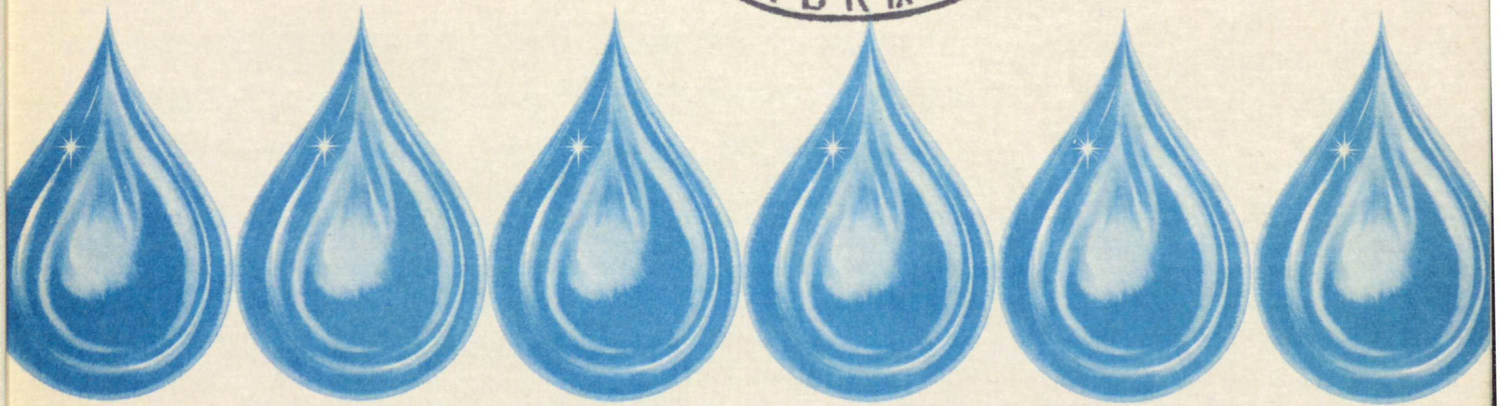
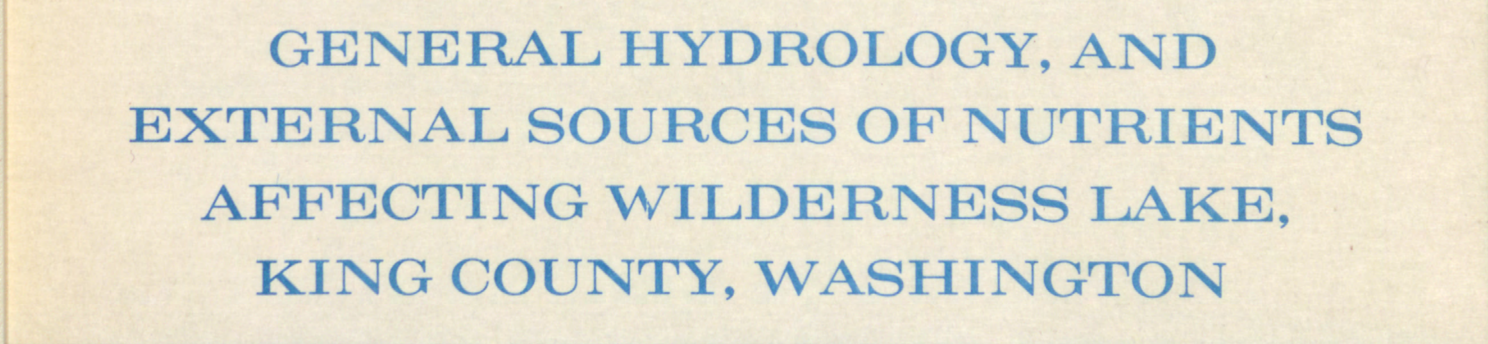


ENVIRONMENTAL FEATURES, GENERAL HYDROLOGY, AND EXTERNAL SOURCES OF NUTRIENTS AFFECTING WILDERNESS LAKE, KING COUNTY, WASHINGTON



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations
Open-File Report 79-63

Prepared in Cooperation With
Municipality of Metropolitan Seattle

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ENVIRONMENTAL FEATURES, GENERAL HYDROLOGY, AND EXTERNAL SOURCES OF NUTRIENTS AFFECTING WILDERNESS LAKE, KING COUNTY, WASHINGTON

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1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

U.S. Geological Survey
1201 Pacific Avenue - Suite 600
Tacoma, Washington 98402

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METRIC CONVERSION TABLE

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	.4047	hectare (ha)
acre-foot (acre-ft)	1,233.6	cubic meter (m^3)
degree Fahrenheit (°F)	Subtract 32, multiply remainder by 0.5556	degree Celsius (°C)

ENVIRONMENTAL FEATURES, GENERAL HYDROLOGY, AND EXTERNAL SOURCES OF NUTRIENTS AFFECTING WILDERNESS LAKE, KING COUNTY, WASHINGTON

By N. P. Dion

ABSTRACT

A water budget prepared for Wilderness Lake, a candidate for lake-quality restoration, indicates that of the 530 acre-feet of water that enters the lake each year, 170 acre-feet is from precipitation and 360 acre-feet is from ground-water inflow. An equal amount leaves the lake, and, of this, 380 acre-feet is by surface runoff, 8 acre-feet is by ground-water seepage, and 140 acre-feet is by evaporation. Based on these amounts of inflow and outflow, the theoretical water-renewal time of the lake is calculated to be 2.6 years.

The annual contributions of nitrogen and phosphorus to the lake from precipitation, natural ground water, and septic-tank leachate are about 920 kilograms nitrogen and 38 kilograms phosphorus. Nitrogen and phosphorus contributions from other sources were not assessed but could be significant.

INTRODUCTION

Background

Wilderness Lake is in southwestern King County, Washington, 22 miles southeast of Seattle and 2.5 miles south of the town of Maple Valley (fig. 1). About one-third of the shoreline of the lake is developed residentially; in addition, a public park, operated by King County, is situated on the northwest shore, and an education center operated by the University of Washington, is on the north shore. (See fig. 2.)

Previous studies (Collings, 1973; Bortleson and others, 1974; Uchida and others, 1976) have indicated that Wilderness Lake is eutrophic and that it frequently develops dense algal blooms. Other indications of the lake's advanced trophic state are dense growths of rooted aquatic macrophytes (Goodpasture and others, 1976) and the depletion of dissolved oxygen in the hypolimnion throughout the summer period of thermal stratification. Most of the nutrients were assumed to have originated from the septic tanks of residential and recreational facilities along the south, west, and north shores. It was further assumed that the nutrients were transported to the lake by ground water. However, little was known about local ground-water conditions.

Because of its advanced trophic state, the lake is being considered as a candidate for restoration by METRO (the Municipality of Metropolitan Seattle). To select an appropriate restoration technique, however, additional information is needed concerning local hydrologic conditions, the nutrient loads responsible for the enriched state of the lake, and the probable sources of those nutrients. In July 1976, METRO arranged with the U.S. Geological Survey for a cooperative study that would provide this information.

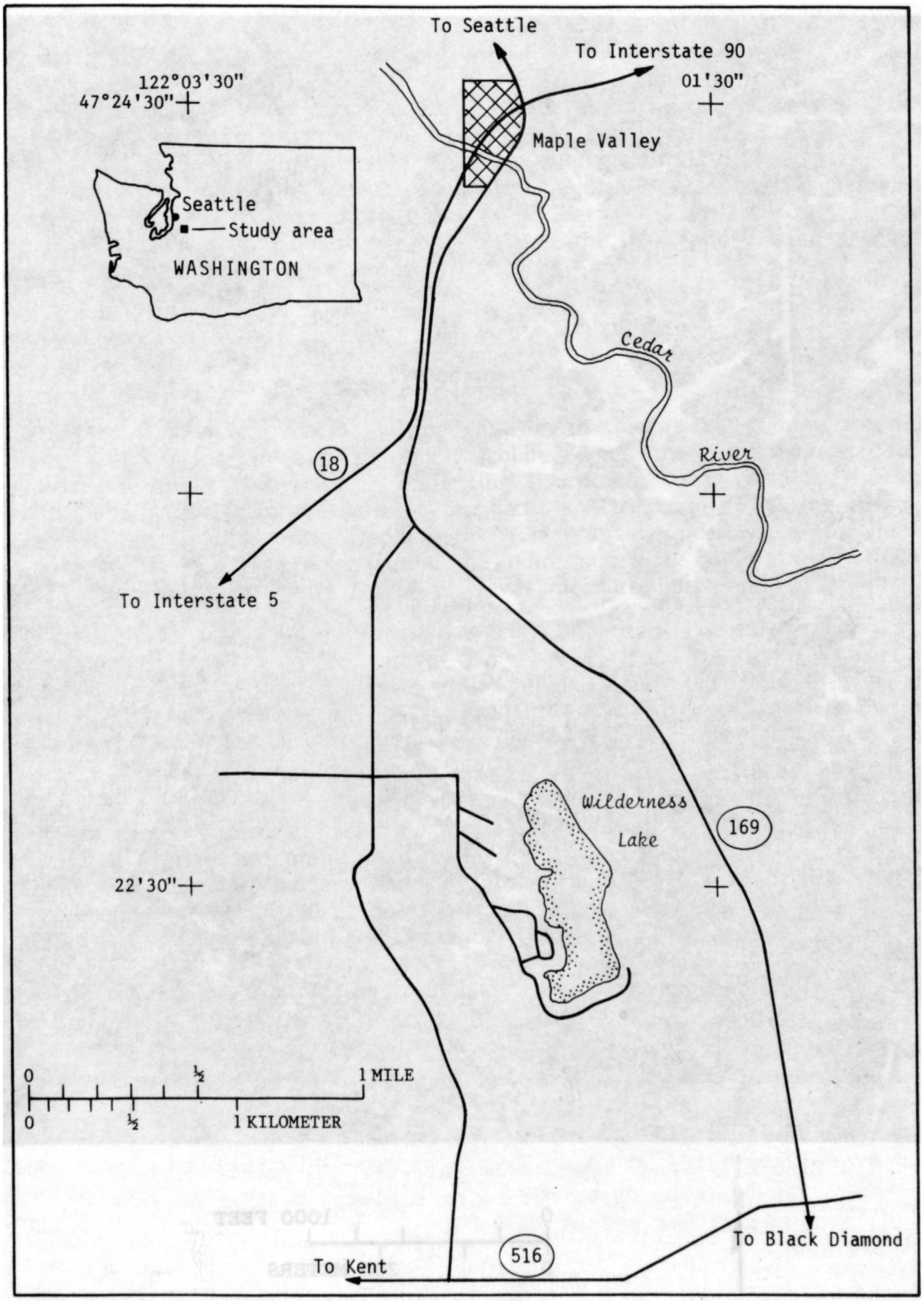


FIGURE 1.--Location of study area.

FIGURE 2.--Wilderness Lake. Photograph taken July 14, 1971, from an altitude of 7,700 feet.

Objectives

A detailed, comprehensive study of nutrient sources affecting Wilderness Lake would be costly and time-consuming. A preliminary reconnaissance appraisal, however, would point out qualitatively the most likely sources of nutrients. This report presents the findings of such a reconnaissance study, which was designed to determine (1) the environmental features of Wilderness Lake, (2) the general hydrologic conditions within about one-half mile of the lake, and (3) the probable external sources of nutrients that affect the lake.

Acknowledgments

The author wishes to express his appreciation to George Lewandowski of the University of Washington, and to Arvid Kobberod of the King County Park Department for their assistance in collecting hydrologic data. The author also wishes to thank METRO for performing chemical analyses and collecting cultural data, the King County Park Department for granting permission to install observation wells on park property, and the numerous well owners who allowed access to their domestic wells for water-level measurements and water-quality sampling.

CLIMATE

The climate in the Wilderness Lake area is of the mid-latitude, west coast marine type, characterized by warm, dry summers and cool, wet winters. The mean annual temperature at Seattle, the point nearest the study area where climatological records are maintained, is 60°F (degrees Fahrenheit) and the mean monthly temperatures in January and July are 41° and 66°F, respectively (fig. 3). The mean annual precipitation at Seattle is 34 inches. July has the lowest mean monthly precipitation (0.63 inch) and December the highest (5.4 inches).

The average annual evaporation from lake surfaces is approximately 23 inches (Kohler and others, 1959).

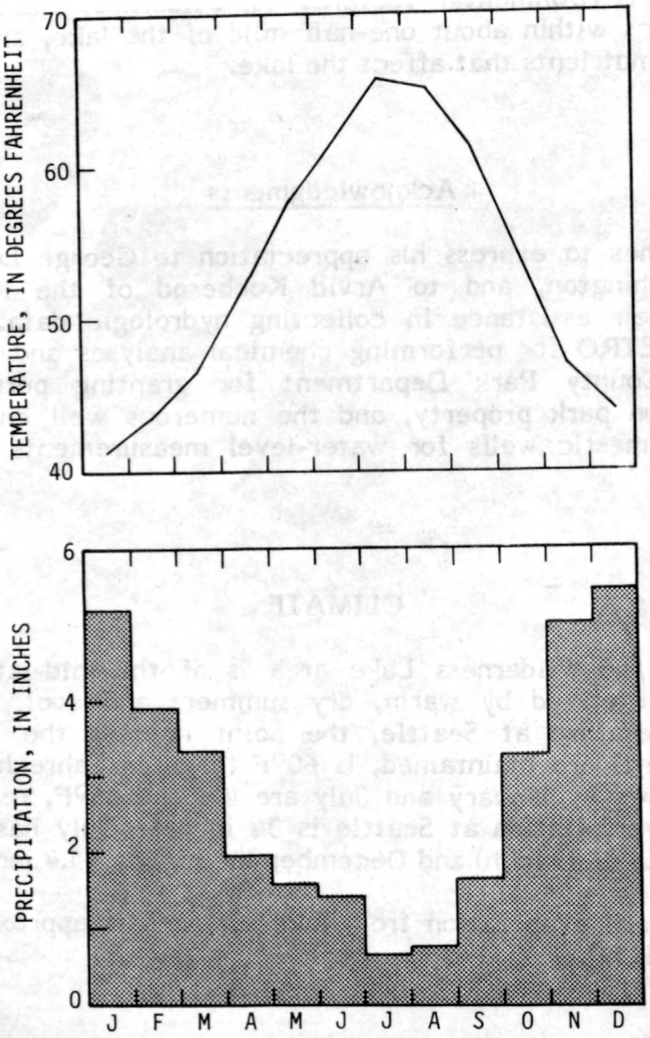


FIGURE 3.--Mean monthly temperature and precipitation at Seattle, Wash. Based on National Weather Service records for period 1931-60.

DRAINAGE BASIN

The drainage basin of Wilderness Lake, including the surface of the lake itself, is 0.66 square mile in extent and drains an area of moderate relief. Hills rise 90-225 feet above lake level on the west, south, and east sides of the lake (fig. 8); a moderately flat plain slopes away from the lake on the north and northwest sides.

The soils of the drainage basin consist chiefly of fine sandy loam and gravelly sandy loam (Poulson and others, 1952). Small areas of peat occur on the west side of the lake, immediately south of the outlet stream.

The surficial geologic materials of the drainage basin, as described by Luzier (1969, pl. 1), consist of older glacial till and younger glacial outwash material. The till is an unstratified, compact mixture of sand and gravel in a matrix of silt and clay. The younger outwash material is composed of stratified and nonstratified sand and gravel deposited by a receding ice lobe. Both the till and outwash are part of the Vashon Drift of Pleistocene age (Luzier, 1969, table 3).

Most of the drainage basin (about 55 percent) is forested. About 26 percent of the basin is occupied by Lake Wilderness Park, the University of Washington Continuing Education Center, and a small arboretum. The lake itself occupies about 16 percent of the drainage basin, and the remaining 3 percent is developed for private residences, most of which are near the south and southwest shores of the lake.

A door-to-door canvass of private residences in early 1977 indicated that 34 homes (with 96 residents) are occupied on a year-round basis and that 8 homes (with 16 residents) are occupied on a summer-only (3-month) basis. Most house lots are about 0.25 acre in size and most residents maintain fertilized lawns. Almost all the year-round residents have laundry facilities in their homes and keep an average of more than two pets (chiefly dogs) per household. There are no central sewer facilities for lakeside residences; domestic wastes are discharged to individual septic tanks. Domestic water supplies are taken chiefly from dug and drilled wells; a few homes withdraw domestic water directly from the lake.

The land on the west side of the lake is occupied by Lake Wilderness Park. The park, which is free to users and open year-round, is used extensively for swimming, picnicking, and boating. Yearly use figures for the period 1971-76 range from 69,800 to 173,000 persons, the number of visitors being dependent in large part on summer weather conditions. Prior to 1968, the land now occupied by the park was a private resort and the maximum number of visitors per day was similar to the present number (Hazel Sheehan, oral commun., 1977). Since 1968 most of the resort buildings have been razed and the swimming facilities at the park have been enlarged and improved.

Domestic water supplies for the county park are drawn from a shallow, large-diameter dug well on the west side of the park; the same well also supplies water to the education center at the north end of the lake. Sewage produced at the park is discharged to a septic tank on the park premises (fig. 8).

The University of Washington Continuing Education Center, located on land owned by King County at the north end of the lake, is used primarily for educational conferences. Attendees are usually housed and fed at the center. The number visiting the center averages about 3,650 persons per year, and the average length of stay is 2.1 days. Domestic water supplies for the center are taken from the dug well on the premises of the park; sewage is discharged to a septic tank north of the center's main building. (See fig. 8.)

CHARACTERISTICS OF THE LAKE

Physical

The shape of a lake's bottom is best portrayed by a bathymetric map, as shown in figure 4. From the bathymetric map a number of morphometric characteristics can be obtained which express certain aspects of the lake shape in numerical terms and which allow quantitative comparisons between lakes. A summary of morphometric features of Wilderness Lake is given below; readers desiring a description of how they are calculated are referred to a report by Dion (1978).

Maximum depth--------------	38 feet
Mean depth-----------------	21 feet
Surface area---------------	69 acres
Volume---------------------	1,400 acre-feet
Shoreline configuration---	1.53 (dimensionless)

Chemical

The chemical characteristics of Wilderness Lake have been described in detail by Bortleson and others (1974) and Uchida and others (1976) for the years 1971 and 1974, respectively. The following synopsis is taken from the results of those investigations.

The specific conductance of water in the upper and bottom layers of Wilderness Lake in 1974 averaged 65 and 73 µmhos/cm (micromhos per centimeter), respectively. This suggests that, with respect to dissolved solids, Wilderness Lake is typical of western Washington lakes.

Seasonal profiles of water temperature and dissolved-oxygen concentration for 1971 are presented in figure 5. As shown in the graph, the lake was vertically homogeneous with respect to temperature and dissolved oxygen in February and November. Thermal stratification was weakly developed in May and strongly developed in August. In May and August, dissolved-oxygen concentrations in the bottom water were at or near zero.

Nutrient data collected from the top water (3-ft depth) and bottom water (33-ft depth) of the lake are presented in figure 6. In the top water, inorganic nitrogen (nitrate plus ammonia) concentrations were moderate in January and February, but decreased as the water temperature increased in spring and summer and dissolved nutrients were assimilated by aquatic plants. Concentrations of orthophosphate (inorganic) phosphorus in the top water were moderate to high most of the year. In the bottom water, concentrations of all nutrients were generally high and increased still further as thermal stratification developed in summer.

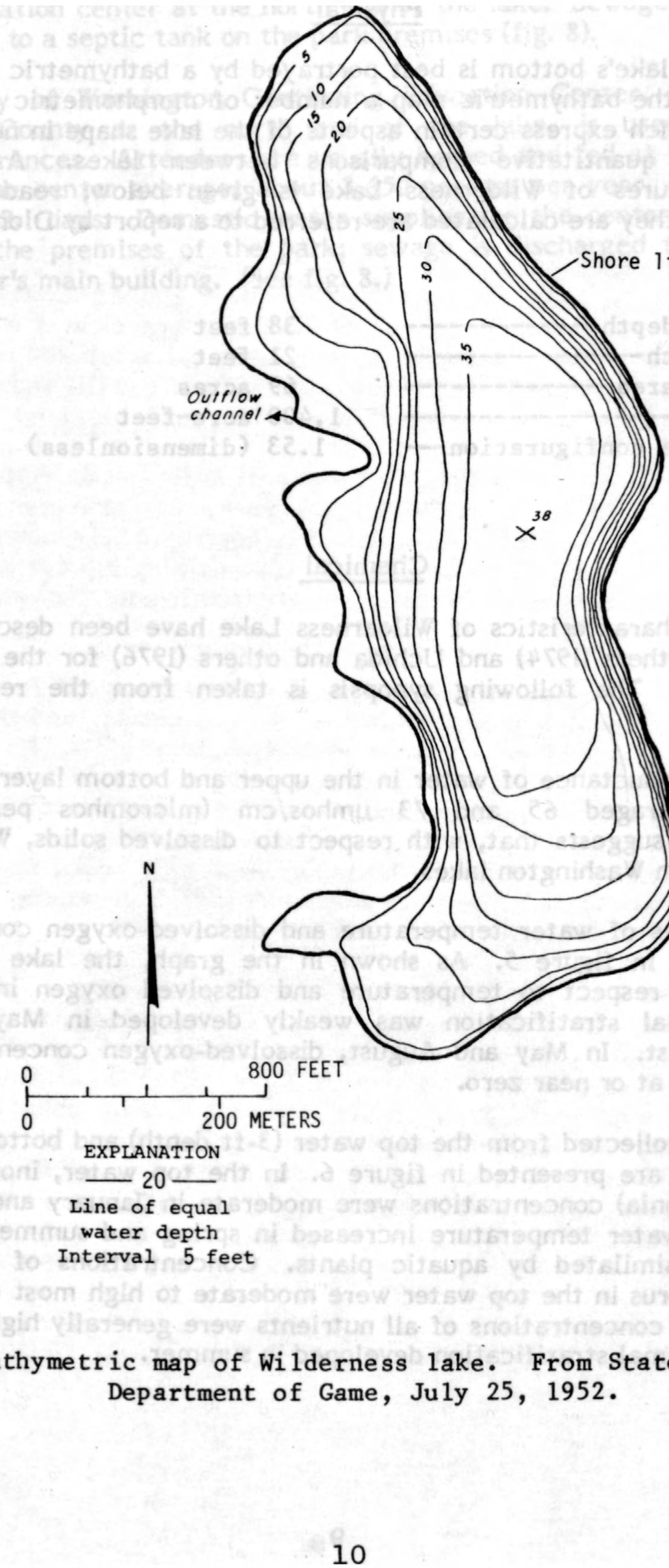


FIGURE 4.--Bathymetric map of Wilderness lake. From State of Washington Department of Game, July 25, 1952.

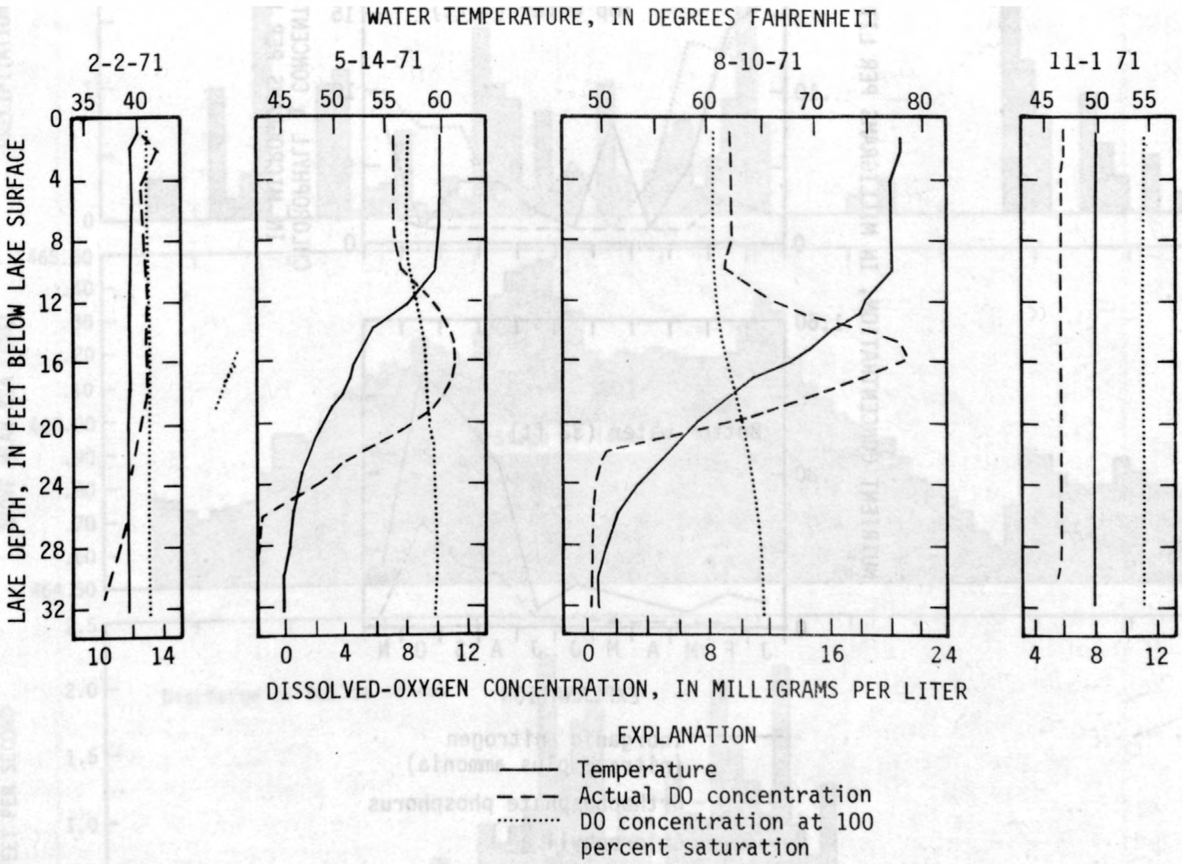


FIGURE 5.--Vertical profiles of lake temperature and dissolved oxygen during winter, spring, summer, and fall. Modified from Bortleson and others (1974).

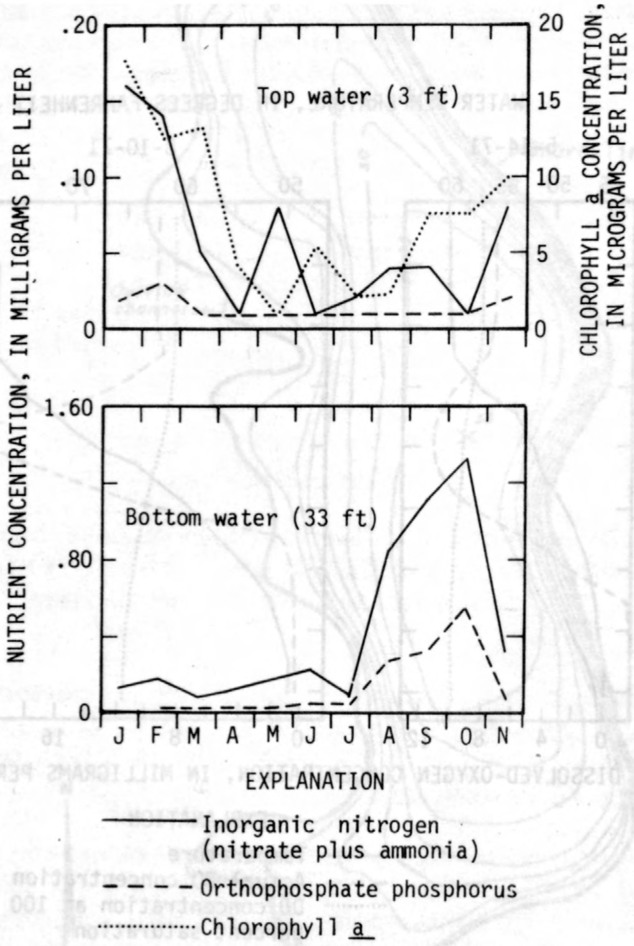


FIGURE 6.--Monthly nutrient and chlorophyll a concentrations in Wilderness Lake, 1974. Top graph is for top water; bottom graph is for bottom water. Modified from B. K. Uchida, METRO (written commun., May 17, 1977).

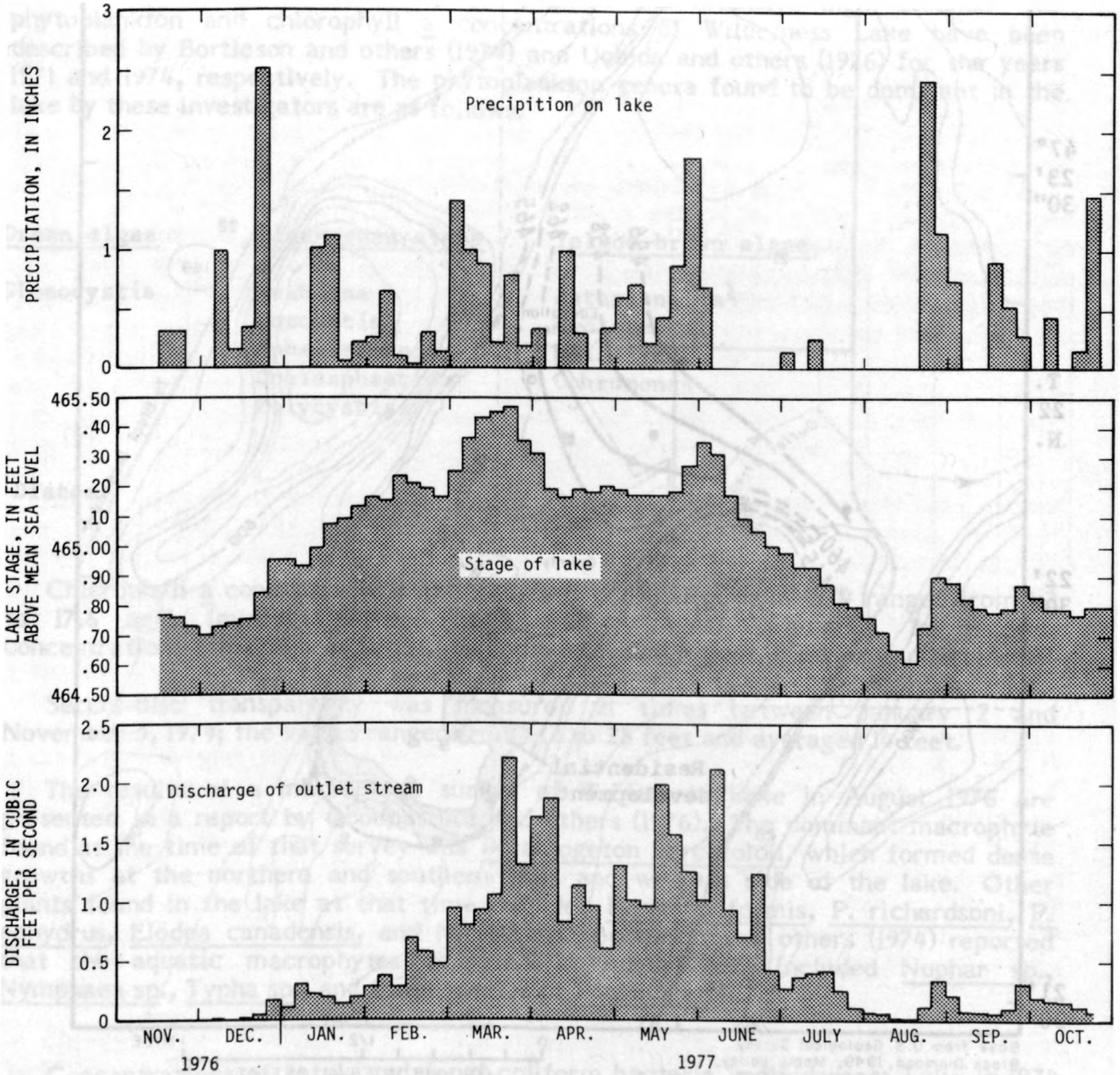
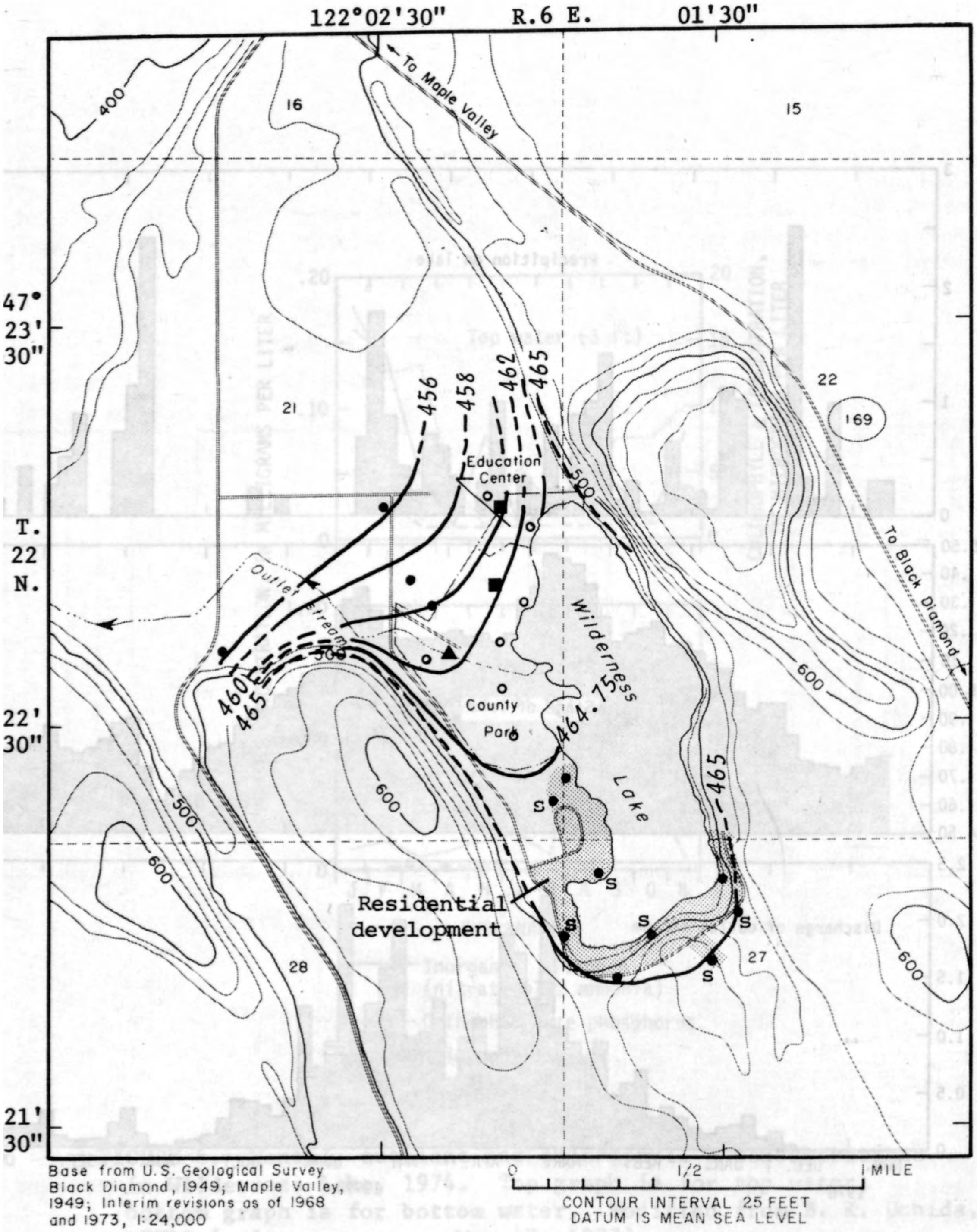


FIGURE 7.--Precipitation, lake stage, and discharge, Wilderness Lake, November 1976-October 1977.



EXPLANATION

▲ Continuous record stream-gaging station

○ Observation well, used for water level measurements

• Domestic well, used for water-level measurements

■ Septic tank

s• Domestic well used for water-level measurements and water-quality sampling

—462— Water-table contour: Shows altitude of water table Dec. 8, 1976. Dashed where approximately located. Datum is mean sea level. Contour interval varied.

FIGURE 8--Ground-water conditions and residential development in the vicinity of Wilderness Lake.

Biological

Wilderness Lake has a history of frequent and intensive algal blooms. The phytoplankton and chlorophyll a concentrations of Wilderness Lake have been described by Bortleson and others (1974) and Uchida and others (1976) for the years 1971 and 1974, respectively. The phytoplankton genera found to be dominant in the lake by these investigators are as follows:

Green algae	Blue-green algae	Yellow-brown algae
Gloeocystis	Anabaena	Asterionella[1]
	Anacystis	Cyclotella[1]
	Aphanizomenon	Melosira[1]
	Coelosphaerium	Ochromonas
	Polycystis	

[1]Diatom

Chlorophyll a concentrations at the 3-foot depth (fig. 6) in 1974 ranged from 1.2 to 17.6 µg/L (micrograms per liter) and averaged 7.6 µg/L. In general, concentrations were highest in autumn and winter and lowest in spring and summer.

Secchi-disc transparency was measured 21 times between January 2 and November 5, 1974; the values ranged from 6.2 to 28 feet and averaged 14 feet.

The results of a macrophyte survey of Wilderness Lake in August 1976 are presented in a report by Goodpasture and others (1976). The dominant macrophyte found at the time of that survey was Potamogeton berchtoldii, which formed dense growths at the northern and southern ends and western side of the lake. Other plants found in the lake at that time included P. zosteriformis, P. richardsoni, P. ephydrus, Elodea canadensis, and Nitella sp. Bortleson and others (1974) reported that the aquatic macrophytes observed in August 1971 included Nuphar sp., Nymphaea sp., Typha sp., and three species of Potamogeton.

Concentrations of total- and fecal-coliform bacteria in Wilderness Lake in 1974 were presented by Uchida and others (1976). Total-coliform-bacteria concentrations ranged from 20 to 3,300 organisms/100 mL (milliliters) but averaged only 20 organisms/100 mL. Fecal-coliform-bacteria concentrations ranged from 20 to 85 organisms/100 mL and averaged 20 organisms/100 mL.

Wilderness Lake has large populations of resident waterfowl and fish. The lake is stocked annually with fingerlings of rainbow trout and silver salmon. In addition, legal-sized rainbow trout are stocked just prior to the opening of the general fishing season. The lake was rehabilitated by the State of Washington Department of Game in September 1952 and again in September 1974. In both instances rotenone was used to eliminate bass and rough fish species in an effort to improve the lake habitat for trout and salmon.

As reported by Uchida and others (1976), Wilderness Lake would be classified as highly eutrophic according to the criteria proposed by Vollenweider (1968), which are based on maximum yearly phytoplankton density. However, according to the criteria of the U.S. Environmental Protection Agency (1974), which are based on mean chlorophyll a concentration, the lake would be classified as mesotrophic.

LAKE HYDROLOGY

Basic Framework and Methods of Analysis

Wilderness Lake receives water by direct precipitation and ground-water inflow, and loses water by surface runoff, evaporation, and ground-water seepage. In order to describe hydrologic conditions in the immediate vicinity of the lake and to facilitate the preparation of a water budget of the lake, these hydrologic characteristics, as well as lake-stage elevation, were measured, calculated, or estimated on a daily basis.

Precipitation was collected and measured in a standard (8-inch) nonrecording precipitation gage located on the roof of a building at the north end of the lake. The gage was read daily by a local observer. The distribution of precipitation during the study period is depicted in figure 7. During the period November 17, 1976-October 23, 1977, Wilderness Lake received 27.6 inches of precipitation, most of which fell as rain. During the period December 1976-September 1977, the precipitation received at Wilderness Lake was about 1 percent higher than the long-term average at Seattle for the December-September period.

Daily evaporation values were estimated by distributing the yearly rate of lake evaporation of 23 inches per year (Kohler and others, 1959) to a daily rate, based on known mean temperatures for individual months. Although numerous factors besides temperature control the rate of evaporation, it was assumed for purposes of this study that temperature was the most important factor. Estimated values of evaporation may differ markedly from actual values on a day-to-day basis; however, over the period of this study, the differences probably tend to compensate.

As mentioned previously, there is no perennial surface runoff to Wilderness Lake and the intermittent inflow is probably small. The outlet stream that drains the lake is unnamed and intermittent; it flows to Jenkins Creek, Soos Creek, and Green River. During the period of study, a continuous-recording gage was maintained on the outlet stream at a point about 700 feet downstream from the lake outlet (fig. 8). A hydrograph of the discharge at that station (fig. 7) shows that higher discharges occurred during the period late March-early June, 1977; these were the result of higher lake stages, also shown in figure 7. In mid-June precipitation decreased, the lake stage receded, and discharge decreased accordingly.

Ground-water conditions in the immediate vicinity of Wilderness Lake were determined by measuring ground-water levels in wells within about 600 feet of the lake. Because of the pattern of residential development, existing wells could be found only on the south and southwest sides of the lake. To augment this network of privately owned domestic wells, seven shallow, small-diameter observation wells were installed on the north and northwest sides of the lake. However, because the land on the east side of the lake is forested, steep, and undeveloped, attempts to install wells there were unsuccessful. The locations of all wells used to measure ground-water levels are shown in figure 8. The measuring points of these wells were referenced to mean sea level. The water-level fluctuations measured in the wells during the study were generally less than 1.0 foot in magnitude.

With respect to ground water, Wilderness Lake is a flow-through lake; that is, ground water seeps into the lake and lake water seeps out of the lake into the ground. As shown in figure 8, ground water enters the lake along the southwest, south, and east shores in a zone approximately 6,400 feet long. No data exist to describe ground-water-flow conditions on the east side of the lake. However, because topographic and geologic conditions there are similar to conditions on the south side of the lake, it was assumed that ground-water-flow conditions also were similar. Water seeps out of the lake and into the ground-water system along the northwest and north sides of the lake in a zone approximately 3,000 feet long. Seepage out of the lake occurs through glacial till, the material encountered during installation of the small-diameter observation wells. Field observations indicate that (1) ground-water flow into the lake also is through glacial till, and (2) some of the flow enters the lake by way of submerged springs.

The volume of water seeping out of the lake was calculated using a standard hydraulic equation. However, because some of the ground water seeping into the lake does so through submerged springs, the equation was not applicable to calculate the volume of inflow; instead, the volume was determined by water-budget equation. Both methods are described in more detail in the water-budget discussion on page 19.

Lake storage is defined as the amount of water stored in the lake at any given lake stage. A change in lake storage, as shown by a change in lake stage, represents the net difference between total lake inflow and total lake outflow. The stage of Wilderness Lake, which was read daily on a staff gage referenced to mean sea level, is shown in figure 7. To simplify the preparation of a water budget, the data-collection phase of this study ended on a day (October 23, 1977) when the lake stage was the same (464.78 feet above mean sea level) as on the first day (November 17, 1976) of data collection. Hence, although the lake stage fluctuated 0.96 foot during the 341-day study, there was no net change in lake storage.

Water Budget

The basic premise of the water budget used in this report is that the amount of water reaching Wilderness Lake equals the amount leaving the lake, plus or minus the change in lake storage. The boundaries of the budgeted system are the lake bottom, shoreline, and water surface. Water enters the lake as precipitation directly on its surface and by ground-water seepage, and leaves as surface outflow, ground-water seepage, and evaporation. The equation used to express this relationship is:

$$Pcpt + GW_{in} = SW_{out} + GW_{out} + Evap \pm \triangle \ Storage \quad (1)$$

Water-budget equations are usually solved for the factor that is most difficult to measure or estimate. The seepage of ground water into Wilderness Lake through submerged springs presents unique difficulties in attempting to calculate the volume of inflow. Therefore, the water-budget equation in this study was solved for ground-water inflow. By rearranging the terms of equation 1, eliminating the change-of-storage term (p. 18), and solving for ground-water inflow, the equation then becomes:

$$GW_{in} = SW_{out} + GW_{out} + Evap - Pcpt \quad (2)$$

A computer program was written to solve equation 2 on a daily and cumulative basis for the duration of the 341-day study. Daily values of measured and estimated volumes (surface-water runoff, evaporation, and precipitation) were entered directly. The rate of seepage outflow from the lake was calculated using the hydraulic equation

$$Q = KIA, \quad (3)$$

where

Q = the rate of seepage from the lake, in acre-feet per day;
K = the hydraulic conductivity of the water-bearing materials beneath the lake, in feet per day (cubic feet per square foot per day);
I = the hydraulic gradient, in feet vertically per feet horizontally; and
A = the cross-sectional area of lakebed through which seepage occurs, in acres.

The hydraulic conductivity (K) of the glacial till penetrated in four wells (fig. 8) was determined using an aquifer test described by Bouwer and Rice (1976); the resulting average value of hydraulic conductivity was 0.26 foot per day. This compares favorably with values given by Todd (1959, p. 53) for similar geologic materials, and with values used by other investigators (Oakes and others, 1975, p. 26) in similar circumstances.

The hydraulic gradient (I) used in the hydraulic equation was calculated for each day of the study and represents the average difference in altitude between the lake stage and ground-water levels in nearby observation wells.

The cross-sectional area (A) of lakebed through which seepage outflow occurs was taken as a zone 3,000 feet long and 50 feet wide (3.44 acres). Recent investigations (McBride and Pfannkuch, 1975; John and Lock, 1977) have shown that seepage from lakebeds decreases exponentially away from the shoreline. Therefore, it was assumed for purposes of these calculations that all seepage from the lake occurred within 50 feet of the shoreline.

The results of the water-budget calculations for the study period are given in table 1; for reference purposes and greater convenience in reporting, values adjusted to a full year also are given. As shown in table 1, of the 530 acre-feet of water entering Wilderness Lake each year, 170 acre-feet is from direct precipitation and 360 acre-feet is from ground-water seepage. Of the equal amount that leaves the lake, 380 acre-feet is by surface-water runoff, 8 acre-feet is by ground-water seepage, and 140 acre-feet is by evaporation.

Based on the values obtained in the water budget, the theoretical water-renewal time--the amount of time required to completely replace the lake volume--is calculated to be 2.6 years.

Because of the vagaries inherent in the collection of hydrologic data, not all components of the water-budget equation could be evaluated with equal accuracy. Estimates of the likely percentages and magnitudes of error were made for each component and are presented in table 2. As shown in the table, the value for ground-water inflow, the parameter for which the water-budget equation was solved, is probably accurate to about 150 percent of the actual value.

TABLE 1.--Summary of water budget calculated for Wilderness Lake

	Volume (acre-feet)		
	Study period[1]	Full year	Percent of total
Water entering lake			
Direct precipitation	160	170	32
Ground-water seepage	340	360	68
Total	500	530	100
Water leaving lake			
Surface-water runoff	360	380	72
Ground-water seepage	7	8	2
Evaporation	130	140	26
Total	500	530	100

[1] November 17, 1976 to October 23, 1977.

TABLE 2.--Estimates of likely errors in component values of the water-budget equation

Term	Source	Magnitude (acre-ft per year)	Likely error (percent)	Magnitude of error (acre-ft per year)
GW_{out}	From hydraulic equation	8	±100	± 8
SW_{out}	Measured directly	380	± 5	± 19
Evap	From literature	140	±30	± 42
Pcpt	Measured directly	170	±15	± 26
GW_{in}	From water-budget equation	360	±150	±540

EXTERNAL SOURCES AND MAGNITUDES OF NUTRIENTS

Many elements and compounds act as nutrients to supply the food for aquatic plants. Nitrogen and phosphorus, however, usually are considered the limiting nutrients for aquatic-plant growth, and as such, were the only nutrients measured during this study. In addition, this study concerned itself only with the external sources of nutrients entering (loading) Wilderness Lake; no consideration was given to the ultimate availability of the nutrients once they reached the lake, nor to the relationship between nutrient loadings and in-lake nutrient concentrations.

Given the existing hydrologic and cultural conditions in the vicinity of Wilderness Lake, the potential external sources of nutrients include direct precipitation, ground-water inflow, storm runoff from lands immediately adjacent to the lake, and such diverse sources as ducks, swimmers, fallen leaves, and boating activity (Allen and Kramer, 1972).

Only the precipitation and ground-water inflow were sampled as part of this reconnaissance study. Runoff from adjacent lands probably occurs during times of intense storm activity, but no such runoff was observed during this investigation. Nevertheless, the potential exists for the washing of excess lawn fertilizers and the fecal wastes of pets into the lake, thereby adding to the nutrient load. The nutrient loads from ducks, swimmers, fallen leaves, and boating activity may also be significant, but sampling these sources was not considered to be within the scope of this investigation. The nutrient loads from fallen leaves and boating activity are probably small. Similarly, wild duck populations do not add significant amounts of nutrients to the water; the ducks feed primarily in the water and merely recycle the nutrients already within the lake system. However, in recycling the nutrients, ducks ingest nutrients tied up in organic matter and redeposit them in a usable form that is conducive to heavy algal growth. Domestic or semiwild ducks contribute nutrients to the water in direct proportion to the amount of feed they are given by individuals. Large flocks of semiwild ducks were observed being fed by picnickers during the period of study.

There is virtually no information in the literature dealing with the contribution of nutrients to a lake by the metabolic wastes of swimmers. Because of the heavy use of Wilderness Lake by swimmers, most of whom are children, this activity most likely constitutes a significant source of nutrients.

Nutrient concentrations in precipitation vary markedly both geographically and seasonally. The precipitation at Wilderness Lake was sampled four times during the course of this study; the average concentrations of inorganic (nitrate, nitrite, and ammonia) nitrogen and of inorganic (orthophosphate) phosphorus were 0.19 and 0.010 mg/L, respectively (table 3). Assuming that the precipitation at Wilderness Lake averages 34 inches per year (the long-term Seattle average), the nutrient loads to the lake annually from precipitation would be 46 kg (kilograms) nitrogen and 2.4 kg phosphorus.

Ground water that moves toward Wilderness Lake was sampled twice during the study by withdrawing water from domestic wells near the south and southwest shores of the lake (fig. 8). The average concentrations of inorganic nitrogen and phosphorus were 0.49 and 0.015 mg/L, respectively (table 3). Assuming that the ground-water inflow to the lake is the 360 acre-feet per year calculated in the water budget, the nutrient loads to the lake annually from the ground water sampled would be 220 kg nitrogen and 6.7 kg phosphorus.

Of the seven domestic wells sampled, all were upgradient of the septic tanks serving the particular properties, as is the practice in keeping with accepted health codes. As a consequence, however, the water sampled was probably more representative of the natural ground water than of the water which is altered by septic-tank leachate and which seeps into the lake. As shown in figure 8, septic tanks which serve the park and education center--and which were suspected of contributing large amounts of nutrients to the lake--are, in fact, downgradient of the lake and therefore cannot contribute nutrients to it.

In order to assess more accurately the nitrogen and phosphorus contributions from the septic tanks that serve residences near Wilderness Lake, a calculation was made of the concentrations and loads that would be expected, under the already-described existing cultural and hydrologic conditions, from the septic tanks in question. Assumptions were made, based on a literature survey, as to expected per capita nutrient loads and the fate of nutrients in the drain fields of the septic tanks. Specifically, it was assumed that (1) homes with laundry facilities contribute 6.5 kg nitrogen and 1.5 kg phosphorus per capita per year, (2) homes without laundry facilities contribute 6.5 kg nitrogen and 0.75 kg phosphorus per capita per year (Uttormark and others, 1974, p. 71-72), and (3) 75 percent of the phosphorus in the septic-tank leachate is adsorbed on earth materials and does not move to the lake. (The degree of phosphorus adsorption, of course, is highly variable and depends in large measure on the amount of clay in earth materials.) The results of the calculation indicate that the leachate from septic tanks serving residences near Wilderness Lake can be expected to contain 1.5 and 0.066 mg/L of nitrogen and phosphorus, respectively (table 3). These values would translate into annual nutrient loads of 650 and 29 kg of nitrogen and phosphorus, respectively. These concentrations and loads do not include the nutrients that occur naturally in the surrounding ground water, and which were discussed separately earlier.

The combined annual contributions of nitrogen and phosphorus from precipitation, natural ground water, and septic-tank leachate are 920 kg nitrogen and 38 kg phosphorus.

TABLE 3.--Nutrient concentrations and loads to Wilderness Lake from external sources

Nutrient	Source			
	Precipitation	Ground water: Natural	Ground water: Septic-tank leachate[a]	Total
	Concentration (mg/L)			
Inorganic nitrogen	[b]0.19	[c]0.49	1.5	2.2
Inorganic phosphorus	[b].010	[c].015	.066	.091
	Load (kg per year)			
Inorganic nitrogen	46.	220.	650.	920.
Inorganic phosphorus	2.4	6.7	29.	38.

[a]Assumes (1) contributions of 6.5 kg nitrogen and 1.5 kg phosphorus per capita per year from homes with laundry facilities; (2) contributions of 6.5 kg nitrogen and 0.75 kg phosphorus per capita per year from homes without laundry facilities (Uttormark and others, 1974, p. 71-72); and (3) adsorption of 75 percent of the phosphorus on soil materials of the drain field.

[b]Average of four analyses of water collected at one site on four dates (January 1, March 8, May 31, and September 20, 1977).

[c]Average of two analyses of water collected at seven sites on two dates (April 6 and September 21, 1977).

SUMMARY AND CONCLUSIONS

Wilderness Lake receives water by direct precipitation and by ground-water seepage; there was no apparent surface-water inflow to the lake during the period of study. Water loss from the lake is by surface runoff, ground-water seepage and evaporation.

A water budget of the lake, prepared for the 341-day period November 17, 1976 to October 23, 1977, and adjusted to a full 365-day year, indicates that of the 530 acre-feet of water that enters the lake each year, 170 acre-feet is from precipitation and 360 acre-feet is from ground-water seepage. Of the equal amount that leaves the lake, 380 acre-feet is by surface runoff, 8 acre-feet is by ground-water seepage, and 140 acre-feet is by evaporation. Based on these amounts of inflow and outflow, the theoretical water-renewal time of the lake is calculated to be 2.6 years, a relatively long time compared to that of most lakes in western Washington.

Hydrologically, Wilderness Lake functions like a large spring; most of the inflow is by ground-water seepage and spring flow and most of the outflow is by surface-water runoff. The amount of ground-water inflow to the lake is 45 times that of ground-water outflow. This is explained, at least in part, by the facts that inflow occurs over an area more than twice as large as that of outflow, and that some of the inflow is through submerged springs that are capable of transmitting large amounts of water.

Although the potential sources of nutrients to the lake include precipitation, ground-water inflow, storm runoff, ducks, swimmers, fallen leaves, and boating activity, only the sampling of precipitation and ground-water inflow fell within the scope of this investigation. However, a calculation was made of the expected nutrient concentrations and loads from septic tanks that serve private residences near the lake. In addition, it was found that the septic tanks which serve the park and education center, and which were suspected of contributing large amounts of nutrients to the lake are, in fact, downgradient of the lake and therefore cannot contribute nutrients to it.

The contributions of nitrogen and phosphorus to the lake from precipitation are about 46 kg nitrogen and 2.4 kg phosphorus per year. Natural ground water annually adds about 220 and 6.7 kg of nitrogen and phosphorus, respectively. Under existing cultural and hydrologic conditions, residential septic tanks can be expected to annually contribute about 650 kg nitrogen and 29 kg phosphorus. The combined annual nutrient loads from precipitation, natural ground water, and septic-tank leachate were determined to be 920 kg of nitrogen and 38 kg of phosphorus. Nutrient contributions from other sources which were not assessed, such as ducks, swimmers, and local "urban" runoff, would increase the loads beyond the observed values.

The loads determined above, combined with the relatively long water-renewal time, help explain the advanced trophic state of the lake described by previous investigators.

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