Water Supply and Waste Disposal Systems for Arctic Communities

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ABSTRACT: The special problems of providing adequate water supply and waste disposal systems for arctic settlements are examined at the community of Frobisher Bay, Northwest Territories. The two existing methods, a trucked and a piped system, are compared for adequacy, reliability and cost. A series of alternative improvements to upgrade community services is proposed. It was concluded that any of the suggested alternatives up to the level of complete piped services are feasible from engineering and economic points of view.

RÉSUMÉ: *Systèmes d'adduction d'eau et d'évacuation des déchets dans les villages de l'Arctique.* Dans le village de Frobisher Bay, Territoires du Nord-Ouest, les auteurs ont étudié les problèmes particuliers d'adduction d'eau et d'évacuation des déchets dans les établissements de l'Arctique. Ils comparent les deux méthodes existantes — système par camion et système par tuyaux — aux points de vue de la suffisance, de la régularité et du coût. Ils proposent une série d'alternatives pour l'amélioration des services publics. Ils concluent que toutes les solutions proposées, jusqu'aux services entièrement assurés par des tuyaux, sont possibles des points de vue économique et technique.

РЕЗЮМЕ. *Водопроводно-канализационные системы для полярных районов.* На примере посёлка Фробишер Бей (Северо-Западные Территории) исследуются специфические проблемы обеспечения селений крайнего севера необходимыми водопроводно-канализационными системами. Проводится сравнение эффективности, надёжности и стоимости двух существующих методов: метода автотранспортных перевозок и метода трубопроводов. Предлагается ряд альтернативных решений для улучшения этого вида обслуживания населения. Сделан вывод, что любая из рассматриваемых возможностей, вплоть до полного обеспечения посёлка трубопроводами, осуществима как с инженерной, так и с экономической точки зрения.

INTRODUCTION

Several factors must be considered in addition to those for most southern communities when planning water supply and waste disposal systems for settlements in northern areas where continuous permafrost occurs.

Climate

The ground is permanently frozen.

Lakes and rivers are frozen and working conditions are difficult for much of the year.

Most settlements are small, varying in population from a few hundred to a few thousand people.

Settlements developed often before the provision of services was considered important resulting in a spread-out and haphazard layout. Extensive replanning must often precede servicing.

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The lifestyle of at least a portion of the community may require different types and levels of housing and services to those commonly used in southern communities.

Some of the housing is of low quality and requires upgrading or replacement before servicing becomes sensible.

Servicing costs are much higher than in the south.

Trained manpower is very scarce.

Many smaller settlements have no central water supply or waste disposal system; all larger settlements do. Present community servicing systems are generally of one of two types; often both exist within one community. They are: a trucked system and a piped system, usually above ground in heated or insulated structures called utilidors.

The trucked system provides delivery of small quantities of water to storage tanks in homes. It may provide liquid sewage pick-up from holding tanks, or "honey-bag" (a plastic bag holding feces and urine) pick-up. Its advantages are lower capital investment, relative independence from town layout, and source of income to the town through high labour requirements.

Its disadvantages are unreliability of operation in bad storms, lower quantities of water delivered, lower standards of fire-fighting ability and high operating costs. Another disadvantage can be that kitchen and bath water must often be discharged directly onto the ground, sometimes causing drainage problems and creating a potential health hazard.

The piped (utilidor) system has the advantages of reliable operation, low operating costs, larger quantities of water delivered, good fire-fighting capacity and collection of all household wastes. Its disadvantages are high capital cost and strong interdependence on town layout. Several other methods have been tried, including summer water distribution systems, low cost utilidors, individual recirculation units for a small complex of buildings, pressure sewer systems, etc., with varying degrees of success or failure. Future research and development may bring about methods of waste disposal which are not water carried. In areas of critical water shortage, multiple reuse of water will become feasible. However, it is more likely that such advanced treatment plants will be community-wide, rather than for an individual household, thus still requiring a distribution and collection system. A complete recirculation system for a household would have to be *simple* to succeed. The record to date with mechanically complex individual units is poor.

At some stage of development of a community, the question arises what system it should adopt or expand. In this paper the question is examined in one community, Frobisher Bay, Northwest Territories. While the results are directly applicable to Frobisher Bay only, the general findings and procedures used are applicable to other northern communities. The emphasis is on providing technical and cost information on alternatives of varying degrees of sophistication and cost, from which a sensible choice can be made for varying degrees of financial capability to afford systems.

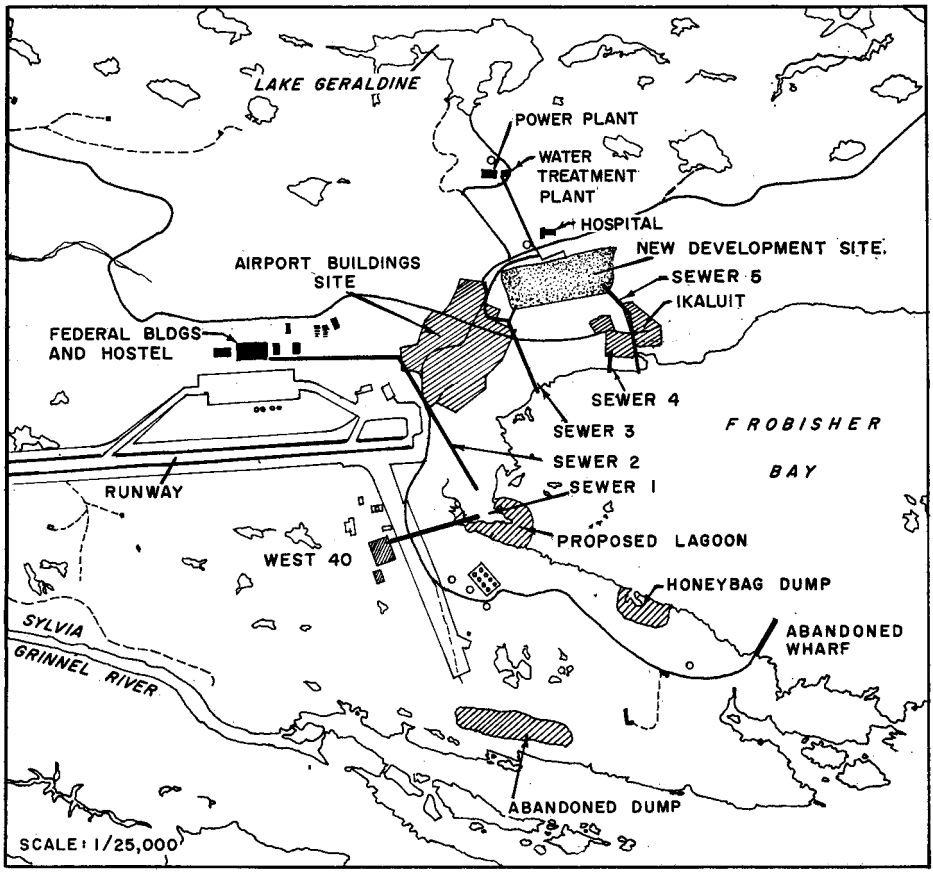

FIG. 1. Frobisher Bay site development. Based on chart by Technical Services Branch (M & C), Canada Department of Indian Affairs and Northern Development, 12 March 1969.

EXISTING CONDITIONS AT FROBISHER BAY

The town of Frobisher Bay has a population of more than 2,300 people. It is situated on Baffin Island, on the western end of Frobisher Bay, at 63° 44′ N., 68° 28′ W. It is now the administrative and educational centre for the Eastern Arctic. While the extent and rate of future growth are subject to considerable speculation, there is agreement that it will grow. A site plan is shown in Fig. 1.

Municipal services are provided by a utilidor system for the central part of the town and by an extensive trucking system for most of the residential area. Water supply is obtained from Lake Geraldine north of the community. It is treated and provides a safe and ample supply of water for the foreseeable future. The main box utilidor runs from the treatment plant to the hospital and new development site. It contains, in addition to water and sewer mains, high-temperature water-mains and returns for central heating. It has several branch lines. The total number of people serviced by the utilidor system is estimated at 1,100.

A contractor holds a five-year contract, starting in 1969, for water delivery,

sewage and "honey-bag" pick-up, and garbage collection for about 310 housing units with an estimated population of about 1,300 people. About 35,000 gallons per day are obtained from a central supply point and delivered by five trucks daily. Houses are equipped with water tanks of 45 to 250 gallons capacity. Households having internal plumbing and sewage holding tanks number 116. These are pumped out, trucked and emptied into a centrally located sewer. Five sewer outfalls discharge untreated sewage into the bay. All remaining households use the "honey-bag" pick-up system for disposal of human waste. Other liquid household wastes from kitchen, bath, laundry, etc., are discharged directly to the ground outside the homes through a drain or by bucket. Table 1 gives a breakdown of housing types and services, and water consumption per household. Water consumptions shown are typical of arctic communities. Houses with no internal plumbing receive about 5 gallons/person/day. In many smaller communities with a less efficient trucking system, this figure is as low as 1 gallon/person/day. It may be augmented by water collected by bucket by the householder.

TABLE 1. Housing and water consumption

Service	*Housing Type*	*No.*	*Water Consumption (gal./unit/day)*
Utilidor	Houses, Row H., Apts. (complete plumbing)	243	86-316
Truck	Houses (complete plumbing)	198	97-165
Truck	Houses (no plumbing)	112	17-24

The capital and operating costs of the utilidor system at Frobisher Bay are not well documented. The main utilidor cost was in excess of the main utilidor at Inuvik, Northwest Territories, which had an estimated cost in excess of $230 per foot. A more recently constructed steel duct utilidor, using vermiculite insulation around the water and gravity sewer, cost $82 per foot. Maintenance and operating costs are not known, but are believed to be low. More extensive information on utilidor design and costs are given by Leitch and Heinke (1970).

TABLE 2. Cost of present trucked system

Service	*Rate*	*Annual Quantity*	*Contractors Annual Charge*
Water (< 100 gal. tank)	$25/1000 gal.	1.5 MG	$ 36,000
Water (> 100 gal. tank)	$18.50/1000 gal.	1.3 MG	24,000
Water & Sewage	$34/1000 gal.	8.5 MG	287,000
Honey-Bags	$1.60/bag	76,000	121,000
Garbage	$2.00/drum	49,000	98,000
	Contractors annual charge		$566,000
	Additional costs (water, etc.)		$ 68,000
	Annual cost of trucked service		$634,000

Contract costs of trucked services vary widely in the many communities in the Northwest Territories using such a system. For this reason, a detailed investigation of the contract costs and the contractors' expenses at Frobisher Bay was carried out. Table 2 summarizes the cost of the present trucked system. Table 3 is an attempt to estimate the contractor's expenses. It shows that the contractor makes an estimated profit of $127,000 per year on total contract cost of $566,000. Table 4 shows the cost of water delivery and sewage or "honey-bag" pick-up per household. The annual costs per household are much higher for a much lower level of service than in southern communities. These unit costs generally agree with similar calculations by Simonen and Heinke (1970) for a proposed trucking system for Fort McPherson, Northwest Territories of $1,350 per household per year.

TABLE 3. Trucking contractor's expenses*

Item	*Annual Cost*
Equipment (10 trucks — $115,000 at 5 years and 8%)	$ 29,000
Maintenance	39,000
Fuel & Supplies	18,000
Wages (25 men at $3.00 (avg.) per hour)	267,000
Administration & Overhead	86,000
Total expenses	$439,000
Total income	$566,000
Estimated profit	$127,000 or 22%

*This estimate was prepared by the authors from general information received from the contractor, Tower Foundation Co.

TABLE 4. Unit Costs of Present Trucked System

Service	*Water Consumption (gal./unit)*	*Annual Unit Cost*
Water & Sewage	165	$2,200
Water & Sewage	107	1,425
Water & Honeybag (internal plumbing)	97	1,330
Water & Honeybag (no internal plumbing & 250 gal. water tank)	24	770
Water & Honeybag (no internal plumbing & 45 gal. water tank)	17	760

Improvements to Dwellings

Dwellings connected to the piped system have interior plumbing and fixtures comparable to those found in modern Canadian homes. In dwellings serviced by truck internal facilities range from a 45-gallon drum water tank, bucket sink and toilet, to a very few dwellings with complete modern plumbing. A replacement program for installing larger capacity water tanks (100 to 250 gal.) with external filling and overflow pipe is now under way. To upgrade all dwellings to have complete modern plumbing would neither be practical nor economical in view of

the quality of the dwellings and the system servicing them. However, a series of alternatives of upgrading internal facilities must be examined before it makes sense to improve the trucking system or extend the piping system. Three levels of alternatives were examined and costs estimated (Deans and Heinke 1971). The alternative chosen is explained in Table 5. The installations suggested are compatible with an improved trucked system or with a future piped system. The only items to be removed when connecting to a piped system are the water and sewage holding tanks. Costs are based on 1971 wage rates of the Department of Public Works, Government of the Northwest Territories.

TABLE 5. Trucked system — upgrading of internal facilities

Installation	*Capital Cost Installed Per Unit*	*Annual Cost (8 years at 8%)*
Toilet and 250 gal. Sewage Tank (Internal Plumbing Exists) (82 Homes)	$365	$ 65
Toilet, 250 gal. Sewage Tank and Internal Plumbing (56 Homes)	$850	$150

NOTE: No improvements are suggested in 56 single room houses because of their overall low quality. They are to be replaced as soon as possible.

Improvements in Trucked System

Water consumption in dwellings which have much improved internal facilities will increase considerably. It would be reasonable to assume that the increases in the amount of water delivered and sewage picked up will reduce unit charges. However, in the following cost comparison the present contract unit charges have been used. The improved trucked system would assure the elimination of the "honey-bag" system, would provide for at least 100 gallons/unit/day water delivery (estimated to be about 20 gallons/person/day, and disposal by pumpout of all household liquid wastes. The operations of the present trucked system are carried out in a generally satisfactory way. The contractor would need to purchase additional trucks to handle the enlarged program. Table 6 summarizes capital and operating costs of the improved trucked system, and gives present operating costs for comparison.

TABLE 6. Cost comparison of present and improved trucked system

Prop. Installation	*Capital Cost* $/unit/year*	*Operat. Cost Imp. Syst. $/unit/year*	*Total Cost Imp. Syst. $/unit/year*	*Operat. Cost Present System $/unit/year*
Nil (Butler Bldgs.)	Nil	1425	1425	1425
Toilet and 250 gal. Sewage Tank	65	1600	1665	1330
Toilet, 250 gal. Sewage Tank and Internal Plumbing	150	1330	1480	765

NOTE: The improved trucked system provides internal plumbing, toilet, water and sewage tanks in all but 56 substandard houses. It would provide for 100-120 gal./unit/day.

*For proposed installations in homes.

Extension of Piped System

Piped services are considered for most sections of the community, not necessarily because it makes economic sense, but for the purpose of cost comparison with the trucked system. It should be emphasized that this is a "rough-cut" conceptual look at the piped system design to permit an approximate cost estimate. A detailed design and cost estimate would need to be carried out later.

The latest available site plan (Department of Indian Affairs and Northern Development Plan, amended April 1971), was used as a basic map. The section not serviced now with a piped system was divided into 4 areas, which would permit complete or partial staging of servicing. Since all of these areas are mainly residential, the decision was made to provide water and sewer services only, not central heating. Should certain office or institutional buildings located within these areas be provided with central heating, additional costs would have to be allowed for.

The utilidor chosen was originally designed by Associated Engineering Services Ltd., Edmonton, for the extension in Inuvik. It consists of a 21-inch diameter corrugated steel pipe arch, insulated with 1½ inch urethane insulation, sprayed in place. It houses a 4-inch or 6-inch asbestos-cement watermain and an 8-inch asbestos-cement sewer. A cost of $100 per foot for the main line and $70 per foot for house connections are used for estimating purposes. For debt retirement and interest, 20 years and 8 per cent were chosen. A great majority of the area can be serviced by gravity sewers. The utilidor may be constructed mainly at grade or just below grade in some areas.

Capital costs are summarized in Table 7, and total estimated cost is $2,880,000. This results in an annual cost of $293,400, or $1,230 per unit connected. Not included in this is the cost of raising some of the housing units to permit gravity drainage to the sewer. It is not expected that this will be a major expense as many of the houses are built on raised gravel pads. The cost of any sewage treatment plant required in the future is not included.

TABLE 7. Capital costs of piped services

Service	*Length, ft.*	*Unit Cost, $*	*Total Cost, $*
Utilidor (Water & Sewer)	19,650	100	1,965,000
Watermain	1,800	60	108,000
Collector Sewer	1,800	60	108,000
Connections (238)	8,650	70	605,500
Force Mains	1,100	85	93,500
Total capital cost			$2,880,000
Total annual cost (20 years at 8%)			293,400
Capital cost per unit — $12,100			
Annual cost per unit — $1,230			

NOTE: This provides for all of the settlement to be serviced by piped water and sewer.

Cost Comparison of Trucked and Piped System

Table 8 gives a comparison of the total annual cost per household for a piped system and a trucked system. The detailed calculations are given by Deans and

TABLE 8. Cost comparison of trucked and piped system (Annual cost = amortized capital cost + operating cost)

	PIPED SYSTEM		TRUCKED SYSTEM	
	Annual Cost *$/unit/year*	*Annual Cost* *$/1000 gal.* *(Water & Sewage)*	*Annual Cost* *$/unit/year*	*Annual Cost* *$/1000 gal.* *(Water & Sewage)*
Range*	1330-1680	14-47	1425-2200	
Avg.	1440	32	1530	36.50**

*Range is caused by different servicing costs due to town layout in different parts of the settlement, and by different water consumption in the trucked system.

**According to present contract price of $34/1000 gal. for delivery of water and pick-up of liquid sewage and $2.50/1000 gal. for water supplied.

Heinke (1971). The figures shown include the cost of water production and distribution, sewage collection, but not sewage treatment. Annual costs for both systems are about equal.

GOALS AND METHOD OF IMPLEMENTATION FOR SERVICES

In attempting to arrive at a workable policy on future requirements for municipal services and environmental control for settlements in the Canadian North, it is important to keep the following in mind:

- An adequate supply of good quality water and proper disposal of wastes and refuse is as important to a northerner as it is to a southerner.
- Maintaining the quality of the natural environment in the north is important.
- Municipal services and environmental control are only two of the many services required such as employment, health care, nutrition, housing, education, recreation, transportation, etc. All these compete for funds that are limited. Decisions on servicing and environmental protection must not be made without due regard to other factors.
- Many settlements exist today without any viable economic base.
- It is not likely or desirable that high quality services will be installed in all settlements. Choices will have to be made.

In light of these general comments, the following conclusions and recommendations are made. They are directly applicable to Frobisher Bay only, but the general findings and procedures used also apply to other arctic communities.

Present Municipal Services

Within the constraints of the physical layout and facilities for municipal services present now in Frobisher Bay, the water treatment and supply, the partial piped system, and the trucked operation are carried out in a generally satisfactory way.

The cost analysis of the trucked service for the community of Frobisher Bay shows that the contractor is not making an excessive profit. It can be expected that a similar service operated by the Hamlet would cost approximately the same. There would be no advantage in establishing a public utility for the contractor provides good service and employs a maximum number of local trades and labour.

Water consumption in Frobisher Bay is reasonable with the exception of the low consumption in houses with no internal facilities; this low consumption is mainly the result of such inadequacies which generally discourage the use of water by the native population.

Proposed Piped Services

The annual cost (capital and operating) of providing a piped service for water and sewage is about the same as that for an improved trucked service. This generally indicates that for the community of Frobisher Bay a piped water and sewer service is economically feasible. A piped system would provide service superior to that of a trucked system and would increase water usage in the low consumption areas. Preliminary estimates indicate a capital cost of $2,880,000 for a complete utilidor system, excluding waste treatment facilities. This averages to an annual capital cost of about $1,230 per unit connected over 20 years. Estimated operating costs increase this to $1,440 per unit per year or to $32 per 1,000 gallons of water supplied and sewage collected. Abandoning the trucking system will, however, result in a substantial loss in wages (about $278,000 annually) to 25 men in the community.

It is recommended that a detailed engineering study for the provision of piped services for Frobisher Bay be started immediately.

Waste Treatment

The present practice of discharging raw wastes to the sea has not resulted in significant pollution problems of the bay (Belleville 1969). However, the discharge of wastes in several places along the beach certainly results in local shore pollution and is an eyesore. Very likely at least partial treatment of wastes will be required by law in the future. This could be achieved by lagooning or a housed treatment plant. It is beyond the scope of this investigation to recommend in favour of any one of these alternatives. In our opinion, the need for provision of piped water and sewer services is higher than that for extensive sewage treatment facilities. It is recommended that a future utilidor system include provision for collection of all sewage in one location by construction of a force main and pumping station. The investigation should include a study of the location and form of treatment most suitable for Frobisher Bay.

Staging

It is realized that the installation of utilidors throughout the community may not be possible at once. In this case a staging program is recommended, the details of which are given by Deans and Heinke (1971).

Internal Facilities and Upgrading of Housing

It is necessary to upgrade internal facilities for about 138 dwellings before providing piped services. The upgrading consists of additional facilities to provide each dwelling with at least minimal internal plumbing facilities; 56 dwellings must be replaced by new housing. All future residences should be provided with rooms which can be converted to bathrooms, so that they would not need to be replaced when the water and sewerage systems are constructed.

Alternatives to Piped System

In the event that piped services cannot be installed, improvements can be made to the existing trucked system through the installation of additional plumbing facilities in 138 homes (econo-flush toilets, sewage-holding tanks and pressure systems). The initial capital expenditure is approximately $80,000. No additional facility would be provided in 56 substandard houses.

The total annual costs per unit, including capital and operating costs, for this alternative would be comparable to that for a piped system, but the water consumption rate would be lower and service less efficient. The costs for these internal improvements are also generally applicable to preparation of the houses for installation of piped services. The existing "honey-bag" system would be eliminated.

Experimental Facilities

The availability of trained technical personnel at Frobisher Bay and the variety of types of housing make it a suitable location for the testing of promising concepts. Future pilot operations in the use of incineration of human waste and garbage, reuse of waste water and others could be carried out here. The experimental pressure sewer system (Cooper 1968) which is installed at Frobisher Bay is an example of a pilot project; however, this installation was not followed by a proper performance and cost evaluation. The Butler housing units would be suitable for a pilot installation of a vacuum sewage collection and conveying system. As they contribute heavily to the water supply and sewage collection quantities, an experimental installation, such as suggested, would probably be self-supporting. Any experimental installation should be followed by a program for recording and analysing performance data and costs.

Investigations at Other Settlements

It is recommended that investigations of alternate methods of servicing for other settlements in the Canadian North be carried out as soon as possible. The emphasis must be on providing alternatives of different degrees of sophistication and cost from which the people and government can make sensible choices.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of the Northern Science Research Group, Department of Indian Affairs and Northern Development, which provided funds for the project under a research contract, and the National Research Council, which provided additional funds under a research grant with G. W. Heinke; and the Department of National Defence, Canadian Armed Forces, for releasing B. Deans from active service to complete the requirements for a Master of Engineering at the University of Toronto.

The authors also wish to express their gratitude to the many individuals in government and industry who supplied information necessary for this paper, in particular J. W. Grainge and his associates J. Shaw and J. Slupsky, Department of the Environment, Edmonton.

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