INLAND WATERS BRANCH

DEPARTMENT OF THE ENVIRONMENT

# *Surface Water Inventory of Canada's Northern Territories*

*R.H. CLARK and E.R. PETERSON*

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# *Abstract*

Surface water inventories of Canada's northern territories involve those areas of Canada draining into the Arctic Ocean, Hudson Bay (north of the Nelson River drainage basin) and to the Pacific Ocean through Alaska. The major river systems are the Yukon River Basin and the Mackenzie River Basin. The available surface water data for the northern areas are insufficient to describe flow variations and, in many cases, even the mean flow of the rivers.

This report reviews the problems of established operation of the hydrometric network which is providing data needed for estimates of averages and streamflow variations and examines proposals for network expansion.

# SURFACE WATER INVENTORY OF CANADA'S NORTHERN TERRITORIES

R.H. CLARK* AND E.R. PETERSON**

An inventory of Canada's water resources in the northern territories offers scope for a discussion which would involve the whole hydrologic cycle. However, most people are concerned with the end result - the amount of water that is available to meet their needs. Whenever a particular scheme is advanced for geographical redistribution of the surface water resources of northern Canada, the inevitable question is, "How much water is there?"

At the present time, the available data are insufficient for accurate estimates of the variations in flow or even of the mean flow of many of the rivers. Availability is not the whole answer, however, as concern must also be given to its usability. For example, although an assured supply of water may be available, it could not be used for the production of hydro-electric power unless a head or differential in elevation can be exploited; in other cases, the quality of the water must meet the minimum standards for the specific use, or can be made to do so economically by modern treatment methods.

Thus, there are many facets to a comprehensive inventory of water resources which should include information on the following:

a) Surface water,

b) Groundwater,

c) Water quality (for both surface and groundwater),

d) Sediment transport,

e) Precipitation,

f) Ice and snow accumulation.

Each of these facets has been the subject of many papers and will continue to challenge engineers and scientists in their attempts to understand the vagaries of nature and to develop our water resources in a manner compatible to our life style.

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This paper will deal with surface water inventories of those areas of Canada draining into the Arctic Ocean, Hudson Bay (north of the Nelson River drainage basin) and to the Pacific Ocean through Alaska.

## NEED FOR LONG-TERM INVENTORY

The flow of rivers represents the integration of all meteorological and hydrological factors operative within a drainage basin; the flow is the only phase of the hydrologic cycle for which reasonably accurate measurements of volume can be made. Groundwater can generally be considered in terms of storage, feeding the rivers so that any depletion of this storage in the long run will appear as a depletion of runoff.

Leonardo da Vinci, nearly 500 years ago, gave a terse description of the dynamism of water resources when he wrote:

> "In rivers, the water that you touch is the last of what has passed and the first of that which comes".

Because of their dynamic nature, water resources must be measured systematically over a considerable period of time in order to define these dynamic characteristics. Consequently, an inventory of water resources can never be considered completed. The average yield of a river basin may be approximated in 5 to 10 years of measurement, but for many uses averages alone are not sufficient.

## BRIEF HISTORY OF CANADA'S SURFACE WATER INVENTORY

A brief history and growth of the surface water inventory in Canada will provide insight to the development and expansion of the network in the northern territories.

The measurement, compilation and analysis of river flow and water level data on a systematic basis began in Canada in 1894. Stream measurement work was initiated in connection with irrigation surveys made by the Forestry Branch of the Department of the Interior. In 1908, the Federal Parliament made its first specific appropriation for gauging streams and determining the water supply in southern Alberta and Saskatchewan; to carry out this program the Hydrographic Survey was established in 1909 with headquarters at Calgary. The program was expanded by the federal government as a result of its own responsibilities and through satisfactory arrangements with the provinces to meet immediate and future requirements as they were then recognized. However, with the return of the natural resources to the prairie provinces in 1930, followed closely by the economic crisis of the Thirties, the program of surface water inventory suffered a substantial reduction and only returned to its pre-Depression coverage after World War II. In recent years through arrangements with the provinces and other federal departments, there has been a considerable and accelerated expansion of the national network based on a growing acceptance of the requirement for long-term hydrometric information. In 1964, under an orderly and co-operative arrangement, the federal pattern of participation in maintaining and operating the national hydrometric network changed when Quebec withdrew from the federal program and took over responsibility for the operation of hydrologic activities in that province. The federal government has continued to operate some stations in Quebec, however, to meet its specific responsibilities.

At the present time the surface water or hydrometric network in Canada is composed of the Water Survey of Canada operating in all the provinces and territories and the Quebec Department of Natural Resources. In addition there are a number of temporary networks operated by the various provinces for which records are not presently included in the inventory. The formal, national network, including that portion operated by Quebec, comprises approximately 2,600 active gauging stations with 1,650 stations (almost two-thirds of the total) located west of the Ontario-Manitoba provincial boundary.

As would be expected, the data network was started in the inhabited, southern parts of Canada and it is only within about the last decade that a substantial effort has extended the network into the northern regions. In 1960, there were 41 stations being operated in the Yukon and Northwest Territories; today the network in this area comprises about 100 stations. Many of these additional stations were installed at the request of, or in co-operation with, the Department of Indian Affairs and Northern Development. This works out to about one station for each 15,000 square miles or about one-tenth the density of gauging stations for the whole of Canada. In the western provinces, there is an average of one station for each 730 square miles or about 20 times the density of the network in the Territories. Data collected at stations which have been discontinued because their specific requirement has disappeared, can also provide useful information on surface water resources. There are about 2,000 of these discontinued stations in Canada.

## MAJOR RIVER SYSTEMS OF THE NORTHERN TERRITORIES

Before discussing water inventories of the northern regions, a brief review of its major river systems would be of interest. More than three-quarters of the region are drained by the following rivers: Yukon, Mackenzie, Coppermine, Back, Thelon (including the Dubawnt), and Kazan. Of these systems, the Yukon and Mackenzie Rivers drain more than half of the area of the continental northern territories. The magnitudes of these rivers are illustrated on Figure 1 which provides a graphical comparison of the average flow of rivers in various parts of Canada. The width of the shaded area is proportional to the average flow in the river at any point along its course.

The northern territories also contain four large lakes. Both Great Bear Lake with an area of 12,275 square miles, and Great Slave Lake with an area of 10,980 square miles, exceed the area of Lake Erie (the fourth largest of the Great Lakes). Lake Athabasca has an area of 3,060 square miles; Dubawnt Lake, with an area of 1,500 square miles, is similar in size to Lake Manitoba.

### Yukon River Basin

The Yukon River Basin, the fifth largest basin on the North American continent, is located within the Cordilleran Region and comprises a drainage area of 330,000 square miles, of which about 106,000 square miles are located in Canada. The Yukon Plateau is a broad, shallow trough which slopes to the northwest and extends throughout the basin. The Yukon River occupies the

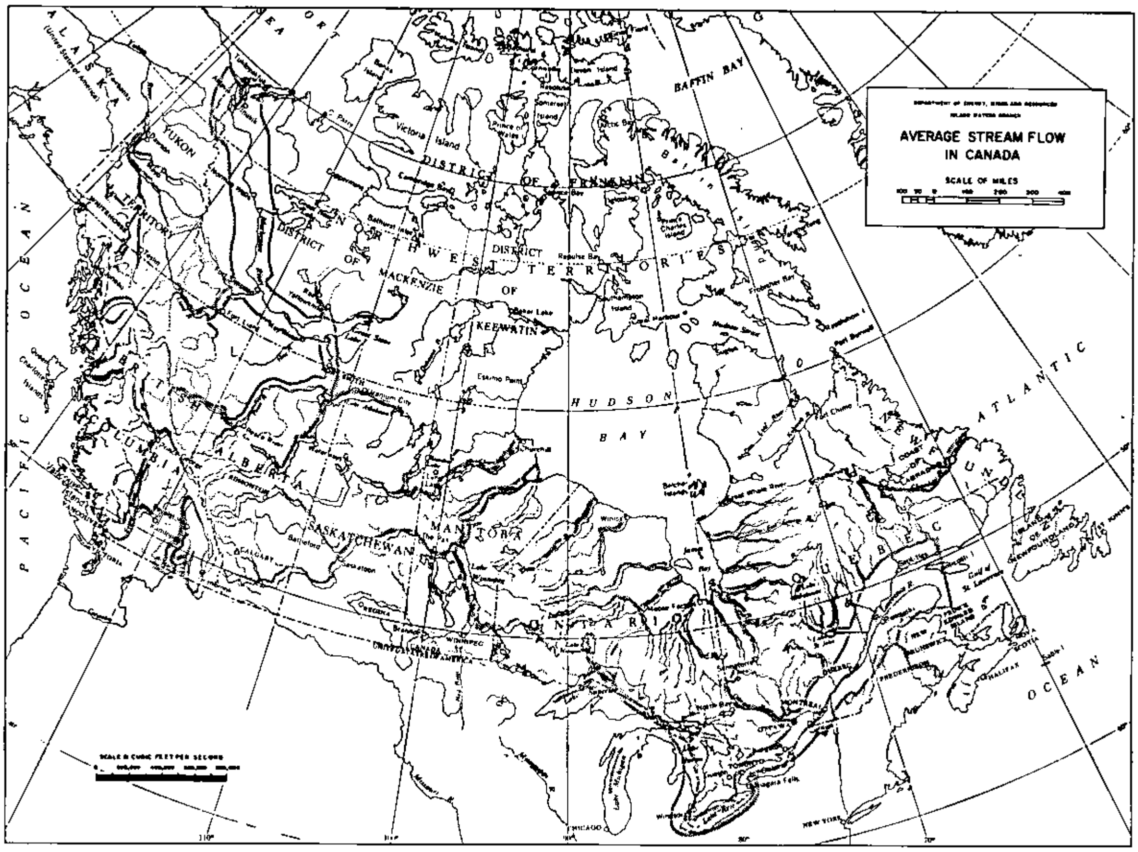


*Figure 1. Graphical comparison of the average flow of rivers in Canada.*

middle of this trough from where the upland rises gradually towards the mountains of the Coastal Range on the west and towards the Rocky Mountains on the east.

The headwaters of the Yukon River rise in a group of lakes in northern British Columbia. From the outlet of Marsh Lake in the Yukon Territory the Yukon River extends for a distance of about 1,800 miles to its mouth at the Bering Sea. In its upper reach, it flows in a northerly and then a northwesterly direction through the Yukon Territory to cross the International Boundary near Eagle, Alaska. Through Alaska, it continues in a northwesterly direction to its confluence with the Porcupine River at Fort Yukon when it turns southwestward to wind its way to the sea.

The important tributaries entering the Yukon River within Canada are the Stewart, Pelly and Teslin Rivers from the east and the White and Takhini Rivers from the west. In addition, there are many smaller tributaries including the historic Klondike River and others such as the Little Salmon, Big Salmon and Nordenskiold Rivers.

The Coast Mountains and St. Elias Mountains that form the western boundary of the Yukon drainage are so continuous and lofty that they form a remarkably effective barrier against Pacific weather influences. To a smaller extent in the east, the Rockies present a barrier against the winter thrusts of cold polar air from the Northwest Territories. However, this barrier is considerably lower and less continuous than that on the west; consequently, continental weather influences in the east are strong, causing occasional, extremely cold periods in the winter.

A large portion of the basin's annual precipitation falls on the uplands and mountainous terrain where it accumulates in the extensive snow fields and glaciers. This area provides the main source of runoff in the watershed. Contribution from direct rainfall is comparatively small as the annual precipitation varies from 8 to 16 inches across the basin and is relatively evenly distributed over the entire year, with no concentrated storms of a magnitude to appreciably raise the levels of the larger rivers.

It is interesting to note that both the Treaty of Washington (1871) and the Boundary Waters Treaty (1909) affect the courses of possible development of the Yukon River. Article XXVI of the Treaty of Washington entitles Canadian and United States citizens to navigate the Yukon River (as well as the Stikine and Porcupine Rivers) from and to the sea, and any works in the river must be such as not to interfere with the use of the river for navigation (see Appendix). In the North Pacific Drainage, there are about 28 streams crossing the boundary between Canada and the United States to which Articles II and IV of the Boundary Waters Treaty would apply (see Appendix).

Mackenzie River Basin

This basin, embracing an area of approximately 696,000 square miles, is the second largest on the continent. Its headwaters are collected by a vast system of rivers which flow into Great Slave Lake. The Mackenzie River has its source in Great Slave Lake from which it flows in a northwesterly direction for about 1,000 miles before discharging into the Arctic Ocean. The physical features of the basin vary from the rugged and mountainous country of the Rocky Mountains to the flat, marshy, treeless wastes of the barren lands which lie to the east of Lake Athabasca. Apart from its two major lakes, Great Bear Lake and Great Slave Lake, the entire basin is studded with numerous smaller lakes.

The Mackenzie River and its tributaries drain a large part of the Northwest Territories, most of northern Alberta and portions of British Columbia, Saskatchewan and the Yukon Territory. The Peace and Athabasca Rivers are the most southerly of the major tributaries and drain the greater part of northern Alberta, a part of eastern British Columbia and a small area in Saskatchewan. The Athabasca River flows in a northerly direction to its mouth in Lake Athabasca. Farther west the Peace River parallels the Athabasca, then turns eastward to empty into the Slave River which connects Lake Athabasca with Great Slave Lake. The Liard River, Great Bear River, and numerous smaller tributaries flow directly into the Mackenzie River.

The major tributaries entering the Mackenzie River from the west and south, other than the Hay River which drains into Great Slave Lake, have their source in higher mountain areas. The Liard, Peace and Athabasca Rivers are typical mountain rivers - their flows are lowest during the winter months and reach their maximum during May to June. This is the period when higher temperatures and rains release stored water from glaciers and snow fields in the mountain areas. Rapids and falls occur in the upper reaches of these rivers while farther downstream the rivers assume a much lower gradient upon entering the Great Central Plain. The Slave River is wide and generally of low gradient; however, there is a fall of about 110 feet which is concentrated mainly at two rapids within an 18-mile reach upstream from Fort Smith, Northwest Territories. These rapids form the only complete barrier to river navigation between Lake Athabasca and the Arctic Ocean. A low gradient and a lack of any rapids or waterfalls permits navigation throughout the entire length of the Mackenzie River.

Runoff from the eastern part of the basin is composed essentially of outflow from Great Bear Lake and local runoff in the vicinity of Great Slave Lake and Lake Athabasca. The topography is irregular for the most part, with numerous lakes scattered throughout the area. Natural storage of water within the basin is considerable. The total water area represented by the larger lakes in the basin (lakes in excess of 100 sq. km. or 38 sq. mi.) is about 5.5 percent of the entire drainage area.

It may be interesting to note that some of the natural flow of the Tazin River, a tributary of the Mackenzie River in the Territories, is stored in Tazin Lake and subsequently diverted to the Charlot River basin for use at the Wellington Lake hydro-electric plant in Saskatchewan. This intra-basin diversion was commenced in 1939 and now amounts to about 1,000 cfs.

## PROBLEMS OF NETWORK OPERATION

Data gathering in the northern regions is raising problems which, although unique, are being solved. However, the establishment and maintenance of hydrometric networks will no doubt continue to remain a much more expensive operation than in the southern regions of Canada. The types of problems encountered in a hydrologic data collection operation in the northerly and remote areas can be illustrated by those associated with the surface water data inventory.

The greatest problem encountered in this inventory is the collection of continuous records under winter conditions. Until recently, most of the equipment and techniques employed had been developed for use in the southern or relatively temperate areas of the country. The adaptation of these to meet the requirements for work in the north have been moderately successful.

Collection of surface water data in northern Canada is often frustrated by physical conditions such as severe low temperatures combined with high winds, "white outs" which make aircraft navigation difficult, extreme ice thickness combined with slush or frazil ice, and the coincidence of the freshet with ice break-up. Therefore, measurement of stream discharge under ice conditions in northern Canada and, no doubt, in other northern countries, provides many challenges. Since the winter work represents a significant proportion of the total field activity in these regions to produce streamflow records, adequate solutions are vital to the operational problems.

Travel for the purpose of streamflow data collection in northern Canada is usually via single-engine aircraft. Common Arctic winter conditions, such as snow cover, drifting snow and ice-fog, conceal river channels, lakes and natural landmarks, making map-reading for navigational purposes extremely difficult. It takes a concentrated effort under prevailing light conditions to locate gauging stations in these circumstances. Aircraft travel also becomes extremely frustrating when hours are spent preparing to fly only to find a grey blanket of ice-fog settling in around the aircraft. To assist navigation under these conditions, gauging stations in the Arctic region are normally equipped with marker pylons, which can best be described as steel tripods, approximately 10 feet in height, with large triangular plates mounted at the apex and painted fluorescent orange. Figure 2 shows a pylon at the gauging station on the Back River.

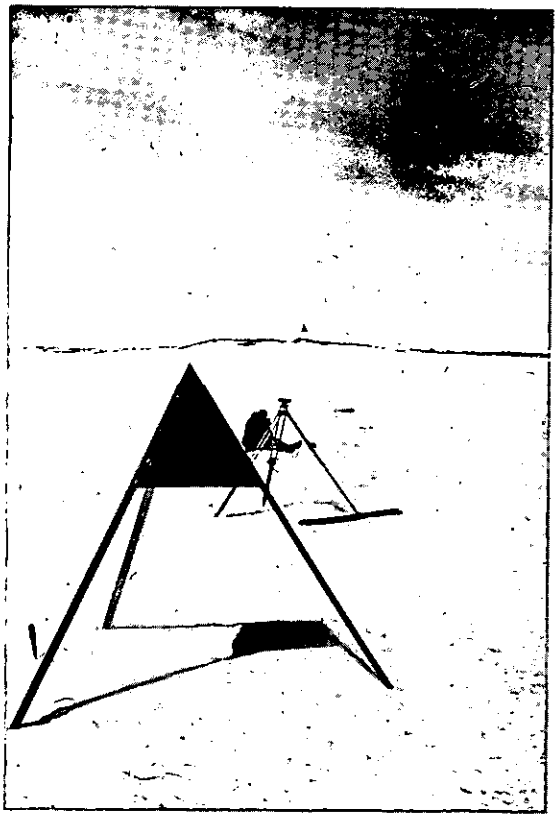

*Figure 2. Pylons marking the gauging station on the Back River.*

In Arctic and sub-Arctic regions, ice thicknesses of nine to ten feet or more, combined with great depths of slush are not uncommon. It is, however, possible to mitigate or circumvent the complicating factors associated with difficult ice cover of this nature by judicious selection of winter measurement sites. For example, it is a rather common occurrence to find reaches of open water immediately below the outlets of large lakes and the erection of a cableway at such a location reduces the problems of winter measurements. A photograph of the cableway installation at the Back River station is shown on Figure 3. Where it is not possible to avoid cross-sections with large depths of ice, ice cutting becomes a major obstacle in the proper conduct of winter discharge measurement programs. A powered ice drill is now a common tool for this purpose. Figure 4 illustrates the great depths of ice that are found at some of the stations, and the manner of making a hole through such thicknesses of ice before drill extensions were devised about five years ago to eliminate the "manhole" method.

*Figure 3. Cableway installation on the Back River.*

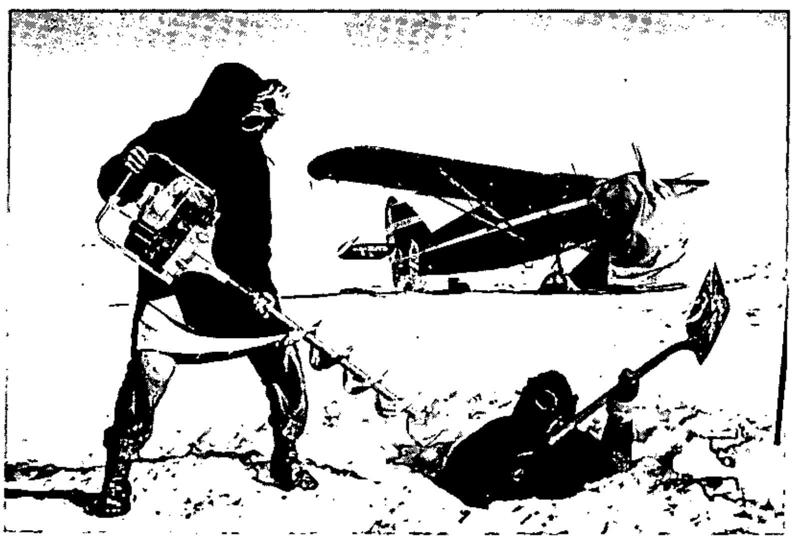

*Figure 4. Powered ice drill.*

Coincident with increased use of the powered ice drill, it became necessary to redesign standard metering equipment in order that it might be accommodated in a drilled hole of approximately eight inches in diameter. Two weight assemblies with a maximum diameter of six to seven inches have been developed by the Water Survey of Canada. Both employ tear-drop shaped weights, with some modifications for lower resistance to the current, and weigh 18 to 35 pounds. Both types have proven to be fairly stable in velocities under 6.5 feet per second. Incorporated within the framework for the weight is a modified pattern 622 Price-type current meter. The entire assembly fits easily through the drilled hole. One type, known as the "Slush-N-All" weight assembly is shown on Figure 5(a) in the nose-up position for passage through the hole, and on Figure 5(b) in its attitude for metering.

*Figure 5(a). Slush-N-All weight assembly in nose-up position.*

*Figure 5(b). Slush-N-All weight assembly in attitude for metering.*

Where the depth of water is greater than 10 or 12 feet, a sounding reel or a handline is used to suspend the weight assembly. The reel is mounted on a collapsible support set on runners. Because of the extremely cold weather, the support is equipped with a chamber heated by catalytic heaters to prevent the meter from freezing while moving from one metering position to the next (Figure 6). Where the depth of water is less than 10 feet, a graduated steel wading rod is used.

*Figure 6. Heated metering sled.*

The problems presented by extreme ice thickness are aggravated further during freeze-up by the formation of thick slush-ice layers which adhere to the under-surface of the ice cover. Slush-ice is formed on the surface of moving water exposed to sub-zero air temperatures. It accumulates in the form of ice panes, slivers and crystals, is swept under newly formed ice blankets and becomes trapped. Heaviest slush-ice formations occur in the early winter and then gradually dissipate or form a part of the solid ice cover. In taking discharge measurements, a sectional, flanged slush pole is used initially to loosen the slush formations sufficiently to allow passage of the weight and meter assembly. Where the slush horizon is unusually thick, specially designed weight assemblies are used for penetration.

Low temperatures, permafrost and rocky terrain preclude the use of conventional float-operated, water-stage recorders. Two types of pressure water-level recorders (both utilize nitrogen bubble systems to transfer river stage to the recording pen) are used to record stages at isolated locations in northern Canada. One type of recorder is the mercury manometer gauge which balances a column of mercury against the pressure due to river stage. In the other recorder, the pressure due to river stage is transferred to the recording pen by means of mechanical linkage developed by the Winnipeg District Office of the Water Survey. Figure 7 illustrates the recorder assembly. To operate at very low temperatures, it is necessary to provide a heated shelter for the mercury manometer gauge in order to maintain the temperature of the mercury above its freezing point. The "Winnipeg" type gauge does not require heat for its operation. Common to both of these instruments, however, is the problem of the Stevens strip chart drive becoming unreliable at temperatures of about -40°F. Consequently, a variety of propane-fuelled heaters are used in the gauge shelters in northern Canada. In most such locations the gauge shelter is built large enough to accommodate several people when weather conditions or schedules necessitate a stopover. Figure 8 is a photograph of a typical cabin and gauge shelter.

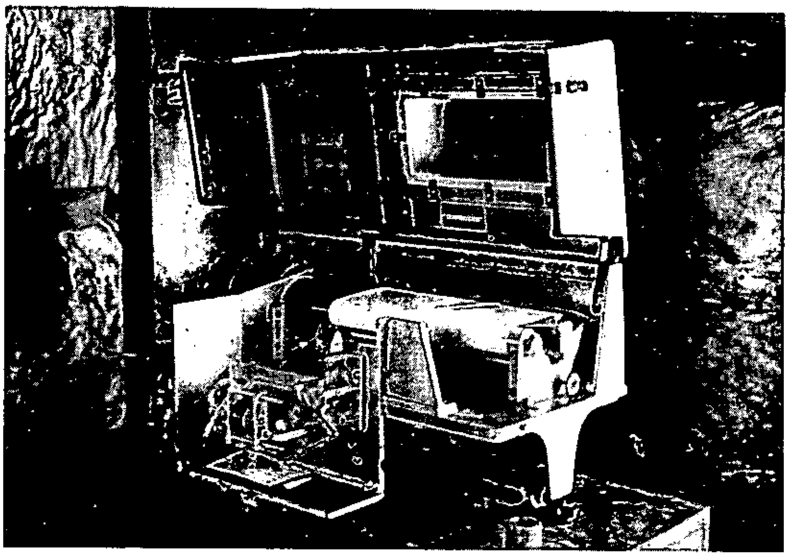

*Figure 7. Recorder assembly with pressure recorder attachment.*

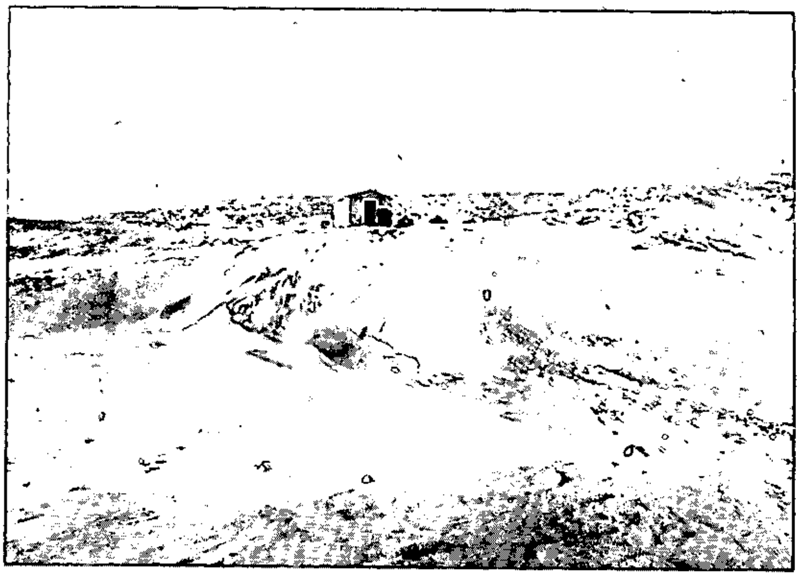

*Figure 8. Typical personnel and recorder shelter.*

In summary then, the problems associated with operating surface water networks in the northern territories of Canada are:

a) sparse population; there are virtually no local residents who can be engaged to take periodic readings of a manual gauge;

b) severe weather; winter temperatures of -45° for extended periods are not unusual and length of open water season is only about 3½ months; ice thicknesses of 8 feet are not uncommon;

c) unsuitable river banks; the banks of most of the rivers are shallow with gradual slopes and are strewn with large boulders making gauge installations difficult and expensive;

d) infrequent visits to the station; at present, only three or four trips are possible per year.

## PROPOSALS FOR NETWORK EXPANSION

As mentioned previously, there are only about 100 surface water gauging stations in the Yukon and Northwest Territories, and these are located mainly in the two major river basins, the Yukon and the Mackenzie. Only one station is operated on each of the Tree, Ellice, Back and Firth Rivers. Three stations are being operated in the District of Franklin - one each on Victoria, Baffin and Cornwallis Islands.

As in the past, the impetus for the expansion of the network continues in response to immediate data needs modified by foresight and judgement. In the mid-fifties the possibilities of hydro-electric developments either on the Yukon River itself (or its tributaries) or by means of diversion into the Alaskan Panhandle were being considered. Hydrometric data were scarce and a number of stations were installed - these form a considerable portion of the 34 presently operating in the Yukon Territory. More recently the possibility of a pipeline along the Mackenzie Valley - gas, oil or both - has arisen. This has led to the upgrading of some 12 hydrometric stations to include sediment transport sampling, and a request for the installation of 11 new stations on the Mackenzie River and its tributaries. Most of these stations will be useful from an inventory point of view but their primary purpose is project or development oriented.

In order to produce a systematic plan for the expansion of the national surface water network, the Water Survey of Canada undertook a series of studies, with the help of consultants, to:

- identify immediate and long-term requirements for hydrometric data by the users, including flow forecasting and apportionment;
- assess accuracy requirements for the various types of hydrometric data;
- assess various techniques for the delineation of hydrologically homogeneous regions;
- apply the techniques utilizing available data;
- recommend the number, approximate location and relative priority of additional hydrometric stations required to assure adequate and economic hydrometric data coverage.

It was concluded from the studies that with the data available the area being considered in this discussion can be divided generally into two main statistical hydrologic regions - one covering the northern parts of the Prairie Provinces and the Northwest Territories, and the other covering most of northern British Columbia and the Yukon. Due to lack of information, the District of Franklin remains unclassified and the Pacific Drainage in northwestern British Columbia, adjacent to the Alaska Panhandle, falls into a different zone.

As a result of the assessment for additional stations (redundancy of data is not a problem for the north), it was concluded that about 16 long-term and benchmark stations should be established in the Yukon and Northwest Territories. In addition there is a requirement for some 60 representative or medium-term stations and some 130 short-term stations to be established over a period of years. These latter stations would be installed to fill in hydrologic detail and to check synthesis of records by various techniques.

Project oriented or development station requirements are difficult to assess and forecast; for example, the request for additional stations for the Mackenzie Pipeline Study was not anticipated at the time of the network planning study. No doubt over the years other similar urgent studies will arise; however, efforts will be made to have development-type stations serve more than one purpose.

If properly integrated, experimental basins can supplement the information collected by a network. This approach calls for a high density of stations over a relatively small area to assess the influence of man-made changes on the hydrologic regime. Assuming three or four such basins in each of the Yukon and Northwest Territories, this would mean some 70 or 80 gauge installations.

Hence, the Water Survey of Canada has as an objective over the coming years, the installation of about 250 new stations in the Yukon and Northwest Territories. It appears that a total of about 350 stations will be required in the area referred to as "northern" Canada.

The development of instrumentation and improved techniques goes hand in hand with network expansion and is particularly true in northern or remote areas. Much thought has been given to the possible utilization of aerial photography of various types. Photographs retrieved from satellites for meteorological purposes are now being used to a limited extent to assess the seasonal advance or retreat of the snow line. Telephoto cameras with fine resolution have been considered for inclusion in the ERTS satellite for distinguishing changes in water levels on various lakes having gentle shoreline slopes. This same satellite will be used in experiments to retrieve data from platforms established at gauging stations; it is hoped to have at least one or two stations in northern Canada included in the initial phase. At the present time these experiments do not appear to provide a breakthrough to new methods of water resource data collection. The need will remain for "general truth" stations for rating, checking and interpretation; a rational development of the present network will enable a smooth and efficient transition to sophisticated satellite data collection. The experimental and research basins will be particularly useful during this transition and will also provide the basis for the development of models for data transfer and the integration of various networks.

The general objective of an inventory is to provide easy access to information arranged in as useful a form as possible. As a first step in this direction the Water Survey of Canada has available some 30,000 station-years of streamflow records in its HYDAT file. Similar files are being developed for meteorological, groundwater (GOWN file) and for water quality. Most of these records are on magnetic tape and are available on request. The Water Survey publishes annually a Surface Water Data Reference Index listing all water level and streamflow stations in Canada, both active and discontinued, along with their geographical co-ordinates and type of record.

With the exception of the meteorological network, there has not been, until recently, much activity in consolidating records in the other hydrologic data collection fields. This does not mean, however, that data do not exist. For example, a number of provinces have a very considerable amount of data available on groundwater and on water quality. Some of these data are becoming available continually, but a Canada-wide network does not exist. A sediment transport network is being developed by Water Survey of Canada but so far embraces only 110 stations, many of which were installed in conjunction with projects under the International Hydrological Decade. A similar but smaller systematic program has been undertaken with respect to the advance and recession of glaciers but at the moment this program involves only seven glaciers in the Western Provinces and the Yukon Territory.

The meteorological network is probably the best known network as most people have had a requirement for the resultant data processed to provide a weather forecast. From the hydrologist's point of view the coverage is probably inadequate in most areas as the network is for general climatological purposes and to provide base data for weather forecasts. This problem is recognized and will no doubt be remedied.

## ESTIMATES OF AVAILABLE SURFACE WATER SUPPLY

Although streamflow information for the northern regions of Canada is meagre and generally applies only to a very limited period of time, the question is, can a reasonable estimate of surface water supply be made. To a degree the answer is yes, but with a fairly low accuracy at this time. Hopefully, the data that would be provided by the proposed network expansion should satisfy the needs for reasonably accurate estimates not only of averages but also for the characteristics of streamflow variations.

The upper limit of water availability may be determined from Figure 9 which shows the mean annual precipitation in Canada and illustrates the distribution of the potential supply in Canada. For the region north of latitude $60^{o}$, the annual precipitation averages between 9 and 10 inches. About 40 percent of this annual precipitation occurs in the form of snow, the percentage being slightly greater in the Yukon and decreasing to the east.

Based on available records, estimates of the average streamflow for some major streams in the region under discussion are shown in the following tabulation.

| Drainage | River | Drainage Area Sq. Mi. | Estimated Average Flow cfs |
|---|---|---|---|
| Pacific | Yukon | 114,800 | 82,000 |
| | Porcupine | 21,500 | 16,000 |
| | Stikine | 19,000 | 39,000 |
| Arctic | Mackenzie | 695,600 | 380,000 |
| | Back | 41,400 | 18,500 |
| | Ellice | 7,700 | 3,100 |
| | Coppermine | 19,400 | 7,700 |
| Hudson Bay | Thelon | 55,000 | 29,700 |
| | Kazan | 27,600 | 19,200 |
| | Churchill | 108,600 | 42,400 |

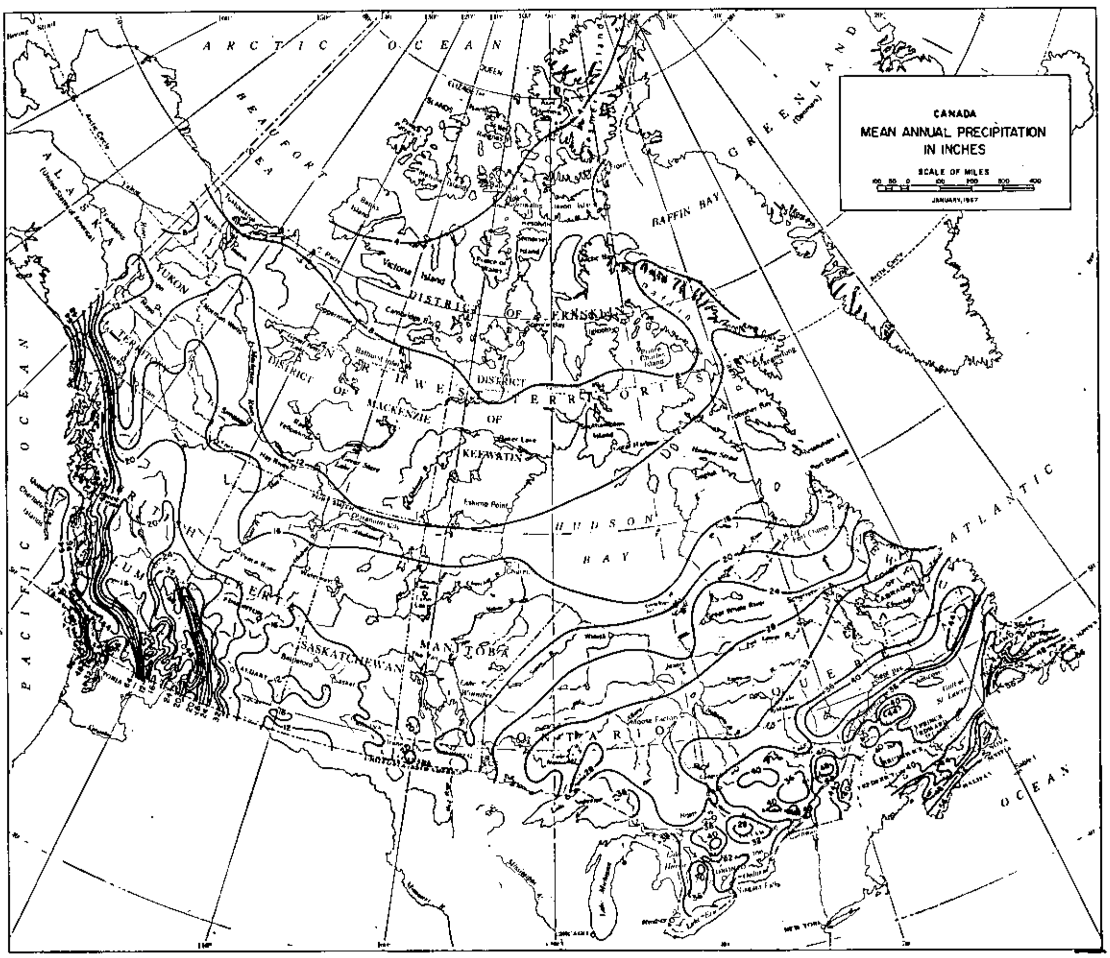


*Figure 9. Mean annual precipitation in inches.*

The Mackenzie River basin comprises one-half of the total Arctic drainage area of 1,383,500 square miles. This total area is estimated to yield an average annual flow to the Arctic Ocean of 585,000 cfs, equivalent to 5.7 inches over this area.

The seasonal fluctuation in flow of typical rivers in Canada is illustrated on Figure 10. Above the tree line in the Canadian Shield, the variation in streamflow, as typified by the Yellowknife River, is not as great as for other rivers in Western Canada indicating the regulating effect of the multitude of small lakes and the relatively low evapotranspiration losses in this region.

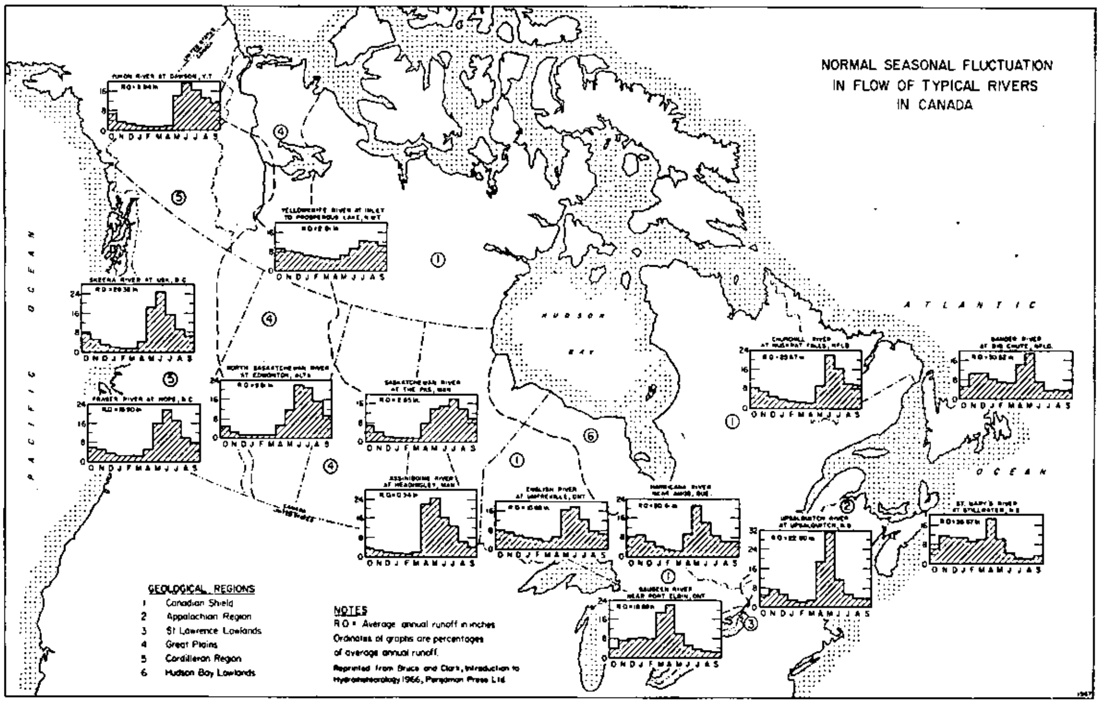


*Figure 10. Normal seasonal fluctuation in flow of typical rivers in Canada.*

A summary of the annual runoff in Canada is illustrated on Figure 11. When these iso-runoff lines are compared to the isopleths of Figure 9, the higher average unit runoff is evident for the Districts of Mackenzie and Keewatin as compared to the southern regions of the Prairie Provinces.

SUMMARY

The expansion and maintenance of a streamflow and water level inventory in the northern region of Canada is beset by many problems arising from a hostile environment and a very sparse population. Adequate funding is necessary for a successful operation but the human element is of prime importance in carrying out the essential field activities. Under study,

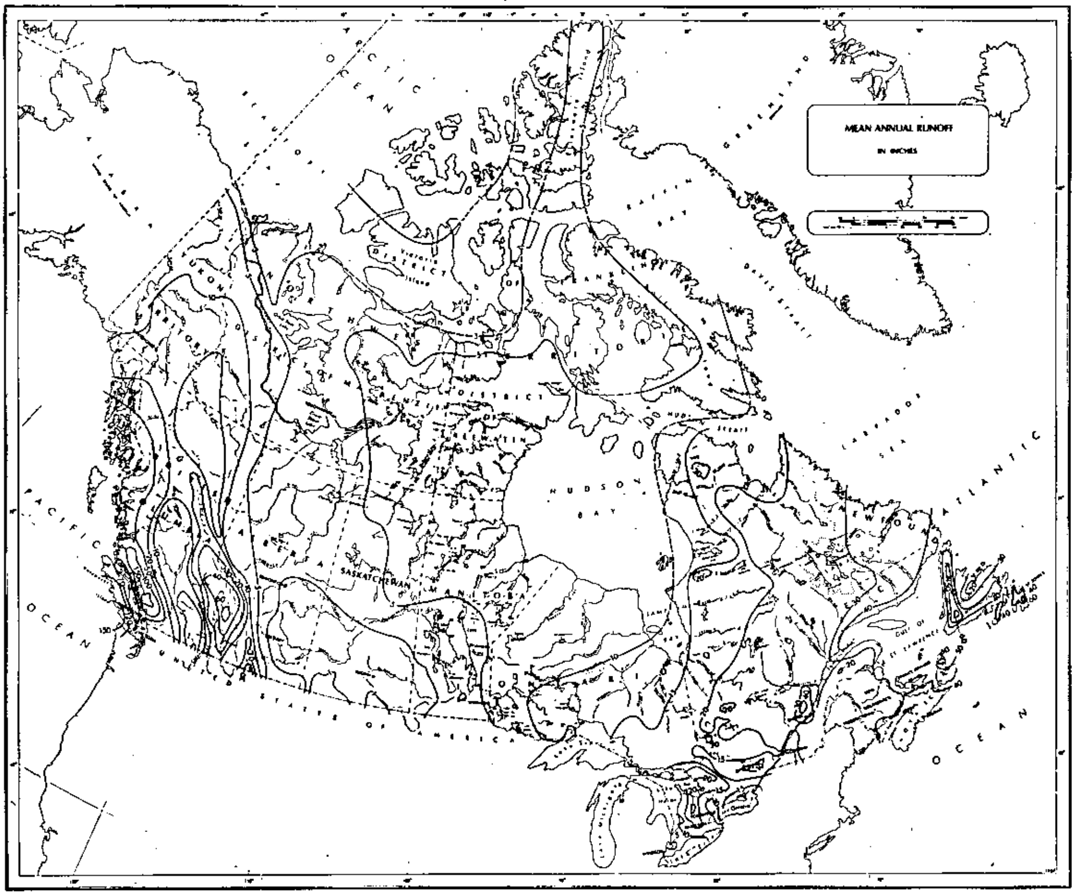

*Figure 11. Estimated mean annual runoff in Canada.*

is the use of satellites in reading out water level information recorded by stream gauging stations but it will likely be several years before this technique of collecting data will be fully operational. However, the use of satellites will not obviate the need for installation and maintenance of streamflow stations. The Water Survey of Canada has a continuing program of research to improve the efficiency of data collection and to review or devise new techniques as required.

Gross estimates of runoff from the northern regions of Canada can be made; however, more accurate estimates of the quantity and variability of this runoff must await the expansion and established operation of the hydrometric network.

## APPENDIX

Article XXVI of the Treaty of Washington, 1871

"The Navigation of the Rivers Yukon, Porcupine and Stikine, ascending and descending from, to, and into the sea shall forever remain full and open for the purposes of commerce to the subjects of Her Britannic Majesty and to the citizens of the United States, subject to any laws and regulations of either country within its own territory, not inconsistent with such privilege of free navigation."

Boundary Waters Treaty of 1909

Article II

"Each of the High Contracting Parties reserves to itself or to the several State Governments on the one side and the Dominion or Provincial Governments on the other as the case may be, subject to any treaty provisions now existing with respect thereto, the exclusive jurisdiction and control over the use and diversion, whether temporary or permanent, of all waters on its own side of the line which in their natural channels would flow across the boundary or into boundary waters; but it is agreed that any interference with or diversion from their natural channel of such waters on either side of the boundary, resulting in any injury on the other side of the boundary, shall give rise to the same rights and entitle the injured parties to the same legal remedies as if such injury took place in the country where such diversion or interference occurs; but this provision shall not apply to cases already existing or to cases expressly covered by special agreement between the parties hereto."

"It is understood, however, that neither of the High Contracting Parties intends by the foregoing provision to surrender any right, which it may have, to object to any interference with or diversions of waters on the other side of the boundary the effect of which would be productive of material injury to the navigation interests on its own side of the boundary."

Article IV

"The High Contracting Parties agree that, except in cases provided for by special agreement between them, they will not permit the construction or maintenance on their respective sides of the boundary of any remedial or protective works or any dams or other obstructions in waters flowing from boundary waters or in waters at a lower level than the boundary in rivers flowing across the boundary, the effect of which is to raise the natural level of waters on the other side of the boundary unless the construction or maintenance thereof is approved by the aforesaid International Joint Commission."

"It is further agreed that the waters herein defined as boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other."