HYDROLOGIC BUDGET FOR EAGLE LAKE NEAR WILLMAR, MINNESOTA

U. S. GEOLOGICAL SURVEY

Open—File Report 80—163

Prepared in cooperation with
Minnesota Department of Natural Resources

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By C. F. Myette

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FACTORS FOR CONVERTING INCH-POUND UNITS TO SI UNITS

Multiply inch-pound unit	By	To obtain SI unit
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4.047	hectare
acre-foot (acre-ft)	1233	cubic meter (m^3)

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ABSTRACT

Eagle Lake occupies 890 acres of a 9,000-acre watershed in central Minnesota. Because of its proximity to Willmar, many homes and summer cabins have been built around the lake. At present (1978), the shore is more than 90 percent developed. One effect of this development is accelerated eutrophication, most commonly shown by algae blooms.

An annual hydrologic budget for Eagle Lake was prepared for the 1978 water year in support of a nutrient study prepared by the University of Minnesota at Morris. Results show that the amount of water that flowed through Eagle Lake in the 1978 water year was 6,670 acre-feet. Inflow to the lake was 45 percent surface water, 22 percent ground water, and 33 percent precipitation. Outflow was 73 percent surface water, 25 percent evaporation, and slightly greater than 2 percent net change in lake storage.

Estimates for the ground-water component were derived both as a residual in the hydrologic-budget equation and by flow-net analyses. The residual value of 1,450 acre-feet compared favorably with the flow-net value of 1,400 acre-feet.

INTRODUCTION

As urban development continues, greater stress is placed on previously undeveloped areas near metropolitan centers. This stress may be expressed in lakes and wetlands by accelerated eutrophication, an increase in mineral and organic nutrients that can have undesirable effects such as algal blooms, which produce unsightly and foul-smelling water.

Eagle Lake at present (1978) has nearly 250 permanent residences, an increase of nearly 100 since 1972 (Straw and others, 1976). In addition, there are 50 seasonal homes and 6 commercial units at the lake. Before June 1974, all domestic wastes in the Eagle Lake area were treated by on-site disposal systems. These systems generally consisted of septic tanks and drainfields. The proximity of the homesites to the lake increases the potential for discharge of sewage into the lake, which increases the nutrient supply. This situation prompted the Eagle Lake Pollution Control Project "Bench Mark Studies" to determine the baseline water-quality and hydrologic conditions before construction of a proposed peripheral sewage-collection system. The sewage-collection system was completed in June 1974, and all units surrounding the lake were connected to it.

Purpose and Scope

This study of the hydrologic budget was made by the U.S. Geological Survey in cooperation with the Minnesota Department of Natural Resources and the University of Minnesota at Morris. Its purpose was to determine the budget for Eagle Lake for the 1978 water year. This report presents the equation from which the budget was derived and the method of determining values for each component of the equation. Data from this study will be used in conjunction with data from a concurrent water-quality study of the lake by the University of Minnesota at Morris. The combined data will be used to assess general water-quality changes since a study by Straw and others (1976).

Location of Area

Eagle Lake is in Kandiyohi County, in central Minnesota, 5 miles north of Willmar (fig. 1). The lake covers 890 acres of its 9,000-acre watershed. Drainage is southward through Hawk Creek to the Minnesota River near Granite Falls.

Previous Investigations

Early studies of the geologic features and geohydrology are described by Winchell and Upham (1888) and Hall and others (1911), respectively. The area has been included in regional studies by Thiel (1944) and Sims and Morey (1972). Van Voast, Broussard, and Wheat (1972) describe the water resources of the Minnesota River - Hawk Creek watersheds. The most recent studies pertaining to water quality are presented by Straw and others (1976) and Latterell and others (1979).

GEOLOGIC SETTING

Rocks underlying the Eagle Lake watershed are of Precambrian, Cretaceous, and Quaternary ages (Sims and Morey, 1972).

The Precambrian rocks form a basement complex of crystalline granite and mica schist (Thiel, 1944). The upper surface of the complex has weathered to a soft kaolinitic clay that is white where it overlies granite and grayish green where it overlies schist (Thiel, 1944).

A relatively thin layer (less than 100 feet) of sedimentary rocks of Cretaceous age overlies the Precambrian rocks (Hall and others, 1911). The Cretaceous rocks are generally soft varicolored shale interbedded with poorly consolidated or loosely cemented siltstone and sandstone.

Glacial drift of Quaternary age overlies the Cretaceous rocks and crops out as shown in figure 2. The drift was deposited during the pre-Wisconsin (more than 35,000 years ago) and Wisconsin (20,000 to 11,000 years ago) Glaciations (Sims and Morey, 1972). The drift ranges in thickness from about 100 to 300 feet and consists largely of (1) till, an

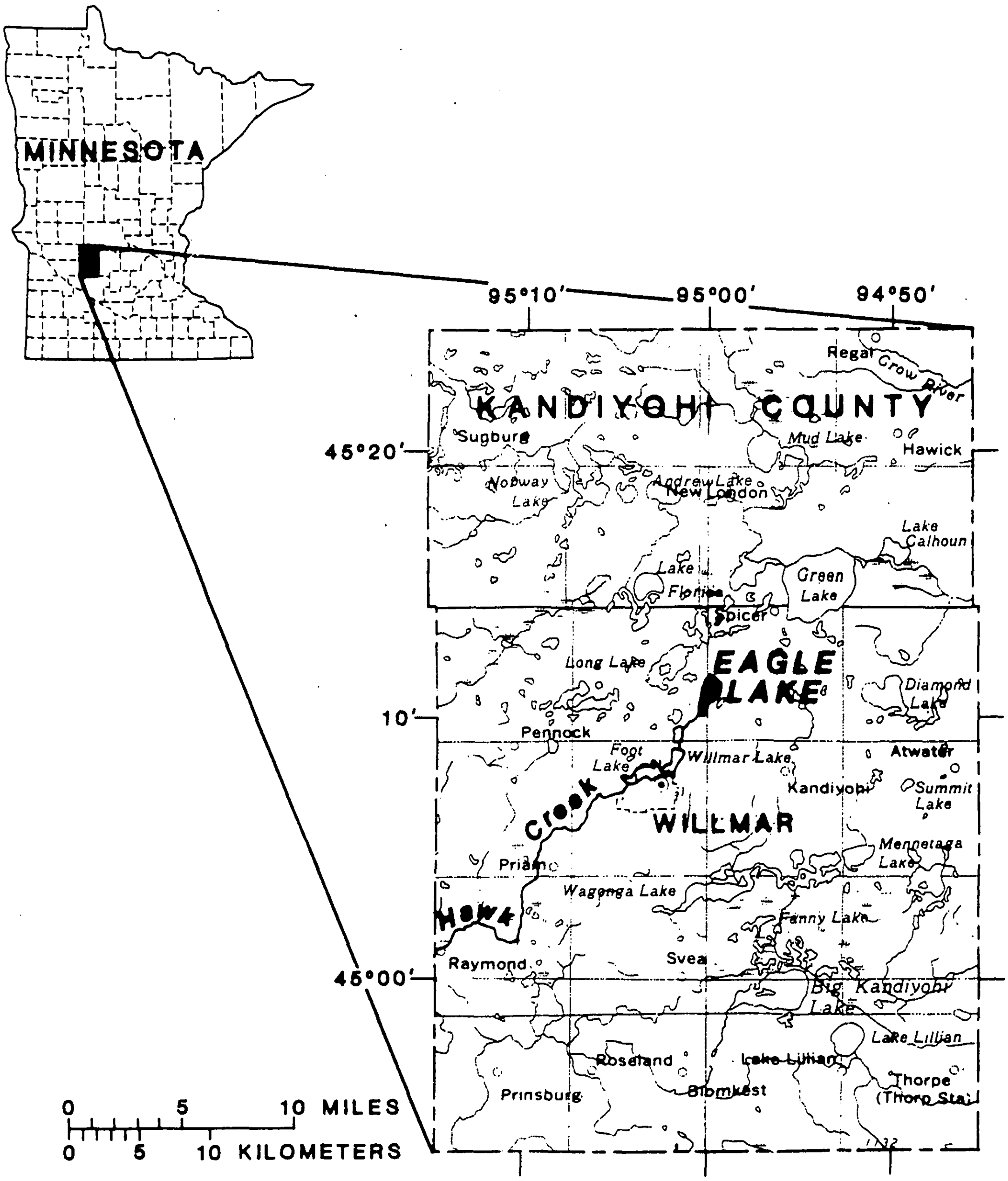

Figure 1.--Index map showing location of Eagle Lake

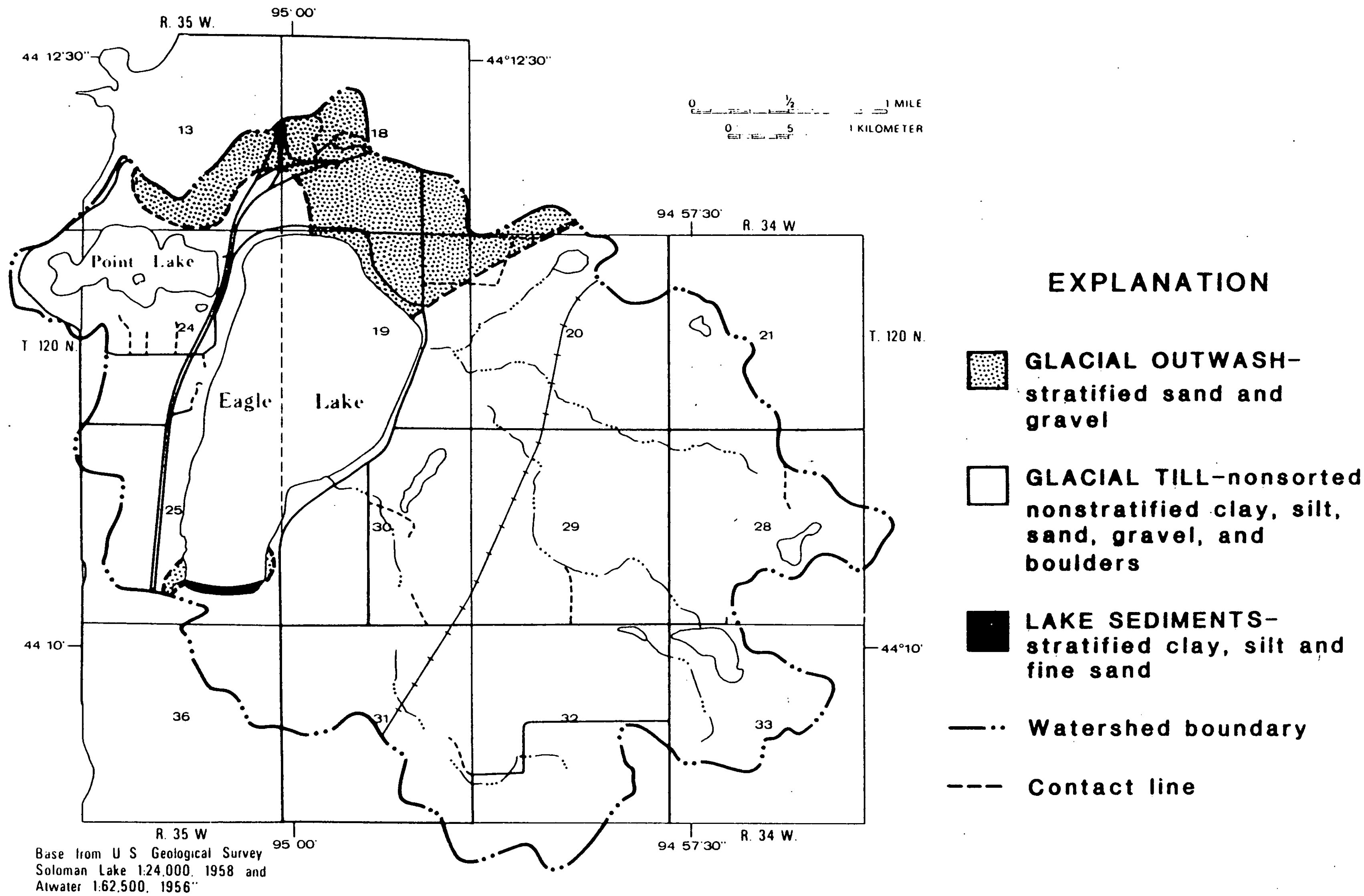

Figure 2.--Generalized surficial deposits of Eagle Lake drainage area

unstratified, unsorted mixture of sand and rock particles ranging from very fine-grained sand to boulders imbedded in a silty clay matrix and (2) stratified sand and gravel deposits of outwash or ice-contact origin. Lake sediments of Quaternary age are about 25 feet thick near the lake outlet and consist primarily of clay, silt, and shell fragments.

METHODS OF INVESTIGATION

Water-resources data were collected during the 1978 water year, extending from October 1, 1977, through September 31, 1978. The components of the budget are presented in table 1.

Hydrologic-Budget Equation

Calculations for the budget were made using the equation:

$$\Delta S = S_I + P \pm \Delta GW - S_O - E \qquad (1)$$

Where: ΔS = Change in surface-water storage,

S_I = Surface-water inflow,

P = Precipitation,

ΔGW = Net ground-water change, ground-water inflow minus ground-water outflow,

S_O = Surface-water outflow,

E = Evaporation.

It should be noted that each component of the budget has inherent errors of estimation due to areal or regional distribution, instrumentation, contouring, or periodic sampling. The components of the budget are presented herein along with descriptions of the methodology used to derive them. Stream and ground-water flow include additional specialized errors that are not inherent in the other components.

Streamflow may have errors introduced by statistical methods of estimates, such as estimates based on stream-rating curves and estimates based on correlation of streams with similar drainage characteristics.

The ground-water component is subject to variability owing to judgment used by various individuals in deriving values for aquifer properties such as hydraulic conductivity and transmissivity. Because these values are based on interpretations of drillers' logs and grain-size analyses, estimates of errors with this type of variability become nearly impossible to assess.

Data for this report are insufficient to estimate the percent of error in each component. However, T. C. Winter (written commun., Sept. 1979) states that errors in hydrologic budgets can range from 5 to 30 percent.

Table 1.--Approximate hydrologic budget for Eagle Lake, 1978 water year
[Units are acre-feet]

Component	Symbol	Annual value
INFLOW TO LAKE		
Surface water.................	SI	3,040
Precipitation.................	P	2,180
Net ground-water change.......	ΔGW	1,450
Total...		6,670
OUTFLOW FROM LAKE		
Surface water.................	SO	4,860
Evaporation...................	E	1,650
Change in lake storage........	ΔS	160
Total...		6,670
Total inflow minus total outflow..........................		0

Streamflow (inflow plus outflow)

Stream discharge was measured monthly during 1978 at 11 inflow sites and 1 outflow site (fig. 3). The measurements were used in developing stage-discharge rating curves for each site. Stream stages at these sites were measured daily from April 25 through September 31, and daily flows for the period were determined from the rating curves. Daily stream discharges were estimated for the period between October 1, 1977, to April 25, 1978, when only monthly discharge measurements were made. Estimates were made by regression analysis correlations with previous records (U.S. Geological Survey, 1973) for these and nearby stations which have similar streamflow characteristics based on drainage area, geologic setting and climatic conditions. Monthly and annual streamflow volumes were calculated in acre-feet (1 foot of water covering 1 acre).

Precipitation and Evaporation

Daily precipitation and evaporation data were obtained from records at the National Oceanic and Atmospheric Administration weather station at Willmar (assumed to be the same at Eagle Lake). Fall and winter evaporation data were not collected at Willmar; therefore, additional data were obtained from the Lamberton Experimental Station at Morris, Minn., 50 miles west-northwest of Willmar. Pan evaporation data were multiplied by 0.7, a coefficient recommended by the Subcommittee on Evaporation of the Special Committee on Irrigation Hydraulics, of the American Society of Civil Engineers (Wisler and Brater, 1954).

Change in Lake Storage

Change in volume of the lake was calculated by multiplying monthly measurements of lake stage by the surface area of the lake. The surface-area values are derived from the bathymetric map produced by the Minnesota Department of Natural Resources.

Net Ground-Water Change

Net changes in ground-water flow were calculated as the residual to balance equation (1). This residual includes all errors of estimation of the other budget parameters. This ground-water flow estimate was compared with ground-water flow rates calculated by flow-net analyses.

Ground water derived as a residual for the budget contains the summation of errors of each component within the equation. Therefore, caution must be exercized when utilizing this value.

The following factors are considered in estimating ground-water flow:

1. permeability of geologic units,

2. change in head (water table) with time,

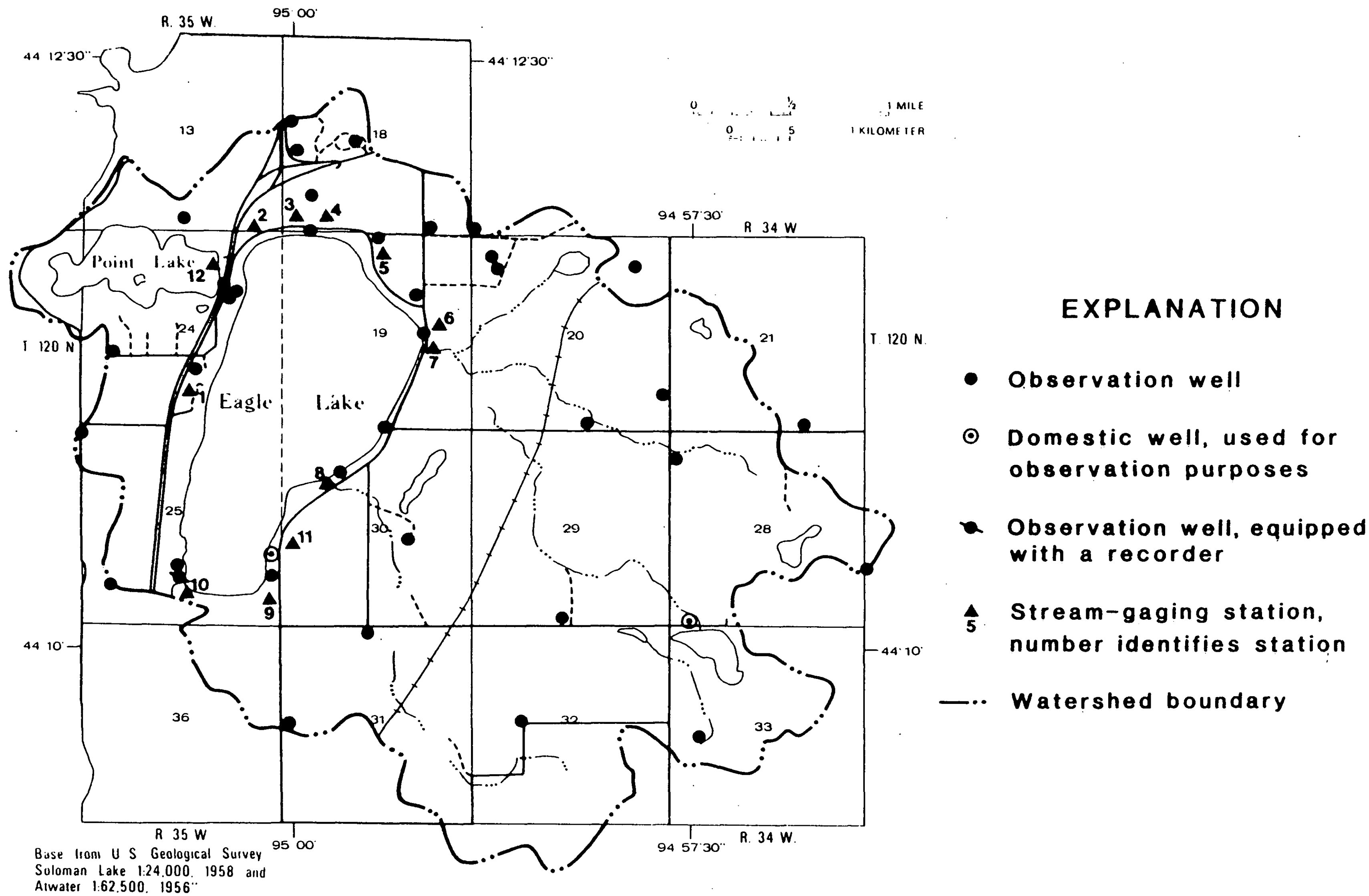

Figure 3.--Observation well and stream-gaging network

3. flow patterns, including flow entering and leaving the lake.

Data collected from well logs and test holes indicate that the permeable outwash and ice-contact sand and gravel deposits on the north and part of the south ends of Eagle Lake are hydrologically significant; most ground water entering the lake comes from these deposits. The small amount of ground water, estimated to be about 2 percent, that is transmitted to the lake from clayey till in the remaining part of the watershed can be ignored.

The configuration of the water table was determined from monthly measurements of water levels in 41 observation wells (fig. 3). A representative configuration of the water-table surface determined from measurements in November 1977 is shown in figure 4. Similar maps were drawn for each month to determine changes in head, gradient, and saturated thickness. Saturated thickness is the vertical distance between the water table and the base of the aquifer (commonly till).

Flow-net analyses are based on the assumption that the direction of ground-water flow (shown by arrows on figure 4) is from a high head or recharge area to a low head or discharge area and at right angles to the water-table contour lines (Heath and Trainer, 1968). A change in the configuration of a flow net may reflect differences in head, permeability, saturated thickness, and (or) recharge-discharge rates (Cedergren, 1967). Flow nets were constructed from monthly water-level measurements. Ground-water flow to the lake was calculated for each month of the water year to account for the seasonal variation by the following form of Darcy's Law:

$$Q = KA\frac{(\Delta h)}{L} \qquad (2)$$

Where: Q = Volumetric flow rate, gallons per day,

K = Hydraulic conductivity, gallons per day per square foot, (value estimated on the basis of grain-size distribution of lithologic samples from test holes),

A = Area of a vertical section through the aquifer, square foot; obtained as a product of the width of the section measured along the contour line, and the average saturated thickness along the contour,

h = Difference in altitude of two adjacent contours, feet,

L = Distance between two adjacent contours, feet.

The monthly data were then used to calculate an annual approximation which was compared to ground water derived as the residual for the hydrologic equation.

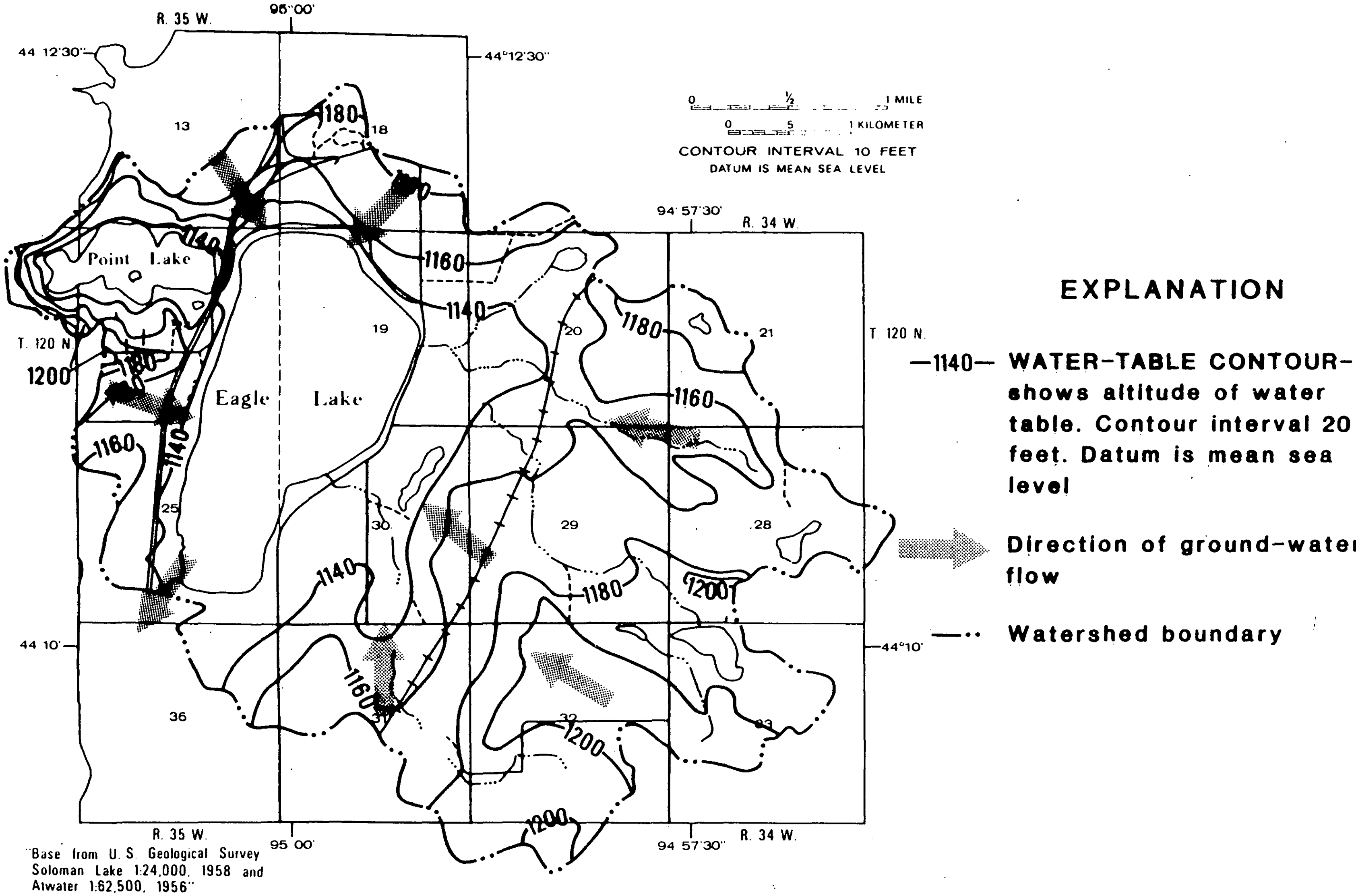

Figure 4.--Water-table surface and generalized direction of ground-water flow of the surficial deposits, November 1977

RESULTS OF STUDY

The following is the calculated volume of flow for each element of the hydrologic budget and the percentage of the total budget it represents:

1. Surface-water inflow equaled 3,040 acre-feet, 45 percent of the total inflow to the lake.

2. Precipitation equaled 2,180 acre-feet, 33 percent of the total inflow to the lake.

3. Net ground-water flow equaled 1,450 acre-feet, 22 percent of the total inflow to the lake.

4. Surface-water outflow equaled 4,860 acre-feet, 73 percent of the total water leaving the lake.

5. Evaporation equaled 1,650 acre-feet or 25 percent of the total water leaving the lake.

6. Change in lake storage accounted for 160 acre-feet, 2 percent of the total water leaving the lake.

The calculation by flow-net analyses of about 1,400 acre-feet for net ground-water change compares favorably with the 1,450 acre-feet of net ground-water change calculated as the residual needed to balance the hydrologic-budget equation.

SUMMARY

The surficial deposits underlying the Eagle Lake watershed are complex glacial deposits consisting of silt, clayey till, sand and gravel outwash, and sand and gravel ice-contact deposits. Ground-water seepage occurs primarily through sand and gravel at the north end of the lake and through silty sand at the outlet. The till surrounding most of the lake is of low permeability and can be treated as a zero-flow zone.

Inflow to Eagle Lake in the 1978 water year was approximately 6,670 acre-feet. Forty-five percent of that amount was surface-water inflow, 33 percent was precipitation, and 22 percent was net ground-water inflow. Outflow was 73 percent surface-water flow, 25 percent evaporation, and 2 percent change in lake storage. The net change was positive for the year; therefore, the lake contained 160 acre-feet more water at the end of the year than it had at the beginning.

Darcy's law was used to calculate theoretical ground-water discharge into and out of the lake. This approximation was used to compare and qualify ground-water flow derived as a residual within the annual hydrologic budget. Based on this equation, the calculated annual net change in ground-water flow to Eagle Lake (ground-water inflow minus ground-water

outflow) was about 1,400 acre-feet in 1978. This value compares favorably with a net annual ground-water change of 1,450 acre-feet derived as a residual of the hydrologic-budget equation.

The hydrologic budget determined in this study represents an approximation for water year 1978 only. Sizable errors are inherent in the components of the water budget determined by the methods outlined in this study. Therefore, any application of this budget to other periods of time must be made with caution because of the additional seasonal and annual variability in values of the terms of the budget equation.

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