WATER AND SEWERAGE SERVICES FOR CANADIAN ARCTIC COMMUNITIES

by

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WATER AND SEWERAGE SERVICES FOR CANADIAN ARCTIC COMMUNITIES

ABSTRACT: In attempting to provide modern water and sewerage services to the non-indigenous inhabitants of Canadian Arctic communities, engineering modifications are necessary owing to the presence of a continuous permafrost zone and a severe climate. Modifications are constraints on communities in that the costs of providing water and sewerage services are augmented to such an extent that most communities are financially unable to provide modern services at a reasonable cost. The inability of communities to provide modern water and sewerage services may inhibit the growth of present communities and influence the location and development of future communities in the Canadian Arctic.

INTRODUCTION

Development of the Canadian Northland is progressing so rapidly that one of the great challenges in this region is and will be the provision of modern amenities to the non-indigenous inhabitants of present and future Canadian Arctic communities at a reasonable cost. Non-indigenous people, who are and will be migrating from the southern parts of Canada to the Arctic for employment, are usually accustomed to or will expect the amenities of modern living. If these people are to remain or are to be attracted to settle in northern settlements for any length of time or permanently, one particular amenity, water and sewerage services at a southern level of convenience, will be in demand. It is or will be incumbent on northern communities, the federal government and the territorial governments to consider and to attempt the provision of modern water and sewerage services to the non-indigenous people of present and future Arctic communities as cheap as possible. Failure to do so may be a constraint in the location and development of Canadian Arctic communities.

STATEMENT OF PROBLEM

In the Canadian Arctic severity of climate and the existence of a continuous zone of permafrost impose constraints in the furnishing of modern water and sewerage services. Whether it be in the procurement of water, the treatment and distribution of water, and the collection and disposal of waste water and sewage, the engineering or technological practices of the temperate regions cannot be applied in the Far North without some type of modification. The modifications necessary in the design, construction and operation of modern water and sewerage services are an additional constraint to the communities in that they increase the cost of providing convenient water and sewerage services.

OBJECTIVES OF THE STUDY

An evaluation of water and sewerage services was established for Canadian Arctic communities in order:

(a) to examine the major constraints that continuous permafrost and severity of climate create in the provision of modern water and sewerage services for the non-indigenous people of present and future Canadian Arctic settlements,

(b) to examine the significant engineering adjustments that must be used to overcome the difficulties created by the continuous permafrost zone and the severe climate in the provision of modern water and sewerage services for northern communities, and

(c) to examine how such constraints may generally influence the location and development of present and future Canadian Arctic communities.

THE AREA OF STUDY

The area of study is the Canadian Arctic or the Far North. The problem of defining the boundaries of a region can be complex. Thus one must appreciate that several ways can be used to delimit a region. Some of the criteria used to define the Canadian Arctic or the Far North are: the Arctic Circle, the 10° C isotherm, the southern limit of continuous permafrost, the 60° north parallel and the northern limit of tree growth.

In this particular study the Canadian Arctic or the Far North refers to that part of Canada, both land and water, north of the southern limit of continuous permafrost (Fig. 1).

THE PHYSICAL ENVIRONMENT

THE CLIMATE

The Far North is located in the Arctic climatic zone. It includes parts of the Yukon Territory, the Northwest Territories and parts of northern Manitoba, Ontario, and Quebec.

The Far North, being such an immense area, has a variation of climatic conditions. Nevertheless, by examining climatic data (Tables 2, 3, and 4) for some selected Arctic stations (Table 1), one can make a few generalizations about the climate. Winters are long and cold. Summers are extremely short and cool. Large temperature ranges exist. The amount of precipitation is sufficiently low that most of the region is a cold polar desert. Although snowfall is less than Southern Canada, it tends to stay on the ground for a longer period of time. With a large number of days in which mean temperatures are 0° C or less, the Far North or the Canadian Arctic is underlain by permafrost.

PERMAFROST

The term permafrost refers to the thermal condition of earth materials under which their temperatures remain below 0° C continuously for a number of years. Permafrost is defined on the basis of temperature alone; any material that has been below freezing continuously for more than two years is called permafrost or more appropriate, perennially frozen ground. The formation of perennially frozen ground is a direct result of an imbalance in the heat exchange at the ground surface whereby heat losses are greater than the annual heat gain (Johnston 1965, p. 2).

The region of permafrost is normally divided into two principal zones, the discontinuous zone in the south, and the continuous zone in the north (Fig. 1). Within the discontinuous zone perennially frozen areas exist together with unfrozen areas; in the continuous zone perennially frozen ground exists extensively and predominates everywhere beneath the ground surface (Fig. 2). The depth of perennially frozen ground varies from about 30 m at the southern limit to more than a 300 m in the northern part of the zone (Table 5 and Fig. 3).

Above the permafrost table, that is the upper surface, there is a layer of rock or soil called the active layer, which freezes in the winter and thaws during the short

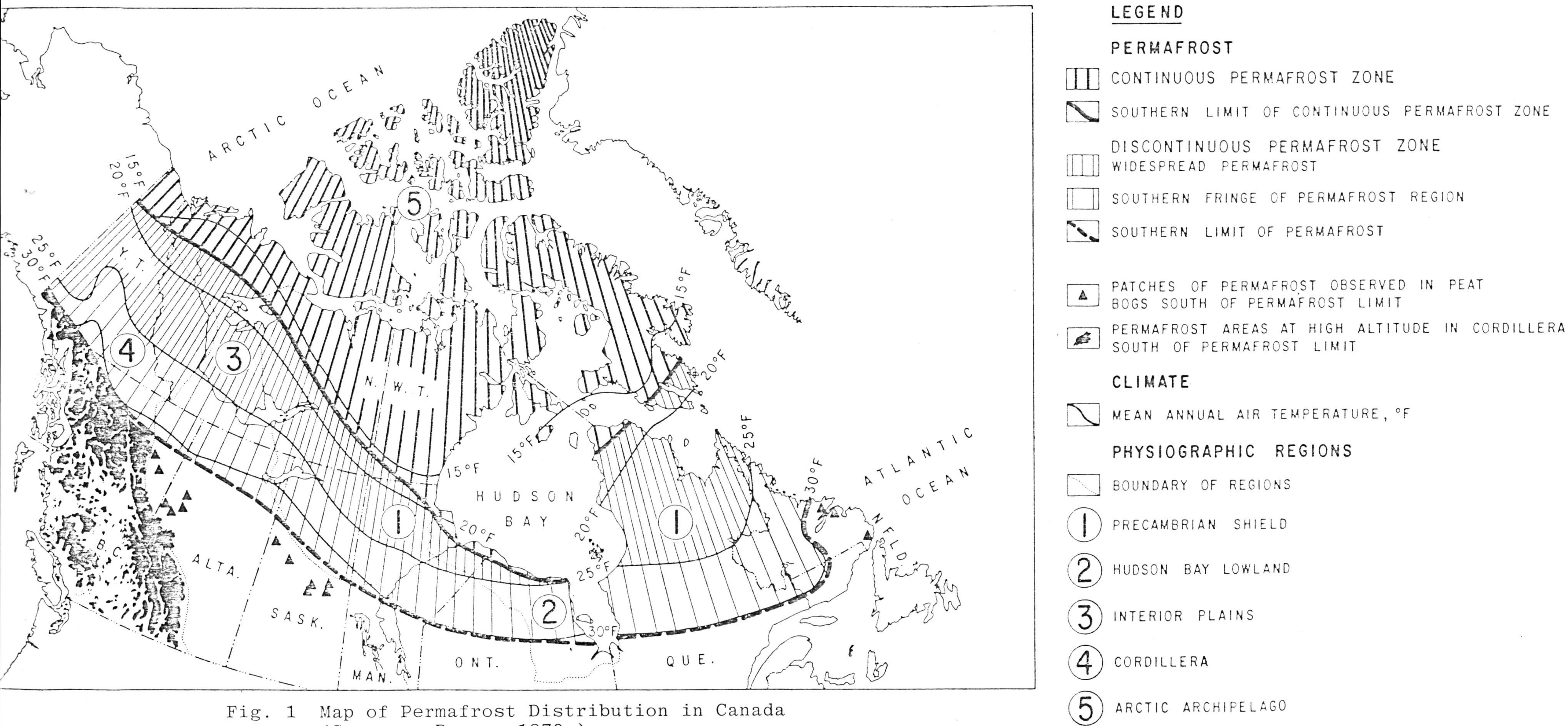


Fig. 1 Map of Permafrost Distribution in Canada
(Source: Brown, 1970.)

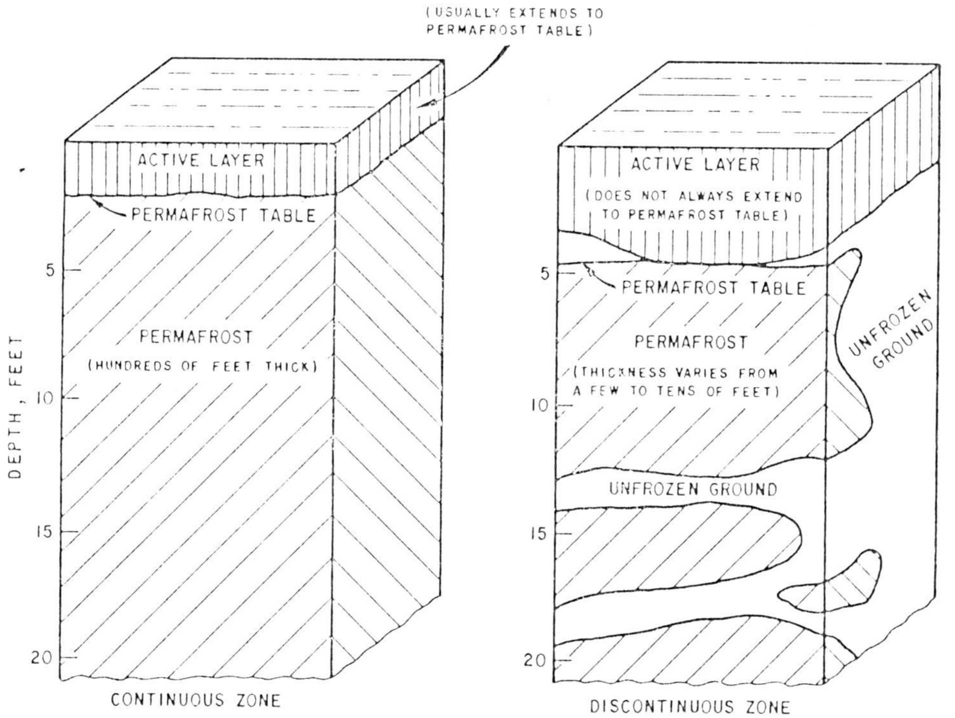


Fig. 2 Typical Profiles in Permafrost Region (Source: Brown, 1970.)

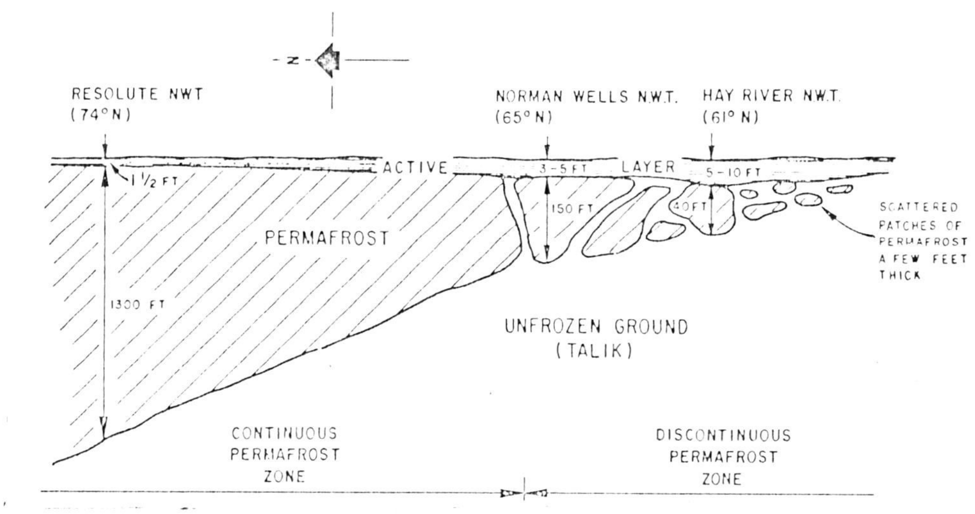


Fig. 3 Typical Vertical Distribution and Thickness of Permafrost (Source: Brown, 1970.)

TABLE 1.

The Location of Selected Far North Climatic Stations

Station	Latitude-North	Longitude-West
	in degrees	
Churchill Manitoba	59	94
Aklavik N.W.T.	68	135
Alert N.W.T.	82	63
Cambridge Bay N.W.T.	69	105
Coral Harbour N.W.T.	64	83
Frobisher Bay N.W.T.	64	68
Resolute N.W.T.	75	94

Source: Hare and Thomas, 1974.

TABLE 2.

Mean Annual Days With Temperature 0° C or less

Station	Mean Annual Days
Churchill Manitoba	255
Aklavik N.W.T.	261
Alert N.W.T.	337
Cambridge Bay N.W.T.	292
Coral Harbour N.W.T.	293
Frobisher Bay N.W.T.	273
Resolute N.W.T.	318

Source: The Department of Transport, Meteorological Branch, Toronto Ontario, 1960.

TABLE 3.

Mean Daily Temperatures (° C)

Station	Months												
	J	F	M	A	M	J	J	A	S	O	N	D	Year
Churchill Manitoba	-28	-27	-20	-11	-2	6	12	6	6	1	12	-22	-7
Aklavik N.W.T.	-29	-27	-22	-13	-1	10	14	11	4	-7	-20	-27	-9
Alert N.W.T.	-32	-33	-33	-25	-11	-1	4	1	-10	-20	-26	-30	-18
Cambridge Bay N.W.T.	-34	-35	-30	-22	-10	2	8	7	-1	-11	-24	-30	-15
Coral Harbour N.W.T.	-30	-30	-25	-16	-7	2	9	8	1	-8	-17	-25	-11
Frobisher Bay N.W.T.	-26	-25	-22	-14	-3	4	8	7	2	-5	-12	-20	-9
Resolute N.W.T.	-33	-34	-31	-23	-10	0	4	3	-5	-15	-24	-29	-16

Yearly Snow (cm) - Churchill 184.3 Aklavik 99.1 Frobisher Bay 78.7
Resolute 247.2

Source: Hare and Thomas, 1974.

TABLE 4.

Mean Precipitation (mm)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Churchill Manitoba	14.0	13.0	17.8	24.1	28.2	40.1	49.0	57.7	52.1	40.4	40.1	20.1	396.1
Aklavik N.W.T.	11.9	10.7	11.2	8.1	8.1	18.3	33.8	36.1	20.1	32.3	21.1	24.4	236.1
Alert N.W.T.	7.6	5.3	7.1	6.6	10.7	13.5	18.0	27.4	27.9	15.8	8.1	8.1	156.1
Cambridge Bay N.W.T.	5.3	4.1	5.6	5.8	7.9	13.5	22.1	26.2	16.3	15.8	8.9	5.6	137.1
Coral Harbour N.W.T.	8.6	10.2	11.7	14.7	17.5	26.4	40.4	43.9	34.5	30.0	17.8	11.4	267.1
Frobisher Bay N.W.T.	24.4	27.9	20.6	22.4	22.9	37.9	53.1	57.9	43.4	41.7	36.8	26.2	415.2
Resolute N.W.T.	2.8	3.3	3.1	5.8	8.6	12.5	26.4	30.5	17.8	15.2	5.6	4.8	136.4

Yearly Snow (cm) - Churchill 184.3 Aklavik 99.1 Frobisher Bay 78.7
Resolute 247.2

Source: Hare and Thomas, 1974.

TABLE 5.

Thickness of Continuous Permafrost Zone for some Far North Stations and Communities

Community	Thickness in m
Asbestos Hill Quebec	273
Churchill Manitoba	30 to 60
Inuvik N.W.T.	91
MacKenzie Delta Lake N.W.T.	76 to 91
Rankin Inlet N.W.T.	303
Resolute N.W.T.	394
Winter Harbour N.W.T.	555

Source: Brown, 1970.

TABLE 6.

Thickness of Active Layer for some Far North Stations and Communities

Community	Thickness in cm
Frobisher Bay N.W.T.	60 to 180
Cambridge Bay N.W.T.	60 to 90
Sachs Harbour N.W.T.	75
Resolute N.W.T.	60
Axel Heiberg N.W.T.	60
Pond Inlet N.W.T.	25
Grise Fiord N.W.T.	30

Source: Brown, 1972.

summer season. During the winter the frozen active layer usually extends to the perennially frozen zone, thus forming an unbroken section of continuously frozen ground (Fig. 2). In the continuous zone the depth of the active layer during the summer varies (Table 6).

As defined previously, the Far North or the Canadian Arctic is in the continuous permafrost zone. It is the existence of an active layer and the presence of the continuous permafrost zone that require special care to be exercised by northern builders.

THE CONSTRAINTS

(a) ON WATER SUPPLY AND WATER QUALITY

For Canadian Arctic communities an adequate and safe supply of water must be located to satisfy the demands of present and future consumers. Sufficient and safe water is necessary for a comfortable living and basic for the sustenance of any community. The availability of water may be the greatest single factor governing the location of communities, and in effect, may determine the future development of a region (Sargent 1963, p. 440).

Subpermafrost water, a type of groundwater, appears to offer the greatest potential for a continuous supply of water in the Far North (Dickens 1959, p. 421). Subpermafrost water is located below the continuous permafrost zone. However its location combined with low temperatures and continuous permafrost do present drawbacks.

The first task is locate a specific area below the continuous permafrost zone, in which the rock or subsurface material would contain sufficient water to justify the high costs necessary to procure the water. Secondly, if the permafrost is hundreds of feet thick, drilling for the water becomes impractical owing to the high costs because deep wells must be drilled; thus a more economic source of water would have to be located and used. Thirdly, even if there is a copious amount of water below the continuous permafrost zone and even if the permafrost is not that thick, the low temperatures and the continuous permafrost zone require precautions in the drilling and operation of wells. Often it is necessary to provide auxiliary heat (steam, hot water) in some form to avoid freezing of the water in the well casing. Wells must be pumped enough to avoid freezing or keep them open. Conversely, there is the danger of excessive pumping. By depleting a large quantity of water in the well, the thermal equilibrium of the permafrost could be disrupted. With water having a higher specific heat than the earth material, the earth material that is located just above the groundwater and possibly some of the material along the sides of the well casing will not be frozen or completely frozen because some heat transfer will take place from the groundwater to the earth material. However, with excessive pumping of the water the specific heat of the water will be lowered. Thus, there is a chance of water freezing. Some of the previously unfrozen earth material will begin to freeze which in turn will increase the stress on the well casing. Therefore, well casings must be anchored firmly in the permafrost zone in order to prevent seasonal frost in the active layer and stresses created by the disruption of the thermal equilibrium of the permafrost ground from crushing, disjointing or otherwise destroying the well casing. Such adaptations increase considerably the cost of procuring this particular source of water.

With relation to water quality, an advantage of subpermafrost water is its low turbidity which eliminates the need for large settling basins generally required by the highly turbid surface sources. However, the subpermafrost water is often brackish and highly mineralized which would necessitate some type of water treatment, such as chlorination (Legget and Dickens 1959, p. 13).

Two other types of groundwater are suprapermafrost, situated between the ground surface and the permafrost table and intrapermafrost which is located in unfrozen or thawed areas within the permafrost zone. Because the continuous zone is so near the surface and because of the low temperatures, these two types of groundwater are not widespread in the Far North. As a source of adequate and safe continuous water supply, they would be insufficient for the far majority of Canadian Arctic communities, both present and future.

The continuous permafrost zone, the active layer, the low temperatures, the engineering adaptations and the difficulty of finding a specific area with sufficient subpermafrost water, increase the costs to develop this source of water to such a great extent that communities and the territorial and federal governments are reluctant to allocate such huge expenditures to develop subpermafrost water as a major source of water supply. Therefore, present and future Far North settlements are likely to depend on surface sources for their water supply. Compared to subpermafrost water, the surface sources are more economic to develop and more accessible.

The Far North is characterized by numerous lakes, streams, ponds and swamps. During the year these bodies of water are the main source of water for most Arctic communities (Table 7). However, with the onset of the long cold winters, some of these bodies of water freeze to the bottom. Bodies of water must be more than 2 to 3 m in depth before they can be expected to provide some water throughout the year. Rarely does the ice cover exceed 2 m in most areas, but the storage space in a lake is very much reduced when a thick ice cover exists (Brown 1970, p. 83).

Communities which depend on surface sources of water that completely freeze to the bottom resort to the melting of ice and snow as their winter source of water (Table 7). For communities located by surface sources that are deep enough (not completely frozen), the liquid water below the ice cover can be used as a supply of water during the winter season.

Few streams or rivers are large enough in the Far North to maintain an appreciable flow throughout the year. The smaller streams and rivers freeze to the bottom. In the larger streams and rivers the formation of frazil ice, which resembles slush, and anchor ice may hinder the use of rivers and streams as a source of water. Frazil ice is formed by the freezing of turbulent water; anchor ice is formed on the bottom of rivers and lakes. These two types of ice can clog the water intake lines. Usually this problem can be controlled with steam lines or some form of heat placed in the intake structures.

The desert like conditions of the cold climate prohibit or make it impractical to use cisterns as a reliable source of water for the entire year. For any water storage reservoir that is constructed, engineering problems must be resolved. The reservoir has to be sufficiently deep so that in the winter enough water is available beneath the ice cover to help satisfy the requirements of the settlement. Reservoirs might accelerate the rate or cause the thawing of the underlying permafrost. Actual construction of the reservoir necessitates the excavation of frozen ground, which is time consuming and expensive.

Low temperatures are pernicious to the quality of water. The freezing action of water tends to concentrate the organic matter of the lake in the unfrozen water below the ice, making it unsuitable for use. Also, ice cover formation freezes or concentrates the dissolved salts in the water below the ice so that there is a high concentration of mineral content (Brown 1970, p. 83).

With long hours of sunlight natural lakes, ponds and swamps in northern areas tend to become highly organic with algae and peat moss, causing some discoloration of the water and also an unpleasant smell or odor (Sargent 1963, p. 440). Large streams or rivers can be turbid mainly due to normal erosion.

In the Far North various treatments to provide a safe supply of water are required.

Certain constraints exist for communities which depend on surface sources for their water supply, particularly with relation to the location and development of communities.

As seen in Table 7, some communities rely on the melting of ice and snow from the completely frozen lakes and rivers as a source of water during the winter. However, it would require the melting of 0.8 to 1 m^3 of snow to provide 67.5 l of water per person per day, a figure generally considered a minimum for adequate drinking, cooking, bathing and laundering purposes (Legget and Dickens 1959, p. 13). High costs of fuel and the labor make such a method impractical for obtaining large quantities such as are required to serve a community. Thus communities that depend on the melting of ice and snow may be somewhat restricted in their size and growth in that people are not going to migrate to a community if the cost of the water is too expensive and too laborious to obtain. Industries or economic activities (such as mining activities which may preprocess the ore before shipment to Southern Canada for processing) which require water and help contribute to the development of a community are not willing to locate in a community if the water supply is inadequate and costly.

Again, by reference to Table 7, it can be seen that some communities rely on lakes as the source of water supply for the entire year. For these communities, despite the low temperatures, the lakes are deep enough so that ample water is below the ice to sustain the community. However, the depth or size of the lake may not be sufficient to meet the demands of future consumers which in turn could curtail the growth of these communities.

Since severity of climate and continuous permafrost limit the practical availability of water to the surface sources, the location of future Arctic communities may be restricted. Numerous factors determine the location of a new settlement but certainly one significant factor will be the availability of an adequate source of water for the entire year. Because the most favourable sources are surface sources (lakes, rivers), future settlements might be strongly influenced to locate by large bodies of water or along the coastline (where most present Arctic communities are located) where an abundance of water would be readily

TABLE 7.

Sources of Water for most Far North Communities 1970 and 1971

Community (population)	Sources
Aklavik (675)	lake and river
Arctic Bay (200)	lake and ice in winter
Arctic Red River (100)	lake - snow and river ice
Baker Lake (900)	lakes
Broughton (120)	stream and lake
Cambridge Bay (420)	lake
Cape Dorset (480)	lake and ice in winter
Chesterfield Inlet (250)	lake and ice in winter
Clyde (370)	lake
Coppermine (500)	river
Coral Harbour (290)	lake and ice in winter
Eskimo Point (470)	lake and ice in winter
Fort McPherson (850)	lake
Frobisher Bay (2300)	lake
Gjoa Haven (100)	lake and stream - ice
Grise Fiord (70)	stream and river
Hall Beach (65)	lake and ice in winter
Holman (180)	lake
Igloolik (530)	two lakes
Inuvik (3500)	lake and river
Pelly Bay (140)	lake and ice in winter
Pond Inlet (300)	stream and lake
Rankin Inlet (550)	lake

TABLE 7.

Continued

Community (population)	Sources
Repulse Bay (200)	lake
Resolute (500)	lake
Sachs Harbour (95)	river - snow and river ice
Spence Bay (125)	lake and ice in winter
Tuktoyaktuk (786)	lake
Whale Cove (150)	lake

Source: adapted from Heinke, 1974.

available to help in the initial establishment of the community and the growth of the community and the surrounding region.

(b) ON WATER TREATMENT

Present and future Canadian Arctic communities are likely to depend on more than one source for their water supply. The quality of water may vary from one source to another and may vary throughout the year. With the diversity of water quality it is difficult to prescribe or recommend specific water treatment methods for all or most Arctic communities. Each possible source of water and the quality of that specific source must be examined and treated by people qualified to recommend the proper treatment processes and design the proper water treatment facilities that are required to treat the "local water" of the community. Regardless of the source, the water in most communities invariably requires some type of treatment. However, the type, the amount, and the cost of water treatment will differ for each community. Again the low temperatures and the continuous permafrost pose problems in that they escalate the costs for water treatment.

Although the principles of water treatment in continuous permafrost areas are the same as elsewhere, the physical features of such treatment must be modified to suit the low temperatures. Aeration, filtration, coagulation, flocculation, sedimentation, chlorination, mixing of chemicals, chemical action, take place at a slower rate because the water is often between 0° C and 4.5° C. The time of mixing and aeration and similar operations must be increased. Chemicals are usually added in greater quantities. Capacities of sedimentation chambers should be made larger than normally provided in the temperate regions (Legget and Dickens 1959, p. 40). Such adaptations to overcome the adversities of the low temperatures are disadvantageous in that the communities must spend more money to treat the water.

To increase the rate at which the different water treatment processes operate, raising the temperature of the water prior to treatment might be advisable in some circumstances. This has been successfully applied to chlorination. At temperatures between 0° C and 9.5° C a chemical action takes place in the solution which removes the chlorine. At 0° C there is practically no chlorine in the solution. This problem was resolved by raising the temperature to 10° C. However, it is important to remember that if the cost of auxiliary heat to raise the temperature of the water surpasses the cost of treating the water at low temperatures, it may be uneconomic or beyond the financial means of the community to heat the water prior to treatment. In addition, the low temperatures dictate that the buildings and equipment be insulated or encapsulated in order to function properly.

Continuous permafrost is a "nuisance" in the treatment of water. The buildings and the equipment must be designed and constructed so as not to disturb the thermal equilibrium of the continuous permafrost zone, and be protected against the freezing and thawing action of the active layer. Again, these adjustments to the permafrost increase the costs of water treatment for present and future Arctic communities.

The methods and sophistication of water treatment processes differ from community to community (Table 8). Larger communities such as Aklavik, Fort McPherson, Frobisher Bay and Inuvik are fortunate to have elaborate treatment plants (by northern standards) to provide good quality water for most of its residents. In these communities the quality of water is such that various treatment processes are required. In addition, these communities have been financially helped by the federal and territorial governments so that most of the people are provided with good quality water. In some of the smaller settlements the main or only method of treatment is chlorination. For some communities such as Tuktoyaktuk it may be the only treatment necessary while in other communities chlorination may be the only treatment that is financially feasible.

It is important to mention that some communities exercise more care or are quite meticulous in carrying out the proper treatment of their water. Other communities are negligent, careless, or irregular in following the proper water treatment procedures. At the community of Holman the water is treated by chlorine. The amount added is checked regularly by the settlement manager, using a testing kit. There have been no complaints concerning the taste of the water, or the overall quality of the water. In the community of Cambridge Bay the water is also treated by chlorination, but there seems to be some confusion concerning what chemical should be added and how much should be added to each tank of water. The water tastes heavily of chlorine. Many residents do not like the taste of the water (Heinke 1974, p. 28). Thus, not only is it imperative that the water be treated but the treatment must be done in the proper manner.

As with water supply, the failure to provide safe water at a reasonable cost could influence the location and development of Arctic communities.

Communities are going to prefer to locate by large sources of water which require a minimum of treatment. Such communities are fortunate because they save greatly in the costs of water treatment, that is providing chemicals, building facilities and equipment to counter the adversities of the low temperatures and the continuous permafrost. Conversely, communities that are located by sources of water that require various water treatment processes, buildings and equipment, are at a disadvantage because large expenditures will be necessary to treat the water.

For example, the community of Tuktoyaktuk depends on a three hectare lake for its main source of water supply. The only treatment necessary is chlorination. This is simply

TABLE 8.

Water Treatment for most Far North Communities 1970 and 1971

Community	Treatment
Aklavik	plant - chlorination
Arctic Bay	no information
Arctic Red River	not chlorinated
Baker Lake	chlorinator - A745 type
Broughton	no information
Cambridge Bay	batch chlorination
Cape Dorset	no information
Chesterfield Inlet	no information
Clyde	no information
Coppermine	batch chlorination
Coral Harbour	no information
Eskimo Point	batch chlorination
Fort McPherson	plant
Frobisher Bay	plant
Gjoa Haven	no information
Grise Fiord	no information
Hall Beach	no information
Holman	chlorination
Igloolik	no information
Inuvik	plant
Pelly Bay	no information
Pond Inlet	no information
Rankin Inlet	chlorination and fluoridation

TABLE 8.

Continued

Community	Treatment
Repulse Bay	no information
Resolute	chlorination
Sachs Harbour	no information
Spence Bay	no information
Tuktoyaktuk	chlorination - truck tank
Whale Cove	no information

Source: adapted from Heinke, 1974.

done by adding a set amount of chlorine to the truck tank each time it is filled. The quality of the water is good. The cost of treating the water is reasonable. At the community of Eskimo Point the conditions are deplorable. The lake-reservoir has failed to provide water of an acceptable physical and bacterial quality. High turbidity, high chloride ion concentration and a high amount of coloration of the water have been reported. The nurses of the community nursing station have attributed the high amount of diarrhea and vomiting to the water supply. No one will drink the water unless it has been boiled for twenty minutes. Proper treatment will be costly. Another source of water supply should be sought because the present source demands too much treatment (Heinke 1974, p. 52). Indeed, present communities will not grow and future communities will not locate and develop if the amount and cost of treatment for their water source is exorbitant. People will be reluctant to remain in or move to settlements if the water is unhealthy.

Not only is it important to have an abundance of water available for present and future communities throughout the year at a reasonable cost, but the water must be of an acceptable quality, that is potable, free of discoloration, odorless, not hard, and safe to use so that the health of the community will not be endangered or jeopardized.

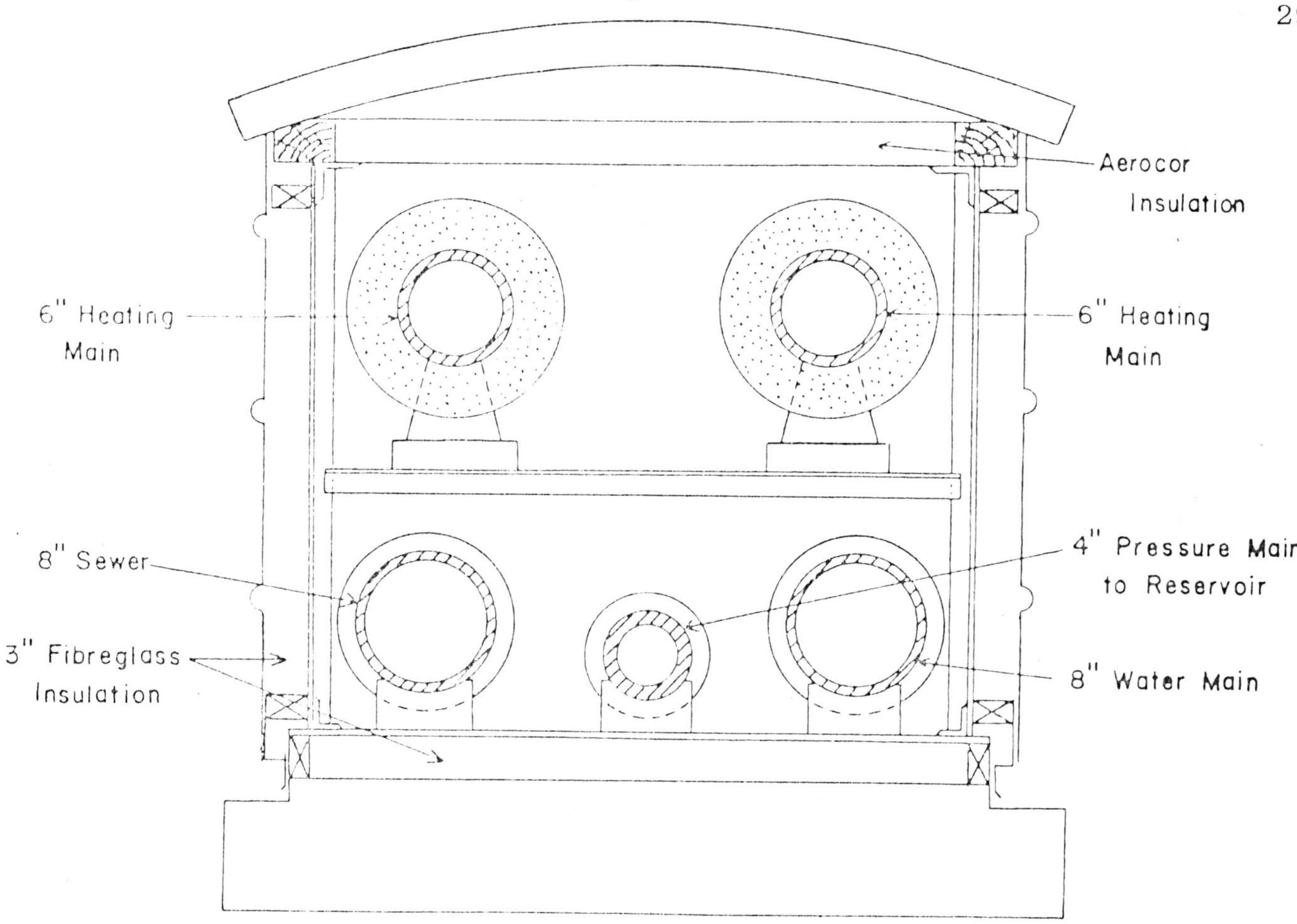
(c) ON WATER DISTRIBUTION

Distribution of water to the non-indigenous population of Canadian Arctic settlements is perhaps the most difficult service to provide at a southern level of convenience and in a form sufficiently economic to be of wide application. Conventional methods of distributing water to consumers, efficiently, conveniently and economically must be modified due to the low temperatures and the continuous permafrost zone. Modifications augment the cost of designing, installing, and operating a modern sophisticated water distribution system to Far North settlements.

In the consideration of a modern water distribution system these major constraints must be taken into account. First, the system must be constructed so that low temperatures will not freeze the water during distribution. Secondly, the system must be built so that melting or thawing of the continuous permafrost table does not occur. Thirdly, the builder of a system must keep in mind the seasonal freezing and thawing of the active layer. Finally, there is the factor of costs for introducing and operating a modern water distribution system in a community.

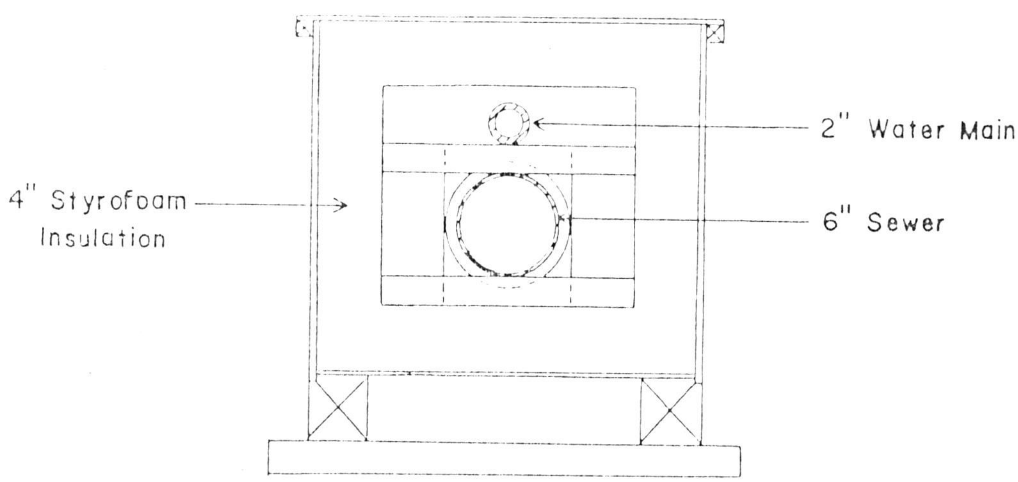
Two popular systems (although by no means the only ones) have been used in an attempt to provide a modern water distribution for Canadian Arctic communities. The first is the utilidor (Fig. 4 and Fig. 5), an insulated or heated conduit which usually contains utility services such as electricity, water and sewerage lines (Hubbs 1963, p. 427). By supplying heat to the water, either at the source or in the distribution system with steam, hot water boilers or electric heaters, freezing of the water can be

Fig. 4



Cross-section View of Inuvik Utilidor
(Source: Cooper, 1967.)

Fig. 5



Cross-section View of Ft. McPherson Utilidor
(Source: Cooper, 1967.)

minimized. Well-designed utilidors greatly simplify the continuous distribution of water in low temperature areas. A second approach is a pre-heated recirculating type water system, which provides for recirculating of water throughout the entire system, including house service connections (Hubbs 1963, p. 427). Of the two systems the utilidor seems the most popular and offers the greatest potential for distributing the water conveniently.

Regardless of the system used or its location, preservation of the continuous permafrost and consideration of low temperatures and the active layer must be dealt with.

If the distribution system (the pipes) is placed in the continuous permafrost zone, it is imperative that the heated water pipes be correctly insulated, wrapped or enclosed. Failure to do so will lead to freezing of the water in parts of the system by the cold temperatures. Proper insulation or enclosure is mandatory to eliminate or minimize heat leakage into the surrounding permafrost zone. Such heat leakage will contribute to permafrost degradation in which thawing of the earth material around the pipe system happens. Thawed permafrost material will lose its bearing or supporting strength, resulting in disruption or breakage of the piped water distribution system. With heat leakage and subsequent permafrost degradation, the insulation itself might become water-logged, thus losing its insulating strength against cold temperatures, which in turn could cause freezing of the water. Therefore, great care must be exercised to avoid disturbing the delicate natural thermal equilibrium in the continuous permafrost zone.

Pipe systems above the ground are sometimes supported by piles. To avoid disruption of the water system, the piles or whatever is used for support should be placed, driven or drilled into the ground to a depth which exceeds the thawing of the active layer during the warm season. Once the piles or supports are in the ground and allowed to freeze in, they develop ample bearing strength (Cooper 1967, p. 34). The pipes should also be supported at a sufficient height above the ground surface to minimize heat transfer into the ground (the active layer).

A system that is placed on the ground surface itself must again be insulated to withstand the low temperatures, avoid permafrost degradation and withstand the freezing and thawing forces of the active layer.

Local conditions will govern the location of a modern piped water distribution system. The conditions of the soil in the area, the difficulties which may arise from frost and thawing action in the active layer and the threat of continuous permafrost degradation will be important factors that influence whether a surface, above-surface or sub-surface system should be introduced to a community. In areas of gravel or coarse sand, where little ice exists, few if any difficulties are experienced with a sub-surface water distribution system; in fine grained soils or organic material with high ice content, considerable difficulties are likely to occur. Unless the active zone and the underlying permafrost are in well-drained non-frost active material extending to considerable depth, 4.5 m, a surface or above-surface system should be used (Legget and Dickens 1959, p. 16). Utilidors that are presently in operation at the communities of Inuvik, Frobisher Bay, Fort McPherson, Baker Lake and Coppermine are on the surface or above the surface. Government buildings and personnel, and some of the non-indigenous people are usually served by the utilidor.

The cost of introducing and operating a modern water distribution cannot be neglected. Technologically, it is possible to install and operate a successful modern water distribution system in Arctic communities (Table 9), but if the expenditures involved are too high for the government (federal and territorial) and the non-indigenous people in the communities, the modern system (utilidor) would be uneconomic or impractical to use. For example, the utilidor surface system at Inuvik cost \$775/m; the utilidettes connecting the individual houses with the utilidor cost \$405/m. Total footage constructed was 4575 m of utilidors and 1675 m of utilidettes (Yates and Stanley 1966, p. 418). Fortunately for the town of Inuvik, the government contributed most of the money to install the utilidor system in the town. Thus, the main drawback of using a modern distribution system such as the utilidor for most Far North communities is the high cost.

Research and experimentation is being conducted to develop a less expensive utilidor. Communities such as Rankin Inlet and Inuvik have made plans for extension of their utilidor service to more residents. The utilidor system is probably the best system for distributing an adequate amount of safe water conveniently to the people. With the development of a more economic type of utilidor it may be possible for present and future Arctic communities to introduce and extend the use of utilidors for their residents.

Because of the exorbitant costs of utilidors, communities that do not have utilidors and even communities which do have them but serve only part of their population have had to resort to simpler but less costly methods of distribution. Some of these methods are sledge, truck, barrel, buckets, waterpoints, and pipes (summer only). The most common method used for water distribution is by truck delivery (Table 9). For example, at Tuktoyaktuk government housing and buildings have individual pressure systems; each house has a water storage tank holding between 810 and 2250 l which is filled twice a week by the trucks (Cooper 1967, p. 28). For most communities truck delivery of water to individual households and buildings have been satisfactory, although periodic problems have been experienced with water contamination, regularity of delivery and cost of the delivery.

Trucks, barrels, buckets, sledge and waterpoints are far from approaching any reasonable level of convenience as known in Southern Canada. However, these inconvenient methods of distribution may be the only sensible economic means for most present and future Canadian Arctic communities unless an economic type of utilidor is developed.

The inability of a community to distribute an adequate and safe amount of water conveniently and economically to its people could be detrimental to the growth or development of the community. This constraint can be clarified with reference to the town of Inuvik, which was the first community north of the Arctic Circle built to provide the normal facilities and services of a Canadian town. In January 1970 Inuvik had a population of 3500 people. The town is expanding rapidly. An estimated population of 7500 is predicted for the year 1985. Already the town is much larger than the 2000 residents anticipated by the original designers. The inadequacy of the water supply system reflects this problem. Improvements will have to be made to the water supply system and the distribution system, both pipe and truck, if the town is to develop and grow as forecasted. Failure to do so may retard the growth and development of the town (Heinke 1974, p. 99). People will hesitate to remain or move to communities if the water distribution system is inconvenient and expensive. Certainly, the development of an economic and convenient method of water distribution which could be adapted by most if not all

TABLE 9.

Water Distribution for most Far North

Communities 1970 and 1971

Community	Methods of Distribution		
	Piped all Year	Piped-Summer	Truck-Home
Aklavik		iron-pipe	
Arctic Bay		plastic	
Arctic Red River			
Baker Lake	utilidor		all year
Broughton			
Cambridge Bay			all year
Cape Dorset		pipes	
Chesterfield Inlet			
Clyde			all year
Coppermine	utilidor		all year
Coral Harbour		plastic	
Eskimo Point			all year
Fort McPherson	utilidor		all year
Frobisher Bay	utilidor		all year
Gjoa Haven			summer
Grise Fiord			
Hall Beach		plastic	
Holman			all year
Igloolik			all year
Inuvik	utilidor		all year
Pelly Bay			summer

TABLE 9.

Continued

Community	Methods of Distribution Truck-Ice	Waterpoints	Other
Aklavik		four	
Arctic Bay	winter		
Arctic Red River		one	buckets
Baker Lake		four	
Broughton	winter	one	
Cambridge Bay			
Cape Dorset	winter	one	
Chesterfield Inlet			buckets
Clyde			
Coppermine			
Coral Harbour	winter		
Eskimo Point			
Fort McPherson		four	individual
Frobisher Bay			
Gjoa Haven	winter		
Grise Fiord	winter		individual
Hall Beach	winter		
Holman			
Igloolik			
Inuvik			
Pelly Bay			individual

TABLE 9.

Continued

Community	Methods of Distribution		
	Piped all Year	Piped-Summer	Truck-Home
Pond Inlet			all year
Rankin Inlet	utilidor		all year
Repulse Bay			all year
Resolute	piped		all year
Sachs Harbour			
Spence Bay			
Tuktoyaktuk			all year
Whale Cove			all year

Community	Methods of Distribution		
	Truck-Ice	Waterpoints	Other
Pond Inlet			
Rankin Inlet			
Repulse Bay			
Resolute			
Sachs Harbour	winter		barrels
Spence Bay			individual
Tuktoyaktuk		six	
Whale Cove			

Source: adapted from Heinke, 1974.

present and future Far North communities would be a catalyst in the growth and development of Canadian Arctic communities.

(d) ON SEWAGE COLLECTION AND DISPOSAL

Like water distribution, continuous permafrost, low temperatures, seasonal freezing and thawing of the active layer and high costs preclude most Arctic communities from providing a modern collecting system for sewerage and waste water and its disposal in an economic and safe manner as known in many communities in Southern Canada. The effectiveness and safety of most methods of sewage collection and disposal are greatly impaired by low temperatures and continuous permafrost (Legget and Dickens 1959, p. 17).

In the Far North the processes of assimilation and decomposition of liquid wastes that occur in soils of temperate regions do not appear to take place at all in permanently frozen ground, and only very slowly in the shallow layers of the seasonally thawed ground. The continuous permafrost prevents proper leaching into the soil and resulting poor drainage causes a veritable cesspool on the surface of the ground where normal practices of disposal in the soil are used. Pit privies and septic tanks which are common methods of sewage and waste water collection and disposal in the temperate regions of Canada are therefore seriously curtailed or virtually eliminated in the Far North. Also, in the collection and final disposal of sewage and waste water, pollution of the Arctic environment and the health of the community must be considered.

Very few modern water carried community sewage collection systems have been installed in Far North communities. In some instances this is partly due to the lack of water, but other important factors are the expense of combating low temperatures, frost action and continuous permafrost. Collecting sewage lines can be kept operative in the Far North only if they are protected from freezing and from differential movement due to frost and thawing action in the active layer and prevented from melting the continuous permafrost zone. Enclosing the sewage collection system in a heated passageway or utilidor (Fig. 4) is probably the most positive and promising way of ensuring trouble-free operation, but again such systems are beyond the financial means of most communities.

The problem of sewage treatment before disposal is perhaps the most difficult water service to perform satisfactorily. The cold climate retards the decomposition of organic compounds and slows any biochemical reaction. Conventional sewage treatment processes to function properly require a warm environment. To provide the necessary heat for sewage treatment processes, to take into account the active layer, and the threat of permafrost degradation, the costs in the design, construction, and operation of sewage treatment plant facilities are greatly increased. Therefore, very few Far North communities have or treat their sewage before final disposal as most communities do in Southern Canada.

Because of the expense very few communities use the utilidor for collection of sewage and waste water. Most of the communities rely on "primitive methods" for collection. Such methods include buckets, the honey bag, or a sewage storage holding tank with organized pickup by truck or track vehicle (Table 10) (Yates and Stanley 1963, p. 415). Waste water is sometimes allowed to drain into the soil around each house or building. However, great care must be taken in discharging heated liquid wastes near a building because the waste water may thaw the continuous permafrost, causing ground water to collect and the building to settle.

Two methods of disposal are in common use in the Far North. The first method is to dispose that is dump or pipe the sewage and waste water into nearest waterway (river, bay, or lake), relying on the water course or the tidal waters to dilute the sewage (Brown 1970, p. 88). A second method is to distribute the sewage and waste water onto the ground at some designated dump site, preferably located away from the community (Table 10). In both methods, there is usually no pretreatment of the sewage or waste water.

Using water courses for disposing untreated sewage has been satisfactory, especially for communities that are isolated and located by large bodies of water. However, this method can be hazardous. For example, if a community is situated on a water course (the source of drinking water for the community) downstream from another community which is discharging its untreated sewage and waste water into the same water course, serious health hazards can be created for the downstream community such as the pollution of its drinking water. At land dumps the continuous permafrost and the shallow active layer do not permit the sewage and waste water to drain into the ground very far, which unfortunately causes the untreated sewage to accumulate at the surface. Hence, disposal of untreated sewage and waste water onto the land at dump sites is unsatisfactory in that the dumps acquire offensive and unsanitary characteristics which aesthetically and environmentally are not desirable.

As the population increases, as present communities grow and as future communities develop, the discharging of untreated sewage and waste water into water courses and onto the ground will become a more significant health matter and the need for treatment facilities more pronounced (Legget and Dickens 1959, p. 18).

Sewage lagoons may be the answer for the disposal and treatment of sewage and waste water for Far North communities. The sewage lagoon is economical, safe, and appears to be one of the acceptable answers to the problem of sewage disposal and treatment (Brown 1970, p. 88). Sewage lagoons provide for both biological and secondary treatment of sewage, if properly constructed, and furnish treatment approaching that in most of the more expensive treatment plants. The initial and operating costs of lagoons are less than for conventional treatment plants.

With the lagoon system the sewage and waste water is dumped or piped into a large shallow depression or pond. The sewage is stored for a period of time, allowing the effluent to decompose aerobically. After the sewage is sufficiently treated the sewage is discharged into a large body of water, usually at a time of the year when there is no danger of contaminating the local water supply.

Nevertheless, there are some problems with this method. Lagoons require a large area of land, 4047 m^2 (one acre) for every hundred people is normally recommended (Dickens 1959, p. 431). In the winter months low temperatures slow down considerably the natural decomposition of the sewage. Therefore, to ensure some aerobic activity and minimize the odors, the depth of the lagoon should be greater than 2 m, so that some liquid water will remain below the ice. The lagoon must be structurally sound to prevent melting of the underlying permafrost and seepage of sewage wastes into the surrounding region (Grainge 1973, p. 68). The long-retention sewage lagoon has been introduced at the town of the Inuvik. The lagoon itself covers 22 hectares, is irregular in shape, and is largely brush-filled. The lagoon has been providing good treatment (Heinke 1974, p. 98). However, further investigation is still required to refine the design and construction criteria for sewage lagoons.

Of the various water and sewerage services in operation in Far North communities, perhaps the collection and disposal of liquid sewage and waste water are the services most poorly carried out. The trucking of honey bags, the individual disposal of honey bags, the permitting of waste water to drain directly onto the ground, the disposal of untreated sewage in water courses or at a land dump are rudimentary. Such methods of collection and disposal are also unsanitary for residents of these communities. Certainly most communities need to operate their present sewage services more carefully or upgrade them if community health problems and destruction of the Arctic environment are to be minimized. Indeed, there is a great need of economic, advanced waste water and sewage collection and disposal systems. The further development of the utilidor and sewage lagoons may be the answers in trying to reach the objective of providing economic sewage collection and disposal for most present and future Arctic communities.

Communities that do not or are slow to improve or upgrade their sewage services could hinder their own growth. Present communities are not going to expand if the environment is aesthetically unappealing, unhealthy or if there is a threat of diseases due to the "crude," careless collection and disposal of sewage and waste water.

Future communities may choose to locate by a large body of water, where an ample area of water is available to dispose and dilute the sewage and waste water and at the same time not pose a serious pollution threat to the community source of drinking of water. Future communities that may wish to use the sewage lagoon system or prefer to dispose of their sewage onto the land may desire a location where a large area of land is available for disposal and the construction of the sewage lagoon.

TABLE 10.

Disposal of Sewage and Waste Water for most Far North Communities 1970 and 1971

Community	Disposal Location	Truck Holding Tanks	Truck Honey Bags
Aklavik	dump	all year	all year
Arctic Bay	dump		all year
Arctic Red River	dump		winter
Baker Lake	dump	all year	all year
Broughton	bay		all year
Cambridge Bay	bay	all year	all year
Cape Dorset	dump		all year
Chesterfield Inlet	dump-bay		all year
Clyde	dump		all year
Coppermine	bay	all year	all year
Coral Harbour	bay		all year
Eskimo Point	dump	all year	all year
Fort McPherson	dump-lagoon		all year
Frobisher Bay	bay	all year	all year
Gjoa Haven	bay		all year
Grise Fiord	dump		all year
Hall Beach	dump		all year
Holman	dump		all year
Igloolik	dump-beach		all year
Inuvik	dump-lagoon		all year
Pelly Bay	dump		all year

TABLE 10.

Continued

Community	Piped	Other
Aklavik		waste water-ground
Arctic Bay		
Arctic Red River		waste water-ground
Baker Lake		
Broughton		individual honey bags
Cambridge Bay		
Cape Dorset		
Chesterfield Inlet		
Clyde		
Coppermine		
Coral Harbour		
Eskimo Point		
Fort McPherson	utilidor	
Frobisher Bay	utilidor	
Gjoa Haven		
Grise Fiord		
Hall Beach		
Holman		
Igloolik		waste water-ground
Inuvik	utilidor	
Pelly Bay		

TABLE 10.

Continued

Community	Disposal Location	Truck Holding Tanks	Truck Honey Bags
Pond Inlet	dump		all year
Rankin Inlet	dump		all year
Repulse Bay	dump-bay		all year
Resolute	lake-ground		
Sachs Harbour	bay		
Spence Bay	bay		
Tuktoyaktuk	dump	all year	all year
Whale Cove	dump-bay		all year

Community	Piped	Other
Pond Inlet		
Rankin Inlet	utilidor	
Repulse Bay		
Resolute	heated line	septic tanks
Sachs Harbour		individual buckets
Spence Bay		individual honey bags
Tuktoyaktuk		waste water-ground
Whale Cove		

Source: adapted from Heinke, 1974.

SUMMARY

Continuous permafrost and low temperatures complicate the provision of modern, convenient, economic water and sewerage services to the non-indigenous people of Canadian Arctic communities. The amount, the quality, and the sophistication of water and sewerage services operating in Far North communities differ greatly from community to community (Fig. 6). Some of the larger communities such as Inuvik, Frobisher Bay, and Fort McPherson have acceptable, workable water and sewerage services; some of the smaller communities such as Igloolik have somewhat primitive services (Fig. 6). The overall influence of continuous permafrost and low temperatures has been and will be to increase the costs of providing modern water and sewerage services because of the engineering modifications that must be introduced.

Scientific and engineering technology has progressed to such an extent that it is plausible to provide modern water and sewerage services to Canadian Arctic settlements. Compared to Southern Canada, few municipalities exist in the Far North. None has a big enough tax base to afford water and sewerage services. Therefore, municipalities have been aided by the territorial and federal governments to provide the services. If Far North communities are to provide modern water and sewerage services and if Far North communities are to develop and grow, it is imperative that the territorial and federal governments continue to financially assist the Far North communities. Additional capital or money will in all likelihood be obtained from the future development of the major extraction industries in the Canadian North, mainly oil and gas and minerals. Some of the profit that hopefully would be obtained from the development of these natural resources could be invested in present and future Arctic settlements to provide and upgrade water and sewerage services.

In the Canadian Arctic much more practical research and investigation are needed to provide modern, simpler, less costly and more reliable water and sewerage services. To reach this objective, the cost involved is admittedly high by southern standards. Hopefully, reductions in cost can be expected as knowledge of permafrost phenomena and engineering techniques improve and design data become more refined and hopefully, better community planning to facilitate economic servicing can be expected to reduce costs substantially.

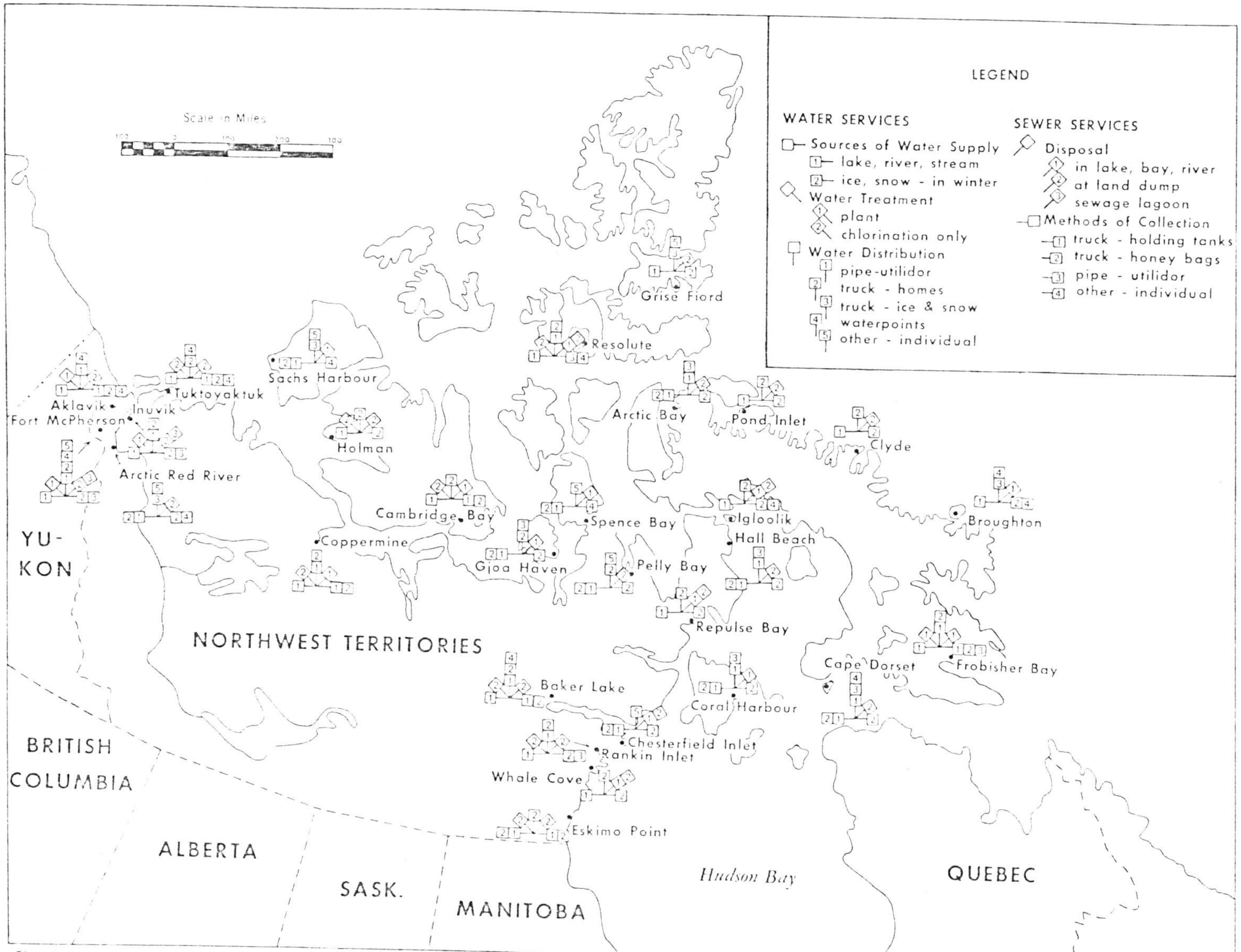


Fig. 6 Water and Sewer Services for the Non-indigenous Population of Most Far North Communities

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