IV.1. WATER AND SEWERAGE PROBLEMS IN DISCONTINUOUS PERMAFROST REGIONS

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This paper deals with waterworks and sewerage problems in discontinuous permafrost regions with particular reference to certain experiences in the Northwest Territories and Yukon Territory in Northern Canada. These two Territories lie north of the 60th parallel covering an area exceeding 1/2 million square miles or about 39 per cent of the total Canadian land and water area. Of this area, only a small part located in the southwestern part of the Northwest Territories and in the southern part of the Yukon is in the discontinuous permafrost zone. Much of the information presented herein is also included in a paper by A.B. Yates, Chief Engineer, Northern Administration Branch, Department of Northern Affairs and National Resources, and the author, presented to the International Conference on Permafrost at Purdue University November 1963.

The problem of water supply and sewage disposal in Northern Canada can generally be considered as two-fold. In the first instance, it is to obtain water supplies of adequate quantity and quality for drinking, culinary, and minimum sanitation requirements and to dispose of human waste, garbage and wash water in a satisfactory and sanitary manner. Washing and bathing has been somewhat of a secondary requirement. Secondly, the problem especially in recent years has become one of providing modern waterworks and water carriage sewerage systems so that inhabitants of the North can enjoy amenities equivalent to those enjoyed by people in other parts of the country. In the final analysis, it is necessary to provide such facilities on a reasonably economic basis.

CURRENT DESIGN APPROACHES

Water Supply and Treatment

Water supply in the discontinuous permafrost zone of Northern Canada can be obtained from surface waters such as lakes, rivers and streams or in a few cases from groundwater. The area is well supplied with rivers, creeks and lakes which provide adequate sources of domestic supply. Some settlements may depend upon ice for their winter water supply.

Groundwater supplies have been used in a few instances in the North to supply individual persons and in some cases community water supplies. There has not been much exploration for groundwater, however, and consequently the potential has not been exploited.

There are some areas where the surface waters are of excellent quality and require little, if any, treatment before being used for domestic supply. In others, because of color and/or turbidity, it may be necessary to provide conventional treatment with coagulation, sedimentation and filtration. In some cases, it may be feasible to draw water at times when the quality is good and store it to supply the needs at other times.

Sewage Disposal

For individuals and settlements where a piped sewage disposal system is not practical, many different methods are used to dispose of sewage in a sanitary manner. Depending on local conditions, these may include methods such as pit privys, cesspits, septic tanks with disposal fields, chemical toilets, etc.

Where there is a community piped sewage collection system or a truck collection system, there are several alternatives for treatment and disposal. The first is simply discharging into a river or lake without pretreatment and depending on dilution.

If dilution is not considered satisfactory, then some form of pretreatment may be required. This may take the form of any type of conventional treatment with or without chlorination. It is questionable, however, whether there are any situations in the North where treatment for reduction of biochemical oxygen demand (B.O.D.) or suspended solids is justified. In most cases, the only justification is for the reduction of coliform organisms. With large rivers such as the Mackenzie, dilution is high and the concentration of coliform organisms low enough to be within accepted standards, except very close to outfall sewers. Where such large bodies of water are available, it may therefore, be important to obtain dispersion of the effluent.

Another method of treatment which has been successful in the North makes use of sewage lagoons or stabilization ponds. Observations made by the Department of National Health and Welfare indicate that under almost any conditions, sewage lagoons can provide the safest and most economical means of sewage treatment for communities and institutions in Northern Canada. Research work is necessary, however, to establish more clearly rational design criteria for such ponds. In the absence of such criteria, engineers are forced to include a large factor of ignorance in their design.

In the more populated parts of Canada and in the United States, certain design criteria have been developed for sewage lagoons. Some of these are arbitrary but more recent ones have been established on the basis of research and experience with operation. Climatic conditions in the North make it rather dangerous to apply these criteria there. Indications are that the operation of lagoons in the summer provides a degree of treatment similar to that obtained in other parts of North America.

In Western Canada, however, the winter operation is another matter. Although the efficiency of aerobic lagoons in Western Canada decreases greatly in the winter months, the carry over of well treated waste provides a dilution of considerable magnitude that improves the effluent over part of the winter. Further north, however, as the period of freeze up becomes longer, much more storage is required to accomplish the same results. In the final analysis, it would seem that if the sewage can be stored over the winter, treated in the summer, and discharged during a few summer months when the effluent is efficiently treated, then the requirements for good treatment and satisfactory health safety are met.

Where an aerobic lagoon is designed, consideration should probably be given to providing greater than normal depths. Seven to eight feet would appear to be justified in order to provide sufficient extra depth for ice and to allow sufficient retention period over the winter at reasonable cost. In the summer, the lagoon can be operated at depths of 3 to 5 feet, if desired. In general, B.O.D. loading should not be a major problem although if deeper lagoons are provided such loading in the spring may be quite high.

Anaerobic lagoons have come into general use in Western Canada and especially in Alberta in the past few years. They have proved to be very economical and satisfactory in most cases. Usually they are utilized ahead of an aerobic lagoon or storage pond, but can be used as the only method of treatment if the receiving stream provides sufficient dilution. It should be pointed out that important decisions on this matter should be based on requirements of the disposal area. There is no justification for spending money to overtreat the sewage unless analysis of the problem can show the need.

Water Distribution

In many northern settlements, trucks or trailers are used to supply water and haul away sewage. It is becoming more apparent, however, that most of the people, especially those living in larger communities, are demanding modern waterworks and sewerage facilities so that they can enjoy the same amenities people have in other parts of the country. The demand has, in the past few years, led to the construction of several modern, but in most cases quite expensive, water distribution systems. Four types of piped distribution systems which may be considered are as follows:

1) The conventional type system with pipe buried below the seasonal frost.

2) Installing the piping within the seasonal frost, but providing sufficient heat to the water and recirculating and/or wasting sufficient water to prevent freezing.

3) Installing insulated pipe within the seasonal frost with less heating but with recirculation and possibly some wasting.

4) Utilidors might be considered in some cases, but their cost is so high that they should normally be constructed only where other alternatives cannot be used.

Sewage Collection

Where modern piped waterworks systems are installed, usually there is also a need for piped sewerage systems. Some of the types of systems that might be considered are as follows:

1) Conventional gravity system constructed below the frost:

Because of the deep frost penetration in most places in the North, this type of system cannot be installed in very many instances. In many cases, however, the system can operate to some extent within the seasonal frost because warm sewage from services prevents freezing, even if the normal frost penetration is a few feet below the bottom of the pipe. Theoretically the pipe could be located within a talik, if one existed, but to depend on this would be dangerous.

2) Gravity system constructed within the seasonal frost, but provided with bleeding of heated water to prevent freezing or located close enough to a heated water system to prevent freezing.

3) Utilidors may be considered but are very expensive and therefore only a last resort.

4) A gravity system within the seasonal frost layer but insulated in order to reduce the heat loss. The author does not know of a system of this type that has been installed. The problem would be to provide insulation that would be waterproof enough to maintain its efficiency through the years.

5) A pressure sewer system.

The author does not know of such an installation, but has suggested it as a possible solution to the problem of sewer systems in soil that is subject to frost action. The pipe could either be insulated or uninsulated depending on the relative cost of heating and insulation. It probably would only be practical to construct such a system if each service contained a septic tank so that solids would not be pumped into the collection system. The provision of a septic tank for each service or possibly for each group of services, depending on the local situation would also provide a means by which the rate of flow could be balanced out, thus allowing the use of a smaller pipe.

EXAMPLES OF SYSTEMS

Four examples of waterworks and sewerage systems for communities in the Northwest Territories and Yukon Territory are discussed below to illustrate the different types of systems and the special problems relating to them. The communities considered are Fort Smith, Yellowknife and Hay River in the Northwest Territories and Dawson in Yukon Territory.

1. Fort Smith, N.W.T.

Fort Smith is a community with a population of slightly more than 1,000 located on the Slave River at the 60th parallel of latitude. It is situated mostly on sand covered with jackpine. In some places there are indications of islands of permafrost, but generally when areas are developed, the permafrost has receded. The waterworks system includes an intake in the Slave River, a supply line, a conventional water treatment plant, a distribution system and ground and elevated storage.

Essentially this system was designed and built according to standard practices in existence in other parts of Canada. There were, however, a few problems which may be considered somewhat unique to the North. The intake and pumphouse was constructed on rock a few feet from the shore and close to some rapids in the Slave River. It was anticipated that there could be a serious problem with frazil ice on the inlet screens. The intake structure was designed to allow water to be drawn from close to the water surface in the summer to obtain water of minimum turbidity, and from close to the bottom in the winter to minimize the frazil ice problem. The inlet screens are designed so they can be removed from inside the structure. Heating facilities are also provided in the intake structure so that water in the intake well can be heated and hot water can be pumped into the inlets. After three years of operation, no difficulty with frazil ice has been experienced.

Another problem was to build a supply line from the intake structure up an unstable hillside to the water treatment plant. There appeared to be frost in the hillside throughout the year and each summer there is slipping along the surface. A buried pipe or piles was impractical, so a pipeline was designed using 6 inch cast iron flexible joint pipe with styrofoam insulation and several expansion joints at different locations on the hill. The pipe between expansion joints is held together by cables and the supports at each joint hold the pipe above the surface to allow longitudinal movement. After movement takes place in the hill, readjustments can readily be made to the pipeline.

The water distribution system is constructed of asbestos-cement pipe buried with a minimum cover of about 11 feet and experience has shown that this is satisfactory in this particular location. Each service is provided with a copper wire from the corporation stop at the main to the curb stop, so that it can be electrically thawed if necessary. There is also provision in the distribution system for heating and circulation through the major loops of the system.

The sewerage system is of conventional design using asbestos-cement pipe to allow a reduction in grades. A minimum cover of 9 feet has been used for the sewerage system and apparently operations are satisfactory.

Sewage treatment is provided in a lagoon. The degree of treatment is not too important as eventual discharge is into the Slave River which provides ample dilution. To date there has been little, if any, discharge to the river because the sewage has percolated into the sandy soil. At the time of the design, anaerobic lagoons were not considered because of the lack of experience with them, but subsequent evidence indicates that they would have been satisfactory.

2. Yellowknife, N.W.T.

The town of Yellowknife, N.W.T. is a mining community having a population of approximately 4,000 people. A modern waterworks and sewerage system was constructed in 1947 and 1948 and serves about 2,700 people.

Yellowknife has an excellent water supply from Great Slave Lake, no treatment other than chlorination being required. The water is pumped from the lake, heated and then pumped to the distribution system through a supply line. In the past some problems were experienced with the supply line and part of it has been laid on the surface of the ground and covered with moss for insulation. This apparently has worked quite satisfactorily and obviously is very economical where pipelines are located through uninhabited areas and there is a continual flow in the pipe.

The water distribution system is a two pipe system having a supply line and return line. Water is kept flowing through these lines and the services continuously and the return line returns to the pumphouse at the lake. The water lines are laid at depths of about 5 feet.

The sewerage system is constructed mostly of corrugated metal pipe and is also relatively shallow and kept from freezing by being located close to the water lines and by bleeding.

Sewage is collected and pumped into a small lake which is utilized as a sewage lagoon or storage pond. The overflow from this lake goes into Great Slave Lake, but health authorities are concerned that this overflow may contaminate the lake water to a dangerous level at a location close to the community. Some study has been done on the operation of the lagoon to determine the magnitude of this problem.

The unit costs of constructing the waterworks and sewerage system at Yellowknife were considerably higher than those at Fort Smith, which is only 150 miles to the south. At the present time, there does not appear to be any permafrost in the developed part of Yellowknife, although when the system was constructed there was a considerable amount of what appeared to be permafrost in the area. This added greatly to the cost of construction.

3. Dawson, Y.T.

Dawson, Y.T. is located about 400 miles northwest of Whitehorse at latitude 64°N. The community was first established during the gold rush of 1898 and the population reached a peak of approximately 50,000. The winter population is now about 500. Waterworks and sewerage systems were put into operation in 1904 and thus are approximately 60 years old. The system is constructed essentially of wood stave pipe, the water system being laid approximately 4 feet deep, although in some places it is as shallow as 6 inches deep. The sewer system in general is not shallower than 4 feet. In the winter, frozen ground surrounds all the pipes. Freezing is prevented by heating the water and bleeding.

At the present time, there are approximately 30 year-round customers and about 40 additional in the summer.

The community is sparsely populated having about one customer to every four lots.

At present most of the heating is provided by electricity produced from a hydro plant with surplus power, so that the increment cost of heating and pumping is not a serious problem. It is anticipated, however, that within the next few years, the hydro plant may be abandoned and a diesel plant installed. It has been estimated that with the present system, the cost of heating by conventional means, such as coal, would be in the order of $90,000 to $100,000 per year. This is an exorbitant cost for about 130 winter customers, and some means of cutting this heating cost has been investigated. One solution suggested is to modify the system by insulating some of the pipes.

The major problem in using insulated pipes buried in the ground would be to find material and construction methods that would assure that the insulation would remain effective for a reasonable period of time. This may be quite difficult if the pipe is buried in areas saturated with moisture.

The important thing to note about the Dawson systems is that it has been possible with enough heating and flow of water to operate water and sewer systems in which the pipes are completely surrounded by frozen ground in the winter time, provided there is enough flow of water and heat available. The other interesting point is that wood stave pipe was used. This material has many good qualities which should not be overlooked for the type of shallow system where strength and a certain amount of flexibility of the pipe may be required.

4. Hay River, N.W.T.

Hay River, N.W.T. is located at the mouth of the Hay River on the south shore of Great Slave Lake. The new Great Slave Lake Railway has recently been completed to Hay River and it is expected that this community will continue to grow. The present population is approximately 2,000 and it is one of the largest communities in the Northwest Territories that is not served with a modern waterworks and sewerage system, although it is expected that one will be constructed within the next year.

The community is located on a deltaic island of silt and sand, most of which is underlain by permafrost. The island is subject to flooding and following a severe flood in the spring of 1963, a new residential subdivision was created on the mainland south of the townsite in which most of the new houses will be built. The new site is above flood level and the foundation conditions are considerably better than those on Vale Island, although they are definitely not ideal.

The problems of installing a waterworks and sewerage system on the island at Hay River were studied prior to the 1963 flood. The soil conditions with frost heaving and permafrost present some very difficult design problems.

At the present time, water supply for the community is obtained from very shallow wells, treated for iron removal and softening and delivered by tank truck. The water available is not, however, adequate to supply a modern piped system and it is necessary to consider alternate sources for future requirements.

The two possible sources are the Hay River and Great Slave Lake. Water in the Hay River is highly coloured and would require complete treatment. On the other hand, samples taken from various distances from the shore in Great Slave Lake indicate that with a distance of 4 miles from the shore, it is feasible to obtain a water of satisfactory quality for use in the community without treatment other than chlorination. Studies have indicated that it is feasible to build a pipeline as far as 7 miles from the shore to obtain water not requiring treatment before it would be economical to use Hay River as a source and construct and operate a complete treatment plant. It is possible that at a distance of 4 miles water can be obtained from below the thermocline and taken into the system at a temperature considerably above freezing. If this can be done it could result in a considerable saving in the annual costs of heating.

It would be a major problem at Hay River to construct and operate a water distribution system and sewage collection system on the island. From tests on frost and permafrost, it appears that a conventional system buried below the frost would not be feasible. A water distribution system could be built with insulated pipe buried just below the surface with heating and recirculation in all lines.

Because of the soil conditions and the expected frost heaving, it would be necessary to construct these lines with materials having relatively flexible joints so that a considerable amount of movement in the pipes could be accepted without damage, or they may be constructed of sufficiently strong material such as a continuously welded pipe to withstand the forces exerted on it by frost heaving.

The sewerage system would be more of a problem. Because of frost heaving conditions, it would be difficult to construct a system of the gravity type and still maintain proper grades. When studying this problem, however, the author conceived the idea of a system with every service having a septic tank from which the effluent would be pumped into pressure lines and thence to a lagoon. This system would probably require insulated pipe and could be kept from freezing, either by recirculation and heating and/or by bleeding. Analyses indicate that the system with bleeding would be the most economical at Hay River because of the expected low increment cost for water. With the very difficult soil conditions in Hay River, an analysis has indicated that this system would be the most economical. Consideration has been given by the Department of Northern Affairs and National Resources to the use of this type of a system for a few buildings at Frobisher Bay, N.W.T. If this is built, then observations on the economics and operating problems can be made along with an assessment of the feasibility for other installations.

When determining whether to build a water distribution system, which bleeds to prevent freezing or uses recirculation with no bleeding, consideration has to be given to the problem of the sewerage system. If there is bleeding of the water system, it is obvious that this will help to keep the sewerage system from freezing.

The question of placing water and sewer lines in the same ditch at Hay River has been considered and it is questionable whether this would be approved by the Department of National Health and Welfare. It is obvious, however, that if a recirculating water system can be placed close to the sewerage pipes, heat from the water system will help to keep the sewage from freezing and less bleeding will be necessary.

CONCLUSIONS

After considering the various problems and experiences in waterworks and sewerage in the discontinuous permafrost regions of the North country, the following conclusions have been drawn:

1) Design criteria presently utilized in the waterworks and sewerage fields should not be applied to problems in the North without a very careful fundamental consideration of the problem.

2) There is a great need for practical research and development in the field in order to develop rational design criteria for application to water and sewerage problems in the North.

3) A theoretical analysis of cost of a pressure sewer system indicated that it has potential under certain circumstances and experience is needed with such a system to assess its usefulness.

4) Because of the high cost of subdivision development in the North, especially of water and sewerage facilities, one of the prime considerations in community design should be to minimize the cost of construction and operation of these facilities. The author has observed several instances where no such considerations have been given and the result has been or will be unnecessarily high construction and possibly operating costs.

Discussion

J.W. Grainge remarked that it is not necessary to make sewage lagoons watertight and many that are not operate satisfactorily. The author agreed and stated that overflow can be eliminated by infiltration into the bottom of the lagoon. The sewage can be passed through 2 feet of material beneath the lagoon and then the requirement for further treatment can be considered.

H.P. Klassen noted that lagoons beside stream banks can disturb the stability of the surrounding soil. Seepage lagoons are satisfactory but care is required where seepage can occur; several examples of this are presently in existence. Stanley replied that each situation must be judged on its own merits. For example, lagoons are not suitable where fissures occur in the underlying bedrock. They are very expensive if located on an impervious river bank.

S.R.L. Harding asked if there was any objection to using in a municipal system, water that is coloured. The author replied that the main problem is that people do not like to use coloured water.

O.F. Simonsen noted the high costs of installing and operating utilities systems in the North and the need for economic analysis. He asked whether presently employed methods of analysis are adequate in terms of the importance of the systems. The author replied that the analytical methods are satisfactory but more field observations are required to give confidence in the results. Simonsen remarked on the need for computer programmes. In Denmark it is possible to purchase such programmes for about $30 plus a few dollars for parameters. Stanley agreed with the need for economic analysis and he reiterated the need for more field observations, more test systems and testing of pipe under different conditions. Much information could be obtained from existing systems and several different materials could be tested simultaneously in new systems.

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