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A
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SURFACE WATER INVENTORY OF CANADA'S NORTHERN TERRITORIES

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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 at specific points. 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 a 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) Ground water,
c) Water quality (for both surface and ground water),
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.

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.

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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 run off.

Leonardo da Vinci, nearly 500 years ago, gave a terse description of the dynamicism 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 so as to be able to define these dynamic characteristics. Consequently, an inventory of water resources can never be considered as 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 has started in the inhabited, southern parts of Canada and it is only within about the last decade that a substantial effort has expanded the network into the northern regions. In 1960, there were 41 stations being operated in the Yukon and Northwest Territories; today the network comprises about 100 stations. Many of these additional stations were installed at the request of, or in cooperation 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 some of its major river systems would be of interest. More than three-quarters of the region are drained by the following rivers: Yukon, Mackenzie, Back, Thelon (including the Dubawnt), Kazan and Coppermine. 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 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 Takini 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 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 not a barrier against the winter thrusts of cold polar air from the Northwest Territorial border. 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, mildly cold periods in the winter.

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

It is interesting to note that both the Treaty of Washington (1871) and the Boundary Treaties (1909) affect the courses of possible development of the Yukon River. Under the Treaty of Washington, Canadian and United States citizens must be paid the Yukon River (as well as the Stikine and Porcupine Rivers) from and to the and any works in the river must be such as not to interfere with the use of the river (see Appendix). In the North Pacific Drainage, there are about 28 streams in the basin between Canada and the United States to which Articles II and IV 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 terrain of the Rocky Mountains to the flat, marshy, treeless wastes of the barren lands towards 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 NWT. The Peace and Athabasca Rivers are the most southerly of the major rivers 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 Peacea, 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 lowest during the winter months and reach their maximum during May to June. This is a period of spring high when water from glaciers and snow in the mountain areas. Rapids and falls occur in the upper reaches of these rivers, and further downstream, the river assumes a much lower gradient upon entering the Central Plain. The Slave River is wide and generally of low gradient; however, there 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 overflow 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 square miles or 38 square miles) 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 Charlo River basin for use at the Wellington Lake hydro-electric plant in Saskatchewan. This intra-basin diversion 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 freshest 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 pylon, which can 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 Black 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 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.

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-Aire" 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.

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.

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 pans, slivers and crystals, is swept under newly formed ice and becomes trapped. Heavy slush-ice formations occur in the early winter and then gradually dissipate or form a part of the solid ice cover. In laying down observation weights, a sectional, flanged slush pole is used initially to loosen the slush formations sufficient 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 -40⁰F. Consequently, a variety of propylene-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.

In summary then, the problem 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 -45⁰F for extended periods are not unusual and length of open water season is only about 3½ months; ice thickness 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. Hydro-metric 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 activity and a request for the installation of 10 or 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 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 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 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 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 coordinates 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 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°, 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.
<table>
<thead>
<tr>
<th>Drainage</th>
<th>River</th>
<th>Drainage Area Sq. Mi.</th>
<th>Estimated Average Flow cfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific</td>
<td>Yukon</td>
<td>114,800</td>
<td>82,000</td>
</tr>
<tr>
<td></td>
<td>Porcupine</td>
<td>21,500</td>
<td>16,000</td>
</tr>
<tr>
<td></td>
<td>Stikine</td>
<td>19,000</td>
<td>39,000</td>
</tr>
<tr>
<td>Arctic</td>
<td>Mackenzie</td>
<td>695,600</td>
<td>380,000</td>
</tr>
<tr>
<td></td>
<td>Back</td>
<td>41,400</td>
<td>18,500</td>
</tr>
<tr>
<td></td>
<td>Ellice</td>
<td>7,700</td>
<td>3,100</td>
</tr>
<tr>
<td></td>
<td>Coppermine</td>
<td>19,400</td>
<td>7,700</td>
</tr>
<tr>
<td>Hudson Bay</td>
<td>Thelon</td>
<td>55,000</td>
<td>29,700</td>
</tr>
<tr>
<td></td>
<td>Kazan</td>
<td>27,600</td>
<td>19,200</td>
</tr>
<tr>
<td></td>
<td>Churchill</td>
<td>108,600</td>
<td>42,400</td>
</tr>
</tbody>
</table>

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.

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 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 of the 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 hereof.

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 damns 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.
FIGURE 2: Pylons marking gauging station on Back River.

FIGURE 3: Cableway installation on Back River.
FIGURE 4: Powered ice drill.

FIGURE 5(a): Slush - N-All weight assembly in nose-up position.
FIGURE 6: Heated metering sled.
FIGURE 7: Recorder assembly with pressure recorder attachment.

FIGURE 8: Typical personnel and recorder shelter.
WATER NORTH OF 60
AVAILABILITY, USES AND MANAGEMENT
ALLAN H. JONES

AVAILABILITY

Canada, the second largest country in the world, has an area of 3.9 million square miles. The Yukon and Northwest Territories comprise nearly 40 per cent of the total area. The Yukon covers 207,000 square miles, equal to that of France. The 1,253,000 square miles of the Northwest Territories is equal to that of India. Fresh water covers 7.6 per (291,000 square miles) of Canada's total land area. It has been estimated that up to 50% of Canada's fresh water resources are located north of the 60th parallel.

However, the measure of a country’s water wealth is not its stored water, but its continuously available supply. The total flow of Canada's rivers is estimated at an average 2,500,000 cubic feet per second. The Mackenzie River alone accounts for a mean flow of 300,000 cubic feet per second, second only to the St. Lawrence (400,000 cubic feet per second), while the Yukon River accounts for 75,000 cubic feet per second. We know that over much of the North annual average precipitation is relatively low, ranging from 16 to 20 inches in the southern Yukon and southwestern Mackenzie District to less than 6 inches along the Arctic coast and over portions of the Arctic Islands. We also know that large quantities of water are held in dead storage by pericambrian rock or permafrost conditions, while very much smaller quantities are available in the form of annual runoff.

There appears to be abundant water in Canada's north, but for most of the region, there is very little information on water resources and almost none on water quality. Because of this situation, together with the rapid acceleration in northern development, more extensive and complete inventories of the freshwater resources in the northern territories must be undertaken. At the same time, realistic projections of future regional demands must be made. Some work is presently underway under the general direction of the Water Survey of Canada, an agency of the federal Department of the Environment. These surveys and studies are being co-ordinated with and assisted by other federal departments, including the Department of Indian Affairs and Northern Development, with water resource interests in the far North.

In addition, an early start needs to be made on identifying major conflicts in water use. Economic vitality will continue to be largely dependent on mining activities, including oil and gas, while hunting and fishing are likely to decline. Water uses associated with wildlife habitat and recreation will increase, as will municipal and hydro power requirements.

TRANSPORTATION

A critical and essential element in any considerations of the North is transportation. The primary objective is that the transportation system be dependable. Granted, the service should be provided as economically as possible but dependability is placed above cost in order of importance. Non-delivery can lead to human hardship and financial disaster, since it may not be possible to effect delivery again for many months. The most prominent characteristic of northern transportation is that it is almost always a mix of the various existing modes. Water transportation has and is pioneering the opening up of the North and it will undoubtedly continue to be a most important method of freighting goods north of the 60th parallel.

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Practically all of the water transportation in the eastern Arctic is by sea. The use of inland water courses is almost non-existent, except for a shuttle service up Chesterfield Inlet to Baker Lake. At the present time, the volume of surface marine transportation in the eastern Arctic is such that it can be confined to the short open season between July and October. It is also, on the whole, limited to the easier parts of the eastern Arctic - Foxe Basin, the Baffin Coast, Parry Channel as far west as Resolute and the north side of Viscount Melville Sound.

Moving to the west, the inland water routes play a major role in the movement of people and material in the Mackenzie Basin, the western Arctic coast and the Arctic archipelago. The Mackenzie River cuts through almost the centre of the area where, from the geological information available, significant reserves of both oil and gas could be developed, particularly in the area of the River's delta and along the Arctic coast to the east and west of that point, and off-shore in the same area. The Mackenzie system also reaches into a number of metal mining regions which include Lake Athabasca, Great Bear Lake and Yellowknife, where in spite of an all-weather road, water transportation still accounts for over 50% of the resupply tonnage.

The River provides access by marine equipment from fairly deep in the interior of the continent to any point on the Arctic coast between Point Barrow and Spence Bay, and to the southern islands of the Canadian Arctic archipelago, as well as to many points within the drainage basin. The flexibility of this water transportation network is rather startling, when you consider that freight can be loaded and delivered without transhipment throughout practically the entire geographic area just described.

The great disadvantage to this transportation mode is, of course, the relatively short period of open water which varies from 75 days along the Arctic coast to 150 days on Lake Athabasca. This drawback is offset to some extent by the tonnage that can be handled in a relatively short time. At high water, 6,000 to 8,000 tons can be handled over most of the River between Hay River and the Arctic Coast in one train barges. This tonnage of freight is approximately equal to what can be carried by a 200 car freight train. By the way, the distance by water from Hay River to the Arctic coast is approximately 1,100 miles.

The fact that water is in its solid state for long periods throughout the year has been used to advantage. The summer shipping lanes become winter highways for convoys of rubber wheeled vehicles escorted by snow plows. Supplies and freight can be moved rapidly and efficiently with minimal damage to the environment. A well established winter route, for example, is from Yellowknife through Rae and along the Cansel River to Port Radium. Another popular route follows the Mackenzie River from Fort Simpson to Norman Wells. The frozen waters of the Mackenzie Delta also provide convenient means for winter travel.

Another important contribution that water makes to transportation in the North is by providing "air fields" for pontoon-equipped aircraft in the summer and ski-equipped craft in the winter.

POWERS

In the Yukon and Northwest Territories power from present development is used almost exclusively to satisfy the needs of local mines, their adjacent settlements and other communities and small centres.

The total generating capacity is about 43 megawatts (26 MW hydro and 17 MW thermal) in the Yukon Territory. In the Northwest Territories the total generating capacity is about 70 megawatts (35 MW hydro and 35 MW thermal). For the sake of comparison, Saskatchewan generates a total of 1,425 megawatts (584 MW hydro and 841 MW thermal).

Some of the principal hydro generating sites are: in the Yukon Territory, Whitehorse Rapids (19 MW) and Mayo River (5.1 MW); in the Northwest Territories, Twin Gorges (18 MW), Snare Rapids (7 MW), Snare Falls (7 MW) and Bluefish Lake (3.3 MW). The figures presented above were extracted from 1969 data.

At present, there exists only local power transmission lines in both the territories. No power grids or interconnections between the territories or between any province are presently in existence. The principal operator of more than 80% of electric power generating facilities in the North is the Northern Canada Power Commission, set up as a Crown Corporation in 1948, with the remainder operated by Yukon Electric and several small plants operated by local mines.

Due to hydrologic conditions in the region, mainly low annual precipitation, short frost free period and the existence of permafrost, there are areas with little or no runoff. However, some sites in the North appear suitable for hydro power generation. A series of water power inventory studies have recently been completed by the Department of Indian Affairs and Northern Development to identify undeveloped water potential in areas where future economic development is expected.

The Pelly River in the Yukon has considerable potential for future development.

In the Northwest Territories, power development on the Kakisa River could yield approximately 20 megawatts and about 10 megawatts could be produced by harnessing the Little Buffalo River. It could very well become feasible, because of increased mining activity in the eastern Yukon, to develop power on the Great Bear River and transmit it over the mountains. The potential here could be as high as 500 megawatts. If a market existed, several hundred megawatts could be produced on the Lochcut River flowing out of Artillery Lake, and the Rapids of the Dead on the Slave River at Fort Smith could possibly be developed to the extent of approximately 2000 megawatts.

Another area that has been studied is on the Sylvia Grinnell River in the area of Froithor Bay on Baffin Island, where approximately 5 megawatts could be generated.

You may be wondering why some of this potential has not been developed for export. The reason is quite simply a matter of economics. The potential market, that is British Columbia and the Prairies, has ample cheap power sources as yet untapped.

INDUSTRIAL AND MUNICIPAL

Perhaps the most significant water users in the North are industries and municipalities. While large quantities of water may be needed to produce gold, or steel or fish or ducks or supply water for domestic and municipal use, that is not to say that the same water cannot be used for each of those different purposes at different times in its use cycle.
The one problem in the reuse of water, however, is that of quality. The various things which man discards into water in the course of his daily domestic life and industrial production, brings about chemical and physical changes, including that of temperature, which constitutes pollution. The problem is somewhat more acute in the North due to climatic conditions and long periods of low temperatures which retard biological decomposition of organic wastes. The general method of treating wastes in the North is by lagooning. Solid wastes are normally disposed of in common designated areas.

In terms of the amount of water used in the North, the data are not too revealing. Water consumption per capita is normally taken to be three times that of southern consumption; in some cases the comparison is said to reach a factor of six. One reason for these rather drastic consumption figures lies in the fact that most piped supply systems are continuously “bled” in cold weather to prevent freezing. For the same reason, sewage systems are continuously “flushed” throughout the winter months. Industries too use large quantities of water by comparison with their southern counterparts.

Once again, however I want to emphasize that the most important aspect of industrial and municipal water use in the North is not one of quantity but rather of quality.

WILDLIFE HABITAT

Water quantity and quality are essential ingredients of wildlife habitat. In the southern regions of Canada, the water habitat is disappearing, thereby putting more pressure on habitat in the North, providing, of course, that the animals involved can adapt to more northerly climatic conditions.

To fish, waterfowl and many fur bears, water habitat is essential to reproduction—fish just do not lay eggs in sewage lagoons and ducks would find it down right uncomfortable nesting in the middle of a highway. While the actual physical take out of water habitat may be relatively insignificant, human activity around developments may influence wildlife in a much larger surrounding area. This is especially true of waterfowl nesting. Another example can be related to fish. Northern installations are built on gravel pads to prevent melting of the permafrost. Gravel supplies are limited in the North, but perhaps the best sources are from stream beds. If the stream bed gravel is extracted improperly, degradation of downstream spawning beds could occur.

As indicated earlier, water quality is as important as quantity. The proper disposal of sewage and garbage is no easy task in northern regions. It is important to wildlife habitat to avoid litter accumulation and contamination of surface waters.

Big river deltas provide important wildlife habitat and water uses that might affect these areas must be very carefully studied. We all know what happened in the Peace-Athabasca delta and, if a lesson has been taught, hopefully the experience will be applied to wildlife in any considerations of water use in such important northern delta regions as the Mackenzie or the Old Crow.

FISHING

The harvesting of fish can legitimately be termed a water use. Most northern inland water bodies yield fish and in some of the larger lakes and rivers, the resource is tapped commercially.

In 1969, a total of 326 persons fished commercially in the Northwest Territories and caught approximately 6 million pounds of fish with a landed value of $1 million. The
most prominent commercial fish are whitefish, lake trout and pickerel. For the same year in the Yukon, approximately 50 commercial fishermen caught about 700,000 pounds of fish valued at $125,000. In addition to white fish and pickerel, chum and spring are caught inland.

Sport fishing could also be classified as a recreational use of water, but in any event, this water use is growing. As you would probably expect, the prime users are non-residents. In 1969, 1,600 resident and 4,000 non-resident fishing licences were issued in the North-west Territories. In the Yukon, 2,800 resident licences and 7,500 non-resident licences were issued. The licence fee structure is not designed to generate income, in fact, it does not even offset the costs of administration. However, some ballpark figures indicate that the non-resident tourist fisherman generates an expenditure of between $75.00 and $100.00 per day. Lodge operators and outfitters charge $600.00 to $900.00 per week, including transportation from southern centres such as Edmonton, Winnipeg and Montreal.

The most sought after species are lake trout, arctic greyling, arctic char and, of course, the somewhat less exotic, pike and pickerel.

RECREATION

Throughout the North there is a speculative air about recreation. Water-based recreation will play an important role in planning and development for this activity in the territories. Recreation enterprises are most active in the Mackenzie Valley and along the Arctic coast and these endeavours usually make direct or indirect use of water. There is, of course, such activities as canoeing, but hunting, fishing, sightseeing and even hiking make extensive use of the water as a support or service commodity. In the Mackenzie District particularly, there are significant areas which, for a short season, are suitably warm enough for such family activities as bathing and water skiing.

In the North, there are numerous distinctive water attractions, such as the 316 foot Virginia Falls on the South Nahanni River. As accessibility improves, these unique water features will take on greater significance from the point of view of recreation.

The marine resources of the Arctic provide viewing attractions and hold hunting and fishing possibilities. As accessibility improves, these resources will increase in importance from a recreation point of view.

WATER MANAGEMENT

The last four or five years have seen increased activity in the administration of water resources in the North. When water is available, it will ultimately be used and, as a consequence, require management. Some legislative tools used for water management have been in the law books for many years. However, recent years have seen increased pressure put on water usage and, to keep pace, new legislation has been enacted. In particular, the Northern Inland Waters Act, and the Canada Water Act provide the framework for water management in the North today.

The Northern Inland Waters Act is designed to provide for the comprehensive management, development and conservation of the water resources of the territories. It makes provision for basin-wide planning for utilization and development, for the licensing of all water development undertakings, and the imposition of the responsibilities for water quality maintenance or restoration on the users of the resource. It also provides for the establishment of territorial water boards to consider licence applications and to effectively coordinate federal and territorial interests in the management of water resources in the two territories.

Regulations made under the Act may prescribe water quality standards for water management areas that are not included in whole or in part within a water quality management area designated under the Canada Water Act. The Regulations may also require an environmental impact statement which will take into account other resources which could be affected either directly or indirectly, by the proposed development. The Act is administered by the Department of Indian Affairs and Northern Development.

The Canada Water Act is intended to provide for the comprehensive planning, development and management of the water resources of Canada's major river basins. The Act is quite similar to the Northern Inland Waters Act, indeed the two pieces of legislation complement each other. However, the Canada Water Act is directed specifically at major river basins, which may limit its application in the North to the Mackenzie system. It will not likely be employed extensively as a management tool in the North. The Department of the Environment administers this Act.

Several single-purpose or resource-oriented pieces of legislation apply to water planning, development, management or regulation in the North.

The Arctic Waters Pollution Prevention Act is designed to prevent pollution of the areas of the Arctic waters adjacent to the mainland and islands of the Canadian archipelago. It deals with pollution arising from shipping, land-based installations and commercial activities such as oil drilling carried out on the continental shelf and there is provision in the Act for the making of regulations covering such activities. Several federal departments have jurisdictional responsibilities under the Act. The Minister of Indian Affairs and Northern Development may make regulations respecting the deposit of waste in Arctic waters from shore-based works and undertakings, the determination of limits of liability for pollution arising from shore-based works and undertakings from works in areas subject to Arctic waters and from works other than from ships in Arctic waters.

The Ministry of Transport has recently amended the Canada Shipping Act to impose heavier fines on pollution resulting from shipping in the Arctic.

The Dominion Water Power Act reserves to the Crown the property rights and the rights to use all water powers in the territories. The Department of Indian Affairs and Northern Development is responsible for administering the Act.

The Minister of the Environment administers the Fisheries Act and the Migratory Birds Convention Act, both of which have an impact on water resource development in the North.

CONCLUSION

In the past single-purpose resource development often took place in spite of or at the expense of other natural resources. And why not? The resource bank seemed inexhaustible. But I think we now realize that our renewable natural resources are not as renewable as we once believed. The resources hang in a delicate balance that we refer to as the environment. The elements of the environment become more fragile with progression northward and the delicate balance becomes more easily tipped.

Water is perhaps the key element in the environment. It is essential to life itself - we must use it, but in using it, a reasonable measure of thought and care can make this valuable resource reusable and in constant supply.
MISUSES OF WATER IN THE CANADIAN NORTH*

J.W. GRAINGE **
J.W. SHAW ***

INTRODUCTION

This paper describes some of the pollution and pollution control in the Canadian north. By Canadian north we mean the Northwest Territories and the Yukon Territory. These two territories, which are 1,304,903 sq mi and 207,076 sq mi respectively, comprise more than 39% of the area of Canada.

The Northwest Territories are divided into three districts: Mackenzie, Keeewatin and Franklin. Mackenzie District includes that part of the mainland lying between the 102nd meridian of longitude and Yukon Territory. Keeewatin District includes that part of the mainland east of the Mackenzie District, with the exception of Boothia and Melville Peninsulas, together with all islands in Hudson and James Bays. Franklin District includes Boothia and Melville Peninsulas and the islands in Hudson Strait and in the Arctic Archipelago, except those adjacent to the coast of the Yukon Territory.

The north covers four basic physiographic areas: the Cordilleran Region which includes the Yukon and the western mountains of the Mackenzie District; the Interior Plains of Mackenzie Lowland; the Canadian Shield area extending eastward from the Mackenzie Lowland to Hudson Bay; and the Arctic Archipelago. An important physiographic feature is the areas of extensive alluvium which forms some of the valleys in the Plains and the Cordillera. The Slave River delta and the Mackenzie delta are two such areas.

Climate

The north contains three climatic regions. The largest the sub-arctic which covers that area south of a line running from the mouth of the Mackenzie, through Amundson Gulf and Bathurst Inlet, across Back River to Edzo Point on Hudson Bay. The sub-arctic has a cool short summer with only one to three months with mean temperatures above 50°F. The second region is the arctic which occupies the area north of the sub-arctic i.e. the arctic coast and islands. The mean temperature of the warmest month is below 50°F but greater than 32°F. The third region is ice-cap i.e. the mean temperature for all months is below 32°F; this region occupies some mountain peaks and ice caps in the eastern arctic islands.

Perennially frozen ground, known as “permafrost”, is widespread throughout the area as a consequence of the extreme cold. Permafrost is aggregating in some locations and degrading in others because of changes in microclimate or land cover.

Precipitation in the north is low. In the Mackenzie valley the total precipitation ranges from 10 in to 13 in including 40 in to 50 in of snow. In the arctic islands, precipitation is even lower, from 6 in to 9 in, except for southeastern Baffin which has 8 in of rain and 70 in to 90 in of snow.

Evaporation is the main form of basin discharge. River runoff is the other means of discharge. The Mackenzie basin is moisture deficient from high evaporation in summer. 1

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* The opinions expressed in this paper are those of the authors and they do not represent the policies of the Departments of Environment and National Health and Welfare of Canada.

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Potential evaporation is estimated at 16.2 in at Yellowknife, N.W.T. and 17.6 in at Fort Simpson, N.W.T. The high water loss is also revealed by examination of river discharge records.

This moisture deficiency is most important in any consideration of water use whether it be extraction or the carriage of wastes. For it is this factor which places a finite limit on the renewability of the north’s water resources. One should not be misled by the apparently limitless quantities of water in the multitude of lakes and the large river basins.

Hydrology

The northern climate imposes its own particular effects on the hydrological cycle. The dramatic change from winter to summer results in days of great hydrological activity after months of hydrological dormancy. In the winter, recharge is in the form of snow which is stored on the land surface, lakes and glaciers.

Evaporation ceases and soil water freezes. Discharge approaches a minimum and is by river runoff under ice, drawing from lake and groundwater storage.

In spring, recharge reaches a peak and is in the form of melting snow and rain which goes into all forms of storage. Discharge also approaches a peak as snow and ice evaporation is at a maximum, evapotranspiration increases, and river runoff rises with the discharge of rain and melting snow and ice.

In late summer, recharge is in the form of rain and glacier melt. Discharge by evaporation and by river runoff is declining.

This cycle of hydrological activity results in the phenomenon of spring breakup and the broad seasonal variation in river water quality such as is shown in Fig. 2 for the Slave River at Forth Smith, N.W.T.

The spring breakup extends from the first melting of snow to the clearing of ice in a river when all that remains is an accumulation of driftwood and debris. Breakup begins at the source of a river and progresses northward and downstream. As the river rises, with runoff from the mountains and the south, the ice is bowed up in the center. The water continues to rise and breaks through in places, submerging the anchor ice. Eventually the anchor ice breaks into small pans which float in shore leads. Later, the main body breaks into large pans. As the water level rises and the current increases, the pans grind against one another and the shore. Ice jams occur at sharp bends, islands and at the mouth where the ice, which moves out fast, forms a barrier and often causes severe floods.

There are two major river basins, the Mackenzie and the Yukon, and a number of smaller but important basins such as the Anderson, Coppermine, Back, Thelon, Dubawnt and Kazan. There is a multitude of lakes including two great lakes, Great Bear Lake, 12,000 sq mi, and Great Slave Lake, 11,170 sq mi. Hydrometric survey data for northern rivers are published annually by Water Survey of Canada.

The Mackenzie River system we will examine more closely because the majority of the population and industrial developments of the N.W.T. are located in and around the Mackenzie valley. The Mackenzie, with a drainage area of 696,700 sq mi and a length of 2,635 miles from the headwaters of the Finlay River to Tuktoyaktuk on the arctic coast, is the largest river in Canada and the seventh largest in the world. The river is a source of water, fish and transportation to the communities along it and also a receiving water for their waste.
DOMESTIC USE OF WATER

Population

The population of the Yukon Territory is about 16,000. The population of the Northwest Territories is about 36,000 with 25,000 in the Mackenzie District, 3,000 in the Keewatin District and 8,000 in the Franklin District. The majority, 22,000, of the population of the Mackenzie District live in communities on the Slave River, around Great Slave Lake and on the Mackenzie River. The largest communities are Fort Smith on the Slave River (population 2,500) at the 60th parallel, Pine Point (population 1,200), and Hay River (population 2,700) on the south shore of Great Slave Lake. Rae (population 1,200) and Yellowknife (population 7,000) on the north shore of Great Slave Lake, Inuvik (population 2,700) in the Mackenzie delta and Frobisher Bay (population 7,000) on Baffin Island.

Water Sources

Most settlements obtain their water from a surface source. Pine Point, Enterprise, Edzo, Fort Liard and Wrigley are served by wells and there is a private well with satisfactory water at Fort Providence. There are no significant groundwater sources in the Shield, but there are important sources in the Mackenzie Lowland and the Cordillera. Much of the groundwater is highly mineralized. Wells have had to be abandoned at Fort Smith and Fort Resolution because of this. The hamlet of Pine Point is considering the use of reverse osmosis to demineralize its well water supply. There is a great variation in water quality: the water of the shield area to the east are clear and colorless, but the rivers from the mountains to the west carry heavy sediment loads in spring and rivers like the Hay, which drain extensive swamps, are as highly colored as strong tea. Settlements using turbid or colored water sources have complete treatment systems. eg, Fort Smith, Fort Simpson, Fort McPherson and Akavik. An exception is Inuvik where turbid Mackenzie River water is pumped to a small lake in which sedimentation occurs. The clarified water is then microstrained, disinfected, fluoridated and treated for corrosion control.

Economic Considerations

The north appears to be rich in natural resources, but, by almost any definition of poverty, the northerners are extremely poor. A 1968 study of the Lower Great Slave Lake area which had a population of 3,775 showed that of the total population reporting income from any source 32.4% earned less than $500, 42.8% less than $1,000, 56% less than $2,000 and 69.9% less than $4,000. The difference in income between the indigenous people (Indians and Metis plus a few Eskimos) and the “other” ethnic groups is substantial.

Similarly, large numbers of disadvantaged people live in other areas. For example, Rae had an average annual per capita income of $275. The treaty Indian population of Fort Simpson had an average annual per capita income of $800. Yellowknife and Fort Smith had smaller indigenous populations, but the existence of Indian shanty towns in both of these settlements attests to the poverty of the indigenous people.

Sanitary Servicing

This poverty must be kept in mind when considering sanitary servicing. Poverty together with the high costs due to the climate and poorly-planned, spread-out communities, make servicing economically unfeasible for most places. In general, only those towns with major white populations have piped water and sewage services. They are Fort Smith, Hay River, Yellowknife, Pine Point, Fort Simpson, Norman Wells, Fort McPherson, Inuvik and Frobisher Bay in the N.W.T. and Whitehorse (and Porter Creek nearby), Dawson, Mayo, Watson Lake and Faro in the Y.T. Most have unserviced native areas. The social discrepancy between unserviced and serviced areas is very apparent.

The majority of communities are largely native. In these communities, water and sewage are hauled respectively to and from residences which have complete internal-plumbing systems and holding tanks. The indigenous people have water delivered to storage barrels and the plastic bags containing toilet sewage are hauled away. Washwater is spilled outside of those residences without plumbing and sewage-holding tanks; and because the ground surface is frozen for most of the year, the liquid does not seep away.

In the spring the melted waste washwater and runoff in a settlement form pools around the houses and bigger pools in the upper road ditches which are dammed by ice-filled culverts. Children often play in the puddles of melted waste washwater and surface runoff. Because of this and also the fact that these pools provide mosquito-breeding grounds, they are an obvious public health hazard.

The cost of servicing some settlements would far exceed the total value of all the buildings in them. For example, the original Inuvik utilidor is quoted as costing anywhere from $200 to $500 a linear foot and the recent wooden utilidor construction cost from $60 to $70 a linear foot. Compare these costs with $7 to $8 a linear foot for a 6 inch water main and $6 a linear foot for 8 inch sewer for typical installations in urban subdivisions in Alberta. The collection of domestic sewage is, therefore, the most difficult problem. Treatment of the sewage, once it is collected, is a less difficult problem.

Sewage Flows

The design of a sewage disposal system is usually based on the hydraulic load i.e. the sewage flow in gallons per day and the organic load i.e. pounds of BOD per day. Costs are increased by the need to provide higher capacity systems where water use is high. The hydraulic loading varies considerably from community to community. See Table 1. In Fort Smith with a normal water distribution system which is deeply buried below the level of frost penetration and where there is no permafrost in the ground, the sewage flow is about 50 igcd which is reasonable for a purely domestic sewage flow. In Hay River where there is sporadic permafrost, water is bled from the mains to maintain movement and avoid freezeups. The result is a sewage flow of 150 igcd. In Yellowknife where sewers are within the water table, there is considerable infiltration and the sewage flow is 117 igcd. In Inuvik a utilidor system, which is heated by superheated water, operates satisfactorily in winter, but in summer the domestic water becomes too hot. Some panels are removed from the utilidor but the water continues to be lukewarm to hot. People waste water trying to obtain cold water with a resulting sewage flow of 127 igcd.

Sewage Treatment

For small communities in the north, the simplest, least expensive and most foolproof method of sewage treatment has proven to be sewage oxidation ponds. Table 1 shows some data on existing lagoon systems.

Package sewage treatment plants, based on biological processes, are subject to very difficult operational problems in the north. Costly designs for collection and treatment result from the extreme climate, permafrost and the frost-heaving soils which occur in many of the sites. The remoteness of the settlements requires the expensive importation of materials, equipment and skilled labor.
As a result, it is sometimes necessary to make compromises with standard design practices. In most communities in the north, it is necessary to improvise to a large extent when planning sewage disposal. The communities are small and remote, yet they have very real problems of contamination of their water supplies illustrated by Table 2 showing coliform concentrations in the Mackenzie River at various settlements.

This contamination of water supplies by sewage is the most important significant misuse of water in the Canadian north at the present time. In most cases, the dilution factor of the sewage in the water bodies is very large, but the proximity of the water intakes to sewage outfalls results in a serious public health hazard.

In most settlements, there are water distribution systems supplying water either by pipe or by truck to most residences. In those settlements with truck distribution water may cost from 2¢ to 3¢ per gallon. Partly as a result of the charges, many local people take water from the nearest water body without regard to possible sewage contamination. Is it a misuse of water not to provide people with an adequate supply of potable water at reasonable cost?

Most settlements are located on the banks of rivers or lakes. Runoff, which may contain much human waste from unserviced settlements in particular, contaminates the water along the shore where people take water. The most important criterion in domestic sewage disposal in the north is therefore, the protection of existing and potential water supply sources.

**Use of Natural Lakes as Sewage Oxidation Ponds**

One of the most tempting short cuts is the use of small natural lakes and sloughs for sewage oxidation ponds. Is this a misuse of a natural water body or not? There are many small lakes. Permafrost restricts the movement of groundwater between local drainage basins and larger basins. Topographic depressions in regions of low relief retain water, the depressions become small lakes. The presence of permafrost results therefore in a hydrologic paradox during summer in that such an area is semi-arid with low precipitation yet contains myriads of lakes. Does it make any fundamental difference to use a natural basin rather than a man-made excavation as a sewage lagoon? There are two illustrations in Yellowknife.

**Niven Lake**

In 1949 when the sewage system was first placed into operation, it consisted of a primary treatment plant with the effluent pumped to a natural lake, the level of which was raised approximately two feet by means of a dam. In May of that year there were only forty service connections to the water and sewer system, and operational problems required a man to be on duty at the sewage plant 24 hours per day. The operational costs were very high. For example, the cost of heat for the digester alone was approximately $100 per month.

In 1961 the sewage treatment plant was abandoned and Niven Lake became a sewage oxidation pond which saved approximately $8,000 per year. The population of the town was then approximately 600, so that the saving was substantial when considered on a per capita basis.

The only man-made changes to the lake were the excavation of a deep hole near the inlet and the construction of a dam at the outlet. The deep hole provides sedimentation and digestion for the sludge. The population is now too large for Niven Lake and it is overloaded. Eventually the lake will be drained and filled to provide building land.

**Kam Lake**

Recently, a consulting engineer has made a report on the possible alternatives for the treatment and disposal of sewage near Kam Lake. Kam Lake is overloaded and also required for other purposes. Building land is in short supply. There is none to spare for a sewage lagoon of the size required for Yellowknife. The most suitable receiving water for the effluent is Kam Lake. This is at the head of a short chain of lakes which discharge into Great Slave Lake in an isolated area.

The receiving water is fixed, and the only consideration is the treatment facility required before discharging the effluent to Kam Lake. Kam Lake contains a high level of arsenic (4 mg/l) from drainage from Con Mine tailings pond.

The most suitable site on the edge of Kam Lake for deep primary lagoons is less than 800 ft from the Yellowknife Correctional Institute. The next most suitable site is approximately a mile further up the lake and a lift station would be required to pump the sewage to it. All things being considered, the extra expense of a mile of forcemain and a lift station is not justified. Raw sewage will, therefore, be discharged deep into Kam Lake which will become a long-retention oxidation pond. Kam Lake, like Niven Lake, is not nearly accessible to the public. Two lakes out of a multitude are being sacrificed for human needs, one for a sewage lagoon, the other for building land. Other lakes are being developed for recreation.

**Effluent Disposal**

Another short cut is the disposal of primary treated effluents to swampland which provides polishing of the effluent before it enters a major water body. At both Hay River and Pine Point effluents from short-retention systems is discharged to inaccessible swampland. Very little evidence of sewage can be found in the drainage which eventually reaches Great Slave Lake. Swamplands being already very fertile, can absorb a greater organic loading without significant change than for example, can a very nutrient-poor lake.

Pollution is relative. The environment can absorb a certain amount of human waste without harm. It is the high density populations and technological developments that cause problems. We should remind ourselves just how small the domestic production is. For example, consider that all the raw sewage from the 25,000 people in the Mackenzie District were to be discharged to the Mackenzie River at Norman Wells which is about midway between Great Slave Lake and the Arctic Ocean. This represents a load of about 4,250 lb of BOD per day at 0.17 lb of BOD per capita per day. The minimum flow at Norman Wells was 105,000 cfs in 1967. At this minimum flow, the hypothetical BOD loading of 4,250 lb per day would increase the BOD of the river water by 7.5 ug/I (parts per billion) which is negligible. Of course the loading is in fact much less than this. Most waterborne sewage is treated in lagoons. There are some private septic tanks and subsurface disposal systems, but these work in only a very few areas. Septic tanks alone is disposed in pit privies or in plastic bags which are buried at the garbage dump. Raw sewage is discharged to the Mackenzie River only at Fort Simpson (contributing population about 600) and Norman Wells (contributing population less than 50). Most sewage at Norman Wells is treated in septic tanks to remove the gross solids.

The amount of human waste discharged is very small but localized problems do occur. The problem of bacterial contamination of water supplies has been mentioned. Back Bay at Yellowknife, which receives the effluent from Niven Lake, is already showing signs of increasing weedsiness. Other important areas that may be affected by the disposal of domestic effluents are the Arctic Ocean and the deltas. Careful consideration must be given in each case to all the possible consequences of the disposal of a sewage effluent no
Sewage Disposal to the Arctic Ocean

Most of the communities along the shores of the Arctic Ocean are very small, and the effects of sewage effluents on the ocean would probably be insignificant. The added nutrient may even be considered to be beneficial, because the Arctic Ocean is not nearly as nutrient-rich as other arctic waters such as the Bering Sea and the Antarctic Ocean, which are consequently much more productive.

Each community would need to be considered individually, and a thorough investigation made before planning the outfall. Primary treatment to remove the solids would be required, because this is fundamental to the various current regulatory standards. Outfalls must be designed to avoid contamination of the beaches where people clean and cut up fish, seals, walruses, narwhale, beluga whales, etc. These foods of the indigenous people should be protected from contamination, because they are frequently eaten without benefit of cooking.

Deltas

There are two deltas of substantial size, namely the Mackenzie and the Slave. Only the former will be dealt with in this report, although all points considered would be significant to the latter.

The Mackenzie delta is not fan-shaped like the average one, but is confined between two ridges, the Richardson Mountains on the west and the Caribou Hills on the east, and as a result is elongated, being approximately 40 miles wide by 140 miles long.

During May of each year the delta is flooded by the runoff from its considerable drainage area.

When this tremendous volume of water reaches the 4,700 sq mi of delta, it spreads out over the whole area. Water in the delta channels rises 15-20 ft. The thousands of elongated lakes that formerly were channels in the delta are filled with flood water, and the delta becomes a vast reservoir until the ice jams move out into the Arctic Ocean and water level falls.

The delta is important as a waterfowl refuge, as a breeding ground for muskrats, mink, beaver and migratory waterfowl including some rare birds as well as ducks, geese, cranes and swans, as spawning grounds for fish, principally inconnu, humpback whitefish, broad whitefish and arctic cisco, and as a tourist attraction. The native people hunt and trap the fur-bearing animals and hunt the birds. They also net the fish, principally for dog food. The water is cold and consequently the growth rate of fish is slow, so that the area could never support commercial fishing.

The productivity of the delta with respect to the animals, birds, fish and trees would be reduced if the delta lakes were not flooded each spring with nutrient-rich waters. The flow out of Great Slave Lake does not vary greatly. The Liard, Peel and Arctic Red Rivers create the flood peaks, and dams on these rivers would probably delay the breakup and reduce the flooding.

INDUSTRIAL USES OF WATER

Mining

There are a number of mines in the Y.T. and N.W.T. and potentially many more. In the N.W.T. mineral production includes lead-zinc at Pine Point, gold around Yellowknife, silver-copper at Echo Bay and in the Camsell River Area on the east of Great Bear Lake, and tungsten copper at Tungsten on the Yukon border. Formerly, pitchblende and nickel were produced in the N.W.T. Potential mining developments are copper in the Coppermine area, iron ore in Baffin, and silver-lead in the Nahanni area.

In the Yukon silver-lead-zinc is mined north of Mayo, lead-zinc at Faro, asbestos at Clinton Creek, copper near Whitehorse, and gold near Carcross and Carmacks. Until very recently, there were still some small placer operations producing gold. Formerly, coal was produced in the Y.T.

The value of mineral production from both Y.T. and N.W.T. was about $150,000,000 in 1968.

Pollution from Mining Wastes

Potential water pollution by toxic substances results from mine drainage, milling process waste waters and leaching from spoil heaps. There is the possibility of lead pollution from the lead-zinc mining at Pine Point, N.W.T., at the Keno Hill mine, Y.T., and at the Anvil mine, Faro, Y.T. Checks are made from time to time, but we are not yet aware of any significant problems.

The water from the dewatering wells around the open pit mines at Pine point contains lead in the concentration about 0.03 mg/l which is less than the acceptable limit of 0.05 mg/l specified in the Canadian Drinking Water Standards and Objectives, 1968.

Arsenic from the gold mining and milling operations at Yellowknife, N.W.T. has contaminated Yellowknife Bay to levels above the limits specified in the Canadian Drinking Water Standards and Objectives. See Table 3. The City of Yellowknife was required to move its water intake from Yellowknife Bay 5 miles away to the Yellowknife River which was not affected by arsenic pollution. It is estimated that 158 lb per day of arsenic are released to Great Slave Lake from Yellowknife Bay. This quantity diluted in the Mackenzie River would produce a concentration of 0.2 ug/l (parts per billion) based on the mean flow of 168,000 cfs at Fort Providence in 1967.

Oil Pollution of Surface Water

Currently, the Norman wells oil refinery is the only one operating in the N.W.T. and it is drawing oil from one oil field which is nearby. Norman Wells is located on the right bank of the Mackenzie River, immediately south of the Arctic Circle.

However, there are geological predictions of oil and gas fields all along the Mackenzie River valley, throughout the western Arctic Islands, and in the Beaufort Sea. The Athabasca oil sands on a main tributary of the Mackenzie River lies south of the N.W.T. border. Currently, there is only one extraction unit operating, but it is likely that there will be forty or so similar operations on the oil sands within a decade or two.

It is likely that there will be a 40 or 48 in oil pipeline carrying crude oil from Prudhoe Bay to Edmonton, with at least one branch which would extend to the Peel Plateau fields near Fort McPherson; and then to the east side of the Mackenzie delta. There will probably be ice breaking oil tankers plowing through the Arctic Ocean carrying oil to Europe and United States.

Oil pollution of water is a small problem as yet, but also a most difficult problem in the Canadian north. One reason for this is the common use of bolted-steel oil storage tanks which tend to leak after a few years of service. Welded-steel tanks are preferable, because they must either be shipped after fabrication in which case they are subject to a high
freight charge based on volume rather than weight. Alternatively, the tanks must be welded in the field, which would require the expensive shipping in of welders and construction equipment such as cranes.

A further problem in many communities is the lack of soil suitable for the construction of berms for storage reservoirs around the tanks. Concrete reservoirs could be constructed, but these would be very costly, particularly if the foundation soil is unstable so that piling would be required.

Small quantities of oil have been spilled when loading and unloading oil barges at various settlements. These result from workmen’s errors. Oil spills from future pipelines will of course be the largest potential source of pollution of waterways, despite the careful plans being made to construct automatic controls for spills if pipeline breaks occur.

Oil spills are inevitable wherever there are oil wells, oil pipelines and oil tankers. A reasonable estimate of the probable spillage of oil is 0.01% of that which is transported by breaking tankers do begin operating in the Arctic Ocean, the amount hauled will reach one million barrels per day within a few years and from two to five million barrels per day within a decade.

Biodegradation of oil takes place in a month or so in the warmer choppy ocean, but it will take a year or years in cold water, especially if it is ice-covered. In the ice-free oceans oil is quickly dispersed into a very thin film. The large surface area allows for a relatively fast rate of decomposition.

The ocean ice protects the oil from biodegradation in two ways. It separates it from the air. Also, it prevents the oil from dispersing so that there is less contact with the little oxygen that there is in the sea water. The underside of the ice is not smooth and level, but lumpy and broken by pressure ridges. Oil released under ice fills the pockets and cavities in the ice and remains there. The probable route of the ice-breaking tankers is through pack ice, the underside of which is very rough.

The oil will not affect the aquatic biota significantly, because the concentration of dissolved oil is too low. However, the effect on mammals and birds is very significant. For example, oil mats the down of water fowl so that the insulation value is lost, the birds then usually die of exposure. Seals get oil in their noses, throats and lungs and suffocate.

Oil Pollution of Groundwater

Some shallow wells have been ruined by fuel oil seeping through the ground from leaking storage tanks. It will be many decades before wells can be developed in those areas again.

Navigation

At present, vessels on the Mackenzie River are discharging raw sewage into the Mackenzie and Slave Rivers. This is minor pollution when they are in the middle of the Mackenzie River or Great Slave Lake, because the numbers of people involved are small. However, it constitutes severe pollution when two boats are docked one upstream of the other if the boats use water directly from the river, or if the people in the settlement take water nearby.

Proposed regulations by the Ministry of Transport will not allow vessels to discharge toilet sewage which has not received secondary treatment to rivers and lakes. The simplest solution would be to provide holding tanks and discharge the contents to shore-based installations at towns where there are treatment facilities. At the present time, costly haulage to these facilities will be required in all cases, because the sewer systems do not extend to the wharf. These extensions would also be very expensive in all cases.

Even secondary treatment of the sewage would not be entirely satisfactory from public health point of view, because the discharges would still contaminate areas where people obtain water. Furthermore, disinfection by chlorination of the secondary effluent is not always reliable. Holding tanks would, therefore be preferable.

Fishing and Fish Packing

Commercial fishing in the north will never be a large industry because fish grow and multiply slowly in the cold, nutrient-poor northern lakes. A six-million-dollar-a-year industry operates in the Great Slave Lake. In former years packing boats and shore-based operations often degraded the immediate surrounding waters, and thereby polluted their own water supplies. Currently, these operations are restricted to just dressing the fish and packing them in ice so that water is not required for washing or processing.

Sports Fishing and Hunting Camps

Camps catering to sports fishing and hunting are scattered throughout the north. The quantities of wastes from these camps are small, but contamination of their own water supplies is uncommon.

Other Industries

It is impossible to predict the future industrial growth of northern Canada with any degree of accuracy. Pulp and paper, for example, will not be significant until there is a shortage of raw material in the more accessible southern locations where logging is more economical.

CONCLUSIONS

In general, pollution of the northern waters is negligible because of the very small population and low level of industrial development. There are instances of localized pollution which constitute public health hazards. For example, bacterial contamination of a water source for a settlement by runoff from the same settlement, about which little can be done except to ensure that all residents receive an adequate quantity of potable water. The problem is usually confined to poorly-planned unserviced settlements.

Increasing development will inevitably involve changing some of the north, but the changes can be minimized and the majority of the land and water resources fully protected by effective planning and management of waste disposal.
### Table 1. Summary of Oxidation Pond Installations, Mackenzie District, Northwest Territories.

<table>
<thead>
<tr>
<th>Location</th>
<th>Longitude</th>
<th>Tributary popu.</th>
<th>Sewage Flow Daily</th>
<th>Per Capita igspcd</th>
<th>Lagoon Type</th>
<th>Average Depth ft</th>
<th>Area acres</th>
<th>Loading lb BOD5/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inuvik</td>
<td>68°21'N</td>
<td>1,500</td>
<td>190,000</td>
<td>127</td>
<td>Single Cell, Long Retention</td>
<td>4</td>
<td>43.5</td>
<td>392</td>
</tr>
<tr>
<td>Norman Wells</td>
<td>65°N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Single Cell, Short Retention. Following Septic Tank</td>
<td>2</td>
<td>0.01</td>
<td>0.49</td>
</tr>
<tr>
<td>City of Yellowknife</td>
<td>62°N</td>
<td>3,500 ('66)</td>
<td>373,000</td>
<td>110</td>
<td>(1 day Short Ret. Combination (Long Retention)</td>
<td>12</td>
<td>0.1</td>
<td>534</td>
</tr>
<tr>
<td>Yellowknife Correctional Camp</td>
<td>62°N</td>
<td>6,000 ('70)</td>
<td>699,200</td>
<td>117</td>
<td></td>
<td>3.2</td>
<td>21.0</td>
<td>636</td>
</tr>
<tr>
<td>Hay River</td>
<td>60°50'N</td>
<td>1,200</td>
<td>180,000</td>
<td>150</td>
<td>Single Cell, Long Retention. Following Ext. Aer. Plant.</td>
<td>3</td>
<td>0.09</td>
<td>-</td>
</tr>
<tr>
<td>Pine Point</td>
<td>61°40'N</td>
<td>900</td>
<td>135,000</td>
<td>150</td>
<td>Two Short Retention Cells.</td>
<td>12</td>
<td>0.263</td>
<td>135</td>
</tr>
<tr>
<td>Town of Fort Smith</td>
<td>60°N</td>
<td>2,000</td>
<td>100,000</td>
<td>50</td>
<td>Two Short Retention Cells.</td>
<td>6</td>
<td>1.67</td>
<td>113</td>
</tr>
<tr>
<td>Fort Smith Airport</td>
<td>60°N</td>
<td>120</td>
<td>4,500</td>
<td>-</td>
<td>Single Cell, Long Retention</td>
<td>4</td>
<td>10</td>
<td>215</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Loading</th>
<th>Theoretical Retention Time Days</th>
<th>Efficiency</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>BOD % Reduction</td>
<td>Solids % Reduction</td>
<td>Coliform % Reduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Winter</td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Inuvik **</td>
<td>-</td>
<td>180 Summer 300 Winter</td>
<td>85</td>
<td>45</td>
<td>91</td>
<td>90</td>
</tr>
<tr>
<td>Norman **</td>
<td>-</td>
<td>23</td>
<td>67</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>City of Yellowknife **</td>
<td>14.8</td>
<td>0.6 &amp; 49</td>
<td>73</td>
<td>60</td>
<td>91</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>17.7</td>
<td>0.3 &amp; 26</td>
<td>59</td>
<td>39</td>
<td>-</td>
<td>69</td>
</tr>
<tr>
<td>Yellowknife Correctional Camp **</td>
<td>-</td>
<td>52</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hay River **</td>
<td>3.07</td>
<td>1.5 Each</td>
<td>41</td>
<td>43</td>
<td>69</td>
<td>81</td>
</tr>
<tr>
<td>Pine Point **</td>
<td>-</td>
<td>17</td>
<td>30</td>
<td>42</td>
<td>15</td>
<td>82</td>
</tr>
<tr>
<td>Town of Fort Smith ***</td>
<td>-</td>
<td>21.5</td>
<td>87</td>
<td>53</td>
<td>95</td>
<td>72</td>
</tr>
<tr>
<td>Fort Smith Airport ***</td>
<td>-</td>
<td>10</td>
<td>80</td>
<td>21</td>
<td>46</td>
<td>56</td>
</tr>
</tbody>
</table>

- Retention time reduced by surface runoff to lagoon.
- Continuous effluent discharge.
- Periodic effluent discharge.

**Table 1** (Continued)

---

**TABLE 2**

**BACTERIOLOGICAL QUALITY OF MACKENZIE RIVER**

(Samples taken near shore in townsite)

<table>
<thead>
<tr>
<th>Place</th>
<th>No. of Samples</th>
<th>MPN per 100 ml Coliforms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min.</td>
</tr>
<tr>
<td>Fort Providence</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Fort Simpson</td>
<td>53</td>
<td>0</td>
</tr>
<tr>
<td>Fort Norman</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>Fort Good Hope</td>
<td>15</td>
<td>0</td>
</tr>
</tbody>
</table>
### SUMMARY OF MINOR SURVEYS IN YELLOWKNIFE BAY, 1968

(Approx. 40 samples in each survey)

<table>
<thead>
<tr>
<th>Date</th>
<th>June 26</th>
<th>July 9</th>
<th>July 22</th>
<th>Aug. 26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.022</td>
<td>0.016</td>
<td>0.011</td>
<td>0.007</td>
</tr>
<tr>
<td>High</td>
<td>0.297</td>
<td>0.180</td>
<td>0.080</td>
<td>0.098</td>
</tr>
<tr>
<td>Low</td>
<td>N.D.*</td>
<td>N.D.</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
</tbody>
</table>

### SUMMARY OF MAJOR SURVEYS IN YELLOWKNIFE BAY, 1967-68

(Approx. 190 samples in each survey)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.120</td>
<td>0.032</td>
<td>0.027</td>
<td>0.048</td>
</tr>
<tr>
<td>High</td>
<td>2.200</td>
<td>0.480</td>
<td>0.871</td>
<td>0.239</td>
</tr>
<tr>
<td>Low</td>
<td>0.020</td>
<td>0.002</td>
<td>N.D.</td>
<td>0.010</td>
</tr>
</tbody>
</table>

* - None Detected.
FIGURE 2
SEASONAL VARIATION OF PHYSICAL QUALITY
SLAVE RIVER AT FORT SMITH, N.W.T.

Δ pH
σ Color
X Turbidity

These results by J. F. J. Thomas

Δ pH
σ Color
X Turbidity
- P.H.E.D. Results.

FIGURE 3
SEASONAL VARIATION IN CHEMICAL QUALITY
SLAVE RIVER AT FORT SMITH, N.W.T.

X Hardness
Δ Calcium

These results by J. F. J. Thomas
Water Survey Report No. 6, Dept. of Mines and Technical Surveys, Ottawa, 1957

- Hardness
Δ Alkalinity
+ Calcium
- P.H.E.D. Results.
INTERBASIN TRANSPORT AND WATER EXPORT

The Forbidden Subject

J.H. HARE, Ph.D., 1

It is indeed a pleasure to be present at this symposium on "Water - A Northern Resource" and I wish to compliment the Water Studies Institute for initiating such an important and timely discussion.

I come here not as an expert in any of the fields usually considered to be important in the field of water resource management. Indeed, any contribution I may make to today's colloquium will be by no means a learned and scientific treatise as might be proposed by a geographer, an economist, an engineer or even an ecologist. I come rather, as one who over the past 5 years has been involved from a layman's standpoint with an overview of the total Canadian water resource picture. I come as a member of the Canadian Water Resources Association, of which I relinquished the presidency just a few months ago.

My presentation therefore is one of a series of personal observations - from travelling throughout Canada, U.S.A., and overseas, discussing with experts in many facets of water resource development and assisting where possible, local and national groups to assess optimum resource utilization.

I am by background a chemist and biologist with main interests in the field of agriculture. I am an ecologist in the sense that I believe firmly in optimal opportunity for natural development. I am not an ecologist in the sense that a moratorium be instigated on all development of resources. Above all I am a realist recognizing that all humans and living organisms in the very act of living and dying add to the interactions of the environment. We are all polluters and in recognizing this we must take steps to minimize the detrimental effects and optimize the beneficial effects for the greatest number of citizen residents for the longest period of time.

Of the six subjects on today's symposium I do not believe any has received as much publicity as this one on water transfer and water export - particularly the latter.

Within recent years the pressures of publicity in ecology and pollution have been extremely strong. This I believe is a very fine development in a developing country. It means that we have a country in which we can take the time to look critically at ourselves. Certainly it is a good sign - one of the signs that Canada is coming of age.

Let us examine a few broad statistics before we enter into a discussion of Canada and the north in relation to water transfer to the south.

The flow of water in the hydrological cycle, i.e. precipitation as rain or snow, and its transfer by gravitational force in streams and rivers to the sea or ocean and return again to the atmosphere is of great importance to us. The history of man has been developed on the basis of the waters of the Nile River, the Tigris and Euphrates, the Ganges, and indeed the St. Lawrence, the Saskatchewan and the MacKenzie Rivers, to name a few.

Total fresh water flow to the oceans has been estimated at 8,400 cubic miles per year (equivalent to 40 million cubic feet per second). Canada's total river flow averages 3.5 million cubic feet per second. Thus Canada, with a population of 22,000,000 (or less than 1% of the world figure) has about 9% of the total water flow. For comparisons sake,

1. J.H. Hare and Associates Ltd., Winnipeg, Manitoba.

Let us look at the water flow rate of some of the major rivers of the world:

<table>
<thead>
<tr>
<th>River</th>
<th>Main Flow (cu. ft./sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon</td>
<td>7,500,000</td>
</tr>
<tr>
<td>Congo</td>
<td>1,400,000</td>
</tr>
<tr>
<td>Mississippi</td>
<td>630,000</td>
</tr>
<tr>
<td>St. Lawrence</td>
<td>400,000</td>
</tr>
<tr>
<td>Fraser</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Lakes are natural storage reservoirs and they act as controls in times of flood and drought. Canada has the benefit of many large lake storage areas and these can and do serve to assist us in overall conservation of water resources.

Lake water of the world totals about 30,000 cubic miles. The African lakes account for 8,700 cu. mi. (29%), Lake Baikal (Russia) 6,300 cu. mi. (21%), and the Great Lakes 5,500 cu. mi. (18%). Canada's total lake area is approximately 292,000 square miles or 7.6% of 3,852,000 square miles of world lake surface.

These figures tell us that Canada is in a favourable position with regard to her share of the world's water resources, both on a factual and per capita basis. Let us then look at water requirements in the world, in Canada and the U.S.A. at the present time, and in the future. With these figures we may be able to form some opinions on whether Canada is in a position to consider the question of water export to the U.S.A.

In early civilization it has been calculated that the water requirements of man were about 3 - 5 gallons per day for all uses. Now just the personal requirements in the daily life of an individual under our high standard of living can range from upwards to 200 gallons per day. Including industrial water usage this figure today is about 1500 gallons per day and it is estimated it could be about 2000 gallons by 1980.

Irrigation is a major type of consumptive use of water. Canada has almost 1,000,000 acres under irrigation, most of this being in southern Alberta (545,000) with about 200,000 in British Columbia. The past few years have seen irrigation development of the water made available by the Gardner Dam construction in Saskatchewan in 1967. To date, about 12,000 acres have come under irrigation and the potential is about 200,000 acres. The development is relatively slow since each farmer must finance his own facilities which amount to a capital expenditure of about $100 per acre. (And the past few years in Saskatchewan have not allowed the farmer to add much in the way of capitalization).

At the present time, consumptive use of water in Canada at 1,000,000 acre-feet is much less than 0.1% of our average water flow of 2.5 - 3.0 billion acre feet per year. This water flow is about twice that of the U.S.A. and our per capita water supply is about twenty times as large. It would appear that because of geographical characteristics it would be impossible for us ever to use more than 100 million acre feet of water for irrigation purposes and it would take a century of continuous construction of systems to arrive at that point. It would appear therefore that Canada will never consumptively use more than 1% of its water flow.

If we should at all be concerned about shortages of water in the distant future -- we might look to Alaskan water as a substitution source as a condition of water movement to the U.S.A.
Water Export

It has been stated by an official of the former Dept. of Fisheries and Forestry that the Americans have never asked Canada for water. At the 1971 meeting of the C.W.R.A. in Regina last June, the Hon. Alvin Hamilton, former cabinet minister in the Diefenbaker government, denied this. He stated that in 1965 the U.S.A. supplied the Canadian government with their past and expected water consumption which was as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>350 billion gallons per day</td>
</tr>
<tr>
<td>1985</td>
<td>700 billion gallons per day</td>
</tr>
<tr>
<td>2000</td>
<td>900 billion gallons per day</td>
</tr>
</tbody>
</table>

They estimated that their availability of water was in the area of 350 billion gallons per day which meant that in the 1980's they would be in a deficit position. Mr. Hamilton suggested that they were asking Canada for about 108 billion gallons per day or 120 million acre feet per year - about the volume of the N.A.W.A.P.A. project or 4% of Canada's water flow.

Stated in another way: in 1900 the U.S.A. total use was 535 gallons per day; in 1960 this increased to 1,500 gallons per day and by 1980 it will be in the area of 2,000 gallons per person per day. Recalling the figures of available river flow, the U.S.A. has only 5,000 gallons per person while we have 94,000 and obviously the rate of flow is not evenly distributed throughout the country. It would seem that the United States is in very grave danger of water shortage in the near future, and they appear to be aware of this!

At the present time many major studies are being conducted in Canada in an effort to assess our water inventory more specifically. These have already been presented on this program today. Some of these studies are being carried out under terms of the new Canada Water Act. One study instituted before the Canada Water Act came into being, and which relates closely to the Saskatchewan area is the Saskatchewan Nelson Basin Study. This study is almost complete and a report is to be finalized early in 1972. In preliminary information from this study, Mr. Reg Bailey, Director of Water Resources, Province of Alberta, stated that twenty-two proposals for diversion of water from one basin to another have been investigated. These diversions would be for optimizing use of water in various geographic areas of the basin. All facets of the diversions, both good and bad, are being assessed.

With the passage of the Canada Water Act and with the recent publicity on pollution there has been an increase in research on our Canadian water resources. Several extremely important projects are under intensive study. To my knowledge however, little effort is being put into any study which relates to the export of water to the U.S.A. This might be because there has been little pressure from south of the border for Canadian water (Alvin Hamilton to the contrary). However let us look at the situation realistically. The Americans have been warned time and again by many persons, notably the Hon. J.J. Greene, and others in the Department of Energy, Mines and Resources, and by other individuals and groups of citizens, that Canada will not condone export of its water under almost any circumstances. To Judge Pope, chairman of the Saskatchewan Water Resources Board and architect of the Prairie Provinces Allocation policy, selling water to the United States would be like renting Parliament Hill to the U.S. Senate.

With such warnings it is not surprising that the United States is looking to other of obtaining or conserving water -- desalination, modification of the atmosphere.

moisture, recycling. It just might be possible that if there is any market for Canada's water now or in the future, it might be eroded if the U.S.A. puts into effect some of these other schemes.

It has been claimed by some groups that any interbasin diversion alters the ecology of both basins to a non-improvable degree. Furthermore, many of these same groups suggest that the U.S.A. is out to grab Canada's water as it has many of our other resources - that Canada's water will be used to flush the toilets of the United States. There were recent "rumours" leaked in a Chicago newspaper that one of the conditions under which the United States might remove the recently imposed 10% surcharge on dutiable Canadian imports would be if Canada aligns with the U.S.A. in a North American resources sharing program, including water.

Unfortunately there have developed on both sides of our borders, large groups of latter-day "new ecologists" who believe only in their own view based primarily on emotional considerations. Also unfortunately we have too few scientific experts in the field of geography, resource biology and economics to cope with these claims. There is a great need for down to earth research and fact finding and judgments based on scientific and economic data. Indeed there is a great need for scientifically trained persons to carry out even more research than we have going now. We need better and more economical methods of measuring our water resources. We need people with water and other natural resources background to become involved in the computerized development of our resources - for it is becoming to be an increasingly more complex subject year by year.

Let us look at the aspects of interbasin transfer first as this is the primary step before we can get into any facet of water export to the U.S.A.

Is interbasin transfer or diversion feasible physically, economically and ecologically? Certainly interbasin transfer is not new in Canada as there have been water diversions constructed since the 19th century. In the prairies this diversion was first aimed at irrigation. In the South Saskatchewan River project we now have diversion into the Qu'Appelle basin with beneficial results for the cities of Regina and Moose Jaw. In addition, the better sources of water for the potash industry development and the enhancement of recreational and wildlife activities are bonuses for the southeastern Saskatchewan region. Similar advantages of multi-use purposes have resulted from the many interbasin transfers at the headwaters of both arms of the Saskatchewan River system.

In many of the above interbasin transfers the objective was in most cases, for a single use such as irrigation, hydro power, or flood control. Subsequently, other uses have been made of these transfers such as improvement in water systems for towns and cities, improved fishing and wildlife habitat and recreation activities such as boating, camping and swimming. In few instances have these single purpose aims been detrimental to the ecology of the supplier or receiver basin.

Despite the above, it is important now however, that in any consideration of water transfer from one basin to another, the total multi-purpose picture both of a local and national (plus international) character must be carefully studied. Any imbalance in ecology or economic standards must be weighed and the program resulting in optimum results from all considerations should be instigated. The key to interbasin transfer then is planning -- and planning with consideration for all facets of the situation. This planning should include not only the water resources involved but all the other resources of the area concerned. Most importantly there should be great concern for human resources.
In considering the sale of any commodity, price is one of the important factors in the deal. What then is the value of water and how can we obtain a measurement of the value? What will the Americans pay for or be able to pay for our water if we did arrange to divert it? Only a little information on this subject is available and few if any studies have been done on it.

The Hon. Alvin Hamilton in an address to the 1971 C.W.R.A. annual meeting suggested two methods for evaluating a price for water. He stated that an American research study in New Mexico indicated that 1 acre foot of water placed into a deficit area added $3,000 per year to the Gross National Product from industrial uses $200 - 300 per year from recreational uses, and $50 per year from agricultural uses. If we were to ship 120 million acre feet annually as we think the Americans might require within the next 20 - 30 years, the increased Gross National Product would be valued at almost $400 billion in increased productivity.

A second method of calculating the value of water is to compare it to the cost of producing fresh water from salt water. Using the U.S. cost estimate of producing water in atomic powered desalination plants at 22 per 1000 gallons, the value of 120 million acre feet would be $8.6 billion per year. Thus we see the value of the amount of water the Americans might need producing an annual revenue of somewhere between $8.6 and $400 billion, a sum of considerable significance even if the lower value were accepted.

Our policy choices in the debate over water export can take three basic forms. One, we can state that we will not consider the subject with the U.S.A. under any circumstances, now or in the future. The second course open is to begin the process of exporting water by the most appropriate and immediate methods. The third choice is to continue to assess the Canadian water inventory (and to accelerate such assessments) and in terms of the dollar value of the water to the U.S.A., devise the procedures by which we might obtain some of this value for Canada.

The Hon. Mr. Hamilton discussed this latter proposal and suggested a method of growth sharing in various industries, such as steel production, which were dependent on water. He worked it in such a way that if Canada provided the U.S.A. with sufficient water to allow for a 4% annual growth in their steel production they would reach 200 million tons by the year 2000. At the same time Canada's steel growth rate (coordinated with the required water supply) would increase at a rate of 15% per year so that we too would be producing 200 million tons by the year 2000.

Mr. Hamilton proposed that we set up a National Water Board to study and regulate water export. This body would be Canadian in composition but could meet as required with its American counterpart to negotiate costs of studies and research. Subsequently, if agreements on export were reached, the Water Board would either turn over administration of projects to the International Joint Commission or carry on under its supervision, whichever was best for Canada.

In the past many proposals for physical methods of exporting water from Canada to the United States have been proposed. Of these, possibly the grandest and one which received the largest counterparty was the proposed North American Water and Power Alliance - proposed by the Parsons Co. of Los Angeles in 1964. It involved the transfer of over 100 million acre feet of water from North-western Canada and Alaska southeastward into the drier parts of Canada, the U.S.A. and Mexico. The scheme did not refer to sale of water - only to the costs of the physical transferral. It was assumed that the benefits of the construction, labour, and material costs would be considerable and a plus factor for Canada. The N.A.W.A.P.A. scheme proposed using the long mountain trenches of British Columbia and the north south valley flows of Washington, Oregon and California as carriers for this water. Many facets of N.A.W.A.P.A. were highly improbable because of the size of construction. Dams and other construction units in locations prone to failure could lead to severe flooding. Just last week, for example, a part of the California Aqueduct system bringing southern California water into Los Angeles gave way and flooded a large section of land.

A major objection in Canada to the N.A.W.A.P.A. scheme would be the development of a supervisory administrative group made up largely of Americans and thereby we would lose sovereignty over our natural resource, an unthinkable fate for any Canadian.

A second proposal is the G.R.A.N.D. (Great Replenishment and Northern Development) project which would involve diversion of water now flowing northward into James Bay. These rivers would be directed southward by canals into the Great Lakes for use by both Canada and the U.S.A.

Maugussen suggested a water diversion scheme that would tap the Peace River and transport the waters southward via the Saskatchewan and Qu'Appelle, Assinboine and Red Rivers, into the U.S.A. and into the Mississippi in North Dakota. Dr. Kuiper of the University of Manitoba has proposed reversing the flow of water out of Lake Winnipeg and northern Manitoba via the Red River into the U.S.A. L.G. Smith (of the U.S.A.) suggested a large scale program whereby water from the Liard and Mackenzie Rivers would flow southward to reservoir storage at 7000 ft. altitude in Montana. From this point water could be diverted either southward and eventually into the Colorado River or eastward into the Missouri - Mississippi system.

Most of the above proposals are extremely costly, even looking to the year 2000. The Americans would probably not be able to pay the cost of water transported by such expensive procedures.

It is important for us to recognize that Americans can get by for many years without Canadian water. Certainly, not having guarantees or options on water from Canada, will force them to more expensive methods of water production - recycling, desalination, weather modification and others.

Possibly more study on Canadian water diversion and export has been carried out by Dr. Arleigh Laycock of the University of Alberta than anyone else. In addition to having written many articles on this subject he recently took a year's sabbatical leave to study the Canadian and American water resources system in detail. The results of this study will be released shortly in book form and should be one of the most comprehensive treatises ever written on Canada's water resources and the feasibility of export.

Dr. Laycock has argued loudly that no future interbasin transfers should be considered unless all of the factors that might be involved are considered jointly. Water cannot be independent of the other resource planning and development functions. Water should have a realistic price attached to it in considering resource development but even so we will find that in comparison to other costs it is a minor item for most industries. Other items such as fuel, power, labour, transportation, etc. are usually much more important in location factors for particular industries. Water on the other hand, may be moved readily in large volumes relatively cheaply. If water is not present it usually can be obtained at relatively low costs.

The mineral industries of Canada for example are not always located at sites where water can easily be obtained. Should these industries be prevented from developing if local water supplies are deficient?
Should we consider moving people to where the water resources are rather than moving water to where the people prefer to live? For example, almost all of our population resides within a short distance of the American border, primarily because of climatic conditions. Agriculture and other general industries are located in this narrow band stretched across the continent. It is impossible for us to consider producing crops such as we now do in areas more northern than presently located. It is much easier to transfer water if necessary by interbasin transfer than to alter temperatures of soil in the far north. Water may be moved. Good land and climate cannot. Water is the most mobile of our resources on a massive scale.

From a social standpoint to what degree should we tell people where they should live? Under normal circumstances it would be better to offer incentives for people not to crowd together in cities and water could be used as a lever to limit such crowding (e.g. Los Angeles). On the other hand it could be used as an incentive for people to live in smaller centres such as the western prairies. For example, with the development of the South Saskatchewan River Scheme, the attractiveness of living in that area of Saskatchewan has improved markedly.

When the South Saskatchewan Dam was first being discussed, irrigation and flood control were the important economic aspects of the project. Other benefits such as the aesthetic, wildlife, recreational features, although not overlooked, had little financial value or planning placed with them. It is just now beginning to be realized that these values may be just as economically important as the primary purposes of the whole project and ecologists are well pleased with the results.

Within the next ten years, Canada, according to statistics, will have a larger addition to its labour force than any of the European countries. Are we to minimize the possibility of jobs for these people because we are not stressing development of our resources? Would it be right for us to tell people that there will be no opportunity for improvement in our economic and social growth because of the imposition of non-growth philosophy and the preservation of the country for natural wilderness? It is not my belief that the inhibition of development is the way of the future. The more rational outlook on the situation is that we can have major water development and enhancement of the environment for man and wildlife at the same time. Using optimum planning and technology, interbasin transfer can be an important part of this development.

Most of the proposed developments that have been discussed previously would be extremely expensive and it is improbable that there would be a market for such water at the prices necessary to pay the costs. Most of these water transfer proposals are certainly valid for the distant future - say 50 to 100 years hence - and we should not lose sight of them in our long range planning.

Rather let us consider the prospects of smaller interbasin transfers that would not only in the near future begin to bring about this export of water to the U.S. but would also serve Canada as well.

At the present time Chicago is allowed to divert 3,200 c.f.s. of water from the Great Lakes to treat its waste products southward through the Illinois River and into the Mississippi River. This program has been most beneficial in minimizing eutrophication in lakes which lower levels than otherwise might have been. It has been suggested that this type of diversion could be expanded for other centers on the southern shores of the Great Lakes and similar diversions southward to the Mississippi River via the Ohio River could come from cities such as Cleveland, Detroit and Buffalo. It is estimated that 25,000 c.f.s. would be needed but the pollution problem of the Great Lakes would be greatly reduced and Canada would benefit from such a program as well as the United States. Replacement supplies would be needed principally because of losses affecting water power and navigational requirements. Extra supplies could be obtained from rivers now flowing north of Lake Superior into Hudson Bay. At the present time we have reversed the flow of some of this water at the Ozhkii River and at Long Lac diversions which originally were for hydro power. It would be important to take advantage of this water and not sell it just to cover construction costs, but to insert an "opportunity price" (the value of the benefits lost in Canada): Also, an allowance should be made from other effects of diversion such as ecological changes that could be righted by these extra monies from the United States.

In our consideration of utilization of waters of the Peace and Athabaska in order to provide supplies for the prairies via the Saskatchewan River system, if export is also considered we might be able to pay for a large part of the costs and development of the prairies into better economic and liveable centres could result.

Another such diversion which has been considered as an aid to providing much needed water for irrigation and other purposes in the beautiful Okanagan Valley of British Columbia is the transfer from Shuswap Lake. If we also included consideration of water export into Washington state the Canadians could accept a significant share of the Canadian development costs.

This then could be the key for Canada to rapidly improve her economic and social conditions at the expense of the needs of our neighbour to the south. If we can improve Canadian standards of living, increase employment, ameliorate unsatisfactory social conditions by the export of 1% of our water flow and at the same time not prejudice our water resources for the future, I believe we will have achieved new heights. This amount of water would be twice the flow of the Colorado River, which is the source of a great deal of water for southern California and will be in the future the salvation of the desert areas of Arizona.

The actual diversion of this water might not be required for many years but if we sold options on it starting in the not too distant future, the assurance of these replacement supplies would alleviate many speculative situations now arising south of the border. All aspects of these water diversions should be studied in considerable depth so that we can make rational decisions.

Closing our eyes to opportunities for commodity exports has never hampered Canadians before. In fact if we don't sell all our wheat surplus in one season there is a great wait from the farm group and the west in general. Nobody has seriously worried about crop deficiencies since the dirty thirties. We are most anxious to ship as much of our depletable energy sources - coal, oil and gas - as we can - and with very little product improvement input prior to export.

Why then must we be so uptight about water? It has been estimated that in 100 years from now our wildest imagined consumption figure will be no more than 4% of our total supply, and in 2 - 300 years, a maximum of 10%. This seems to leave a considerable volume of water which otherwise would flow into the ocean unused and would be much less productive than its potential.

It would not be essential that any water export agreements negotiated with the U.S.A. be permanent by any means. We would not want to have contracts in perpetuity because of the changing (increasing) value as the years go by. If we did, we would have to make wild guesses at the costs of maintaining the water supply which in all likelihood
would make present costs prohibitive for any development whatsoever. It is usually true that long term contracts in any deal are not good for either the buyer or the seller.

However despite the fact that I appear to be totally in favour of water export I am first of all a Canadian and since we hold the cards, would want the factors weighed in our favour. We should develop a national water use policy before any further steps are taken toward water export. This policy should make us masters in our own house and we should be able to face the Americans with definite propositions. We could begin to initiate marketing discussions with them and could consider water export not as a single use development but as a part of an overall plan for all Canadian resource development. Many of the things we would like to do in Canada but cannot afford as a country -- might be achievable because of financing from south of the border. Revenue from the sale of just 1% of our water flow could be greater than one billion dollars on an annual basis. If we put it on option this might even be increased. The great expenditures on opportunity costs and environmental improvements and the construction of storage areas would make great contributions to ecological developments -- i.e. wildlife, fish, flora, etc. In addition to the enhancement of many areas of the north the southern regions also would benefit greatly -- Great Lakes improvement over pollution, better water for recreational use, more water for urban and industrial use -- all would enhance Canada both productively and in attractiveness.

Optimum results of interbasin transfer will only result if optimum planning and programming is brought about. I am a firm believer in positive thinking and optimism. I feel we should at least keep the doors of opportunity open and not contain ourselves in darkness of ignorance and apathy.

This is not to say that even those who have firmly opposed water export are completely wrong. I believe when we look at it seriously, both groups are saying the same thing about our water resources, i.e. that we must know more about them prior to making any moves in any direction. To this I agree and with the instigation of the Canada Water Act two years ago with its framework for cooperative development and its enabling capacity for future development, is a step forward. The new Department of Environment which already has encompassed many units of other Departments which in the past have been overlapped on each other, appears definitely to be taking the proper steps forward. At least we are getting faster approaches to our water inventory, and the several major joint studies being conducted by the Department are all to the good.

But we still seem to have the hangup about looking at water export. Just because a person window shops it doesn't mean he has to buy. I feel that a definite philosophy has to be set up concerning water export and the negativeism that exists in Canada at the present time be altered with a more positive approach. Subsequently this philosophy should be conveyed to our neighbours to the south and the present wall of animosity might be relaxed somewhat.

We don't have to sell our birthright. We don't have to molly coddle. We merely have to face up to practicality and stand up to be counted in this opportune moment. I believe we have the expertise in our own country that will allow us to set our own course for the future. We can study the total resource situation, focus in on the problems and opportunities of water development and direct our future activities for the optimum good of all Canadians.

At a recent seminar in Regina sponsored by the Canadian Council of Resource Ministers the subject of water export to the U.S.A. was discussed. The following is a summation of the discussion and the recommendations of that eroue:

1. We should be actively looking at water export -- both the positive and negative factors. A greater knowledge of the total situation is needed since it is so fraught with political and emotional overtones.

2. Basic policy decisions must be considered and culminated, e.g. should water be brought to the people, or people brought to the water.

3. A study framework should be set up and should include:
   (1) Availability of water supplies
       (a) desk research (low cost)
       (b) field research (moderate cost).
   (2) Demand.
      We should determine Canada's long time need and continue reviewing and updating it. Similar consideration of the U.S. demand both now and in the future based on:
      (a) no water available from Canada.
      (b) some option on Canadian water.
   (3) Conceptual engineering and environmental impact.
      We need to develop comprehensive physical aspects of the ultimate basin optimum utilization. Consideration should be given at the same time to concurrent development of other resources of the area.

   The effect of the engineering projects on the environmental changes must be closely assessed and plans for optimizing ecologic improvement be drawn up.

   (4) Engineering and Environmental Planning.
      The actual project designs for the engineering and minimizing environmental impact must be drawn up. From these the costs of the projects may be estimated.

   (5) Economic and Social Aspects.
      A full economic analysis should be conducted including in it the interrelationships of water resource development with other resource development. There should be full consideration of the social economics and an evaluation of the initiation of these projects on the total social picture. Some of these latter effects may be quite intangible but their weight should be considered nevertheless.

   (6) Jurisdictional.
      Obviously the legal implications of interbasin transfer of water are manifold. It is important that all aspects of legalities be discussed, agreed upon and tabulated in detail prior to initiation of projects.

   (7) Financing.
      Method of financing the studies, surveys, field testing, feasibility and final project itself must be worked out. The cost sharing by municipality, state, province, or federal governments must be arranged and agreed upon. User benefit ratios for the various water uses are not easy to calculate but agreement on these is important.
(8) Political implications.

Throughout all the steps of interbasin transfer runs a thread of the political implications. It is important to bring all of these to light and have agreement on these by all parties concerned.

At this conference there was a good cross section of Canadians - - teachers, civil servants, businessmen, social workers, farmers, politicians and others. Although not all agreed that water export should be implemented there was the feeling, even among the most vehement for minimizing ecological change, that we should be aware of all the plus and minus factors of interbasin transfer and that water export at least should be looked at in overall planning for the future of our water resources.

It is still many years before we will be actually discussing with the United States the sale of water or exchange of growth rates in various industries. In the interim we should be examining the alternative choices of action and planning as to how we might finance and implement them when the time comes.

Right now, for example, despite our having just completed the South Saskatchewan system with the Gardiner Dam, it appears there will be further need for water in the prairies in the near future. According to Mr. Hamilton, if we spend about $300,000,000 over the next 20 -30 years we could put into storage about 10 million acre feet of water. It would mean we would have water for development in the prairies when Ontario, and the U.S.A. may be looking for industrial locations due to crowding in those areas.

In connection with my remarks with reference to interbasin transfer and water export, we need a national water policy for Canada. Such a policy should be based on as many facts as is possible to obtain. Once the objectives for the immediate and intermediate future are set, actions taken for these periods must be in agreement with long range objectives as well.

In conclusion, Canada is one of the great sources of natural wealth in the world. Certainly of the known resources water is the greatest and is the key to the whole structure of our success. With confidence in our human abilities and with international planning in mind, we stand to improve our own water resources with lowered costs to Canadians for the long term future.

WATER AND MAN
IRVING K. FOX

The topic I have been assigned to speak about this afternoon is Water and Man. Certainly any effort to be comprehensive about this subject would lead one into a discussion of the many services that water provides for man, extending from his reliance upon water to live to the contributions that water makes to the aesthetic aspects of the environment he uses. I do not propose to discuss what all of these services are and how important they are to human welfare. To review their contribution to human well-being would be to describe the obvious. Instead I propose to focus on the problem of adding a man's values to the resources we have at our disposal. There are certain ways of measuring the value of services that are related to water and some of the implications of these values for the way we go about dealing with our water resources. If we look at the matter in this way, we will find that water is more than something to drink, a necessary element of crop production, a producer of hydro-electric power, a medium for transportation, and a base for recreation. In brief, what I propose to do is to examine in a relatively broad way the values that people seem to pursue, how these relate to water and some of the implications of these values for the way we go about the management of water resources.

THE VALUES PEOPLE PURSUE

In our effort to be rational about the use of water resources, we have developed procedures for evaluating benefits and costs because we believe that in this way it is possible to arrive at policies and programs that will contribute most to the welfare of people. I have participated in such analyses and I consider that they are worthwhile. At the same time, many of us now feel that our efforts to measure benefits and costs have been based upon an oversimplified view of the values that people seek. We have looked at human beings as individuals motivated primarily by the desire to increase the quantity of goods and services that they can utilize. Here I use the terms "goods and services" to refer to the items that have been included in the conventional measures of economic growth or gross national product. Today most of us who are deeply involved in water resources management recognize that this measure of value by itself is not a satisfactory one and that it is incumbent upon us to find more sophisticated ways of measuring the values associated with the development and use of water.

I doubt if one can find a commonly accepted classification of the various values that people pursue. However, to illustrate what I mean let us look at the classification suggested by a prominent political scientist, Professor Laswell. He identified eight basic values. These are power, enlightenment, wealth, well-being (or health), skill, affection, rectitude (which includes both righteousness and justice), and deference (or respect). It has been suggested by another political scientist that in addition to these eight substantive values, man also desires other ways of enjoying them. He wishes security, that is, he wants to be able to rely on having a given value in the future. Also, he wants liberty. He wishes to be able to act in accordance with his own personality and without having to make a great effort at self-denial or self-control and without being subjected to external constraints.

I am not suggesting that this is the best classification of values that can be devised. My purpose in presenting these is to remind you of how complex the motivations of people are. A review of Professor Laswell's eight basic values together with our desire for security and liberty suggests that we are taking a very narrow approach when we seek to evaluate water resources in terms of the goods and services that are normally valued through market forces. I believe that most of us would agree that people, in addition to seeking goods and services, are also motivated by such interests as a desire for enlightenment, for well-being, for skill, for affection, for rectitude and for deference. These desires

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may be reflected in one way or another in the way we price goods and services of the conventional type but often they are not.

In addition to recognizing that people are motivated by a complex set of values rather than following the stereotype behavior of the economic man, it is also necessary to take into account that individuals vary greatly in the priorities that they give to the various values which they pursue. Some people feel a tremendous need for power. Others are highly motivated by the desire for affection and others above all else wish to be wealthy. The same applies to goods and services, ranging from fish and electricity to recreation and the aesthetic aspects of water. Simply stated individual value preferences vary greatly. Thus, if we seek to manage water resources so as to provide the greatest benefit to society, we must take into account these different priorities that each individual places upon different values. And this is no small task.

While value preferences and priorities among values, vary greatly among individuals, society is held together by certain common values which all people hold or which all members of society are expected to hold. While every organized society has its own set of common values, in Western Europe and North America the common values which bind our societies together are often referred to as the principles of democracy. It is easy to be cynical about democracy; to consider that the term has become a platitude of political oratory. It is my judgement, however, that it is not practicable to examine in any rigorous way how society can realize the greatest satisfaction from water resources without beginning with a specification of the common values of society. Without this specification, no basis exists for deciding what is best for society.

The point to which I’ve been leading in this discussion of values is a relatively simple one. It is that any effort to maximize net benefits to society from water resources must take into account:

First, that the values that people pursue are complex.
Second, that individual value preferences vary greatly, and
Third, society is held together by certain commonly accepted values.

Thoughtful consideration of these three facts will, I believe, provide perspective on the nature of the task we face in getting the most for mankind out of water resources, whether it be in northern or southern Canada or some other place in the world. The place to begin with this consideration is by enquiring into the common values of our society.

THE COMMON VALUES OF DEMOCRACY

While we do not have the time to explore this matter in any great detail, let me sketch briefly what appear to be the basic value premises underlying a democratic society.

First is the norm of participation or representation. Generally, we believe that an individual should have a reasonable opportunity to participate or to be represented in decisions that affect him. We find this concept reflected in classical economic theory where it is assumed that decisions are reached in a competitive market by the buyer and the seller - the two individuals who receive all benefits and bear all costs. In the Greek city state, each citizen participated in meetings where all governmental decisions were made. These classic conditions seldom exist in the modern world. Nevertheless, I believe that most of us assume that an individual has the right to participate or be represented by someone who reflects his views in decisions that are made which affect his welfare.

Second and closely related to the foregoing point is the view that the individual or his representative should have the best practicable information that can be provided to use in determining the course of action he considers best in dealing with a decision that affects him. Again, under classical economic theory it is assumed that buyers and sellers have perfect knowledge of the alternatives available to them and the consequences of each. Although not as explicitly stated, democratic political theory assumes an informed citizenry.

Thirdly, there is the concept which I will call rectitude. This is an ethical norm concerned with what is right and just in relation among individuals in a society. It includes the concept of integrity, the idea that agreements entered into will be honoured and that information will be communicated in good faith. It also includes the concept of efficiency by which we refer to the realization of maximum net benefits to society. We believe that efficiency is desirable because an inefficient solution to a problem means that someone will receive less benefits than it is possible to provide. It also includes the concept of equity, the idea that individuals should not be discriminated against because of such factors as status, race, age, sex and so on, and that individuals will not impose costs upon others and that where preferences conflict, procedures will be followed which give a careful balancing to the differing interests.

And fourth is the concept of liberty. Here we believe that our institutions should provide freedom to the individual to satisfy his preferences to the extent that the exercise of such freedom is compatible with the norm of rectitude to which we have referred.

VALUES AND WATER RESOURCES MANAGEMENT

What are the implications of this assessment of values for water resources management? It implies that we who seek to be experts in water management cannot presume to know what is best for society because what is best is determined by the value preferences of the many people of which society is composed. Studies reveal that experts seldom reflect accurately the value preferences of the public in general. Thus, we have no right to decide-only to inform those who represent the various elements in our society. This assessment implies that a benefit-cost analysis cannot tell us what solution is best; it only provides helpful information for people to utilize in making their choice. It implies that the only way that the benefits and costs associated with water use can in fact be measured is through procedures which reflect and balance the differing value preferences of members of society. It implies above all else that one of the major problems in water resources management is the development of institutions which make possible full realization of the common values of our society. I can state with conviction that in the United States this is the foremost problem in the water resources field.

There, we suffer from water pollution, not because we do not have the technical know-how to manage water quality but because our institutions do not conform to the criteria I have identified. People suffer from the destruction of fisheries not because the technology of flood control and the understanding of how flood plain lands should be managed are deficient. It is because our institutions are inadequate. The same comment applies to every aspect of water management in the United States. Since I have lived here such a short time I cannot presume to be knowledgeable about Canada. However, my limited exposure suggests that institutional limitations constitute a major water problem here as well. But what specifically are the deficiencies to which I refer?
THE INSTITUTIONAL PROBLEM

The issues we face in the design of institutions for water resources management revolve around the questions which flow from the value premises I described. These questions may be expressed as follows:

1. In a given water management situation, how can we assure the generation of information about the alternative courses of action that might be pursued, specify the consequences of each and communicate this information faithfully to the individuals who are affected and their representatives?

2. How can we assure participation or representation of those affected in the decisions that are made and avoid the domination of decision-making by minorities with a specialized interest?

3. How can we assure that water resources management is undertaken efficiently and the benefits therefrom equitably distributed among members of society?

These are not simple tasks. In my own experience, water management institutions have been deficient on all three of these points. Water management agencies have failed to develop satisfactory information about the alternatives available and frequently when they have had this information, they have failed to communicate it faithfully. We have seen water resources management decisions dominated by a minority of those affected thereby. Finally, it is doubtful that water resources management has been undertaken in as efficient a manner as one should expect and I question whether the benefits and costs of water development have been distributed in an equitable fashion.

The technical complexity of water resources, the intricate technology that we have developed (and which is constantly changing) and the even greater complexity of social behaviour makes the design of institutions that conform to the criteria specified a difficult task. Yet, it is my view that it is a problem area in which carefully designed inter-disciplinary research can make a major contribution. We hope at U.B.C. to take part in such an effort.

CONCLUDING NOTES

I would be remiss if I did not conclude this discussion of human values and water resources by commenting upon a concept that I feel deeply about personally.

Values change and in recent years we have seen a growing concern about the impact of man upon the ecological system of which he is a part. Twenty-five years ago a forester by the name of Aldo Leopold called for a land ethic - a way of living which preserved a reasonable balance within the ecological system. Many are now echoing the concern of this thoughtful, sensitive man. Water is an important component of the ecological system of which he spoke.

It is not practicable with the large human population in the world today to live without having an impact on the environment. But Leopold's call for an ethic reminds us of the solemn nature of many of the water resources decisions we have made or that we are considering which may profoundly alter the natural ecology. This does not mean that water is not to be managed for human benefit. It does mean that we should be sensitive to the consequences of what we may be doing, that we should minimize risks to other species, that we should recognize that the future welfare of mankind is intricately interwoven with other forms of life.

This is a point that I think is particularly relevant to water management in the north. There, as I understand it, the ecological system is held together in such a tenuous way that it can be easily destroyed, with what may be far-reaching consequences for human beings as well as other species. Here we have a dramatic and poignant reminder that the values that man lives by determine both his immediate well-being and his long range destiny.