II. 5. GROUND WATER IN THE PERMAFROST REGIONS OF THE YUKON, NORTHERN CORDILLERA AND MACKENZIE DISTRICT*

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In a discussion of the hydrogeology of a large area comprising the Mackenzie District and the Yukon Territory, it is, at present, possible to make only broad generalizations as to groundwater availability. The presence of permafrost in this area has often deterred engineers from contemplating the use of groundwater as a source of water supply. There are, therefore, little water well drilling data available for use as concrete evidence of the presence and direction of movement of groundwater in particular localities. Data available on climate, run-off, and geology are, however, sufficient to show that groundwater is present throughout areas of discontinuous permafrost and that rocks are saturated in the same manner as in humid temperate regions. It is only in some areas of continuous permafrost that groundwater flow is unlikely.

For descriptive purposes, the northwest can be classified into three type regions; the regional selection being based on geology and climate. The first region is the Precambrian rock region in the east part of the Mackenzie District. The second region comprises two areas of sedimentary plains which are, (a) the Mackenzie plain and (b) the Porcupine plain. The third region is the Cordillera which occupies much of the area west of the Mackenzie River.

THE PRECAMBRIAN REGION

Climatically this is a dry sub-humid region where potential evapotranspiration calculations indicate a moisture deficiency during the summer time (5). Precipitation ranges from 8 inches to 10 inches per year. In common with many other parts of Canada, the only effective period of groundwater recharge occurs during the Spring break-up when the snow melt contributes to infiltration in areas where permafrost is not present. The region is poorly drained as indicated by the abundance of lakes. Streamflow data are non-existent on some of the main rivers, such as the Coppermine, so it is not possible to make any estimates of groundwater flow to rivers or of bank storage.

In the areas where continuous permafrost exists, field

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evidence indicates that infiltration of water does not occur. This is apparent after observing the frost-thrusting of jointed rocks in which water has frozen while entering the joint system at the surface and caused heaving of the rocks. Further evidence of the absence of infiltration is provided by the presence of intermittent streams in valleys such as the Coppermine where dry creek beds, typical of an arid land, are visible. These creeks are dry immediately after surface water run-off has been completed because any seepage which could occur in these areas of continuous permafrost is influent. Other evidence for the absence of infiltration is provided by mines which are usually dry, except where fracture zones permit influent seepage of water from surface reservoirs such as nearby lakes.

Locally, in a few places referred to as being within areas of continuous permafrost, there are reports of springs which build up extensive ice-sheets during the winter. Tyrrell commented on these and named them crystocrenes (ice fountains) (8). Douglas and later authors have also observed and described these features (2). It is possible that these springs are the result of seepage from a lake or creek located at a higher level.

The rocks of the region are igneous, metamorphic and sedimentary, and the only possible movement of groundwater is through joints and fissures in rock and by permeation through unconsolidated sands. Fractures rarely extend to a depth of more than two hundred feet; thus any effective groundwater flow must be near surface if present at all. Many of the rocks are unfractured thus preventing groundwater movement. Although rock outcrop is extensive, there are also many areas covered by glacial drift and muskeg.

The Precambrian region may therefore be classified as one where groundwater flow is very small and where the only effective source of groundwater for domestic supply is in alluvial or glacial sands adjacent to streams or lakes. In a few localities, adequate groundwater supplies for a home could be obtained from wells drilled into jointed rocks that are not frozen and which are near a surface water supply. The only wells that have been used or attempted in the region have been at construction camps where sand points have effectively supplied water. A deep diamond drill hole was once put down at Rae, N.W.T. but this was a failure because it was drilled in unjointed granite.

THE PLAINS REGION

(a) The Mackenzie River plain is climatically similar to the Precambrian region in that it is also within a dry sub-humid zone. Precipitation is slightly higher than in the Precambrian region ranging from 10 to 12 inches per year. Run-off data are meagre or non-existent. A groundwater level recorder was recently installed at Pine Point south of Great Slave Lake, which will record the times of groundwater recharge occurring generally at the time of snowmelt.

Geologically the plain is composed of flat-lying sedimentary rocks consisting mainly of limestones, dolomites and shales. The geology of most of the plain has been mapped at the reconnaissance scale. Some of the carbonate rocks locally contain solution channels through which there is considerable groundwater flow; but for the most part groundwater flow is along joint planes. Good local permeability is developed within some limestone reef and sandstone formations. The region differs from the Precambrian region in that overall permeability of the rocks is higher and because groundwater flow can occur at much greater depths in a system of sedimentary rocks.

Data obtained from observation of springs and from chemical analysis of river waters show that lakes and rivers receive groundwater by effluent seepage throughout the entire region except in areas of continuous permafrost. Thus most of the land south of the Arctic Circle has groundwater movement towards the rivers.

A typical area where springs are visible is along the south and northwest shores of Great Slave Lake where seepage of water that is high in sulphates and chlorides is seen at localities such as Sulphur Point, High Point and Windy Point. The temperature of waters in these small springs is 37°F. Groundwater outflow to lakes also occurs along the line of the Palaeozoic-Precambrian contact between Great Slave Lake and Great Bear Lake. This can be seen in Lac la Martre and Lac Tempier, and lakes along this line are the places of natural groundwater discharge. It has not been possible to determine if this seepage occurs north of Great Bear Lake because that area is heavily drift-covered.

Chemical analysis of river waters also reveals the effect of groundwater flow from the near surface muskeg waters and from deeper flow in the underlying carbonate rocks. The near surface flow, known as interflow, is water that has received a typical red colouration from organic matter in muskegs. Many rivers receiving waters from the swampy areas of the Mackenzie plain have this red colouration which is greatest in the summer time. This can be seen in such rivers as the Redknife, Willow, Rabbitskin and Hay. The degree of colouration is measured by comparison with a standard cobalt-platinum colour scale. Hay River has a high colouration throughout the year (6); but the colouration diminishes during the winter with the decrease in interflow, and it is probable that sampling of similar rivers would show a diminution of colour in winter.

The presence of deeper groundwater flow toward rivers is indicated by chemical analyses of such rivers as the Little Buffalo which is high in sulphates, and also by rivers such as the Saline River and Vermilion Creek south of Norman Wells,N.W.T. which are rivers with highly mineralized waters that have been derived from groundwater flow.

Springs are present along the main channels of drainage such as the Mackenzie River; and flowing water wells have been drilled during oil exploration work along the shores of the Mackenzie (3). This phenomenon is to be expected in an area of groundwater discharge.

Water well drilling has been attempted at some settlements in the Mackenzie plain. The most northerly operating well is at Wrigley, N.W.T. airport. Drilling at Fort Good Hope, N.W.T. was a failure because the fine-grained glacial drift was frozen and deeper drilling into the underlying limestone would have yielded saline waters which are difficult to demineralize with the present arrangements in small settlements. Exploration holes further north in the valley have encountered water in unfrozen gravels.

Drilling has also been carried out at Fort Smith, N.W.T. and Hay River, N.W.T. At both places the high mineral content of the groundwater has prevented any extensive development, although a well is used at Fort Smith airport and wells are in use at Hay River.

In general, it may be said that waters in the Mackenzie plain will be high in sulphates at shallow depths, and highly saline at great depth and at places of upward leakage in valley bottoms. The only places where waters of low mineral content are to be found are in the alluvium adjacent to rivers where much of the water is derived from bank storage.

(b) The Porcupine plain is an area about which little information is available. It may, at present, be classified as an area where drainage is poor, permafrost is widespread and thick and the only groundwater potential is at considerable depths where saline waters occur in the sedimentary rocks.

THE CORDILLERAN REGION

Climatically this is a more humid region where precipitation ranges from 12 to 18 inches per year. Excellent run-off data are available on the flow of the Yukon River and some of its tributaries. These data have been obtained because of the interest in hydroelectric development in the region. Good estimates of groundwater baseflow and bank storage are, however, not possible because the rivers drain large lakes and because the precise gauging of river flow in winter is difficult. It is sufficient here to say that river valleys of the Cordilleran region, having deep deposits of till or of river sediments in unglaciated parts, are valleys in which there must be considerable bank storage of water between flood seasons.

The region comprises many mountain ranges, plateaux and valleys. These consist of folded sedimentary rocks in the Franklin, Mackenzie and Richardson Mountains. Towards the west there are various intrusive and altered rocks in the mountains and plateaux which make the geology more complex.

The potential aquifers in the region are glacial sands and gravels and alluvium. Locally some fractured rock formations are aquifers, such as fractured limestones and the Tertiary basalts.

The practical understanding of permafrost and the use of groundwater is of longer standing in the Yukon than in regions to the east. Historically the region has had two periods of development when engineers attended to these problems. The first period was at the end of the 1890's when mining in the perennially frozen gold bearing gravels of the Klondike was begun. The need to remove the muskeg blanket prior to thawing the ground was realized when dredging operations began. The technique of thawing the ground by cold water injection was adapted early in the 1930's. At an early phase in the work in the Klondike it was realized that water under pressure could exist under the perennially frozen gravels at those places where the depth to bedrock was great. Tyrrell commented on this when describing an artesian well in the Klondike (7).

The second phase of permafrost study and groundwater development in the region began in 1942 when the construction of the Alaska Highway was undertaken. Engineers of the U.S. Army realized that water wells would be a much more economic means of obtaining water for maintenance camps than from surface intakes; consequently they requested the U.S. Geological Survey to examine all potential camp sites and to advise where drilling should be undertaken. (The author is very grateful to the U.S. Geological Survey for making available the notes of Dr. C. V. Theis who successfully selected many sites for wells along the highway.) As a consequence of this work, wells were drilled along the highway and along the Canol pipeline route. Most of these wells have been abandoned with the closing of the camp sites; but the use of wells at small settlements has continued. In almost every location these wells obtain water from sand and gravel lenses within the valley bottoms. In the Shakwak Valley there are flowing wells at mileposts 1124, 1095 and at Destruction Bay which are reported to have been drilled through permafrost. The maximum reported thickness of permafrost at these wells is at milepost 1095 where frozen ground was reported to occur from 35 to 125 feet. The temperature in this flowing well was found to be just above 32°F, and the well has a heating coil in it because it is found that a build-up of ice occurs periodically. The heat coil is switched on when this occurs.

The highest capacity wells in the region are at Whitehorse, Y.T., and Dawson, Y.T. In Whitehorse, the wells obtain water which is mainly derived from bank storage in gravels adjacent to the river and this water is reported to vary in temperature from 39°F to 40.5°F. The wells are used in winter because the water is warmer than the river water which is the summer source of supply. The wells at Dawson obtain water by induced infiltration from the Klondike River; the bank of the river being composed of gravels at the location of the wells. The water is steam heated to 39°F prior to distribution along the water lines.

THE USES OF GROUNDWATER

Groundwater may be used for two purposes in these regions. 1. As a source of water supply for communities. 2. As a source of heat for communities.

1. A source of community water supply. There is no place in the north which is inaccessible to well drilling rigs and great advantage could sometimes be taken of the presence of drilling rigs in the north to put down wells where necessary. However, the effective use of wells will best occur when problems of well construction are properly overcome and when demineralization is practical in some locations.

The simplest type of well is the wire-wound stainless steel well point, usually of 2 1/2 inches diameter, which can be drilled or jetted down into alluvial or glacial sand aquifers. Wells of this type are far superior to dug wells; indeed the author has noticed that dug wells eventually deteriorate into nothing more than polluted holes in the ground because they always suffer from surface water contamination. Because surface infiltration in sands is rapid, it is essential to plan sewage disposal with care to avoid contaminating wells. In areas of thin discontinuous permafrost, it is possible to thaw the frozen ground by cold water injection.

Most high capacity aquifers in the north are in sands and gravels and it is essential to realize that wells in sands will require well screens. There are a number of reported well failures which have been caused by fine sands or silts entering a well and plugging the casing. This can be prevented if adequate precautions are taken by the engineer and the contractor to ensure the well is properly developed and made free of sand. This usually requires the installation of a well screen which is designed according to the grain size of the sands in the aquifer; and, in some cases, it is necessary to install a sand or gravel wall around the well screen. The techniques for doing this are standard procedure for experienced well drilling contractors; and although these techniques involve much higher capital costs for the installation of a well, they are nevertheless essential to provide satisfactory operation.

The waters in most glacial aquifers in all three regions can be chemically classified as calcium bicarbonate water which is entirely satisfactory for drinking. There is an increase in sulphate content with depth. All deep rock wells in the sedimentary plains are saline. The author wishes to point out that research into demineralization of saline waters has reached a point now where small domestic demineralizers are coming onto the market, and it may soon be possible to evaluate the use of these machines which may be of great value for treating water all year round in some northern localities. In some locations the high iron content of groundwater may make treatment necessary.

2. A source of heat for communities. The thickness of permafrost at any locality depends on the average annual temperature at the surface and on the geothermal gradient below the surface. The rate of increase of temperature varies with location and the methods of measuring the true geothermal gradient in bore holes are difficult owing to the time-lag before equilibrium is restored after drilling. Temperature logs are obtained in oil well drilling by lowering an electrode which consists of a length of platinum wire that is set in a rubber coating. The platinum is exposed to the mud in the drill hole where it rapidly acquires the temperature of the fluid in which it is immersed. Changes in temperature produce changes in resistance which can be correlated at surface to a change in temperature and this is recorded. The electrode is raised from the bottom of a hole to the top and a log of temperature against depth is recorded. Temperature logs are run in oil wells to distinguish sands from shales because the thermal conductivity of sands is greater than of shales; but these logs are used mainly to determine the top of the cement in a well after cement has been set. This record is obtained because the cement generates heat while setting. Some temperature logs have been run to determine permafrost thickness.

Reference to the temperature logs of some of the exploration wells drilled in the north shows that the thermal gradients are of the order of magnitude of one degree Fahrenheit per 65 feet of depth.

Thermal gradients of wells in the prairies vary from about 50 to 70 feet per degree Fahrenheit. Thus at depths of 5,000 feet temperatures of 130°F are common (1).

In some localities it is unnecessary to drill to these depths for warm waters. These places are the ones where rock faulting or other structural features have permitted groundwaters to percolate down to considerable depths and to emerge again in the form of thermal springs. The term "thermal spring" is used here because it applies to springs where the water has a temperature higher than the mean annual temperature; many thermal springs are hot springs.

Thermal springs rarely occur in isolation; usually there are several springs in one locality where water emerges from a number of rock fractures. At some springs most of the water is discharged into a river below the level of the bank so that most of the discharge is invisible.

All the thermal springs in the north are in the Cordilleran region. Among the best known springs in the Mackenzie District are those near Wrigley where waters ranging in temperature from 70°-80°F emerge from the Roche-qui-trempe-a-l'eau just north of the settlement on the east side of the river. The total flow of these springs is estimated at 70 gpm at the surface; most of the individual springs are, however, only seepages. Other large springs occur on Old Fort Island (mile 336 Mackenzie River); the temperature of these flows was found to be 53°F in August 1960 and the largest flow from one individual spring was estimated to be 300 gpm. Another large spring is at the entrance to the first Canyon of the South Nahanni River where springs emerge from silts, sands and gravels along the river bank. The warmest water recorded there was found to be 98°F. Hot springs occur further up the South Nahanni River in the Selwyn Mountains (4) and up the Flat Creek.

There are also a number of thermal spring locations in the Yukon Territory. The best known of these being the Takhini Springs (temperature 116°F) and various springs in the McArthur Range. In all these places the flow can be expected to be continuous throughout the year and the temperature is fairly constant.

The author has made reference to thermal springs and natural sources of heat within the earth, not only because they prevent the development of permafrost, but because they can be utilized. Although a heat pump does involve much capital cost and design difficulties, it is nonetheless a method of obtaining a lot of heat for a community throughout the year in a cold region. There are many places in western and northern Canada where this heat could be developed.

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Discussion

J.M. Robinson enquired whether water occurs in thermal belts in the mountains, to which the reader of the paper replied that there is little information on this but these thermal belts may be a source of hotsprings.

D.R. Nichols asked if the reader developed any hypothesis for the causes of the high salinity of deep subpermafrost groundwater that seems to characterize large areas in permafrost regions, not only in Canada but also in Alaska and Siberia. The reader stated that salt occurs in rocks at depths of several thousand feet as in the Prairies. As the water moves in the ground it should start out as a bicarbonate solution and end up as seawater. There is little salt water in unconsolidated sediments although some has been encountered south of Great Slave Lake. F.E. Crory commented that it is possible to have an aquifer resulting in artesian flow without the existence of a lake, to which the reader added that water occurs in mines beneath the permafrost in Canada's permafrost region. In the Con Mine at Yellowknife, N.W.T., water under high pressure was encountered at the 2,300 foot depth. The pressure which was measured was almost equal to the hydraulic pressure. Drainage was attempted without success and it appeared that the water had moved through thawed zones in the permafrost. Water was encountered also in Eldorado Mine at Port Radium, N.W.T. on Great Bear Lake. T. Lloyd remarked that Porsild reported groundwater in permafrost in the Disko Island area of west Greenland.