No. 2.

CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
TOPICAL REPORT NO. 28

NORTHERN SETTLEMENTS NO. 1

PRELIMINARY NOTES

BY

L. V. BRANDON

OTTAWA
1960

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PRELIMINARY NOTES ON GROUND WATER AND PERMAFROST

DISTRICT OF MACKENZIE N.W.T.

By

L. V. Brandon

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INTRODUCTION

This report has been written following a visit by the writer to most of the towns and settlements in the District of Mackenzie during July and August 1960.

The report comprises some brief notes on the geology and ground water potential at each settlement and has been written as a consequence of requests for information on water supply from several different agencies. It is part of a more extensive study of ground water and permafrost in Northern Canada.

The writer wishes to thank the missionaries, Hudson's Bay Company managers and government officers for their kindness while he visited each settlement.

General Geology

All the settlements except Inuvik are in areas which have been mapped by the Geological Survey of Canada. Therefore reference is made to the most recent geological map and report on the locality prior to discussing the area, and geologic descriptions have been kept to a minimum because the reader may refer to the published maps whenever necessary. Where the height of river banks are mentioned the height referred to is the average height during August.

Many of the palaeozoic dolomites and limestones in the west half of the Great Slave Lake region and in the Mackenzie River valley are aquifers, but in many localities they contain saline and sulphurous water which requires demineralising. However, water for fire protection purposes could be available at immediate notice from such aquifers if stand-by wells were drilled into them. Chemical analyses of waters from wells, springs and some rivers are shown in Appendix 1.

Rocks in the Precambrian regions are satisfactory aquifers for domestic supplies only where the rocks are fractured; in most places, however, the supplies from these rocks are negligible.

The best source of ground water is from sands and gravels in alluvium or in glacial drift. Aquifers of this type require properly constructed wells.

Well points and Drilling Methods

Because the best supplies of water can be obtained from sand aquifers attention is drawn to the possibility of putting down well points by jetting (with a centrifugal pump which is available in most settlements) or by driving. Well points should be of manufactured wire-wound stainless steel or everdur metal and should not be of the brass gauze type. A properly installed well point will yield larger quantities of water than a dug well and provides a cleaner and safer method of obtaining water. All dug wells are susceptible to pollution.

It is often too difficult to jet or hand drive a well point beyond 15 feet depth. In this case it is necessary to bring in a well drilling rig to put down a screened well.

Successful water well drilling is a technique requiring a knowledge of the type of equipment needed to drill a well in a certain locality, and a knowledge of the type of casing, screen and pump that should be installed. It is a phase of engineering which has suffered through the practise of accepting the lowest tender on a vaguely worded contract where more experienced contractors could have performed much better work, albeit at higher prices.

The drilling rigs at present in use in the Mackenzie Valley are rotary machines used in the oil industry. These drills are used extensively in the prairies by water well drilling companies which have the personnel experienced in sampling soils and in installing screens and developing a well. Many oil well drilling crews have little experience in drilling water wells.

Drilling rigs in the mining areas of the District are diamond drills. These drills can be used for drilling 6 inch diameter wells to shallow depths, however there are few diamond drillers who are experienced in soil sampling and well drilling techniques.

The mobilising cost of bringing churn, air-percussion, or reverse-circulation rigs to some localities may be high but it may be necessary in some cases in order to instal a proper well.

Soils Engineering and Permafrost

Earth slides and erosion are common features apparent in many parts of the region. However, the writer has only once referred to this here where it is of present significance.

It is noticeable that some settlements in the District are at locations which have grown up around a temporary trading post on sites which are unsuitable for the economic construction of present day utilities and docks. In some places the settlements remain although the trade has diminished and better sites for habitation remain unoccupied.

Permafrost is a considerable problem in foundation engineering problems, but research and experience have overcome much of this. Permafrost in rock is not a serious problem in mining or in oil well drilling. Though in some mines many feet of drill rods have sometimes been lost after a temporary pump failure when ice has frozen in the rods. The low temperature of rock was a problem when grouting at the Snare River damsite since the grout froze too soon. The depth of permafrost in a number of mines was recorded by Lord (1951)* and more depth of frost data have become available with continued exploration in the region.

Permafrost makes the use of wells difficult where the frost is deep and continuous; that is to say in areas north of the Arctic Circle. However, well points could be used in summer time on the Arctic coast. The writer noted one drilling operation during 1960 which encountered excellent ground water supplies in gravels below the bank of the Mackenzie River at Loon River which is almost on the Arctic Circle. The presence of permafrost merely increases the difficulty of well construction but does not prevent the use of wells. A rough calculation shown in Appendix 2 shows that little heat is required from the water in an aquifer - or from a small built-in heat unit if necessary - to prevent the formation of ice. It is only in zones of deep permafrost that wells become impracticable.

There are settlements where the turbidity of the river water and the high cost of river intakes, filtration plants and pipelines make the cost of using river water uneconomic. At some of these places wells could be used for water supply where water is obtained from normal ground water flow, bank storage or by induced infiltration from the river.

The writer realizes that the problem of waste disposal is greater than the problem of obtaining water in many northern localities. It is hoped that these notes are of some use for those concerned with this problem.

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* Dates in parentheses refer to publications listed in the selected bibliography.

GREAT SLAVE LAKE REGION

Fort Smith (G.S.C. Map 607A, J.T. Wilson 1938)*

A comprehensive report on Water and Sewerage systems for Fort Smith was completed in 1958 by the firm of Stanley, Grimble, Roblin Ltd., Consulting Engineers, Edmonton. The writer has made considerable use of this engineering report.

The town is situated on the west bank of the Slave River and is about 120 feet above river level. The silty sandy soils throughout the whole area are derived from post glacial lake and dune deposits. The sands are 30 - 40 feet thick and overlie clays which were deposited when Glacial Great Slave Lake covered the area. Locally a few feet of weathered rock and sand and gravel overlie the bedrock. The bedrock comprises granitic rock under the settlement. These granites outcrop in the river bank at the water intake and in the Rapids of the Drowned.

Wells were used in the area prior to the construction of the water system. These wells obtained water from the surface sands and silts which overlie the clay. The wells were hand dug and were, therefore, of small capacity owing to poor construction and absence of screens.

A drilling programme was carried out in 1958 to locate adequate ground water supplies. The well logs from this testing programme are shown in Table 1. The location of the holes are shown on Figure 1. Three of the test wells encountered local aquifers in gravels and fractured granite below the clay. The wells were able to yield between 20 - 40 gpm during extensive pumping tests. From the test pumping data the writer estimates these local aquifers to have transmissibilities of the order of 1,000 gpdf; the storage coefficient is low

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* Map numbers and names in parentheses refer throughout this report to the most recent Geological Survey map and report on the area.

as the aquifers are artesian. The hardness of the water in these aquifers exceeded 600 ppm*, and for this reason ground water supplies were not developed.

A log of a well drilled at the airport is shown in Table 2. It is probable that the semi-artesian aquifer between 20 and 46 feet could be developed for about 50 gpm if it were properly screened.

The whole Fort Smith area has a perched water table in the surface sands overlying the clay; the depth of this aquifer varies with the depth to clay. Seepage of this water occurs along the river bank.

Permafrost is reported to be present sporadically along the bank above the river, and in locations with a moss cover. The lenses are only a few feet thick and are certainly discontinuous. The frost retreats when the vegetative cover has been removed.

Bell Rock and Salt River. (G.S.C. Paper 58-11, R. J. Douglas)

Bell Rock is a prominent outcrop of brecciated dolomite and limestone on the west side of Slave River nine miles downstream from Fort Smith. Drilling was carried out at the docksite in the summer of 1945. The borings showed that river silts overlie the dolomites. Flowing artesian water was encountered in one borehole from an aquifer between the silts and the underlying dolomite.

Borings were carried out in July 1955 at the site of a proposed bridge over Salt River. The drill logs record the presence of silts overlying limestone and red clay. It is almost certain that the red clays referred to were shales of Ordovician age which are known to underlie dolomites and limestones in this locality.

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* Chemical analyses of wells and springs are shown in Appendix 1.

It is recommended that any foundation drilling carried out in this region be required to prove at least thirty feet of sound rock, since large solution channels may have developed in these rocks and the rock formations may be cavernous. Water passing through solution channels in beds of gypsum and salt in these rock formations has made the water in the Salt and Little Buffalo Rivers unpalatable. The salt springs in the area have been described by Camsell (1916).

Fort Resolution (G.S.C. Paper 58-11, R.J. Douglas)

The settlement and airport are located on dune and lake sands and silts. There is a large gravel and cobble ridge extending westwards 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.

A well dug to a depth of 14 feet under the Roman Catholic Mission contains a few feet of unpotable mineralised water. Deep well drilling at Fort Resolution would yield considerable supplies of saline and sulphurous water; therefore, well drilling is not recommended here if potable water is required, unless the cost of a complete demineraliser is also allowed for. Properly constructed well points may be successful in the lake shore.

Snowdrift (G.S.C. Map 51-6A, F.Q. Barnes)

The settlement in Christie Bay is located on a small bay. Bedrock beneath the settlement is argillite and arkose; the rock is folded and may have sufficient fractures to yield small supplies of water from drilled wells. Glacial drift is present and well points might be successful. The writer has not visited this settlement.

Latham Island - Yellowknife. (G.S.C. Maps 48-17 A & B, 49-26, 50-34, 52-24 and 52-28; Henderson & Brown)

Municipal water supply for Yellowknife is obtained from the lake. The geology of the area has been mapped in detail.

Water is not supplied to Latham Island. The island consists largely of outcrops of gabbro, and basalts and quartzites of the Yellowknife group of rocks. There is no chance of obtaining water from the bedrock unless drilling were carried across one of the fault zones, and at these locations the supplies are uncertain. Water might be obtained from well points installed into the glacial drift and sands along the northwest side of the island. Permafrost is present on this shore but it is doubtful if any layers near the lake are deep. Permafrost has been reported to depths of 250 feet in the mines.

Rae. (G.S.C. Paper 59-11, Douglas and Norris).

The settlement is located on some granite outcrops on the south-east shores of Marian Lake. The lake is shallow around the settlement, being only about 5 feet deep in places one hundred feet off shore. The water is locally polluted, particularly in the spring. There is no hope of obtaining fresh water from wells on land because the granite is unfractured. A 700 foot deep diamond drill hole at the Roman Catholic Mission provides evidence for this as the hole is dry.

The Mission has tried to obtain good supplies of fresh water by sinking a brass well point through the lake-bottom clay silts. This well point has apparently encountered a sand aquifer below the silts and above the granite at a depth of about 30 feet. The sand was reported to yield clear water and the static water level was found to be the same as lake level. The writer recommended in a letter, dated July 16th 1960, to the Department of Northern

Affairs and National Resources that if a drilling rig and crew were brought to the settlement they might successfully instal good wells around the settlement. The wells would have to be located about 75 feet off-shore, and would require properly designed wire-wound well-screens. If the aquifer between the lake clay silts and the rock is fine then the wells may also require a sand-gravel pack. Wells of this type would yield sufficient water to the settlement provided there is a sand aquifer from three to four feet thick.

Hay River (G.S.C. Paper 58-11, R.J. Douglas)

The town and the airport are located on Vale Island. Information on the logs of wells drilled at this site have been made available to the writer by Stanley, Grimble, Roblin Ltd., Consulting Engineers; and by Big Indian Drilling Co. Ltd. The consulting engineers have made extensive reports on engineering problems at this town.

The logs of the wells are shown on Table 3, and the locations are shown on Figure 2. The island comprises deltaic sands and silts which overlie lake clays and glacial deposits. Shale of the Fort Simpson formation was encountered in seven of the drill holes at about 70 feet.

Wells 9, 10, 11 and 14 were test pumped after installing a 10 foot long 15 slot wire-wound screen. Well 9 was pumped dry immediately, but the other three wells were able to yield 2 - 6 gpm during pumping tests of several hours duration. The transmissibilities of these thin lens-like aquifers is extremely low, being less than 300 gpdf; nevertheless they are able to yield small quantities of water.

Permafrost was present in some of the drill holes, being deepest in hole 12. The ground water temperature from three of the pumped wells was between 38° - 40° F in June 1958.

It is probable that wells capable of yielding 2-4 gpm could be successfully drilled at the Indian Reservation on the right side of the east channel. The wells would be less than 30 feet deep and would require properly designed well screens and they may also need sand and gravel packs. This work should only be attempted by experienced well drilling companies.

Table 1.

Logs of wells drilled in 1958 at Fort Smith by Big Indian Drilling Co. Ltd., Calgary. (Stanley, Grimble, Roblin Ltd., Consulting Engineers). Location of holes shown on Fig. 1.

Hole	From	To (ft)	Description
No. 1	0	20	Sand
	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

Depth to water 115 ft.
A five foot 60 slot screen was set at 177 ft. depth and the well was pumped at 15 gpm with a drawdown of 28 ft.
Hardness of water was 940 ppm.

Hole	From	To (ft)	Description
No. 2	0	17	sandy brown clay
	17	30	sand
	30	35	silty clay
	35	153	soft blue clay
	153	158	granite

Depth to water prior to pumping from fractured granite aquifer 33 ft. Drawdown 45 ft. after pumping 24 hours at 25 gpm.
Hardness of water 696 ppm.

Hole	From	To (ft)	Description
No. 3	0	5	Sandy brown clay
	5	15	silty sand
	15	40	sand
	40	45	silty clay
	45	149	soft clay
	149	155	granite

Hole abandoned as dry

Hole	From	To (ft)	Description
No. 4	0	10	sandy brown clay
	10	35	sand
	35	45	silty clay
	45	50	silty blue clay
	50	173	soft blue clay
	173	180	granite wash

Depth to water 56 ft.
Test pumping was carried out (without a screen) from the granite was aquifer. Yield was 40 gpm for 88 ft. drawdown.

Hole	From	To (ft)	Description
No. 5	0	63	Sand
	63	87	silty blue clay
	87	173	soft blue clay
	173	205	clay
	205	211	granite

No aquifer worth testing.

Hole	From	To (ft)	Description
No. 6	0	36	Sand
	36	42	silty clay
	42	167	soft blue clay
	167	185	Granite

No aquifer worth testing.

Table 2.

Log of Fort Smith Airport Test well drilled in 1950 under supervision of Division of Works and Services, Dept. of Northern Affairs and National Resources.

Location: Airport Building.

Depth (ft)	From	To	Description
	0	10	Silty brown sand
	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.

A 40 foot well here is reported to yield enough water for airport barrack requirements.

Table 3.

Logs of wells drilled at Hay River by Big Indian Drilling Co. Ltd. in June 1958.

Hole No. 1.

Depth (ft)	
0 - 34	Sand clay & rocks
34 - 90	clay
90 - 231	hard shale
231 - 244	soft shale
244 - 249	hard shale ledge
249 - 370	calcareous shale
370 - 390	limestone (gas odour)

Hole No. 2.

Depth (ft)	
0 - 16	sandy brown clay
16 - 36	soft blue clay
36 - 64	clay and rocks
64 - 190	soft shale
190 - 363	soft shale with hard stringers
363 - 370	limestone

Hole No. 3.

0 - 10	silt
10 - 23	clay and sand
23 - 27	gravel (water) and sand
27 - 84	clay and boulders
84 - 175	shale
175 - 290	hard shale with intermittent ledges
290 - 340	limestone (gas and sulphurous water)

Hole No. 4.

0 - 8	reddish beach sand
8 - 18	fine grey sand
18 - 25	course grey sand
25 - 41	grey clay and gravel seams
41 - 55	grey clay
55 - 77	clay and boulders
77 - 189	shale
189 - 200	hard shale (gas)

Hole No. 5

0 - 10	clay and silt
10 - 21	soft clay (sandy)
21 - 33	brown sand
33 - 41	reddish clay and pebbles
41 - 42	boulders
42 - 76	blue clay with rocks
76 - 80	shale

Hole No. 6

0 - 1	clay
1 - 8	fine red beach sand
8 - 25	coarser grey sand
25 - 30	clay with sand seams
30 - 45	soft clay
45 - 56	soft gravel & clay
56 - 62	clay

Static water level 3 ft. from surface.

Table 3 contd.

Hole No. 7

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 & pebbles
39 - 69	grey clay and pebbles
69 - 70	shale

Hole No. 8

0 - 1	clay
1 - 10	sand, frost at 5 ft.
10 - 11	wood
11 - 14	dirty frozen sand
14 - 26	silt
26 - 28	silt & 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' from surface.

Hole No. 11

0 - 18	frozen silt & clay
18 - 25	sand
25 - 28	silt
28 - 30	clay

Static Water Level 2.75' from surface.

Hole No. 12

0 - 4	sand
4 - 15	frozen sand
15 - 30	frozen silt & 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' from surface.

MACKENZIE RIVER REGION

Fort Providence (G.S.C. Paper 58-11, R.J. Douglas)

The settlement is located on a steep bank about forty feet above the Mackenzie River. The bank is composed of glacial lake clays and till; the clays contain some boulders. Drainage is poor throughout the settlement. The river water is clear at this part of the Mackenzie River throughout much of the year. The Roman Catholic Mission obtain their water from a direct intake to the river; this intake was successfully constructed many years ago at the time when the river level was low just before a freeze-up. There is a shallow dug well below the basement of the house occupied by the Hudson's Bay Company manager; this well has to be pumped frequently during the summer as it fills with seepage water from the clay. The water is of poor quality having a hardness exceeding 2,600 ppm and is not used for drinking.

The nearest deep oil exploration well (Northwest Territories No. 1) was put down 1.5 miles southeast of the settlement several years ago. The log of the well shows that shale of the Fort Simpson formation was reached at a depth of 175 feet and that shales continued for the next thousand feet. Below these shales there were some limestone and dolomite beds; the hole was abandoned at a depth of 1,670 feet. Drilling for potable water in these rocks is not recommended because the water will be sulphurous.

The best hope of obtaining ground water in the vicinity of the settlement is from sand and gravel layers which may overlie the shale bedrock and underlie the surface clays. There is no certainty of any sand and gravel beds being continuous, but if they are present they should supply quantities of the order of 10 gpm from properly constructed wells. It is probable that ground water would be hard and high in both calcium sulphate and sodium chloride.

Jean Marie Creek. (G.S.C. Paper 58-11, R.J. Douglas)

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

There is a dug well 14.5 feet deep to ice and 4.5 feet square outside the schoolhouse. The well was constructed in July 1958 and is cribbed all round. The well had less than six inches of water in it in August 1960 and the bottom of the well was composed of ice which had frozen-in the pump line. Chemically the few gallons of available water were good, except for a slightly high nitrate content (5 ppm); however, this nitrate content must be expected from a well of this construction. It is apparent that a well of this type is a cistern and the only method of maintaining a water supply here is to pump water into the cistern from the river whenever necessary; at the same time it would be necessary to make sure that the continued growth of the ice is prevented.

An oil exploration hole, drilled nearby several years ago was known as British American, Hudson Bay Jean Marie Creek No. 1 well. The log of the well shows that shale was encountered at a depth of 20 feet and that there were more than 1,700 feet of shale below.

Fort Simpson. (G.S.C. Report 58 - 11, R.J. Douglas)

The town is situated on an island by the left bank of the Mackenzie River at the junction of the Liard River with the Mackenzie. The houses are on the east side of the island where they overlook the Mackenzie River. The island is composed of alluvial silts with some sands and gravels; there are wood fragments and peat layers in some localities at various depths. The north and south ends of the island are made up of sand and silts terraces only a few feet above the river. At the Hudson's Bay Co. store the bank is steep and is 40 feet above the river; going northward along the road through the town the bank is 30 feet above the river at the Roman Catholic Hospital and it is only about 20 feet above the river near the Agricultural station. The shores on the east side of the island are strewn with many boulders which have been derived from glacial drift. The west side of the island is lower than the east side. Bedrock is not exposed anywhere on the island. There is an outcrop of the Fort Simpson shales on the opposite bank of the river in the cliffs along the Harris River. It is probable that the depth to rock beneath Fort Simpson Island is many hundreds of feet.

More than ten dug wells have been constructed on the island and the locations of these wells are shown in Figure 3. The wells vary in depth from 35 feet to 48 feet. Most of these wells are now abandoned since the town has a new water system. The water levels in these wells varies with the fluctuations in the level of the river. The chemistry of the water in these wells varies considerably, the wells at the Hudson's Bay Company and the Indian Agency being too saline and too hard to drink. The two wells at the Roman Catholic Mission are good, although one well has a fairly high nitrate content. Peat may have made other wells unsuitable.

Permafrost was reported to have been present in the old well at the Experimental Farm; and the Hudson's Bay Co. well had a permafrost layer at 11 feet depth which was reported to be 10 feet thick when it was dug. It is apparent that permafrost lenses exist locally in silts on the island but they do not extend below river level where sand and gravel beds are found.

The writer considers good supplies of ground water could be obtained from well points at both the north and south ends of the island. It is probable that high capacity wells yielding more than 100 gpm could be constructed anywhere along the east side of the island if they were properly drilled, screened and gravel packed. Such wells would obtain water by induced filtration from the river, and once steady pumping was in progress the quality of the water would be good.

There are three dug wells at the airport each about 26 feet deep which obtain adequate supplies of water from sand beds. There is no record of any permafrost there. The airport is 9 miles south of Fort Simpson Island on the Liard River.

Wrigley. (G.S.C. Memoir 273, G.S. Hume)

The settlement is on a terrace about 30 feet above the left bank of the river. The topsoil contains peat and organic layers along with surface silts. Glacial boulders are strewn along the river shore and glacial till may be present beneath the silts and clays. Drilled wells might obtain good water beneath the settlement. Permafrost is reported to be present in excavations. The location of the settlement is shown on Figure 4 and further reference is made to this area later in this report under a description of the thermal springs near Wrigley.

The airport is about 7 miles south of the settlement on a high sand and gravel terrace above the right bank of the river.

Water is supplied to the camp from a drilled well which was put down in 1959. The well is reported to be 150 feet deep, and depth to rock is reported to be 250 feet. The well obtains water from gravel beds and the water is under artesian pressure; it was not possible to measure the depth to water when the writer visited the site. Permafrost is not present here and there is no doubt that greater supplies of ground water could be obtained if necessary.

Fort Norman. (G.S.C. Memoir 273, G.S. Hume)

The settlement is on two terraces above the right bank of the Mackenzie River near it's junction with Great Bear River.

The visible geologic succession consists of silts and sands on the top terrace which overlie approximately twenty feet of silty glacial till. Tertiary sandstone and conglomerate cliffs can be seen underlying the till at the mouth of the Great Bear River and this formation underlies the whole Fort Norman settlement. The sandstone and conglomerate are fairly well cemented, contain a few thin coal seams and have developed a slight vertical jointing.

A 20 foot deep excavation under the Roman Catholic Mission contains seepage water; this is a cistern rather than a well and the nitrate content of the water in the well is high indicating probable surface pollution. Permafrost is present in the silts and till in the settlement.

The digging of wells in this settlement is not recommended. However, the writer considers that it is probable that good supplies of water could be obtained from wells which have been drilled to depths at least fifty feet below the level of the river and which have penetrated the sandstones and conglomerate. Drilled wells in the sandstone may require screens as the sand is liable to cave under continuous pumping. The chemistry of the water from the sandstone should be good if prolonged pumping is undertaken to obtain induced infiltration from the river. Work of this nature should only be undertaken by drilling companies experienced in the construction of high capacity wells. It is unlikely that permafrost is deep near the river.

Well points could be used along the beaches of the river during the summer time to obtain good supplies of filtered water.

Norman Wells. (G.S.C. Memoir 273, G.S. Hume)

Water for the townsite is obtained from Bosworth Creek. The soils and permafrost conditions have been extensively studied by R. A. Hemstock whose report on the area was published in 1953.

The Northern Research Group of the National Research Council Division of Building Research are undertaking further studies there.

Fort Good Hope. (G.S.C. Memoir 273, G.S. Hume)

The settlement is on the right bank of the Mackenzie River two miles downstream from the north end of the Ramparts. The Ramparts are a seven mile stretch of the river which flows between 200 foot high cliffs of white limestone.

The banks at the settlement are about 60 feet above the river near the Roman Catholic Mission and the Hudson's Bay Co. store; at the Department of Transport houses and at the new school the banks are over 100 feet high. There is some low land between the school and the D. O. T. Buildings. Extensive gravel deposits are found in the region of the settlement. A high esker ridge running from northeast to southwest is located about two miles north of the settlement. Swampy areas are present in low-lying places to the north of the settlement.

It is probable that a direct hydraulic connection exists between Jackfish Creek and the Mackenzie River; in which case drilled wells could be successfully put down in the south part of the settlement in spite of the presence of permafrost. Drilling for fresh water should not be undertaken in the underlying limestones since the water will be sulphurous.

Bank erosion is occurring in the narrow ledge between Jackfish Creek and the Mackenzie River bank.

Arctic Red River. (G.S.C. Memoir 273, G.S. Hume)

The settlement is on the west bank of the Mackenzie River at the junction of the Arctic Red River.

Sandstone and shale of the Imperial formation outcrop on the rock bluff below the Roman Catholic Mission, and depth to rock throughout most of the settlement is probably less than 20 feet. There are two clay and peat terraces in the settlement. Permafrost is reported to be within a few feet of the surface in most places, and it is probably several hundred feet thick. At Point Separation a few miles downstream permafrost is reported to be 700 feet thick.

Water is obtained during the summer from a pond located near the school.

Fort McPherson. (G.S.C. Memoir 273, G.S. Hume)

The settlement is on 60 foot high banks above the Peel River. Shale outcrops occur along the river bank below the Hudson's Bay Company store; and the same shale was encountered in excavations near the new school. Silts overlie the shales. Permafrost is present throughout the whole area and it is presumed to be thick.

Fresh water is obtained from a lake near-by.

Inuvik.

Soils and permafrost are being actively investigated in the Delta of the Mackenzie River by the Northern Research group of the National Research Council Division of Building Research. They have published several reports on this subject, thus there is no need to extend any further descriptions of soils in the delta region.

A number of outcrops of limestone and sandstone occur in the region of the east channel of the Mackenzie River. At Inuvik airport a rock quarry exposes pre-Silurian red and green dolomite, silty dolomite and dolomitic sandstone and some shale. The beds are faulted.

LIARD RIVER

Fort Liard. (G.S.C. Paper 59-6, R.J.W. Douglas and D.W. Norris)

The settlement is at the junction of Petitot River and Liard River; it is on the right bank of both rivers. The banks are composed of silt and sand with boulder and gravel layers about thirty feet down, though these are not clearly visible along the river bank.

There are four dug wells in the settlement which vary from 27 feet to 33 feet in depth. The supply of water for domestic needs from these wells is reported to be adequate. Considerable difficulty was encountered in digging some of the wells owing to boulder beds below 20 feet. Therefore, well points would not be satisfactory here. A churn (percussion) drill would be necessary at this settlement to instal high capacity wells. The level of the water in the wells fluctuates with the levels of the rivers; it is probable that high capacity wells could be installed here. The temperature of the water in the Roman Catholic Mission well was 34°F.

Sandstones and shales outcrop on the left bank of the Petitot River opposite the settlement.

Nahanni Butte. (G.S.C. Paper 60-19, R.J.W. Douglas and D.W. Norris)

The settlement is at the junction of South Nahanni River with the Liard River. The main part of the settlement is on the south side of Nahanni River, but there is also a trading post on the north side of the river.

The whole land area comprises alluvial silts and sands; the sands being fine grained. Ground water levels here will vary with river levels. Wells could be installed at this settlement and would require fine slotted wire-wound screens.

ARCTIC COAST

Tuktoyaktuk.

The settlement is situated on a narrow tongue of land on the edge of Kugmallit Bay. The coastline has all the appearances of a drowned shoreline as long arms of the sea extend up the coast depressions.

The beaches are composed of cobbles, gravel and sand. Underlying beds of silt, which are bound together by matted vegetation, are also present on the beach. To the south of the settlement and probably underlying it at depth there is a loose gravelly glacial till which has been derived from the hills to the south. Much of the soil in the settlement contains peat and vegetation and this is underlain by beds of sand with some gravel, these beds contain many ice wedges and lenses, which are several feet thick. The ice wedges are formed by the freezing of water from recent precipitation which has percolated down through the surface sands. The formation of these ice wedges has caused local uplift in the land surface. The sand cliffs and ground ice on the ocean side of the settlement are undergoing rapid erosion. It is probable that erosion will alter the shape of this shoreline considerably during the next few decades.

A sample of water taken from the sea proved to be fresh. It is probable that fresh water can be obtained here on many occasions throughout the year because water in much of the bay is from the Mackenzie River. If well points were driven into the beach gravels and sands and adequately protected from the sea and ice it would be possible to pump suitable water from here whenever the salinity of the water is found to be low.

The pingos and other permafrost features along this shoreline have been extensively described elsewhere in the literature on this subject.

Coppermine. (G.S.C. Map 18-60, J.A. Fraser)

The location of this settlement at the mouth of the Coppermine River is shown on Figure 5.

Rock on the west bank of the river and underlying much of the settlement is composed of diabase sills between dolomite and shale. Rock outcrops near the school, around the Anglican Mission and throughout most of the west part of the settlement.

One hundred yards west of the new school a small creek, meandering out of swampy ground to the south, flows through a sandy area into the sea just east of the Roman Catholic Mission. Clay and boulders overlying rock are visible along the sea-shore. The geologic section on the shore near the Catholic Mission consists of several feet of beach sands overlying a clay till which overlies rock. There is a small sandy delta at the outflow of the creek.

Samples of water taken from the sea-shore show that the water is fresh, and this is not surprising since the main flow of the Coppermine River passes in front of the settlement. It would be possible to obtain fresh water throughout many months of the year if well points were installed in the sands at the mouth of the small creek on the shoreline. The well points would have to be adequately protected.

SPRINGS

Some of the sedimentary rock formations in the Slave River and Mackenzie River Valley contain permeable layers which permit considerable ground water flow. The region is one in which many springs can be expected to occur. Among the thermal springs in the region are the following:

Roche-qui-trempe-a-l' eau, Wrigley

A series of small thermal springs ranging in temperature from 70° - 80° F are located on the east bank of the Mackenzie River about $2\frac{1}{2}$ miles north of Wrigley.

More than 12 springs occur in a distance of $\frac{1}{4}$ mile along the river. The water issues from small fissures and joints in the grey and black shaly limestones which outcrop along the river. Most of the flows are between 2 - 20 gpm, but in one locality, where water emerges from a talus slope, there is a total flow of about 70 gpm. The springs are less than 50 feet above the river and water may also be emerging below river level. Several old dormant cones and solution channels are visible 50 - 100 feet above the river where mineralised water has emerged from fissures higher up and has then been sealed off by the build-up of calcareous deposits and by the cementation of talus. It is therefore apparent that changes in the quantity and pressure of flow have occured in recent times. Bright green and vari-coloured algae flourish in some of the small springs.

The geologic structure (Douglas and Norris - personal communication) is a south plunging anticline which has a dip of 45°W on the river side and a dip of 20°E on the east side. Faulting has occurred in the anticline on the eastern flank. The core of the anticline is composed of brecciated grey dolomite and limestone of the Bear Rock formation; this is overlain by younger beds on the west side of the anticline which are fine grained grey limestones of the Nahanni formation; and these comprise the principal "rock by the riverside". The structure is illustrated in Figure 4.

The source area of the water may be in the Franklin mountains which lie to the east where the Bear Rock formation outcrops again. This formation has many cavernous solution channels and is therefore a good natural conduit. Presumably the water flows west from the Franklin mountains through the Bear Rock formation, and it may also pass through salt beds in the underlying Cambrian rocks. The hydrostatic head from the mountain area is sufficient to force the water up in the fractured and faulted zone of the anticline where it emerges from fissures and joints. The heat source may be an intrusion.

Samples of water were taken for chemical analysis. The water is saline and it also has a high calcium sulphate content. Small veins of gypsum and calcite and fragments of fluorite are present in the limestones and these have been derived from the spring water. A saline creek one mile downstream contains water which is chemically similar to the water from the springs. One sample of water from the springs was analysed for Tritium in the Atomic Energy Commission Laboratories, Chalk River. The analysis showed a count of 2.85 ± 0.15 T.U. (where 1 T.U. = 1 tritium atom per 10^{18} hydrogen atoms). The purpose of this analysis was to obtain an estimate of the age of the water. There are at present insufficient analyses of water in the area to permit any conclusions as to the age of the water, but the data are recorded for future reference.

There is a possibility that water from warm springs will in some future time be used as a source of heat in communities when the design of heat pumps has been improved. It might,therefore, be of interest to note that if a hole were drilled on the west side of the Mackenzie River on the axis of the anticline the boring may encounter some warm waters in the Nahanni formation and in the rocks below. However, the depth to this potential heat source could be many hundreds of feet since the plunge of the anticline may be steep.

Old Fort Island

Springs occur on the south island of Old Fort Island (mile 336) in the Mackenzie River. The principal spring bubbles up from sands and is surrounded by vegetation. It's estimated flow in August 1960 was 300 gpm. Several other small springs and seeps occur within a 100-yards radius of the main spring, and other flows can be seen emerging from small rock fissures further away. The total flow in the area may be about 1,000 gpm.

The island is formed by a fold in the grey limestone of the Nahanni formation which has a regional dip of 10° West at the south end of the island. Small veins of calcite can be seen in the limestone; fluorite is also present. The water is high in Calcium Sulphate which may be derived from gypsum in the Bear Rock formation. The temperature of the water was found to be 53°F, and therefore it can be considered to be slightly thermal. Williams (1921) reports that more mineralised springs occur near a creek opposite the island.

South Nahanni Hot Springs

Thermal springs are located on the right bank of the South Nahanni River just below the first canyon and above Clausen Creek. Water from the springs emerges from silt, sand and gravel bars along the riverside. The principal springs are over 100 yards from the river, and in one place there is a mud-bottomed pool 25 feet by 30 feet in diameter for use as a bathing pool. The temperature at the warmest part of the pool is 95°F; one of the flows by the river has a temperature of 98°F. It is probable that most of the water from the springs is discharged directly into the river below river level. The estimated flow of a small creek of warm mineralised water from the pools is 300 gpm.

The rock outcropping near the springs and at the entrance to the canyon is dark grey limestone of the Nahanni formation. The rocks are part of the south limb of a gentle anticline plunging to the southeast.

The water from the springs is saline and also has a high calcium sulphate content. An odour of hydrogen sulphide pervades the whole area. A Tritium count analysis gave a value of 3.64 ± 0.18 T.U. and a Lithium content of 2.0 ppm.

Flat River

Thermal springs are known to occur near the headwaters of the Flat River in the Selwyn Mountains.

Cold springs in the Mackenzie River region

Reference has been made to sulphur springs in this area by Whittaker (1922), Williams (1922), and Hume (1954).

Evidence for the flow of ground water is indicated by the chemistry of waters in the Saline River and in Vermilion Creek.

Great Slave Lake region

Several cold springs are located on the shores of Great Slave Lake and there is ground water discharge into the lake from the Palaeozoic rocks on the west side of the lake.

The springs at High Point and Sulphur Point are small flows of about 10 gpm and in each case the water seeps up in several different pools. The temperature of the water is 37°F. Several springs occur on the northwest side of the lake in the Windy Bay region. The water is derived from the Pine Point and Presqu'ile dolomites and limestones and from gypsum and salt beds below these formations.

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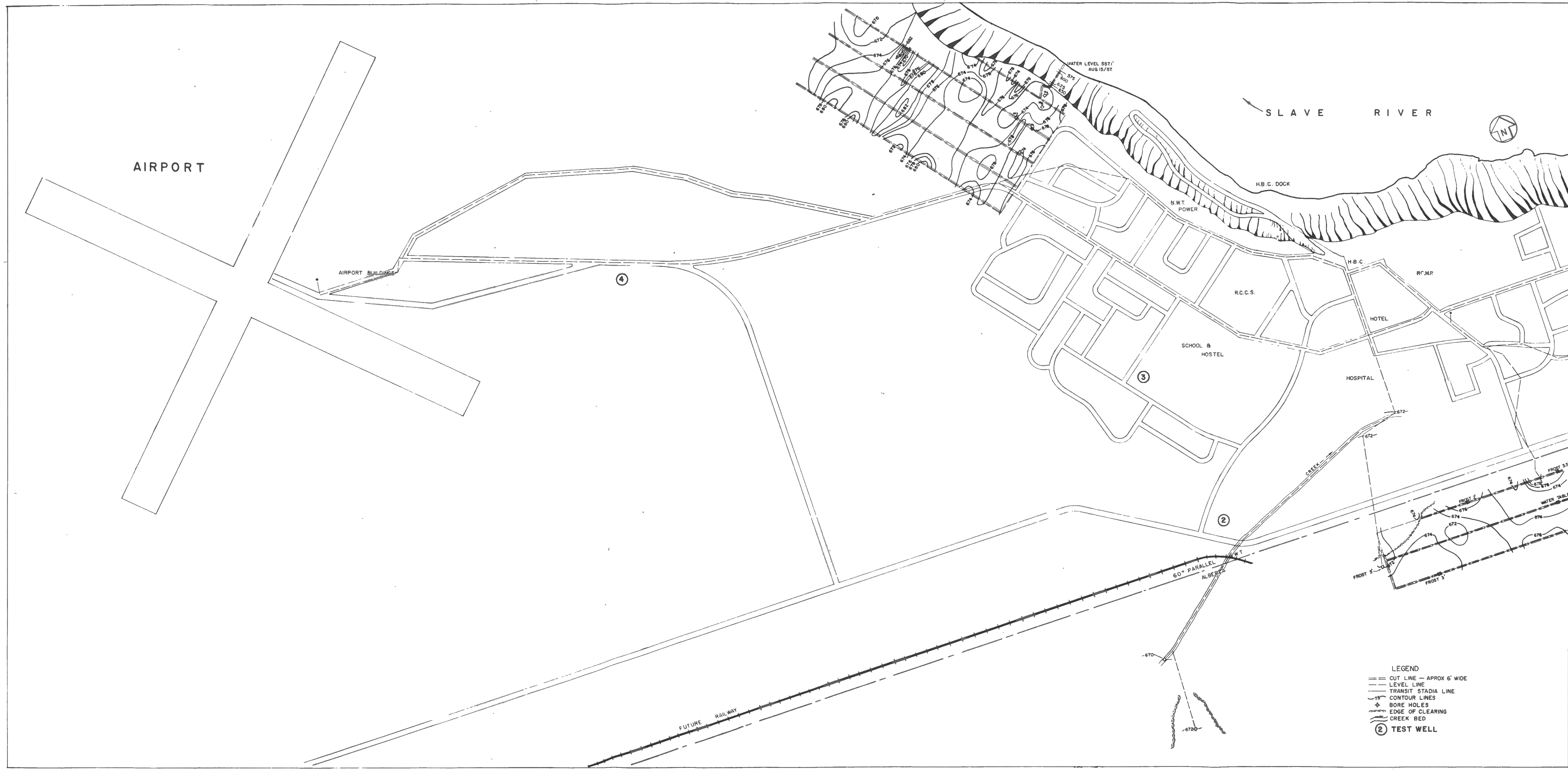


FIGURE 1

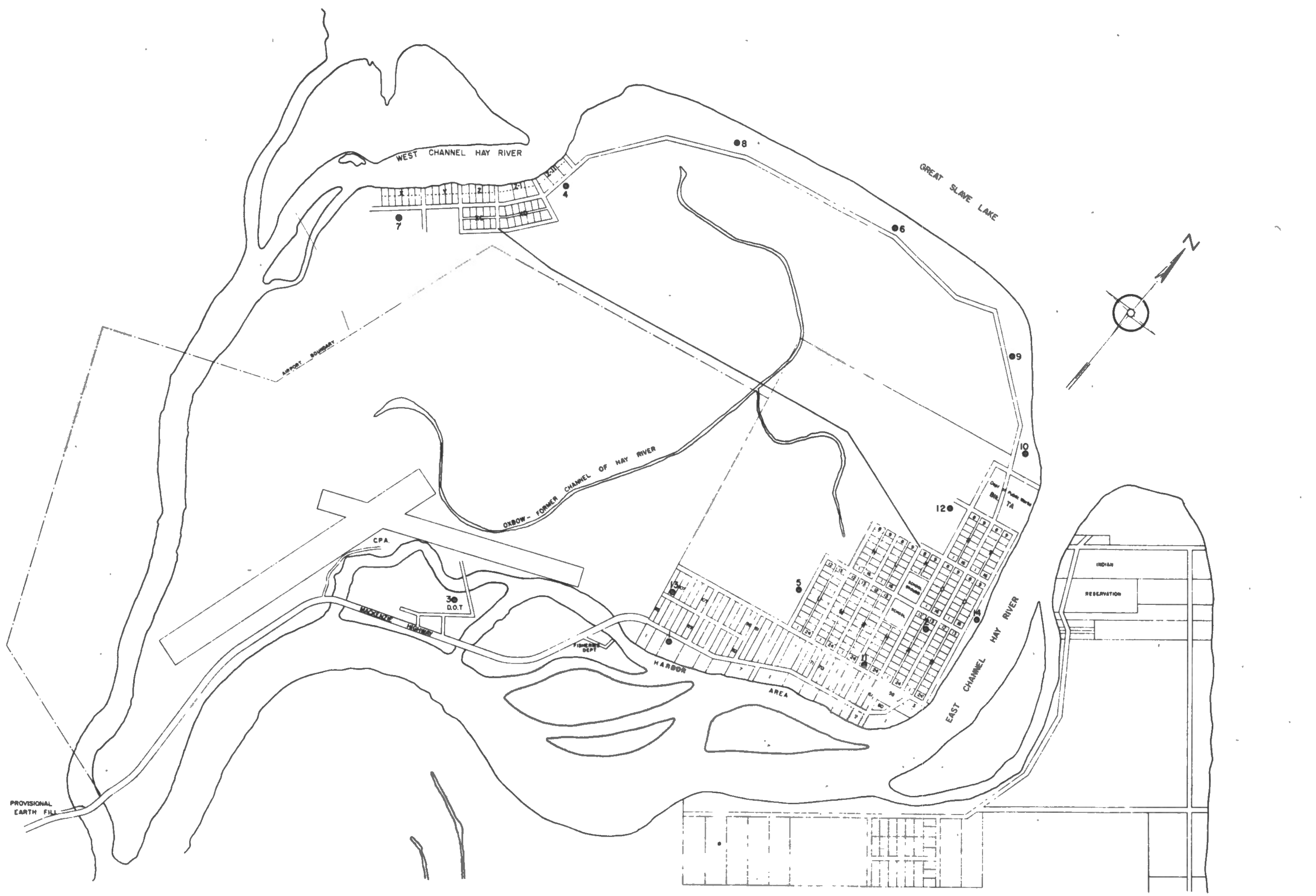
GOVERMENT OF CANADA
DEPT OF NORTHERN AFFAIRS & NATURAL RESOURCES
DIVISION OF WORKS & SERVICES.

STANLEY, GRIMBLE, ROBLIN Ltd.
PROFESSIONAL ENGINEERS — EDMONTON, ALTA.

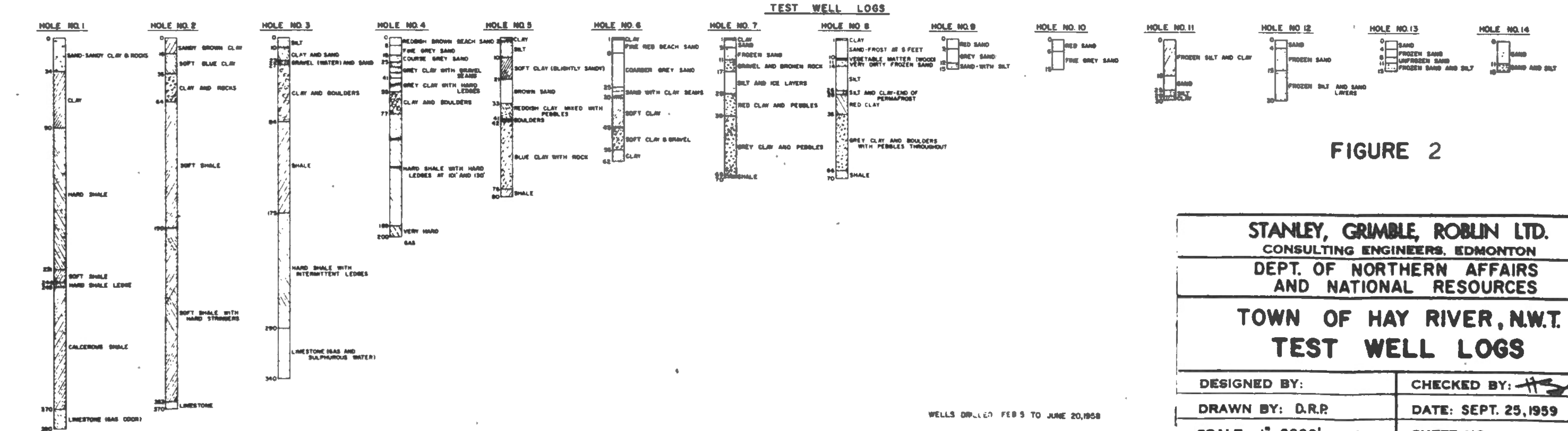
TOWN OF FORT SMITH

FIELD WORK

DESIGNED BY: J.KERR	CHECKED BY:
DRAWN BY: R.C.M.	DATE: OCT. 31/1957
SCALE: 1" = 1000'	SHEET NO. OF:
JOB NO: 222	DWG NO:



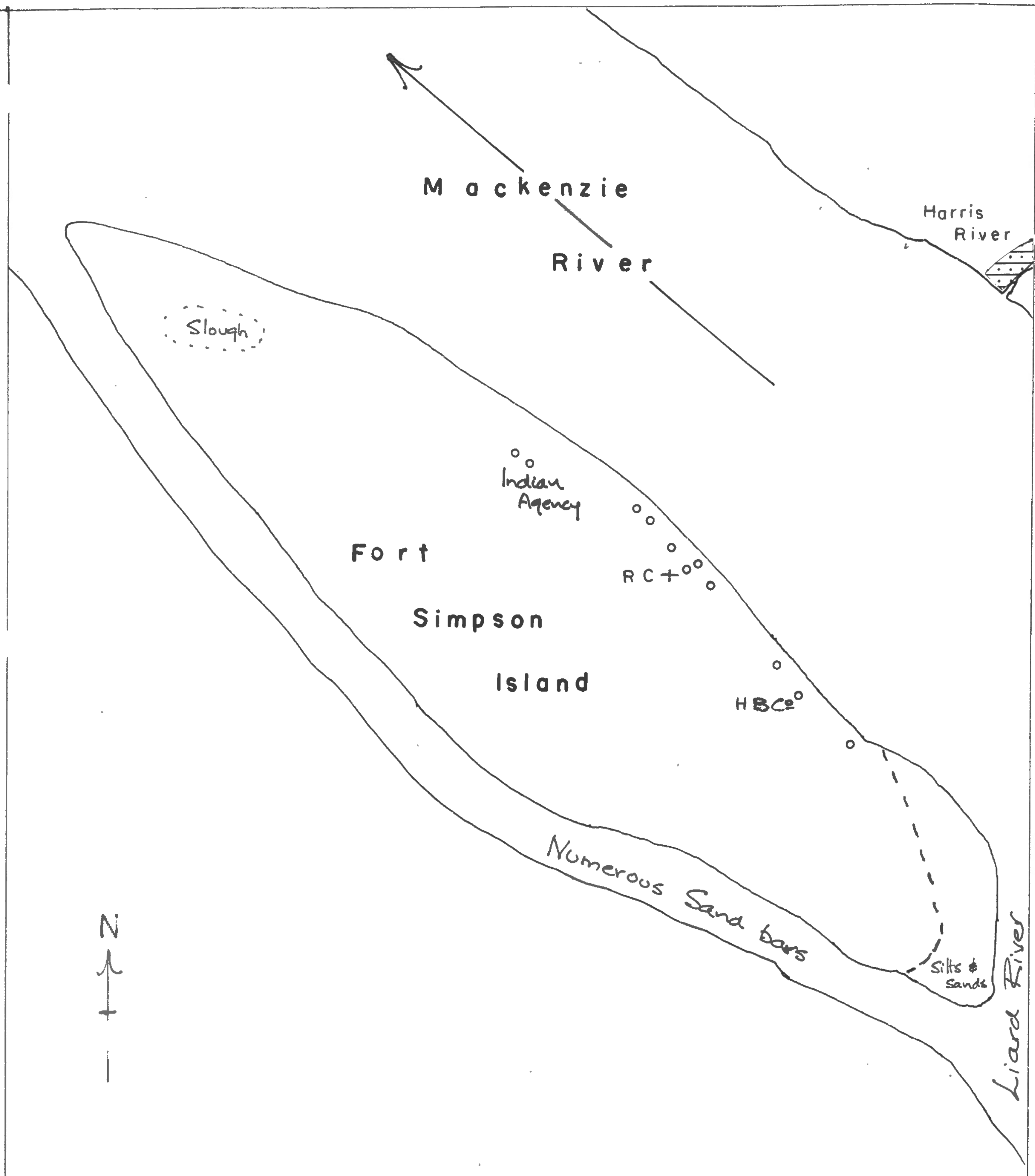
TEST WELL LOGS



WELLS DRILLED FEB 5 TO JUNE 20,1958

FIGURE 2

STANLEY, GRIMBLE, ROBLIN LTD. CONSULTING ENGINEERS, EDMONTON	
DEPT. OF NORTHERN AFFAIRS AND NATIONAL RESOURCES	
TOWN OF HAY RIVER, N.W.T. TEST WELL LOGS	
DESIGNED BY:	CHECKED BY:
DRAWN BY: D.R.P.	DATE: SEPT. 25, 1959
SCALE: 1" = 2000'	SHEET NO.: OF:
JOB NO.: 227-2	DWG. NO.:



o Dug well.

Simpson Shales

FORT SIMPSON

Scale Approx 3" – 1 mile.

Fig 3. L.F.B.

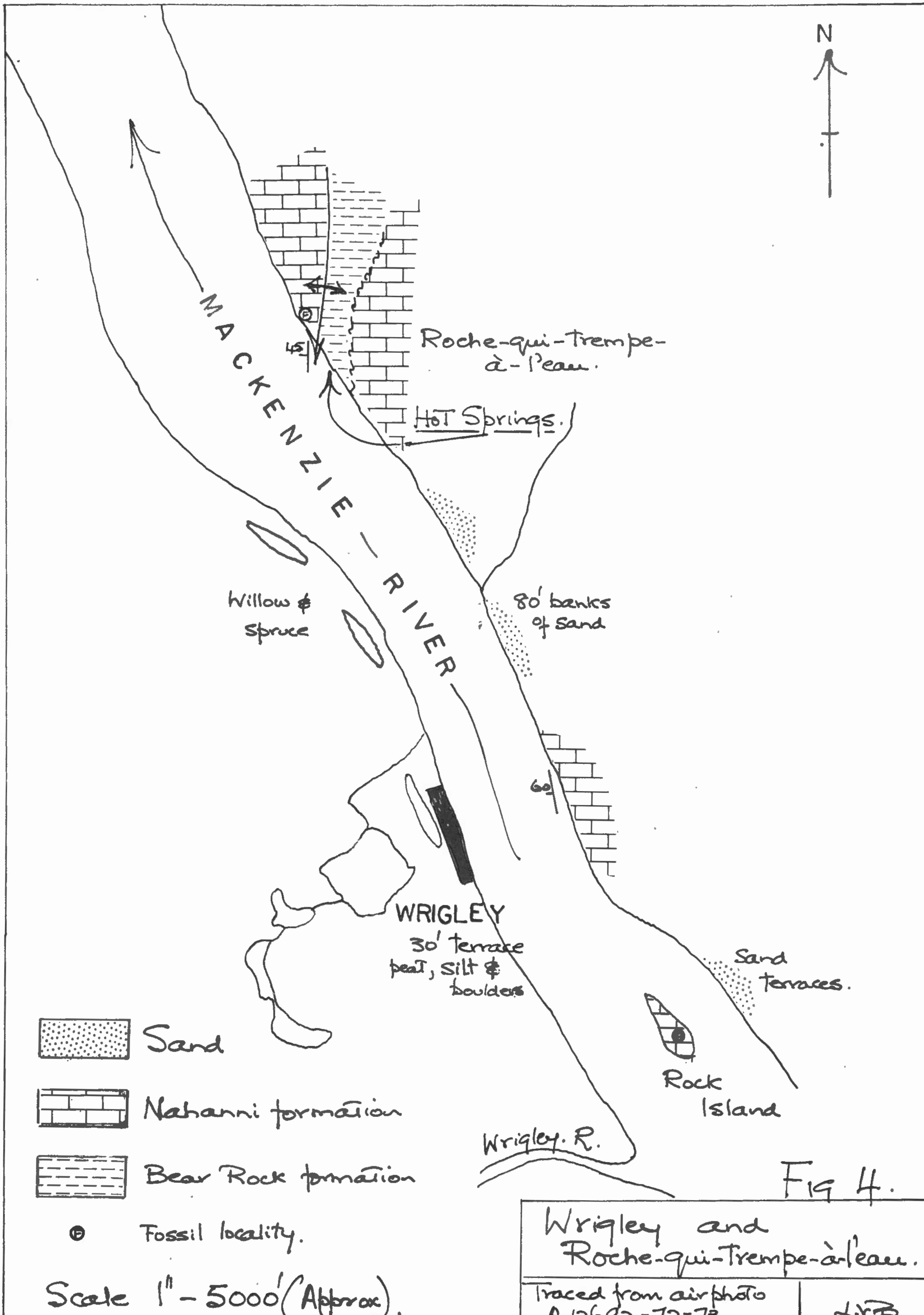


Fig 4.

Wrigley and Roche-qui-Trempe-à-l'eau.

Traced from air photo A 12692-72-73.

L.V.B.

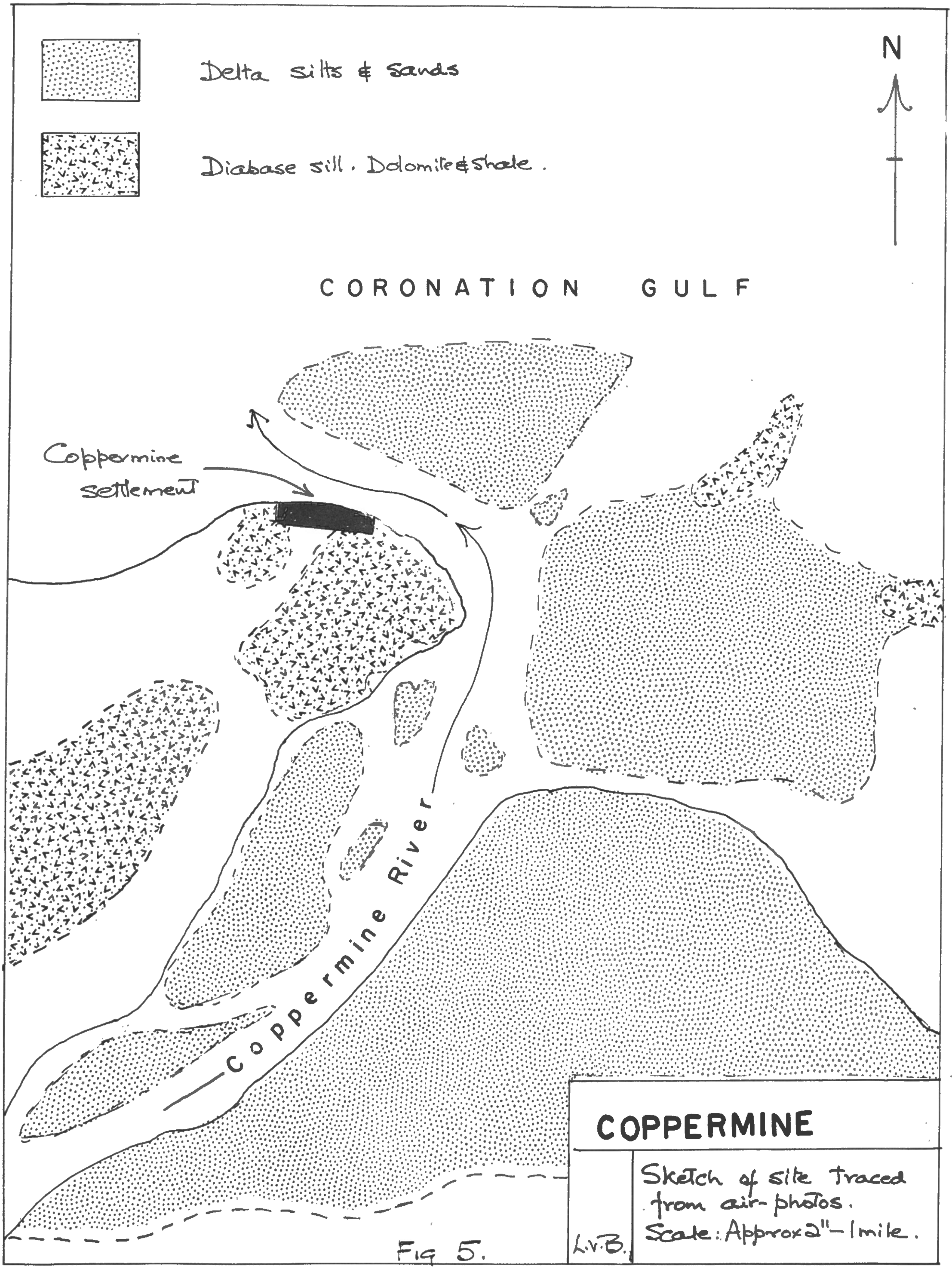

Delta silts & sands
Diabase sill. Dolomite & shale.
N
CORONATION GULF
Coppermine settlement
Coppermine River
COPPERMINE
Sketch of site traced from air-photos.
Scale: Approx 2" – 1 mile.
L.V.B.

Fig 5.

LOCATION	COPPERMINE			TUKTOYAKTUK			FORT SIMPSON				FORT NORMAN	WRIGLEY	FORT PROVIDENCE	JEAN MARIE CREEK	FORT RESOLUTION	MACKENZIE HIGHWAY		PINE POINT		FORT SMITH		
	¼ mile upstream Coppermine River	10 ft. offshore opposite creek in settlement	Small creek in settlement	Seashore west side of settlement by RCMP post	Thawed permafrost ice in sand cliff at beach by RCMP post	Lake in settlement	Hudson's Bay Company House (at tap)	RC Mission (old well)	RC Mission (well at Boiler House)	Airport (tap in garage)	Well at RC Mission	Well at airport	Basement well at Hudson's Bay Company House	Dug well at school	Lake water at new jetty	Well at Mile 28	Well at Mile 32	Townsite well	Shaft N 42	Well No.1	Well No.2	Well No.4
Date	Sept.20/60	Sept.23/60	July 10/60	Aug.31/60	Aug.31/60	Sept.1/60	Aug.3/60	Aug.3/60	Aug.3/60	Aug.3/60	Aug.11/60	Aug.9/60	July 30/60	Aug.1/60	July 23/60	Sept.13/60		July 20/60	July 20/60	1958	1958	1958
Appearance and Odour		reddish deposit					clear			clear			clear	grey brown deposit								
pH	7.4	7.6	7.6	7.6	6.8	7.4	8.0	8.0	8.0	.8.2	7.7	8.1	7.9	7.6	7.8	8.0	8.1	.8.1	8.0			
Colour	25	25	75	50	30	35	15	15	15	15	25	15	(colloids)	90	35	20	15	15	15			
Conductivity	82.8	84.0	208.8	773.6	50.3	2488	9043	386	1063	794.9	1346	553.7	3880	395.7	3349	372.8	798.1	1114	539.3			
Hardness: Total	39.0	42.4	98.2	167	22.7	350	878	186	464	454	732	308	2654	191	142	201	299	632	293	765	650	755
Non carbonate	0.3	0.1	4.2	72.6	2.8	171	461	35.9	154	8.4	330	18.9	2374	9.8	52.7	6.9	0	458	65.5			
Calcium	9.0	9.5	22.5	33.3	5.4	79.5	279	56.7	113	95.8	124	79.2	497	56.5	42.0	58.0	61.9	126	70.0			
Magnesium	4.0	4.5	10.2	20.4	2.2	36.8	44.1	10.8	44.0	52.1	103	26.7	344	12.1	9.0	13.8	35.0	77	28.6			
Sodium	0.7	0.5	5.5	83.4	0.9	360	1615	7.4	57.0	10.9	21.2	1.6	74.0	3.3	13.0	1.8	59	10.0	2.8			
Potassium	0.4	0.4	0.6	3.8	0.7	12.5	9.5	1.4	2.3	2.4	4.9	2.5	24.5	11.0	1.3	1.5	4.7	2.0	1.0			
Iron total	0.08	0.11	0.28	2.7	10.3	0.78	0.33	0.14	0.02	0.24	0.52	0.04	0.21	0.42	0.2	0.24	0.5	0.16	0.51	0.3	0.3	0.3
Manganese	0.0	0.0	0.0	0.0	0.4	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.01			
Copper	0.03	0.01																				
Zinc	0.0																		1.0			
Lead																			0.46			
Bicarbonate	47.2	51.6	115	115	24.3	219	508	183	378	543	491	352	341	221	109	237	377	211	277			
Sulphate	2.7	2.7	5.9	51.1	4.6	23	220	35.2	164	19.7	283	19.9	2197	19.2	60.0	9.8	64.1	463	53.4	425	408	396
Chloride	0.7	1.0	8.2	153	1.4	682	2747	9.7	62.9	2.0	18.2	0.8	24.6	3.2	15.1	1.0	38.5	0.4	4.1	192	100	186
Fluoride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.0	0.0	0.1	0.0	0.0		0.3			
Nitrate	0.0	0.0	0.0	0.1	0.0	2.8	1.6	1.4	16	1.0	55	5.0	312	5.0	0.2	0.0	1.0	0.0	16	0.0	0.0	0.0
Silica	1.4	1.7	4.7	3.0	0.5	0.6	7.2	3.8	5.9	14	7.1	7.7	9.1	16	3.8	6.8	8.5	9.5	11			
Sum of Constituents	42.1	45.7	114	404	28.0	1305	5174	217	652	465	858	317	3651	219	198	209	458	791	323	1310	1220	1262
% Sodium	3.7	2.5	11	51	7.3	68	80	7.9	21	4.9	5.9	1.1	5.7	3.5	16.5	1.9	30	3.3	2.0			

L. V. B.

LOCATION	SOUTH NAHANNI RIVER HOT SPRINGS : CLAUSEN CREEK				ROCHE QUI TREMPE A L'EAU HOT SPRINGS, WRIGLEY				GREAT SLAVE LAKE REGION			OLD FORT ISLAND	M A C K E N Z I E R I V E R T R I B U T A R I E S								HAY RIVER	
	A	B	C	D	A	B	C	Creek 1 mile south of springs	Spring at High Pt. near Buffalo River	Spring at Sulphur Point	Spring at Windy Point	Spring on island in Mackenzie River	Redknife R.	Trout R.	Rabbitskin R.	Root R.	Willow R.	Keele R.	Saline R.	Vermillion C.	Well No. 6 in town	Hay River
Date	Sept.9/60	Sept.9/60	Sept.9/60	Sept.9/60	Aug.9/60	Aug.9/60	Aug.9/60	Aug.9/60	July 27/60	July 26/60	Sept.9/60	Aug.8/60	Aug.1/60	Aug.1/60	Aug.2/60	Aug.7/60	Aug.7/60	Aug.10/60	Aug.10/60	Aug.12/60	May/58	Jan/53
Appearance and Odour	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S				green brown deposit					silty						
pH	6.8	6.9	7.1	7.4	7.7	7.8	7.7	8.0	7.9	8.1	7.7	7.9	7.8	7.7	7.4	8.1	7.7	7.9	8.3	8.3		7.7
Colour	15	15	15	15	10	10	10	30	15	10	20	10	90	60	110	25	160	25	40	40		100
Conductivity	8606	8469	8636	8390	17981	17511	17880	13596	14397	3160	921.7	1535	262.6	162.2	185.6	352.5	281.9	339.7	2380	1308		531
Hardness: Total	1646	1629	1650	1619	3229	3118	3249	2573	3077	1877	150	886	138	87.9	92.7	180	109	167	269	772	280	
Non carbonate	1424	1413	1418	1366	3078	2967	3095	2391	2816	1625	62.2	703	7.0	6.6	0.0	45.4	18.6	63.5	74.3	579		
Calcium	470	460	470	452	925	895	946	743	713	483	41.1	250	42.0	26.3	24.0	48.7	28.5	43.5	64.6	230		65
Magnesium	116	117	116	120	223	215	215	174	315	163	11.5	64	7.9	5.4	7.8	14.1	9.2	14.1	26.1	48.0		16.7
Sodium	1176	1066	1076	1054	3220	3075	3420	2500	2340	112	124	27.5	4.5	2.2	5.1	4.3	17.0	4.6	413	26.0		22.5
Potassium	73.5	72.5	75.0	72.5	34.5	32.5	33.0	27.0	6.9	2.9	1.5	2.0	0.5	0.7	0.7	0.7	0.7	0.6	1.3	1.7		3.0
Iron total	0.03	0.13	0.12	0.10	0.11		0.20	0.39	0.01	0.03	0.11	0.03	0.41	0.5	0.17	0.22	0.65	0.17	0.4	0.03	2	
Manganese	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Copper																						
Zinc									0.0	0.0												
Lead									0.0	0.0												
Bicarbonate	271	263	283	308	184	185	188	222	318	307	107	223	160	99.1	106	164	110	126	237	235		163
Sulphate	660	738	732	698	2810	2744	2832	2198	2550	1577	62.3	683	7.4	9.0	10.7	47.0	17.4	62.2	98.0	582	13	13
Chloride	2277	2231	2271	2208	5226	5033	5200	3980	3869	124	192	36.9	2.5	1.1	2.0	3.7	25.4	5.5	622	25.2	23	8.2
Fluoride	0.6	0.6	0.6	0.6	3.0		3.0	1.75	1.6	0.0	0.0	1.0	0.0	0.4	0.0	0.1	0.0	0.1	0.0	0.4		
Nitrate	4.0	0.8	0.2	3.2	0.8		0.4	0.4	2.4	0.2	0.0	0.4	0.0	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.0	1.0
Silica	26	28	28	29	24		24	17	9.4	10	2.9	6.6	6.8	4.1	3.9	3.5	4.4	3.5	4.2	5.0		
Sum of Constituents	4942	4844	4908	4788	12556	12000	12766	9750	9964	2624	488	1180	150	98.3	106	203	157	197	1347	1035	422	326
% Sodium	60	57	57	57	68	68	69	68	62	12	64	6.3	6.6	5.1	11	4.9	25	5.6	77	6.8		17.3

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APPENDIX 2.

Suppose a well is drilled through a permafrost zone and obtains water from an aquifer below. If the water is not under artesian pressure it will not rise in the well and therefore it will not freeze. If it is under artesian pressure it will rise to it's piezometric level which may be in or above the permafrost zone. The water will diffuse heat around the well casing and it is necessary to obtain an idea of the quantity of heat required to prevent refreezing.(Latent heat not being considered here).

An approximate solution can be obtained on the following assumptions:

Assume: T (initial Temperature difference) $= 2^\circ F$

k (Thermal conductivity) $= 0.53$ fph

c (specific heat) $= 0.33$

ρ (density) $= 111$ lbs ft^3

α (Thermal diffusivity) $= 0.015$ fph.

These are values for a sandy clay of 15% moisture.

To determine the quantity of heat to diffuse to a radius (r) of one foot in a time (t) of 100 hours. Applying the line source equation (Heat Conduction - Ingersoll, Zobel, and Ingersoll page 147).

$$T = \frac{S'}{2\pi\alpha}\int_{r\eta}^{\infty}\frac{e^{-\beta^2}d\beta}{\beta} = \frac{S'}{2\pi\alpha} I(r\eta) = \frac{Q'}{2\pi k} I(r\eta)$$

The values of the integral are given in the Text.

$$\therefore \quad S' = \frac{2\pi\alpha T}{I\,r\eta} = \frac{2\pi \times 0.015 \times 2}{I(0.41)} = \frac{4 \times \pi \times 1.5 \times 10^{-2}}{6.84 \times 10^{-1}} = \underline{0.275}$$

$$\left(\eta = \frac{1}{2\sqrt{\alpha t}} = 0.41\right)$$

$$Q' = S'c\rho = 0.275 \times 0.33 \times 111 \approx 10 \text{ BTU/hr/ft}$$

This is a small unit of heat, and it is apparent that in areas where permafrost is only about fifty feet deep that water from the well or heat from a small built in heater will be sufficient to keep the well operating.

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