UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

HYDROLOGIC SETTING OF WILLIAMS LAKE, HUBBARD COUNTY, MINNESOTA

By D. I. Siegel and T. C. Winter

Open-File Report 80-403

Prepared in cooperation with

Minnesota Department of Natural Resources

Division of Waters

St. Paul, Minnesota

1980

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For the convenience of those readers who prefer to use International System (metric) units rather than inch-pound units, the conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.093	square meter (m^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
foot per foot (ft/ft)	0.3048	meter per meter (m/m)

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada, formerly called "mean sea level". The datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts.

Brand names used in this report are for identification only and do not represent endorsement of the product by the U.S. Geological Survey.

HYDROLOGIC SETTING OF WILLIAMS LAKE,
HUBBARD COUNTY, MINNESOTA

---

by D. I. Siegel and T. C. Winter

ABSTRACT

The hydrology and geology of Williams Lake watershed was studied to evaluate the accuracy of various methods used to determine precipitation and evaporation in lake water-balance studies and to define a lake and ground-water system according to approaches suggested by theoretical modeling studies. Regression analysis between estimated and measured precipitation at the lake showed that the accuracy of regionalization techniques is dependent on the closeness of the data network to the lake. For individual storms, the average-value method was found to be better than either the weighted average or isohyetal methods of determining precipitation, but it was least accurate in estimating 14-day average precipitation. The amount of evaporation calculated by the mass-transfer method ranged from 2 to 7 inches per month from July to October 1978, depending on the method used to determine the mass-transfer coefficient. Test drilling indicated that 30 to 150 feet of sand and gravel overlies till in the Williams Lake watershed. A sand lens about 50 feet thick occurs within the till.

The configuration of the water table and vertical-head gradients measured from July to December 1978 indicate that ground water moves into the lake from the south and east and moves from the lake into the ground-water reservoir to the west. Preliminary numerical models indicate that the sand lens within the till is effectively isolated from the flow system interacting with the lake and that both inseepage and outseepage were about 1.4 inches from mid-July to mid-October 1978. When estimated as a residual in a water balance, ground water showed a net outseepage only of 1.47 inches.

INTRODUCTION

Background

The number of lakes that have water-quality and water-level fluctuation problems is increasing in Minnesota and throughout the nation because of the increasing use of lakes for their economic, recreational, and aesthetic values. To deal with these problems, government agencies are investing increasing amounts of time and money on lake management and restoration projects. High-quality hydrologic information is basic to the preparation of nutrient budgets, which are commonly used to determine the extent of lake deterioration and the success of management and restoration projects.

A lack of understanding of hydrologic processes as they relate to lakes has led to inadequate instrumentation and analyses of data. This has resulted in inaccurate and misleading water and nutrient budgets, particularly in evaluation of the ground-water component of the budget studies.

To better understand the role of lakes in the hydrologic system, the U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources, recently began a program of theoretical and field studies of lake hydrology. The initial phases of the program involved numerical simulation of theoretical ground-water flow patterns in the vicinity of hypothetical lakes. After analyses of a wide variety of hypothetical lake and ground-water settings in both two dimensions (Winter, 1976; 1978a) and three-dimensions (Winter, 1978b), it became clear that experimental field sites were necessary to obtain realistic estimates of the temporal fluctuations and configuration of the water table, anisotropy of the geologic units, and geometry of the ground-water system. Field data from lakes are needed also to evaluate errors associated with different techniques of measuring the other components of the hydrologic system interacting with lakes, such as precipitation, evaporation, and streamflow.

Accordingly, the U.S. Geological Survey has identified eight general environments of natural lakes in the United States that have significantly different hydrogeologic and (or) climatic settings. At these sites, it is intended eventually to examine all hydrologic components interacting with the lakes, including associated chemical and biological aspects. One of the eight general lake environments, a lake in glacial drift and in a climatic setting where precipitation approximately equals lake evaporation, occurs in Minnesota and is the subject of this report.

Williams Lake, in north-central Minnesota (fig. 1), was selected from several because it met the following criteria:

1. The lake is in an area of thick drift. This condition maximizes the possibility of ground-water flow systems of different magnitude.

2. It is one of a series of lakes at sucessively lower altitudes on a regional topographic slope. This condition enables the study of movement of ground water between lakes.

3. It has no streams flowing in or out. This condition allows better evaluation of errors in measuring the ground-water and atmospheric-water components of lake water budgets.

4. It has a drainage basin relatively free of development.

5. It has cooperative property owners within the drainage basin, so the entire lake environment would be accessible for study.

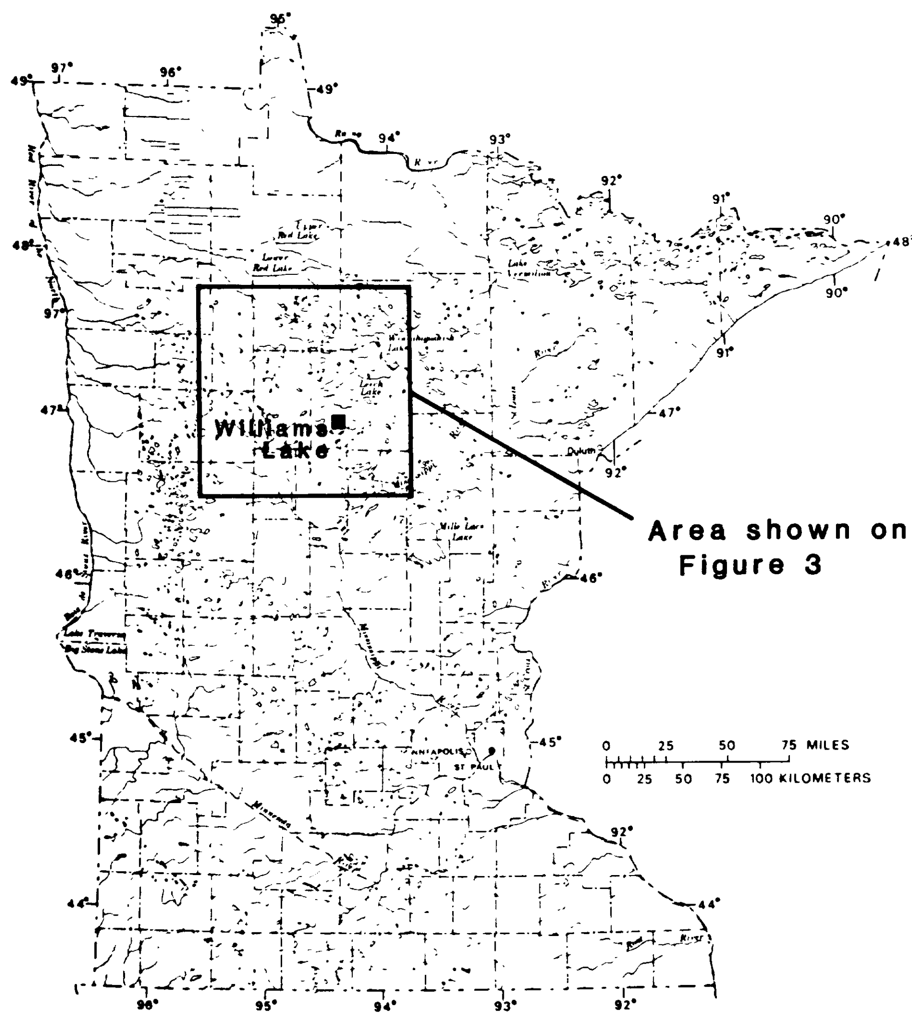


Figure 1.--Location of Williams Lake

Purpose and Scope

The overall purpose of the long-term hydrologic studies of Williams Lake is to define its interaction with all other components of the hydrologic system, to concentrate on the interaction of the lake and ground water according to new approaches suggested by theoretical modeling studies, and to evaluate the accuracy of various methods of determining all components of the hydrologic system interacting with the lake.

The purpose of this progress report, which covers the first year of the project, is to (1) describe the physiographic, soil, vegetation, hydrologic and climatic setting of Williams Lake, (2) describe the work during 1978, and (3) provide an example of the long-term study approach by analyzing data from mid-July to mid-October, 1978.

Acknowledgments

The Williams Lake watershed is nearly all privately owned; therefore, a study such as this is not possible without the cooperation of the landowners. We are indebted particularly to Ken Chase, who allowed us to test drill, construct wells, and place equipment on his property. Other property owners who allowed test drilling and well construction on their land include Lloyd Wallin, Charlie Minor, and Clifford Chase. Ken Chase and Charlie Minor also provided assistance in data collection.

Well and Test-Hole Numbering System

The method of numbering wells and test holes is based on the U.S. Bureau of Land Management's system of subdivision of public lands. The Williams Lake area is in the fifth principal meridian and base-line system. The first segment of a well or test-hole number indicates the township north of the base line; the second, the range west of the principal meridian; and the third, the section in which the well is situated. The lowercase letters a, b, c, and d, following the section number indicate the location of the well in the section. The first letter denotes the 160-acre tract, the second denotes the 40-acre tract, and the third denotes the 10-acre tract. The letters are assigned in a counterclockwise direction beginning with the northeast quarter. Consecutive numbers beginning with 1 are added as suffixes to distinguish wells within a given 10-acre tract. Figure 2 illustrates the method of numbering. Thus, the number 140.32.12ddbl identifies the first test hole or well in the NW1/4 SE1/4 SE1/4, sec. 12, T. 140 N., R. 32 W.

PHYSICAL SETTING

Location

Williams Lake is in southeastern Hubbard County, about 150 miles north-northwest of Minneapolis-St. Paul, and about 40 miles south-southeast of Bemidji (fig. 1). It lies mostly in the S1/2, sec. 12, T. 140 N., R. 32 W., and its south tip is in the SW1/4, SW1/4, SE1/4 of sec. 12.

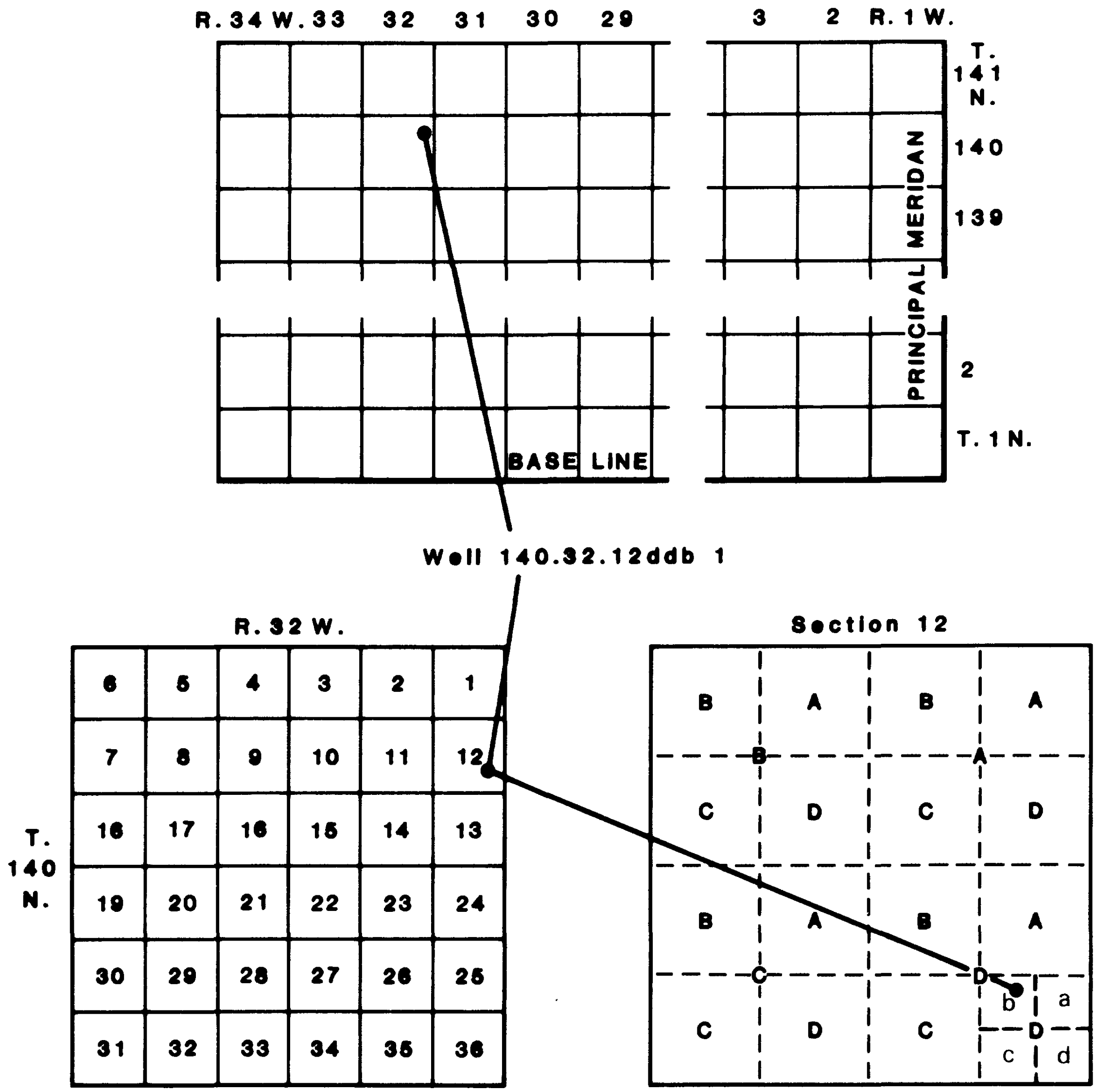


Figure 2.--Well and test-hole numbering system

Regional Physiographic Setting

Williams Lake is situated on a topographic ridge (fig. 3) that forms a major drainage divide between the Crow Wing and Mississippi River drainage systems (Minnesota Department of Conservation, Division of Waters, 1959). Although the Williams Lake watershed is on the south slope of the Itasca moraine complex (the east-west trending ridge where altitude is largely greater than 1,500 feet above the NGVD of 1929) it is separated from the highest part of the moraine by the lowland that lies at an altitude less than 1,300 feet (fig. 3).

Local relief is greater than 100 feet. The lake is about midway between Crystal Lake, which is about 14 feet higher, and Mary Lake, which is about 16 feet lower in altitude. Morphometric characteristics of Williams Lake are given in table 1.

The surficial geologic materials in the Williams Lake drainage basin are mostly sand and gravel. Although the Minnesota Soil Atlas (Arneman and others, 1969) shows Williams Lake on a small northern projection of the Park Rapids-Staples outwash plain (fig. 4), the local physiography is characteristic of ice-contact deposits.

The lake is 2 miles east and 3 miles south of the Itasca moraine, which was formed by the Wadena lobe of Wisconsin Glaciation and which consists largely of silty, sandy till. The Wadena lobe moved into Minnesota from the northwest. The St. Croix moraine, about 5 miles east of the lake, was deposited by ice that moved northwest out of the Lake Superior basin and consists of drift that is less calcareous than drift deposited by the Wadena lobe. The proximity to Williams Lake of these two drift types could conceivably have a bearing on the subsurface geology and ground-water quality in the vicinity of the lake.

Soils and Vegetation

The soils in the Williams Lake watershed (fig. 4) are sandy, poorly drained, and light colored (Arneman and others, 1969). Those of the nearby Itasca moraine complex are silty or loamy, well drained, and light colored.

Vegetation is characterized by a fairly continuous mixed coniferous-deciduous forest; the trees are nearly all second growth. Forest clearance occurred in the late 1800's, and parts of the forest within the lake's drainage basin were cut only a few years ago. A few openings in the forest northwest of the lake are covered by grasses and herbs.

General Climatic Setting

The climate is characterized by wide extremes of temperature from winter to summer. Mean monthly maximum temperatures for July are slightly higher than 80°F (Baker and Strub, 1965), whereas mean monthly

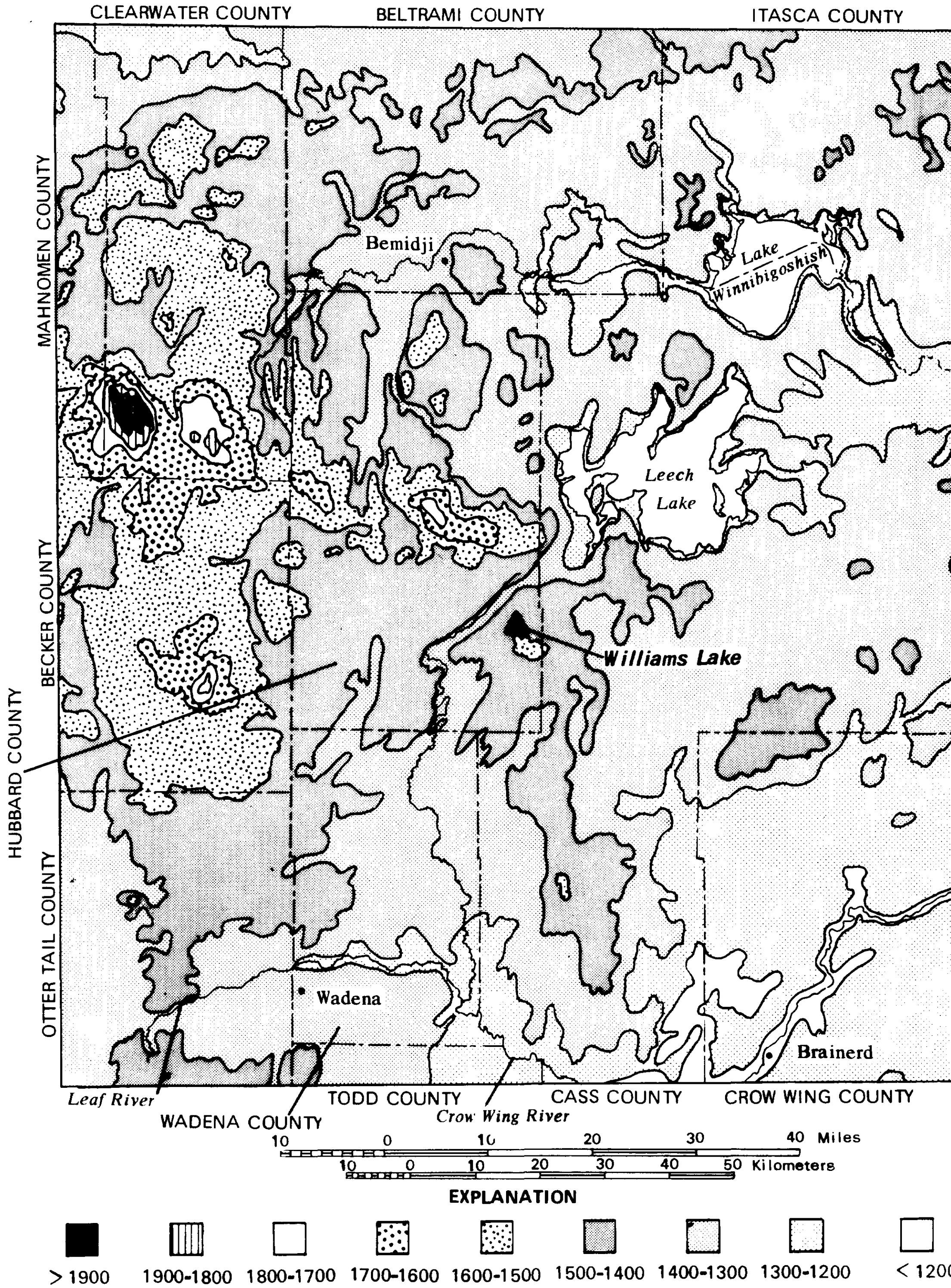


Figure 3.--Regional topographic setting of Williams Lake

Table 1.--Morphometric characteristics of Williams Lake

Surface area	=	90 acres
Drainage basin area	=	560 acres
Maximum depth	=	35 ± 3 feet
Mean depth	=	17 feet
Maximum length	=	3,220 feet
Orientation	=	NW - SE
Maximum width	=	1,740 feet
Mean width	=	1,240 feet
Volume	=	6.7×10^7 cubic feet
Development of volume	=	1.5
Length of shoreline	=	9,430 feet
Development of shoreline	=	1.3

Definitions:

$$\text{Mean depth} = \frac{\text{lake volume}}{\text{lake area}}$$

$$\text{Development of volume} = \frac{3(\text{mean depth})}{\text{maximum depth}}$$

$$\text{Development of shoreline} = \frac{\text{length of shoreline}}{2\sqrt{(\text{area of lake})}}$$

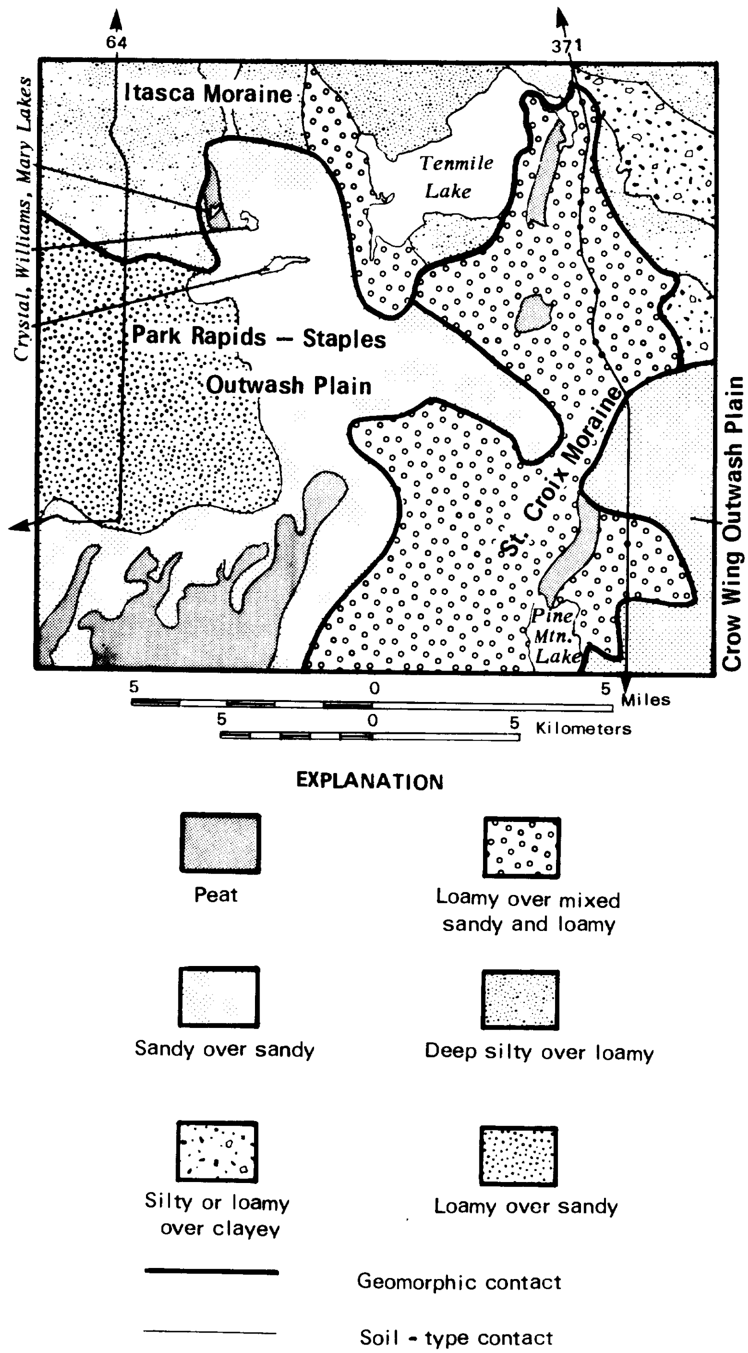


Figure 4.--Soil types and geomorphic features around Williams Lake

maximum temperatures for January are less than 20°F (National Atlas, 1970). Frost occurs about 8 months of the year, generally from September 21 to May 20 (Baker and Strub, 1963).

Long-term average precipitation is about 26 inches (Baker and Strub, 1967), and the ground is covered by more than 3 inches of snow during slightly more than 90 days. The average annual lake evaporation for the area, based on the period 1946-55, is about 26 inches (Kohler and others, 1959).

HYDROLOGY

Instrumentation

Atmospheric water

Although quantitative measurement of precipitation and evaporation will be emphasized later in the study, instrumentation to determine evaporation by the mass-transfer method was used from June to October 1978 to obtain preliminary data. Instrumentation to obtain concurrent data for both the mass-transfer and energy-budget methods will be installed and operated in 1979 and 1980. Locations of all instrumentation are shown on figure 5.

A Weathermeasure P501-I remote recording rain gage and P521 event recorder were used to monitor rainfall. The rain gage has a standard 8-inch-diameter orifice and a tipping-bucket mechanism. The buckets are calibrated to tip after each 0.01 inch of rainfall.

Climatic variables measured to estimate evaporation by the mass-transfer method include air temperature, lake-water surface temperature, humidity, and wind speed.

Air temperature and humidity were measured by a Belfort hygrothermograph, which records both variables on a single dual-channel chart. Air temperature was sensed by a bimetal assembly, and humidity was determined by the expansion or contraction of a human-hair element.

Temperature of the lake-water surface was recorded by a Marshalltown (Model 2200) recorder mounted on a raft near the middle of the lake. Windspeed was measured by a Belfort totalizing anemometer, also mounted on the raft, at a height approximately 7 feet above the water surface. The anemometer is also connected to the Marshalltown recorder, and every 10 miles of wind passage is recorded by a tic on the edge of the temperature chart.

The instruments were serviced weekly, when readings of air and water temperature were made with independent thermometers to adjust the recording instruments. Humidity was checked with a sling psychrometer during the weekly visits.

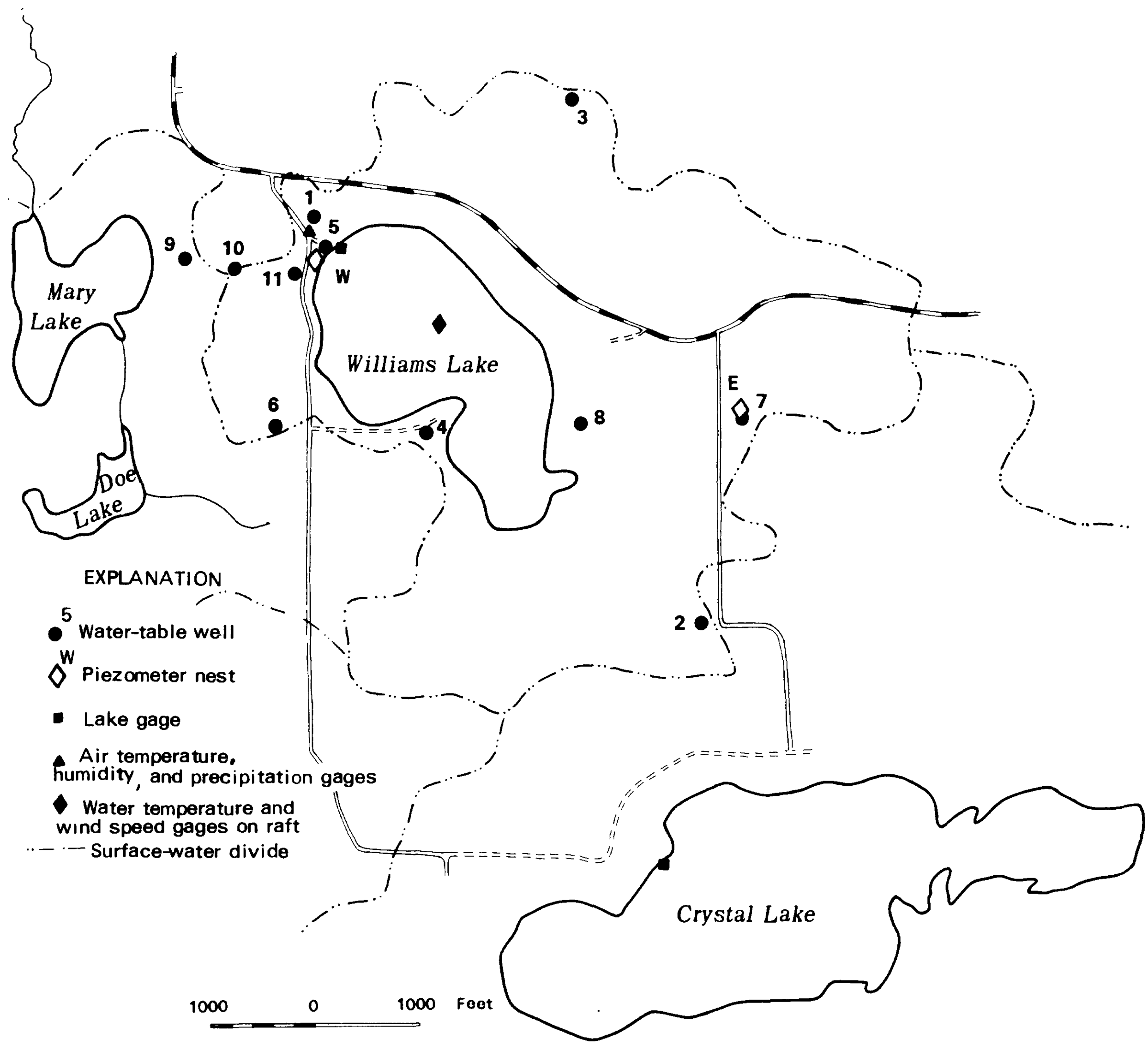


Figure 5.--Location of hydrologic instrumentation at Williams Lake

Surface water

Lake levels were measured daily from a staff gage from July 5 to September 14, 1978. A recording lake gage was constructed September 14, 1978, to continuously monitor lake stage throughout the year. The gage is a stilling-well type located on the lake shore (fig. 5) and equipped with an A-30 recorder.

Ground water

Eleven water-table wells and seven piezometers were installed at Williams Lake to determine the configuration of the water table and vertical potentiometric gradients. Thirteen test holes were drilled to determine the stratigraphy of the glacial materials underlying the watershed. Eleven of the test holes were drilled by auger to depths between 37 and 142 feet, and two test holes were drilled by rotary methods to depths of about 400 feet. Water-table wells were screened about 5 feet below the water table in the augered test holes or in holes drilled immediately adjacent to them. Near the northwest shore of the lake, piezometers were placed at depths of 40, 70, 100, 130, 180, and 299 feet to determine vertical head gradients. Similarily, a piezometer was placed next to and about 200 feet deeper than a water-table well on the eastern boundary of the watershed. Description of the lithologies penetrated by test holes and construction of the piezometers are given in table 2. Geophysical logs of the two deep test holes are given in figures 6 and 7.

The piezometers in each set, or "nest," were constructed with a petal basket (fig. 8), a device that aids grouting the well with cement, so there will be no interference of heads between the depth at which the screen is set and overying parts of the ground-water system. The piezometers were grouted in place with 40 to 60 feet of cement above the basket.

The coarse surficial materials encountered made it difficult to prevent caving of the drill hole during placement of the casing and petal basket. Ten to 15 feet of coarse sand filled the hole above the petal baskets in piezometers WLN-70 and WLN-100 before grouting could be completed.

Piezometers deeper than 100 feet were constructed with 2-inch steel casing. Shallower piezometers were constructed with 1 1/4-inch schedule-80 PVC pipe.

Cores of lake sediment were taken along an east-west traverse of Williams Lake (fig. 9) to determine the thickness and general distribution of the organic material on the lake bottom and for use in future limnological and geochemical studies. Organic, gelatinous sediment (gyttja) is about 20 feet thick near the center of the lake. Along the western shore, about 3 feet of marly sediment overlies medium to

Table 2.--Test hole, water-table well (WT), and piezometer (P) construction data

Location (1)	Well number (2)	Type of well (3)	Total depth of test hole below land surface, in feet (4)	Screen length, in feet (5)	Total depth of well below land surface, in feet (6)	Height of casing above land surface, in feet (7)	Altitude at land surface, in feet (8)	Lithology (9)	Depth below land surface, in feet (10)
140.32.12bca[1]	WL-1	WT	107	2	62	3.1	1425.29	Sand; brown, fine, medium to well sorted.	0-14
								Sand; brown, fine to medium, silty, some gravel.	14-17
								Sand; brown, fine.	17-42
								Sand; brown; fine, silty, some gravel.	42-62
								Sand; gray, medium to fine, some coarse sand, uniform and clean.	62-107
140.32.13aaa	WL-2	WT	82	2	82	4.2	1452.44	Sand; brown, fine to very fine, some medium to coarse, some gravel and silt.	0-45
								Sand; brown, fine to very fine, some medium to coarse, some gravel.	45-82

1 Well placed in new hole 62 feet deep, next to 107-foot test hole.

Table 2.--Test hole, water-table well (WT), and piezometer (P) construction data--Continued

Location (1)	Well number (2)	Type of well (3)	Total depth of test hole below land surface, in feet (4)	Screen length, in feet (5)	Total depth of well below land surface, in feet (6)	Height of casing above land surface, in feet (7)	Altitude at land surface, in feet (8)	Lithology (9)	Depth below land surface, in feet (10)
140.32.12aba	WL-3	WT	142	2	124	4.0	1487.65	Sand; brown, medium to coarse.	0-22
								Sand; brown, medium to coarse, some large gravel.	22-52
								Sand; brown, medium to coarse, some gravel and pebbles.	
140.32.12cad	WL-4	WT	112	3	52	4.0	1412.31	Sand; brown, medium to coarse, silty, some lenses slightly coarser.	0-112
								Till; contains silty clay.	112
140.32.12bbd1	WL-5	WT	102	3	15.8	4.5	1383.24	Sand; gray, medium to coarse, medium to well sorted.	0-12
								Sand; greenish gray, medium to coarse, "slushy", poorly sorted, silty.	12-97
								Till; gray, clayey, silty, sharp contact.	97

140.32.12cbd	WL-6	WT	42	3	32.0	4.0	1401.07	Sand; brown, silty, fine.	0-27
								Sand; gray, silty, some clay.	27-42
140.31.7 cbc	WL-7	WT	137	2	128.3	4.0	1497.05	Sand; brown, some pebbles.	0-22
								Sand; brown, medium to coarse, well sorted.	22-57
								Sand; brown, medium to coarse, some coarse to very coarse, pebble size.	57-72
								Sand; brown, medium to coarse, silty.	72-137
140.32.12dbd[1]	WL-8	WT	57	3	25	4.0	1395.77	Sand; brown, medium to coarse, clean.	0-25
								Sand; gray, medium to coarse, silty.	25-34
								Till; sandy silt mixed with granules, more clayey with depth.	34-57

[1] Well placed next to test hole.

Table 2.--Test hole, water-table well (WT), and piezometer (P) construction data--Continued

Location (1)	Well number (2)	Type of well (3)	Total depth of test hole below land surface, in feet (4)	Screen length, in feet (5)	Total depth of well below land surface, in feet (6)	Height of casing above land surface, in feet (7)	Altitude at land surface, in feet (8)	Lithology (9)	Depth below land surface, in feet (10)
140.32.12bcc	WL-9	WT	74	3	46.1	4.0	1409.28	Sand; dark brown, silty, medium to coarse, some pebbles at top.	0-12
								Sand; light brown, very well sorted, medium to fine.	12-27
								Sand; brown to gray, coarse to granule sized, little silt.	27-74
140.32.12bcc[1]	WL-10	WT	132	3	54.3	4.0	1422.47	Sand; light brown, medium to fine, well sorted.	0-17
								Sand; light brown, medium to fine.	17-47
								Sand; gray, coarse to very coarse, no silt.	47-132

140.32.12bcd[2]	WL-11	WT	37	2	36.4	4.0	1403.29	Sand; dark brown, medium, silty, some clay.	0-7
								Silt; dark brown, clayey.	7-22
								Sand; gray, medium to fine.	22-37
140.32.12bdd2[3]	WLN-299	P	418	4	299	4.0	1489.28	Sand and gravel, brown to gray.	0-133
								Till; gray, clayey.	133-150
								Sand and gravel, gray.	150-178
								Till; gray, clayey.	178-248
								Sand and gravel, gray.	248-253
								Till; gray, clayey.	253-269
								Sand and gravel, gray.	269-312
								Till; gray clayey, interbedded with lenses of sandy till.	312-418

1 Well is in test hole which caved in at 52 feet.
2 Well placed in new hole 16 feet deep.
3 Well placed in new hole drilled adjacent to the test hole.

Table 2.--Test hole, water-table well (WT), and piezometer (P) construction data--Continued

Location (1)	Well number (2)	Type of well (3)	Total depth of test hole below land surface, in feet (4)	Screen length, in feet (5)	Total depth of well below land surface, in feet (6)	Height of casing above land surface, in feet (7)	Altitude at land surface, in feet (8)	Lithology (9)	Depth below land surface, in feet (10)
140.31.7cbc[1]	WL-12	P	400	4	344	4.5	1488.78	Sand and gravel, brown to gray, clean.	0-157
								Till; gray, silty.	157-193
								Till; gray to brown, sandy.	193-237
								Sand; brown, medium to coarse.	237-242
								Till; gray, silty.	242-250
								Sand; gray, medium to very coarse.	250-273
								Till; gray, clayey.	273-285
								Sand; gray, silty.	285-300
								Till; gray, silty.	300-345
								Till; gray, clayey.	345-360
								Till; red, clayey.	360-374
								Till; gray, sandy.	374-390
								Till; gray, clayey.	390-400

140.32.12bdd3 WLN-180	P	180	1	180	4.0	1394.49	—	—
140.32.12bdd4 WLN-130	P	130	1	130	4.4	1396.124	—	—
140.32.12bdd5 WLN-100	P	100	1	100	4.0	1395.62	—	—
140.32.12bdd6 WLN- 70	P	70	2	70	4.0	1395.86	—	—
140.32.12bdd7 WLN- 40	P	40	1	40	4.0	1399.18	—	—

[1] The bottom 56 feet of the test hole were grouted prior to the well installation.

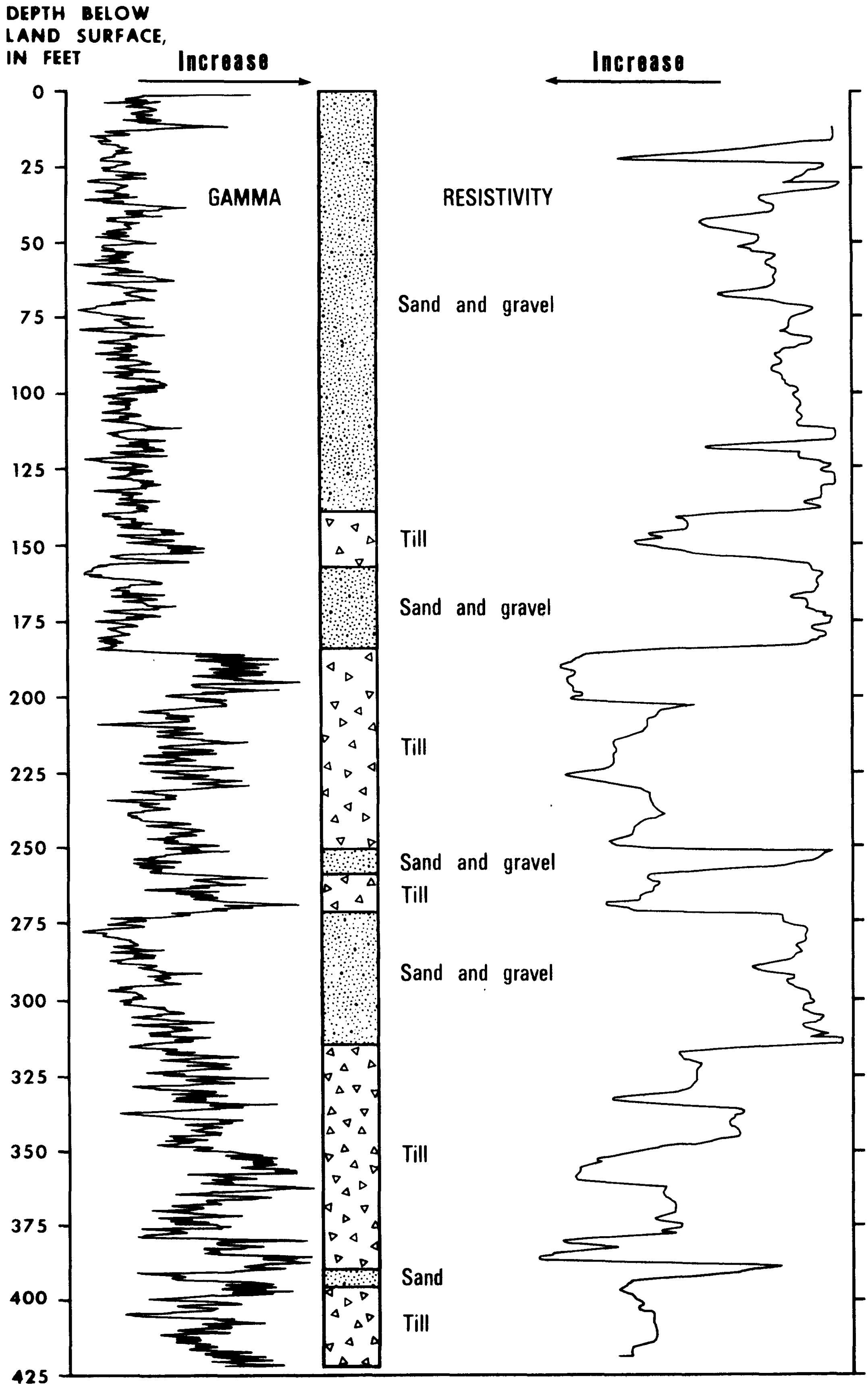


Figure 6.--Geophysical and lithologic logs of test hole WLN-299

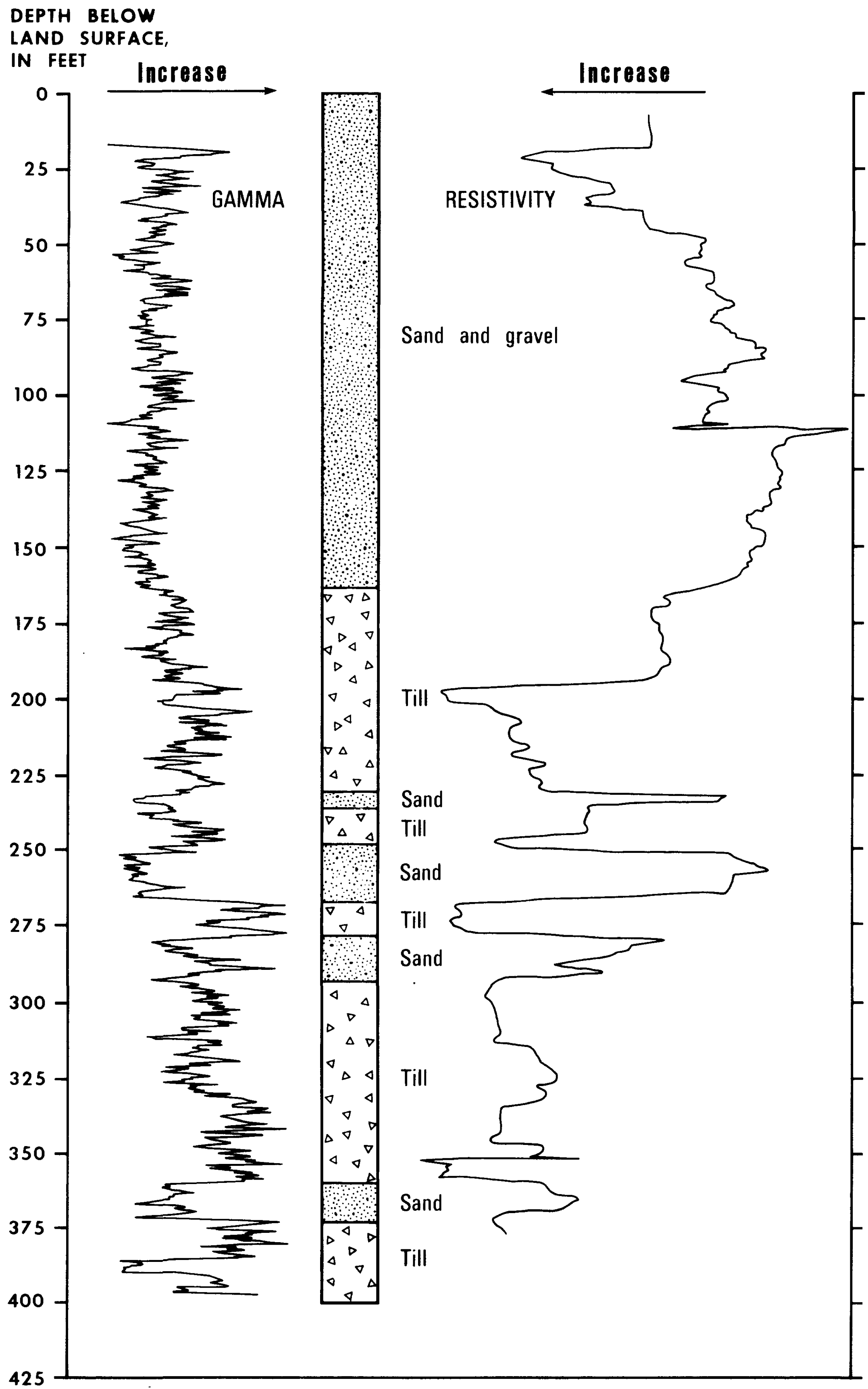
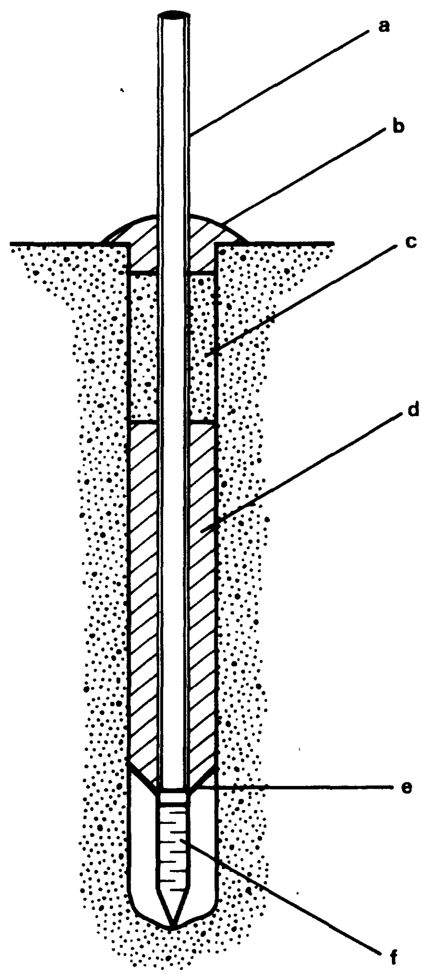


Figure 7.--Geophysical and lithologic logs of test hole WL-12



EXPLANATION

a Casing above ground

b Cement plug above backfill

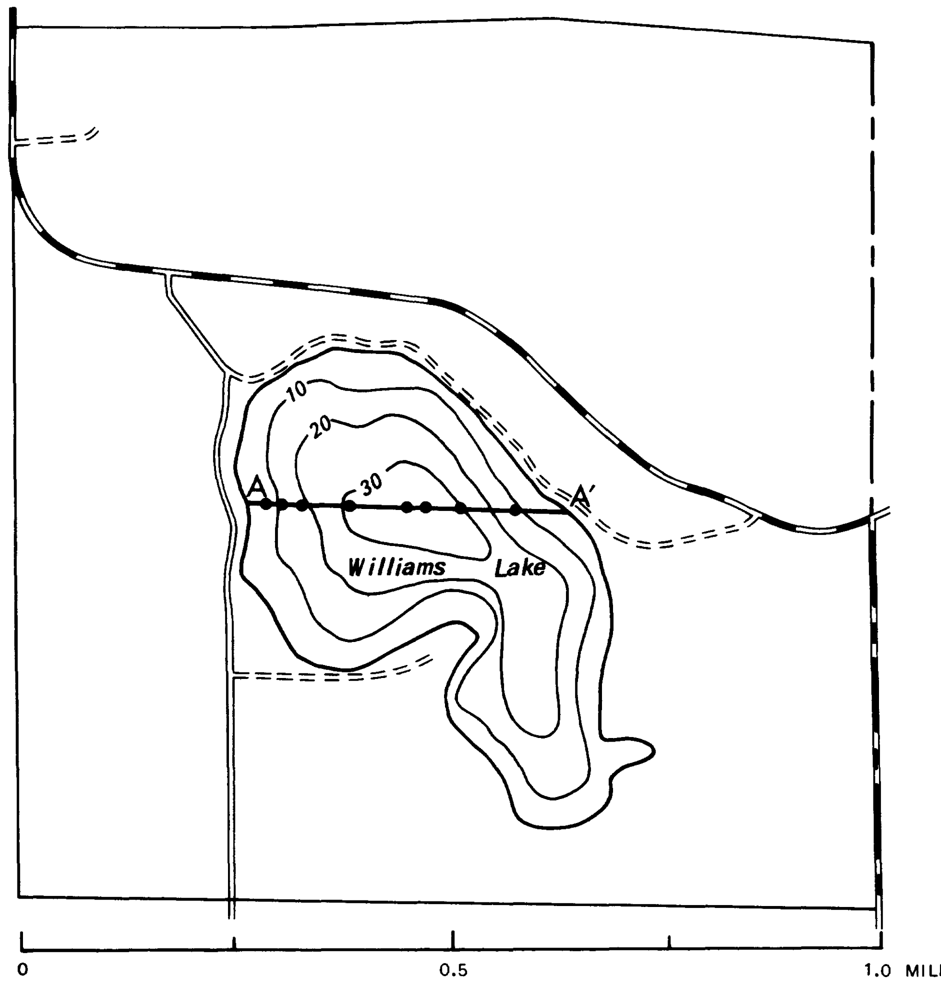
c Backfill

d Cement grout on top of petal basket

e Petal basket

f Screen

Figure 8.--Diagram showing piezometer construction



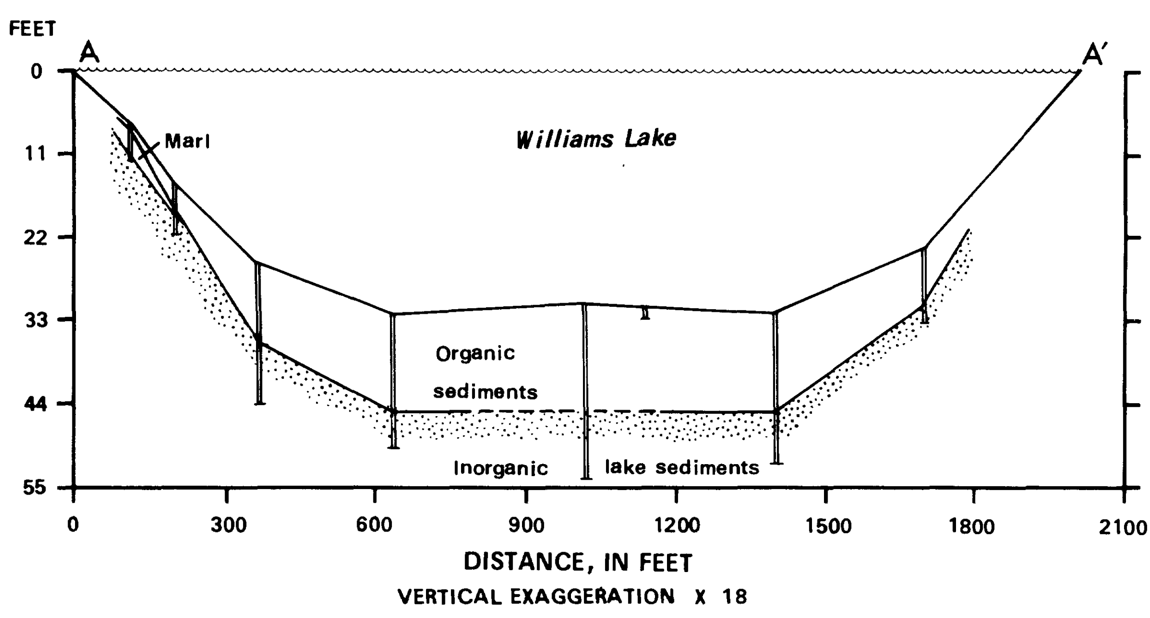


Figure 9.--Map and geologic section of sediments underlying Williams Lake

coarse sand. Sediments below the gyttja are interbedded silt, sand, and clay. The contact between the edges of the gyttja and marly sediments has not yet been mapped, so the width of the wave-washed littoral zone is not accurately known.

Altitudes of measuring points

The altitude of all wells and lake gages above an arbitrary datum were determined by use of a continuous level line from the benchmark well (WLN-299).

A common practice in determining altitudes of measuring points in lake studies is to consider the lake surface itself as a level plane of reference. Levels are run from the lake surface to various points around the lake. To test the assumption of a level lake surface, first order levels were run on a relatively calm day from the lake shore to two selected wells. These were then compared to the altitudes determined from the continuous line. The levels differed by 0.12 foot at well 8, across the lake from the bench-mark well (WLN199), and by 0.01 foot at well 4, on the same side of the lake as the bench-mark well.

It is probable that the pile up of water on the downwind side of Williams Lake may have caused the difference in altitudes. The difference of 0.12 foot observed at well 8 suggests that the assumption that lake surfaces are level may lead to large errors, even on relatively calm days. Error in determining altitudes by this method increases as larger lakes are considered and as the roughness of the lake surface (wind effect) increases.

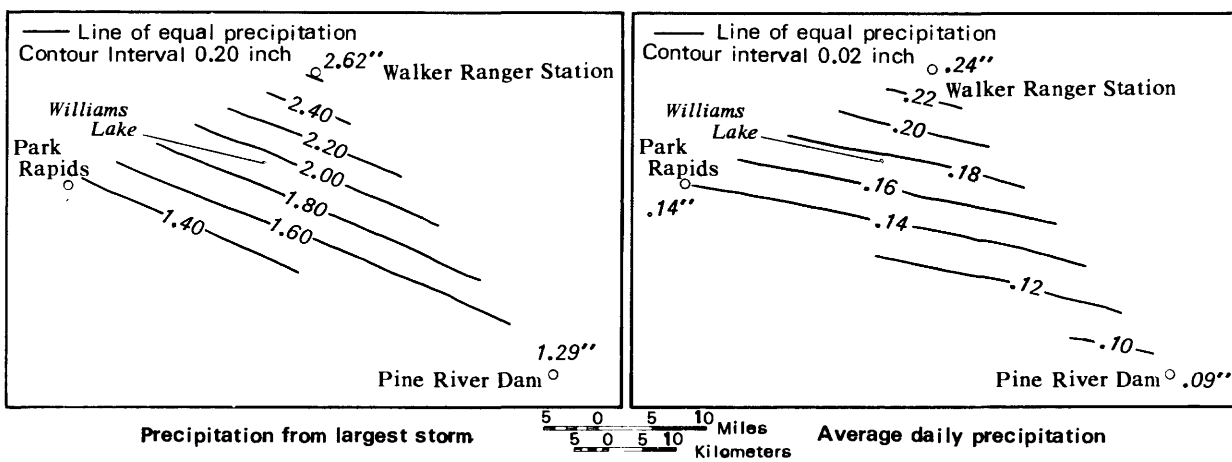
Preliminary Analysis

Atmospheric water

Precipitation

In most lake studies, precipitation is measured or estimated by one or a combination of three ways: (1) a recording gage is placed at the lake, (2) several graduated containers are placed near the lake and read periodically by local observers, and (3) data from the National Weather Service network are used. Errors in estimating precipitation are related to the types of gages used, placement of the gages, and the method used to regionalize and apply point data to the specific lake of interest.

To evaluate errors in different methodologies of estimating rainfall on a lake, data from a large and a small rain-gage network were compared with data from the recording gage at Williams Lake by use of three regionalization techniques. The large network consists of National Weather Service (NWS) stations at Park Rapids, Walker Ranger Station, and Pine River Dam (fig. 10). The small network includes three stations of the Deep Portage Conservation District (DP) network (fig. 11). The three



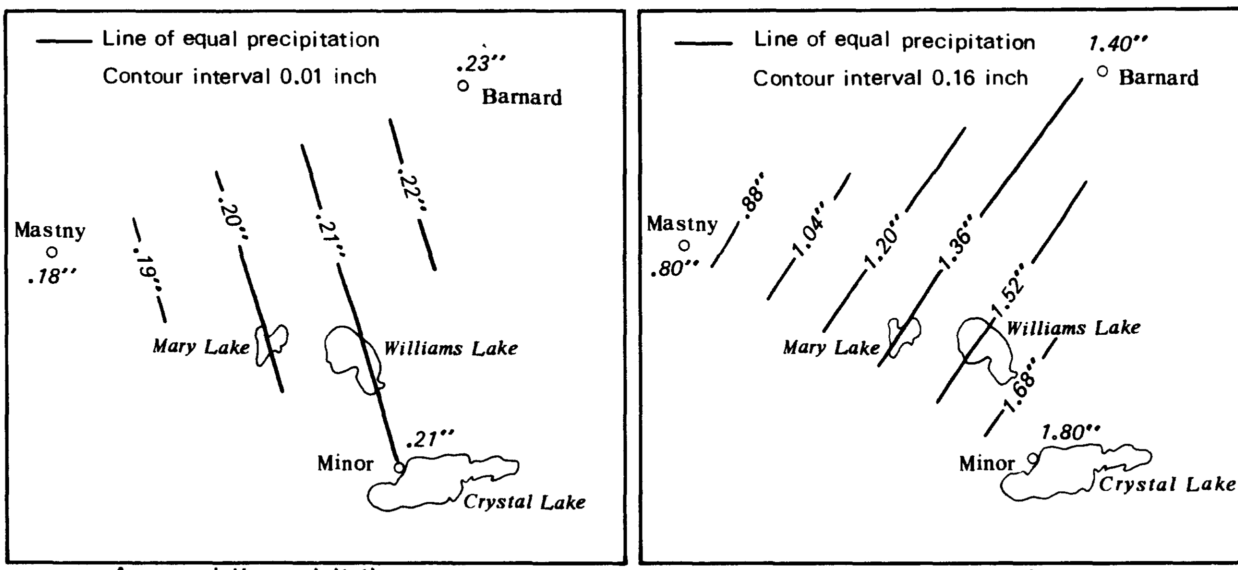
Precipitation from largest storm during June 14 - 16, 1978

Mean = 1.74 inches
Weighted average = 2.03 inches
Isohyetal value = 1.95 inches

Average daily precipitation June 15 - 28, 1978

Mean = 0.16 inch
Weighted average = 0.19 inch
Isohyetal value = 0.18 inch

Figure 10.--Isohyets and comparison of three regionalization methods to estimate precipitation at Williams Lake by use of data from the large-scale network of the National Weather Service



Average daily precipitation
June 15 - 28, 1978

Mean= 0.207 inch
Weighted average = 0.208 inch
Isohyetal value = 0.207 inch

1 ½ 0 1 Mile
1 ½ 0 1 Kilometer

Precipitation from largest storm
during June 14 - 16, 1978

Mean = 1.33 inches
Weighted average = 1.49 inches
Isohyetal average = 1.53 inches

Figure 11.--Isohyets and comparison of three regionalization methods to estimate precipitation at Williams Lake by use of data from the small-scale network of the Deep Portage Conservation District

regionalization techniques are average, weighted average, and isohyetal value. Comparison was made for 14-day average precipitation data and for the largest storm during each 14-day period. Examples of isohyetal maps for a 14-day average value and for the largest storm within that same period are shown in figure 10 for the NWS network and in figure 11 for the DP network. Precipitation values for the three regionalization methods are given on the figures. Hydrographs of precipitation at all seven stations are shown in figure 12.

Comparison of six data sets for major storms and 14-day averages show the deviation from absolute rainfall recorded at Williams Lake for eight 14-day periods (fig. 13). For the 14-day average data, the differences between recorded and NWS calculated rainfall are less than 0.03 inch for 7 of the 8 periods. However, for the period August 9 to 23, the NWS data differ from the recorded data by more than an inch. For the same period, the DP data closely approximate that of the Williams Lake gage.

Significant differences in data for the largest storm occurred between regionalized and recorded information for the two networks for the periods June 14 to June 23, June 28 to July 12, and August 9 to 23. However, the DP data correlated more closely to the Williams Lake gage than the NWS data for the later period. Based on this preliminary comparison, isohyetal values for storm precipitation seem to be no better than values obtained by simpler averaging techniques.

A more quantitative comparison of the precipitation data was made by regression analyses (fig. 14 and table 3). The analyses show the value of on-site data compared with data from more distant stations. The variance of the regression lines (table 3) is a measure of the distance individual data points lie from a mathematically determined exact correlation line. Variance of the DP data is about one order of magnitude less than the NWS data, regardless of the regionalization method used. For major storms, the variance for the average-value method is less than that of the weightedaverage or isohyetal methods for both the NWS and DP networks. For biweekly averages, however, the variance of the regression for the average value is greater than that for the weighted-average method or the isohyetal method for both networks. Because of the small number of sample sets, future results could be considerably different as more data are accumulated and analyzed during the project.

Evaporation

Evaporation from lake surfaces is generally estimated from evaporation-pan data or taken from published maps, which are based on pan data. In many studies, the data are obtained from the nearest National Weather Service station and modified by adjusting the pan value by a pan-to-lake coefficent. The coefficient commonly used, 0.7, was determined by use of annual averages, but it has been incorrectly used for monthly data in many studies.

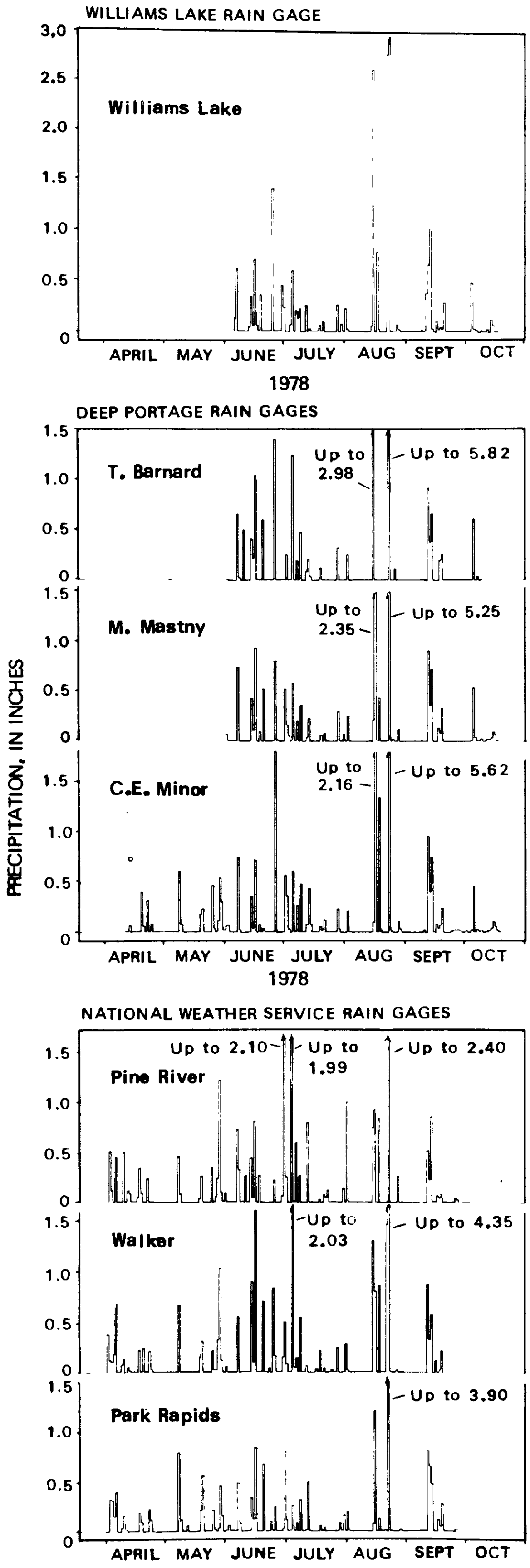


Figure 12.--Precipitation at and in the general region of Williams Lake, 1978

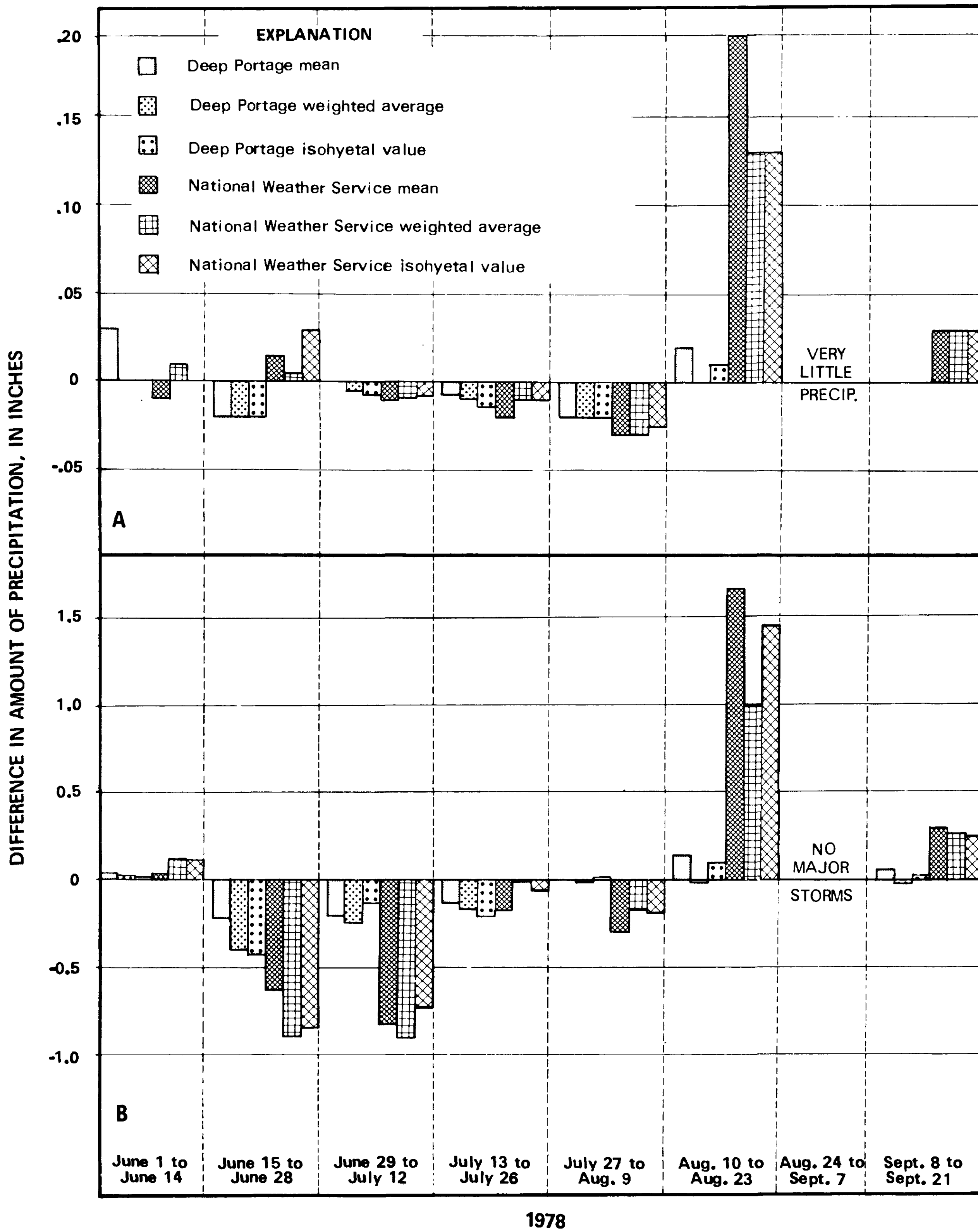


Figure 13.--Difference between precipitation as measured by the recording gage at Williams Lake and that estimated by three regionalization techniques by use of both small-scale (DP) and large-scale (NWS) networks

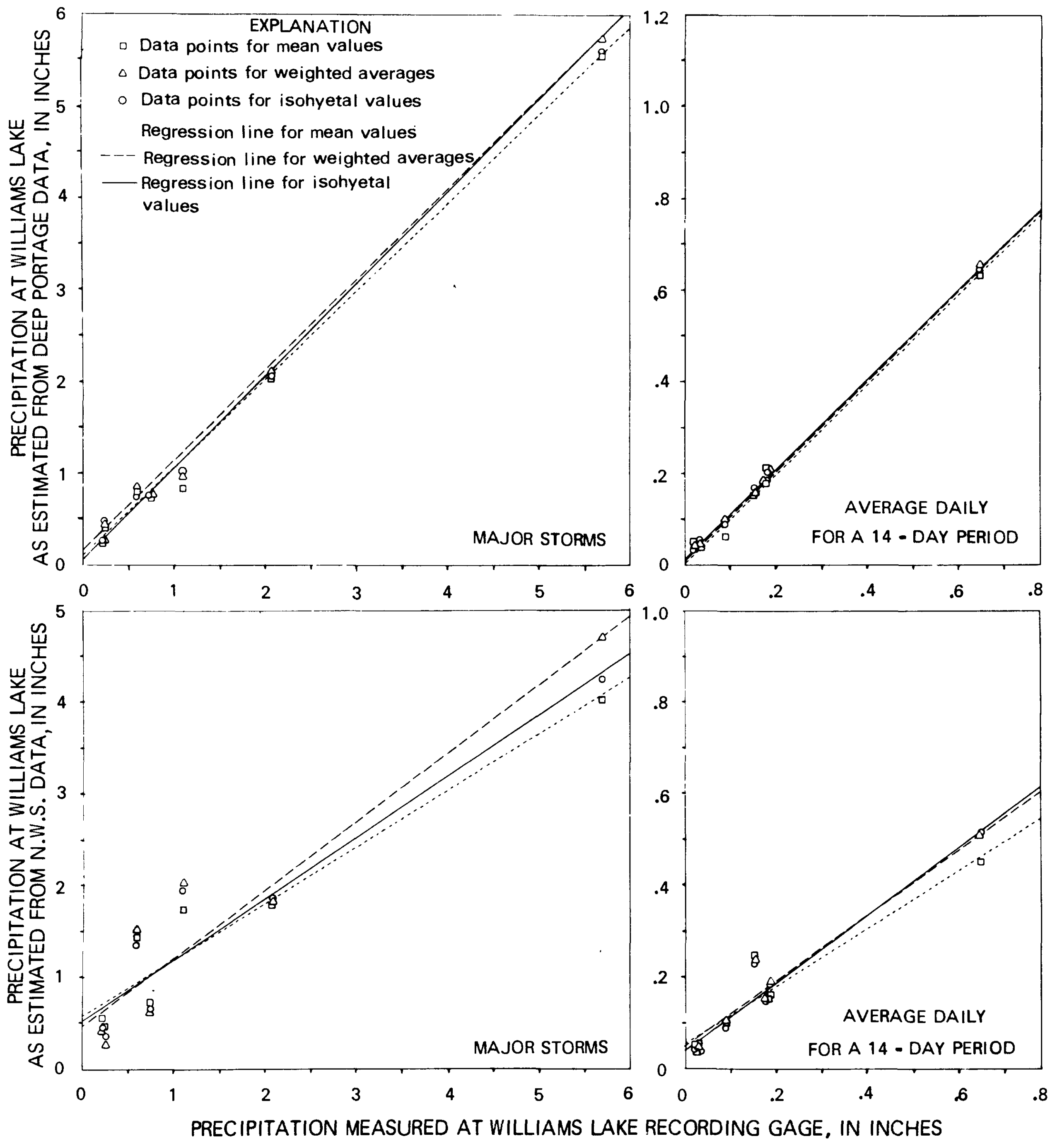


Figure 14.--Lines of regression between precipitation at Williams Lake by different regionalization techniques by use of data from both a large-scale (NWS) and small-scale (DP) gage network

Table 3.--Variance of the regressions relating calculated precipitation from network gages to recorded precipitation at Williams Lake

	Major storm data			Biweekly data		
	Average	Weighted average	Isohyetal value	Average	Weighted average	Isohyetal value
DP Minor - Mastney - Barnard Data	0.015	0.027	0.032	0.000118	0.000074	0.000074
NWS Park Rapids - Pine River - Walker Data	.141	.261	.201	.00222	.00160	.00156

Two other methods of estimating lake evaporation are the mass-transfer and energy-budget methods. Both techniques will be used at Williams Lake for the next several years. Because of financial limitations, only mass-transfer instruments were installed and operated on Williams Lake from mid-June to mid-October 1978. Energy budget instrumentation, which is far more extensive and costly, will be placed on Williams Lake in 1979 and operated for at least two open-water seasons. The energy budget method is more accurate that the mass-transfer method and is used to determine a coefficient needed for the mass-transfer method. (See below.)

Evaporation determined by the mass-transfer method uses the following relationship:

$$E = Nu(e_o - e_a) \tag{1}$$

Where: E = evaporation from lake surface,

N = mass-transfer coefficient,

u = wind speed at 7 feet above the water surface,

e_o = saturation-vapor pressure calculated from the temperature of the surface water,

e_a = vapor pressure of the air at height, a, above the water.

Values for the terms in the mass-transfer product, $u(e_o - e_a)$, are obtained from wind-speed, water and air temperatures, and relative humidity instruments on or near the lake. The most accurate method to determine N, an empirical coefficient, is by relating the mass-transfer product to an accurate independent measurement of evaporation, which, according to evaporation research (Harbeck and others, 1958; Gunaji, 1968), should be by an energy-budget method. The mass-transfer coefficient is unique to a lake. Once the coefficient is determined accurately by the energy-budget method, evaporation in subsequent years of a study can be accurately calculated by the mass-transfer method alone.

An alternate but less-accurate method of estimating N is to relate the mass-transfer product to change in lake stage (ΔH) for periods of no precipitation. This assumes that the change in lake stage is the result of evaporation only. It can be used for other periods if precipitation and stream inflow or outflow (if present) are uniformly distributed over the lake surface. However, small errors in measuring stream discharge can result in large errors in stage correction (Turner, 1966). Williams Lake has no streams interacting with it.

The data used to determine the mass-transfer product and a preliminary value of N are shown in figure 15. Three periods of no rainfall (fig. 12) were available for the plot. Two more periods were used that

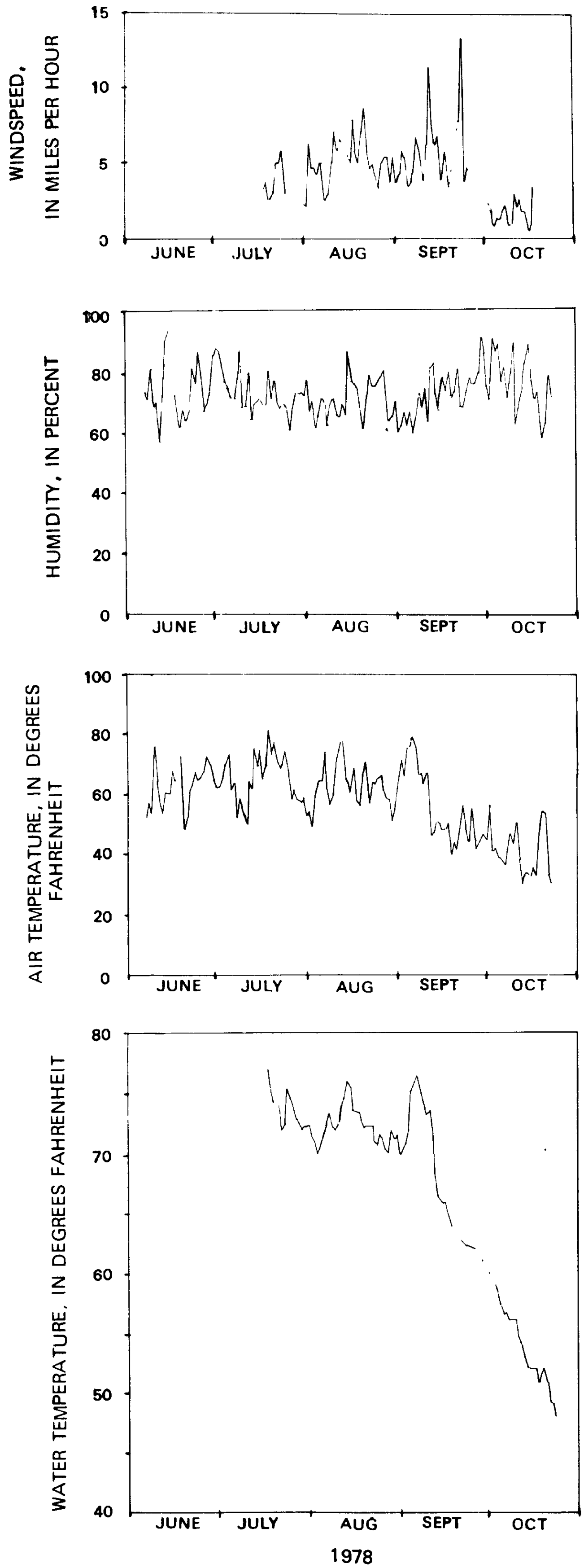


Figure 15.--Windspeed, humidity, air temperature, and water temperature at Williams Lake, June-October 1978

required only minor lake-stage fluctuation corrections caused by small amounts of rain. The mass-transfer coefficient was calculated as the slope of the least-squares regression line relating ΔH to $u \Delta e$. The value calculated for Williams Lake, 0.00357, is based on only five data points (fig. 16) and is, therefore, subject to considerable error.

Harbeck (1962) developed a functional relation that can be used for estimating values of N, which relates lake-surface area to N values determined in several other studies. An alternate N value for Williams Lake calculated from this relation is 0.00270.

Evaporation from Williams Lake was calculated by use of both the change in stage and Harbeck estimates of N (table 4). Results show a difference (calculated by using two different N values) in evaporation. The difference of about 2 inches for both August and September emphasizes the importance of accurately determining N for a given lake.

Surface water

Williams Lake has neither inflow nor outflow streams. The lake might receive overland flow, but the effect on the hydrology of the lake is unknown. Although not planned for study in this project, overland flow remains an unknown that will be studied in later phases of the long-term Williams Lake project.

Lake-stage data for Williams Lake were collected from July to December 1978 (fig. 17). The limited data indicate a relatively stable hydrologic system, because lake-level fluctuations are less than 1 foot for the latter half of 1978. In July and early August 1978, the lake level delined until the major storms in mid-August. After the storms, the lake level rose until early September and then generally declined until mid-November. During late November and December, the level remained relatively constant.

Ground water

Ground-water flow is controlled by the geologic framework through which the water moves and by the distribution of hydraulic potential within the ground-water system.

Although 30 to 150 feet of sand and gravel underlies the watershed, the test-hole data show a complex sequence of sand and till units, suggesting a complicated ground-water flow system. Because water-level data are available for only about 5 months (figs. 18, 19, and 20) and extensive interpretation of these data would be highly speculative, water-level data from August 1, 1978, were chosen to provide an example of the ground-water flow system interacting with the lake.

The configuration of the water table is shown in figure 21. Generally, the map shows ground-water movement into the east side of Williams Lake and outseepage from the west side of the lake into the ground-water

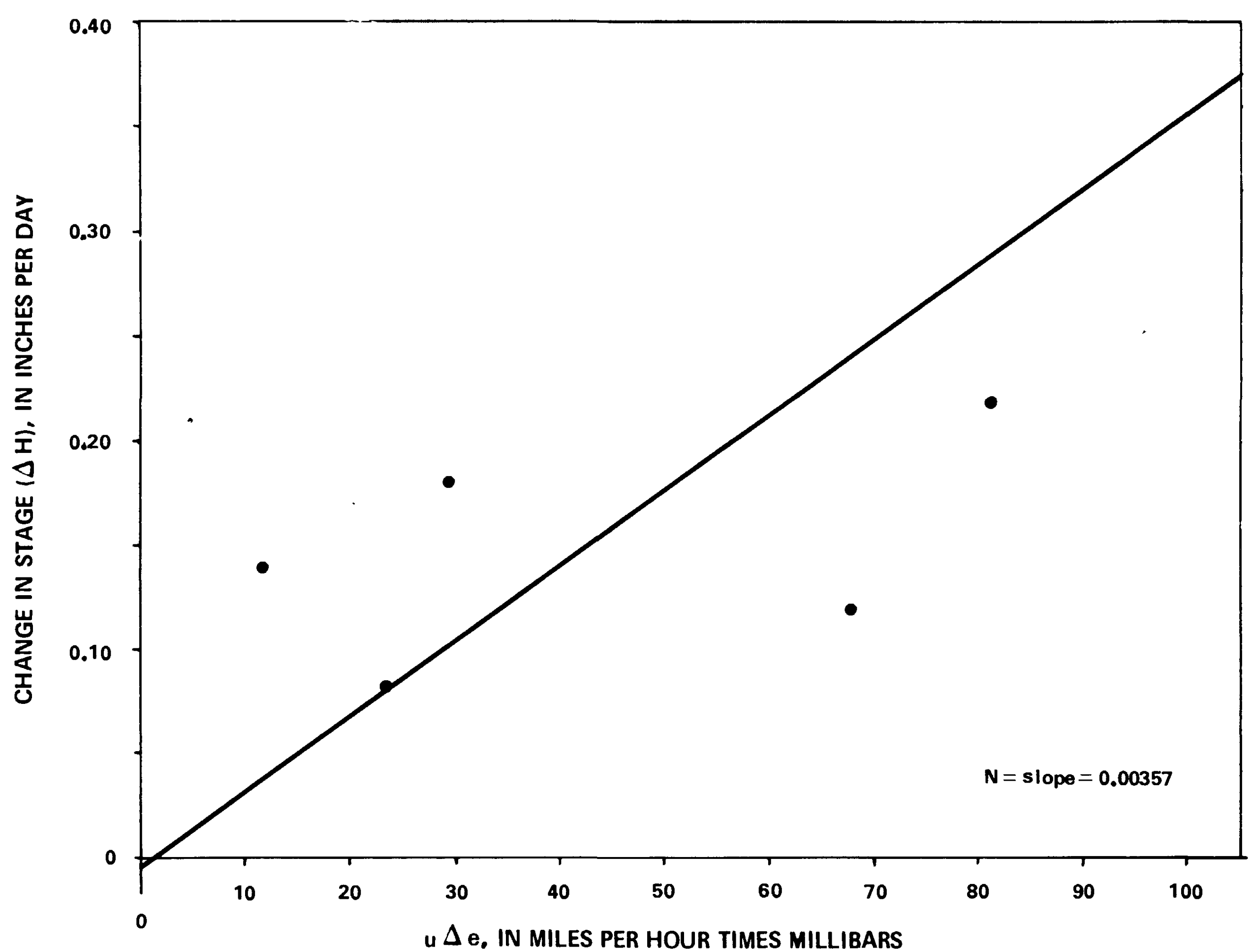


Figure 16.--Line of regression between the change in stage (ΔH) of Williams Lake and mass-transfer product (uΔe)

Table 4.--Evaporation from Williams Lake, July 18 to October 17, 1978

	Mass-transfer coefficient, N			
	0.00357 (from H data)		0.00270 (from Harbeck, 1962)	
	inches	millimeters	inches	millimeters
July 18 to August 1	3.54	89.9	2.69	68.3
August 2-31	7.43	188.7	5.62	142.7
September 1-30	7.13	181.1	5.31	134.9
October 1-17	0.95	24.1	0.79	20.1

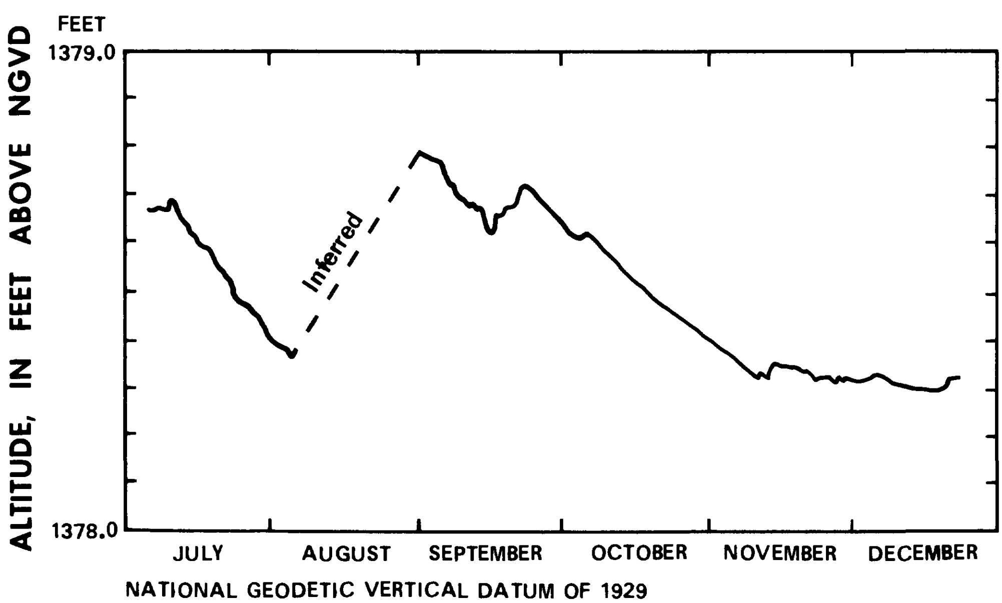


Figure 17.--Hydrograph of Williams Lake stage, July-December 1978

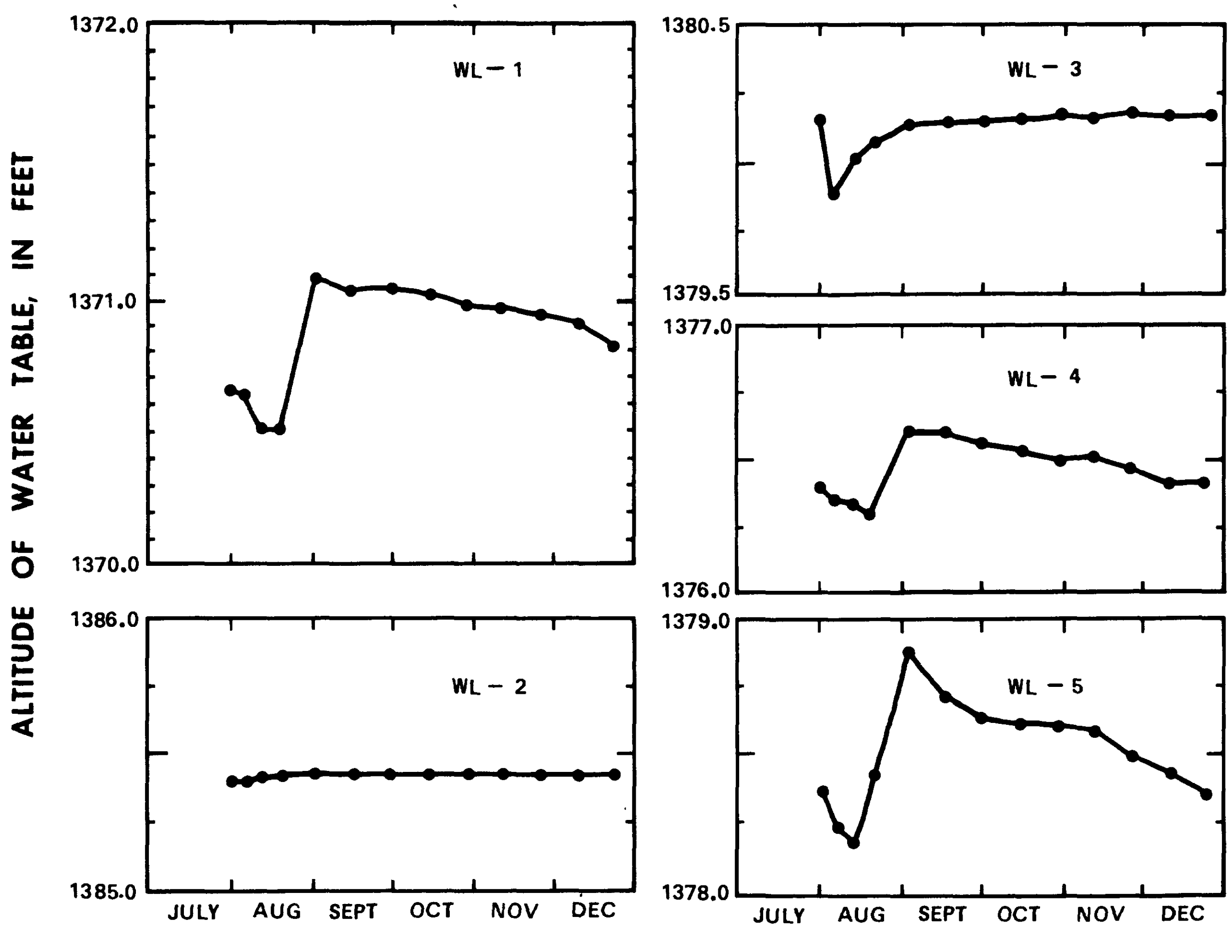
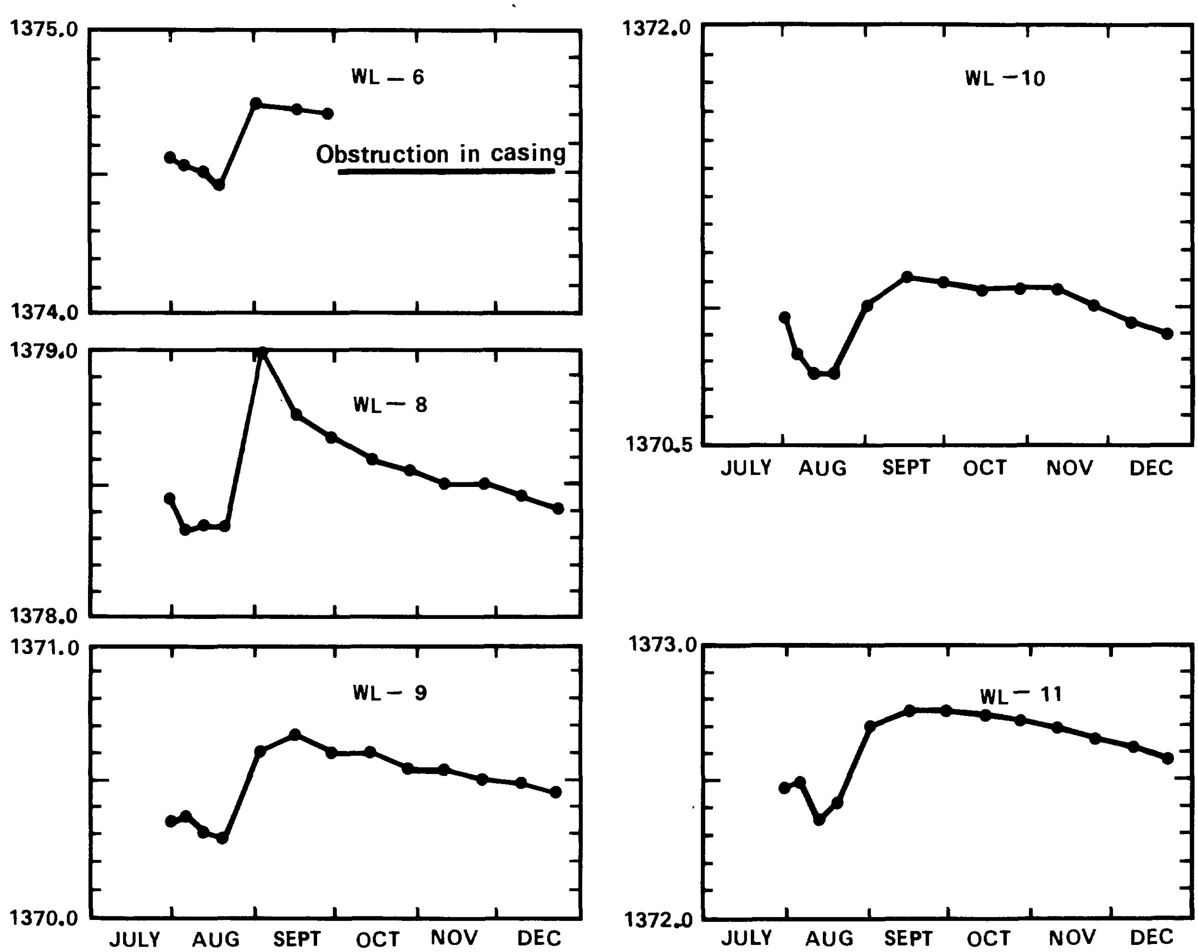


Figure 18.--Hydrographs of



water-table observation wells

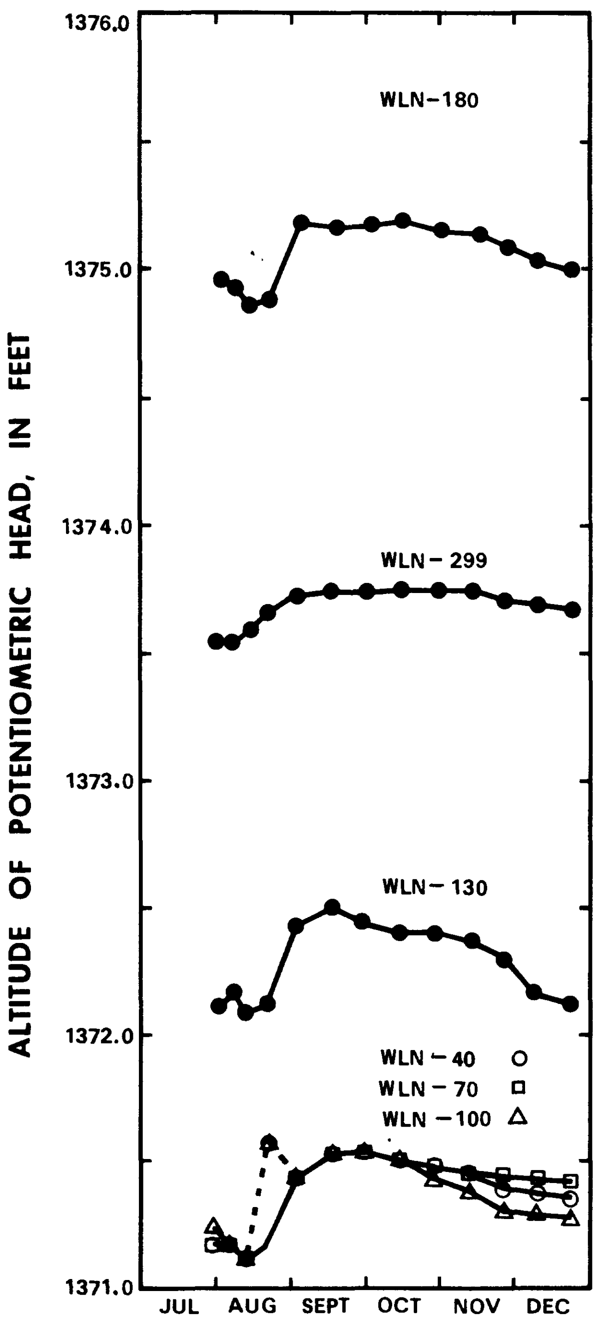
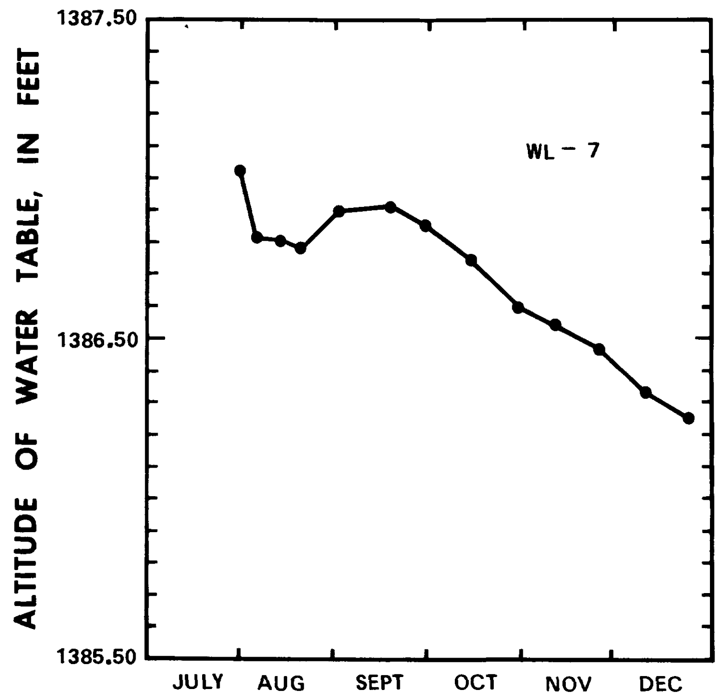


Figure 19.--Hydrographs of potentiometric heads at west piezometer nest



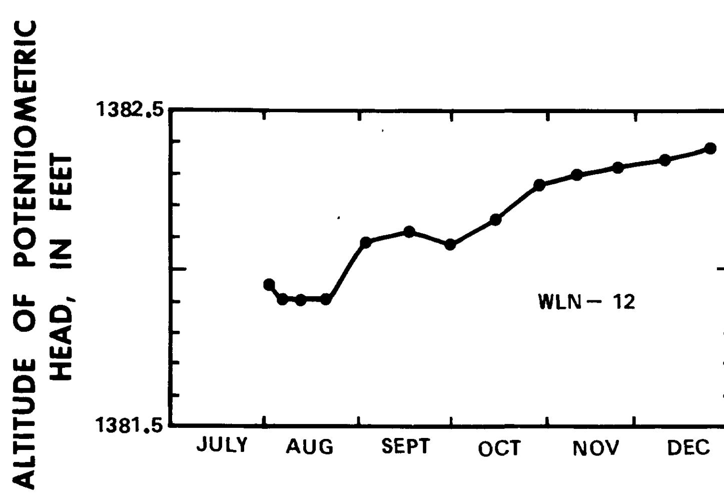


Figure 20.-- Hydrographs of potentiometric and water-table heads at east piezometer nest

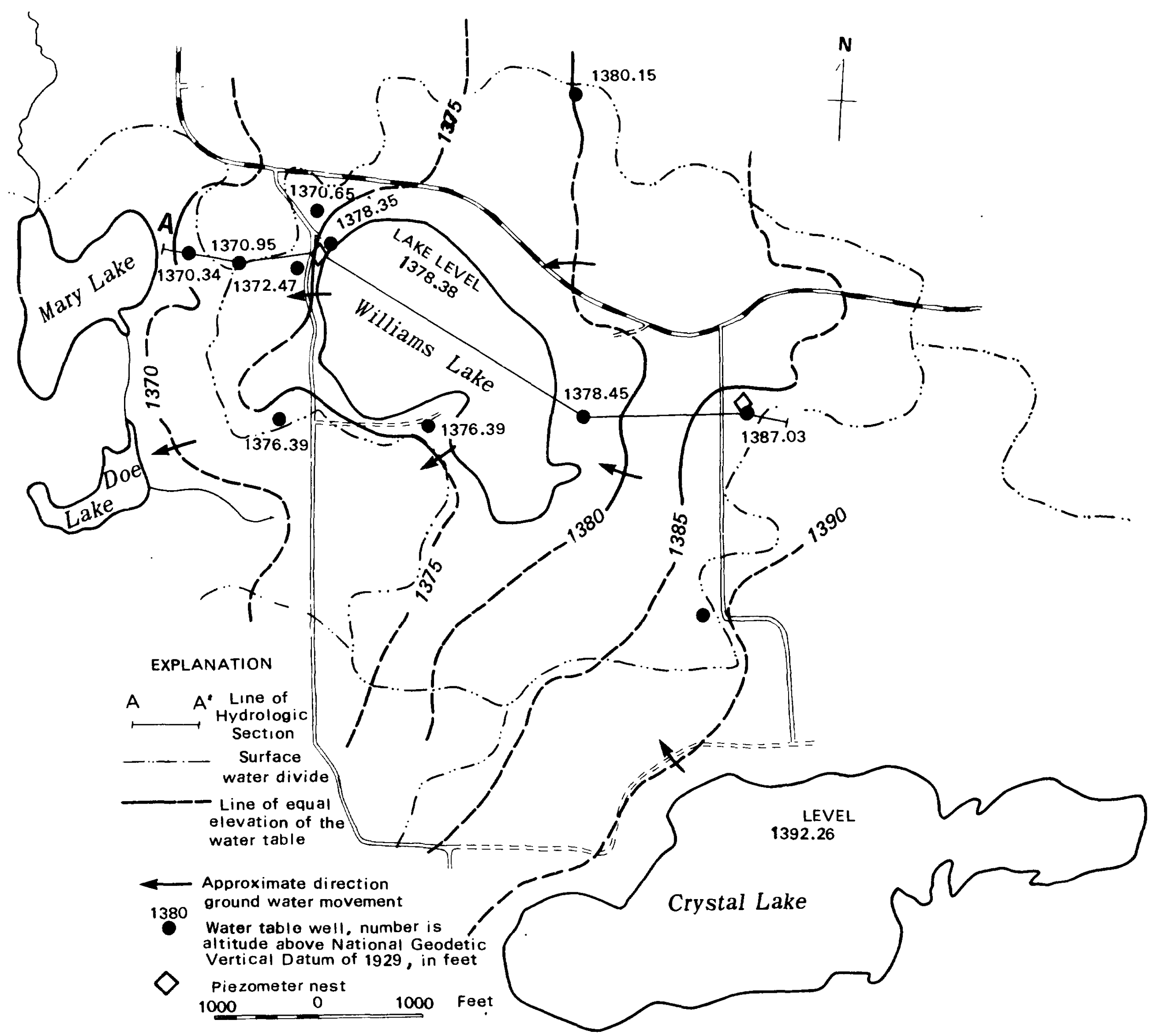


Figure 21.--Configuration of the water table near Williams Lake, August 1, 1978

reservoir. One water-table well was constructed between Williams and Crystal Lakes, but it apparently is plugged (fig. 18); therefore, the configuration of the water table between the two lakes is not known.

Water-table maps provide only a two-dimensional areal view of ground-water movement. Water-level data from the piezometers provide the third (vertical) dimension of ground-water flow. The vertical distribution of hydraulic potential is shown most accurately at the two piezometer nest locations (fig. 22). At the east nest, the head gradient is downward through the uppermost till from the upper sand to the deep sand unit. At the west nest, a slight downward gradient exists within the upper sand, and the gradient within the underlying till is upward in the upper part and downward in the lower part.

Uncertainty concerning the geology and ground-water movement between the nests is considerable, particularly in the zone underlying the east side of the lake. This uncertainty is caused by lack of knowledge of the continuity of the uppermost till and the lower major sand unit. An additional test hole and piezometer on the east side of the lake, probably near water-table well Wl-8, would resolve the questions. An arrow suggests upward movement from the till to the upper sand unit on the east side of the lake near well WL-8, but this is speculative. It is not known whether all the ground water in the uppermost sand is part of a local flow system interacting with the lake or if some ground water is part of regional ground-water movement passing at depth beneath the lake.

Further data are needed to determine if water in the deep sand unit is recharged near the east edge of the watershed, as suggested by the downward movement through the till, or if the water is moving into the Williams Lake area from a source farther east. Data are also needed to determine where water in the deep sand discharges. Modeling the flow system would provide an evaluation of several alternate interpretations and is discussed in the next part of this report.

Numerical models of flow

One of the principal goals of the long-term study is to evaluate the interaction of the lake and ground-water system through numerical modeling. One of the greatest benefits of modeling is the ability to test revised concepts at various stages of the project to guide further data collection.

Two vertical-plane (two-dimensional) models were developed during this first year of the study. The first model was developed soon after water-table wells were constructed in the fall of 1977, before the altitudes of the wells were determined by leveling and before any deep test holes were drilled. Preliminary data indicated, however, that the water

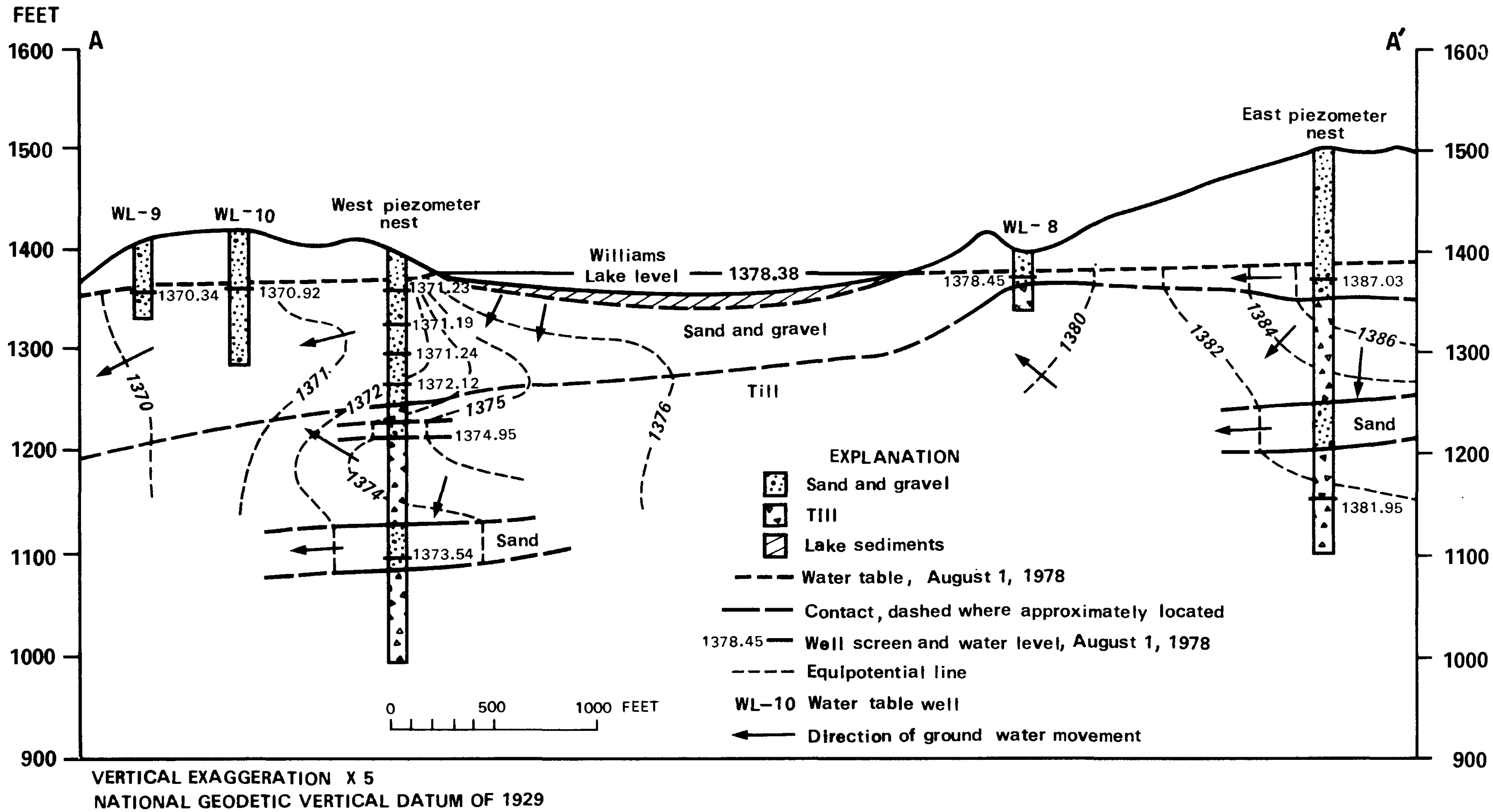


Figure 22.--Hydrologic section based on potentiometric head distribution, August 1, 1978

table was deep beneath the land-surface highs and that its altitude differed only slightly from the lake surface. No information was available on the stratigraphy of the deeper drift or on potentiometric heads at depth. Total drift thickness was estimated to be 300 feet (Tufford, 1966).

For the initial model, it was assumed that a water-table mound 2 feet above lake level existed on the west side of the lake, and a mound 4 feet higher than lake level existed on the east side. Model runs were steady-state analyses; the sides and bottom of the sections were assumed to be no-flow boundaries. The only parameter adjusted in the model was anisotropy (Kh/Kv).

The initial model showed that Williams Lake tends to have outseepage through part of the lake bed when the anisotropy is 100 (section A on fig. 23). The water-table mound on the west side, however, causes inseepage through part of the littoral zone on the west side of the lake. The area of outseepage increases to a little more than half of the lake bed if anisotropy is increased to 500. If the anisotropy is decreased to 50, a stagnation point (Winter, 1976) develops beneath the west end of the lake, and outseepage ceases (section B on fig. 23).

The first update of the initial model incorporated data collected in 1978 and includes the stratigraphy and geometry of the units underlying the lake and the distribution of hydraulic head along the water table and at several points within the ground-water system. The updated steady-state analysis (fig. 24) by use of the new 1978 field data is intended for comparison to results from the initial model (section A on fig. 23).

The base of the updated model was changed from the altitude of 1,200 feet in the initial model to 1,100 feet based on test-drilling and leveling data. The lower sand and gravel were considered to be continuous and was the base of the modeled system in the western and central parts of the area. The till beneath the lower sand and gravel was modeled as the base of the system in the eastern part.

In the first analysis, by use of the updated model (section A on fig. 24), hydraulic heads were not specified for the lower sand and gravel unit. The analysis shows outseepage through the western littoral zone and nearly all the deeper parts of the lake bed; the entire littoral zone on the east side of the lake has inseepage. The large head gradient across the upper till unit indicates that the till tends to hydraulically isolate the lower sand and gravel unit. There is a head drop of only a little more than a foot across the entire lower sand and gravel unit.

In the second analysis by use of the updated model (section B on fig. 24), a head loss of 12 feet (1383 to 1371 feet, altitude) from east to west was specified in the lower sand-unit, as indicated by the field data shown in figure 22. The analysis of this setting shows again how the upper till unit tends to isolate the upper sand from the

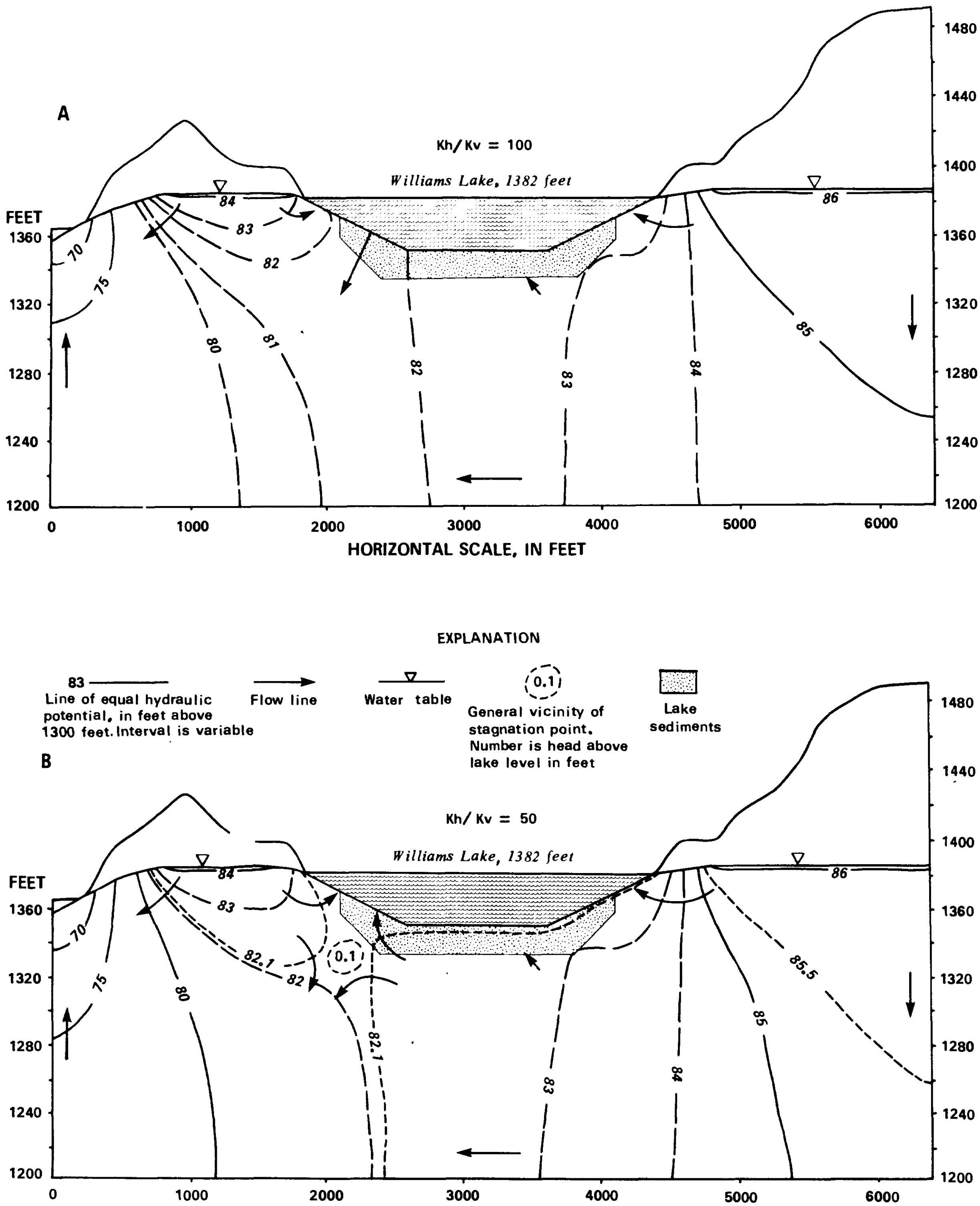


Figure 23.--Initial numerical simulation of ground-water flow near Williams Lake

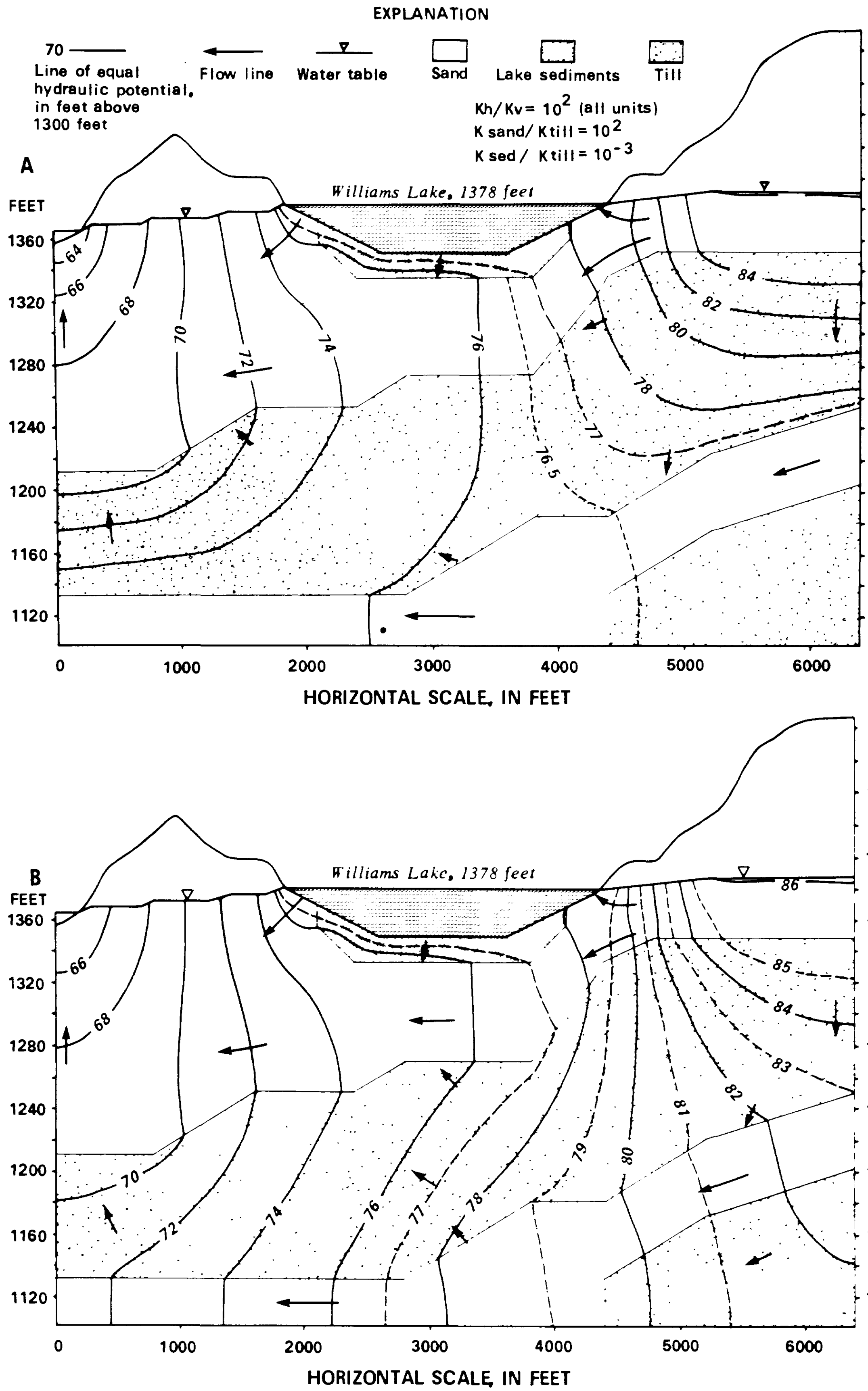


Figure 24.--Updated numerical simulation of ground-water flow near Williams Lake by use of hydrogeologic information obtained during 1978

lower sand. The distribution of head in the upper sand is nearly indentical in both analyses. The major difference in the two analyses is the distribution of head within the upper till unit.

It is not the intention of the authors to report on model calibration at this time. Definitive modeling can be done only with considerable additional data on the water table and potentiometric head distributions. However, the preliminary models show the benefits of using modeling to guide future work. For example, additional data to define the continuity of the upper till unit is critical because the unit largely controls the hydraulic connection between the deeper sand, the upper sand, and the lake.

PRELIMINARY WATER BALANCE

A preliminary water budget of Williams Lake was determined from data collected from mid-July to mid-October 1978. Precipitation recorded by the Williams Lake gage was 13.24 inches. Evaporation, calculated from Harbeck's mass-transfer coefficient, was 14.41 inches. The change in lake stage over the 3-month period was -2.64 inches. Ground water, determined as the residual, constituted a net outseepage of 1.47 inches for the 3-month period. Using the relationship,

$$GW = E - P \pm H \qquad (2)$$

where: H = change in lake stage,

P = precipitation,

E = evaporation,

GW = ground-water discharge or recharge to the lake,

then: $-1.47 = 14.41 - 13.24 - 2.64$.

Ground-water discharge can be estimated independently by the relationship:

$$Q = KIA \qquad (3)$$

where: Q = ground-water discharge (L^3T^{-1}),

K = hydraulic conductivity (LT^{-1}),

I = hydraulic gradient (dimensionless),

A = cross-sectional area (L^2).

Hydraulic conductivity of the upper sand was assumed to be 5 ft/d. It was assumed that the east half of the lake has inseepage and the west half has outseepage and that the hydraulic gradient is uniform. The hydraulic gradient, 0.0089 ft/ft, was determined from figures 21 and 22, and is about the same on both sides of the lake. To estimate the areas needed to solve equation 3, the modeled sections (figs. 23 and 24) give a good estimate of the areas of inseepage and outseepage. Inseepage occurs in the littoral zone on the east side of the lake, and outseepage occurs through the lake bottom sediments and in the littoral zone on the west side of the lake. The part of the ground-water flow system that interacts with the lake on each side is about 25 feet wide and 4,500 feet long, (or 112,500 ft^2).

The quantity of water moving through the fine-grained lake sediments was also calculated. The area of lake bed covered by sediments is about 4.5×10^6 ft^2. These sediments are estimated to have a vertical hydraulic conductivity of 0.1×10^{-5} ft/day and a hydraulic gradient across them of 0.25 ft/ft.

Based on the above estimates and assumptions, the quantity of inseepage on the east side of the lake is 2,000 ft^3/d or about 0.0013 ft/d over the surface of the lake. Because the values are the same for the west side of the lake, there is an equal amount of outseepage. The outseepage through the lake sediments is small, only about 1.13 ft^3/d or the equivalent of 3×10^{-7} ft/d of lake stage, and is, therefore, ignored in the following discussion.

Over the 3-month preliminary study period, the inseepage and outseepage each amounts to about 1.4 inches (0.1 foot) of water. This very approximate estimate points out the danger of estimating ground-water flux as a residual. Residuals show only net inseepage or outseepage. Williams Lake showed equal amounts of inseepage and outseepage for the 3-month period, whereas the residual showed only outseepage.

The crudeness of the ground-water estimate demonstrates the need for certain additional data. For example, the estimate could change merely by changing the cross-sectional area of the ground-water flow field interacting with the lake, the hydraulic gradient, and the hydraulic conductivity.

WATER QUALITY

Analyses of two water samples that were collected from Williams Lake indicate that the water is moderately hard and of the calcium magnesium bicarbonate type (table 5). It is similar to the type of ground water generally found in Hubbard and Cass Counties (Oakes and Bidwell, 1968; Lindholm and others, 1972). When expressed as milliequivalents per liter, bicarbonate, calcium, and magnesium constitute over 90 percent of the respective anions and cations in the water. Most of the small amount of iron present, less than 50 ug/L, may be complexed or adsorbed

Table 5.--Chemical analyses of Williams Lake water
[data is in milligrams per liter except as indicated]

PARAMETER	FEBRUARY 19[a] 1978	AUGUST 26[b] 1977
Air temperature (°C)	-13.0	23.0
Alkalinity, total (as CaCO/3)	98.0	82.0
Bicarbonate	120.0	100.0
Boron, dissolved (ug/L)	------	30.0
Calcium, dissolved	28.0	20.0
Carbon, dissolved organic	4.8	------
dioxide	3.0	------
Reservoir depth (feet)	30.80	------
Fluoride, dissolved	------	0.1
Hardness, noncarbonate	7.0	0.0
total	110.0	82.0
Iron, dissolved (ug/L)	0.0	------
total (ug/L)	10.0	30.0
Magnesium, dissolved	8.6	7.7
Manganese, dissolved (ug/L)	10.0	------
Nitrogen, NO/2 as N	0.00	------
NO/3 as N	0.04	------
dissolved Kjeldahl	0.50	------
NH/4 as N	0.07	------
suspended Kjeldahl	0.09	------
total as N	0.63	0.99
total organic N	0.52	------
total Kjeldahl as N	0.59	0.98
NO/2+NO/3, total as N	0.04	0.01
dissolved as N	0.04	------
Oxygen, dissolved (percent)	75.0	------
dissolved	9.7	------
pH, field	7.8	7.9
Phosphorus, dissolved	0.00	------
total	0.01	0.02
Potassium, dissolved	1.4	1.0
Silica, dissolved	------	1.4
Sodium, dissolved	1.6	1.1
Specific conductance, field (mho/cm)	201.0	160.0
laboratory	201.0	189.0
Sulfate, dissolved	------	2.2
Water temperature (°C)	2.5	20.5

[a] Collected 9.6 feet below the lake surface near location of lake core #4.

[b] Collected 10 feet from shore at lake surface.

onto suspended organic material or sediments. The lack of dissolved iron and manganese contrasts with high levels of iron reported in water from domestic wells around the lake.

Nutrient concentrations in Williams Lake are relatively low. Concentrations of phosphorous are near the detection limit for the analytical method. Most of the dissolved nitrogen is nitrate and ammonia. Total Kjeldahl nitrogen, a measure of ammonia and the amount of nitrogen in organic material, was 0.39 mg/L less in February 1978 than in August 1977. Nitrate plus nitrite was 0.03 mg/L greater in February than in August. The inverse relationship between Kjeldahl nitrogen and nitrate plus nitrite implies biological fixation of nitrogen during the summer. A phytoplankton identification in the lake water in February 1978 (table 6) indicated that 96 percent of the phytoplankton were, in fact, nitrogen-fixing, filamentous blue-green algae. However, the total count of phytoplankton, 3,700 cells/mL, was at least three orders of magnitude less than is generally found in lakes subject to algal blooms.

Analyses for dissolved-oxygen concentration at depths of 6.6, 9.8, and 26.2 feet in February 1978 showed concentrations decreasing from 10.9 mg/L near the lake surface to 4.0 mg/L near the lake bottom. The oxygen concentration is lowest near lake bottom during winter because of the lack of mixing under ice and the oxidation of organic material on the lake bottom. Consequently, the data from the partial profile of the oxygen concentration suggests that Williams Lake is probably oxygenated during most of the year.

FUTURE STUDY NEEDS

Short Term

The remainder of the first phase of the Williams Lake study will consist of data collection and the determination of evaporation by the energy-budget method. Energy-budget instrumentation will be installed as soon as possible in 1979. Depending on the adequacy of the 1979 data, the energy-budget studies may be extended through 1980. Mass-transfer instruments will continue to be operated concurrently with energy-budget instruments.

The analysis of ground water interacting with Williams Lake would benefit from several additional water-table wells and one or two deep test holes. The deep test holes would be placed near WL-8 and WL-2 and penetrate the lower sand and gravel aquifer. The additional information to be gained thereby would not only improve the model analyses of the interaction of Williams Lake with the ground-water system, but would also provide a more accurate estimate of the quantity of seepage.

An accurate map of lake-sediment composition and distribution is needed to improve estimates of inflow and outflow. Also, lake-stage data are needed for Mary Lake and the small wetland between Williams and Mary lakes to better define the hydrogeologic system downgradient from Williams Lake.

Table 6.--Phytoplankton identification, Williams Lake February 1978

3,700 Cells/mL

Organism Name	Common name		Cells/mL	Percent
Chlorophyta	Green algae			
.Chlorophyceae				
..Chlorococcales				
...Characiaceae				
....Schroederia			11	0
		Totals	11	0
Chrysophyta				
.Bacillariophyceae	Diatoms			
..Centrales	Centric			
...Coscinodiscaceae				
....Cyclotella			17	0
..Pennales	Pennate			
...Fragilariaceae				
....Asterionella			110	3
		Totals	127	3
Cyanophyta	Blue-green algae			
.Cyanophyceae				
..Hormogonales	Filamentous blue-green			
...Oscillatoriaceae				
# ....Oscillatoria			3,600	96
		Totals	3,600	96
Euglenophyta	Euglenoids			
.Euglenophyceae				
..Euglenales				
...Euglenaceae				
....Euglena			6	0
....Trachelomonas			6	0
		Totals	12	0
Pyrrhophyta	Fire algae			
.Dinophyceae	Dinoflagellates			
..Peridiniales				
...Glenodiniaceae				
....Glenodinium			11	0
		Totals	11	0

Note.--Cell/mL values are based on actual counts and reported to two(2) significant figures.
- Dominant organism; greater or equal to 15 percent.
Analysis method: Glass chamber, inverted microscope.

Long Term

Because evaporation from Williams Lake will be known with considerable accuracy, it will be an ideal site to test and develop alternate methodologies for estimating evaporation. The mass-transfer instrumentation will continue to be maintained in subsequent years for this purpose. Data collection on lake-ground-water interchange will be continued in greater detail. Statistical parameter-estimation techniques will be applied to the modeling of lake-ground-water interaction.

Recent and ongoing theoretical work has shown that the growth and dissipation of water-table mounds are critical to the inseepage-outseepage relations between lakes and the ground-water system. A study of infiltration and flow in the unsaturated zone is needed to better understand the growth and dissipation of these mounds and their effect on inflow and outflow.

Information on overland runoff, which is rarely considered in lake water-balance studies, is also needed. The controversy over the amount of water involved in overland runoff (Hewlett and Troendle, 1975; Freeze, 1972;) in different geologic and climatic settings needs to be investigated in the framework of Minnesota lakes. Williams Lake would be an ideal field site for such studies.

The Williams Lake area, because of the data available and present hydrologic instrumentation on the lake, would be ideal to examine the relationship between wetlands, the ground-water system, and lakes. It would also be ideal to examine chemical and biological processes and fluxes within a lake and between a lake and its watershed.

SUMMARY

Precipitation was measured at Williams Lake and estimated by the average-value, weighted average-value, and isohyetal methods. Estimates of precipitation were made by use of regional data from the National Weather Service and more local data from the Deep Portage Network. The variance of regression lines between estimated and measured precipitation was about one order of magnitude better for the more local Deep Portage data than for the large-scale regional National Weather Service data and was independent of the regionalization method used. The average-value method was the most accurate of the regionalization techniques in estimating precipitation at Williams Lake from major storms and least accurate accurate in estimating 14-day cumulative precipitation.

Evaporation from Williams Lake was determined by the mass-transfer method. Depending on the method of estimating the mass-transfer coefficient, calculated evaporation for any given month from July to October 1978 differed by as much as 2 inches.

Test drilling in the Williams Lake watershed indicates that 30 to 150 feet of sand and gravel overlies till of indeterminate thickness. A sand lens about 50 feet thick occurs east and west of the lake about 100 feet below the contact between the upper sand unit in the till. The bottom of Williams Lake is covered by as much as 20 feet of organic sediment.

In the first half of August 1978, the water table around Williams Lake gradually declined until heavy rainfall during August 14-23 caused it to rise several tenths of a foot. The configuration of the water table and vertical-head gradients showed that Williams Lake receives inseepage from the ground-water reservoir on the east side and has outseepage to the ground-water reservoir on the west side. Preliminary numerical models of the ground-water flow system suggest that (1) water in lower sand is relatively isolated from water in the uppermost sand, (2) water in the uppermost sand is in good hydraulic connection with Williams Lake, and (3) outseepage from the lake occurs through the western margin and deeper parts of the lake bottom. Calculating ground water as a residual of the water-balance equation, the estimated water balance from mid-July to mid-October showed a net outseepage of 1.47 inches from the lake. However, calculations based on the preliminary numerical models suggest that the total ground-water interaction with the lake was about 1.4 inches of both inseepage and outseepage.

Williams Lake water is hard and of the calcium magnesium bicarbonate type. Most nitrogen is Kjeldahl nitrogen, implying biological fixation of nitrogen in the summer. Filamentous blue-green algae are the dominant phytoplankton in the winter. Dissolved oxygen was 4 mg/L near the bottom of the lake in February 1978, suggesting that the lake is oxygenated to some degree thoughout the year.

REFERENCES

Arneman, H. F., and others, 1969, Minnesota Soil Atlas Brainerd Sheet: University of Minnesota Agricultural Experimental Station Miscellaneous Report 90-1969, 36 p.

Baker, D. G. and Strub, J. H., 1963, Climate of Minnesota, part II, the agricultural and minimum temperature-free season: University of Minnesota Agricultural Experimental Station Technical Bulletin no. 254.

____ 1965, Climate of Minnesota, part III, temperature and its application: University of Minnesota Agricultural Experimental Station Technical Bulletin no. 248.

____ 1967, Climate of Minnesota, part V, precipitation facts, normals, and extremes: University of Minnesota Agricultural Experimental Station Technical Bulletin no. 254.

Freeze, R. A., 1972, Role of subsurface flow in generating surface runoff, 2 upstream source areas: Water Resources Research, v. 8, no. 5, p. 1272-1283.

Gunaji, N. N., 1968, Evaporation investigations at Elephant Butte Reservoir in New Mexico, in Geochemistry, precipitation, evaporation, soil-moisture, hydrometry: General Assembly of Bern, International Association of Scientific Hydrology, publication 78, p. 308-325.

Harbeck, G. E., Jr., 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory: U.S. Geological Survey Professional Paper 272-E, p. 101-105.

Harbeck, G. E., Kohler, M. A., Koberg, G. E. and others, 1958, Water-loss investigations: Lake Mead studies: Geological Survey Professional Paper 298, 100 p.

Hewlett, J. D., and Troendle, C. A., 1975, Non-point and diffused water sources: a variable source area problem: American Society of Civil Engineers, Irrigation and Drainage Division, Proceedings of Symposium on Watershed Management, Logan, Utah, August 11-13.

Kohler, M. A., Nordenson, T. J., and Baker, D. R., 1959, Evaporation maps for the United States: U.S. Weather Bureau Technical Paper no. 37, 13 p.

Lindholm, G. F., Oakes, E. L., Ericson, D. W., and Helgesen, J. O., 1972, Water resources of the Crow Wing River watershed, central Minnesota: U.S. Geological Survey Hydrologic Investigations Atlas HA-380.

Minnesota Department of Conservation, 1959, Hydrologic atlas of Minnesota: Division of Waters Bulletin 10, 182 p.

Oakes, E. L., and Bidwell, L. E., 1968, Water resources of the Mississippi headwaters watershed, north-central Minnesota: U.S. Geological Survey Hydrologic Investigations Atlas, HA-278.

Tufford, S. P., 1966, Drift thickness map of Minnesota: Minnesota Geological Survey unpublished map.

Turner, J. F., 1966, Evaporation study in a humid region, Lake Michie, North Carolina: U.S. Geological Survey Professional Paper 272-G, 150 p.

U.S. Geological Survey, 1970, National Atlas of the United States of America: 417 p.

Winter, T. C., 1976, Numerical simulation analysis of the interaction of lakes and ground water: U.S. Geological Survey Professional Paper 1001, 45 p.

____ 1978a, Ground-water component of lake water and nutrient budgets: Verh. International Verin. Limnology, v. 20, p. 438-444.

____ 1978b, Numerical simulation of steady state three-dimensional ground-water flow near lakes: Water Resources Research, v. 14, no. 2, p. 245-254.