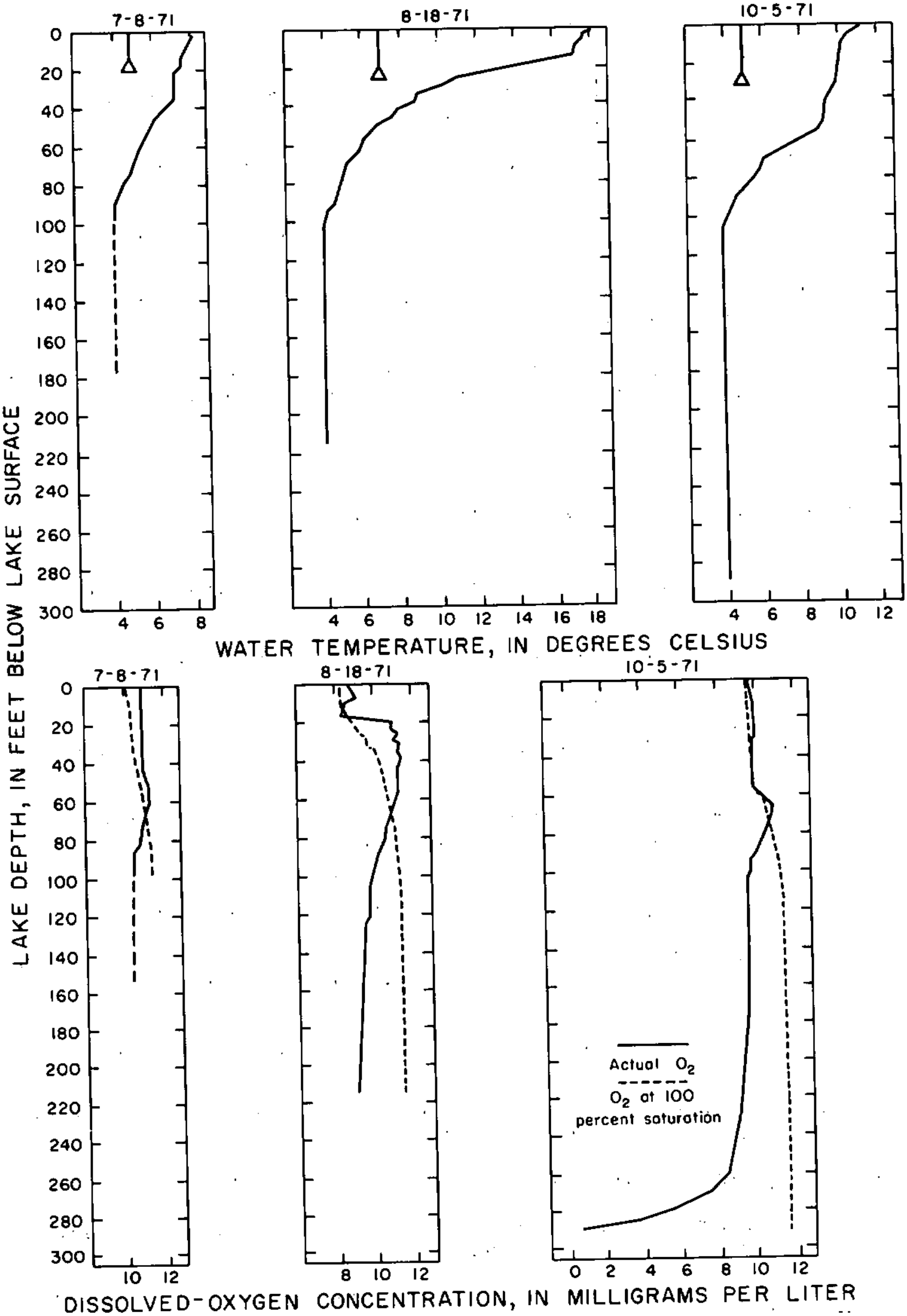

FIGURE 69.—Selected 1971 seasonal profiles of lake temperature and DO concentration, Walupt Lake near Packwood. Secchi-disc-visibility depths are indicated by bases of triangles on temperature profiles.

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I. Glossary of Limnological and Hydrological Terms

Acre-foot
Volume of water required to cover 1 acre to a depth of 1 foot and equal to 43,560 cubic feet.

Algal bloom
A large, abnormal population of phytoplankton which may often form objectionable scums and odors upon decomposition. Frequently, 0.5 to 1 million cells per liter constitutes a bloom.

Biomass
The weight of all living material present in a unit area at a given time, expressed as weight per unit area or volume. In this study biomass refers to the net plankton portion of all living material present at a given time.

Chlorophyll *a*
A photosynthetic pigment which is the most abundant and important pigment in living plant material.

Clarke-Bumpus sampler
Plankton sampler which is equipped with a flowmeter and counter calibrated to determine the volume of water passing through the net.

Clinograde
The stratification curve of temperature or of a chemical substance in water that exibits a sloping profile from the surface downward into deeper water.

Cultural eutrophication
The acceleration of the natural process of nutrient enrichment in a lake as a result of man's activities.

Development of volume
The ratio of the mean depth to the maximum depth.

Diatoms
Algae having silicious cell walls that persist as a skeleton after death.

Ephemeral stream
A stream that flows only in direct response to precipitation, and whose channel is at all times above the water table.

Epilimnion
The upper mixing portion of lake having a fairly uniform warm temperature.

Eutrophication
Process by which lake waters acquire a high nutrient concentration and hence a rich organic production.

Glacial drift
Rock debris that has been transported by glaciers and deposited, either directly by the ice or by the glacial melt water. The debris may or may not be heterogeneous.

Glaciofluvial deposits
Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.

Hypolimnion
The deeper waters of a lake where the temperature is characteristically uniform and cooler than in the epilimnion and mixing is poor or nonexistent.

Intermittent or seasonal stream
A stream that flows at certain times of the year when it receives water from springs or from some surface source such as melting snow or glaciers.

Kame
An irregular ridge or hill of stratified glacial drift.

Kettle lake
Basin formed by the melting of masses of ice buried or submerged in glacial drift.

Land-use categories

Residential
Predominant use is single family residences with lot sizes usually 1 acre or less. Where residentially developed land and highway right-of-way jointly use shoreland, dominant use is considered residential.

Commercial
Retail sales, business offices, shopping centers, community services, marinas, parking, and related commercial enterprises.

Industrial
Manufacturing and fabrication industries.

Recreational and open space
Campgrounds, public access to water, scout camps, resorts, parks, gold courses, church camps, and wetlands.

Agricultural
Grazing and crop land.

Forestry
Private and public forest lands and tree farms.

Undeveloped lands
Refers to unplatted areas, not yet built upon for residential, commercial, or industrial use. For example, forestry use is considered undeveloped.

Length of lake
The shortest distance across the lake between the two most widely separated points on the lakeshore.

Limnology
Pertaining to study of lakes.

Littoral
The shoreward zone of a body of water.

Loam
Soil material that contains a mixture of clay, silt, sand, and organic matter.

Macrophyte
Large plant, macroscopic size (visible to the naked eye).

Marsh
Periodically wet or continually flooded areas with the surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants.

Mean breadth of lake
The area of the lake divided by its length.

Mean depth
The volume of the lake divided by its area.

Mean slope
The average slope of the side of the lake which is approximated from

$$\text{mean slope (percent)} = 1/n\,(1/2\,L_0 + L_1 + L_2 \ldots L_{n-1} + 1/2\,L_m)\,Z_m/A \times 100$$

where n is the number of equal contour intervals, m is the number of contour lines, Z_m is the water depth of the line used, and A is area of the lake surface (Hutchinson, 1957).

Mesotrophic
Water with an intermediate concentration of nutrients.

Meso-eutrophic
Water with intermediate to high concentrations of nutrients.

Metalimnion
The entire transition zone between the epilimnion and hypolimnion where the temperature gradient is often very sharp.

Micron
A unit of length equal to 10^{-6} of a meter and usually denoted by the symbol μ.

Monomictic
Lakes that circulate during one period in the year, usually in the winter.

Moraine
Glacial drift deposited chiefly by direct glacial action.

Muck
Highly decomposed organic material in which the original plant parts are not recognizable. Contains more mineral matter and is usually darker than peat.

Nannoplankton
A phytoplankton with a size classification of 10-50 microns for the largest dimension. Smaller than net plankton.

Net plankton
The plankton organisms which are of such size that they can be strained from the water by means of a net.

Nutrient
Essential and trace elements needed for plant growth. Essential elements include C, N, P, O, and H.

Oligo-mesotrophic
Water with low to medium concentrations of nutrients.

Oligotrophic
Water with a low nutrient concentration and hence a small organic production.

Orthograde
A stratification curve (such as for temperature or dissolved oxygen) for a body of water which has a straight vertical profile as compared to clinograde.

Peat
Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed organic matter accumulated under conditions of excessive moisture.

pH
The negative logarithm of the hydrogen-ion concentration, expressed as a number from 0 to 14. A pH of 7 is neutral, a pH of less than 7 is acidic, and a pH of greater than 7 is basic.

Photic zone
The depth zone in a lake in which sufficient light is available for photosynthesis.

Photosynthesis
Elaboration of organic matter (carbohydrate) from CO_2 and H_2O with the aid of light.

Phytoplankton
The plant portion of the plankton.

Plankton
The floating assemblage of communities of microscopic-size plants and animals in free water.

Primary production
The weight of new organic material created by photosynthesis, or the energy it represents.

Primary productivity
The production divided by a period of time, expressed as milligrams of organic matter per meter squared per day.

Riparian
Pertaining to the banks of a body of water.

Rough broken land
Land with very steep topography and numerous intermittent drainage channels.

Seston
A collective term referring to the total amount of suspended matter in the lake.

Shoreline population
Refers in this report to residences located on and near lake shoreline, usually within 500 feet of the shoreline.

Standing crop
The weight of organic material that can be sampled or harvested at any one time from a given area.

Till
Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion.

Tuff
Volcanic ash usually more or less stratified in various states of consolidation.

Volume of the lake
The volume of a lake is computed from

$$V_{n\text{-}m}=1/3(A_m+A_n+\sqrt{A_m A_n})\ (n\text{-}m)$$

where A_n is the area of the upper surface of a contour stratum and A_m is the lower surface of the same stratum, the height of the stratum is n-m. A series of horizontal slices (from lake-map contour intervals) are computed and summed to obtain the total volume of the lake (Hutchinson, 1957).

Water year

The 12-month period October 1 through September 30, designated by calendar year in which it ends.

Zooplankton

The animal portion of the plankton.

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