IV.3. EFFECT OF A LAKE ON DISTRIBUTION OF PERMAFROST IN THE MACKENZIE RIVER DELTA

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(Summary)*

INTRODUCTION

The thawing effect of water in contact with permafrost is a problem of major concern to engineers engaged in northern construction. Improper drainage which allows water to pond adjacent to or under structures such as buildings, roads or airstrips, nearly always results in an increased depth of thaw of the perennially frozen ground. In many cases the performance of the structure is seriously affected even to eventual failure. The degradation of permafrost by water is of even greater concern when dykes or dams are constructed on perennially frozen ground and large areas are flooded by the water impounded behind them. The design and performance of these structures and the stability of the underlying frozen foundation material is dependent on a knowledge of the rate at which thawing will take place and the depth to which the perennially frozen ground will thaw. There is little information presently available, however, to indicate the magnitude of these factors. Mathematical analyses can and have been made, in some cases, but because of complex boundary conditions and lack of pertinent data, such as mean annual ground and water temperatures and the geothermal gradient, it is difficult to obtain an exact picture of the effects which might be expected and are of prime importance to the designer.

One method of improving knowledge of the thawing effect of water on permafrost, however, and of providing some guidance for future engineering design is by studying the present level of permafrost under natural bodies of water in the north, such as lakes and streams. Members of the Division of Building Research carried out a drilling programme in April 1961, therefore, to determine the distribution of permafrost under and adjacent to a lake in the Mackenzie River delta near the new townsite of Inuvik, N.W.T.

DESCRIPTION OF SITE

The Mackenzie River delta, which is approximately 50 miles wide and 100 miles long, is a low, flat area interlaced and dissected by numerous small meandering channels and is spotted with thousands of stagnant lakes.

* The full paper will be published by the Division of Building Research, National Research Council, Ottawa.

One of the lakes was selected for investigation following a preliminary study of aerial photographs and a field reconnaissance in 1960 of a portion of the delta within a 10-mile radius of Inuvik (Figure 1). This lake, located about 5 miles southwest of the town is approximately circular, having a diameter of about 900 feet. Like all delta lakes, it is shallow, being only about 4 feet deep at its centre (Figures 2 and 3).

The dense forest vegetation around the lake studied is typical of the climax developed in the lower valley and delta of the Mackenzie River. The dominant species is white spruce, the largest trees growing to a height of 50 feet. Also present are black spruce, willow and alder with scattered stands of tamarack. The largest trees growing in the surrounding area and close to the edge of the lake are as much as 220 years old. The apparently continuous moss cover is about 1 inch thick.

In making such a study it was considered important to choose a body of water that had been in existence for a sufficient period of time to have approached a condition of thermal equilibrium with the frozen ground beneath. It was realized that the selection of a delta lake is somewhat questionable because it is situated in what is essentially an old river bed and that there might be considerable effect on the occurrence of permafrost due to the large number of lakes and channels in the immediate vicinity. For such a study, however, this situation offered the advantages of accessibility from Inuvik and easier drilling and sampling because of homogeneous soils conditions.

DESCRIPTION OF INVESTIGATION

The investigation consisted primarily of a drilling and sampling operation whereby holes were bored to various depths at four locations (Figure 2). Continuous coring was carried out for the full depth of Holes Nos. 1 and 3 and good undisturbed cores of most of the materials encountered were obtained. Representative samples were taken for identification and classification testing of the soils, moisture (ice) content determinations, pollen analysis and carbon-14 age determinations.

A number of hand probings were made to determine the extent of the permafrost table beneath the edge of the lake. Surveys were carried out on a grid pattern on the lake to obtain snow depths, ice thickness, water depths and bottom contours (Figure 2). Two thermocouple cables were also installed as part of the study to measure ground temperatures - one 100 foot cable was placed in Hole No. 3 (132 feet west of the lake) with sensing junctions at the 25, 50 and 100 foot depths, and a 200 foot cable was placed in Hole No. 4 (550 feet from the lake) with points at 5 foot intervals from the ground surface to 25 feet, and at the 50, 75, 100, 150, and 200 foot depths.

DRILLING AND SAMPLING

A standard type diamond drill equipped with hydraulic feed was used to drill and sample the various materials encountered (Figure 4). The presence of permafrost, and the subnormal air temperatures which occurred during April, greatly complicated the drilling and sampling operation. Water, obtained from the lake at a temperature of 33°-35°F, was used as a circulating fluid except for one unsuccessful attempt to use arctic grade fuel oil. When using water, drilling techniques had to be modified slightly and great care taken to prevent freezing of equipment in the hole.

Double tube core barrels were used to obtain undisturbed cores of the perennially frozen ground. Two-inch diameter cores were taken from the ground surface to a depth of about 100 feet. Below this, 1-inch diameter cores were obtained. In the hole at the centre of the lake, where no frozen ground was encountered, samples were obtained using a piston-type tube sampler to about 120 feet. Below this depth a double tube core barrel was used giving 1-inch diameter cores.

DISCUSSION OF RESULTS

The drilling investigations showed that the sediments beneath the centre of the lake (Hole No.1) were unfrozen to bedrock at a depth of 230 feet. On the other hand, permafrost did occur for the full depth of each of the three holes west of the lake (Figure 5a). These observations were substantiated by ground temperature measurements taken in May 1961 which are plotted in Figure 6.

The hand probings showed that the permafrost table extended out from shore under the edge of the lake and sloped steeply down (Figure 5b). Ten feet from the bank, the permafrost table occurred 15.5 feet below the ice surface; 12 feet from the shore - at a depth of 19.7 feet; and, at 15 feet, was greater than 22 feet below the ice.

From these observations, it is evident that the lake, although quite shallow and of small dimension, has a very marked influence on the distribution of permafrost. It is probable that the bottom of the thaw basin under the lake is located in the bedrock some tens of feet beneath the sediments. The thawing effect of the lake is confined, however, to the ground lying under the lake as evidenced by the presence of permafrost under the shoreline. The thermal effect of the lake extends into the surrounding area for some distance away from the shore as evidenced by the ground temperature observations.

Extrapolation of the two temperature profiles, assuming a straight-line gradient, produces a thickness of permafrost of about 250 feet at Hole No. 3 (132 feet west of lake) and about 300 feet at Hole No. 4 (550 feet west of lake). It is assumed that the permafrost shelves under the edge of the lake in the form of a wedge with its base curving back and downwards toward the shoreline.

The deep thaw basin under such a small and shallow lake suggests that the present environmental conditions and characteristics of the lake have prevailed for a long period of time. This assumption is supported by several features of the lake observed in the Spring of 1961. The shoreline appears to be stable as evidenced by the presence of trees as old as 220 years. It appears that flooding of the lake and surrounding area occurs at intervals of a few years but probably does not occur every year. Such flooding occurred in May 1961 when the water in the Mackenzie delta reached a record high level. Previous flooding is indicated by two features. Firstly, the moss cover is very thin and poorly developed - spring flood deposited material, killing or hindering its growth. Secondly, silt marks on tree trunks indicate an extreme high water mark about 5 feet above the present ground surface - i.e., about 20 feet above the winter ice level of a main delta channel nearby.

Observations of ice thickness and water depth in the spring of 1961 suggest that it is unlikely that the lake freezes to the bottom, even during the most severe winter. As a result, a layer of water is continuously in contact with the underlying sediment, thus maintaining a thawed condition in them. During the winter of 1960-61, air temperatures and snowfall were below normal, a situation most conducive to thick ice formation in lakes. Nevertheless, the lake, although only about 4 feet deep, was not frozen to the bottom. In April 1961, the ice cover was about 2 1/4 feet thick and the average depth of water was 1 1/2 to 2 feet.

Three main conclusions can be stated regarding the effect of the lake on the distribution of permafrost. Firstly, the existence of the lake in its present form has caused the formation and maintenance of a thaw basin several hundred feet deep. Secondly, the thawing effect of the lake is confined to the ground lying under the lake as evidenced by the presence of permafrost under the shoreline. Nevertheless, the increasing thickness of the permafrost inland from the shore indicates that the thermal effect of the lake extends for some distance beyond its perimeter. These conclusions are supported by an analysis of the thermal situation at the lake using methods reported in the following paper by W. G. Brown (Figure 5c).

In conjunction with the determination of the permafrost distribution by drilling, undisturbed core samples were obtained from

Holes Nos. 1 and 3 giving the following soil profile:

0' - 100' -	Thinly stratified sandy silt with layers of decomposed organic material throughout. The content of organic material was particularly high at the bottom of this layer.
100' - 180' -	Fine to medium sand with thin layers of organic material, spaced at irregular intervals throughout the full depth.
180' - 230' -	Very dense clay containing scattered small pebbles from the 206 to 221 foot depth and a high concentration of pebbles in the bottom 9 feet above bedrock. No pebbles were found in the top 26 feet of the clay stratum.
Below 230' -	Bedrock (dolomitic limestone).

Visible ice segregation in the form of horizontal and irregularly oriented layers was confined mostly to the top 30 feet. Below this depth, the soils were solidly frozen but only random thin ice layers, occurring in predominantly silty or clayey soil, were noted. Sandy material was well bonded by ice not visible to the eye. Moisture content determinations indicate a decrease with depth.

The soils profile revealed by drilling and sampling suggest that the subsurface materials are of glacial and post-glacial origin. It is possible that the clay occurring below the 180 foot depth is till overlain by marine clay. The change to sand containing thin layers of organic material at the 180 foot depth may indicate the beginning of deltaic deposition continuing to the present. The formation of permafrost began probably with the initiation of deltaic deposition.

Further investigations of the distribution of permafrost under lakes are proposed for the near future.

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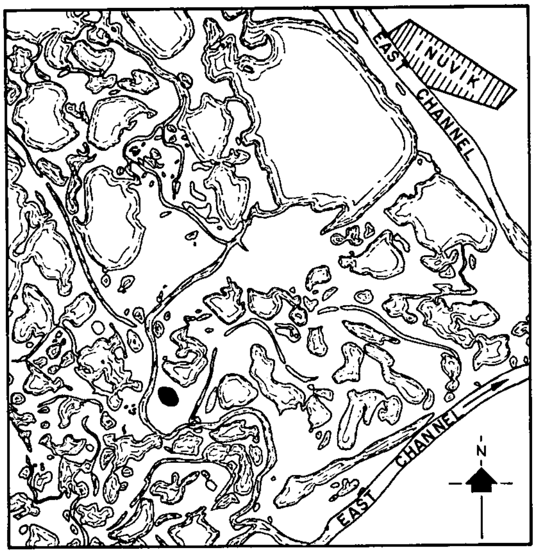
Discussion

R. G. Howard reported that at Inuvik, N.W.T., probings beneath the ice in Twin Lakes revealed the existence of permafrost at a depth of 9 feet below the lake bottom. He asked how this related to the findings of the authors. G.H. Johnston stated the possibility that Twin Lakes freezes to the bottom and the proximity of a large perennially frozen land mass might be the cause of permafrost existing at such a shallow depth.

J. M. Robinson wished to know if there was any indication of decaying vegetable matter in the lake bottom sediments. Johnston replied that there was evidence of decaying vegetation at the bottom of the lake.

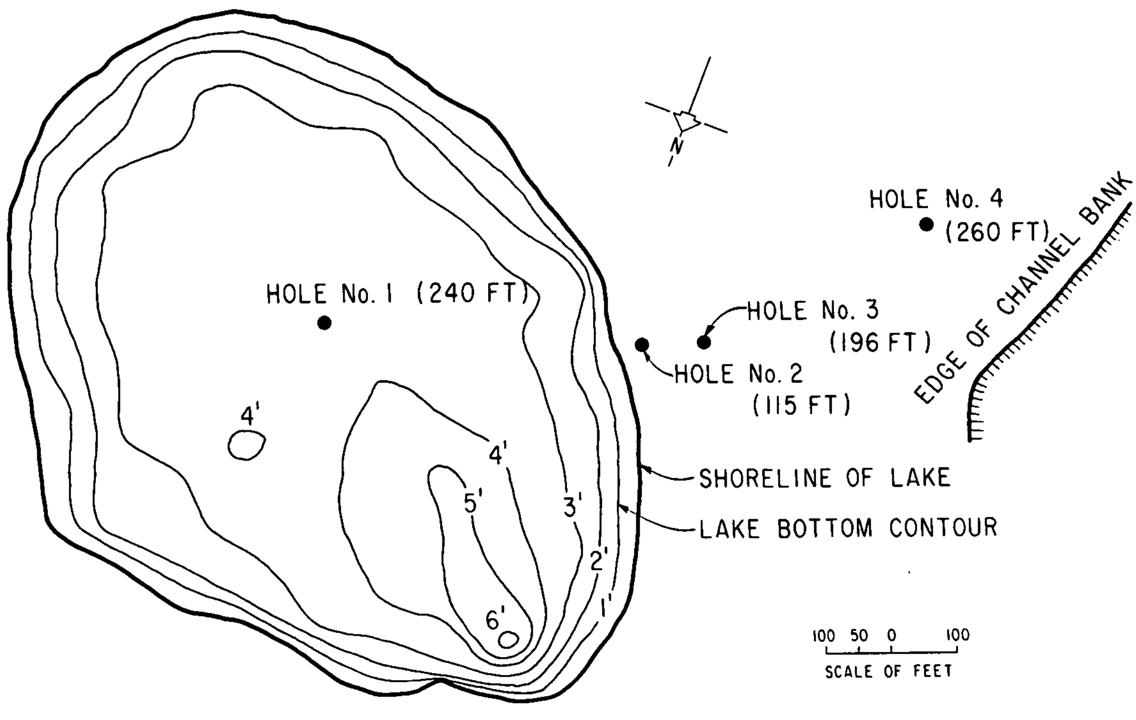


MACKENZIE DELTA LAKE INVESTIGATIONS

LOCATION OF LAKE
(shown in black)

1/2 0 1
SCALE OF MILES

FIGURE 1



(DEPTH OF HOLES IN BRACKETS)

MACKENZIE DELTA LAKE INVESTIGATIONS

LAKE BOTTOM CONTOURS AND BOREHOLE LOCATIONS, APRIL 1961

FIGURE 2

Fig. 3 Aerial view of Mackenzie River delta lake investigated April 1961. View looking east from about 1000 feet altitude taken July 1960. Note dense forest vegetation around lake (right centre).

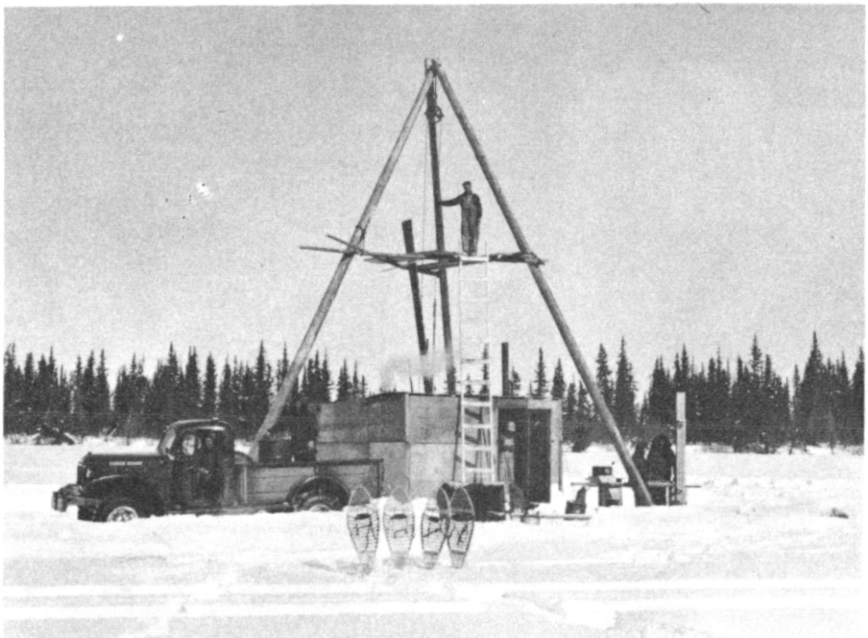
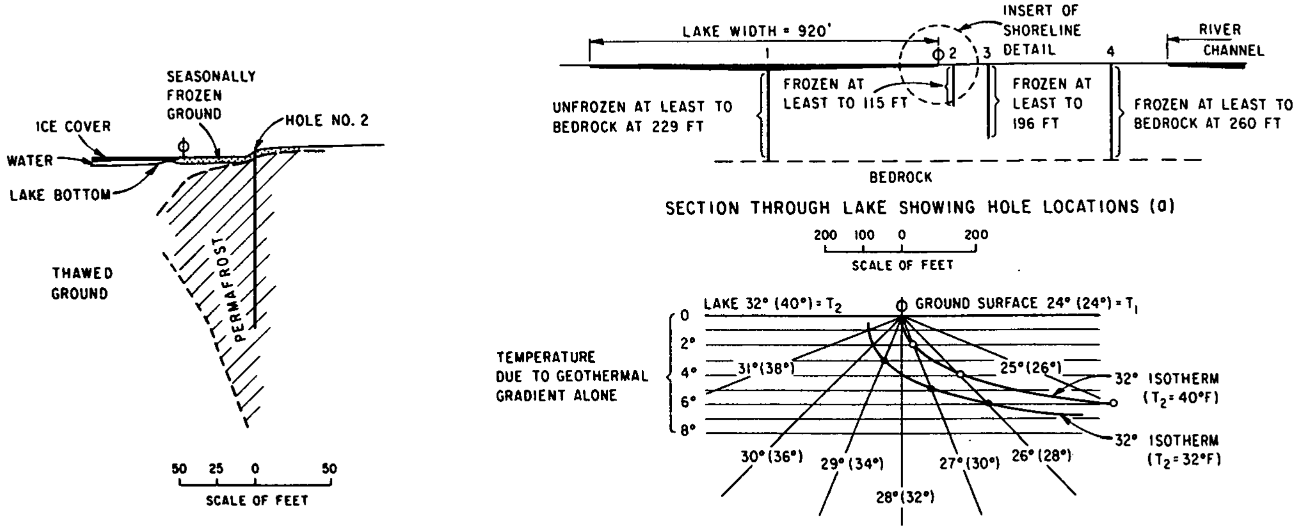


Fig. 4 Drill set-up at Hole No. 1 (centre of lake). Note core sampling table to right of drill shack and depth of snow cover.



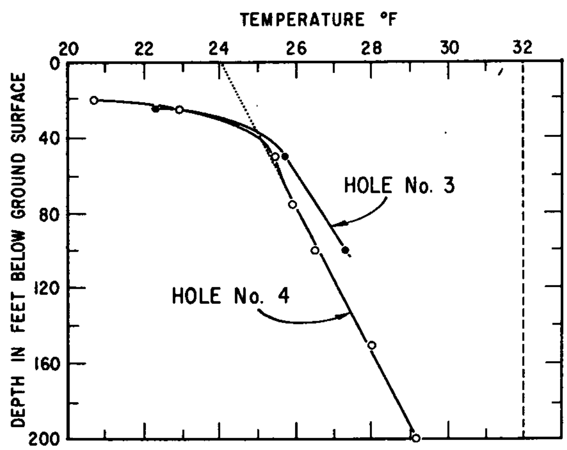
SHORELINE DETAIL (b)

APPROXIMATE POSITIONS OF THE PERMAFROST BASE NEAR THE LAKE EDGE (c)

MACKENZIE DELTA LAKE INVESTIGATIONS

ϕ SYMBOL INDICATES POSITION OF LAKE-LAND JUNCTION

FIGURE 5



MACKENZIE DELTA LAKE INVESTIGATIONS

GROUND TEMPERATURES – MAY 1961

FIGURE 6