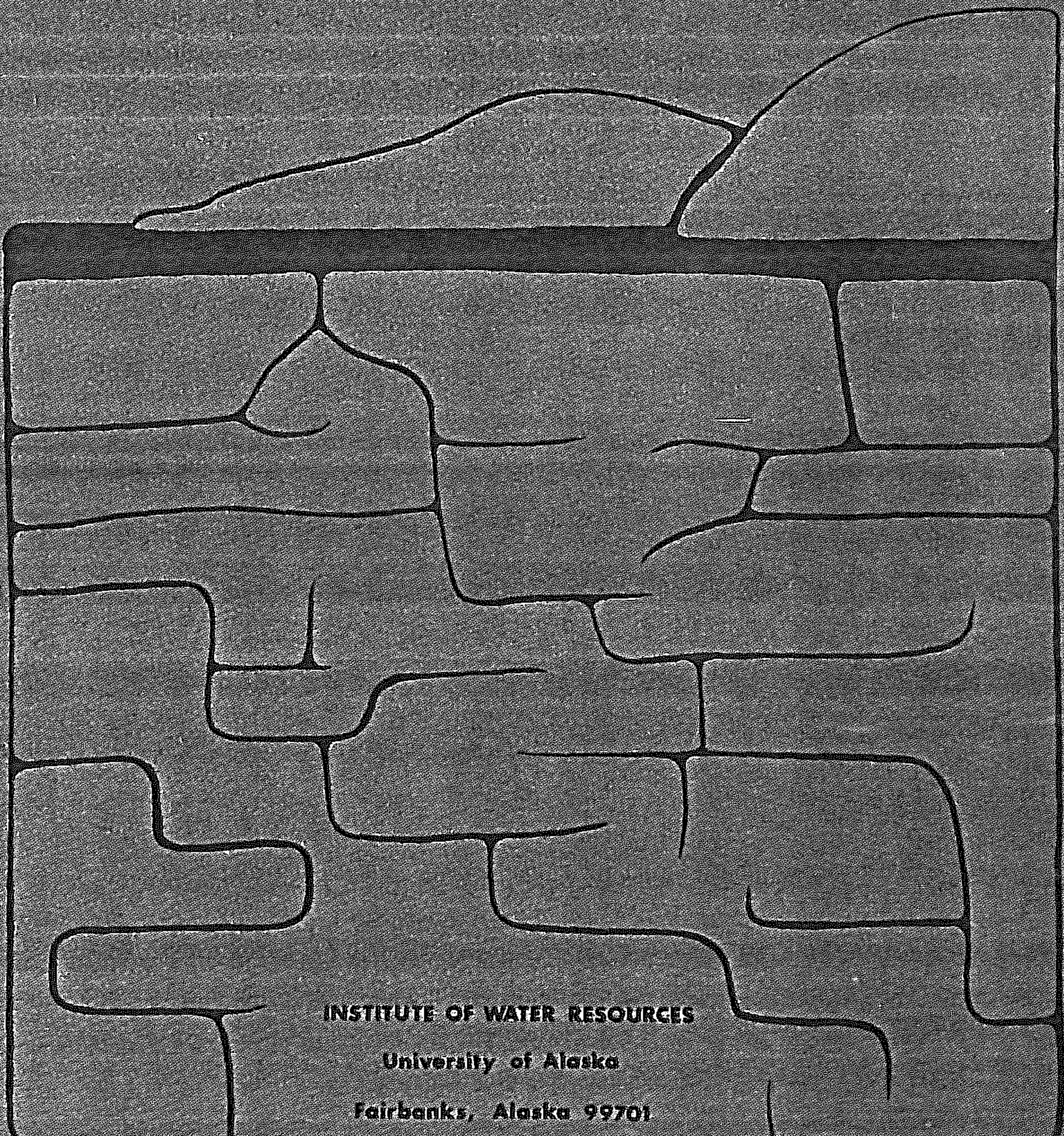
# WATER BALANCE OF A SMALL LAKE IN A PERMAFROST REGION



INSTITUTE OF WATER RESOURCES
University of Alaska
Fairbanks, Alaska 99701

# WATER BALANCE OF A SMALL LAKE IN A PERMAFROST REGION

by

Charles W. Hartman
and
Robert F. Carlson

Report No. IWR-42 September, 1973

Water balance of a small lake in a permafrost region
Charles W. Hartman, Robert F. Carlson

# WATER BALANCE OF A SMALL LAKE
# IN A PERMAFROST REGION

by

Charles W. Hartman
Research Engineer

and

Robert F. Carlson
Director

INSTITUTE OF WATER RESOURCES
University of Alaska
Fairbanks, Alaska

Report No. IWR-42 September, 1973

## ACKNOWLEDGEMENTS

*The work upon which this report is based was supported in part by funds (Project A-031-ALAS) provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Act of 1964, as amended.*

CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# INTRODUCTION

The existence of permafrost in arctic and subarctic regions may have a great effect on the water cycle. In areas where it is prevalent, permafrost acts as an aquiclude, preventing recharge of the groundwater by precipitation and increasing evapotranspiration. The net result is concentration of water near the surface and decrease of groundwater storage beneath the permafrost.

In most subarctic areas permafrost is not continuous, but is found in discontinuous masses of various thicknesses depending upon such parameters as groundcover, soil type, and presence or absence of lakes and rivers. In these areas the presence of permafrost may affect the water balance, but be of less importance on a regional scale.

Lakes modify the adjacent permafrost regime. The freezing of the water in a lake during winter absorbs heat which would otherwise be released from the ground surface. This results in a raising of the mean annual temperature around the lake with a consequent decrease in the permafrost level in the ground near the lake. The depth to permafrost beneath a pond or lake is dependent partially upon the area and depth of the lake (Johnston and Brown, 1964).

Normally in permafrost areas potential groundwater flow is concentrated in the active layer, usually only inches to a few feet thick. In areas where ponds and lakes are numerous, however, their effects on the permafrost may be cumulative, and underground connections may be found between them, much as the passages in a sponge (Fig. 1). If this type of connection is prevalent, the potential groundwater flow increases greatly due to the larger thawed cross-sectional area. From a regional water-balance viewpoint, this increase of groundwater component is important.

There are several methods of measuring the extent of connection of a pond with the regional groundwater system. One obvious way is to drill and examine cores for permafrost. In addition, tracer studies could be used to assess the amount of groundwater flow. Kane and Slaughter (1973) assessed groundwater recharge to a lake by use of vertically distributed piezometers.

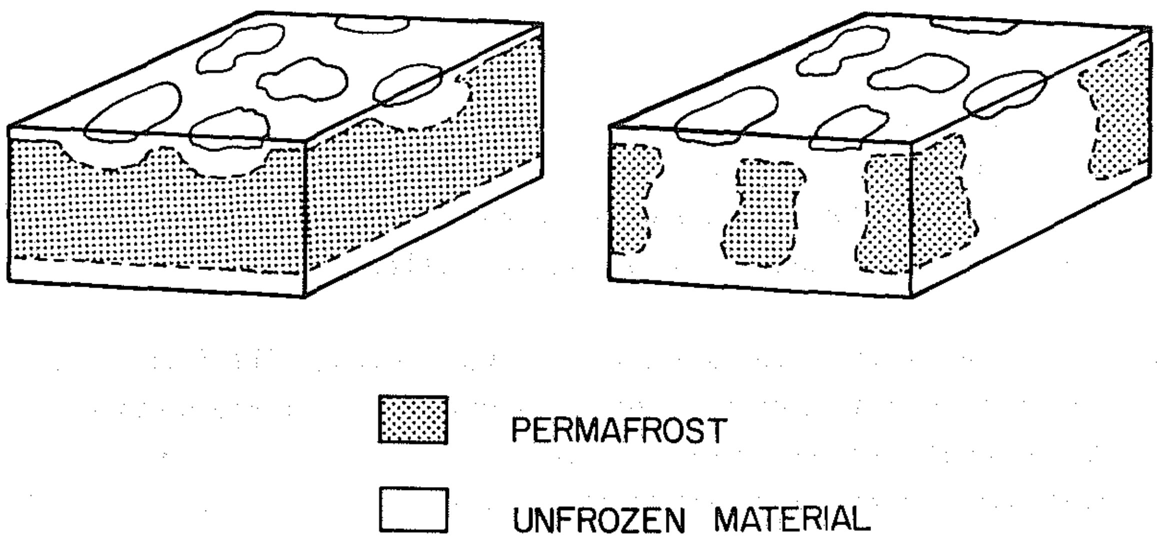



*Fig. 1. Possible effect of water bodies on the permafrost regime*

This study, performed in 1970, investigated possible interconnection of a small lake with the adjacent groundwater system by examining its water balance. In addition, the lake surface was lowered by pumping to induce a response from the groundwater regime near the lake. The response to the drawdown indicated the extent of interconnection between the lake and others in the area.

# BACKGROUND INFORMATION

A small lake in the Goldstream Valley area of the Alaskan interior near Fairbanks was chosen as the study area (Fig. 2). The lake, located near the University of Alaska, Fairbanks, was easily accessible and the area had been previously studied making available much background information on the character of the formations and permafrost. For the drawdown portion of the study, another lake at a lower elevation was available for receiving the pumped water from the lake.

A map of the study area is shown in Fig. 3. The lake area is approximately 2.2 acres, with a maximum depth of 11 feet. The lake morphometry is also shown in Fig. 3. The lake has no obvious inlet or outlet and is located in a poorly drained permafrost area. It appears that the lake was formed by the process of melting of massive ground ice in the permafrost (Wallace, 1948). A forest fire caused the death of most of the trees around the lake, but some existing trees on the bank lean toward the lake and some trunks extend into the water because of bank slumping. From these indications, it appears that the thaw lake is still in a stage of active enlargement. Other ponds in the area appear to be at approximately the same stage of development.

Vegetation in the area consists of tussocks and moss on the ground, brush of willow and alder, and a few black spruce and tamarack up to 15 feet high.

Since Fairbanks lies almost in the center of Alaska, with large mountain ranges both to the north and south, the climate is extremely continental. The temperatures varies from 90°F to -60°F. One can expect monthly mean temperatures of 60°F in July and -11°F in January. The sunshine duration varies greatly, from a maximum of over 21 hours in June to less than 4 hours in January.

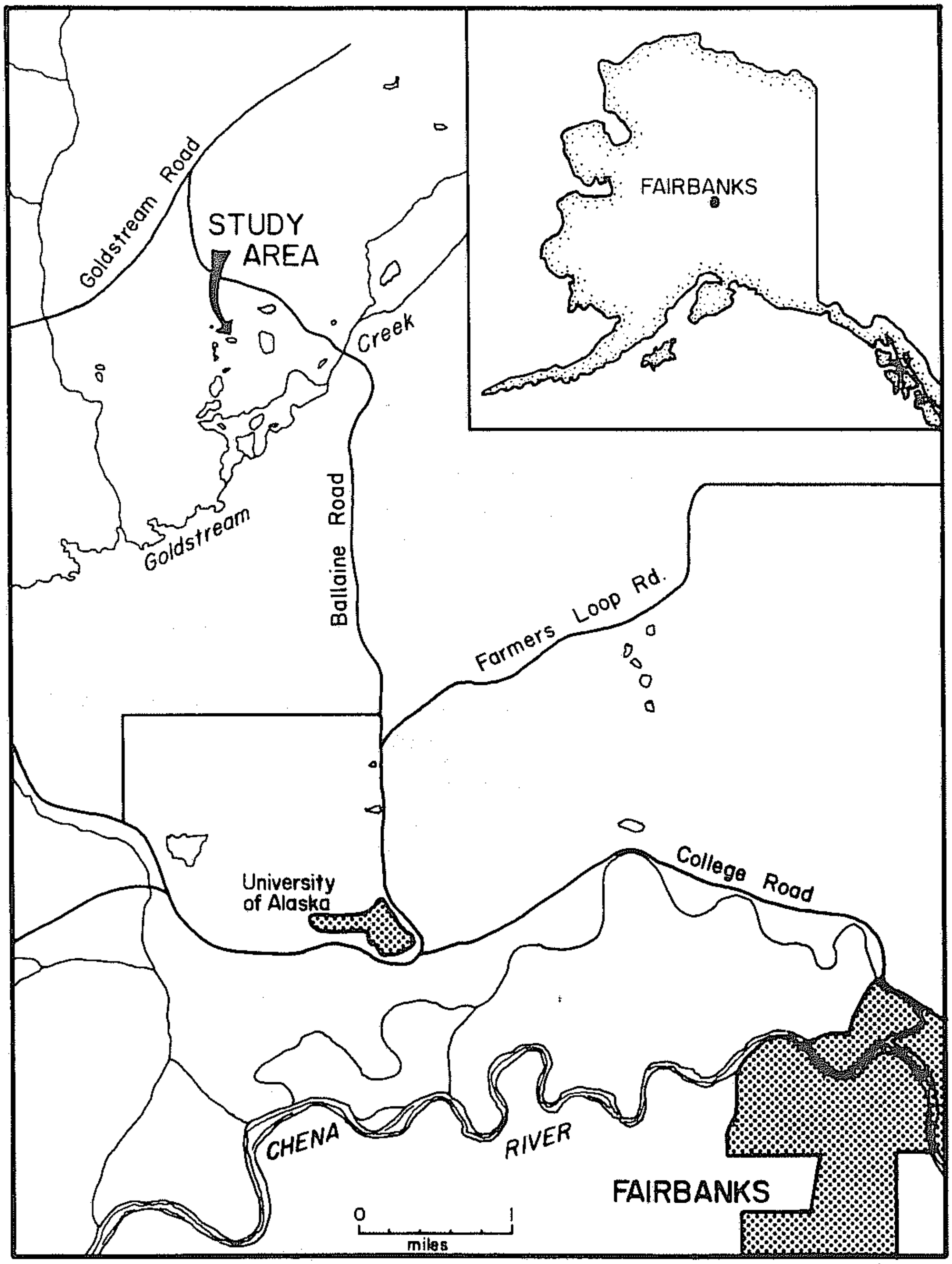



*Fig. 2. Project location map*

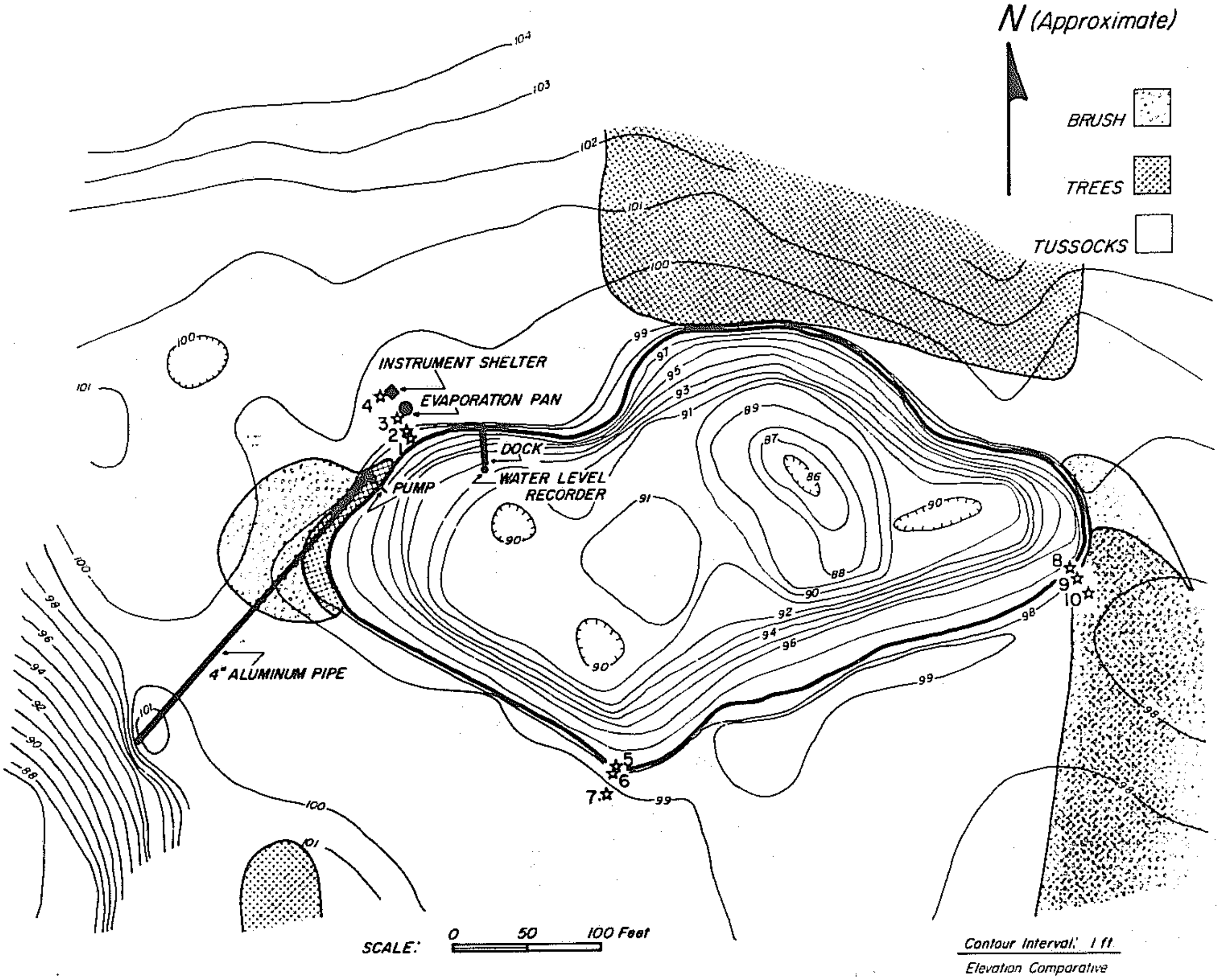



*Fig. 3. Topographic map of the lake with vegetation, lake morphometry, and equipment location*

Precipitation in the Fairbanks region is fairly light, with an annual water equivalent of about 12 inches. Since 1931, values of annual precipitation have ranged from a low of 5.5 inches/year to a high of 17.5 inches/year. Rainfall intensities are usually low with the exception of local thunderstorm activity during the summer months. Snow is typically on the ground from October to April with spring breakup occurring the the first week in May. In spite of low rainfall, saturated areas are common because of the presence of permafrost and low evaporation rates.

The dominant land forms of the Fairbanks area are rolling hills composed of Birch Creek schist, a slaty and schistose formation of Precambrian age consisting for the most part of metamorphosed sedimentary rocks with some metamorphosed igneous intrusions. Weathering varies from place to place, but generally is significant to depths of at least 50 to 75 feet. Loess (wind-blown silt), possibly derived from the flood plain of the Tanana River, blankets most of the hills to depths up to 100 feet. In the valleys, retransported loess, organic silt, and river gravels are found, in many places to great depths. The origin of the silt deposited in the valleys has been the center of much controversy. Cederstrom (1963) discussed this controversy at some length, but did not support any particular hypothesis; it appears that there is no universally accepted process of deposition.

At the study area in Goldstream Valley, the formation where the lake is located is designated QSO on the Geologic Map of the Fairbanks (D-2) Quadrangle, Alaska by Péwé (1958). This formation has the following description:

> "Organic silt, QSO; unconsolidated; incorporates much organic material, both plant and animal; well sorted, less than 20% clay; color brown or grayish black, locally mottled by decomposed vegetation; numerous large masses of ground ice. Contains large oval shaped areas of perennially frozen peat. QP, with high ice content; composed of dense undecomposed plant remains consisting mostly of sphagnum mosses; color brown to black."

The same formation was described by Tuck (1940) as an almost black, frozen, fine-grained sediment containing much organic material, some vertebrate remains, and many ice lenses. The inorganic portion is described as being made up predominantly of quartz and mica with smaller amounts of feldspar, hornblende, rutile, garnet, epidote, and other minerals.

In most of central Alaska, discontinuous permafrost is present, but in some areas permafrost is continuous and thick over large areas. Goldstream Valley is one of these locations. Here, permafrost thicknesses of 150 feet are common; maximum depth is approximately 175 feet (Péwé 1958). Two test borings near the area studied are described in Péwé's report. One, approximately 3/4 mile southeast of the lake, found silt for the first 44 feet, then gravel to bedrock at 119 feet. Permafrost was found from 2 feet depth to 128 feet. Another, located over 1 mile east, found silt for the first 60 feet, then creek gravel to bedrock at 108 feet. Permafrost was present throughout the whole depth.

Ground ice is commonly found in the silt soil as massive ice lenses, wedges, small segregations, and irregular masses. Typically, ice is abundant only in the upper 25 feet of the silt and greatly decreases with depth. The melting of the ground ice creates thaw lakes. The maximum depth is controlled by the amount of ice in the sediments and, of course, the depth of thaw. Depths of thaw lakes rarely exceed 15 feet (Wallace, 1948). Wallace used changes in direction of tree growth to estimate rate of growth of thaw lakes. This method leads to estimated rates of retreat of bank of 2.3 to 7.5 inches per year.

## NATURE OF FLOW

In any region, water is found in various amounts in separate components of the hydrologic system. In order to understand the hydrology of a region, one must study these components and their relationships to each other.

In the Goldstream Valley area, water is stored in the form of surface water, groundwater, and as ice in the permafrost. During the winter, it is also stored as snow. Short term changes in storage must obviously occur, but the sum of input and change in storage must equal the output from an area.

Input to the system is from precipitation, both in the form of rain and snow. The average annual rainfall is 7.4 inches and the average annual snowfall is 4.1 inches, water equivalent. Water in the form of snow is stored until the spring thaw. At this time, the lakes and ponds in the area fill to capacity and excess water runs off. If there were no extensive communication with a regional groundwater system, the lake levels would vary during the summer only as a result of rainfall and evaporation. Change in storage of water in the form of ice in the permafrost might occur over a long period of time, but should be negligible within one year. On the other hand, if there were an extensive connection with a groundwater system, lake level would also be a function of groundwater pressure head. Thus, lake levels would probably be less sensitive to direct rainfall and evaporation.

By pumping water from a small lake, a response may be artifically induced from the groundwater system around the lake in much the same way as groundwater flows into a well. If there are absolutely no thawed areas around the lake, drawdown can be easily computed from the volume of water removed from the lake. In this case, there should be no rise in water level after pumping ceases. If the thawed area around the lake is small, drawdown should be rapid, with a small rise in water level after pumping ceases. If there is an extensive groundwater aquifer around the lake, then pumping should elicit a smaller amount of drawdown, and lake level should return to its former level relatively rapidly.

## EXPERIMENTAL PROCEDURES

Field equipment was transported into the area during the early part of August, 1970, a dock was built for sampling from boats, and a stilling-well was installed in the lake to support a water level recorder. A Class A evaporation pan was installed according to the procedures outlined by World Meteorological Organization (1970), along with a rain gage and a thermometer shelter with maximum-minimum thermometers. Throughout the period of 12 August, 1970, through freezeup, the following parameters were measured at least several times each week: maximum and minimum air temperatures, wet and dry bulb temperatures, maximum and minimum temperatures on water surface in pan, wind totals above evaporation pan, water levels in the evaporation pan, and lake water level (measured continuously with a water level recorder).

A 4 inch Marlow Model 4E2S pump driven by a Ford Model 172D diesel engine was used for the drawdown test. A straight inlet pipe was installed 20 feet into the lake and about 2.5 feet below the water surface. Quick-lock aluminum irrigation pipe, 4 inches in diameter, was used between the pump and the discharge pond (Fig. 3). At the end of the irrigation pipe, a 6 inch steel pipe and orifice plate was attached and used in connection with a mercury manometer.

Well points were driven through the active layer at several locations around the lake. Most of these did not function properly and were not used during the pond drawdown tests. In place of the wells small pits were dug with a hand shovel to the top of the permafrost level (approximately 2-3 feet). A reference bar was erected across each pit and water levels were read below the reference bar. For those well points that were operational, water levels were referenced to the top of the well-point.

Cross-sections for pits 1-4 are presented in Fig. 4. The distances between them and their relative elevation are shown proportionally with vertical distances exaggerated. A description of all pits is given in Table 1 (see Fig. 3 for location).

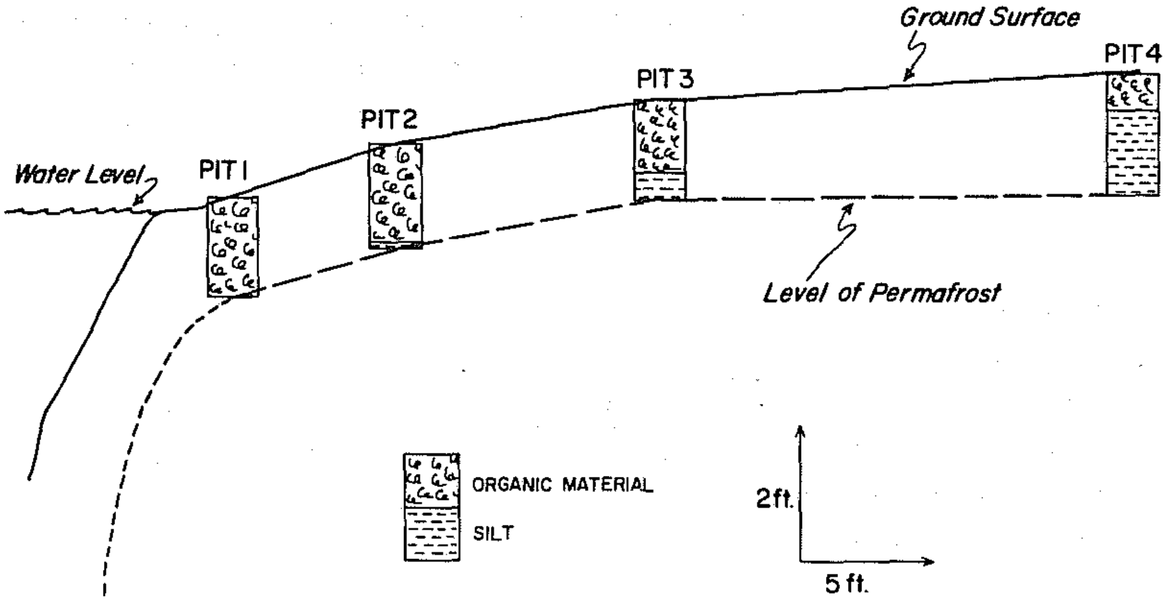



*Fig. 4. Cross-section of pits 1-4 in place*

TABLE 1: DESCRIPTION OF OBSERVATION PITS

| Pit No.* | Depth to Permafrost | Remarks |
|---|---|---|
| 1 | 18 inches | all organic material |
| 2 | 19 inches | 18" organic material, 1" silt below |
| 3 | 18 inches | 10" organic material, 8" silt below |
| 4 | 22 inches | 7" organic material, 15" silt below |
| 6 | 24 inches | all organic material |
| 7 | 22 inches | all organic material |

Notes:

* Pits 5, 8, 9, and 10 are driven well-points.

Discharge measurements were made during the drawdown tests by standard orifice-manometer and trajectory methods.

Evaporation from the thaw pond was estimated by adjusting the Class A pan evaporation for heat loss or gain by the method discussed by the World Meterological Organization (1970).

## RESULTS

The natural surface input-output to the lake during the study due to rainfall and evaporation are shown in Fig. 5.

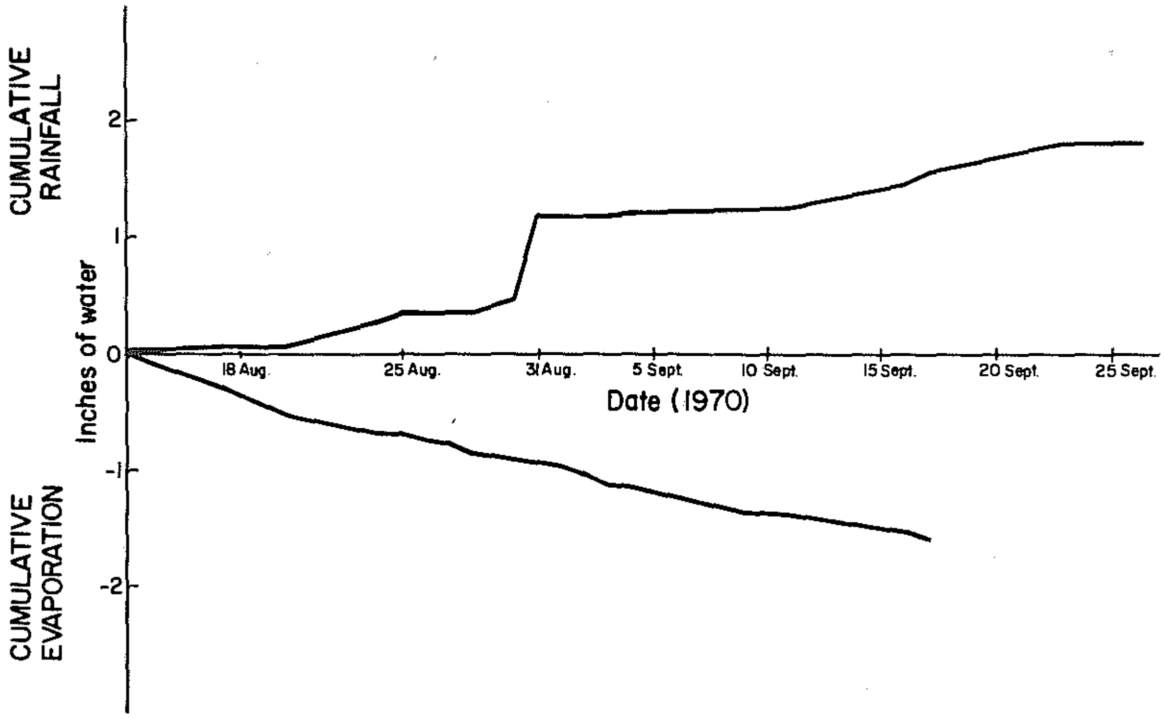



*Fig. 5. Cumulative precipitation and evaporation at lake*

The lake was pumped twice, on September 9, 1970 and September 16, 1970. Each time, a water level drop of about 3.5 inches was obtained. The results of discharge measurements are presented in Table 2. In addition, discharge was obtained by multiplying lake area by the drawdown as a rough check; this is also shown in Table 2.

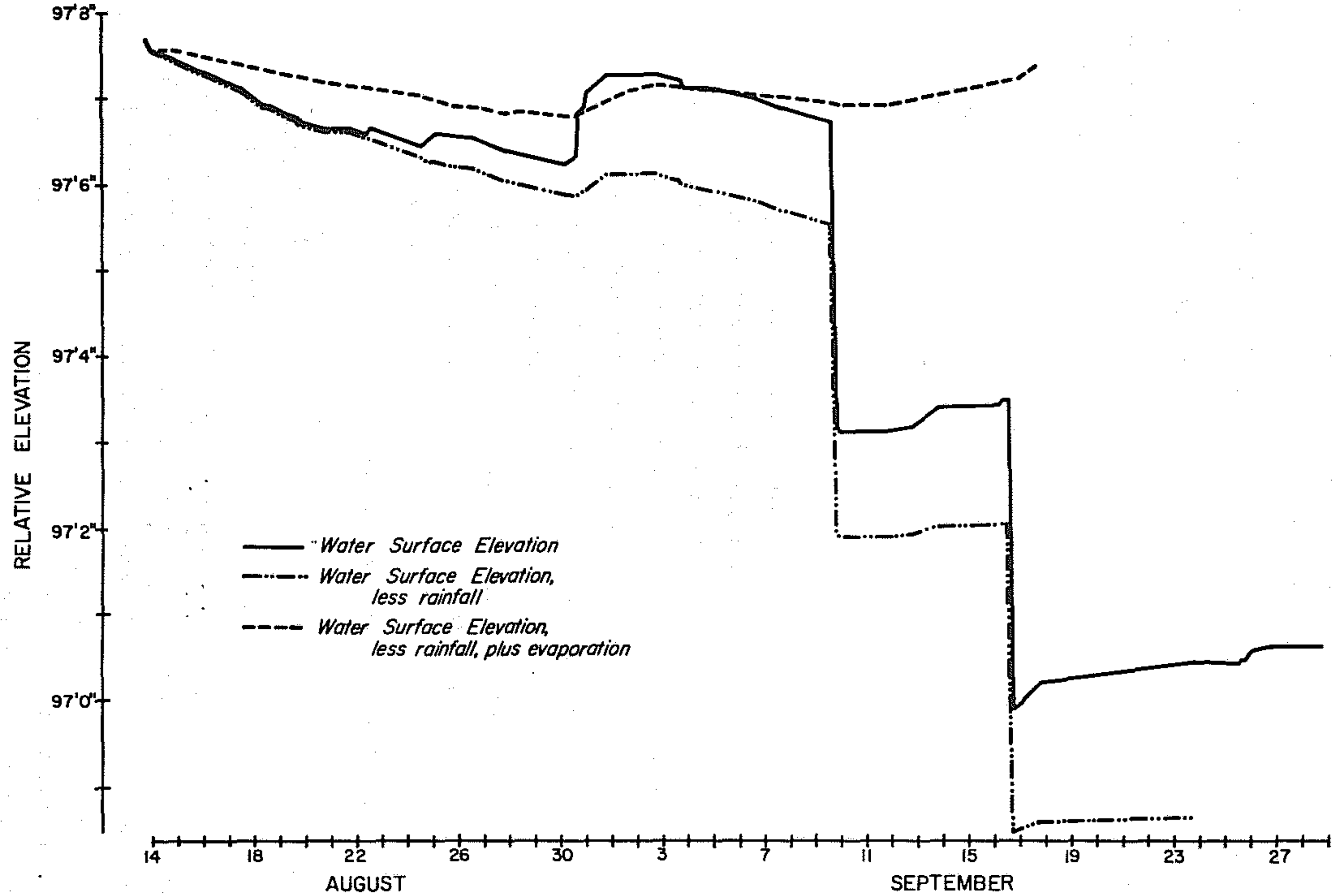



*Fig. 6. Lake level versus time, both uncorrected, and corrected for evaporation, precipitation, and pumping*

TABLE 2. TOTAL DISCHARGE COMPUTED FOR DRAWDOWN TESTS

| | Volume-cubic feet | |
|---|---|---|
| | September 9 | September 16 |
| Manometer | 30,010 | 27,998 |
| Trajectory | 28,227 | 28,831 |
| Lake Volume | 28,652 | 29,038 |

The lake level was continuously monitored throughout the study (Fig. 6). In order to assess possible groundwater recharge, the effects of precipitation and evaporation had to be removed from the water level graph. To do this, cumulative rainfall, shown in Fig. 5, was subtracted from the water level graph. As precipitation was not measured daily, it was subtracted during those periods when the lake level was obviously rising rapidly. At any one place on the curve, an error could be produced involving the rainfall during that period over which it was last measured, but not for the periods before. The effect of evaporation was applied to the water level curve in much the same manner as the rainfall except that it was added rather than subtracted.

The curve produced when the effects of rainfall, evaporation, and pumping are removed is presented in Fig. 6, along with actual water level. The water surface level in the adjusted curve changed less than 0.3 inches from August 14 through September 17, when pan evaporation was no longer measured because of ice formation in the pan. From examination of the curve, a few errors seem apparent. For one, it seems that the estimation of evaporation may possibly be lower than it should be, since the curve drops slightly during the warmer period of the study. It is also obvious that recharge from the active layer near the lake after rainfall was not taken into effect. During light precipitation this is probably not important, but after an intense rainfall such as occurred on August 30, 1970 (0.69 inches), a rise occurs in the connected curve over the next three or four days.

During the pumping, which in each case lasted about six hours, water levels in the test pits and well points were measured at hourly intervals. Drawdown curves were plotted for each series of test pits. For example, the free water surfaces for test pits 1-4 before and immediately after pumping on September 9, 1970 and September 16, 1970 are shown in Fig. 7.

The abrupt change in slope of the drawdown curve at the interface of the silt and peat indicates that it is the relatively impermeable silt which controls groundwater flow rather than the existence of permafrost.

After the first pumping test, the lake level rose only 0.15 inches in one week, and a portion of this was probably caused by rainfall. After the second test, the water level was monitored for ten days and a total water level rise of 0.7 inches was recorded. Approximately 0.4 inches of precipitation occurred during the same period. The slight additional rise was very likely caused by recharge from the shallow peat layer surrounding the lake.

The water balance and effect of the pumping tests on the lake level strongly indicates that there is probably no connection between the lake and any large groundwater source, as lake level depended almost completely on the volume of water pumped from it. Although the thaw pond was undoubtedly formed by the degradation of permafrost and therefore owes its existence to it, it seems probable that the relatively low permeability of the silt in which the pond lies accounts for its isolation from the adjacent groundwater system.

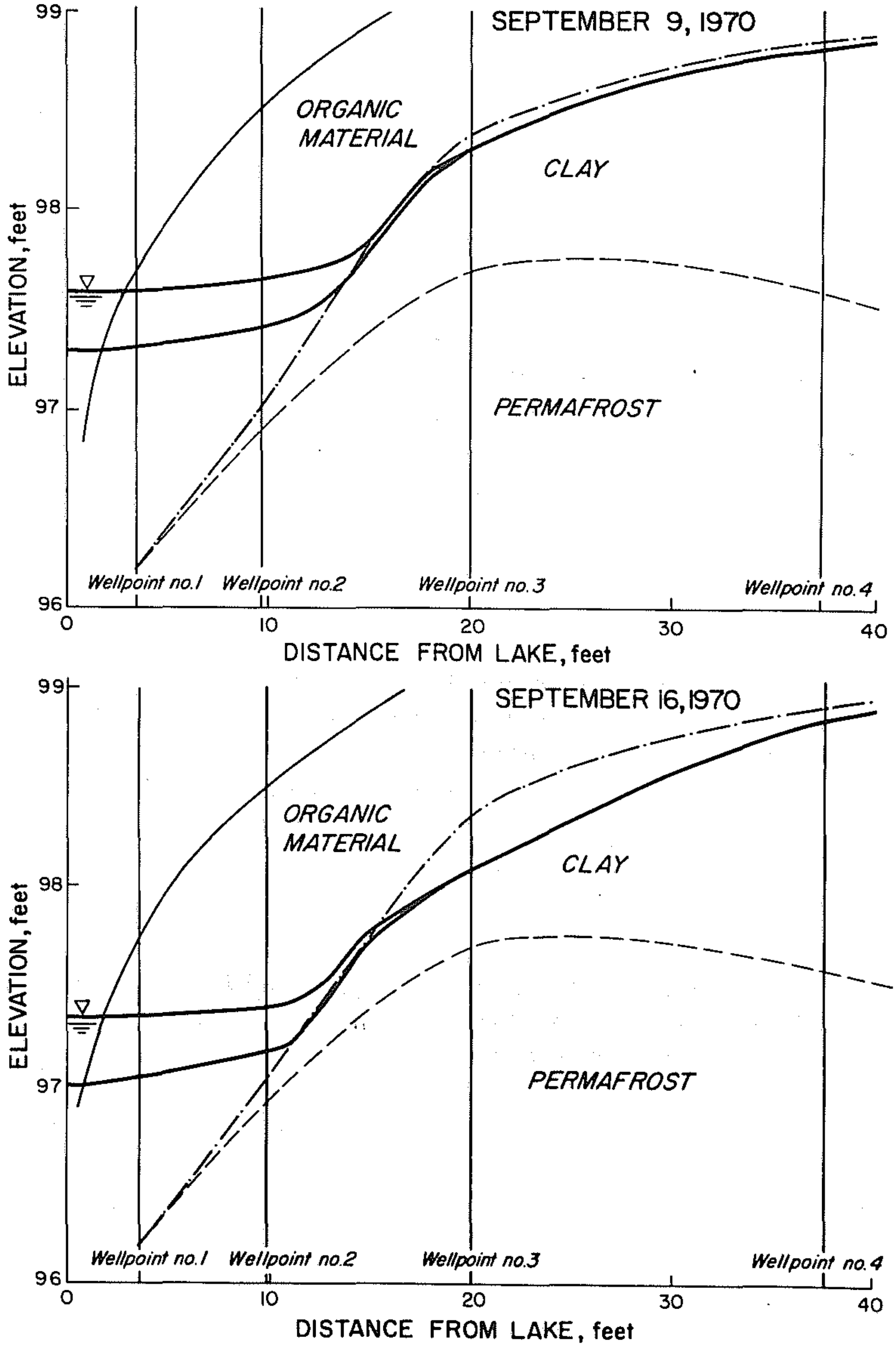



*Fig. 7. Drawdown in pits 1-4 as a result of pumping on September 9 and September 16, 1970*

## SUMMARY

This investigation was concerned with the study of the water balance of a small thaw lake and its relationship to other lakes in the same area. By pumping water from the lake, a response was induced which allowed study of the dynamics of the active layer surrounding the lake and determination of the amount of groundwater recharge and interconnection of the lakes.

From the results of the drawdown tests, as well as from the climatological data gathered, it was concluded that there is little or no hydraulic connection between the lake and any possible groundwater system.

The pond probably routinely fills with water during the spring runoff. After this period the level is essentially controlled throughout the rest of the season by rainfall and evaporation. A small amount of recharge occurs from the shallow peat layer around the lake after intense rainstorms. There appears to be no hydraulic connection between the pond and the groundwater system below the permafrost, or between ponds above the permafrost, because of the relatively impermeable silt.

# LITERATURE CITED

Cederstrom, D. J. (1963). Groundwater resources of the Fairbanks area, Alaska. Geological Survey Water Supply Paper 1590, U. S. Government Printing Office, Washington, D.C.

Johnston, G. H. and Brown, R. J. F. (1964). Effect of a lake on distribution of permafrost in the Mackenzie River delta. *Arctic*, V. 17, No. 3, 162-175.

Kane, D. L. and Slaughter, C. W. (1973). "Recharge of a Central Alaska Lake by Subpermafrost Groundwater," North American Contribution to the 2nd International Permafrost Conference, Yakutsk, U.S.S.R., U. S. National Research Council.

Péwé, T. L. (1958). Geology of the Fairbanks (D-2) Quadrangle, Alaska. Map G.Q.-110, Geologic Quadrangle Maps of the United States, U.S.G.S., Washington, D.C.

Tuck, R. (1940). Origin of muck-silt deposits at Fairbanks, Alaska. *Geol. Soc. America Bull.*, V. 51, 1295-1310.

Wallace, R. E. (1948). Cave-in lakes in the Nabesna, Chisana, and Tanana river valleys, eastern Alaska. Journal of Geology, V. 56, No. 3.

World Meteorological Organization (1970). *Guide to Hydrometeorological Practices*, 2nd. Edition WMO-No. 168 T.P. 82, Secretariat of the World Meteorological Organization, Geneva, Switzerland.