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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 64-39

GROUNDWATER HYDROLOGY AND WATER SUPPLY IN THE DISTRICT OF MACKENZIE, YUKON TERRITORY, AND ADJOINING PARTS OF BRITISH COLUMBIA

(Report, 25 figures, 3 plates, 14 tables)

L. V. Brandon

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Abstract

Groundwater is effluent in regions of discontinuous permafrost in the Interior Plains and the Cordillera. Groundwater flow in the Precambrian Shield is considered to be negligible. Winter baseflow records, chemical analyses of river waters, the presence of springs, and the local occurrence of halophytic flora provide evidences of groundwater movement in regions where no piezometric data from borings are available. Quantitative information on the groundwater contribution to the Upper Liard basin is obtained from the relation between discharge and specific conductance. This relation could be used elsewhere if more data were available.

Several thermal springs in the Cordillera derive their heat from deep circulation of meteoric waters. The heating of meteoric waters by an exothermic reaction with sulphides in rock may contribute heat to water in two springs discharging sulphate waters.

Groundwater is available for domestic and community supplies in the glaciated valleys in the Cordillera and in alluvium in other regions. It is used or can be used in many settlements and towns. Whitehorse and Dawson are the largest towns with well fields.

GROUNDWATER HYDROLOGY AND WATER SUPPLY IN THE DISTRICT OF MACKENZIE, YUKON TERRITORY AND ADJOINING PARTS OF BRITISH COLUMBIA

INTRODUCTION

This report is based on a reconnaissance study of the groundwater hydrology of the District of Mackenzie (527,490 square miles), Yukon Territory (207,076 square miles), and a small adjacent part of British Columbia.

Field work was carried out during the summers of 1960 and 1961, when the writer travelled by aeroplane, canoe, and car over part of the area and visited settlements, type locations, and places where springs are known to occur.

The report is in three parts. The first part outlines the groundwater hydrology of the area and indicates the effect of physiography and geology on streamflow. The second part describes a number of thermal springs in the area. The third part describes the availability of groundwater in many towns and settlements.

ACKNOWLEDGMENTS

Thanks are due to the following companies for information on wells and other groundwater data: Big Indian Drilling Co. Ltd., Calgary, Alta.; Consolidated Mining and Smelting Co., Trail, B.C.; International Water Supply Co. Ltd., Vancouver, B.C.; Stanley, Grimble and Roblin, Consulting Engineers, Edmonton, Alta.; and T.J. Stinson, Yukon Well Drilling, Whitehorse, Yukon. The U.S. Geological Survey kindly provided information on wells drilled during construction of the Alaska Highway. Mr. J.F.J. Thomas of the Industrial Waters Section, Mines Branch, Department of Mines and Technical Surveys carried out the chemical analyses of the water samples taken in the field.

PHYSIOGRAPHIC REGIONS

The area described is in parts of three physiographic regions: the Precambrian Shield, the Interior Plains, and the Cordillera. Geological Survey of Canada maps 1048A (1957)[1] and

[1] Dates and/or names in parentheses refer to publications cited in References.

Table I

Monthly and Annual Averages of Daily Mean Temperature (°F) at Nine Localities
(from Meteorological Branch Records, Department of Transport)

Locality \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dawson City	-16.0	-11.4	-06.0	28.4	46.6	57.0	59.8	54.6	43.1	27.4	0.20	-12.8	23.7
Whitehorse	05.2	06.8	21.3	31.8	45.5	54.6	56.2	53.6	46.0	34.4	14.6	03.2	31.1
Watson Lake	-07.6	-01.2	16.0	31.2	46.5	56.4	58.7	55.0	46.2	34.0	08.3	-07.8	28.0
Coppermine	-19.0	-20.5	-13.8	01.0	21.8	38.5	49.0	46.6	36.3	19.3	-03.8	-15.2	11.7
Fort McPherson	-19.2	-15.4	-06.4	11.4	34.0	52.6	58.4	53.1	38.8	20.0	-04.3	-15.4	17.3
Fort Simpson	-15.1	-09.4	04.3	25.4	44.6	57.4	62.4	57.7	46.6	30.8	06.0	-11.0	25.0
Port Radium	-13.0	-13.5	-01.3	13.4	34.0	47.2	53.6	50.8	40.9	27.4	06.3	-09.4	19.7
Yellowknife	-14.7	-14.2	01.4	17.3	38.9	53.3	60.9	56.7	44.9	31.0	07.2	-12.9	22.5
Fort Smith	-13.4	-08.7	05.4	26.2	45.2	55.4	61.2	56.8	44.2	31.7	09.8	-07.0	25.6

1055A (1958), on the scale of 1 inch to 20 miles, show the broad outlines of the bedrock geology of the area. The Glacial Map of Canada (Geol. Assoc. Can., 1958) shows the main features of the surficial geology of the area. Geological maps on the scale of 1 inch to 8 miles and on larger scales have been published for many parts of the area. Because the population of the area is small, hydrologic information on precipitation, evaporation, streamflow, groundwater levels, and soil moisture is fragmentary in some localities and non-existent in most.

Figure 1 shows the physiography of the area and outlines the principal drainage basins. Figure 2 shows the regions of the Precambrian Shield, the Interior Plains, the Cordillera, and areas of extensive alluvium, which fills some of the valleys in the Plains and the Cordillera.

CLIMATE

The area studied contains three climatic regions. The largest, comprising the southern two thirds of the area, is classified as subarctic, i.e. it has a cool, short summer with only one month to three months with mean temperatures above 50°F. The second region is tundra, i.e. the mean temperature of the warmest month is below 50°F but above 32°F; this region occupies the whole arctic coast and some of the high ground in the mountains. The third region is ice-cap, i.e. the mean temperature for all months is below 32°F; this region occupies the mountain peaks in the Cordillera (Atlas of Canada, 1958).

Monthly and annual averages of daily mean temperature for nine selected weather stations in the area are listed in Table I. The mean annual temperature ranges from 11.7°F to 31.1°F for those places where records are available. Throughout most of the area the mean annual temperature is below 32°F.

GROUNDWATER HYDROLOGY

HYDROLOGIC REGIMEN

In subarctic and tundra climates the rate of the hydrologic cycle differs from the rates of cycles of temperate and tropical zones because the intense cold of winter and the dramatic change from winter to summer result in days of great hydrologic activity after months of hydrologic dormancy. A brief description of the recharge, storage, and discharge parameters in this cold environment follows.

Recharge

Recharge is derived from precipitation in the form of rain and snow. The mean annual precipitation of the eastern and northern parts of the District of Mackenzie ranges from 6 to 12 inches per year. South of Great Slave Lake, in the Mackenzie Valley, and throughout most of the Yukon, precipitation ranges from 10 to 14 inches per year. Much higher precipitation occurs in some mountain districts, particularly in the St. Elias Range in southwestern Yukon.

All regions are usually snow-covered by the end of October. The snow melts toward the end of April in the Yukon Valley, throughout May in most of the District of Mackenzie, and during the first weeks of June along the Arctic Ocean coast and in the high ground in the Cordillera.

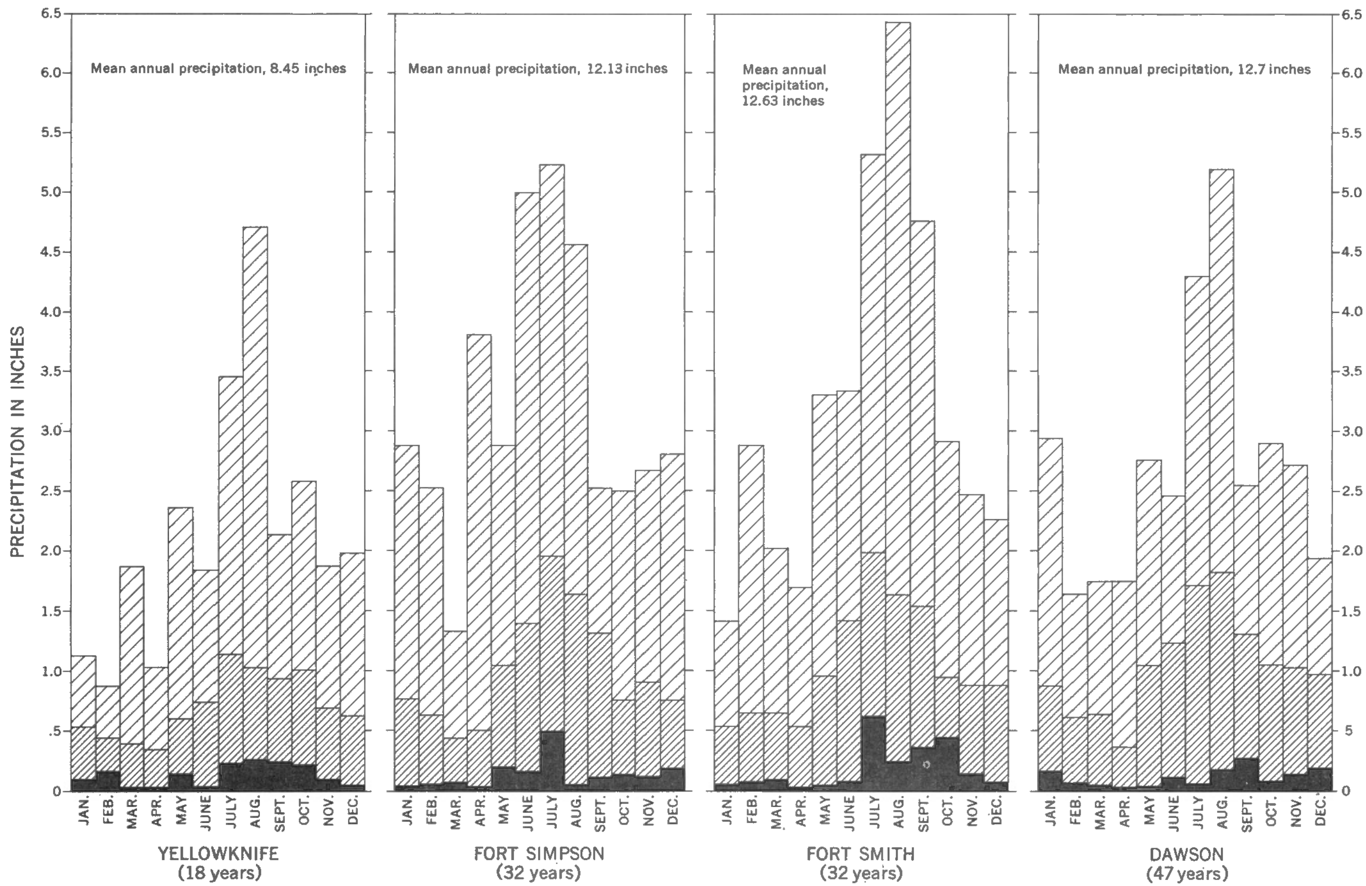
Figure 3 shows the maximum, mean, and minimum monthly precipitation at Fort Smith, Fort Simpson, Yellowknife, and Dawson. Precipitation is recorded as rainfall plus one tenth of snowfall. These data show that there are considerable differences in the monthly precipitation maxima and minima at these stations.

Figure 4 shows cumulative departure graphs from mean annual precipitation at Fort Smith, Fort Simpson and Dawson. These graphs indicate that Fort Smith had a period of lower-than-average rainfall from 1939 to 1951, and that Fort Simpson had a period of lower-than-average rainfall from 1937 to 1947.

Storage

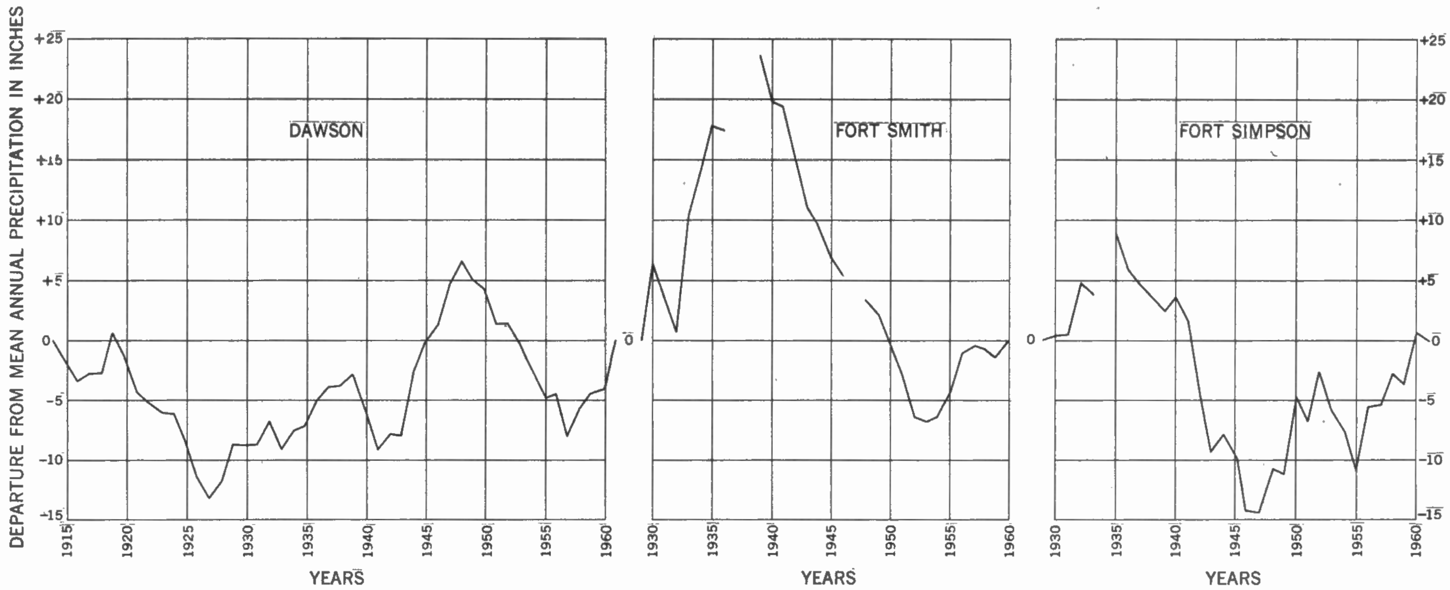
After recharge, water moves to storage and to discharge. Gravity, surface tension, and solar energy draw water to its point of discharge. Recharge is not a continuous process, but discharge is continuous, owing to the presence of storage facilities in every drainage basin.

There are four zones of water storage: lakes, groundwater, soil water, and glaciers. In each of these zones water is moving, sometimes very slowly, towards discharge. There are also interchanges between the zones of storage. Thus water from a glacier may move into a lake, whereas water from soil storage may move into groundwater storage.



Data from records of the Department of Transport, Meteorological Branch

Figure 3. Histograms showing maximum, average, and minimum precipitation



Data from records of the Department of Transport, Meteorological Branch

Figure 4. Cumulative departure graphs for the mean annual precipitation

Discharge

Evaporation and river run-off are the means of basin discharge. Evaporation, the main form of basin discharge, is discussed here. River run-off, the other means of discharge, is discussed with the descriptions of various river basins.

Evaporation may be divided into these four components: (1) evaporation from snow and ice; (2) evaporation from open water; (3) evapotranspiration from vascular plants; and (4) evaporation from tundra where the presence of rock outcrops and non-vascular plant vegetation can be expected to result in a particular evaporation pattern.

The first studies of evaporation in the District of Mackenzie were made by Sanderson (1948) who pointed out that the Mackenzie basin is moisture deficient, from high evaporation in summer.

Table II shows the monthly potential evaporation computed by the writer using the Thornthwaite (1948) heat index and nomograph from mean monthly temperature data at four weather stations.

Table II

Potential Evaporation (Inches)
(Calculated from Temperature Data from
Canada Department of Transport)

	Fort Smith	Yellowknife	Fort Simpson	Whitehorse
May...........	2.4	1.6	2.3	2.6
June	3.9	3.7	4.2	4.0
July...........	4.9	4.8	4.9	4.2
August	3.8	3.9	3.9	3.5
September	2.0	2.2	2.3	2.4
October........	-	-	-	0.5
Total..........	17.0	16.2	17.6	17.2

These potential evaporation computations give an indication of the order of magnitude of evaporation. Sanderson (1950) carried out field studies at Norman Wells in August 1949 to compare computed potential evaporation with field measurements of evaporation, and showed a good correlation for that month. Brown (1961) compared evaporation measurements in five places with different types of vegetation at Norman Wells and compared the results with the Penman (1956) formula. These field studies are still in progress.

Indication of high water loss by evaporation in summer can be seen north from Yellowknife where small closed lakes show varied vegetation rims around their edges. High water loss by evaporation is also revealed by inspection of river discharge records (discussed later).

Seasonal Recharge-Discharge Relationship

The climate of the area is such that the sequence of hydrologic events may be summarized by describing the main events of recharge and discharge at four different times during the year.

In February, recharge is in the form of snow and is stored on the land surface, lakes, and glaciers. Discharge approaches a minimum and is by river run-off under ice. The discharge water is derived from lake and groundwater storage.

In May, recharge reaches a peak and is in the form of melting snow and rain. This goes into all forms of storage. Discharge approaches a peak as snow and ice evaporation is at a maximum and evapotranspiration increases. River run-off rises with the discharge of melting snow and ice.

In August, recharge is in the form of rain and glacier melt. Discharge by evaporation declines from its mid-summer peak and river discharge starts to decline.

In November, recharge in the form of snow goes to storage above ground. Discharge by evaporation ceases. Soil water freezes and run-off once more draws solely on lake and groundwater storage.

Permafrost

Perennially frozen ground, known as "permafrost", is widespread throughout the area as a consequence of the extreme cold. The sources of heat above and below ground, together with the facilities for heat transfer, determine rock and soil temperatures. The heat sources above ground are solar radiation and back radiation. Therefore exposure to sun, cloud cover, temperature, and evaporation rate are among the factors that determine ground temperature. Also, vegetation, snow cover, texture, and moisture content of soil are among the factors that affect heat transfer on and in the ground. The source of heat below ground is the internal heat of the earth, and the transfer of this heat depends on the thermal conductivity of rock and the presence of groundwater. The internal heat source may be assumed to be constant at any one location during recent time; it is much less than solar radiation during summer, which varies greatly. Permafrost is aggrading in some locations and degrading in others because of changes in microclimate or land cover. Muller (1947) and Black (1950) have given extensive descriptions of permafrost, and Leggett, Dickens and Brown (1961) have outlined permafrost investigations in Canada.

Field Evidence

Field evidence for the presence of permafrost is usually obtained by drilling or digging. Periglacial features, e.g. solifluction, tundra polygons, and features of patterned ground described by Washburn (1956), and frost thrusting in jointed rocks described by Yardley (1951), are evidence of permafrost or relic permafrost. Permafrost in mines can be seen in abandoned drifts, which are lined with ice crystals and present a beautiful spectacle when seen in candlelight.

Permafrost phenomena associated with the freezing of percolating groundwater and the formation of ground-ice have been described in various forms in permafrost literature[1]; e.g. Tyrrell (1904) made one of the earliest descriptions of buried ice-sheets, which he named "crystophenes", and Muller (1959) described pingos (large frost mounds). Ground-ice in the form of various ice wedges can be seen in recently exposed cut-banks in some permafrost areas.

Seismic studies show that the presence of permafrost can be detected by the increased seismic velocity of frozen ground. G.D. Hobson (personal communication) found that frozen muck in the Klondike area had seismic velocities of 10,000 feet per second and the underlying frozen gravels had velocities of 14,000 fps. In unfrozen ground these velocities would be about 4,000 and 5,000 fps, respectively.

Distribution

The distribution of permafrost in Canada was first mapped by Jenness (1949) and a more recent compilation of the areal distribution of permafrost has been made by Brown (1960). The boundary

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[1]An annotated bibliography of Canadian permafrost literature has been made by Cook (1958).

of the approximate southern limit of continuous permafrost outlined by Brown is shown on Figure 2. Discontinuous permafrost occurs in the southern part of the area studied.

The depth of permafrost varies greatly. MacCarthy (1952) estimated a depth of 1,300 feet at South Barrow, Alaska. Misener (1955) estimated a depth of 1,280 feet at Resolute Bay, Cornwallis Island, N.W.T., and seismic work in the Isachsen-Deer Bay area (Hobson, 1962) may indicate greater permafrost depths there. Permafrost thicknesses are much less in areas south of the arctic circle and depend partly on distance from a river or lake and thickness of overburden. Lord (1951) recorded the presence and absence of permafrost in several mines. Data on rock temperature, which are available from logs run in oil exploration wells, only show minor fluctuations in thermal conductivity rather than rock temperature, because the drilling disturbs the temperature surrounding the bore-hole. Jenness (1949) recorded a thermal gradient of .0258°F per foot for borings at Norman Wells.

Groundwater in Permafrost

Groundwater may occur in three different zones in permafrost. Water is stored during the summer in the "active zone", which is the thawed zone above the permafrost and which varies from a few inches to about 3 feet in depth. Groundwater is present in thawed zones, "taliks", within permafrost. It may also be present below permafrost. These have been referred to as suprapermafrost, intrapermafrost, and subpermafrost groundwaters (Tolstikhin, 1941). In both the intrapermafrost and subpermafrost zones groundwater is moving slowly from a region of recharge to one of discharge. Flowing wells occur in some valley bottoms where drills have penetrated permafrost and reached subpermafrost waters.

Effect of Permafrost

There are various construction, hydrologic, and water-supply problems peculiar to a permafrost region. Construction problems have been described extensively in engineering literature, e.g. Pihlainen (1955).

The hydrologic effect of permafrost is that it restricts the movement of groundwater between local drainage basins and larger basins. Topographic depressions in regions of low relief retain water from surface run-off and the thawed water from the "active zone". The deep infiltration of these waters from high ground to large flow systems is restricted and the land surface depressions become small lakes formed from local flow systems. The presence of permafrost results therefore in a hydrologic paradox during summer in that such an area is semi-arid with low precipitation, yet contains myriads of lakes. The presence of dry creek beds indicates that run-off is rapid in permafrost regions of pronounced topographic relief owing to the absence of infiltration. The lack of infiltration combined with low bank-storage results in the presence of ephemeral streams, which carry off snow melt and rainfall only.

Water-supply problems peculiar to a permafrost region are described in the section on water supply, later in this report.

Groundwater Flow

Groundwater moves from a high fluid potential towards a lower fluid potential under the influence of gravity. Consequently topographically high areas are groundwater recharge areas and topographically low areas tend to be areas of groundwater discharge. The flow is of three types:

1. Intergranular permeation through unconsolidated rock, e.g. gravel, sand, and clay.
2. Joint, bedding plane, and fracture flow whereby water moves through the spaces between rocks along joints, fractures, and fault zones.
3. Solution channel flow whereby water moves through enlarged conduits that have been formed by dissolution of rock in a sedimentary stratum.

The rate of groundwater flow by intergranular permeation is described by Darcy's law, which may be written as:

$$V_z = -K\left(\frac{dh}{dz}\right)$$

where v represents velocity, k represents the coefficient of permeability peculiar to the granular material through which the water is moving, h represents the total head where total head equals the sum of elevation and pressure head (Hubbert, 1953), and z represents distance in the direction of flow. The ratio $-\frac{dh}{dz}$ is the hydraulic gradient.

The coefficient of permeability k can be calculated from laboratory tests on a sample taken from the field. The density and viscosity of the fluid passing through the intergranular space affect the velocity of flow. Therefore it is necessary to distinguish between k_o, which is the physical permeability constant depending

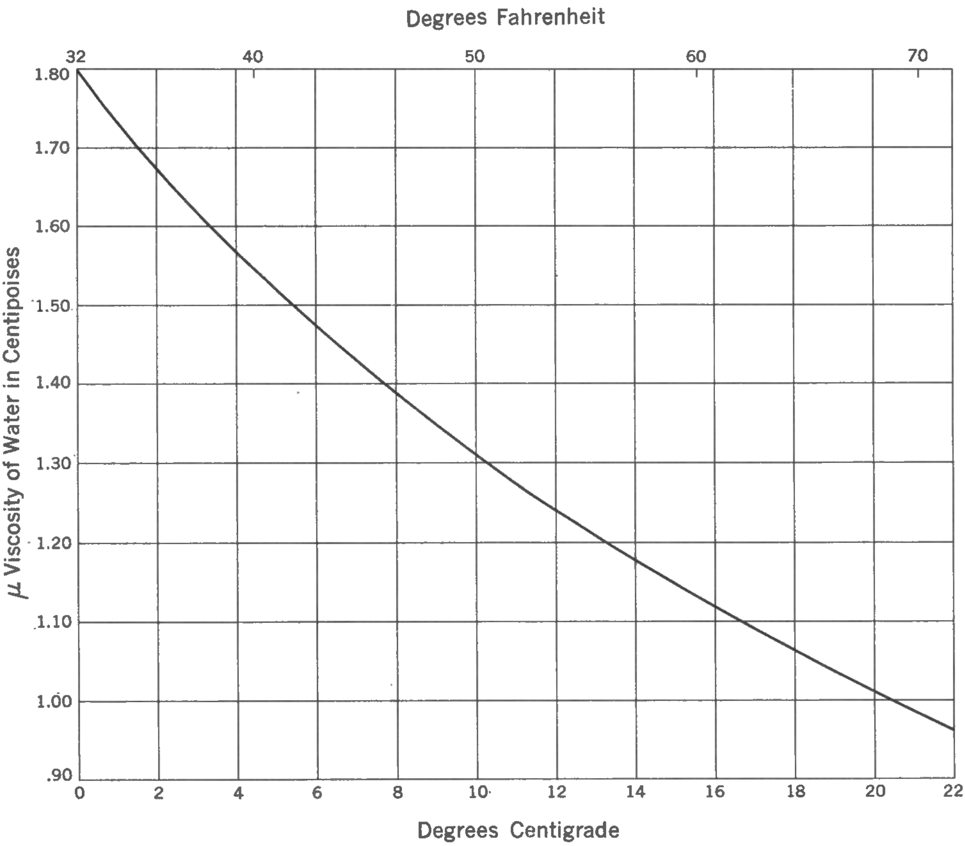


Figure 5. Relation between viscosity of water and temperature

on the shape, grain size, and structure of the permeable medium, and k, the overall coefficient of permeability. The relation between k and k_o is:

$$k = \frac{k_o \gamma w}{\mu}$$

where γ w represents unit weight of the fluid and μ represents viscosity (Muskat, 1946).

The Darcy equation corrected for viscosity of fluid should then be written:

$$V_z = \frac{k_o \gamma w}{\mu} \quad \frac{dh}{dz}$$

This adjustment is significant in a subarctic climate because the velocity can be seen to be inversely proportional to the viscosity of the fluid passing through the permeable medium.

Figure 5 shows the relation between viscosity and temperature. The groundwater temperatures in the area under discussion range from 32 to 40°F and have viscosities ranging from 1.55 to 1.79 centipoises. In temperate regions where groundwater temperatures are from about 50 to 65°F the viscosity ranges from 1.05 to 1.30 centipoises.

The flow of groundwater through rock joints and solution channels is also retarded by increased viscosity.

BASIN HYDROGEOLOGY

To find out if groundwater flow occurs and to find the effect of groundwater flow on hydrology it is necessary to bring together geology, river-discharge measurements, spring and river chemical analyses and drilling data for various basins. Consequently some river hydrographs and many river chemical analyses are presented in descriptions of particular basins. These are used to find out if there is evidence of groundwater flow, and they are compared to find out if the available data are typical of wider and similar regions.

Three basins are discussed in this report — the Great Slave Lake, Mackenzie River, and Yukon River basins (see Fig. 1). Discontinuous permafrost is present locally in the southern parts of these basins; continuous permafrost is present in the northern parts.

Great Slave Lake Basin

Great Slave Lake has a surface area of almost 11,000 square miles and is at an elevation of 514 feet. Lake levels are highest early in August and lowest in April. The maximum recorded difference in levels since measurement began in 1938 is 3.22 feet at Yellowknife, and 3.70 feet at Fort Resolution. Strong northwest winds in summer sometimes cause a high lake level at Fort Resolution. Barometric pressure differences over the lake also influence lake levels.

Drainage into the lake is from two different physiographic and geologic regions — the Precambrian Shield, and the Interior Plains. Drainage from the lake is by Mackenzie River. The mean annual flow of Mackenzie River at Fort Providence has been estimated at 170,000 cubic feet per second, the maximum outflow being of the order of 300,000 cfs and the minimum outflow 50,000 cfs (unpub. records, Water Resources Branch, Department of Northern Affairs and National Resources).

Figure 6 shows some of the streams, springs, and sampling points around Great Slave Lake.

Precambrian Shield

Topography — The eastern part of Great Slave Lake basin is a plateau with a myriad of lakes. Most lake levels are at an elevation between 1,100 and 1,400 feet, except on the west side of the shield, where lake elevations are lower. General relief north of the lake is moderate, though the terrain locally is rugged. Steep hills rise 500-800 feet out of the east side of Great Slave Lake. Rivers are fast flowing and have many riffles and small waterfalls.

Geology — Archaean rocks comprising basalts, andesites, and altered folded greywacke, quartzite, slate and arkose of the Yellowknife Group are the oldest rocks in the region. These rocks predominate in the Indian Lake district, in Gordon Lake and Beaulieu River valley, around the shores of Mackay Lake and around Yellowknife. However, granitic rocks of both Archaean and Proterozoic age are the principal rocks of this part of the Precambrian Shield. The general bedrock geology of the Great Slave Lake basin is shown on GSC Map 1055A (1958), on a scale of 1 inch to 20 miles, and in greater detail on other various geological maps on a scale of 1 inch to 4 miles.

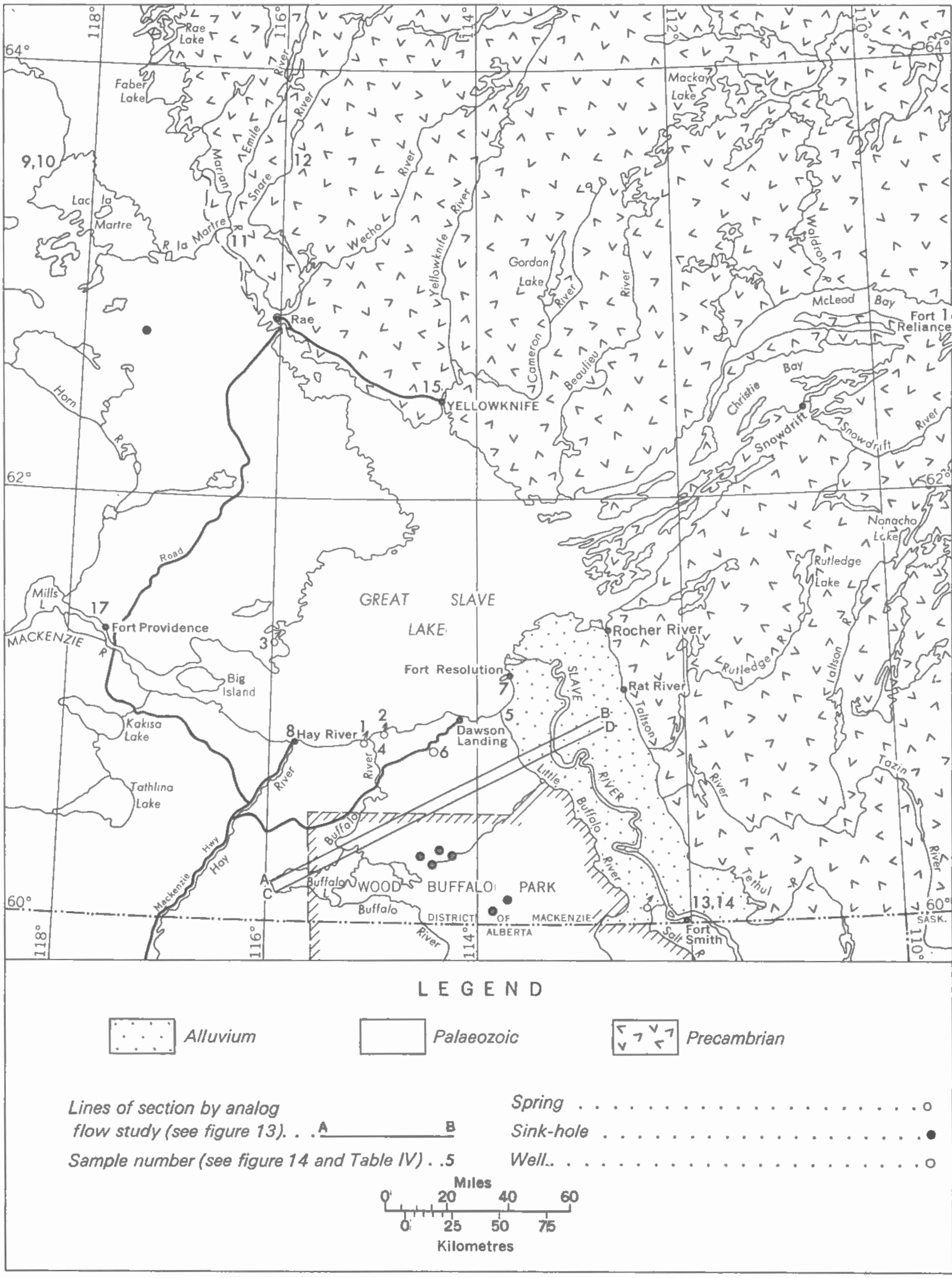


Figure 6. Location of springs, and sampling points for chemical analyses (see Table IV, and Figure 14)

The area has been glaciated and, as a result, the tops of hills and steep slopes are bare rock and most of the depressions are filled with glacial drift. Eskers, drumlins, and moraine are noticeable in many areas. Cobble beaches, lake terraces, and lake deposits are found on the west side of the shield, inland from and well above the present level of Great Slave Lake. The maximum reported elevation of these beaches is 1,050 feet (Kidd, 1936).

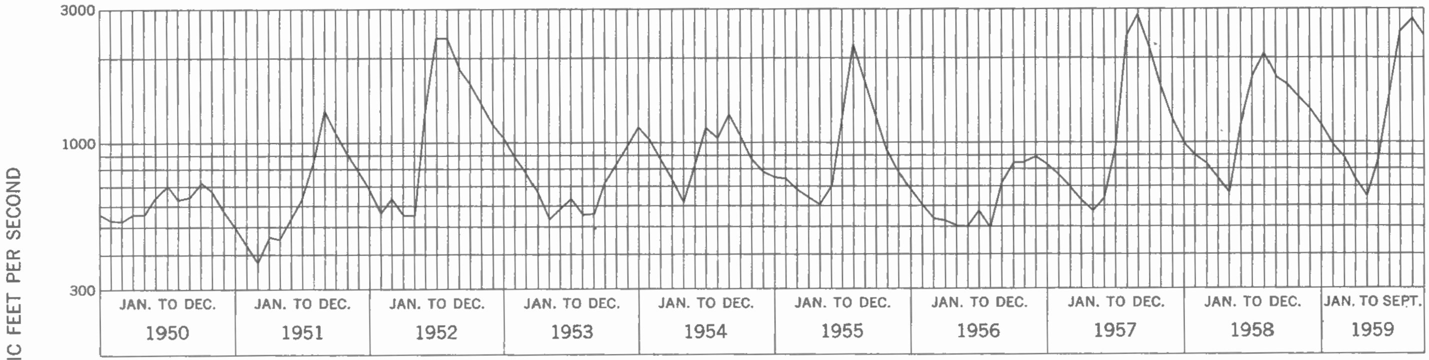
Vegetation — The southern part of the area is fairly well timbered, spruce, birch, and jack pine being the most abundant trees. Barren grounds, north of the tree-line (Fig. 1) are found in the Artillery Lake - Mackay Lake area. A detailed flora of the region has been published by Porsild (1955).

Drainage — The drainage pattern of the Precambrian Shield, which developed in a terrain of resistant and mainly massive rocks, has been made complex and random by glaciation. Rocks outcrop along many lakeshores, but the infilling of glacial drift has caused the local damming of streams and the formation of numerous lakes. These lakes are the main reservoirs of water in each basin. Soils are poorly developed and the storage of water in the soil zone is restricted to swamp and muskeg depressions.

Comparison of Streamflow — Available streamflow data on Yellowknife and Snare Rivers covers a period of more than ten years. Hydro-electric power dams are established on both rivers. Figure 7 shows mean monthly discharge for the two rivers, from data published by the Water Resources Branch, Department of Northern Affairs and National Resources. The records show a similarity of low and high flow for the two river basins during the same period of time.

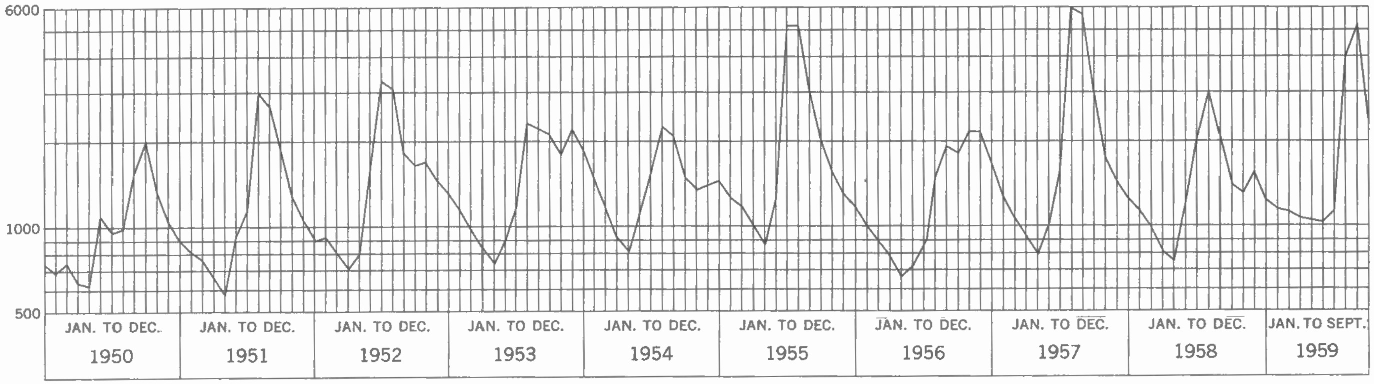
Streamflow data covering short periods of time are also available for Emile, Lockhart, Taltson, and Snare Rivers. The record on Snare River is for a period prior to the construction of the first dam. Discharge curves for these rivers are shown on Figures 8 and 9. The records show that low flow occurs in April.

The relatively high discharge of Emile River in December-January 1947-48, of the Taltson in December-January 1953-54, and of both the Lockhart and the Snare in 1945 is surprising. It should also be noted that both the Snare and Yellowknife Rivers maintained relatively high flows in December of 1953 and 54. Precipitation for these years at Yellowknife and Fort Smith is not high. The precipitation at Yellowknife for the three months October-December 1945 was 2.75 inches, for October- December 1947 it was 1.76 inches, and for October-December 1953 it was 2.55 inches. The mean monthly temperature at Yellowknife in November is 7.2°F and



STATION 75B3, YELLOWKNIFE RIVER AT PROSPEROUS LAKE

Data from Water Resources Branch, Northern Affairs and National Resources, Papers 109, 113, 117, 121, 125, and 127 Paper 127



STATION 75A3, SNARE RIVER AT BIGSPRUCE LAKE

Data from Water Resources Branch, Northern Affairs and National Resources, Paper 127

Figure 7. Mean monthly discharge, Snare and Yellowknife Rivers

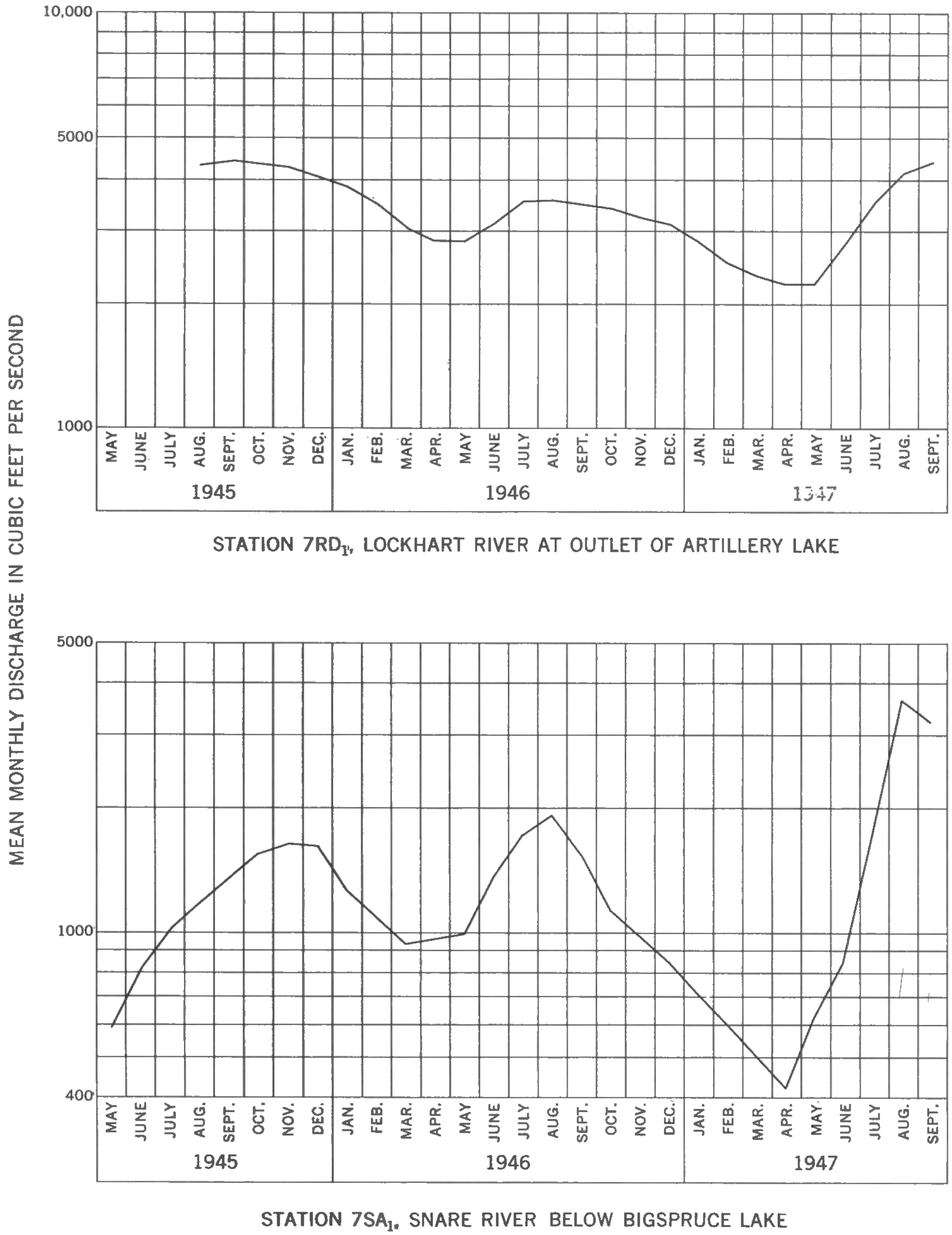


Figure 8. Mean monthly discharge, Lockhart and Snare Rivers

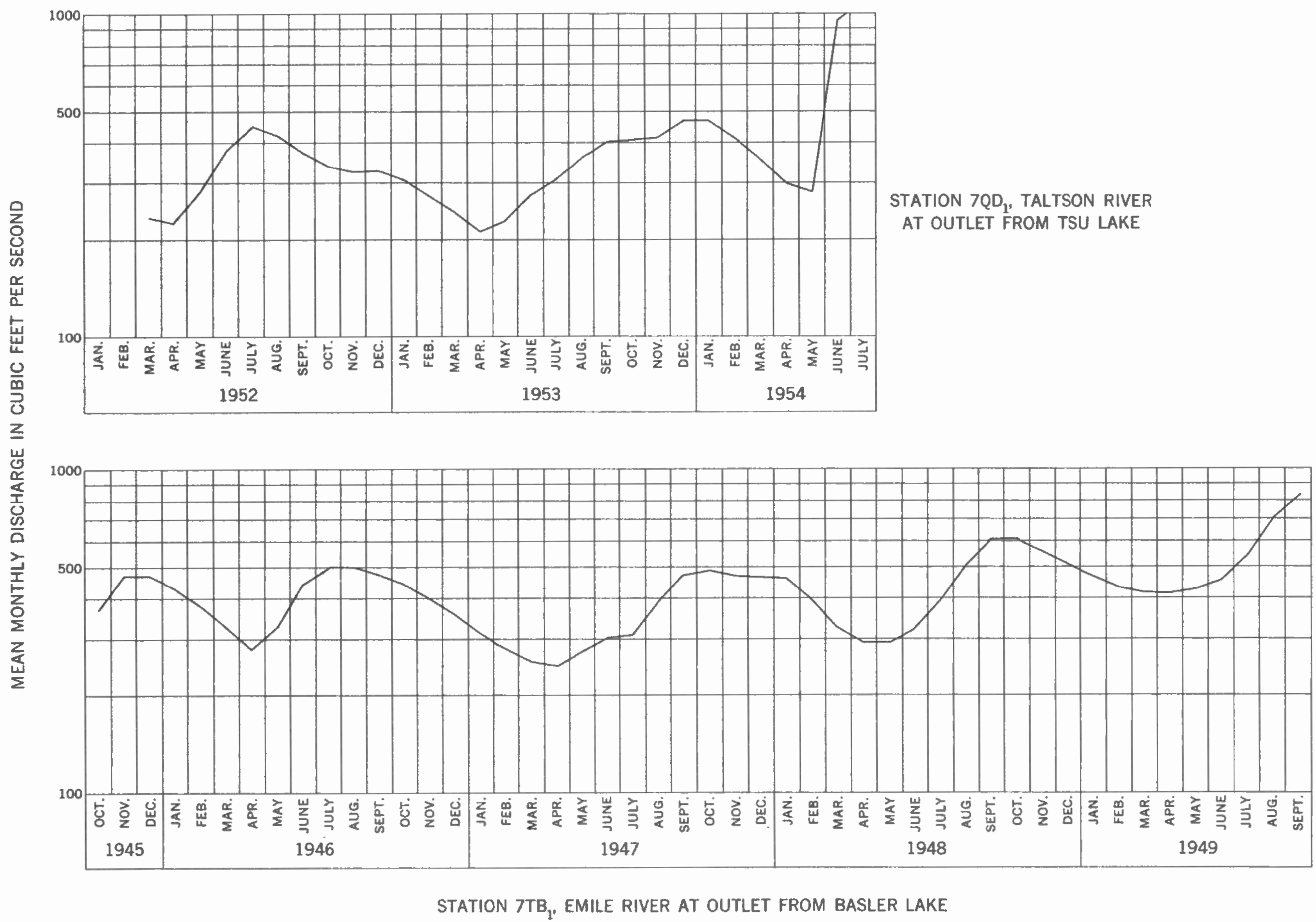


Figure 9. Mean monthly discharge, Taltson and Emile Rivers

in December it is -12.9°F. Therefore high December flows are probably derived from effective recharge to lakes by snowmelt and precipitation during a temporary thaw. This is a time when open water evaporation has been reduced to a minimum, so all recharge can go into river discharge. Alternately these high winter discharges may be due to icing conditions during freeze-up, which result in damming of waters and delayed discharge.

Figures 10 and 11 are graphs showing flow-duration curves of discharge per square mile; they have been plotted logarithmically against per cent of time in order to permit comparison of the regimen of these rivers. The periods of discharge recorded are very short, but because the physiography, geology and climate have many similarities a tentative comparison is justifiable. The method suggested by Lane and Lei (1950) has been followed and a stream variability index, i.e. standard deviation σ of each curve has been computed. A coefficient of variation (C_v) which is equal to the standard deviation divided by the mean flow ($\overline{y}$) so that

$$C_v = \frac{\sigma}{\overline{y}}$$

has also been calculated, following the suggestion of Ven Te Chow (Lane and Lei, 1950). The results, together with other basin discharge data, are plotted on Table III. These show that for the short records available the shapes of the discharge rating curves of Taltson, Emile, and Lockhart Rivers are similar. All these rivers, though of different area, are flowing from basins of similar environment with extensive lake storage. Lockhart River flows out of the largest lake system of the three and from an area that is largely north of the tree-line. The Snare River flow-curve varies more than the others; this may partly be due to the short period of record.

<u>Groundwater Flow</u> — To find the extent of groundwater flow in a basin it is necessary to describe how groundwater moves in the region and find what evidence there is for groundwater contribution to lakes and streams.

There are no wells in the region, but there are several mines. Most of the mines are dry and many of the workings in the higher drifts are in permafrost. Heavy flows of water have been encountered in fault zones in mine workings below lake levels, but indications are that groundwater movement in the rocks is restricted to these fault zones and to zones of extensive jointing and rock fracturing. Groundwater movement in glacial deposits is by permeation in unfrozen ground. Eskers are highly permeable if not frozen, but other glacial deposits (such as till and lake clay) have a low permeability.

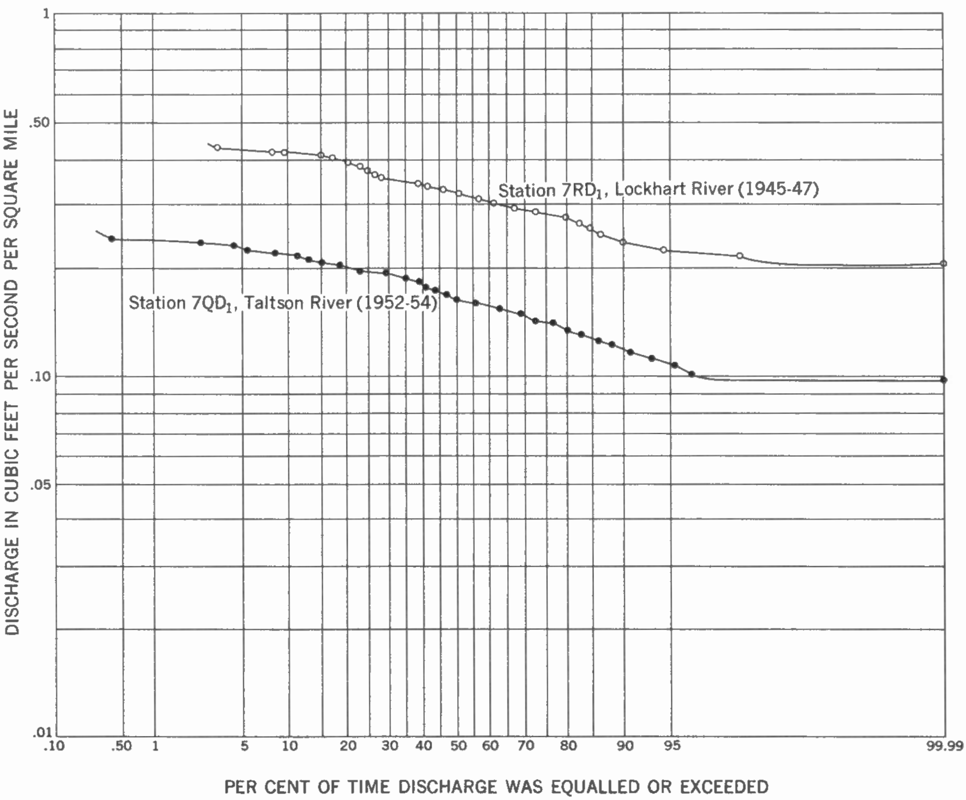


Figure 10. Flow duration curves, Lockhart and Taltson Rivers

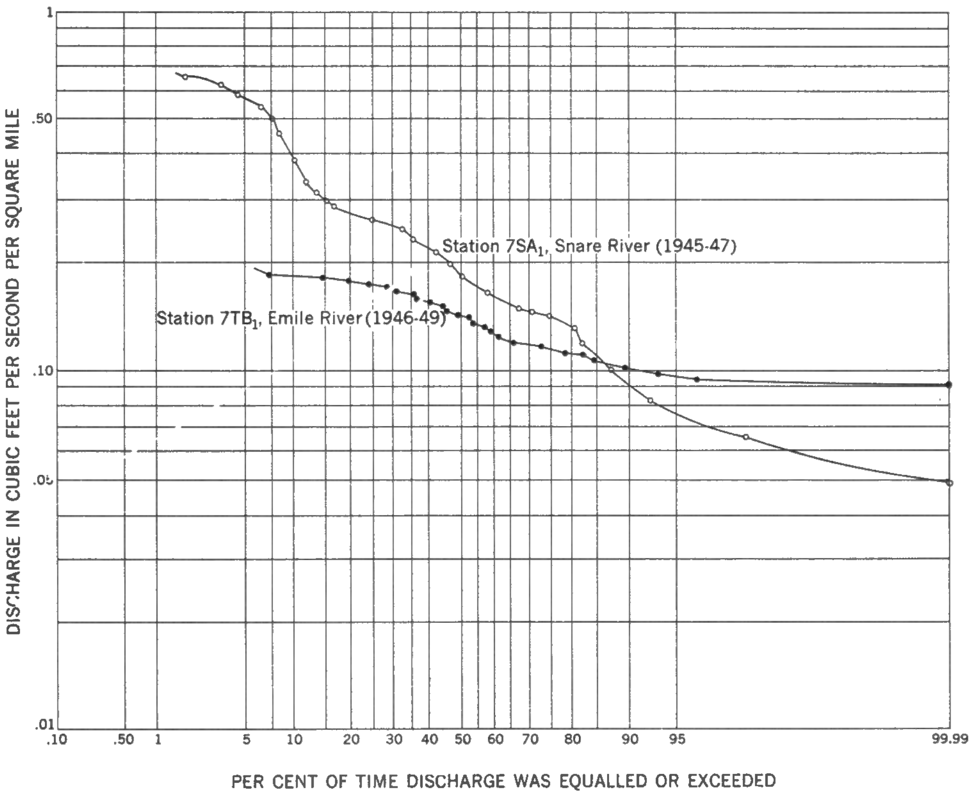


Figure 11. Flow duration curves, Snare and Emile Rivers

Table III

Basin Discharge Data for Lockhart, Taltson, Emile, and Snare Rivers

River	Station	Years of Record	Area (square miles)	Discharge in Cubic Feet per Second				Run-off Depth in Inches on Drainage Basin	σ	C_v
				Mean	Mean per Square Mile	Mean Monthly Minimum	Mean Monthly Minimum per Square Mile			
Lockhart	$7RD_1$	1945-47	10,220	3,330	.32	2,600	.25	4.4	0.063	0.20
Talston	$7QD_1$	1952-54	20,685	3,700	.18	2,300	.11	2.3	0.032	0.19
Emile	$7TB_1$	1946-49	2,620	450	.17	312	.12	2.2	0.032	0.23
Snare	$7SA_1$	1945-47	6,000	1,300	.22	650	.10	3.0	0.13	0.61

Location	Springs at High Point near Buffalo River	Springs at Sulphur Point	Spring at Windy Point	Buffalo River, 1 mile upstream	Little Buffalo River, at mouth	Pine Point, townsite well	Great Slave Lake at Fort Resolution (at jetty)	Hay River (Thomas Water Survey No. 8)	Lac Tempier A	Lac Tempier B	Emile River, near Rae (Thomas Water Survey No. 8)	Snare River (Big Spruce Lake) (Thomas Water Survey No. 8)	Slave River at Fort Smith (Thomas Water Survey No. 8)	Slave River at Fort Smith (Thomas Water Survey No. 8)	Great Slave Lake at Yellowknife (Thomas)	Great Slave Lake at McLeod Bay - Fort Reliance (Thomas)	Mackenzie River at Fort Providence (Thomas)	Slave River delta (Rawson, 1950)	Outpost Island (Rawson, 1950)	Christie Bay (Rawson, 1950)	McLeod Bay (Rawson, 1950)	McLeod Bay (Rawson, 1950)
Month and year	7/60	7/60	9/60	7/60	8/61	8/61	7/60	7/52	8/61	8/61	9/52	Average	3/53	6/52	Average	8/56	8/56	6/46	8/45	7/46	8/45	8/49
Appearance and odour			Sediment	Sediment										Turbid								
pH	7.9	8.1	7.7	7.4	7.5	7.6	7.8	7.6	7.7	7.8	7.3	8.3	8.1	7.7	7.4	6.9	8.1					
Colour	15	10	20	Colloids	25	0	35	120	15	15	5		15		10	20	10					
Conductivity	14397	3160	921.7	186.1	3110	1135	334.9	411	317	330	40.7	48	378	205	83.9	26.48	230					
Hardness: total	3077	1877	150	82.1	1499	669	142	188	180	195	16.4	20.8	146	101	28.7	9.2	95.3					
Hardness: non-carbonate	2816	1625	62.2	18.1	1394	518	52.7	95.3	24	25	2.2	0.0	15.7	9.8	0.8	0.2	13.3					
Calcium	713	483	41.1	21.2	549	125	42.0	52.2	20.6	41.6	4.8	5.7	43.6	31.5	7.7	2.2	28.8	3.1	28.8	25.0		3.1
Magnesium	315	163	11.5	7.0	31.3	86.8	9.0	13.9	31.3	22.2	1.1	1.6	9.1	5.4	2.3	0.9	5.7	7.0	6.5	5.7		1.8
Sodium	2340	112	124	5.9	262	10.8	13.0	12.7	3.7	2.4	1.2	4.2	25.7	3.4	3.4	0.5	8.5	12.9		3.0		
Potassium	6.9	2.9	1.5	1.1	1.7	1.8	1.3	2.0	2.0	1.1	0.8	1.8	1.9	1.7	1.1	0.4	1.1					
Iron (total)	0.01	0.03	0.11	1.3	0.12	6.00	0.20		0.06	0.05												
Manganese	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0												
Total Solids																		160	140	111	22	23
Bicarbonate	318	307	107	78.0	128	184	109	113	190	208	17.3	24.8	159	111	34.0	11.0	100	111.5	120	82.5		18.4
Sulphate	2550	1577	62.3	23.0	1296	522	60.0	109	25.3	24.7	4.7	3.8	30.9	13.8	8.2	0.8	20.8	25		16.0		
Chloride	3869	124	192	5.1	420	0.6	15.1	4.8	2.5	1.0	1.0	0.6	26.8	3.3	3.6	0.6	9.3	12.0		6.0		
Fluoride	1.6	0.0	0.0	0.4	1.2	1.15	0.1		0.45	0.48	0.05		0.05			0.0	0.0					
Nitrate	2.4	0.2	0.0	0.6	0.4	0.0	0.2	0.7	3.9	0.4	0.1			0.4	0.7	0.8	1.2					
Silica	9.4	10	2.9	2.5	7.2	7.4	3.8		8.0	6.1			6.4	3.1	1.7	0.5	4.5					
Sum of constituents	9964	2624	488	105	2631	846	198	256	192	202	23.9	33	223	118	45.5	12.2	129					
Per cent Sodium	62	12	64	13	27.5	3.4	16.5	12.7	4.2	2.6	12.9	30.3			19.7	9.6	16.0					

Table IV. Chemical analyses of springs and rivers, Great Slave Lake, District of Mackenzie

The hydrographs (Figures 7, 8, and 9) of Lockhart, Taltson, Emile and Snare Rivers show minimum flow discharges and baseflow. Physiographic and geological factors of the region indicate that the minimum flows are largely from lake storage. Confirmation of this is obtained from an examination of the chemical analyses of the streams. Analyses 11 and 12 in Table IV, show the dissolved mineral contents of Emile and Snare Rivers. These contents are low in comparison to those of a region where there is a large contribution of groundwater. Analyses by Thomas (1957) show that there is relatively little change in the dissolved mineral content of the Snare River throughout the year, and analyses by Rawson (1950) show that the waters from the McLeod Bay arm of Great Slave Lake have a much lower mineral content than the rest of the lake. Four partial analyses by Rawson are shown in Table IV.

It is concluded, therefore, that groundwater contribution to rivers in the region is negligible and that groundwater is stored in unconsolidated glacial deposits in swamps and depressions, where it provides moisture for vegetation.

Interior Plains

Topography — The contrast between the rugged terrain of the eastern part of Great Slave Lake and the rolling drift-covered plain on the west side has been noticed by most travellers in the region. On the south side of the lake the interior plain rises gently out of the alluvium of Slave River valley. Low discontinuous escarpments face northeast. Buffalo Lake has an elevation of 870 feet and receives water draining from the northeastern side of the Caribou Mountains, which rise out of the plain to an elevation of 3,000 feet 50 miles farther south.

North of Great Slave Lake the border between the Precambrian Shield and the plains extends through Marian Lake, Faber Lake and Hottah Lake to Great Bear Lake. The plains are a low-lying, heavily wooded terrain with many shallow lakes. North of Lac la Martre is a southwest-facing escarpment where the plains rise to Cartridge Mountain, which is more than 1,000 feet in elevation.

Geology — Precambrian rocks are overlain by a succession of flat-lying Ordovician and Devonian sedimentary rocks. Cretaceous sediments overlie the Upper Devonian rocks west of the Great Slave Lake area in the Horn Plateau and Trout Lake region.

Table V

Summary of Geological Succession in the Interior Plains on the West Side of Great Slave Lake

Era	Period or Epoch	Predominant Lithology	Outcrop Area	Groundwater Movement
Cenozoic	Recent and Pleistocene	Alluvium	Slave River	Permeable flow
		Lacustrine sands and clays, glacial till, and gravel	Widespread over whole area	
		UNCONFORMITY		
Mesozoic	Cretaceous	Sandstone and shale; some argillaceous limestone	Cartridge Mtn.- Horn Plateau-Trout Lake area	Flow along bedding planes and joints. Some permeable flow through less consolidated sandstone
		UNCONFORMITY		
Palaeozoic	Late Devonian	Shale, some limestone reefs	West of Buffalo Lake and Hay River	Flow along bedding planes and joints; permeation through reefs
		UNCONFORMITY (?)		
	Middle Devonian	Limestone, vuggy dolomite	Pine Point, Windy Point, Horn River	Joint flow, some permeable flow through reef and some solution channel flow
		Gypsum, dolomite, limestone; breccia	Lac la Martre, Little Buffalo escarpment	Solution channel flow; (karst topography); joint flow
		UNCONFORMITY		
	Ordovician	Red shale and dolomite; gypsum and salt	La Martre Falls and River	Solution channels and joint flow
		UNCONFORMITY		
Precambrian		Granite; altered sedimentary and volcanic rocks	Faber Lake, Marian Lake, Fort Smith and westwards	Considered as an aquiclude, though joint flow near the surface may occur

Table V is a summary of geology based on reports of Douglas (1959) and Douglas and A.W. Norris (1960). The presence of solution channels in gypsum beds and in beds of carbonate rocks of the lower Palaeozoic strata is important in the groundwater flow of the region. This is discussed later.

A mantle of glacial drift overlies the entire area. Preglacial sands and gravels are overlain by glacial till in some places (Craig, in Douglas, 1959). Lacustrine clays and sands extend up to elevations of about 900 feet. These were laid down in an extensive glacial lake, which was noted by McConnell (1890) and was described by Cameron (1922). Craig (1964) has named the lake "Glacial Lake McConnell" and outlined its extent north to Great Bear Lake and south to Lake Athabasca. Evidences of the glacial lake are seen in the beach terraces and strandlines, which are prominent above the shore of present Great Slave Lake (Plate I).

Vegetation and Soils — The region is well wooded, chiefly with Canada spruce and jack pine. A detailed study of the flora has been made by Raup (1935), who divided the vegetation into three groups — upland forest, upland lakeshore vegetation, and muskeg vegetation.

The soils are classified as predominantly grey wooded soils with peat (Atlas of Canada, 1959). A soils map of the Slave River alluvium has been published by Day and Leahey (1957). Alkaline and saline soils have been noted in open meadows in the Wood Buffalo Park and Salt River Plain regions.

Drainage — Slave River flows above the boundary between the Precambrian and Palaeozoic rocks on the south side of Great Slave Lake. It is the largest river draining into the lake, and at Fort Smith (lat. 60°N) it contains the flow of a drainage basin covering about 234,000 square miles to the south. Continuous discharge records are not available, but the two published records are at maximum and minimum flow seasons. These random measurements are: June 11, 1921 - 296,000 cfs; March 28, 1931 - 49,400 cfs.

North of latitude 60°N, Slave River meanders through a large alluvial plain, which is more than 30 miles wide in places, and fills an ancient drainage system. Before reaching the alluvial plain the river has received much effluent groundwater flow. This groundwater flow is continuous throughout the year and has a higher mineral content than the surface run-off water, which brings a great flood of water with a low dissolved mineral content into the stream. The variations in conductivity of water samples of the river taken at various times in the year are shown on Figure 12, based on chemical data obtained from Thomas (1957). The figure shows that during seasons of high flow (May to August) the water has a specific conductance ranging around 200 microhms whereas during low-flow periods (March, April) the conductance may rise above 500 microhms. Many more water samples and additional discharge records are necessary to establish the relation between groundwater and surface-water run-off.

Slave River carries a large sediment load down to Great Slave Lake.

Published discharge records for Hay River during the years 1929 to 1931 show flows of 1,850 cfs in October declining to a minimum flow of 400 cfs in February (Water Resources Paper, 1933). As the river drains an area of 19,200 square miles, the baseflow discharge per square mile is about 0.02 cfs. Most of this discharge can be attributed to groundwater flow because lakes are small and because the sulphate content of the river water indicates groundwater contribution.

Groundwater Drainage — The major groundwater discharge in the Interior Plains is towards Great Slave Lake. This discharge is diverted near streams that intercept the groundwater flow. Minor groundwater discharge locations are in depressions superimposed above the main flow system. The two systems are described separately.

Major Discharge:

Evidence for major discharge is obtained from field observation of springs and from the chemistry of the rivers in the region. Springs occur along the shore of Great Slave Lake at High Point (Plate I), Sulphur Point, and Windy Point (Figure 6) where mineralized groundwater is being discharged (Table IV). Springs are also found at the foot of Salt River and the Little Buffalo River escarpment. The saline springs of Salt River have been described by Camsell (1917) and Cameron (1922). Deep wells drilled near the lakeshore can be expected to flow. (The hole at elevation 538.9 feet Cominco G-4 reported by Douglas (1959) flowed at 374 feet.) The water of Little Buffalo River is too highly mineralized to be potable.

The movement of groundwater is through sink holes, solution channels, and joints in the Middle Devonian and Ordovician rocks. The sink holes can be seen on the trail from Fort Smith to Hay River and in the Nyarling Valley. Soper (1941) described the

PLATE I.

High Point on south shore of Great Slave Lake showing old shoreline terraces and white sulphate precipitate from cold springs.

RCAF Airphoto A14799-8

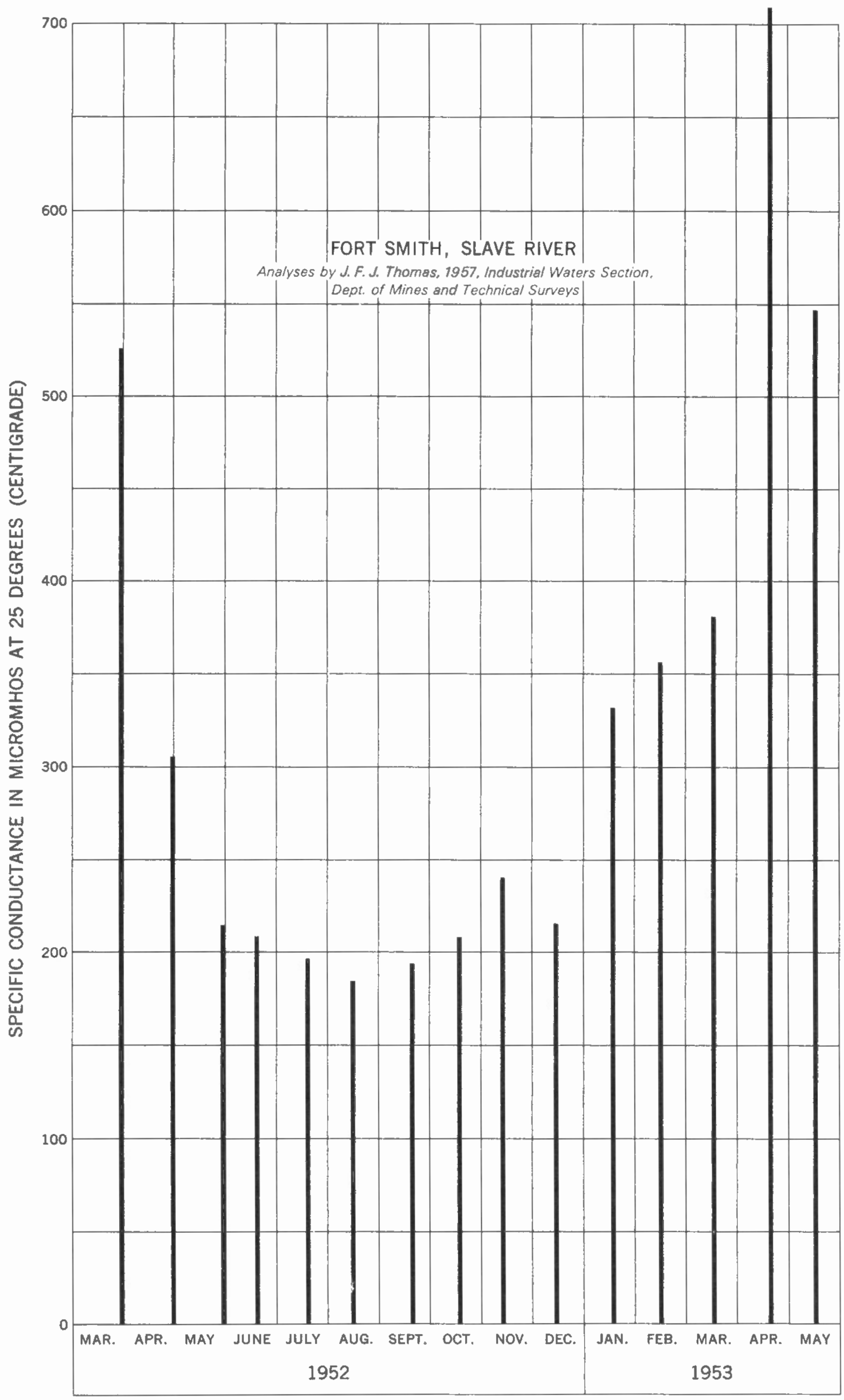


Figure 12. Seasonal variation of water conductivity, Slave River

karst topography of the Nyarling district as "a land of underground streams". The joint pattern consists of two vertical joint systems trending N 20°W and N 70°E, perpendicular to the bedding within the sedimentary strata (D.K. Norris, personal communication).

Day and Leahey (1957) reported that no saline soils occur east of Little Buffalo River, although they are present west of the river. The high mineral content of Little Buffalo River together with the absence of saline soil east of it suggest that the river is intercepting all groundwater drainage towards the Slave River delta. The flow system under these circumstances can be represented in a first estimate by a simple two-dimensional electric analog model, the Palaeozoic rocks being assumed for the model as permeable (conducting) and the Precambrian as impermeable (non-conducting). The model experiment described below was done by R.O. van Everdingen of the Geological Survey of Canada.

Two northeast-southwest cross-sections (Figs. 13a, b) of the region south of Great Slave Lake were prepared to scale (Figure 6 shows line of cross-sections). The vertical scale was different from the horizontal scale, and assumed depths to the Precambrian Shield were made. A conducting medium (Teledeltos paper) was cut out to the same size as the first cross-section. This represented the Palaeozoic rocks. An electric field plotter of the null reading type, calibrated to 1/10 of 1 per cent, was used to determine the potential distribution. A potential of 100 per cent was maintained along the line representative of Buffalo Lake, and potentials of 7 1/2 per cent and zero were maintained at Little Buffalo River and Slave River respectively. The field found is shown on Figure 13a. The second cross-section (Fig. 13b) was prepared with a hump arbitrarily cut out of the lower edge to represent a high in the Precambrian rocks. A potential of 100 per cent was introduced at the left (west) edge to represent flow from higher ground west of the cross-section, and potentials of 4 1/2 and 2 1/2 per cent were maintained at Little Buffalo and Slave Rivers. The resulting field is shown on Figure 13b. Figures 13a and 13b illustrate the major flow pattern in the area, and suggest by analogy how Little Buffalo River intercepts the main groundwater flow system, thus acquiring a high mineral content. The exaggeration of vertical scale was necessary for the experiment; a true scale would merely compress the flow lines and further divert them to Little Buffalo River. A representation of this kind is justified where the rocks have a uniform joint pattern, even though the groundwater maintains a number of preferred lines of flow through solution channels. The compression of flow lines in one part of the major flow system due to an impermeable ridge, e.g. a Precambrian ridge, may have resulted in pressure changes, which caused a

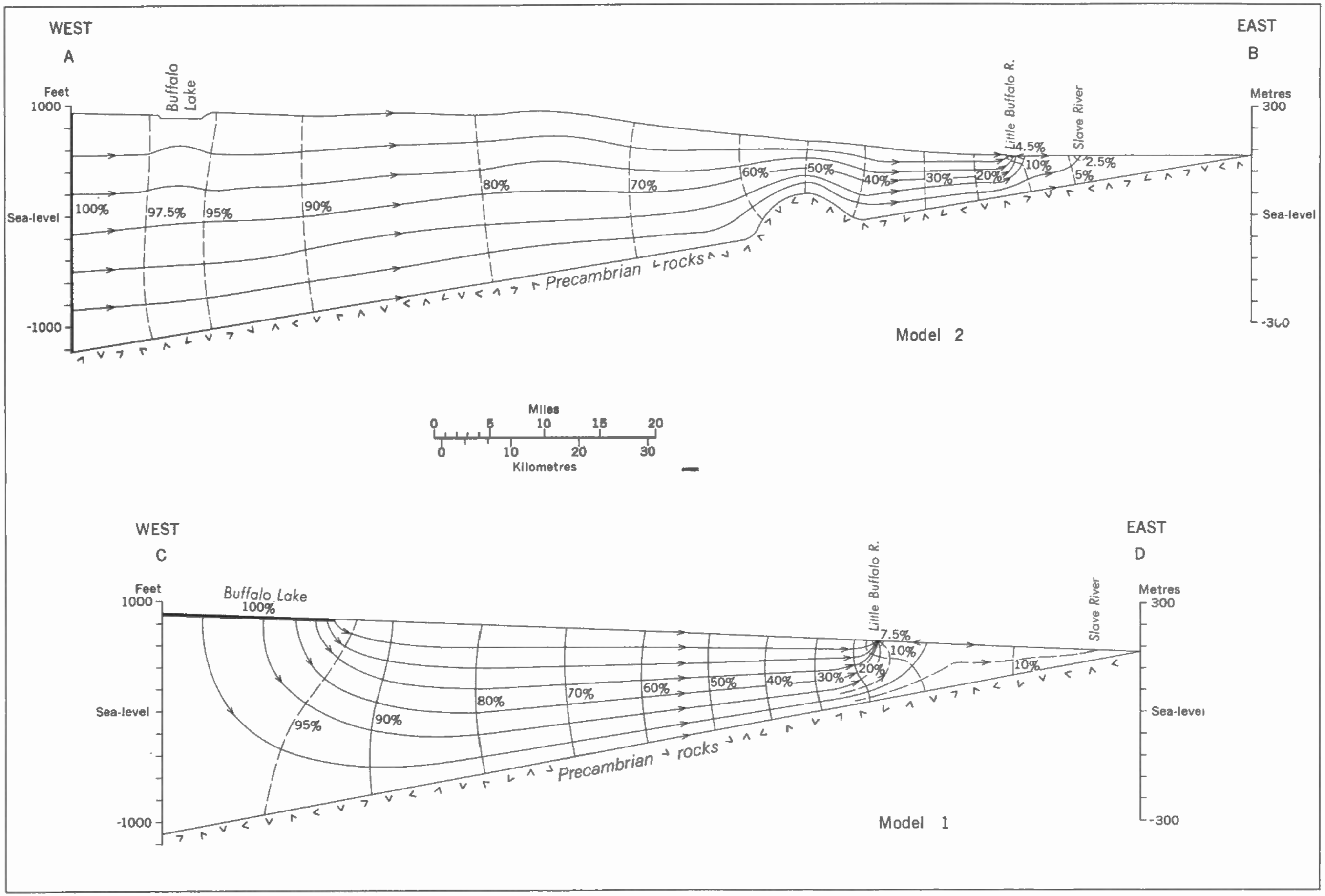
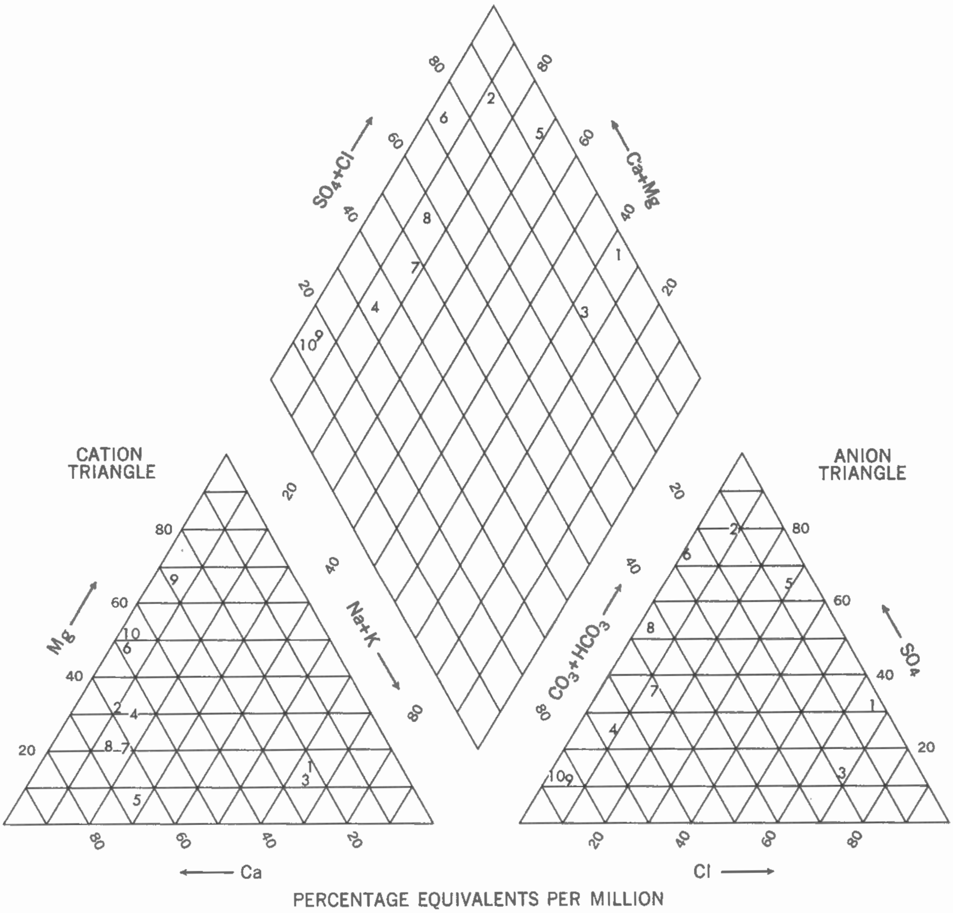


Figure 13. Electric analog flow system south of Great Slave Lake. For location see Figure 6. Instrumentation by R. van Everdingen



LOCATION OF ANALYSES

1. Springs at High Pt., south shore, Great Slave Lake
2. Springs at Sulphur Pt., south shore, Great Slave Lake
3. Springs at Windy Pt., northwest shore, Great Slave Lake
4. Buffalo River, one mile upstream
5. Little Buffalo River, at mouth
6. Pine Point townsite well
7. Fort Resolution, Great Slave Lake
8. Hay River (Thomas, 1957)
9. Lac Tempier A
10. Lac Tempier B

Figure 14. Chemical analysis diagram of waters from springs, rivers, and lakes, Great Slave Lake basin (see also Figure 6 and Table IV)

deposition of dissolved minerals from the groundwater. Such a condition may have played a part in the formation of the lead-zinc deposits at Pine Point.

The high and varied sulphate and chloride content in the groundwaters may be attributed to dissolution of gypsum and salt beds within the Lower Palaeozoic rocks. It should be pointed out, however, that groundwaters at the discharge end of a major flow system can be expected to be high in sulphates and chlorides, because they have gone through the metamorphism from bicarbonate to sulphate to chloride waters outlined by Chebotarev (1955). Figure 14 is a chemical analysis diagram that compares the waters from springs and rivers referred to above.

Minor Discharge:

Saline and alkaline soils are found in depressions in Wood Buffalo Park and the Salt Plains. A halophytic flora is associated with these plains. Raup (1935) studied this flora in detail and described it from a typical area of the Salt Plain near Heart Lake. He noted that the centre of a saline area had no vegetation and that a ring of vegetation surrounds the barren ground. He described these as follows (Raup, 1935, p. 55):

"At the edge of the barren space is a rich growth of glasswort Salicornia europaea, which is bright red in colour, shading to bluish green at the drier edge of its zone. Associated with it are Puccinellia Nuttalliana, Suaeda depressa, Spergularia salina, and Plantago oliganthos. Puccinellia Nuttalliana grows in tufts and becomes the primary species in the next association, which is a rather narrow one all around the depression. The species in the Salicornia association persist and are joined by Glaux maritima, Triglochin maritimum, Chenopodium rubrum, and Distichis stricta. The last becomes primary in places. Along the muddy margins of salt streams and around brine springs the flora is largely made up of Triglochin maritimum, Salicornia europaea, and Glaux maritima."

This association of halophytes is similar to that found by Meyboom (1962) in Saskatchewan where the halophytic flora are growing in a region of groundwater discharge. The salt plains of this region are considered to be areas where mineralized groundwater is being discharged from the main flow systems by evaporation.

Recharge — A continuous groundwater-level recorder was installed at the Pine Point mine in 1961, but information on the time and rate of recharge is inadequate. It is presumed that some recharge occurs during snow melt. A sample of water from a 250-foot-deep well at Pine Point was analyzed and found to have 2.88 tritium units (R.M. Brown, Atomic Energy of Canada, personal communication). This analysis indicates an age of 30 $\pm$ 10 years since precipitation.

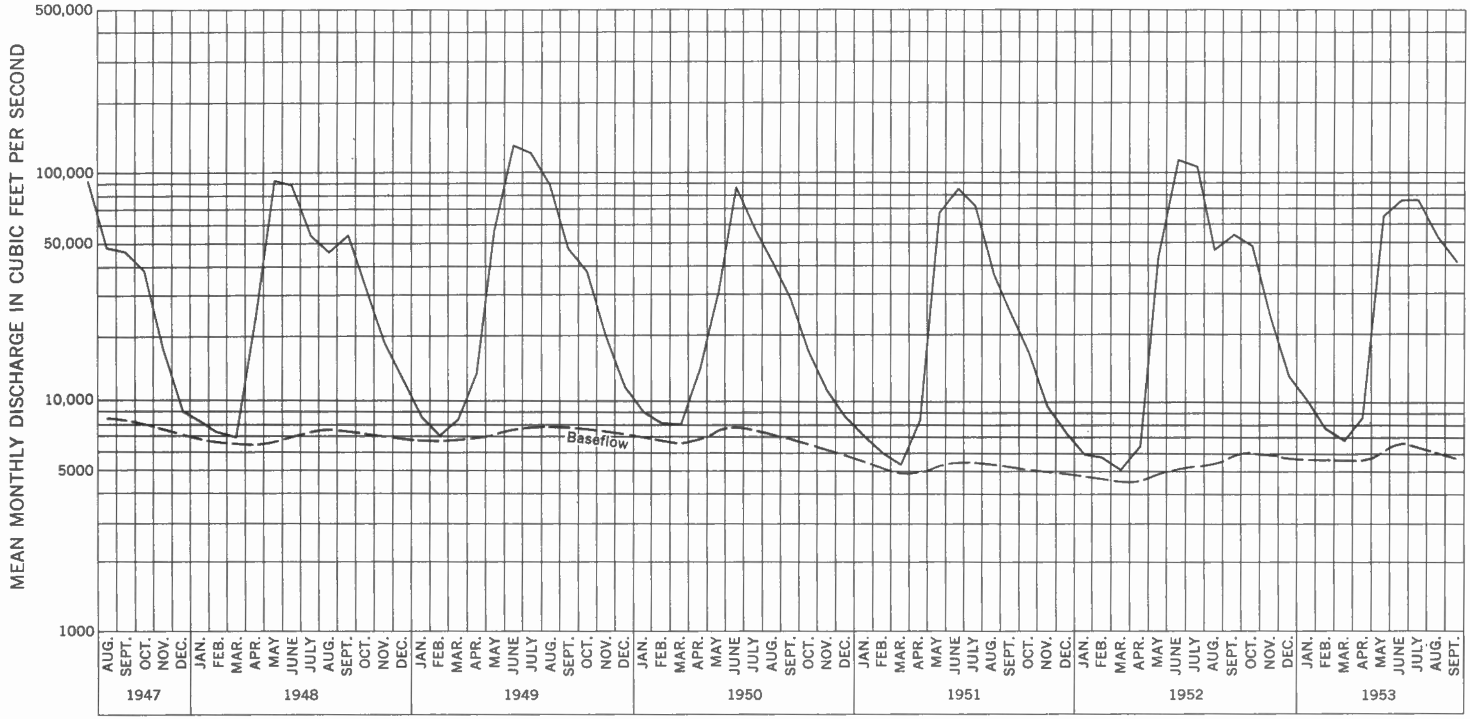
Mackenzie River Basin

The distance from Big Island, on the west side of Great Slave Lake, to Point Separation, where the Mackenzie River widens to its delta, is 915 miles. Over this distance the river falls 510 feet and gathers the drainage of the Great Bear Lake basin in the east, the Liard River drainage in the southwest, and the drainage of the Mackenzie Mountains and part of the Selwyn Mountains in the west.

Physiography — The physiography of this vast drainage system has been classified and described by Bostock (1948). The region described by him may be summarized as follows:

1. Interior Plains, a region of flat-lying sedimentary rocks with low topographic relief.
2. Mackenzie Plain, an extension of the interior plain, which was left undisturbed when the front structures of the Mackenzie Mountains were formed.
3. Franklin Mountains, which extend in an arc from Nahanni Butte in the south towards the Ramparts south of Fort Good Hope. They comprise the Nahanni, Camsell, McConnell, and Norman Ranges, which rise to elevations of 4,000 to 5,000 feet.
4. Mackenzie Mountains, comprising the Canyon and Backbone Ranges, which rise to elevations of 7,000 feet.
5. Selwyn Mountains, which rise to peaks over 8,000 feet.
6. Liard Basin, which comprises the Liard, Hyland, and part of the Nisutlin Plateaux, together with drainage from the east side of the Cassiar Mountains and the north ridge of the Rocky Mountains. The Liard Plain is situated above the Liard Plateau where the river cuts through the Cordillera.

Geology — The geology of the area has been described in several reports since it was first mapped by McConnell (1890). These reports include Camsell and Malcolm (1919), Hume (1954), and Douglas and D.K. Norris (1961, 1962).



STATION 10BE$_1$, LIARD RIVER AT LOWER LIARD CROSSING, MILE 496, ALASKA HIGHWAY

Figure 15. Mean monthly discharge, Liard River

Flat-lying Palaeozoic sediments extend throughout the plains and plateaux regions. These rocks are overlain by Cretaceous sediments in a number of places, the largest areas being the west shore and south plain of Great Bear Lake, the plain east of Liard River from Fort Liard towards Tathlina Lake, and the plain on the west side of Mackenzie River opposite Fort Norman. Tertiary sandstones overlie the Cretaceous rocks south of Fort Norman. The whole region has been glaciated so that glacial drift mantles the area.

The mountains are composed of folded and faulted Palaeozoic rocks. Granitic rocks intrude these rocks in Selwyn Range and in Cassiar Mountains.

Vegetation — The vegetation of the lowlands comprises boreal forest. Tree-line in the Upper Mackenzie valley is at elevations of 3,500-4,000 feet. The flora have been described by Porsild (1951) and Jeffery (1961).

River Discharge — The mean annual discharge of Mackenzie River below Arctic Red River is estimated to be 280,000 cfs (Water Resources Branch). No published discharge records are available. Discharge records of Liard River obtained at the gauging station at Liard Crossing on the Alaska Highway are shown in Figure 15. These show that the river has a baseflow exceeding 5,000 cfs.

Groundwater Flow — Groundwater flow is by permeation in the glacial deposits and alluvium. It is probable that permeable flow also occurs in the partly consolidated Tertiary sediments. Flow along joints and bedding plains occurs within the consolidated sediments. Two formations of particular significance are the Bear Rock Formation, a massive brecciated dolomite and limestone of Middle Devonian age, and the Cambrian shale, salt, and gypsum beds, named the Mount Cap and Saline River Formations, which outcrop in the Franklin Mountains. These formations contain solution channels and are thus important local aquifers. Outcrops of these formations are shown on maps by Hume (1954) and Douglas and Norris (1962).

Evidence of groundwater flow is obtained from springs, from the chemistry of streams, and from drilling records.

1. Springs:

A number of springs are well known near river banks. Whittaker (1922) reported: "on Sulphur Creek, a small tributary of Horn River, are several small sulphur springs, one of which is

Location	Redknife River	Trout River	Rabbitskin River	Root River	Willow River	Keele River	Saline River	Vermilion Creek	Liard River at Watson Lake (Thomas, 1957)	Liard River at Watson Lake (Thomas, 1957)	Great Bear River (Thomas, 1957)	Bosworth Creek (Thomas, 1957)	Arctic Red River (Thomas, 1957)	Peel River at Fort McPherson (Thomas, 1957)	Peel River at Fort McPherson (Thomas, 1957)	Mackenzie R. at Fort Good Hope (Thomas, 1957)	Mackenzie R. at Fort Good Hope (Thomas, 1957)	Mackenzie River at Aklavik (Thomas, 1957)	Mackenzie River at Aklavik (Thomas, 1957)	Liard River at Fort Simpson (Thomas, 1957)	Liard River at Fort Simpson (Thomas, 1957)
Month and year	8/60	8/60	8/60	8/60	8/60	8/60	8/60	8/60	3/53	6/52	7/52	10/56	3/53	3/53	6/53	6/56	11/56	10/52	2/53	3/53	5/53
Appearance and odour				Silty																	Turbid
pH	7.8	7.7	7.4	8.1	7.7	7.9	8.3	8.3	7.6	7.7	7.9	8.1	7.4	7.7	7.8	7.8	8.2	8.0	7.6	7.6	7.9
Colour	90	60	110	25	160	25	40	40	10	20	0	20	10	10		40	20	10	5	5	
Conductivity	262.6	162.2	185.6	352.5	281.9	339.7	2380	1308	328	123	154	619	357	423	199	219	290	342	424	433	194
Hardness: total	138	87.9	92.7	180	109	167	269	772	164	63.9	66.1	299	141	206	93.9	96.8	128	169	217	207	96.3
Hardness: non-carbonate	7.0	6.6	0.0	45.4	18.6	63.5	74.3	579	5.4	9.7	14.1	121	47.0	40.8	30.7	21.5	24.5	48.1	54.8	35.8	16.1
Calcium	42.0	26.3	24.0	48.7	28.5	43.5	64.6	230	45.9	18.9	15.3	75.3	44.5	56.3	26.7	27.6	30.7	48.9	57.4	57.4	29.9
Magnesium	7.9	5.4	7.8	14.1	9.2	14.1	26.1	48.0	12.0	4.1	6.8	26.9	7.2	15.8	6.6	6.8	12.6	11.3	18.0	15.5	5.3
Sodium	4.5	2.2	5.1	4.3	17.0	4.6	413	26.0	1.7	1.0	4.2	16.5	14.5	8.6	3.4	6.1	8.8	7.2	6.0	11.5	2.5
Potassium	0.5	0.7	0.7	0.7	0.7	0.6	1.3	1.7	0.6	0.4	0.3	1.0	1.7	1.6	1.5	1.0	1.3	1.8	1.3	2.0	1.0
Iron (total)	0.41	0.5	0.17	0.22	0.65	0.17	0.4	0.03			0.11	0.04									
Manganese	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
Bicarbonate	160	99.1	106	164	110	126	237	235	193	66.1	63.4	216	114	201	77.1	91.8	126	147	198	209	97.8
Sulphate	7.4	9.0	10.7	47.0	17.4	62.2	98.0	582	10.1	8.8	14.7	130	50.6	53.1	35.6	21.9	31.7	61.9	56.4	37.7	18.9
Chloride	2.5	1.1	2.0	3.7	25.4	5.5	622	25.2	0.2	0.5	5.8	16.3	18.3	4.6	1.4	7.5	10.2	2.1	4.4	13.7	0.6
Fluoride	0.0	0.4	0.0	0.1	0.0	0.1	0.0	0.4		0.3	0.05	0.20				0.00					
Nitrate	0.0	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.8	0.3	0.4	0.8	0.6	1.0	0.6	4.0	0.8	0.8	2.4	0.8	1.2
Silica	6.8	4.1	3.9	3.5	4.4	3.5	4.2	5.0	30	6.2	4.2	3.8	14	15	4.4	4.0	5.3	11	6.9	23	7.3
Sum of constituents	150	98.3	106	203	157	197	1347	1035	197	73.6	83.1	379	207	255	118	125	163	218	251	265	115
Per cent Sodium	6.6	5.1	11	4.9	25	5.6	77	6.8			12.1	10.6	18.1	8.3	7.1	11.7	12.9	8.3	5.6		

Table VI. Chemical analyses of waters, Mackenzie River Valley, District of Mackenzie accompanied by a considerable flow of hydrogen sulphide. These springs apparently originate in the Horn River shales." Hume (1954) refers to sulphur springs, particularly those associated with the Fort Creek shales and the Bear Rock Formation. Descriptions of two thermal springs in Mackenzie Valley are given later.

2. Chemistry of Streams:

Mackenzie River increases its sediment load and its dissolved mineral content in its course downstream. The sediment load is acquired mainly from rivers from the west; for the tributary streams on the east carry a low sediment load. The dissolved mineral content is acquired mainly by effluent groundwater seepage to the river and to its tributaries. Table VI shows analyses of a number of river samples taken by the writer or by Thomas (1957). Of particular significance are the analyses of Saline, Vermilion and Bosworth Creeks, which rise in the Franklin Mountains and which are receiving waters of high sulphate and chloride content. The sulphates are derived from the Bear Rock Formation and the chlorides from the Saline River Formation.

The dissolved mineral content of a river that is constantly receiving groundwater flow varies with total flow, owing to the diluting effect of surface run-off waters, which have a low mineral content. Mineral content and discharge are therefore inversely related and, as a first approximation, would plot as a hyperbola on squared graph paper where mineral content during recession is plotted on the x axis and discharge at sampling times during recession is plotted on the y axis. Hem (1959) has shown that there is a close relation between specific conductance and total dissolved solids in water samples, consequently specific conductance is a good indicator of dissolved mineral content. Therefore the measurement of conductance and discharge provides a method of assessing the relation between groundwater flow and surface run-off in valleys where groundwater is effluent. An example of this is shown in Figure 16, where the discharge of the Liard River is plotted against specific conductance. The data are obtained from analyses published by Thomas (1957). The graph has been plotted on logarithmic paper and expressed as an equation. The equation of discharge and conductance for this part of the river basin is found to be

$$\text{Log } y = 11.4 - 3 \text{ Log } x$$

where the general equation would be of the form:

$$\text{Log } y = k - a \text{ Log } x.$$

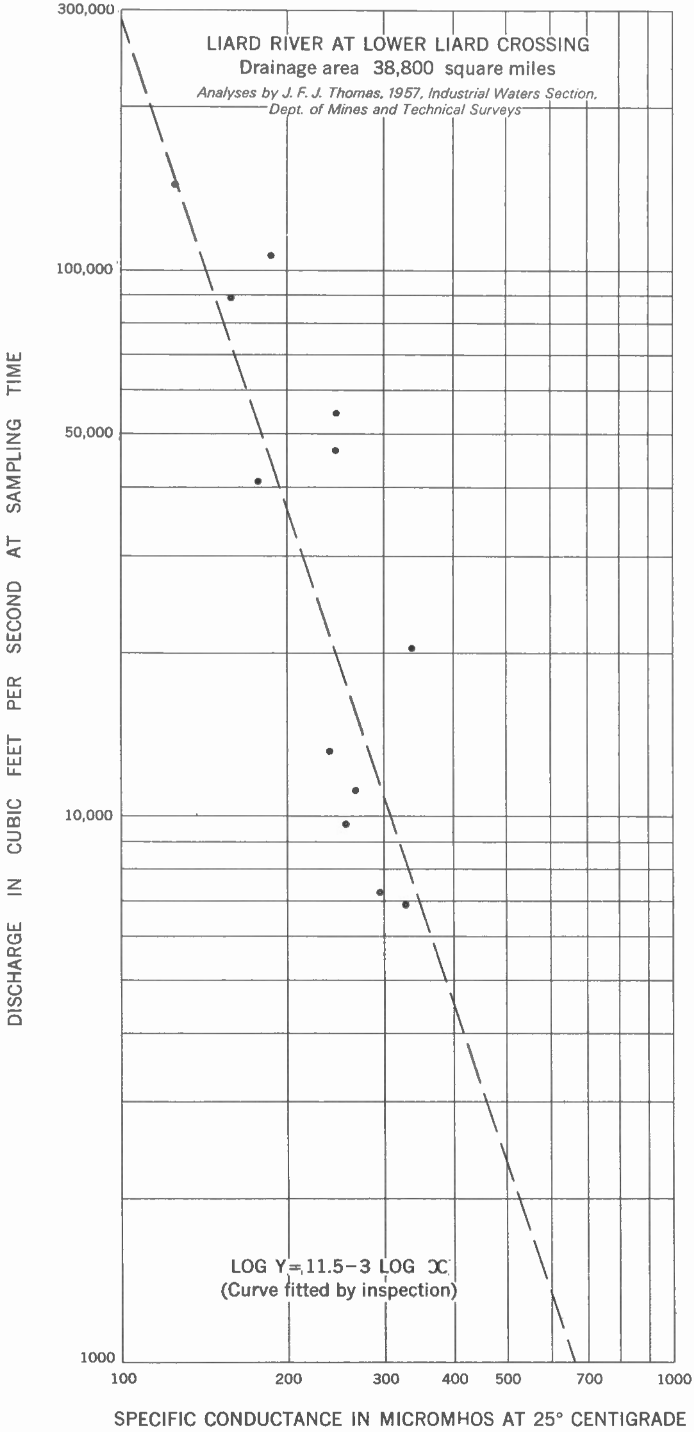


Figure 16. Relation between discharge and conductivity of water, Liard River

Groundwater in the Liard Plain, which is predominantly a region of alluvium and glacial drift, can be expected to have a conductivity of about 500 microhms. Therefore at least 2,000 cfs of flow is groundwater.

3. Drilling Records:

Wells drilled beside the Mackenzie River may be expected to show an increase in head with depth of drilling. Stewart (1945) has shown that this occurs in wells in the Norman Wells field. Hubbert (1953) has used data from this field as evidence for hydrodynamic entrapment of oil where groundwater flow is taking place.

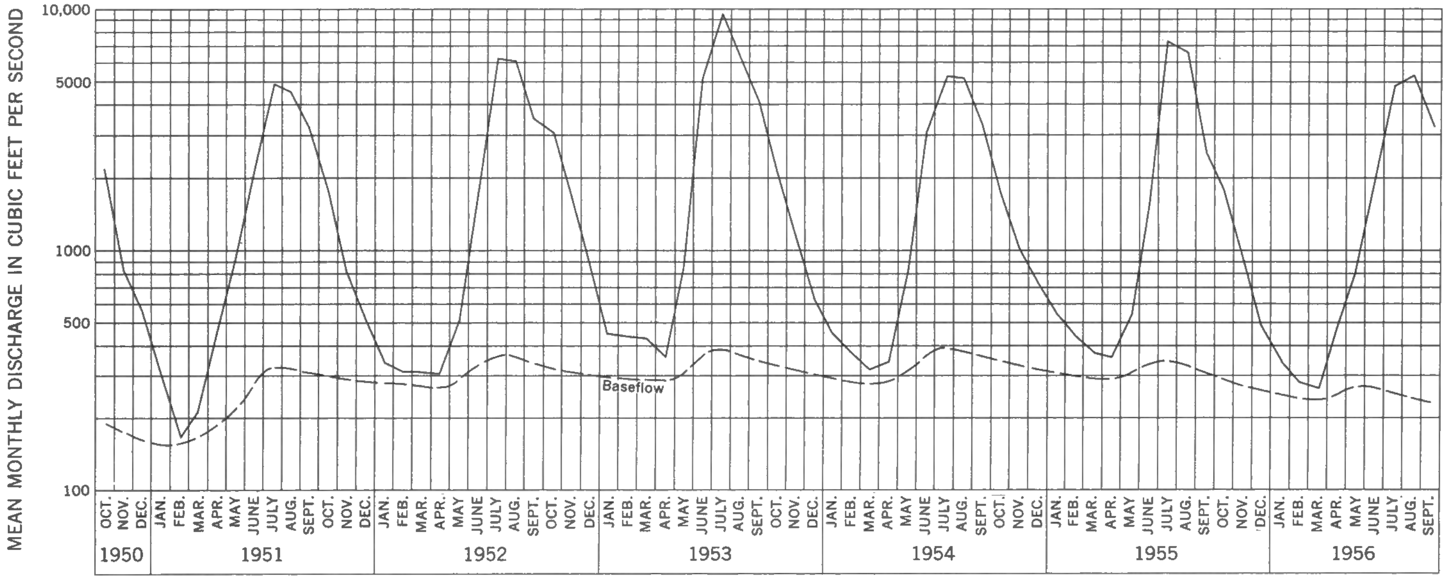
Yukon River Basin

Yukon River flows out of the lake chain headed by Atlin, Tagish, and Bennett Lakes. Below Whitehorse it is joined by Takhini River, which flows from Kusawa Lake. At Dawson, more than 300 miles from its source and more than 1,000 feet lower in elevation, the river drainage area and flow have been increased by Teslin River (which has a greater flow than Yukon River), and Pelly, White, and Stewart Rivers, and many other tributaries. The hydrologic and physiographic conditions are different from those in the Mackenzie and Great Slave Lake basins.

Physiography — The drainage area of Yukon River at Dawson is 106,000 square miles, comprising the east slopes of the Coast Mountains above Atlin and Tagish Lakes, the Teslin, Lewes, Pelly, MacMillan, and Stewart Plateaux, and Pelly and Kluane Ranges. Bostock (1948) has systematically described the physiography of these plateaux and ranges, and of the Shakwak and Tintina Valleys. Tintina Valley joins Yukon Valley downstream from Dawson.

Geology — Intrusive rocks and altered sediments comprise most of the consolidated rocks in the area. Map 1048A (Geological Survey of Canada, 1957) outlines the principal bedrock formations on a scale of 1 inch to 20 miles.

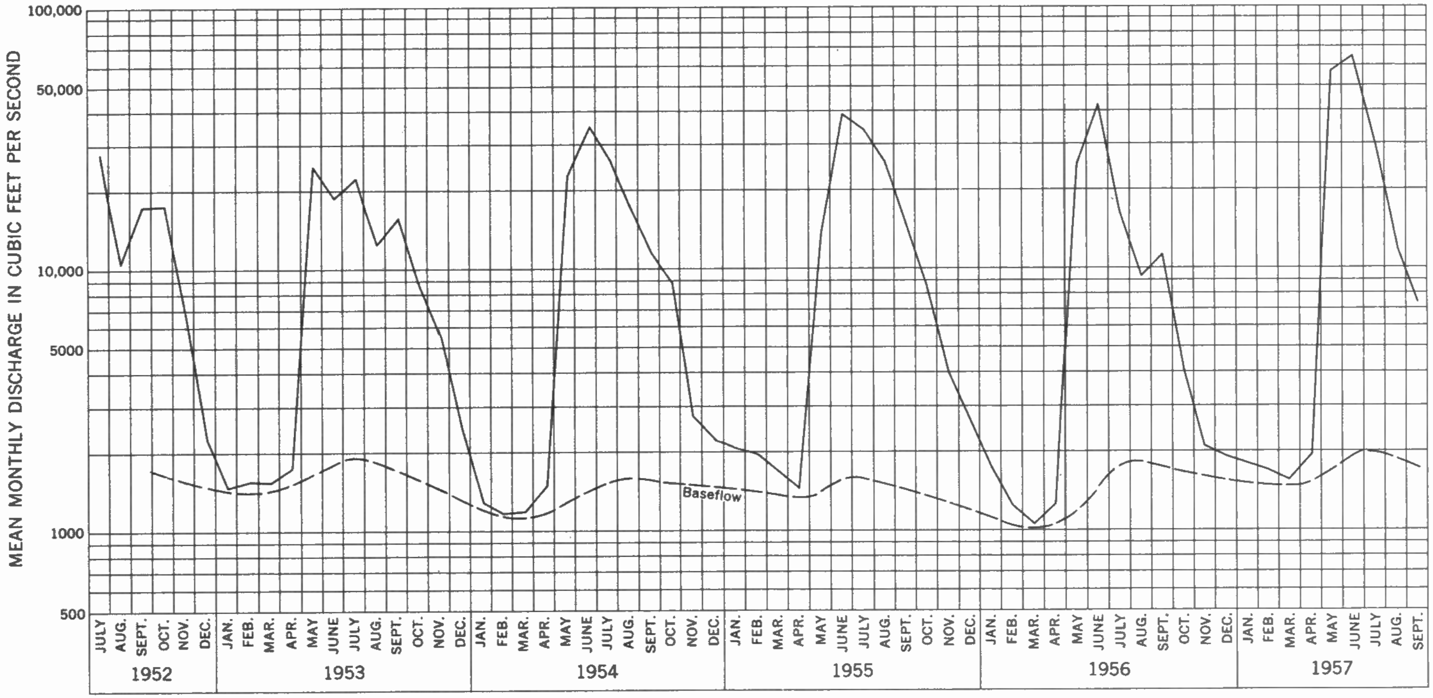
The southern part of the region has been glaciated and the rivers flow through wide valleys filled with glacial drift, glacial-lake silts, and alluvium. The Glacial Map of Canada (Geological Association of Canada, 1958) outlines the extent of glaciation. Downstream from Fort Selkirk the Yukon River enters the unglaciated area. There it is deeply entrenched in the Yukon Plateau, flowing along a valley in which rocks outcrop at a few localities and which contains broad gravel terraces at other places.



STATION 9AC$_1$, TAKHINI RIVER NEAR WHITEHORSE
(Drainage area, 2,370 sq. miles)

Data from Water Resources Branch, Northern Affairs and National Resources, Papers 114, 118, 122

Figure 17. Mean monthly discharge, Takhini River

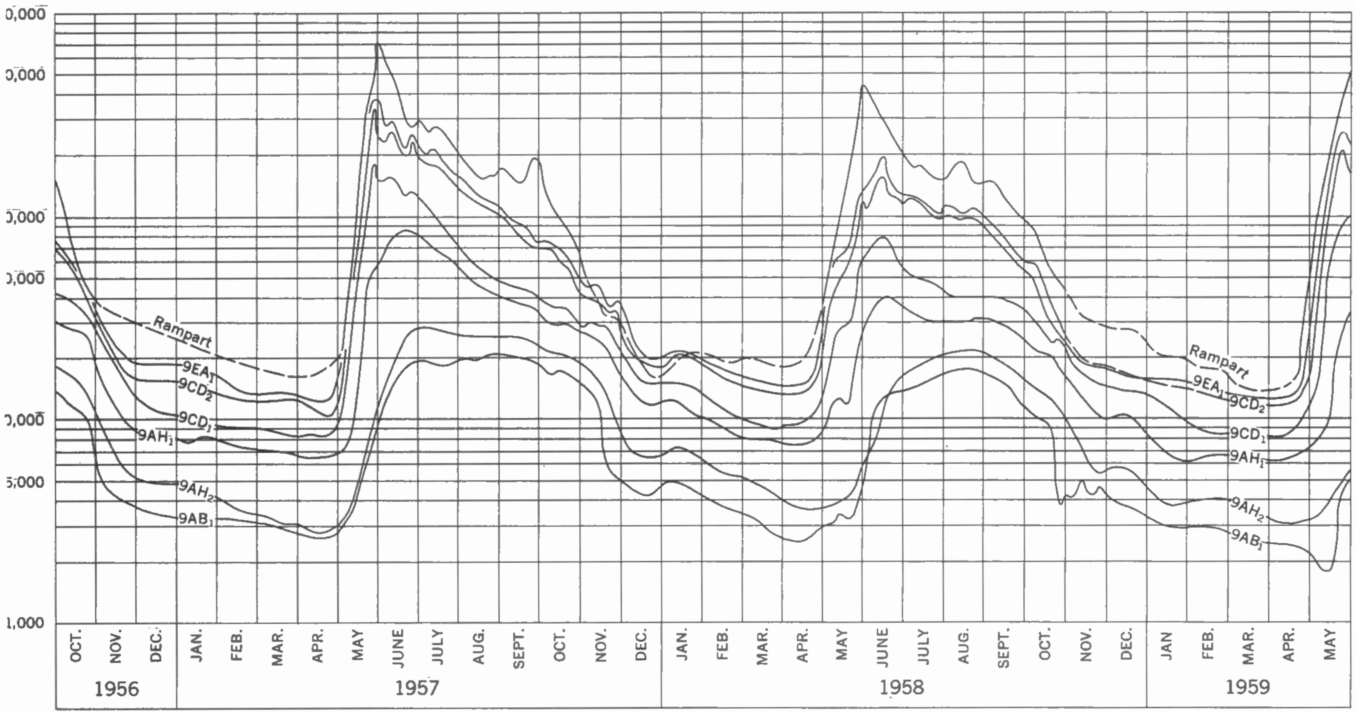


STATION $9BC_1$, PELLY RIVER AT PELLY CROSSING

(Drainage area, 19,700 sq. miles)

Data from Water Resources Branch, Northern Affairs and National Resources, Papers 114, 118, 122, 124

Figure 18. Mean monthly discharge, Pelly River



STATIONS $9AB_1$, $9AH_2$, $9AH_1$, $9CD_1$, $9CD_2$, $9EA_1$, AND RAMPART, ALASKA

Data from Water Resources Branch, Northern Affairs and National Resources, Paper 124, and U.S.G.S. Water Supply Papers 1500, 1570 and 1640.

Figure 19. Mean monthly discharge, Yukon River

Vegetation — Boreal forest, with white spruce predominating, extends through the valleys. Timber-line reaches up to 4,000-4,500 feet. The vegetation is more luxuriant at the foot of Kluane Range where precipitation is greater than in regions farther north.

Surface Drainage — Hydrographs of Takhini, Pelly, and Yukon Rivers (Figs. 17, 18, and 19) show the discharges at various gauging stations. The locations of the stations are shown on Figure 2.

The components of the Yukon hydrographs may be classified as (1) a flood flow in May and June, (2) a surface run-off and interflow component lasting through the late summer and autumn, and (3) a baseflow component, which is lake storage and groundwater flow in winter. The baseflow recession of the Yukon River (Figs.17, 18, and 19) appears fairly constant throughout the months of January to March for each gauging station, and it is for this period that a baseflow recession curve can be drawn.

During the freezing period, ice crystals form and collect into ice pans. Williams (1955) has described the formation of ice pans on Yukon River at Beaver, Alaska. The thickening of the ice pans clogs the main channel of the river so that discharge is restricted. The reduced river velocity from friction with ice cover and the reduced cross-sectional area of flow, lead to a rise in river level upstream. Therefore discharge records throughout the freezing period of October, November, and December may be unreliable for calculating the recession rate.

A comparison of flow-duration curves of the Takhini, Yukon (at Dawson), Pelly, and Stewart Rivers has been made, and flow-duration curves showing discharge per square mile against per cent of time are shown in Figures 20 and 21. These show that there are similarities between the Yukon and Takhini Rivers on the one hand and the Pelly and Stewart Rivers on the other. The stream variability indices and coefficients of variation have been computed and are shown with other relevant basin discharge data in Table VII. The similarities between Stewart and Pelly Rivers may be attributed to their hydrologic, physiographic, and geologic environments. Both flow out of wide glaciated mountain ranges in similar terrain.

Groundwater Flow — Evidences of groundwater flow are obtained from (1) baseflow records, (2) drilling records, (3) chemical analyses, and (4) soils and vegetation.

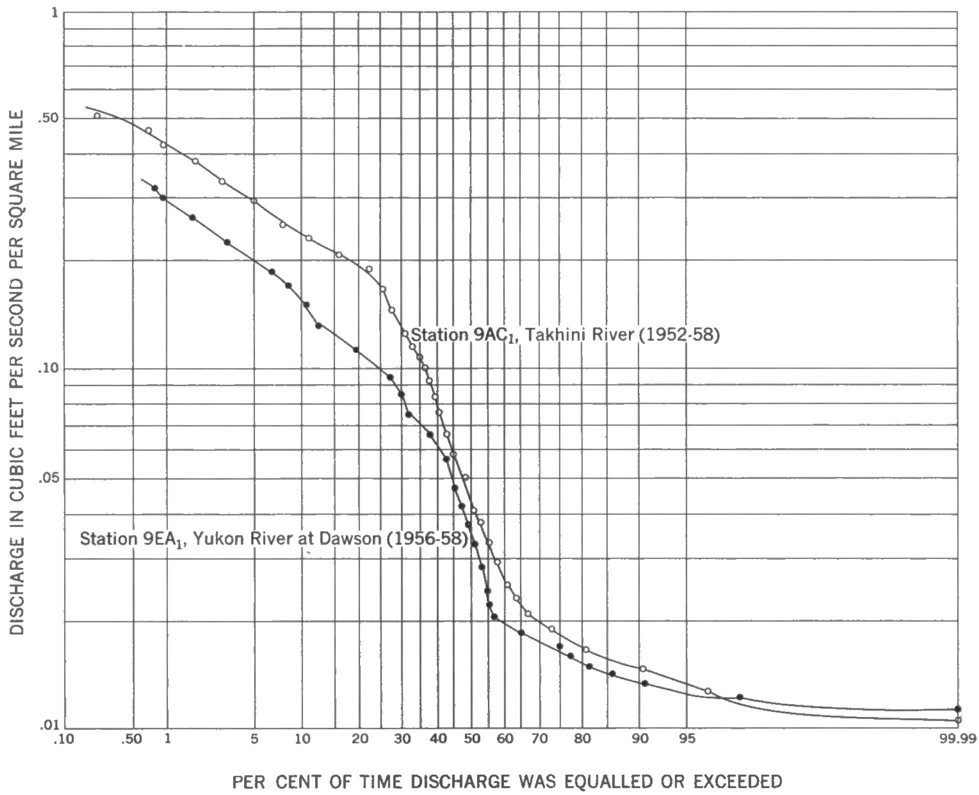


Figure 20. Flow duration curves, Takhini and Yukon Rivers

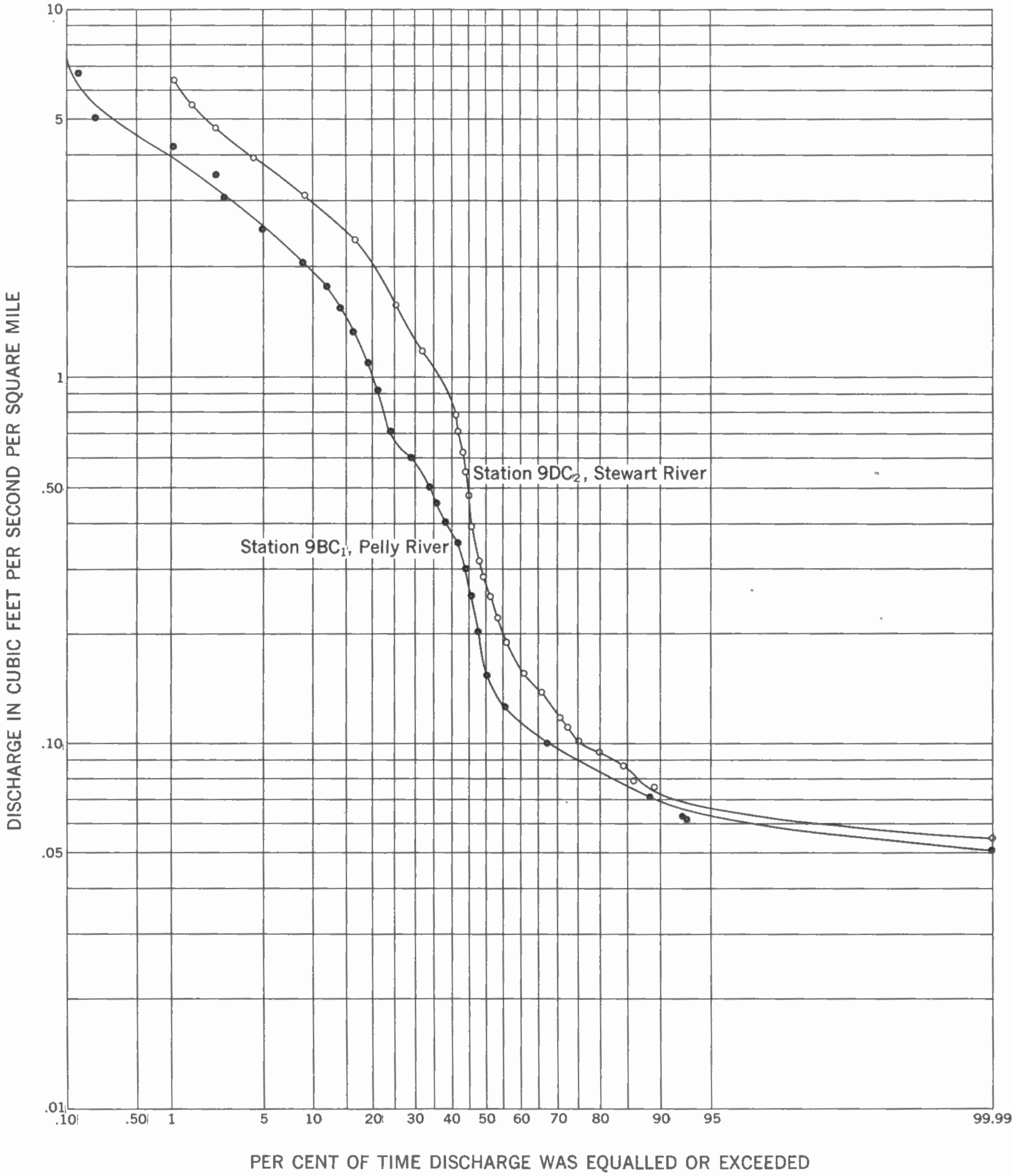


Figure 21. Flow duration curves, Pelly and Stewart Rivers

Table VII

Basin Discharge Data, Takhini, Yukon, Stewart and Pelly Rivers

River	Station	Years of Record	Area (square miles)	Discharge in Cubic Feet per Second				Run-off Depth in Inches on Drainage Basin	σ	C_v
				Mean	Mean per Square Mile	Mean Monthly Minimum	Mean Monthly Minimum per Square Mile			
Takhini	$9AC_1$	1952-58	2,370	2,160	.91	322	.14	11.7	.095	1.00
Yukon at Dawson	$9EA_1$	1956-58	106,000	70,500	.67	14,000	.13	9.1	.06	1.00
Stewart	$9DC_2$	1955-57	12,600	14,500	1.1	950	.07	15.6	.76	1.3
Pelly	$9BC_1$	1954-57	19,700	12,800	.65	1,400	.07	9.1	1.03	.87

Location	Yukon River at Whitehorse (Thomas, 1957)	Yukon River above Pelly River mouth (Owen)	Yukon River 5 miles below Pelly River (Owen)	Yukon River 1 mile above White River (Owen)	Yukon River above mouth of Klondike River (Owen)	Yukon River above mouth of Klondike River (Owen)	Pelly River at Granite Canyon (Owen)	Pelly River at Pelly Crossing (Owen)	Pelly River at Pelly Crossing (Owen)	Stewart River at Stewart Crossing (Owen)	Klondike River 1/3 mile upstream (Owen)	Klondike River 1/3 mile upstream (Owen)	Urasco Lake – south side (near Carcross)	Spring, north end of Urasco Lake	Peel River 22 miles above junction with Wind River (Owen)	Porcupine River 11 miles upstream from International Boundary (Owen)	Rat River 7 miles east of Summit Lake (Owen)	Rat River 40 miles east of Summit Lake at entrance to Mackenzie (Owen)
Month and year	10/52	6/60	6/60	7/60	8/60	9/60	6/60	8/60	9/60	9/60	8/60	9/60	7/61	7/61	8/62	6/62	7/62	7/62
Appearance and odour					Turbid													
pH	7.8	8.0	7.7	7.6	7.9	7.8	7.7	8.0	7.9	7.7*	7.6	7.7	7.8	7.8	7.9	7.3	7.2	7.4
Colour	5	20	30	25	20	30	20	20	30	25	25	30	0	0	45	35	35	35
Conductivity	90	125.4	177.5	143.3	222.2	139.2	180.6	184.6	211.8	218.7	186	207	509	629	273	120	195	140
Hardness: total	43.1	63.7	83.5	73.2	111	101	89.6	91.0	117	125	94.6	103	248	327	140	58.0	81.5	64.9
Hardness: non-carbonate	3.9	3.8	16.2	12.8	26.0	21.4	21.6	21.3	31.7	36.7	32.5	33.8	106	77.0	36.4	11.2	48.2	22.9
Calcium	13.6	18.3	22.8	19.9	30.6	28.3	24.0	24.5	31.3	33.0	25.0	27.9	49.5	59.1	38.4	17.0	19.1	17.7
Magnesium	2.2	4.4	6.5	5.7	8.4	7.5	7.2	7.3	9.6	10.4	7.8	8.1	30.3	43.6	10.8	3.8	8.2	5.0
Sodium	1.3	1.4	1.2	1.2	2.5	2.4	1.2	1.3	1.5	1.2	1.5	1.6	11.0	11.8	2.1	1.1	4.3	2.3
Potassium	0.9	0.8	0.8	0.6	2.4	1.1	0.6	0.7	0.6	0.4	0.5	0.4	1.4	2.1	0.3	0.5	0.5	0.5
Iron (total)	0.08	0.33	1.1	0.59	40	0.59	1.7	0.71	0.22	0.25	0.79	0.54	0.47	0.09	0.58	1.57	0.20	1.5
Manganese		Tr	0.0	Tr									0.00	0.02				
Zn													0.05	0.06				
Bicarbonate	47.8	73.3	81.3	73.6	104	97.2	83.1	85.0	105	108	75.7	84.1	174	304	127	57	40.6	51.2
Sulphate	5.9	6.0	18.5	12.6	28.1	25.2	22.0	23.7	33.9	37.9	32.1	36.1	126	102	36.8	10.7	52.5	23.2
Chloride	0.4	0.2	0.0	0.2	0.8	0.8	2.0	0.9	0.3	0.6	0.5	0.5	1.4	2.2	1.2	1.3	3.2	2.0
Fluoride	0.10			0.1	0.03	0.0							0.31	0.36	0.2	0.1	0.21	0.12
Nitrate	Tr	0.4	0.6	0.0	0.0	0.1	0.8	0.4		0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.2
Silica	3.5	6.1	6.4	5.7	6.4	6.7	5.9	5.9	7.4	4.7	6.1	6.6	11	14	3.7	9.2	2.7	3.1
Sum of constituents	51.5	73.7	96.9	82.2	130	120	105	107	136	141	111	123	317	385	156	64.9	111	79.3
Per cent Sodium	6.0	4.5	3.2	3.4	4.5	4.8	2.8	3.0	2.7	2.0	3.3	3.2	8.7	7.2	3.1	3.9	10	7.1

Table VIII. Chemical analyses of waters, Yukon Territory

1. Baseflow data for the rivers described above are shown in Table VII. The baseflow of the Pelly River exceeds 1,000 cfs and may be attributed to groundwater because the river has no large lake storage. The baseflow of the Yukon and Takhini Rivers is partly groundwater and partly lake storage.

2. Successful wells drilled in the wide glaciated valleys show that groundwater is present; reference to these is given later. Tyrrell (1903) recorded and described the first flowing well in a valley where permafrost is present. This well was drilled in the Klondike Valley.

3. Data on the chemical analyses of streams are shown in Table VIII. Many of the samples were obtained by E.B. Owen (personal communication).

An analysis of water from a small lake (Uranco Lake) 6 miles north of Carcross in Watson River valley is shown together with an analysis of water from a spring flowing into the lake. The lake is in glacial drift and the spring emerged from sands above clay in a wooded area on its north side. The lake sample was taken at the south end of the lake, but its similarity to the spring water analysis indicates that the groundwater flow into the lake is the main source of lake water.

4. The soils in a few depressions in Takhini Valley are alkaline and saline. Cairnes (1917) obtained samples from the largest salt-encrusted area near Champagne. On analysis this was found to be composed mainly of sodium and calcium sulphate. Day (1962) mapped the locations of similar soils and reported the presence of *Salicornia* sp. and salt-tolerant grasses. The writer considers that these soils have developed in depressions where groundwater is emerging and evaporating from small flow systems similar to those referred to above in the area south of Great Slave Lake.

Near Atlin, B.C., there are extensive hydromagnesite deposits in depressions that have been formed by upward leakage of groundwaters from underlying peridotites. Young (1915) described the extent of these deposits.

Other Basins

Several major basins in the area studied by the writer have not been described, e.g. the basins of Thelon, Coppermine, Porcupine, and Peel Rivers. Data on these basins are insufficient to show whether groundwater flow occurs. The basins are in areas of more extensive and deeper permafrost.

Low flows on three northern rivers are as follows (data from Water Resources Branch):

River	Discharge cfs	Date	Location
Coppermine	1580	Apr. 19, 1932	Below Bloody Falls
"	2030	Apr. 25, 1935	" " "
Porcupine	644	Feb. 11, 1962	At Old Crow
"	701	Apr. 10, 1962	" " "
Peel	833	Feb. 10, 1962	Above Canyon Creek
"	731	Apr. 9, 1962	" " "
"	858	Feb. 7, 1963	" " "

Some chemical analyses of Peel River from samples obtained by E.B. Owen are shown in Table VIII. These analyses indicate some groundwater contribution, but this can be expected to be relatively small. In areas of continuous permafrost along the Arctic Coast where no infiltration occurs there can be no continued groundwater flow.

Conclusions

Data presented in descriptions of basins of Great Slave Lake, Mackenzie River, and Yukon River show that in the Precambrian Shield groundwater flow is negligible, and in the Interior Plains and the Cordillera groundwater is effluent to the rivers. Winter baseflows, chemical analyses, local occurrences of halophytic flora, and local drilling data are evidences at some places of groundwater flow. More flow may be expected to occur in rocks in the Interior Plains owing to the presence of solution channels in Palaeozoic formations and to jointing in flat-lying bedding planes in sedimentary strata. Much of the groundwater flow in the Cordillera is probably in the alluvium and glacial drift.

THERMAL SPRINGS

The area studied by the writer contains several hot springs. It also contains several cold springs, which may be included as thermal springs because their water temperature is 10 or more degrees higher than the mean annual temperature of the terrain around them.

The temperatures of both groundwater and rocks increase with depth. Beach (1952) has shown varied thermal gradients in the prairies and has presented equations relating increased temperature with depth in certain oil fields. Some temperature logs from wells in the north show an increase of about one degree per 60 feet. The thermal gradient varies with lithology and location and is affected by permafrost at the surface.

The occurrence of warm groundwater in springs can, in many localities, be attributed to the warming of meteoric waters, which have passed through a deep flow system and emerge at the ground surface because of topography and geologic structure. Such waters may be called normal thermal springs.

Other springs, which may be called anomalous thermal springs, occur at a high elevation in valleys in the western Cordillera. The high temperature cannot be attributed to the heating of meteoric waters in a deep flow system because the geologic framework does not permit a deep flow system to exist there. Therefore the anomalous temperature must be attributed to one of two explanations. The first and most probable is the heating of meteoric waters during an exothermic chemical reaction of these waters with minerals present in rocks in a shallow flow system. The second explanation is the heating of meteoric waters by a high thermal aura which may surround recent intrusive rocks.

DESCRIPTIONS OF SOME THERMAL SPRINGS

Roche-qui-Trempe-à-l'Eau, Wrigley, District of Mackenzie

A series of small springs extends along the east bank of Mackenzie River over a distance of more than 1/4 mile, starting from a point about 2 miles downstream from Wrigley.

Geology — The geologic structure in this region is illustrated in the map and cross-section in Figure 22. This section has been drawn from the map by Douglas and Norris (1962). Limestone breccia of the Bear Rock Formation and shale, salt, and gypsum of the Saline River Formation outcrop in McConnell Range to the east of Mackenzie River and dip westward beneath the Nahanni Limestone and Fort Simpson Shale. The rock strata, which are thrust upwards in two faults, are domed around the northwest side of Mount Gaudet, and plunge to the southwest on the river side of the hill known as Roche-qui-Trempe-à-l'Eau.

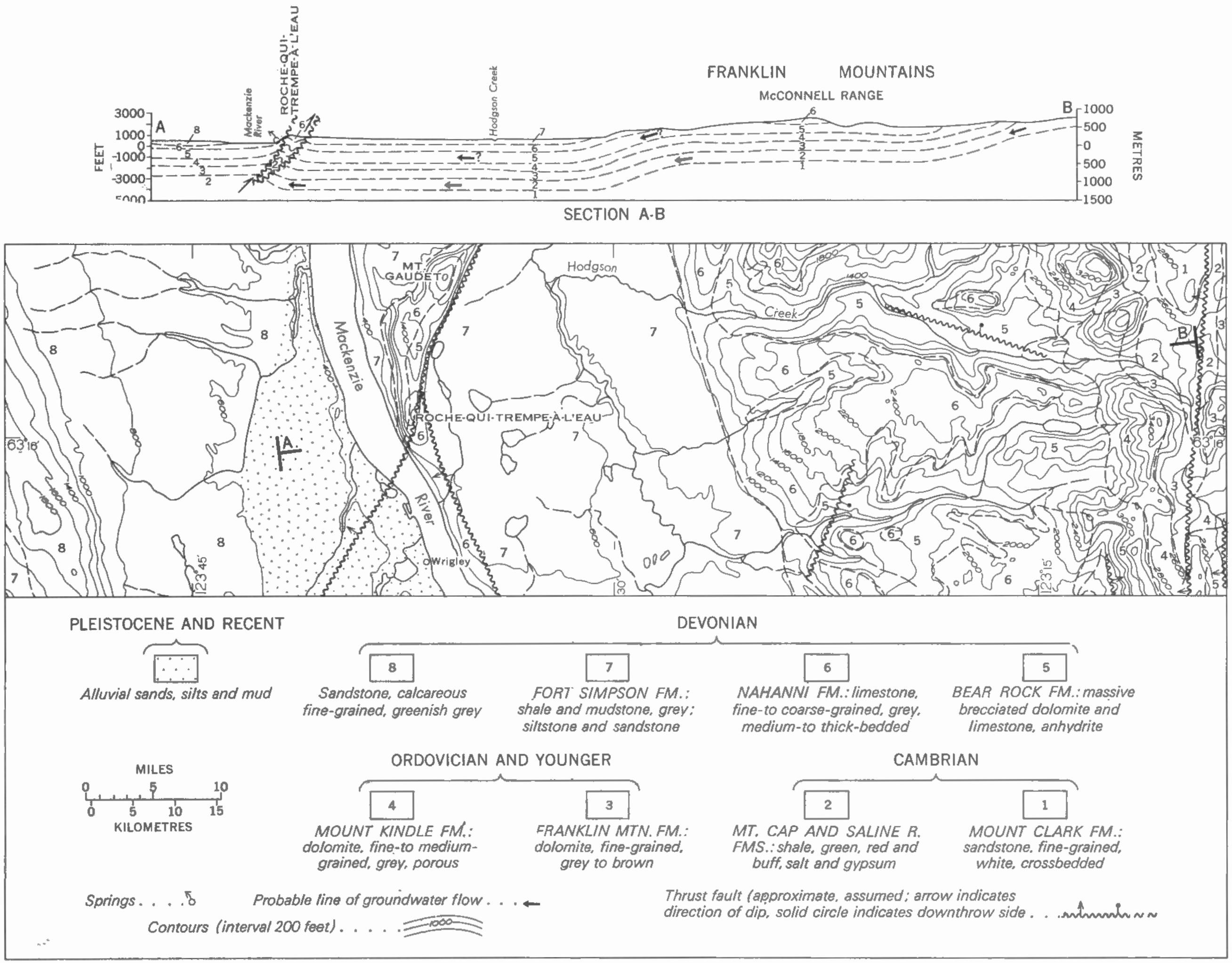
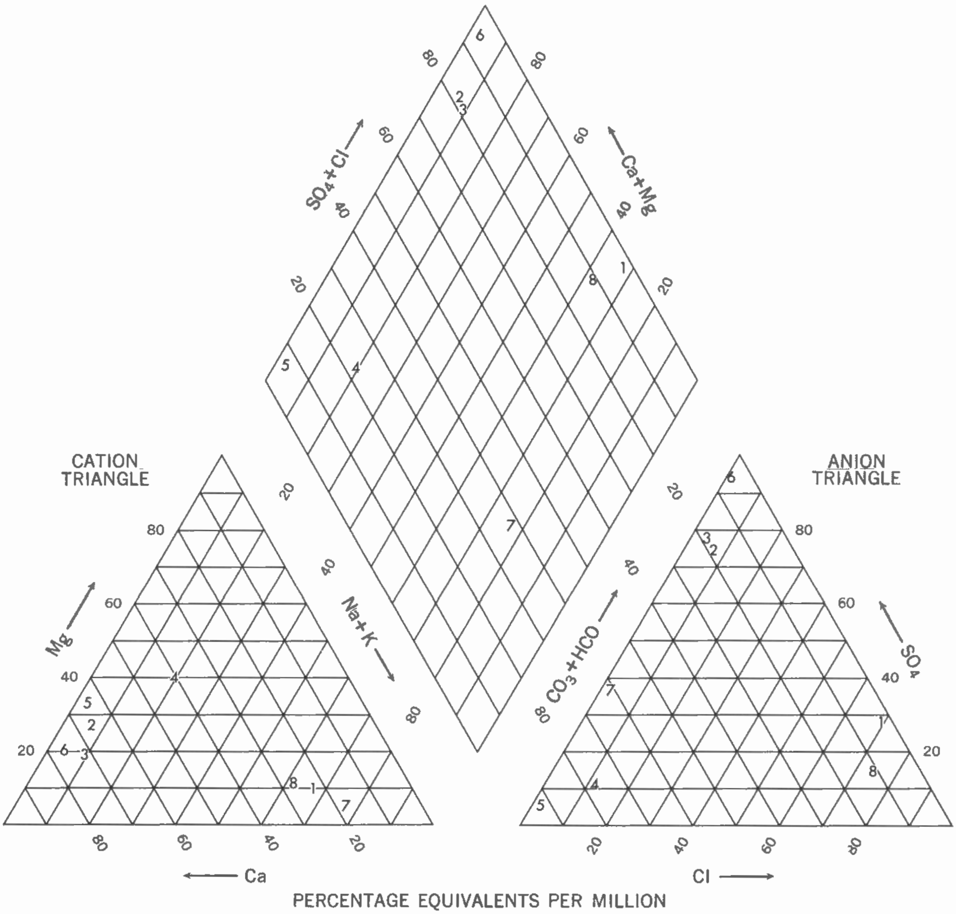


Figure 22. Geological map and cross-section illustrating flow system to springs at Roche-qui-Trempe-à-l'eau. (Geology from Douglas and Norris,1962)

Location	A Roche-qui-trempe-à-l'eau	B Roche-qui-trempe-à-l'eau	C Roche-qui-trempe-à-l'eau	Creek one mile north of Roche-qui-trempe-à-l'eau	Old Fort Island	Liard River Crossing	Portage Brûlé-Liard	Atlin, warm springs	Takhini	McArthur Range (Bostock)	A Clausen Creek, South Nahanni River	B Clausen Creek, South Nahanni River	C Clausen Creek, South Nahanni River	D Clausen Creek, South Nahanni River
Month and year	8/60	8/60	8/60	8/60	8/60	7/60	8/61	7/61	7/61	11/39	9/60	9/60	9/60	9/60
Appearance and odour	H_2S	H_2S	H_2S			Clear	Sediment	Clear	Sediment	H_2S	H_2S	H_2S	H_2S	H_2S
pH	7.7	7.8	7.7	8.0	7.9	8.1	7.3	7.7	7.5	9.5	6.8	6.9	7.1	7.4
Colour	10	10	10	30	10	8	0	0	0		15	15	15	15
Conductivity	17981	17511	17880	13596	1535	1301	1217	401	2676		8606	8469	8636	8390
Hardness: total	3229	3118	3249	2573	886	738	627	209	1854		1646	1629	1650	1619
non-carbonate	3078	2967	3095	2391	703	589	32.8	1.4	1746		1424	1413	1418	1366
Calcium	925	895	946	743	250	234	125	55.1	586	10	470	460	470	452
Magnesium	223	215	215	174	64	37	76.5	17.3	95.1	5	116	117	116	120
Sodium	3220	3075	3420	2500	27.5	15	40.6	2.6	30.1	50	1176	1066	1076	1054
Potassium	34.5	32.5	33.0	27.0	2.0	9.8	34.0	0.7	7.7		73.5	72.5	75.0	72.5
Iron (total)	0.11		0.20	0.39	0.03	Tr	0.82	0.04	0.62		0.03	0.13	0.12	0.10
Manganese	0.0	0.0	0.0	0.0	0.0	0.02	0.08	0.0	0.0		0.1	0.1	0.1	0.1
Cu, Pb, Zn						Zn 0.3		Zn 0.06						
Bicarbonate	184	185	188	222	223	182	725	253	132		271	263	283	308
Sulphate	2810	2744	2832	2198	683	566	77.0	11.3	1721	50	660	738	732	698
Chloride	5226	5033	5200	3980	36.9	18.5	63.6	0.8	1.5	2	2277	2231	2271	2208
Fluoride	3.0		3.0	1.75	1.0	3.2	0.33	0.14	4.4		0.6	0.6	0.6	0.6
Nitrate	0.8		0.4	0.4	0.4	3.0	0.0	0.0	7.6		4.0	0.8	0.2	3.2
Silica	24		24	17	6.6	52	40	14	41		26	28	28	29
Sum of constituents	12556	12000	12766	9750	1180	1036	814	226	2559	177	4942	4844	4908	4788
Per cent Sodium	68	68	69	68	6.3	4.1	12	2.6	3.4		60	57	57	57

Table IX. Chemical analyses of thermal spring waters (see also Figure 2)



LOCATION OF ANALYSES

1. Roche-qui-trempe-à-l'eau, Dist. of Mackenzie
2. Old Fort Island, Mackenzie River, Dist. of Mackenzie
3. Liard River crossing, British Columbia
4. Portage Brûlé on Liard River, British Columbia
5. Atlin, Warm Springs Bay, British Columbia
6. Takhini, Yukon Territory
7. McArthur, Yukon Territory, (analysis incomplete)
8. Clausen Cr., South Nahanni R. Dist. of Mackenzie

Figure 23. Chemical analyses diagrams of thermal spring waters (see also Table IX)

Water Quality — Water issues from small rock fissures and bedding planes in more than twelve places along a 1/4-mile stretch of the rock bank. The flows are small, about 2-20 gpm, but in one locality water emerges from a talus slope with a total flow of about 70 gpm. Several fissures and beds of travertine, 100 feet or more above the river, are the remains of old springs that have ceased to flow because of a decline in head or because the fissures have become sealed. The flows of water were all within 50 feet of the level of Mackenzie River at the time of the writer's visit in 1960. They have been described by Williams (1922). The temperatures of the flows were found to vary from 70 to 88°F.

The waters are highly mineralized and can be classified as saline (Table IX and Figure 23). A sample taken in August 1961 and analyzed for tritium content by Atomic Energy of Canada Ltd. (R.M. Brown, personal communication) was reported to contain 2.85 $\pm$ 0.15 T.U. This indicates an age of water of 30 $\pm$ 10 years if there have been no additions of post-1954 water to the aquifer.

Flow System — The outcrops of the Bear Rock and Saline River Formations in McConnell Range appear to be the source area of the water for the springs. Groundwater may collect and enter solution channels and fractures of these formations in the mountain valleys. It then flows through these formations where it acquires a raised temperature before emerging in the thrust-fault zone. The high saline content and relatively high temperature indicate that the Saline River Formation rather than the Bear Rock is the predominant aquifer. The massive bedded limestones of the Nahanni Formation apparently act as a confining layer in part of the flow system, but thrust faulting has opened the bedding planes and joints of the limestones where they dip at 30 to 45-degree angles along the river side, thus permitting water from the thrust fault zone to emerge along a spring line.

Vegetation — Spring waters seep out to form a small creek north of the main rock outcrops. A halophytic plant community around this creek has been described by Lindsey (1953, p. 49), who visited the site and reported that Scirpus rufus was the dominant species and "also abundant were Triglochin maritimum and Plantago eriopoda; common species were Gentiana raupii, Glaux maritima and Hordeum jubatum."

Old Fort Island, District of Mackenzie

The springs at Old Fort Island (mile 336, Mackenzie River) were first described by Williams (1922), who observed springs on the smaller of the two islands in the river and in a small clearing 60 yards from the right bank of the main river.

Geology — Nahanni limestones comprise the rock outcrops of the small island and the southern part of the main island. The limestones are overlain in the north part of the large island by Fort Simpson Shale. The island is part of the southern extremity of the main structural element of McConnell Range where it comprises "gently-west-dipping middle Devonian rocks underlain by a northwest-dipping thrust fault" (Douglas and Norris, 1961, p. 25).

Water Quality — Although the springs are cold they were classified as thermal because their temperature was 53°F when sampled in August 1960. This is about 15°F warmer than ground-waters would be from a shallow flow system in the region.

The principal flow of water on the island is in a spring where water bubbles up into a small sandy pool surrounded by dense vegetation. The pool is shallow and limestone may be within 5 feet of the surface. The flow was estimated to be 300 gpm. Several other small springs and seeps occur within a 100-yard radius of the main spring and other flows emerge from rock fissures farther away. The total flow in the area may be about 1,000 gpm.

The waters are not highly mineralized, having a conductivity of 1,535 microhms. They are classified as calcium sulphate waters.

Flow System — On the basis of the local topography and structure it can be assumed that the waters have entered solution channels in the Bear Rock Formation, which outcrops in McConnell Range east of Mackenzie River. The water has then been conveyed through this aquifer to the discharge area of Mackenzie River, where it emerges through fissures in the Nahanni Limestones along the thrust fault. The slightly raised temperature of the emerging waters is acquired from the thermal gradient.

Clausen Creek, South Nahanni River, District of Mackenzie

Springs occur along the right bank of South Nahanni River below the rock wall of the first canyon and upstream from Clausen Creek.

Geology — Dark grey limestone of the Nahanni Formation forms the limb of an anticline plunging gently to the southeast (Douglas and Norris, 1960). Erosive action of the river has cut the limestone to form a steep canyon wall. Below the canyon the river banks are lined with sand and gravel alluvium and the spring waters emerge by upward leakage through alluvium. The principal source of spring water is in a channel along the edge of the rock wall, 100 yards from the river. A pool 25 to 30 feet in diameter has been formed naturally by water bubbling upwards into an area of river mud. Visitors have extended the pool by making a small dam.

Water Quality — The flow of water from the main pool was estimated to be about 300 gpm. There is so much seepage of water along the banks that it is difficult to estimate the total flow of the springs, and much of the water is probably discharged directly into the river below river level.

The temperature of the water in part of the pool was 95°F; one of the flows beside the river had a temperature of 98°F.

The principal constituent of the waters is sodium chloride. The waters are not as highly mineralized as those of Roche-qui-Trempe-à-l'Eau but are, nevertheless, saline waters, which are emerging from a deep flow system. An odour of hydrogen sulphide pervades the region of the springs. A tritium count analysis of a sample taken in September 1960 was reported (R.M. Brown, Atomic Energy of Canada, personal communication) to be 3.64 ± 0.18 T.U., the lithium content being 2.0 ppm. This (like the tritium data given at Roche-qui-Trempe-à-l'Eau) indicates an age of water of about 30 ± 10 years after the water was deposited if the tritium is of entirely cosmic origin and if there have been no additions of post-1954 tritium.

Flow System — The Nahanni limestones, at the top of the Middle Devonian section, are underlain by thousands of feet of Devonian and older Palaeozoic limestones and dolomites. The structure and lithology of these rocks are such that solution-channel flow and rock-fracture flow are probable. It is therefore concluded that water percolates into these rocks higher up in the Nahanni Plateau, that it enters into a deep flow system, gaining its temperature from depths below 5,000 feet, and that the flow system reaches a point of natural discharge at the foot of the plateau escarpment. The presence of hydrogen sulphide indicates that there may also be a gain of heat from an exothermic chemical reaction.

Liard River Crossing, British Columbia

The springs at this locality are in a provincial park adjacent to the Alaska Highway near milepost 497.

Geology — Middle Devonian carbonate rocks are overlain by clastic Devono-Mississippian strata, which are gently dipping down slope. The area has been mapped by Gabrielse (1961).

Water Quality — The springs consist of two main pools, which are used for bathing. The upper pool has a temperature of 106 to 108°F in summer, and the lower pool 118°F. The flow of water out of the lower pool was estimated to be about 1.5 cfs in August 1961. The waters are predominantly calcium sulphate waters.

Flow System — The springs are at an elevation of 1,500 feet at the foot of hills that rise to 3,000 feet. It can be assumed that the recharge area is in the hills to the north and that waters are flowing through bedding planes in Devonian limestones to a discharge area in the valley. A detailed description of the area and surrounding flora has been published by Porsild (1961).

Portage Brûlé Springs, British Columbia

Springs occur on the left bank of Liard River downstream from its junction with Coal River and between two of the Portage Brûlé rapids.

Geology — Silurian dolomites outcrop along the river bank in the area of the springs and dip 85°NE. Devonian carbonate rocks outcrop in heavily wooded country north of the springs. The region has been mapped by Gabrielse (1961).

Water Quality — Six flows emerge in a 150-yard stretch of the river bank. The flows are small, varying from 5-10 gpm, and emerge from solution channels in dolomite, which are surrounded by travertine (Plate IIA). The warmest flow was found to be 112°F; some flows were 90°F. The water is predominantly a calcium bicarbonate water.

Flow System — The relatively low mineral content is indicative of a short flow system. The recharge area is probably in the hills to the north, which rise to over 2,500 feet. Groundwater may flow along the jointed rocks to emerge at the discharge area, which has an elevation of 1,550 feet.

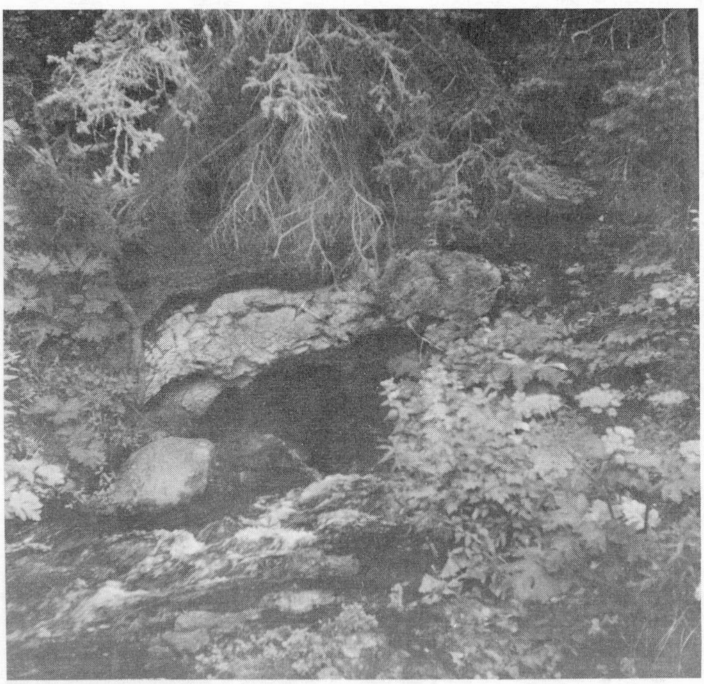
O'Donnel River, Atlin, British Columbia

Thermal springs in the lower part of O'Donnel River valley south of Atlin have been known for many years. One spring emerges at the site of an abandoned homestead beside the trail to O'Donnel. Another large spring a mile farther up the trail is known locally as "The Grotto" (Plate IIB).

LVB 8-1-61

A.
Portage Brûlé Hot Springs on Liard River, showing dolomite encrusted with travertine (T) around the springs.

PLATE II



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B.
Groundwater emerging from a solution channel in limestone near O'Donnel River, Atlin, B.C.

Geology — Steeply folded beds of limestone and limestone breccia of the Cache Creek Group underlie glacial drift. These rocks and associated chert, argillite, greenstone, and greywacke outcrop extensively in the O'Donnel River valley and on Sentinel Mountain to the north and in Laurie Range to the east (Aitken, 1959).

Water Quality — The warm springs beside the abandoned homestead at about 2,500 feet elevation have a temperature of 80°F and a flow of about 1 cfs. The water bubbles up through sand and gravel in a small pool about 10 feet square. The waters are calcium bicarbonate waters with a low mineral content.

At a slightly higher elevation a mile away is "The Grotto", a spring that emerges from a solution channel in a fold in the limestone. When visited in August 1961 it had a flow of approximately 5 cfs and a temperature of 48°F.

Flow System — The recharge area for the springs is in the high ground to the north and east where water can enter solution channels in the limestone. The flow system is probably short because the waters are low in mineral content, which indicates a rapid transit through a small flow system. The different and relatively low temperatures are also evidence of a shallow flow system. The large spring is a cold spring, which has received about a 10°F rise in temperature so the water probably goes to a depth of only about 500 feet before emerging.

Takhini Hot Spring, Yukon Territory

The spring is located about 1 1/2 miles north of Takhini River and about 6 miles west of the Dawson road.

Geology — The spring water bubbles up into a cribbed well, which has been built around a natural pool formed in the glacial drift. Limestone and greywacke outcrop 150 yards north of the spring and rise more than 500 feet above the valley. These rocks dip to the west and are faulted (Wheeler, 1961).

Water Quality — The spring waters are piped to a swimming pool and have a flow of about 50 gpm and a temperature of 116°F. The waters are calcium sulphate waters.

Flow System — Small lakes in depressions between the hills to the north of the valley are a natural source area for the waters, which may flow along a fault zone before emerging in the spring at the edge of Takhini Valley.

McArthur Hot Springs, Yukon Territory

Several springs flow into Hotspring Creek below McArthur Range (lat. 63°05'N, long. 135°42'W). The surrounding area was mapped by Bostock (1947).

Geology — Mesozoic or younger granites have intruded and altered older sediments, which have been metamorphosed to pyritiferous slates. The granites outcrop around a cirque, which is above a valley filled with alluvium and underlain by slates.

Water Quality — H. S. Bostock (personal communication) reports that he found the temperature of the waters at the hottest place to be 128°F. The flow may be estimated at 500 gpm from the main hot spring area. The waters have a low mineral content and are sodium sulphate waters.

Flow System — The recharge area is probably at the head of the cirque, where meltwater may enter joints in the intrusive granite. The waters flow through the joints and emerge from an alluvial fan at the foot of the cirque after flowing through the highly pyritiferous slates and slate alluvium. Bostock (personal communication) has suggested that oxidation of the pyritiferous slates generates the heat acquired by the spring waters. The emergence of sulphate waters and the release of hydrogen sulphide are certainly evidence of an acid reaction with iron pyrite.

Upper Flat River and South Nahanni River, District of Mackenzie

Several thermal springs occur in the upper parts of Flat River and South Nahanni River valleys. The flora around one spring near a lake known as "Hole-in-the-wall Lake" (lat. 61°57'N, long. 127°13'W) has been described by Porsild (1961).

The absence of a halophytic flora around the springs and the high elevation of discharge are indicators that the springs are emerging from a small flow system. The heat used in raising the temperature of the water is probably derived from an exothermic chemical reaction, as in the McArthur springs.

COMPARISON OF CHEMICAL ANALYSES

Table IX shows analyses of the waters in the springs referred to above, and Figure 23 permits comparison of their analyses. The springs fall into four groups: (1) calcium magnesium bicarbonate springs at O'Donnel River and Portage Brûlé; (2) calcium magnesium sulphate springs at Old Fort Island, Liard River Crossing, and Takhini; (3) saline springs at Roche-qui-Trempe-à-l'Eau and Clausen Creek; and (4) a sodium sulphate spring in McArthur Range.

The writer believes that the first three groups are representative of the size and depth of the flow system through which the waters have passed and that the Chebotarev (1955) sequence of bicarbonate-to-sulphate-to-chlorite metamorphism of waters has occurred. There have also been massive contributions of sulphate and chloride in the springs at Roche-qui-Trempe-à-l'Eau and Old Fort Island. Heat from an exothermic reaction with sulphides in limestone may have contributed to the high temperature of springs with sulphate waters.

Thermal waters from flow systems similar to that at Roche-qui-Trempe-à-l'Eau could be used as a heat source if a heat pump were designed to make use of the warm waters.

GROUNDWATER SUPPLY

All settlements in Northern Canada are situated near a lake or a river, and may therefore choose either a surface supply of water, or a well or well field if a communal water supply is required. The choice is a matter of economics involving both capital and maintenance costs.

COMPARISON OF SURFACE AND GROUNDWATER COSTS

Surface Waters — The advantages of surface waters are: (1) soft water, and (2) abundant supply. The disadvantages are: (1) heavy construction and maintenance costs, which include an intake, filtration plant, and pipelines; and (2) variation in temperature and freezing problems.

Groundwaters — The advantages of groundwater are: (1) constant temperature; and (2) low construction and maintenance cost because filtration is not necessary and because proper spacing of wells may reduce pipelines. The disadvantages are: (1) hardness, and (2) testing and development problems.

Pumping costs vary, but groundwaters may require less lift because piezometric levels near a lake or river are higher than surface water levels.

TESTING AND DEVELOPING GROUNDWATER

There are four phases of groundwater development for a community supply.

1. Location of Aquifer. This may be done by geological inspection of a site, by test drilling, and by geophysical methods. The best aquifers are generally in alluvium (e.g. Whitehorse and Dawson well fields), which can be located by site inspection. The wide glacial-drift-filled valleys of the southern Yukon contain permeable lenses, which can be located by test drilling. The jointing and fracturing of rock gives an indication of the anticipated yield of a well, but test drilling is generally required. The location of a preglacial valley or the presence of sand lenses in clay requires seismic, resistivity, or electrologging geophysical techniques. A comparison of these methods in different parts of Canada has been made by Hobson, Wyder, and Brandon (1962).

2. Quantitative Testing of Aquifer. This is done by performing standard pumping tests after or during the test drilling program. The methods have been outlined by Todd (1959) and are an essential phase of a development program.

3. Chemical Testing of Aquifer. The length and depth of a flow system affect the mineral content of groundwater. Waters in small flow systems are generally of excellent quality. Waters emerging from extensive flow systems may be too hard or too saline for domestic use (e.g. water from lower Palaeozoic rocks on the west side of Great Slave Lake).

4. Well-Field Construction. This is sometimes the most neglected phase of groundwater development, but it is just as important as the others. Well-drilling techniques require engineering skill and experience. Among the varied techniques are: (a) rotary drilling with mud, which is a successful method in the Plains but is impractical in heavy boulders or crystalline bedrock; (b) percussion drilling with cable-tool drill, a certain method of making a hole in any type of ground; (c) reverse circulation drilling, which drills large-diameter wells in alluvium and glacial drift; (d) jet drilling, which is satisfactory for installing shallow sand points in alluvium that is not frozen; (e) diamond-drilling, which is only satisfactory for wells in jointed rock where a small domestic supply is required and if a special small-diameter pump has been obtained; and (f) air-percussion and air rotary drills, which are capable of drilling in any type of ground.

Wells in alluvium or glacial drift require well screens and may require a gravel or sand pack outside the screen.

Dug wells are a false economy because they frequently become polluted from the surface and they do not have the capacity to yield as much water as a drilled well equipped with a screen.

PERMAFROST AND WATER WELLS

Drilling in the north is expensive because of high transportation costs and the need to keep personnel and machinery warm. Warm or saline water is circulated when rotary or diamond-drilling in permafrost. Cederstrom and Tibbits (1961) have discussed and compared water-well drilling techniques in permafrost and concluded that cable-tool drilling is the most satisfactory. It is probable that air-percussion rotary drills would also drill successfully in permafrost.

Regions where permafrost is many hundreds of feet thick cannot be expected to yield good groundwater supplies, but valleys containing patches of permafrost less than a hundred feet deep may contain excellent aquifers. Shakwak Valley in the Yukon contains several wells that have been drilled through permafrost.

The maintenance of a well in permafrost may require the use of a heating coil in the well casing to prevent freezing.

WATER SUPPLY AT TOWNS AND SETTLEMENTS

District of Mackenzie

Fort Smith Area

References: Wilson (1939, Map 607A); Douglas (1959, Map 27-1958).

The town of Fort Smith is situated on the southwest bank of Slave River, on a sand plain about 125 feet above river level (Fig. 24).

Geology — Precambrian granite outcrops in the Rapids of the Drowned, at the river intake of the town's water-filtration plant, and on the north shore of the river. At Bell Rock, 8 miles west of the town, Palaeozoic breccia, limestone, and gypsum outcrop on the bank of Slave River. The surficial geology comprises lake sands overlying lake clays. These were deposited when glacial Lake McConnell (Craig, 1964) covered the region. The sands are exposed along the steep bank of the river where they can be seen overlying blue clay. Small springs and groundwater seepages are present along the line of the sand-clay contact.

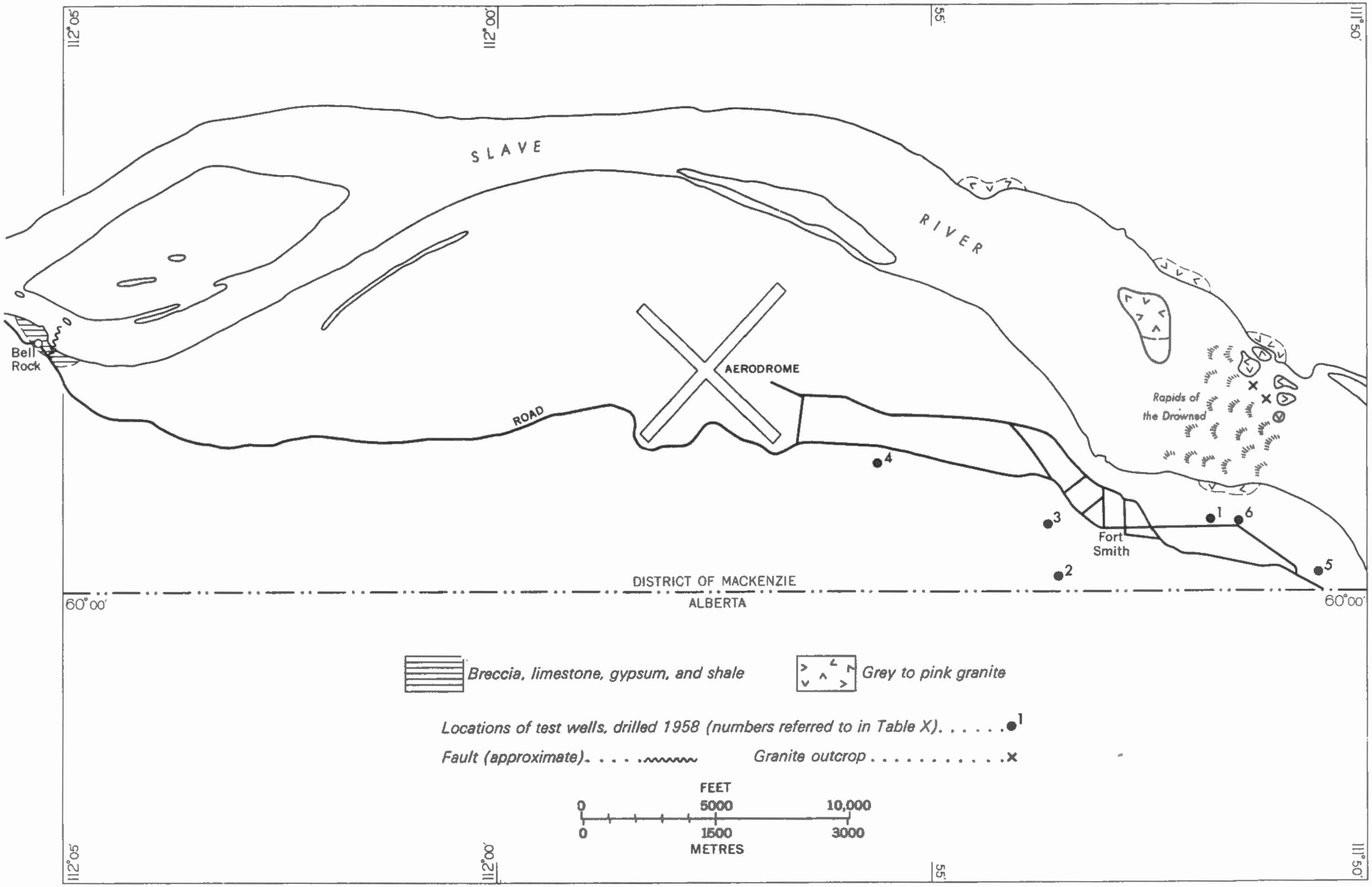

Figure 24. Geology and location of test wells, Fort Smith

Water Supply — The present water supply is obtained from a newly constructed river filtration plant. Wells were used in the town prior to the construction of the filtration plant. C.H. Stockwell (unpublished report, on file Geological Survey of Canada) visited the town in 1930 and noted that there were fifteen dug wells in sand which varied in depth from 19 to 36 feet. The shallower wells were in the southern part of the town, whereas in the northern part the wells were a few feet deeper because of the natural slope of the groundwater table towards the river. The water in these wells was very hard with a high iron content. Two chemical analyses, made on samples taken in 1930, indicated that the water was a calcium bicarbonate water with total dissolved solids ranging from 420 to 490 ppm. Six wells were drilled in the town prior to 1930. Two of these were drilled to granite, which was encountered at depths of 161 and 165 feet. The well logs show that approximately 25 feet of sand overlies silts and clays and sand lenses.

In 1950 a well was drilled at the airport. The log of this well is shown in Table X. The well yields water from sands at a depth of approximately 40 feet. In 1958 a well-drilling program was carried out to test for a town supply of water. Six holes were drilled; the locations of the wells are shown on Figure 24 and the logs of the holes are recorded in Table X. The test drilling results showed that in three of the wells, thin aquifers of small area extend below clay in gravels and fractured granite. Test pumping yielded 15-40 gpm and the drawdown data indicate that the aquifers have a transmissibility ranging in value around 1,000 gpdf. The water was very hard and further well testing was abandoned.

At Bell Rock borings were undertaken at the docksite by the Department of Public Works for foundation testing in 1945. The tests showed that alluvial silts overlie the limestone. Water flowed in one test well from an aquifer between the silts and limestone.

The Department of Public Works also carried out foundation testing in July 1955 at the site of a proposed bridge over Salt River. Drill logs record silts overlying limestone and shale.

In the region of Fort Smith, drilled wells 30-40 feet deep with properly designed well screens or sand points can be expected to yield about 40 gpm from the sand aquifer that overlies the clay. The water may be very hard and may have a high iron content so that water treatment will be necessary if the water is to be used domestically. Deep drilling is not recommended owing to the increased mineral content of water with depth. This increased mineral content can be expected to continue west of Fort Smith towards Bell Rock, where Palaeozoic limestones underlie the lake clays and overlie the granite. Solution channels conveying water

Table X

Logs of Wells Drilled at Fort Smith, District of Mackenzie

Airport test well drilled in 1950 under supervision of Division of Works and Services, Department of Northern Affairs and National Resources.

Depth (feet)	Description	
0-10	Silty brown sand	A 40-foot well here is reported to yield sufficient supply for domestic requirements.
10-16	Silty grey sand	
16-20	Brown silty clay	
20-46	Quicksand	
46-151	Silty blue clay	
151-160	Silty brown clay	
160-173	Silty blue clay	
173	Rock (limestone)	

Wells drilled in 1958 at Fort Smith by Big Indian Drilling Co. Ltd., Calgary (Stanley, Grimble, Roblin Ltd., Consulting Engineers). Locations of holes are shown on Figure 24.

Test Well No.	Depth (feet)	Description	Test Results
1	0-20	Sand	A 5-foot, 60-slot screen was set at 177-foot depth and the well was pumped at 15 gpm with a draw-down of 28 feet. Hardness of water was 940 ppm.
	20-25	Coarse sand	
	25-30	Finer sand ?	
	30-35	Silty sand	
	35-40	Fine silty clay	
	40-175	Soft blue clay	
	175-178	Sandy gravel	
	178-185	Granite	
2	0-17	Sandy brown clay	Depth to water prior to pumping from fractured granite aquifer, 33 feet. Drawdown 45 feet after pumping 24 hours at 25 gpm. Hardness of water 696 ppm.
	17-30	Sand	
	30-35	Silty clay	
	35-153	Soft blue clay	
	153-158	Granite	

Table X (cont.)

Test Well No.	Depth (feet)	Description	Test Results
3	0-5	Sandy brown clay	
	5-15	Silty sand	
	15-40	Sand	Well abandoned
	40-45	Silty clay	
	45-149	Soft clay	
	149-155	Granite	
4	0-10	Sandy brown clay	Depth to water 56 feet. Test pumping was carried out (without a screen) from the granite wash aquifer. Yield was 40 gpm for 88 feet draw-down.
	10-35	Sand	
	35-45	Silty clay	
	45-50	Silty blue clay	
	50-173	Soft blue clay	
	173-180	Granite wash	
5	0-63	Sand	No aquifer at depth worth testing.
	63-87	Silty blue clay	
	87-173	Soft blue clay	
	173-205	Clay	
	205-211	Granite	
6	0-36	Sand	No aquifer at depth worth testing.
	36-42	Silty clay	
	42-167	Soft blue clay	
	167-185	Granite	

with a high sulphate and chloride content may be present in the Palaeozoic rocks.

Erosion — The clay banks of Slave River at Fort Smith are being undercut. Slides and continued erosion may be expected.

Fort Resolution

Reference: Douglas (1959, Map 27-1958).

The settlement of Fort Resolution is situated on the south shore of Great Slave Lake in Resolution Bay.

Geology — Dune and lake sands, silts, and beach deposits comprise the surficial material at the settlement. A gravel and cobble ridge extends westward at the north end of the airport runway. Limestone and dolomite of the Pine Point Formation outcrop at Mission Island and north of the airport. These limestones and dolomites underlie the settlement.

Water Supply — Water is obtained from the lake. A dug well 14 feet deep at the Roman Catholic Mission contains a few feet of highly mineralized water. Deep well drilling would probably yield considerable supplies of saline water from upward leakage of groundwater that is being discharged into Great Slave Lake and which is thought to be saline at the eastern extremity of the Palaeozoic basin.

Dawson Landing and Pine Point

References: Campbell (1957); Douglas (1959, Map 27-1958).

Geology — Limestone and dolomite outcrop along the shore of Great Slave Lake at Dawson Landing, and a few outcrops occur in the plains south of the lake. Strand lines of raised shorelines (Craig, in Douglas, 1959) extend as sand ridges up to an elevation of 900 feet.

Water Supply — Groundwater is being discharged into Great Slave Lake from the jointed Palaeozoic rocks. The water is highly mineralized in some springs so that drilled wells in rock may yield very hard water. Water of good quality may be obtained from surficial sands. The chemical analyses of the townsite well and mineshaft water at Pine Point are given in Table XI. The depth to water at the mineshaft is 100 feet.

Location	Fort Smith			Hay River	Fort Providence	Mackenzie Highway		Pine Point		Jean Marie Creek	Fort Simpson				Wrigley	Fort Norman	Coppermine		Tuktoyaktuk		
	Well No. 1	Well No. 2	Well No. 4	Well No. 6 in town	Basement well at H. B. Co. house	Well at Mile 28	Well at Mile 32	Townsite well	Shaft N42	Dug well	H. B. Co. house (tap)	R. C. Mission (old well)	R. C. Mission (at boiler house)	Airport, D. O. T. (tap in garage)	Airport well, D. O. T.	R. C. Mission well (dug)	Small creek in settlement	Ten feet off-shore	On seashore, west side of settlement, by RCMP	Thawed ice wedge, in sand, by RCMP	Lake in settlement
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Well depth (ft.)	185	158	180	62	10	60	12			14	40		48	26	150	20					
Date of sample	1958	1958	1958	1958	7/60	9/60	9/60	7/60	7/60	8/60	8/60	8/60	8/60	8/60	8/60	8/60	7/60	9/60	8/60	8/60	9/60
Appearance and odour					Clear					Sediment	Clear			Clear							
pH					7.9		8.0	8.1	8.0	7.6	8.0	8.0	8.0	8.2	8.1	7.7	7.6	7.6	7.6	6.8	7.4
Colour					Colloids	15	15	15	15	90	15	15	15	15	15	25	75	25	50	30	35
Conductivity					3880	798.1	372.8	1114	539.3	395.7	9043	386	1063	794.9	553.7	1346	208.8	84.0	773.6	50.3	2488
Hardness: total	765	650	755	280	2654	299	201	632	293	191	878	186	464	454	308	732	98.2	42.4	167	22.7	350
: non-carbonate					2374	0	6.9	458	65.5	9.8	461	35.9	154	8.4	18.9	330	4.2	0.1	72.6	2.8	171
Calcium					497	61.9	58.0	126	70.0	56.5	279	56.7	113	95.8	79.2	124	22.5	9.5	33.3	5.4	79.5
Magnesium					344	35.0	13.8	77	28.6	12.1	44.1	10.8	44.0	52.1	26.7	103	10.2	4.5	20.4	2.2	36.8
Sodium					74.0	59	1.8	10.0	2.8	3.3	1615	7.4	57.0	10.9	1.6	21.2	5.5	0.5	83.4	0.9	360
Potassium					24.5	4.7	1.5	2.0	1.0	11.0	9.5	1.4	2.3	2.4	2.5	4.9	0.6	0.4	3.8	0.7	12.5
Iron (total)	0.3	0.3	0.3	2	0.21	0.5	0.24	0.16	0.51	0.42	0.33	0.14	0.02	0.24	0.04	0.52	0.28	0.11	2.7	10.3	0.78
Manganese					0.0	0.0	1.0	0.0	0.01	0.0	0.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.4	0.0
Cu, Pb, Zn									Pb 0.46 Zn 1.0									Cu 0.01			
Bicarbonate					341	377	237	211	277	221	508	183	378	543	352	491	115	51.6	115	24.3	219
Sulphate	425	408	396	13	2197	64.1	9.8	463	53.4	19.2	220	35.2	164	19.7	19.9	283	5.9	2.7	51.1	4.6	23
Chloride	192	100	186	23	24.6	38.5	1.0	0.4	4.1	3.2	2747	9.7	62.9	2.0	0.8	18.2	8.2	1.0	153	1.4	682
Fluoride	0.0	0.0	0.0	0.0	1.0	0.0	0.0		0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate					312	1.0	0.0	0.0	16	5.0	1.6	1.4	16	1.0	5.0	55	0.0	0.0	0.1	0.0	2.8
Silica					9.1	8.5	6.8	8.5	11	16	7.2	3.8	5.9	14	7.7	7.1	4.7	1.7	3.0	0.5	0.6
Sum of constituents	1310	1220	1262	422	3651	458	209	791	323	219	5174	217	652	465	317	858	114	45.7	404	28.0	1305
Per cent Sodium					5.7	30	1.9	3.3	2.0	3.5	80	7.9	21	4.9	1.1	5.9	11	2.5	51	7.3	68

Table XI. Chemical analyses of wells, District of Mackenzie

Hay River

Reference: Douglas (1959, Map 27-1958).

The old town of Hay River is located at the delta of Hay River on the south shore of Great Slave Lake. The first settlement and mission was on the east side of the east channel of the river. In 1942, after the construction of an airstrip, settlement and town development began on Vale Island. In 1963 preparations were underway to move the townsite to the left bank of the river south of Vale Island.

Geology — Vale Island and the shores adjacent to the east and west channels of Hay River are all part of the delta of Hay River. Strand lines of beach deposits from Glacial Lake McConnell are found south of the delta. The sediments underlying the old town are fine-grained sands, silts, and clays. Glacial clay and boulders underlie these deltaic materials. Palaeozoic shales of the Fort Simpson Formation underlie the recent deposits. The low-lying deltaic region is subject to flooding because the spring break-up of the river occurs earlier than in Great Slave Lake.

Water Supply — Test drilling for groundwater was carried out in 1958. A description of the well logs is given in Table XII and the locations of the holes are shown on Figure 25.

The deltaic and glacial sediments were found to be 60-90 feet deep on Vale Island. Drilling was continued in four holes down into shale and limestone of the Fort Simpson Formation, but the presence of gas and highly mineralized water showed that groundwater suitable for the town could not be obtained by deep drilling.

Test pumping was carried out on wells Nos. 9, 10, 11, and 14. A 10-foot-long, 15-slot, wire-wound screen was installed in each well prior to test pumping. Well No. 9 was pumped dry, but the other wells were able to yield 2-6 gpm during tests lasting several hours. The transmissibilities of these thin lens-like aquifers are extremely low, being about 300 gpdf or less, but with careful well-screen construction it is possible to have low-yield wells in the deltaic materials. Chemical analysis of water from one well is given in Table XI.

Permafrost was found in some of the wells. The greatest thickness of frost was reported to be from 4 to 30 feet in hole No. 12.

Chemical analyses of Hay River water have been reported by Thomas (1957).

Table XII

Logs of Wells Drilled at Hay River, District of Mackenzie

Wells drilled by Big Indian Drilling Co. Ltd. in June 1958 (Stanley, Grimble, Roblin Ltd., Consulting Engineers, Edmonton).

Depth (feet)	Hole No. 1	Depth (feet)	Hole No. 2
0-34	Sand clay and rocks	0-16	Sandy brown clay
34-90	Clay	16-36	Soft blue clay
90-231	Hard shale	36-64	Clay and rocks
231-244	Soft shale	64-190	Soft shale
244-249	Hard shale ledge	190-363	Soft shale with hard stringers
249-370	Calcareous shale	363-370	Limestone
370-390	Limestone (gas odour)		
	Hole No. 3		**Hole No. 4**
0-10	Silt	0-8	Reddish beach sand
10-23	Clay and sand	8-18	Fine grey sand
23-27	Gravel (water and sand)	18-25	Coarse grey sand
27-84	Clay and boulders	25-41	Grey clay and gravel seams
84-175	Shale	41-55	Grey clay
175-290	Hard shale with intermittent ledges	55-77	Clay and boulders
290-340	Limestone (gas and sulphurous water)	77-189	Shale
		189-200	Hard shale (gas)
	Hole No. 5		**Hole No. 6**
0-10	Clay and silt	0-1	Clay
10-21	Soft clay (sandy)	1-8	Fine red beach sand
21-33	Brown sand	8-25	Coarser grey sand
33-41	Reddish clay and pebbles	25-30	Clay with sand seams
41-42	Boulders	30-45	Soft clay
42-76	Blue clay with rocks	45-56	Soft gravel and clay
76-80	Shale	56-62	Clay
			Static water level 3 feet from surface.

Table XII (cont.)

Hole No. 7

Depth (feet)	
0-1	Clay
1-5	Sand
5-11	Frozen sand
11-17	Gravel and broken rock
17-28	Silt and ice layers
28-39	Red clay and pebbles
39-69	Grey clay and pebbles
69-70	Shale

Hole No. 8

Depth (feet)	
0-1	Clay
1-10	Sand, frost at 5 feet
10-11	Wood
11-14	Dirty frozen sand
14-26	Silt
26-28	Silt and clay, end of permafrost
28-38	Red clay
38-66	Grey clay and boulders
66-70	Shale

Hole No. 9

0-5	Red sand
5-12	Grey sand
12-15	Sand with silt

Hole No. 10

0-6	Red sand
6-15	Fine grey sand

Static water level 2.8 feet from surface.

Hole No. 11

0-18	Frozen silt and clay
18-25	Sand
25-28	Silt
28-30	Clay

Static water level 2.75 feet from surface.

Hole No. 12

0-4	Sand
4-15	Frozen sand
15-30	Frozen silt and sand layers

Hole No. 13

0-4	Sand
4-8	Frozen sand
8-11	Unfrozen sand
11-15	Frozen sand and silt

Hole No. 14

0-11	Sand
11-15	Silt and sand

Static water level 1.5 feet from surface.

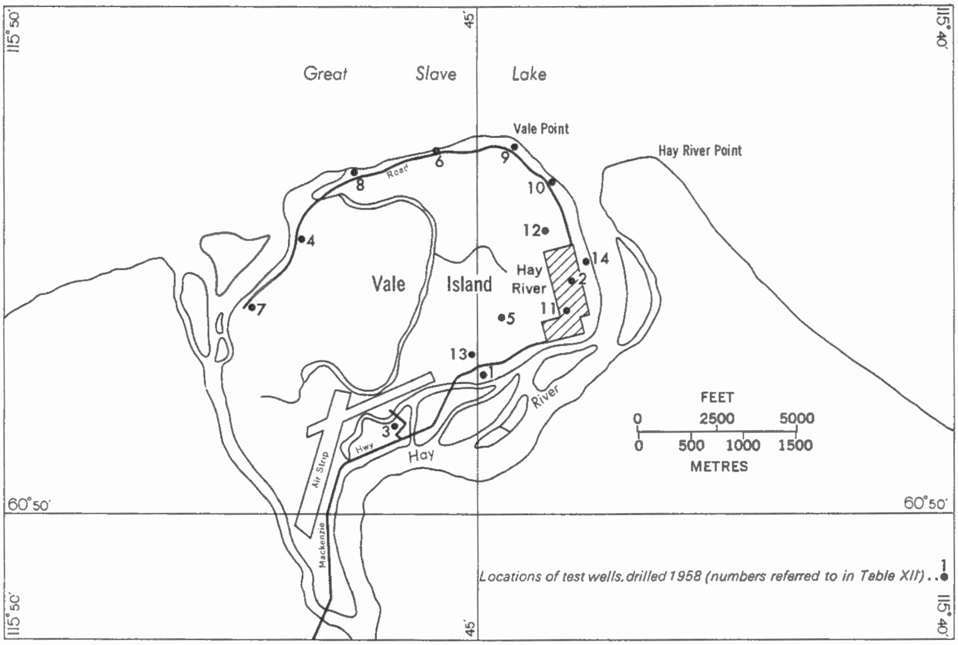

Figure 25. Locations of test wells, Hay River

Mackenzie Highway

Reference: Douglas (1959, Maps 27-1958, 28-1958).

Strand lines of beach deposits occur along the Mackenzie Highway south of Hay River to an elevation of about 870 feet. These beach sands and gravels overlie glacial till and sand and gravel.

Good supplies of groundwater can be obtained from wells drilled into post-glacial or interglacial sands in this region. Chemical analyses of water from a well at mile 28 and one at mile 32 are in Table XI.

Snowdrift

Reference: Barnes (1951, Map 51-6).

The settlement of Snowdrift is on the southeast shore of Great Slave Lake in Christie Bay.

Geology — Steeply dipping red arkose outcrops at many places along the shore and in the settlement. Much of the rock is massive, but fissile beds are present. The arkose strikes N55°E, with an average dip of 75°SE. Boulders from glacial till are scattered along the shore and there is a shingle beach north of the settlement. Patches of peat are present in depressions.

Water Supply — Water is hauled from the lake. Rock is sufficiently jointed to permit the movement of groundwater, but the steep dip of the bedding may necessitate drilling to about 100 feet to intercept enough bedding joints to yield a good supply. The groundwater can be expected to be slightly harder than lake water but otherwise of excellent quality. Pollution of groundwater can occur locally if septic tanks are installed.

Fort Reliance

Water for the settlement of Fort Reliance is obtained from Great Slave Lake. An analysis by Thomas (1957) is given in Table XI.

Yellowknife

References: Henderson and Brown (1952); Boyle (1961); Copp, Crawford and Grainge (1956).

Geology — Rocks of the Yellowknife Group, comprising andesites, basalts and dacites, outcrop throughout the townsite and mining area. Granite outcrops west of the town near the airport. The terrain is rugged with extensive outcrop, but the rock depressions are filled with a mantle of sand, gravel, and glacial deposits.

Water Supply — Water for the town of Yellowknife is obtained from Great Slave Lake. Groundwater movement occurs along fault zones in rock, and there may be groundwater movement in sands and gravels where permafrost is absent.

Rae

Reference: Douglas and Norris (1960, Map 48-1959).

Geology — The settlement of Rae is situated on outcrops of granite on the southeast shore of Marian Lake. The lake is shallow and turbid, around the settlement being only 5 feet deep in places 100 feet offshore and having a clay bottom. The lake clay overlies the granite, but there are probably lenses of sand between the clay and granite.

Water Supply — A diamond-drill hole put down to a depth of 700 feet in granite, at the Roman Catholic mission hospital, showed that the granite is too massive to allow movement of groundwater.

A brass well-point was put down through the lake clay 100 feet offshore. This well-point obtained water from fine sands below the clay and above granite, but the operation was unsatisfactory because the screen was too coarse and became plugged with sand.

Lac La Martre

Reference: Douglas and Norris (1960, Map 48-1959).

The settlement of Lac La Martre is on a small headland on the southeast side of Lac La Martre.

Geology — The area is underlain by Ordovician dolomite, but there are no outcrops along the lakeshore. The surficial deposits consist of sands more than 20 feet thick.

Water Supply — The sands should be a satisfactory aquifer and a drilled well equipped with a screen should yield 20-40 gpm. The water may be fairly hard. Drilling into the dolomite may yield water with a higher mineral content.

Fort Providence

Reference: Douglas (1959, Map 28-1958).

The settlement of Fort Providence is on a steep bank about 40 feet above Mackenzie River.

Geology — The surficial deposits are glacial-like clays and till. An oil exploration well (Northwest Territories No. 1) was drilled 1 1/2 miles southeast of the village. The log of this well (Douglas, 1959) showed that the drift is 175 feet thick, and is underlain by shale from 175-1,310 feet, thin limestone, dolomite and anhydrite. Rock does not outcrop in this low-lying part of the upper Mackenzie Valley.

Water Supply — The Roman Catholic Mission obtain their water from a river intake. This was successfully constructed many years ago at a time when the river level was low just before freeze-up. The river water is of excellent quality and is clear.

Drainage is poor throughout the settlement owing to the high clay content of the glacial deposits and to the level terrain. A shallow dug well below the basement of the Hudson's Bay Company House contains seepage water with a high mineral content (Table XI). Well drilling in the settlement would probably yield mineralized water with a high sulphate and chloride content.

Jean Marie River

Reference: Douglas (1959, Map 28-1958).

The settlement of Jean Marie River is at the junction of Jean Marie River and Mackenzie River. The houses are on a boulder clay bank about 20 feet above the river.

Geology — Glacial till and clay overlie Simpson shale. Rock does not outcrop near the settlement but the log of British American, Hudson Bay Jean Marie Creek No. 1 well drilled near the settlement (Douglas, 1959) shows 20 feet of glacial drift overlying more than 1,400 feet of shale.

Water Supply — There is a dug well 14.5 feet deep at the schoolhouse. The well was almost dry when inspected by the writer in August 1960 and was frozen at the bottom. A chemical analysis of the water is given in Table XI. It is apparent that dug wells in frozen clay and till are cisterns rather than wells and that they are inadequate for domestic supplies.

Fort Simpson

Reference: Douglas (1959, Map 28-1958); Pihlainen (1961).

The settlement of Fort Simpson is on an island beside the left bank of Mackenzie River, downstream from its junction with Liard River. The island is about 3 miles long and more than 1/2 mile wide. An airport lies 9 miles south of Fort Simpson.

Geology — Simpson shale outcrops at the mouth of Harris River, which flows into Mackenzie River opposite the island of Fort Simpson. There are no other rock outcrops in the vicinity. The island is composed of stratified alluvial silts with lenses of fine sand and gravel; clay beds and peat layers and wood fragments occur within the strata. The alluvium can be seen on the east side of the island by the Hudson's Bay Company store where the top of the river bank is about 40 feet above the mid-summer level of the river. The west side of the island and the upstream and downstream ends are low-lying ground with old channel lines and sloughs.

Pihlainen (1961) has reported on the locations of thirty shallow test borings made for a permafrost study, and on the soil analyses of the samples collected from the borings.

Water Supply — Mackenzie River water flowing past the settlement is derived chiefly from Liard River and has a higher sediment load than the main Mackenzie River water, which flows along the opposite (right) bank. A river-intake and water-treatment plant built in 1960 supplies part of the community.

More than ten wells have been dug on the island, some of which were still in use in 1961. The wells range in depth from 35 to 48 feet. Water levels in some wells are reported to vary with fluctuation in the level of the river. Permafrost was present in several of these wells and is widespread throughout the settlement to a depth of about 18 feet.

Chemical analyses of waters from three wells are given in Table XI. The Hudson's Bay Company well is saline and other abandoned saline wells occur in the settlement. This salinity could be attributed to upward leakage into strata of low permeability. The consequences of upward leakage may not be so discernible in more permeable beds, which contain bank storage water from the river.

Three dug wells at the airport, each about 26 feet deep, obtain adequate supplies of water from sand beds.

Fort Liard

Reference: Douglas and Norris (1959, Map 31-1959).

The settlement of Fort Liard is at the junction of Petitot and Liard Rivers.

Geology — Lower Cretaceous sandstone and shale outcrop on the left bank of Petitot River near its junction with Liard River. These rocks underlie the settlement. The river bank is composed of silts and sands with boulder and gravel layers. Much of the surficial material overlying rock is coarse-grained alluvium containing large rounded boulders.

Water Supply — Four wells in the settlement, dug in alluvium and boulders, range in depth from 27 to 33 feet. They are reported to yield adequate supplies of water. The presence of boulders has made well digging difficult. A percussion drill could be used to install a screened well, which should have a high capacity. The temperature of water in one well was 34°F.

Nahanni Butte

Reference: Douglas and Norris (1960, Map 23-1960).

The settlement of Nahanni Butte is near the junction of South Nahanni and Liard Rivers. The main part of the settlement is on the south side of South Nahanni River, but there is also a trading post on the north side.

Geology — The flat-lying ground near the settlement is composed of fine-grained alluvial sands and silt. Dolomite and limestones outcrop 1 mile to the north.

Water Supply — Water is hauled from the river or obtained from a dug well. The fine-grained sands and silts should yield at least 5-20 gpm from a screened and gravel-packed well.

Wrigley

Reference: Douglas and Norris (1962, Map 45-1962).

The settlement of Wrigley is on the left bank of Mackenzie River below its junction with Wrigley River. The airport is about 7 miles south of the settlement on the right bank of the river.

Geology — Steeply dipping limestones of the Nahanni Formation outcrop on the right bank of Mackenzie River opposite the settlement, on Rock Island, and at the hot springs. Rock does not outcrop in the settlement where silts and peat layers overlie river alluvium and glacial deposits.

Water Supply — Water is hauled from the river. It may be possible to obtain domestic supplies from a well drilled into the alluvium and glacial deposits. Permafrost is reportedly present. The airport is situated on an extensive sand and gravel terrace more than 100 feet above the river. A drilled well reported by Department of Transport to be 150 feet deep but with 109 feet of casing obtains a sufficient supply of water. A chemical analysis of the airport water is given in Table XI.

Fort Norman

Reference: Hume (1954, Map 1032A).

The settlement of Fort Norman is at the junction of Great Bear and Mackenzie Rivers.

Geology — Tertiary sandstone and conglomerate containing thin coal seams outcrop along the bank of Great Bear River and underlie the settlement. The rock is partly cemented and has a slight vertical jointing. Glacial drift and silt and sand are exposed in two terraces overlying rock. Most of the dwellings in the settlement are built on these terraces.

Water Supply — Clear water is hauled or pumped from Great Bear River. Mackenzie River water has a heavy sediment in summer. A cistern under the Roman Catholic Mission has been dug to a depth of 20 feet and retains seepage water. The temperature of the water was found to be just above 32°F. Permafrost is present in some excavations.

Drilled wells would probably yield a good supply of water from the sandstone underlying the settlement.

Norman Wells

References: Stewart (1945); Hume (1954, Map 1032A).

The refinery, townsite, and airport of Norman Wells are on the right bank of Mackenzie River.

Geology — Upper Devonian sandstones and shales of the Imperial and Fort Creek Formations underlie the townsite. Cretaceous sandstones overlie the Devonian sediments on the west side of Mackenzie River and under Bear Island. Logs of the first borings for oil in the vicinity were described by Stewart (1945) and further published descriptions of the geology have been made by Hume (1954). The thickness of glacial drift and alluvium ranges from about 20 to 300 feet. Permafrost is present.

Water Supply — Water is obtained from Bosworth Creek.

Fort Good Hope

Reference: Hume (1954, Map 1033A).

The settlement of Fort Good Hope is on the right bank of Mackenzie River, 2 miles downstream from the north end of The Ramparts.

Geology — Glacial drift, clay, and alluvium cover limestone of the Ramparts Formation. The thickness of the glacial deposits exceeds 100 feet in places. Northeast of the settlement is an esker of sand and gravel. Much of the settlement is about 100 feet above the river, but there is a low terrace of alluvium beside Jackfish Creek.

Water Supply — Water is obtained from Jackfish Creek and the Mackenzie River. Test drilling was carried out for water in 1961, but this was not successful owing to the fine-grained nature of the glacial deposits and because permafrost is present.

Fort Franklin

Reference: Geological Survey of Canada Map 1055A (1958).

The settlement of Fort Franklin is in Keith Arm of Great Bear Lake near the lake's outlet to Great Bear River.

Geology — Surficial deposits comprising sand and gravel derived from raised beaches, and glacial boulders, are spread along the shore. Peat layers and organic soils have formed on the permafrost ground. Cretaceous sandstone and shale underlie the area but do not outcrop.

Water Supply — Water is obtained from the lake.

Arctic Red River

Reference: Norris, Price and Mountjoy (1963, Map 10-1963).

The settlement of Arctic Red River is at the junction of Arctic Red River and Mackenzie River.

Geology — Upper Devonian sandstone and shale outcrop on the rock bluff below the Roman Catholic Mission, and the depth to rock throughout most of the settlement is probably less than 20 feet. Two terraces of clay with peat beds extend across the settlement. Permafrost is reported to be within a few feet of the surface.

Water Supply — During the summer, water is obtained from a pond near the school.

Fort McPherson

Reference: Norris, Price and Mountjoy (1963, Map 10-1963).

The settlement of Fort McPherson is on the east bank of Peel River.

Geology — Upper Devonian shale outcrops on both sides of the river. Shale was encountered in excavations near the new school at a depth of 2 to 3 feet. Silts overlie the shale. Permafrost is present throughout the area and is presumed to be several hundred feet deep.

Water Supply — Water is obtained from a lake nearby.

Inuvik

References: Norris, Price, and Mountjoy (1963, Map 10-1963); Pihlainen (1962).

The town of Inuvik is situated on the east side of the Mackenzie River delta, approximately 75 miles from the Beaufort Sea.

Geology — Carbonate rocks and siltstone and sandstone of Cambrian age outcrop in a quarry near the airport, and are overlain by glacial drift and alluvium. A kame (?) terrace extends along the townsite.

Permafrost is thought to be several hundred feet thick. Soil-test drilling and foundation testing are described by Pihlainen (1962).

Water Supply — Water is obtained from a lake east of the town.

Tuktoyaktuk

References: Muller (1959); Norris, Price, and Mountjoy (1963, Map 10-1963).

The settlement of Tuktoyaktuk is situated in Kugmallit Bay.

Geology — The indented coastline indicates a drowned shoreline with long arms of the sea extending up coastal depressions.

A loose gravelly till, which has been derived from the hills to the south, is exposed in borrow pits south of the settlement. The till is overlain by sand with some gravel, which is exposed along the shoreline and in cellar excavations in the settlement. Ice-wedges more than a foot thick extend laterally through the sands. The sands are overlain by a peat loam soil. Beaches of cobble, gravel, and sand extend along the west side.

Pingos north and south of the settlement and other permafrost features are prominent (Muller, 1959).

Erosion of the shoreline is so active that the shape of the coast may alter considerably within the next few decades.

Water Supply — The inhabitants of Tuktoyaktuk obtain water by melting ice and snow. A sample of water taken from the sea proved to be fresh rather than saline. Mackenzie River water is apparently discharged to the ocean along this shore at some stages of tide and wind.

Coppermine

Reference: Fraser (1960, Map 18-1960).

The settlement of Coppermine is at the mouth of Coppermine River on the shore of Coronation Gulf.

Geology — Proterozoic dolomite and shale intruded by diabase sills form steep outcrops south of the settlement and on the west bank of the river. In the settlement, rock is exposed near the school, near the Anglican Mission, and farther west near the shore; it also outcrops in the delta. A small creek rising out of swampy ground flows west of the new school, meanders through beach sands and enters the sea near the Roman Catholic Mission. A section on the beach near the creek's delta shows several feet of marine sand overlying a clay till, which overlies rock. The coast is a raised shoreline.

Water Supply — Water for the settlement is hauled from Coppermine River. Analyses of water from the creek and water from the shore of Coronation Gulf are given in Table XI. Coppermine River water apparently flows past the settlement so that fresh water could be obtained from the creek or the beach in summer. Well points in the creek sands may operate through much of the year if freezing is prevented.

British Columbia

Coal River (Mile 543, Alaska Highway)

A well was drilled to 70 feet at the military construction camp at Coal River; the aquifer is sand and gravel. The static water level of the well after drilling was 27 feet below surface and the well had a capacity of 5 gpm.

Location	Watson Lake		Teslin	Whitehorse	Alaska Highway							
	Hotel well	Motel well	RCMP well	Well No. 1, municipal	Mile 923, Casa Loma Motel	Mile 1016, RCMP	Mile 1016, Brewsters Motel	Mile 1016, Bekkes Motel	Mile 1018, Agricultural Experimental Farm well	Mile 1026, Haines Pump Station well	Mile 1083, Military well by Kluane Lake	Mile 1083, hotel
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Well depth (ft.)		58				60	62			87		99
Date of sample	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61
Appearance and odour	Sedi-ment	Sedi-ment	Red sedi-ment	Clear	Clear	Clear	Clear	Clear	Sedi-ment	Clear	Clear	Clear
pH	7.9	7.7	8.0	8.0	8.3	8.4	8.0	8.1	7.7	8.2	8.1	8.3
Colour	5	0	0	0	0	0	0	0	5	0	0	0
Conductivity	702	346	1042	368	470	571	628	689	1571	331	612	768
Hardness: total	204	168	618	159	247	300	333	352	563	176	269	400
Hardness: non-carbonate	57.5	5.5	250	31.0	26.6	20.4	56	111	514	20.1	95.7	103
Calcium	56.9	49.5	95.8	28.3	72.5	33.6	44.8	44.9	117	53.3	30.2	43.0
Magnesium	15.0	10.8	91.9	21.4	15.9	52.5	53.6	58.3	66	10.3	47.0	71.0
Sodium	60.5	5.8	6.3	12.2	4.8	9.9	10.2	14.4	140	1.6	26.4	16.6
Potassium	5.2	1.2	2.9	1.9	1.4	4.5	4.7	5.6	6.6	0.9	4.5	4.8
Iron (total)	0.02	0.27	2.9	0.27	0.02	0.18	0.02	0.04	1.7	0.15	0.17	0.54
Manganese	0.0	0.04	0.14	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.01	0.12
Cu, Pb, Zn												
Bicarbonate	179	198	449	156	268	341	337	294	59.9	189	211	362
Sulphate	28.8	7.2	249	55.9	35.6	40.2	77.9	141	804	20.4	157	142
Chloride	48.4	10.2	2.2	0.9	1.4	0.7	0.7	1.5	1.6	0.4	0.7	0.8
Fluoride	0.06	0.06	0.73	0.24	0.25	0.34	0.29	0.38	0.82	0.08	0.44	0.37
Nitrate	125	4.7	0.0	0.8	0.4	0.8	1.1	2.1	0.4	0.4	0.5	0.4
Silica	31	14	15	12	17	14	15	14	12	10	20	18
Sum of constituents	458	201	685	210	282	330	374	426	1178	191	390	476
Per cent Sodium	38.5	6.9	2.2	14	4.0	6.6	6.2	8.0	35	1.9	17	8.2

Location	Alaska Highway						Dawson	Mayo				
	Mile 1083, CN telegraph office	Mile 1095, motel	Mile 1124, Donjek Pump Station	Mile 1202, hotel well	Mile 1202, Ida's Motel	Mile 1202, Customs House	City, main well	Forest office	D.O.T. Building	Well near Anglican Mission	Chateau Mayo Hotel	Atlin, British Columbia, cold spring
Sample No.	13	14	15	16	17	18	19	20	21	22	23	24
Well depth (ft.)		158	141	62	110		38					
Date of sample	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61	7/61
Appearance and odour	Clear	Sedi-ment	Sedi-ment	Clear	Sedi-ment	Clear	Clear	Clear	Clear	Orange ppt.	Clear	Sedi-ment
pH	8.2	8.0	8.0	8.1	8.0	8.0	7.6	7.5	7.5	3.6	7.5	7.7
Colour	5	0	25	5	25	5	5	5	5	15	20	0
Conductivity	656	508	727	525	805	482	204	190	295	2692	255	5824
Hardness: total	332	232	401	272	411	252	96.5	98.1	147	1028	124	4878
Hardness: non-carbonate	89.4	0.0	0.0	50	35.1	30.6	27.4	17.2	19.3	1028	29.7	0.0
Calcium	38.5	42.2	72.1	84.7	125	82.1	25.4	26.3	41.1	246	32.2	8.8
Magnesium	57.3	30.8	53.7	14.6	23.8	11.3	8.0	7.9	10.7	101	10.6	1180
Sodium	14.2	19.3	9.9	3.8	23.6	3.7	2.1	1.5	4.7	74.2	3.4	30.3
Potassium	4.1	5.0	6.4	1.4	5.6	1.6	0.8	0.7	1.3	4.8	1.0	9.2
Iron (total)	0.63	0.05	3.4	0.01	0.08	0.09	0.02	0.14	1.5	394	0.39	7.4
Manganese	0.02	0.3	0.2	0.01	0.5	0.03	0.01	0.01	0.17	6.7	0.01	0.14
Cu, Pb, Zn												Cu 0.21
Bicarbonate	296	288	509	270	458	270	84.2	98.4	155	0	115	5961
Sulphate	121	40.9	1.6	13.9	9.1	22.0	29.8	17.0	25.4	1693	33.9	60.5
Chloride	0.8	1.9	2.6	10.2	24.8	5.2	1.5	0.4	3.4	105	0.8	14.0
Fluoride	0.44	0.29	0.46	0.08	0.16	0.08	0.14	0.08	0.10	1.45	0.13	0.08
Nitrate	0.8	1.2	0.4	32	63	8.3	1.4	1.5	0.4	1.4	0.5	0.0
Silica	17	23	26	13	24	15	6.2	4.8	6.7		4.6	74
Sum of constituents	400	306	424	306	525	282	117	109	170	1055	144	4311
Per cent Sodium	8.4	15	5	2.9	11	3.1	4.5	3.2	6.4	8.5	5.6	1.3

Table XIII. Chemical analyses of wells, Yukon Territory and British Columbia

Lower Post (Alaska Highway)

The community of Lower Post is on the left bank of Liard River opposite its junction with Dease River.

Geology — A plain of glacial till overlain by glacio-fluvial and fluvial sands and silts extends throughout the area. Underlying shales of Devonian and Mississippian age do not outcrop. The houses on the river bank are on a fluvial terrace of gravel and fine sands.

Water Supply — Water is obtained from wells or from the river. High-capacity wells require well screens, owing to the presence of fine sands. The mission school has a sand and gravel packed well equipped with a 15-foot screen set between 29 and 44 feet below the surface. On test the well could yield more than 100 gpm. The water is hard.

Atlin

References: Young (1915); Cummings (1940); Aitken (1959).

The town of Atlin is situated on the east shore of Atlin Lake.

Geology — Beach deposits and glacial drift overlie serpentinite and peridotite. Deposits of hydromagnesite, which extend throughout depressions and swampy ground east of the town, have been described in detail by Young (1915). The hydromagnesite has been formed by upward leakage of groundwater and evaporation.

Water Supply — Water for the town is obtained from the lake. Wells in the town have a high magnesium bicarbonate content. The chemical analysis of water from a spring in the north part of the town is given in Table XIII.

Yukon Territory

Watson Lake (Mile 635, Alaska Highway)

Geology — Glacial till overlain by glacio-fluvial gravels and sand fill the valley around the townsite and airport. Excellent aquifers occur within these sediments.

In the townsite is a glacial till ridge on the southwest side, which is overlain on the northeast and lake side by gravels.

Water Supply — Several wells in the town and at the airport range in depth from 30 to 70 feet. During highway construction in 1944 wells that were excavated in gravels near the lake yielded 100 gpm on test. Chemical analyses of wells are shown on Table XIII. The high nitrate content of one well suggests that pollution is occurring in a gravel aquifer.

Alaska Highway, Watson Lake to Whitehorse

The Alaska Highway passes through wide glaciated valleys filled with glacial drift and alluvium. The bedrock geology has been mapped by Lord (1944), Mulligan (1954), and Poole (1955). The following water-well data are available from highway construction records.

Mile 733. Swift River

A well drilled for the military camp beside the river had a depth of 37 feet. The capacity exceeded 10 gpm.

Mile 804. Teslin

Five drilled wells in the village of Teslin obtain small but adequate supplies. Information on well depths is uncertain, but water is possibly obtained from thin sand lenses in glacial-lake silts and glacial drift. An analysis of the RCMP well water shows that it has a high iron content. Well screens would improve the yield of wells in Teslin.

Mile 837. Johnson's Crossing

Logs of two wells drilled at Johnson's Crossing during construction of the Alaska Highway show that 35 to 40 feet of gravel overlies approximately 180 feet of silts. Water was obtained from fine sand below the silts, but the wells were abandoned owing to insufficient yield.

Mile 910. MacRae

Drilled wells supplied the army camps at MacRae during construction of the Alaska Highway. The wells were drilled in 1943 and are no longer in use. The well driller's logs indicate that glacial drift is more than 100 feet thick. The yields of three different wells were 28, 35, and 50 gpm, according to construction records.

Whitehorse

Reference: Wheeler (1961).

The town of Whitehorse is situated on alluvial flats along Yukon River. The airport is on the top of a steep silt escarpment, slightly more than 200 feet above the town.

Geology — Quaternary basalts outcrop near the dam (the site of the old rapids) and in Miles Canyon. These basalts have been cut through by Yukon River. The river has also cut the high silt banks of a proglacial lake and has deposited alluvium on banks surrounding the present channel.

Water Supply — The town has a river intake and a well field. Test drilling for water was carried out in 1954. The logs of two test holes drilled on the west side of the bridge that crosses the river are shown in Table XIV. Foundation borings carried out in 1955 showed that coarse-grained alluvium was more extensive on the east side of the river, consequently it was decided to put in a well field on that side. At present three wells are situated about 3,000 feet south of the bridge. The wells yield from 200-320 igpm, the variation of yield being caused by great local changes in the permeability of the alluvium. A chemical analysis is given in Table XIII.

The temperature of groundwater varies from 38 to 40°F. This is warmer than river water during the winter and is one of the reasons for using well water.

There are several drilled wells in the district around Porter Creek. The chemical analysis of one is recorded in Table XIII. The varied nature of the glacial drift makes it impractical to predict well yields at any one location. A test-drilling program would probably locate a good aquifer in the glacial drift. Thus a community well could supply a number of homes.

The percolation of groundwater through fractures and bedding planes in the silt has caused local erosion and sliding at Whitehorse airport.

Table XIV

Logs of wells drilled at Whitehorse, Y.T.

A. Test borings on west side of Yukon River at Whiskey Flats (1954). (Data provided by International Water Supply Co. Ltd., Vancouver, B.C.)

Hole 1		Hole 2	
Depth	Description	Depth	Description
0-1	Silty sand	0-8	Coarse dirty gravel
1-10	Coarse dirty gravel	8-12	Silty clay and gravel
10-43	Silt	12-50	Silty clay
43-92	Silty clay		
92-107	Dirty sand		
107-115	Coarse sand, clay		

B. Description of town wells, lot 340, east side of Yukon River; inside diameter, 10 inches; screen lengths, 10 feet. (Drilled and installed by International Water Supply Co. Ltd., Vancouver.)

No. 1		No. 2	
Depth	Description	Depth	Description
0-3	Topsoil	0-15	Dirty gravel
3-19	Dirty gravel	15-40	Sand and gravel
19-30	Clean coarse gravel		
30-40	Coarse gravel, siltier		
Capacity: 320 igpm. Specific capacity: 64 igpm/ft. S.W.L. 6 feet.		Capacity: 315 igpm. Specific capacity: 29 igpm/ft. S.W.L. 9 feet.	

No. 3	
Depth	Description
0-9	Dirty gravel
9-27	Silty clay
27-35	Sand and gravel
35-48	Gravel
Capacity: 200 igpm. Specific capacity: 6.5 igpm/ft. S.W.L. 9 feet.	

Alaska Highway, Takhini to the Alaska Boundary

From Takhini to the Alaska boundary the highway passes through Takhini, Dezadeash, and Shakwak Valleys. These wide valleys are filled with alluvium, stratified silts, and glacial drift. The bedrock geology of the surrounding hills has been mapped by Bostock (1952), Kindle (1952) and Wheeler (1961).

Water wells are used in a number of places within these valleys. The depths and logs of some of these wells are unknown. A compilation of known data follows.

Mile 1016.

There are several wells in the settlement at Mile 1016, with well depths between 60 and 100 feet. One hole was drilled to 360 feet at Haines Inn, but was abandoned. The wells are in glacial drift and need screens if improved yields are required. Chemical analyses are given in Table XIII.

Mile 1018.

A well in the valley 1 mile east of the agricultural experimental farm buildings was sampled by the writer in August 1961. The temperature was found to be 36°F. Chemical analysis shows that the water has a high sodium sulphate content.

Mile 1026.

The well at the pipeline pump station obtains water from a sand-gravel aquifer at a depth between 61 and 71 feet. The static water level was reported to be 51.5 feet below surface prior to test pumping. The well had a capacity of 6 gpm when pumped.

Mile 1083. Destruction Bay

Two wells drilled during the 1940's for the military construction camps at Destruction Bay are still in use. They are located on the Kluane Lake side of the Alaska Highway. The wells are between 75 and 95 feet deep and obtain about 10 gpm from sand and gravel.

A well drilled at the hotel was put down in 1954 to a depth of 99 feet. Permafrost was reported. The well has a small flow.

Mile 1095.

A flowing well (about 20 gpm) at the motel is about 158 feet deep and yields water from a gravel aquifer. The driller reported that frozen ground was encountered during the drilling. The temperature of the water was just above 32°F. The well starts to freeze up at times, but complete freezing is prevented by switching on a heat coil, which has been installed in the well.

Mile 1124.

The well at the Donjek pump station has a flow of 1-2 gpm. The depth is 141 feet.

Several wells were drilled in this part of the valley during 1943 and again in 1952. The depths of these wells were between 150 and 235 feet. Frozen ground was encountered in two of the wells during drilling operations. One well yielded more than 30 gpm on a short test; others were abandoned owing to insufficient capacity.

Mile 1164.

There is an abandoned well at a disused army campsite near the crossing of Koidern River. Permafrost is present in the area and the well froze when not in use. A log of the well indicates that depth to rock is 42 feet and that the well was drilled to 230 feet.

Mile 1202.

Several wells at this community obtain water from sand and gravel lenses at depths of between 60 and 110 feet. Permafrost has not been reported in the drill logs. Chemical analyses of three wells are recorded in Table XIII. The waters in these wells have a high nitrate content.

Whitehorse-Dawson Highway

Wells are used for local water supplies at the crossing of Pelly River and at Carmacks. Good water supplies can be obtained without difficulty from wells in the river alluvium at these locations.

Dawson

The town of Dawson is on the right bank of Yukon River below its junction with Klondike River.

Geology — The town is built on muskeg and alluvium. Bedrock comprises diabase, which outcrops at the Klondike bridge and behind the townsite.

Water Supply — The city obtains water from two wells beside Klondike River at its mouth. The wells have been excavated into sand and gravel alluvium. One well is 38 feet deep. The water temperature is raised by steam heating at the pump house.

Mayo

The town of Mayo is on the right bank of Stewart River.

Geology — River alluvium consisting of silt and sand underlies the area.

Water Supply — Most of the wells in the town are sand-points, which have been hand-driven through alluvium. Domestic supplies are adequate from these wells and are of good quality except in the southeastern part of the town alongside Stewart River. In that locality adequate supplies are difficult to obtain owing to the presence of silt. Permafrost is present in some locations. Water in one well near the Anglican Mission has a high iron sulphate content and is not used.

Carcross

Reference: Wheeler (1961).

The community is situated at the outlet of Bennett Lake.

Geology — Dune sands extend throughout the settlement and along the highway. The sands overlie alluvium and glacial drift.

Water Supply — Water is obtained from wells in the sands. A high-capacity well would require a screen.

Old Crow

The settlement of Old Crow is on the right bank of Porcupine River below its junction with Old Crow River.

Geology — The buildings in the settlement are on a bank of river alluvium, which is 30 feet high at its upstream end and descends to a gravel-cobble beach downstream. Organic layers can be seen in the river bank alluvium. The river bank is being eroded. Half a mile downstream from the settlement is a 40-foot cliff on the north bank consisting of buff sandy alluvium that is well consolidated and is overlain by lake silts and clay. Vivianite is present in the silts. On the south bank of the river are extensive swamps and peat.

Water Supply — Water for the settlement is hauled from the river. A test drilling program would have to be carried out to determine whether water could be obtained from the alluvium. Permafrost is present.

REFERENCES

Aitken, J.D.
1959: Atlin map-area, British Columbia; Geol. Surv. Can., Mem. 307, p. 80.

Atlas of Canada
1959: Geog. Br., Canada Dept. Mines Tech. Surv.

Barnes, F.Q.
1951: Preliminary map, Snowdrift, Northwest Territories; Geol. Surv. Can., Paper 51-6.

Beach, Floyd K.
1952: Geothermal gradients in the Canadian Plains; Can. Oil and Gas Ind., Nov. 1952, pp. 43-46.

Black, R.F.
1950: Permafrost; Smithsonian Rept., pp. 273-301.

Bostock, H.S.
1947: Mayo, Yukon Territory; Geol. Surv. Can., Map 890A.

1948: Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel; Geol. Surv. Can., Mem. 247, p. 101.

1952: Geology of Northwest Shakwak Valley; Geol. Surv. Can., Mem. 267.

Boyle, R.W.
1961: The geology, geochemistry and origin of the gold deposits of the Yellowknife district; Geol. Surv. Can., Mem. 310.

Brown, I.C.
1950: Fort Resolution, Northwest Territories; Geol. Surv. Can. Paper 50-28.

Brown, R.J.E.
1960: The distribution of permafrost and its relation to air temperature in Canada and the U.S.S.R.; Arctic, vol. 13, No. 3, pp. 163-177.

1961: Potential evapotranspiration and evaporation observations at Norman Wells, N.W.T.; Water Res. Br., Canada Dept. North. Affairs Nat. Res., Proc. Hydrol. Sympos. No. 2, Canada, pp. 123-127.

Cairnes, D.D.
1917: Investigations and mapping in Yukon Territory; Geol. Surv. Can., Sum. Rept. 1916, pp. 33-34.

Cameron, A.E.
1922: Hay and Buffalo Rivers, Great Slave Lake, and adjacent country; Geol. Surv. Can., Sum. Rept. 1921, pt. B, pp. 1-44.

Campbell, N.
1957: "Stratigraphy and structure of Pine Point area, N.W.T." in Structural Geology of Canadian Ore Deposits, vol. II, 6th Commonwealth Mining Metall. Congr.; Can. Inst. Mining Metall., pp. 161-174.

Camsell, Charles
1917: Salt and gypsum deposits of the region between Peace and Slave Rivers, Northern Alberta; Geol. Surv. Can., Sum. Rept. 1916, pp. 134-145.

Camsell, C., and Malcolm, W.
1919: The Mackenzie River Basin; Geol. Surv. Can., Mem. 108.

Cederstrom, D.J.
1961: Occurrence and development of ground water in permafrost regions; U.S. Geol. Surv., Circ. 275.

Cederstrom, D.J., and Tibbits, G.C.
1961: Jet drilling in the Fairbanks area, Alaska; U.S. Geol. Surv., Water Supply Paper 1539-B.

Chebotarev, I.I.
1955: Metamorphism of natural waters in the crust of weathering Geochim. Cosmochim. Acta, vol. 8, pp. 22-48, 137-170.

Cook, Frank A.
1958: Selected bibliography on Canadian permafrost; Geog. Br., Canada Dept. Mines Tech. Surv., Biblio. Ser. No. 2.

Copp, S.C., Crawford, C.B., and Grainge, J.W.
1956: Protection of utilities against permafrost in Northern Canada; J. Am. W.W. Assoc., vol. 48, No. 9, pp. 1155-1167.

Craig, B.G.
1964: Glacial Lake McConnell and the surficial geology of parts of Slave River and Redstone River map-areas; Geol. Surv. Can., Bull. 99.

Cummings, J.M.
1940: Saline and hydromagnesite deposits of British Columbia; B.C. Dept. Mines, Bull. 4, p. 158.

Day, J.H.
1962: Reconnaissance soil survey of the Takhini and Dezadeash Valleys; Res. Br., Canada Dept. Agriculture, p. 78.

Day, J.H., and Leahey, A.
1957: Reconnaissance soil survey of the Slave River Lowland in the Northwest Territories of Canada; Experimental Farms Serv., Canada Dept. Agriculture, p. 43.

Douglas, R.J.W.
1959: Great Slave and Trout River map-areas, Northwest Territories; Geol. Surv. Can., Paper 58-11.

Douglas, R.J.W., and Norris, A.W.
1960: Horn River map-area, Northwest Territories; Geol. Surv. Can., Paper 59-11.

Douglas, R.J.W., and Norris, D.K.
1959: Fort Liard and La Biche map-areas, Northwest Territories and Yukon; Geol. Surv. Can., Paper 59-6.

1960: Virginia Falls and Sibbeston Lake map-areas, Northwest Territories; Geol. Surv. Can., Paper 60-19.

1961: Camsell Bend and Root River map-areas, District of Mackenzie, Northwest Territories; Geol. Surv. Can., Paper 61-13.

1962: Dahadinni River and Wrigley map-areas, District of Mackenzie; Geol. Surv. Can., Paper 62-33.

Fraser, J.A.
1960: North-central District of Mackenzie; Geol. Surv. Can., Map 18-1960.

Gabrielse, H.
1961: Rabbit River map-area; Geol. Surv. Can., Map 2-1961.

Geological Association of Canada
1958: Glacial Map of Canada, 1 inch to 60 miles.

Geological Survey of Canada
1957: Geological Map of the Yukon Territory, Map 1048A, 1 inch to 20 miles.

1958: Geological Map of the District of Mackenzie, Map 1055A (2 sheets), 1 inch to 20 miles.

Hem, John D.
1959: Study and interpretation of the chemical characteristics of natural water; U.S. Geol. Surv., Water Supply Paper 1473.

Henderson, J.F., and Brown, I.C.
1952: The Yellowknife greenstone belt, Northwest Territories; Geol. Surv. Can., Paper 52-28.

Hobson, G.D.
1962: Seismic exploration in the Canadian Arctic Islands; Geophysics, vol. 27, No. 2, pp. 253-273.

Hobson, G.D., Wyder, J.E., and Brandon, L.V.
1962: Aquifer exploration in Canada by geophysical methods; J. Am. W.W. Assoc., vol. 54, No. 9, pp. 1073-1081.

Hubbert, M.K.
1953: Entrapment of petroleum under hydrodynamic conditions; Bull. Am. Assoc. Petrol. Geol., vol. 37, No. 8, pp. 1954-2027.

Hume, G.S.
1954: The Lower Mackenzie River area, Northwest Territories and Yukon; Geol. Surv. Can., Mem. 273.

Jeffery, W.W.
1961: Notes on plant occurrence along lower Liard River, N.W.T.; Nat. Mus. Canada, Bull. 171, pp. 32-115.

Jenness, J.L.
1949: Permafrost in Canada; Arctic, 2, pp. 13-27.

Kidd, D.F.
1936: Rae to Great Bear Lake, Mackenzie District, Northwest Territories; Geol. Surv. Can., Mem. 187.

Kindle, E.D.
1952: Dezadeash map-area; Geol. Surv. Can., Mem. 268.

Lane, E.W., and Lei Kai
1950: Stream flow variability; Trans. Am. Soc. Civil Eng., vol. 115, pp. 1084-1134.

Leggett, R.F., Dickens, H.B., and Brown, R.J.E.
1961: Permafrost investigations in Canada; Geology of the Arctic, vol. II, pp. 956-969.

Lindsey, A.A.
1953: Notes on some plant communities in the northern Mackenzie Basin, Canada; Botanical Gazette, vol. 115, No. 1, pp. 44-55.

Lord, C.S.
1944: Geological reconnaissance along the Alaska Highway between Watson Lake and Teslin River, Yukon and British Columbia; Geol. Surv. Can., Paper 44-25.

1951: Mineral industry of District of Mackenzie, Northwest Territories; Geol. Surv. Can., Mem. 261, p. 323.

MacCarthy, G.R.
1952: Geothermal investigations on the Arctic slope of Alaska; Trans. Am. Geophys. Union, vol. 33, pp. 589-593.

McConnell, R.G.
1890: Report on an exploration in the Yukon and Mackenzie Basins, Northwest Territories; Geol. Surv. Can., Ann. Rept. (new ser.), vol. 4, pp. 1888-89, pt. D.

Meyboom, P.
1962: Patterns of groundwater flow in the Prairie profile; Proc. Third Can. Hydrol. Sympos., Nat. Res. Council.

Misener, A.D.
1955: Heat flow and depth of permafrost at Resolute Bay, Cornwallis Island, N.W.T.; Am. Geophys. Union, vol. 36, No. 6, pp. 1055-1060.

Muller, Fritz
1959: Beobachtungen über Pingos; Med. om Grønland, bd. 153, Nr. 3.

Muller, S.W.
1947: Permafrost or permanently frozen ground and related engineering problems; U.S. Geol. Surv., Spec. Rept., Strategic Engineering Study 62, 2nd ed., Edwards Brothers, Ann Arbor, Mich., p. 231.

Mulligan, Robert
1954: Teslin map-area, Yukon; Geol. Surv. Can., Paper 54-20.

Muskat, M.
1946: The flow of homogeneous fluids through porous media; McGraw Hill Book Co., New York, 1937, reprinted by J.W. Edwards, Ann Arbor, Mich., 1946.

Norris, D.K., Price, R.A., and Mountjoy, E.W.
1963: Northern Yukon and northwestern District of Mackenzie; Geol. Surv. Can., Map 10-1963.

Penman, H.L.
1956: Evaporation: an introductory survey; Netherlands J. Agr. Sci., vol. 4, No. 1.

Pihlainen, J.A.
1955: Permafrost and buildings; Div. Building Res., Nat. Res. Council, Bull. No. 5, p. 27.

1961: Fort Simpson, N.W.T., engineering site information, soil and permafrost conditions; Div. Building Res., Nat. Res. Council, Tech. Paper 126.

1962: Inuvik, N.W.T., engineering site information; Div. Building Res., Nat. Res. Council, Tech. Paper 135.

Poole, W.H.
1955: Wolf Lake area, Yukon; Geol. Surv. Can., Paper 55-21.

Porsild, A.E.
1951: Botany of southeastern Yukon adjacent to the Canol Road; Nat. Mus. Canada, Bull. 121, p. 399.

1955: The vascular plants of the western Canadian Arctic Archipelago; Nat. Mus. Canada, Bull. 135, p. 226.

1961: The vascular flora of an alpine valley in the Mackenzie Mountains, N.W.T.; Nat. Mus. Canada, Bull. 171, pp. 116-130.

Porsild, A.E., and Crum, H.
1961: The vascular flora of Liard Hotsprings, B.C., with notes on some bryophytes; Nat. Mus. Canada, Bull. 171, pp. 131-196.

Raup, H.M.
1935: Botanical investigations in Wood Buffalo Park; Nat. Mus. Canada, Bull. 74, p. 174.

Rawson, D.S.
1950: The physical limnology of Great Slave Lake; J. Fish., Res. Bd., Canada, vol. 8, No. 1.

Sanderson, Marie
1948: Drought in the Canadian Northwest; Geog. Rev., vol. 38, pp. 289-299.

1950: Potential evaporation at Norman Wells; Geog. Rev., vol. 40, pp. 636-645.

Soper, J.D.
1941: History, range and home life of the northern bison; Ecol. Monog. II, pp. 347-412.

Stewart, J.S.
1945: Recent exploratory deep well drilling in Mackenzie River valley; Geol. Surv. Can., Paper 45-29.

Thomas, J.F.J.
1957: Mackenzie River and Yukon River drainage basins in Canada, 1952-53; Mines Br., Canada Dept. Mines Tech. Surv., Water Surv. Rept. No. 8.

Thornthwaite, C.W.
1948: An approach toward a rational classification of climate; Geog. Rev., vol. 38, pp. 55-94.

Todd, D.K.
1959: Ground water hydrology; John Wiley & Sons, Inc., p. 336.

Tolskikhin, N.E.
1941: Groundwater in the frozen zone of the lithosphere; Gosgeolizdat, Moscow-Leningrad, 1941.

Tyrrell, J.B.
1903: A peculiar artesian well in the Klondike; Eng. and Mining J., vol. 75, p. 188.

1904: Crystophenes or buried sheets of ice in tundra of Northern America; J. Geol., vol. 12, pp. 232-236.

Water Resources Branch, Canada, Dept. Northern Affairs and National Resources:
The following Water Resources Papers are referred to: 68 (1929-31), 71 (1931-33), 75 (1933-35), 88 (1939-41), 101 (1945-47), 105 (1947-49), 109 (1949-51), 113 (1951-53), 117 (1953-55), 121 (1955-57), 125 (1957-58) (in Arctic drainage basin); and: 106 (1946-48), 110 (1948-50), 114 (1950-52), 118 (1952-54), 122 (1954-56), 124 (1956-58) in Pacific drainage and Yukon Territory.

Washburn, A.L.
1956: Classification of patterned ground and review of suggested origins; Bull. Geol. Soc. Amer., vol. 67, pp. 823-866.

Wheeler, J.O.
1961: Whitehorse map-area; Geol. Surv. Can., Mem. 312.

Whittaker, E.J.
1922: Mackenzie River district between Great Slave Lake and Simpson; Geol. Surv. Can., Sum. Rept. 1921, pt. B, pp. 45-55.

Williams, M.Y.
1922: Exploration east of Mackenzie River between Simpson and Wrigley; Geol. Surv. Can., Sum. Rept. 1921, pt. B., pp. 56-66.

Williams, R.
1955: Observations of freeze-up and break-up of the Yukon River at Beaver, Alaska; J. Glaciology, vol. 2, No. 17, pp. 488-495.

Wilson, J.T.
1939: Preliminary map, Fort Smith area, Northwest Territories; Geol. Surv. Can., Paper 39-11.

Wright, G.M.
1956: Geological notes on eastern District of Mackenzie, Northwest Territories; Geol. Surv. Can., Paper 56-10.

Yardley, D.H.
1951: Frost-thrusting in the Northwest Territories; J. Geol., vol. 59, pp. 65-69.

Young, G.A.
1915: Hydromagnesite deposits of Atlin, British Columbia; Geol. Surv. Can., Sum. Rept. 1915, pp. 50-61.